



**US Army Corps  
of Engineers®**  
Engineer Research and  
Development Center



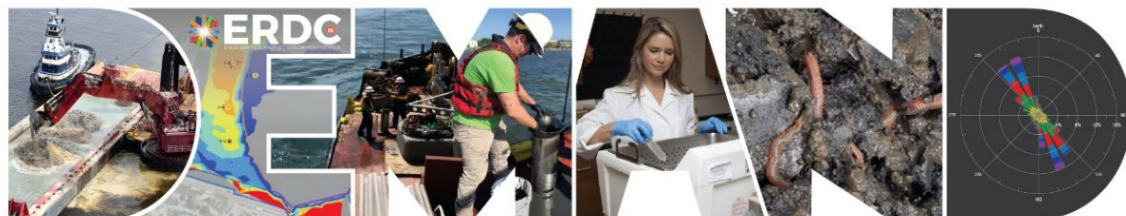
*Dredging Operations Environmental Research*

# **Advances in Dredged Material Evaluations for Inland and Ocean Aquatic Placement**

**Modernized Processes and Supportive Tools**

Alan J. Kennedy, David W. Moore, J. Daniel Farrar, Guilherme  
R. Lotufo, Burton C. Suedel, Susan E. Bailey, Paul R.  
Schroeder, Paige M. Krupa, Taylor E. Rycroft, and Trent C.  
May

May 2023



**Dredging Evaluation Management, Analysis and Networked Documentation**

**The US Army Engineer Research and Development Center (ERDC)** solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at [www.erdclibrary.on.worldcat.org/discovery](http://www.erdclibrary.on.worldcat.org/discovery).

To search for other technical reports published by ERDC, visit the ERDC online library at <http://www.erdclibrary.on.worldcat.org/discovery>.

# **Advances in Dredged Material Evaluations for Inland and Ocean Aquatic Placement**

## **Modernized Processes and Supportive Tools**

Alan J. Kennedy, David W. Moore, J. Daniel Farrar, Guilherme R. Lotufo, Burton C. Suedel,  
Susan E. Bailey, Paul R. Schroeder, Paige M. Krupa, Taylor E. Rycroft

*US Army Engineer Research and Development Center  
Environmental Laboratory  
3909 Halls Ferry Road  
Vicksburg, MS 39180-6199*

Trent C. May

*US Army Engineer Research and Development Center  
Information Technology Laboratory  
3909 Halls Ferry Road  
Vicksburg, MS 39180-6199*

Final Technical Report (TR)

Distribution Statement A. Approved for public release: distribution is unlimited.

Prepared for US Army Engineer Research and Development Center  
Environmental Laboratory  
3909 Halls Ferry Road  
Vicksburg, MS 39180-6199

Under Project 19-11, "Dredging Evaluation Management, Analysis and Networked  
Documentation (DEMAND) Tool," Dredging Operations and Environmental  
Research (DOER) Program; Civil Direct—Funding Account Code RT19-11,  
AMSCO Code 089500

## **Abstract**

As part of the US Army Corps of Engineers' mission to evaluate and move dredged material (DM) to maintain navigation channels, environmental evaluation of the prospective material is required by the Code of Federal Regulations. While existing guidance manuals provide useful guidance to DM regulators, they are over 30 years old and not reflective of the latest science. However, efforts to update procedures and publish the documents individually or as a combined dredging manual have been thus far unsuccessful. These issues, coupled with a lack of consistent reporting and decision documentation, lead to delays arising from challenges addressing project-specific issues not clearly covered within the existing guidance, revisiting previously resolved issues or negotiating disputes between permitting authorities. This technical report provides a path toward modernization of the environmental compliance aspects of DM evaluation guidance in part through software executables guiding the management and decision process and through a structured, evidence-based approach. The value added is an updated approach to DM testing and evaluation decisions.

# Contents

|                                                                                                                                                                                                       |            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>Abstract.....</b>                                                                                                                                                                                  | <b>ii</b>  |
| <b>Figures and Tables.....</b>                                                                                                                                                                        | <b>vii</b> |
| <b>Preface.....</b>                                                                                                                                                                                   | <b>x</b>   |
| <b>1 Introduction.....</b>                                                                                                                                                                            | <b>1</b>   |
| 1.1 Background.....                                                                                                                                                                                   | 1          |
| 1.2 Objectives.....                                                                                                                                                                                   | 2          |
| 1.3 Approach .....                                                                                                                                                                                    | 3          |
| 1.4 Brief summary of laws and regulations.....                                                                                                                                                        | 3          |
| 1.4.1 Marine Protection, Research, and Sanctuaries Act (MPRSA).....                                                                                                                                   | 3          |
| 1.4.2 Clean Water Act (CWA).....                                                                                                                                                                      | 4          |
| 1.5 Dredging process and management overview.....                                                                                                                                                     | 5          |
| 1.5.1 The dredging process .....                                                                                                                                                                      | 5          |
| 1.5.2 Dredged material (DM) management alternatives .....                                                                                                                                             | 6          |
| 1.6 Framing the dredging evaluation .....                                                                                                                                                             | 6          |
| 1.6.1 Conceptual model (CM) .....                                                                                                                                                                     | 8          |
| 1.6.2 Assessment of potential environmental impacts.....                                                                                                                                              | 10         |
| 1.6.3 Initial evaluation.....                                                                                                                                                                         | 12         |
| <b>2 Supplemental Tools: Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) and Dredging Evaluation Visualization, Organization and Integration Database (DEVOID).....</b> | <b>16</b>  |
| 2.1 Description and purpose of the software applications.....                                                                                                                                         | 16         |
| 2.2 Acquisition of the applications.....                                                                                                                                                              | 16         |
| 2.3 Running the applications .....                                                                                                                                                                    | 16         |
| 2.4 Remainder of technical report .....                                                                                                                                                               | 16         |
| <b>3 Sampling and Analysis Logistics.....</b>                                                                                                                                                         | <b>17</b>  |
| 3.1 Reference sediments .....                                                                                                                                                                         | 18         |
| 3.2 Collection of reference sediment.....                                                                                                                                                             | 19         |
| 3.3 Reference sediment sampling approaches .....                                                                                                                                                      | 20         |
| 3.3.1 Reference point approach.....                                                                                                                                                                   | 20         |
| 3.3.2 Reference area approach.....                                                                                                                                                                    | 20         |
| 3.3.3 Periodic reference approach .....                                                                                                                                                               | 20         |
| <b>4 Testing and Assessment of the Water Column.....</b>                                                                                                                                              | <b>21</b>  |
| 4.1 Discharge of DM into the water column.....                                                                                                                                                        | 21         |
| 4.2 Evaluation of impacts to the water column.....                                                                                                                                                    | 22         |
| 4.3 Water-column pathway initial evaluation .....                                                                                                                                                     | 24         |
| 4.4 Water-quality criteria (WQC) and water-quality standards (WQS) .....                                                                                                                              | 26         |
| 4.5 Desktop screening to estimate concentrations considering partitioning.....                                                                                                                        | 29         |
| 4.6 Comparison of the liquid phase to WQC and WQS .....                                                                                                                                               | 31         |
| 4.6.1 Elutriate preparation.....                                                                                                                                                                      | 31         |

|           |                                                                                                                                            |           |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 4.6.2     | Chemical analysis of elutriate for determining compliance with WQC and WQS .....                                                           | 34        |
| 4.6.3     | Disposal in impaired systems .....                                                                                                         | 36        |
| 4.7       | Evaluation of impacts using biological testing.....                                                                                        | 36        |
| 4.7.1     | Evaluation of elutriate toxicity to water-column receptors .....                                                                           | 37        |
| 4.7.2     | Preparation of elutriate dilutions .....                                                                                                   | 38        |
| 4.7.3     | Test organisms, assessment end points, and test methods.....                                                                               | 40        |
| 4.7.4     | Toxicity from ammonia .....                                                                                                                | 45        |
| 4.7.4.1   | General considerations.....                                                                                                                | 45        |
| 4.7.4.2   | Identifying ammonia toxicity .....                                                                                                         | 46        |
| 4.7.5     | Reporting and interpretation of water-column toxicity results .....                                                                        | 47        |
| 4.7.5.1   | Interpretation of elutriate toxicity test results.....                                                                                     | 47        |
| 4.7.5.2   | Interpretation and use of toxicological end points .....                                                                                   | 50        |
| 4.7.6     | Determining the limiting permissible concentration (LPC) .....                                                                             | 52        |
| 4.7.6.1   | Defining the LPC .....                                                                                                                     | 52        |
| 4.7.6.2   | Selection of an application factor (AF) .....                                                                                              | 53        |
| 4.7.6.2.1 | Persistent versus nonpersistent contaminants .....                                                                                         | 54        |
| 4.7.6.2.2 | Type of test end point: survival versus development .....                                                                                  | 55        |
| 4.7.7     | Water-column toxicity assessment .....                                                                                                     | 57        |
| 4.8       | Initial mixing and the numerical mixing models .....                                                                                       | 58        |
| 4.9       | Operational and engineering controls .....                                                                                                 | 62        |
| <b>5</b>  | <b>Assessment of Potential for Benthic Toxicity .....</b>                                                                                  | <b>63</b> |
| 5.1       | Overview of the evaluation of potential for benthic toxicity .....                                                                         | 64        |
| 5.1.1     | Supporting lines of evidence (LOEs) .....                                                                                                  | 67        |
| 5.1.2     | Sediment toxicity identification evaluation (TIE) .....                                                                                    | 68        |
| 5.2       | Initial evaluation of potential for biological effects.....                                                                                | 68        |
| 5.2.1     | Use of previous technical determinations or evaluations .....                                                                              | 69        |
| 5.2.2     | Benthic toxicity screening evaluation using sediment chemistry .....                                                                       | 70        |
| 5.2.2.1   | Calculation of mean sediment quality guideline quotient (mSQGQ) for estuarine and marine sediments.....                                    | 72        |
| 5.2.2.2   | Calculation of mSQGQ for freshwater sediments.....                                                                                         | 73        |
| 5.2.2.3   | Conclusion on potential for benthic toxicity using sediment chemistry.....                                                                 | 74        |
| 5.3       | Primary LOE for assessing potential for benthic toxicity: sediment toxicity tests measuring acute survival.....                            | 75        |
| 5.3.1     | Control and reference sediment .....                                                                                                       | 76        |
| 5.3.2     | Species Selection.....                                                                                                                     | 76        |
| 5.3.3     | Sediment toxicity test interpretation.....                                                                                                 | 82        |
| 5.3.4     | Statistical analysis of survival data.....                                                                                                 | 82        |
| 5.4       | Primary LOE for assessing potential for benthic toxicity: sediment toxicity tests measuring chronic survival and sublethal end points..... | 83        |
| 5.5       | Supporting LOEs for assessing potential for benthic toxicity .....                                                                         | 85        |
| 5.5.1     | Benthic toxicity evaluation using sediment chemistry.....                                                                                  | 85        |
| 5.5.2     | Benthic toxicity evaluation using porewater chemistry .....                                                                                | 86        |
| 5.5.2.1   | Evaluation of hydrophobic organic compounds pore-water chemistry data .....                                                                | 86        |

|          |                                                                                                         |            |
|----------|---------------------------------------------------------------------------------------------------------|------------|
| 5.5.2.2  | Evaluation of metal pore-water chemistry data.....                                                      | 87         |
| 5.5.3    | Evaluation of bioaccumulation data to infer potential for effects to the<br>benthos.....                | 89         |
| 5.5.4    | Influence of noncontaminant-related causes of toxicity.....                                             | 90         |
| 5.6      | Whole-sediment TIE.....                                                                                 | 90         |
| 5.7      | Integration of LOEs and decision-making.....                                                            | 92         |
| 5.8      | Operational and engineering controls .....                                                              | 94         |
| <b>6</b> | <b>Assessment of Potential for Contaminant Impacts Resulting from Benthic<br/>Bioaccumulation .....</b> | <b>95</b>  |
| 6.1      | Scope of a bioaccumulation evaluation .....                                                             | 95         |
| 6.2      | Chemicals with bioaccumulation potential .....                                                          | 99         |
| 6.3      | Initial evaluation of bioaccumulation potential.....                                                    | 101        |
| 6.4      | Bioaccumulation testing.....                                                                            | 102        |
| 6.4.1    | Bioaccumulation test species .....                                                                      | 103        |
| 6.4.2    | Bioaccumulation steady state.....                                                                       | 105        |
| 6.4.3    | Procedures for termination of bioaccumulation tests .....                                               | 106        |
| 6.4.4    | Analysis of organism tissue.....                                                                        | 107        |
| 6.5      | Bioaccumulation test data preparation.....                                                              | 108        |
| 6.6      | Bioaccumulation test data interpretation .....                                                          | 108        |
| 6.6.1    | Comparison of bioaccumulation test data to reference conditions.....                                    | 108        |
| 6.6.2    | Evaluation of potential effects using bioaccumulation modeling.....                                     | 110        |
| <b>7</b> | <b>DEMAND and DEVoid Application User's Guide .....</b>                                                 | <b>112</b> |
| 7.1      | DEMAND tool .....                                                                                       | 112        |
| 7.1.1    | Installation of docker desktop.....                                                                     | 112        |
| 7.1.2    | Installation of the DEMAND application .....                                                            | 114        |
| 7.1.3    | Running the DEMAND application .....                                                                    | 116        |
| 7.1.4    | Using the DEMAND application.....                                                                       | 118        |
| 7.1.4.1  | Starting screen .....                                                                                   | 118        |
| 7.1.4.2  | New dredging operation screen.....                                                                      | 119        |
| 7.1.4.3  | Home screen.....                                                                                        | 120        |
| 7.1.4.4  | DMMUs screen .....                                                                                      | 121        |
| 7.1.4.5  | Contaminants of potential concern (COPCs) screen .....                                                  | 122        |
| 7.1.5    | Go back.....                                                                                            | 123        |
| 7.1.6    | Save functionality.....                                                                                 | 123        |
| 7.1.7    | Print report functionality.....                                                                         | 124        |
| 7.2      | Stopping the DEMAND application .....                                                                   | 124        |
| 7.3      | DEVoid tool.....                                                                                        | 126        |
| 7.3.1    | Installation of the DEVoid application.....                                                             | 127        |
| 7.3.2    | Running the DEVoid application.....                                                                     | 127        |
| 7.3.3    | Using the DEVoid application .....                                                                      | 131        |
| 7.3.3.1  | Application interface fields .....                                                                      | 132        |
| 7.3.3.2  | Data document schema definitions .....                                                                  | 133        |
| <b>8</b> | <b>Summary .....</b>                                                                                    | <b>134</b> |
|          | <b>References.....</b>                                                                                  | <b>135</b> |

|                                                |            |
|------------------------------------------------|------------|
| <b>Appendix A.....</b>                         | <b>158</b> |
| A.1 Plaintext version of Figure 1-1 .....      | 158        |
| A.2 Plaintext version of Figure 1-3 .....      | 158        |
| A.3 Plaintext version of Figure 4-2 .....      | 160        |
| A.4 Plaintext version of Figure 4-4 .....      | 161        |
| A.5 Plaintext version of Figure 4-9 .....      | 162        |
| A.6 Plaintext version of Figure 4-10.....      | 164        |
| A.7 Plaintext version of Figure 5-2 .....      | 165        |
| A.8 Plaintext version of Figure 6-1 .....      | 166        |
| <b>Abbreviations.....</b>                      | <b>169</b> |
| <b>Report Documentation Page (SF 298).....</b> | <b>173</b> |

# Figures and Tables

## Figures

|                                                                                                                                                                                                                                                                                                                                                                 |    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 1-1. A generic conceptual model (CM) for dredged material (DM). (Accessible version available in Appendix A.1.).....                                                                                                                                                                                                                                            | 9  |
| 1-2. CM for open-water sediment placement. (Modified from Kennedy et al. 2015, 2. Public domain).....                                                                                                                                                                                                                                                           | 9  |
| 1-3. Relationships between components of the conceptual model (source, exposure pathways, receptors) and subsequent sediment testing and evaluation methods for aquatic placement of DM. (Accessible version available in Appendix A.2.).....                                                                                                                   | 11 |
| 4-1. Bioassay testing.....                                                                                                                                                                                                                                                                                                                                      | 22 |
| 4-2. Water-column evaluation process. (Accessible version in Appendix A.3.) .....                                                                                                                                                                                                                                                                               | 24 |
| 4-3. Consideration of relative effects and modes of toxic action.....                                                                                                                                                                                                                                                                                           | 27 |
| 4-4. Evaluation of water-quality criteria (WQC) and water-quality standards (WQS) compliance. (Accessible version available in Appendix A.4.).....                                                                                                                                                                                                              | 28 |
| 4-5. Elutriate preparation procedure. (NOEC—no observable effect concentration; LOEC—lowest observable effect concentration; MATC—maximum allowable toxicant concentration; LC <sub>50</sub> —median lethal concentration.).....                                                                                                                                | 33 |
| 4-6. Elutriate toxicity bioassay setup. ....                                                                                                                                                                                                                                                                                                                    | 38 |
| 4-7. Embryos of the marine bivalve <i>Mytilus galloprovincialis</i> (top left), embryo of the sea urchin <i>Arbacia punctulata</i> (top right), freshwater cladoceran <i>Daphnia magna</i> (bottom left), and mysid <i>Americamysis bahia</i> (bottom right). ....                                                                                              | 42 |
| 4-8. Larva of the freshwater fish <i>Pimephales promelas</i> (left) and of the marine and the estuarine fish <i>Menidia beryllina</i> (right). ....                                                                                                                                                                                                             | 42 |
| 4-9. Flowchart for determining toxicological end points for an elutriate toxicity test. Test end points may then be related to the limiting permissible concentration (LPC) using Figure 4-10.(Accessible version in Appendix A.5.).....                                                                                                                        | 49 |
| 4-10. When acute toxicity is observed, this figure provides the process to determine the LPC, with consideration to the type of contaminant causing the toxicity and the type of toxicological end point assessed (AF—application factor; NAS 1972—NAS-NAE CWQC 1972). (Accessible version available in Appendix A.6.) .....                                    | 55 |
| 4-11. Comparison of Marine Protection, Research and Sanctuaries Act (MPRSA) and Clean Water Act (CWA) definitions of <i>initial mixing</i> . ....                                                                                                                                                                                                               | 59 |
| 5-1. A vertical cross-sectional image showing an overburden approximately 5 cm thick that resulted from open-water discharge of DM in Corpus Christi Bay, Texas. (Reproduced from Wilber et al. 2005, 2. Public domain.) .....                                                                                                                                  | 64 |
| 5-2. Illustration of the weight-of-evidence (WOE) approach for determining benthic impacts of DM prior to open-water placement. (Accessible version available in Appendix A.7.) .....                                                                                                                                                                           | 66 |
| 5-3. Laboratory whole-sediment sediment toxicity testing set up for a 10-day amphipod test (left) and a 10-day midge test (right) using a water-delivery apparatus. ....                                                                                                                                                                                        | 76 |
| 6-1. Decision-making process for the evaluation of bioaccumulation of contaminants from DM. Consider each dredged material management unit (DMMU) for each contaminant of potential concern (COPC) and cycle through this chart until all COPC are addressed (that is, repeat this process for each COPC). (Accessible version available in Appendix A.8.)..... | 97 |

|                                                                                                                                                                                                                                                       |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 7-1. The Docker Desktop Application Settings icon.....                                                                                                                                                                                                | 113 |
| 7-2. The Docker Desktop Application Settings–General section. ....                                                                                                                                                                                    | 113 |
| 7-3. The Docker Desktop Application Settings–Resources section.....                                                                                                                                                                                   | 114 |
| 7-4. Guidance for extracting the Dredging Evaluation Management, Analysis and<br>Networked Documentation (DEMAND) application.....                                                                                                                    | 116 |
| 7-5. <i>Top</i> , Docker Desktop command window listing the DEMAND Application. <i>Top</i> ,<br>highlights how the containerized DEMAND Application is started. <i>Bottom</i> , the proxy<br>container with the OPEN IN BROWSER button selected. .... | 117 |
| 7-6. Starting screen. ....                                                                                                                                                                                                                            | 118 |
| 7-7. New Dredging Operation screen.....                                                                                                                                                                                                               | 119 |
| 7-8. Home screen.....                                                                                                                                                                                                                                 | 120 |
| 7-9. DMMU screen. ....                                                                                                                                                                                                                                | 121 |
| 7-10. COPCs screen. ....                                                                                                                                                                                                                              | 122 |
| 7-11. Populated DMMU with COPCs. ....                                                                                                                                                                                                                 | 123 |
| 7-12. Example of a project-specific report generated by the application (earlier version<br>shown).....                                                                                                                                               | 124 |
| 7-13. STOP Button. ....                                                                                                                                                                                                                               | 125 |
| 7-14. Quitting Docker Desktop.....                                                                                                                                                                                                                    | 125 |
| 7-15. Dredging Evaluation Visualization, Organization and Integration Database (DEVOID)<br>program logo.....                                                                                                                                          | 126 |
| 7-16. Launching of the RStudio application.....                                                                                                                                                                                                       | 128 |
| 7-17. Open the DEVOID project.....                                                                                                                                                                                                                    | 129 |
| 7-18. Loading the source code. ....                                                                                                                                                                                                                   | 129 |
| 7-19. User may initially see the source code upon launch.....                                                                                                                                                                                         | 130 |
| 7-20. Opening screen of the DEVOID application. ....                                                                                                                                                                                                  | 131 |
| 7-21. Example of data visualization output for the DEVOID application. ....                                                                                                                                                                           | 131 |

## Tables

|                                                                                                                                                                            |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 1-1. Exclusions from testing under the Marine Protection, Research, and Sanctuaries Act<br>(MPRSA) and the Clean Water Act (CWA) (language as appears in regulations)..... | 14 |
| 4-1. Summary of media used in elutriate toxicity testing. Testing of each medium is<br>required as a treatment in biological testing unless otherwise specified.....       | 39 |
| 4-2. Test species and recommended methods routinely used for elutriate toxicity testing....                                                                                | 43 |
| 4-3. Possible test outcomes, data interpretation, actions.....                                                                                                             | 51 |
| 4-4. Nonexhaustive list of alternative AFs that provide protection from chronic exposure.<br>Additional alternative AFs can be found in Kennedy et al. (2015).....         | 57 |
| 4-5. Summary of discharge types, hydrodynamic conditions, and applicable models and<br>methods for evaluation of initial mixing. ....                                      | 61 |
| 5-1. Effects range median values (ERMs) for use in deriving effects range median<br>quotients (ERMQs).....                                                                 | 73 |
| 5-2. Probable effect concentrations (PECs) for use in deriving PEC quotients (PEC-Q).....                                                                                  | 74 |
| 5-3. Summary of standard benthic and epibenthic toxicity tests.....                                                                                                        | 78 |

|                                                                                                      |     |
|------------------------------------------------------------------------------------------------------|-----|
| 5-4. General acceptability ranges for ammonia in recommended marine sediment toxicity tests.....     | 81  |
| 5-5. Summary of chronic and chronic-sublethal toxicity tests.....                                    | 85  |
| 5-6. Interpretation of a Phase I toxicity identification evaluation (TIE) toxicity test results..... | 92  |
| 6-1. Suitable species for use in benthic bioaccumulation tests. ....                                 | 104 |
| 7-1. Chemistry. ....                                                                                 | 133 |
| 7-2. Bioassay database. ....                                                                         | 133 |

## Preface

This technical report prepared for the US Army Engineer Research and Development Center—Environmental Laboratory (ERDC-EL) under Project RT-19-11, “Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) Tool,” Dredging Operations and Environmental Research (DOER) Program; Civil Direct—Funding Account Code RT19-11, AMSCO Code o89500. The program manager was Dr. Todd Bridges.

Development of this technical note was led by the Environmental Risk Assessment Branch (EPR) of the Environmental Processes and Engineering Division (EPED), ERDC-EL. At the time of publication of this report, Mr. Jay Lindsay was chief, EPR; Mr. Warren Lorentz was chief, EPED; Dr. Jennifer Seiter-Moser was technical director for civil works, Environmental Engineering and Sciences; and Dr. Edmond J. Russo Jr. was the director of EL.

COL Christian Patterson was commander of the ERDC, and Dr. David W. Pittman was director of ERDC.

# 1 Introduction

## 1.1 Background

The United States has about 25,000 mi<sup>1</sup> of navigable waterways, which annually transport over 2.3 billion short tons of commercial goods (IWR 2012). These navigable waters are critical for commerce, recreation, and national defense. Approximately 300 million cubic yards of sediment are dredged annually to maintain navigable waterways (USACE 2012). The majority of sediment (approximately 200 million cubic yards annually) is dredged by the US Army Corps of Engineers (USACE); the remaining sediment is dredged by ports, private contractors, and others. The USACE and the US Environmental Protection Agency (USEPA) jointly manage dredging projects by issuing permits.

Dredged material (DM) placement into inland and ocean waters is subject to the Clean Water Act (CWA),<sup>2</sup> the Marine Protection, Research, and Sanctuaries Act (MPRSA),<sup>3</sup> and the National Environmental Policy Act (NEPA).<sup>4</sup> Under these laws, environmental impacts must be evaluated before DM is placed into the aquatic environment.

While several dredging guidance documents were initially published in the 1970s, followed by newer versions in the 1990s, it has been more than 20 years since national documents were updated. Select USACE divisions and USEPA regions have created regional implementation manuals (RIMs) or regional implementation agreement (RIA) manuals to accommodate the absence of an updated, contemporary national guidance manual (EPA-GLNPO and USACE-LRD 1998; EPA-R6 et al. 2003; USACE-SAD and EPA-R4 2008; USACE-NAN and EPA-R2 2016; USACE-NWS et al.

---

1. For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52 and 345–47, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

2. Federal Water Pollution Control Act of 1948, 33 U.S.C. §§ 1251–389. (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap26.pdf>.

3. Marine Protection, Research, and Sanctuaries Act of 1972, Pub. L. No. 92-532, 86 Stat. 1052–63. <https://www.govinfo.gov/content/pkg/STATUTE-86/pdf/STATUTE-86-Pg1052.pdf>.

4. National Environmental Policy Act of 1970, 42 U.S.C. §§ 4321–47. (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title42/pdf/USCODE-2021-title42-chap55-sec4321.pdf>.

2018).<sup>5</sup> The current national documents remaining in use include the following:

1. The ocean testing manual (OTM) for dredged evaluations conducted under the jurisdiction of MPRSA, titled *Evaluation of Dredged Material Proposed for Ocean Disposal—Testing Manual* (EPA-OW and USACE 1991), also known as the *Green Book*
2. The inland testing manual (ITM) for dredging evaluations conducted under the jurisdiction of the CWA, titled *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S.—Testing Manual* (EPA-OW and USACE-OCRD 1998)

The state of the science has progressed substantially since the publication of both documents, leaving much of the guidance outdated. Yet, efforts to update antiquated procedures and publish the documents individually or as a combined dredging manual have been unsuccessful.

Somewhat more recently (2003), the upland testing manual (UTM) guidance document focusing on DM placement in upland environments, titled *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore, or Upland Confined Disposal Facilities — Testing Manual* (USACE 2003), was released. In 2004, a joint USACE and USEPA document titled *Evaluating Environmental Effects of Dredged Material Management Alternatives—A Technical Framework* (EPA-OW and USACE 2004) was published.

## 1.2 Objectives

This technical report publishes guidance language from previous attempts to update the OTM/ITM, including a high-level risk management approach. The goal of this updated guidance is to modernize the process of gathering sufficient information on a dredging activity's impacts to biota and the aquatic ecosystem to make a technical determination (called a *determination* in MPRSA and a *factual determination* in CWA).

This document also provides a brief user guide to two supplementary companion computer-based tools to assist in navigating and documenting decisions for the evaluation of DM:

---

5. Provided as examples and do not represent a comprehensive list.

1. Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) tool (see Section 7.1)
2. Dredging Evaluation Visualization, Organization and Integration Database (DEVOID) (see Section 7.3)

### 1.3 Approach

This technical report focuses on aquatic management of DM; the UTM (USACE 2003) should be referenced for upland placement management options, and the framework and recently published beneficial use manual should still be referenced for general guidance regarding DM management strategies such as beneficial use (Keil et al. 2022). The report compiles updates to the ITM and OTM that were written collaboratively but not previously published.

### 1.4 Brief summary of laws and regulations

USACE and USEPA jointly oversee the removal, transport, and placement of DM in the United States. Three main laws regulate dredging in inland and ocean waters: the MPRSA, the CWA, and the NEPA. Certain dredging projects may be subject to other federal laws, including the Coastal Zone Management Act,<sup>6</sup> Endangered Species Act,<sup>7</sup> and historic resource laws (for example, the Rivers and Harbors Act of 1899<sup>8</sup>). This summary focuses on the MPRSA and CWA.

#### 1.4.1 Marine Protection, Research, and Sanctuaries Act (MPRSA)

The MPRSA of 1972 is the primary law concerning placement of DM into the ocean (waters seaward of the territorial sea's baseline), including transport of DM for placement into ocean waters.<sup>9</sup> MPRSA Section 103 gives USACE the authority to regulate transport of DM for ocean placement through issuance of permits, subject to review by USEPA.<sup>10</sup> 40

---

6. Coastal Zone Management Act of 1972, 16 U.S.C. §§ 1451–67. (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title16/pdf/USCODE-2021-title16-chap33.pdf>.

7. Endangered Species Act of 1973, 16 U.S.C. §§ 1531–44. (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title16/pdf/USCODE-2021-title16-chap35.pdf>.

8. Act of March 3, 1899, 33 U.S.C. §§ 401, 403–404, 406–409, 411, 413–15. (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap9.pdf>.

9. Pub. L. No. 92-532, 86 Stat. 1052–63.

10. Pub. L. No. 92-532, 86 Stat. 1055–56.

CFR Parts 227–28, developed by USEPA, describe the criteria for assessing these permits.<sup>11</sup>

Additionally, USACE performs an evaluation of the DM for transport before placement, as described in 33 CFR Parts 320–30 and Parts 335–37.<sup>12</sup> During the evaluation, USACE is required to take several factors into account, including navigation, economic and industrial development, foreign and domestic commerce, and alternatives to ocean placement. USEPA conducts an independent review within 15 days of receiving the report from USACE (or 30 days for an extension); if USEPA decides that the planned project does not comply with the necessary criteria, it is required to notify, in writing, the USACE District Engineer.<sup>13</sup> If USACE determines placement in ocean waters is necessary as there are no reasonable alternatives, it may ask USEPA for a waiver to allow the proposed action.<sup>14</sup>

Section 102 of MPRSA authorizes USEPA to designate placement sites in the ocean for DM.<sup>15</sup> If feasible, USACE uses these specified sites. However, if impractical, USACE may work with the USEPA to choose another site that meets USEPA criteria, as authorized by MPRSA 103. Section 102(a) of MPRSA states that a permit cannot be approved for transport of sediment if placement intentionally infringes relevant water quality standards.<sup>16</sup>

#### **1.4.2 Clean Water Act (CWA)**

The CWA was enacted to “restore and maintain the chemical, physical, and biological integrity of the nation’s waters.”<sup>17</sup> The ocean discharge criteria

---

11. 40 C.F.R. § 227, <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part227.pdf>; 40 C.F.R. § 228, <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part228.pdf>; note: CFR—Code of Federal Regulations.

12. 33 C.F.R. §§ 320–30, <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-chapII.pdf>; 33 C.F.R. § 335, <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part335.pdf>; 33 C.F.R. § 336, <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part336.pdf>; 33 C.F.R. § 337, <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part337.pdf>.

13. 40 C.F.R. § 225.2(e). <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part225.pdf>.

14. 40 C.F.R. § 225.3(b). <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part225.pdf>.

15. Pub. L. No. 92-532, 86 Stat. 1054–55.

16. Pub. L. No. 92-532, 86 Stat. 1054.

17. 33 U.S.C. § 1251(a).

in Section 403 of the CWA are similar to the criteria provided in MPRSA Sections 101–103.<sup>18</sup>

Section 404 of the CWA (as regulated by 40 CFR 230) is the main law regulating the placement of DM and fill material into the waters of the United States (the territorial sea and inland waters).<sup>19</sup> Under Section 404(b)(1), the USEPA works with USACE to enact regulations regarding DM and fill material placement to prevent unacceptable environmental impacts.<sup>20</sup> This cooperation allows USACE and USEPA to designate whether aquatic sites are suitable for placement of dredge and fill materials. When issuing permits, USACE is required to consider the least environmentally harmful alternatives available, including management options other than aquatic placement. Section 404 gives the USEPA oversight of the permitting process, including the ability to veto permits issued by USACE.

Section 401 of the CWA gives states a role in permitting; permit applicants are required to provide state-issued certification that the proposed project will meet applicable state water-quality standards.<sup>21</sup> For projects on Native American reservations and other locations where the state does not have jurisdiction, this certification is issued by the USEPA or Tribal government.

## **1.5 Dredging process and management overview**

### **1.5.1 The dredging process**

Dredging is essential for creating and maintaining safe navigational channels to allow efficient transport of goods on waterways. Channels are widened and deepened to accommodate shipping traffic. Dredging may be performed with mechanical or hydraulic equipment and is conducted in three phases: removal or excavation, conveyance, and placement. There are two main types of dredging projects—maintenance and new-work construction. Maintenance involves removing recent sediment deposits in a waterway to restore its original dimensions. New-work construction creates new navigational access (for example, widening, deepening, or

---

18. 33 U.S.C. § 1343; Pub. L. No. 92-532, 86 Stat. 1053–56.

19. 33 U.S.C. § 1344; 40 C.F.R. § 230, <https://www.govinfo.gov/content/pkg/CFR-2018-title40-vol27/pdf/CFR-2018-title40-vol27-part230.pdf>.

20. 33 U.S.C. § 1344(b)(1).

21. 33 U.S.C. § 1341.

extending an existing channel). Certain sediments encountered in new work, such as compacted clays, glacial material, and rocks, can be difficult to excavate.

### **1.5.2 Dredged material (DM) management alternatives**

The different options available to dredging project managers during the placement phase are referred to as *DM management alternatives*. When choosing the best management option for a project, several factors should be considered, including environmental effects, technical feasibility, and economic viability. The DM may be placed in open water, nearshore, around an island, or at an upland location. There are two categories of sediment management: placement with a beneficial purpose and placement with no intended benefit. Beneficial use of DM occurs when sediment placement has social, economic, or environmental benefits (USACE 1987). Beneficial use is preferential to disposal with no benefit and can include habitat restoration or enhancement, shore stabilization, contaminant isolation, island formation, and other land development projects (for example, topsoil for parks and recreational facilities).

## **1.6 Framing the dredging evaluation**

This report and its companion tools are intended as supplementary guides to assist users in determining the suitability of DM placement in the aquatic environment, in accordance with the regulations of MPRSA (Section 103) and CWA (Section 404). The goal of the MPRSA and CWA evaluation processes is to gather sufficient information to reach a technical determination.

Using a lines of evidence (LOE) approach, this technical report presents a risk-based method for determining whether placement of DM in the aquatic environment will have unacceptable impacts. LOE are gathered from categories of information useful to the decision-making process including previous evaluations, changes in site conditions, physical, chemical, and biological information, species presence and abundance, and proposed project actions. Since it is impossible for a single test to effectively be used for all DM placement scenarios,<sup>22</sup> LOE are critical to

---

22. 40 C.F.R. § 230.61.

the evaluation process. LOE are used to produce a weight of evidence (WOE) that informs the technical determination.

This report's risk assessment and management process can generally be summarized by the nine steps outlined below. It is important to note that the user may stop at any point that sufficient information is available to reach a technical determination.

1. Use readily available or historic information, including the DEVOID tool (see Section 7.3), to conduct screening evaluations and inform development of conceptual model (CM; see Section 1.6.1).
2. Use a conceptual model (CM) to identify relevant exposure scenarios and data requirements.
3. Generate a quality assurance project plan (QAPP), including a sampling and analysis plan (SAP), to provide data quality objectives based on the CM.
4. Engage stakeholders and collect documentation and signatures offering concurrence to the QAPP and SAP.
5. Perform sediment and water sampling, physical and chemical analysis, and biological and toxicological testing in accordance with the QAPP and SAP.
6. Interpret the generated data as LOE to support a final management decision.
7. If required, evaluate operational and engineering controls to manage identified risks to an acceptable level.
8. Implement the DM disposal plan with necessary controls.
9. Perform adaptive management and monitoring at the placement site as required for risk management.

The technical determination substantiates whether the project is in compliance with applicable CWA and MPRSA regulations. A technical determination can have one of three possible outcomes:

1. The DM is suitable for aquatic placement.
2. The DM is suitable for aquatic placement if certain conditions are met to reduce adverse impacts.
3. The DM is not suitable for aquatic placement.

Insufficient information may be the reason why a DM is considered unsuitable for aquatic placement. If more information is collected to better

understand or reduce the project's potential risks, the technical determination may be revised.

### **1.6.1 Conceptual model (CM)**

The first step in a dredging evaluation is creating a CM that takes into account the planned operational approach and the proposed placement site. The CM, which can be a written document or a visual representation, identifies project scenarios that could result in contaminant exposure to ecological or human receptors or undesirable environmental effects (Bridges et al. 2005; EPA 1998). The goal of a CM is to explain how the dredging project could potentially expose organisms to contaminants in the sediment.

When developing this CM, readily available information is gathered to see whether there is sufficient information to make a technical determination without further data collection. Useful LOE include previous dredging evaluations, physical and chemical analysis, biological tests, scientific literature, and other relevant data. Section 1.6.3, "Initial Evaluation," provides more detail on making a technical determination during the initial evaluation.

The two figures below provide examples of CMs (Figures 1-1 and 1-2). Figure 1-1 is a generic CM that is relevant to the majority of dredging scenarios, depicting the potential contaminants' source, pathway, and receptors. The figure focuses on two major exposure pathways for aquatic DM placement—water column and benthic.<sup>23</sup> Figure 1-2 is a more specific CM, depicting open water (offshore or deep water) placement of sediment using a hopper or barge. In this scenario, the vessel instantly releases DM into the water-column release zone.

---

23. 40 C.F.R. 230.61(b)(2); 40 C.F.R. 230.61(b)(3).

Figure 1-1. A generic conceptual model (CM) for dredged material (DM).  
(Accessible version available in Appendix A.1.)

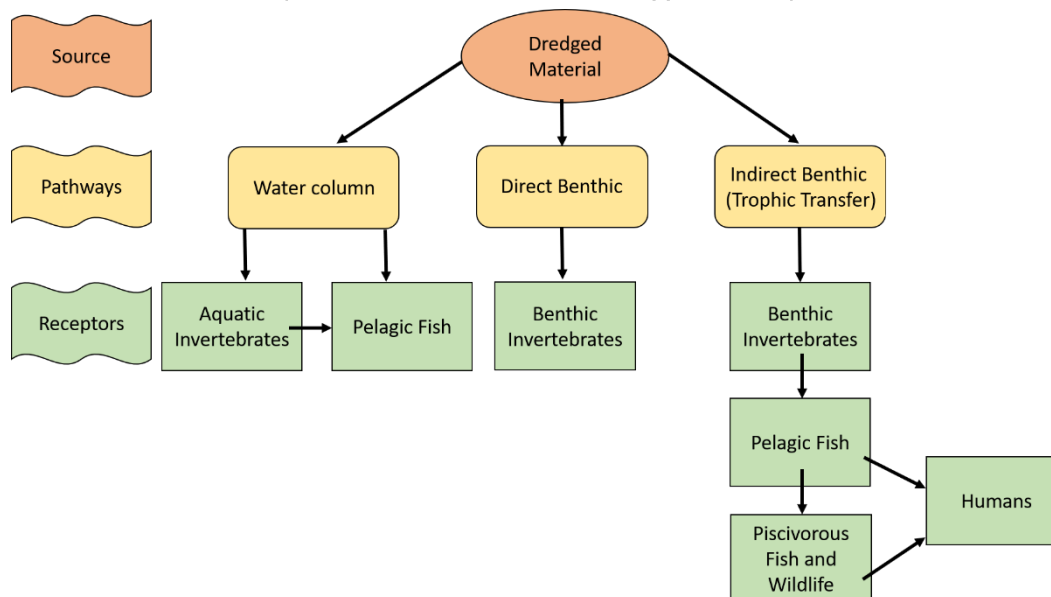
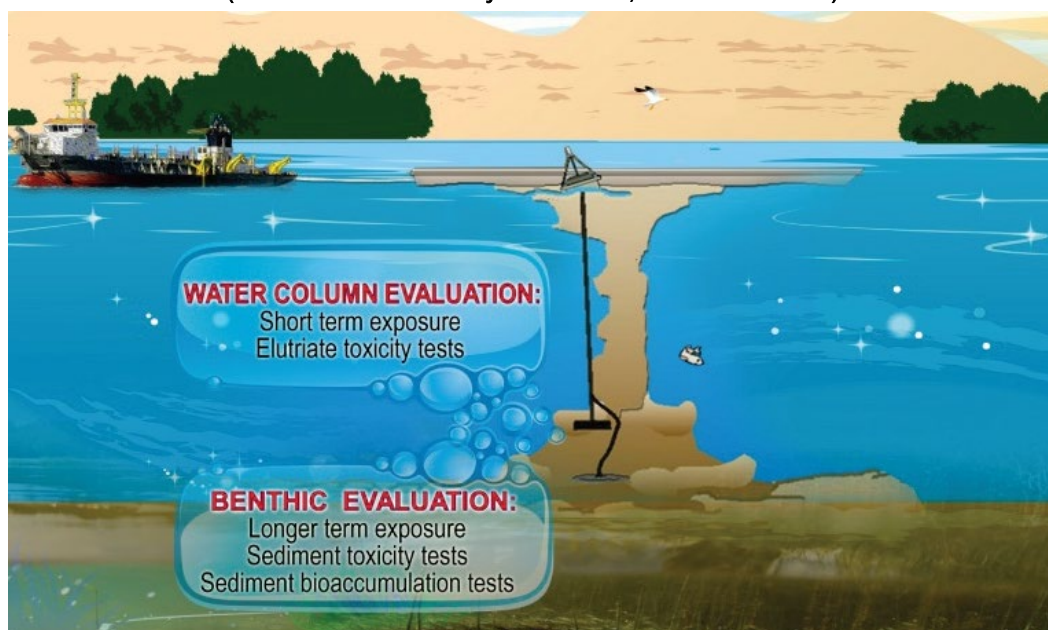


Figure 1-2. CM for open-water sediment placement.  
(Modified from Kennedy et al. 2015, 2. Public domain).



When examining the benthic pathway, both direct and indirect environmental effects should be considered (Figure 1-2). Direct effects include the uptake of bioavailable chemicals in the sediment, which could potentially result in toxicity to sediment-dwelling organisms at the placement site. The whole sediment toxicity test, described in Section 3, is used to evaluate direct impacts of sediment-borne contaminants on

benthic invertebrates. Indirect effects deal with trophic transfer (transport through the food chain) of contaminants. This type of transfer can occur if benthic organisms, after biouptake and bioaccumulating contaminants of potential concern (COPC) from the environment, are then consumed by a predatory animal. Indirect effects on benthic organisms are also tested in the whole-sediment bioaccumulation test,<sup>24</sup> further described in Section 6.

If insufficient information is available for the technical determination when conducting the initial evaluation, the user should proceed to the next step of the dredging evaluation: considering potential exposure scenarios. The CM from the initial evaluation is updated with this newly collected data.

### **1.6.2 Assessment of potential environmental impacts**

Once the CM is developed and potential undesirable environmental impacts of the project are outlined, ecological risks are evaluated using LOE.<sup>25</sup> The WOE approach evaluates individual LOE to reach a technical determination (Figure 1-3).

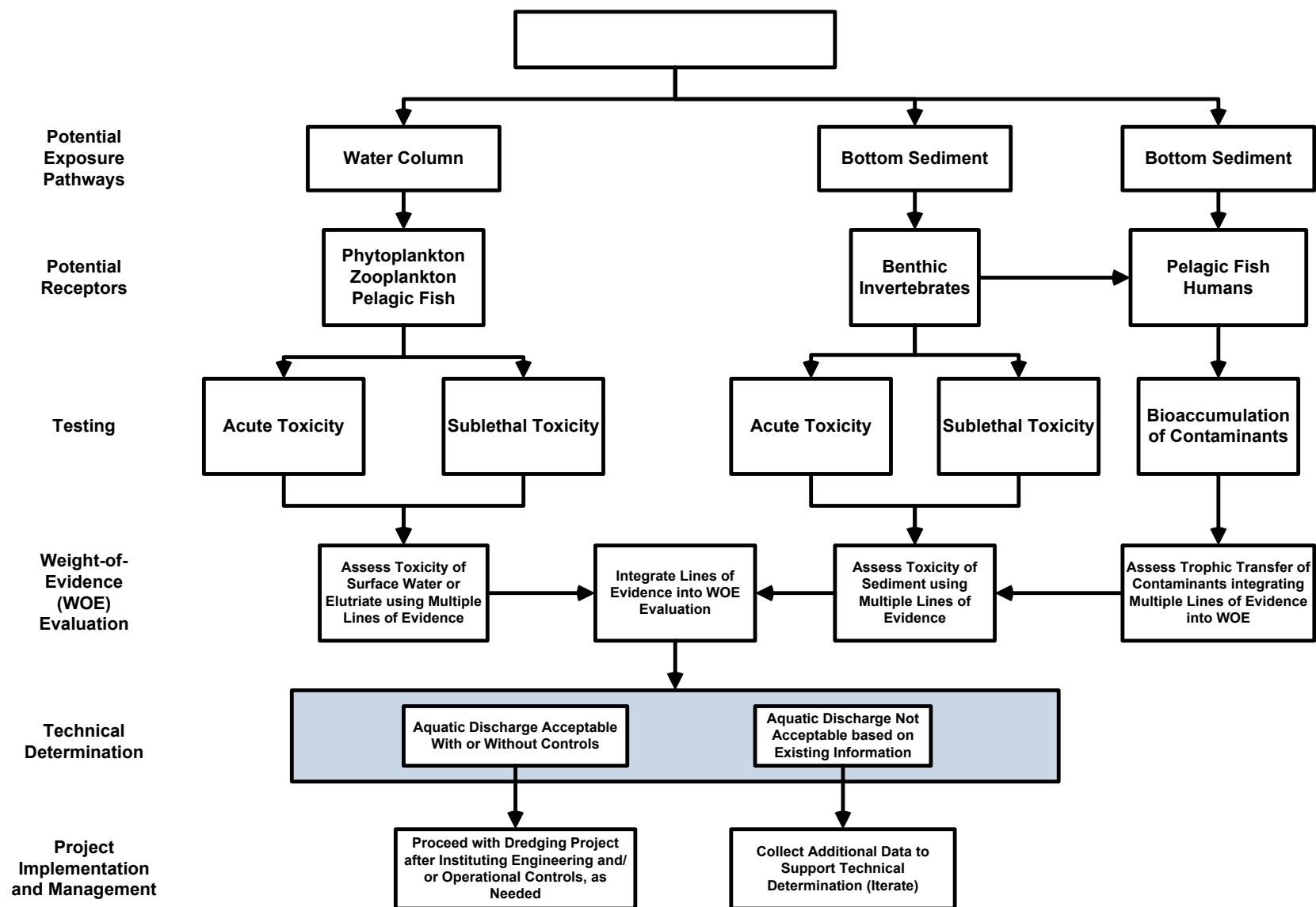
The relationships identified in the CM—the source, exposure pathways, and receptors—directly relate to subsequent testing and evaluation, the results of which inform the technical determination and risk management decision (Figure 1-3). Placement of DM leads to potential direct and indirect exposure pathways in the water column and benthos. Toxicity testing requirements are chosen according to the organisms (receptors) present at the placement site. Toxicity test data and other LOEs are used to create a WOE used for the technical determination. This technical determination may find that operational or engineering controls are needed to reduce adverse environmental impacts. If a technical determination cannot be made with the available information, further information and data should be collected. This process illustrates how the CM should be used to inform and guide the dredging evaluation process.

---

24. 40 C.F.R. 227.6(c)(3).

25. 40 C.F.R. 230.11; 40 C.F.R. 227 Subpart B.

Figure 1-3. Relationships between components of the conceptual model (source, exposure pathways, receptors) and subsequent sediment testing and evaluation methods for aquatic placement of DM. (Accessible version available in Appendix A.2.)



If the risk evaluation determines that adverse effects of sediment placement are unacceptable, risk management options can be considered. Risk management approaches can be carried out via operational or engineering controls. Operational controls, such as reducing sediment volume during placement events by performing several smaller sediment placements, intend to reduce exposure to elevated levels of COPC. Engineering controls, such as capping contaminated sediment with a clean layer of sediment, aim to reduce or eliminate potential exposure pathways. Physical or numerical models, pilot studies, and professional knowledge can be used to estimate the effectiveness of these control methods.

The technical determination is made according to a level of uncertainty deemed appropriate for the project. However, in situations where greater certainty is required, the technical determination may include requirements that necessitate particular conditions be met when implementing the project (for example, turbidity measures within 10% of background). Adaptive management techniques can be used to address uncertainty in a systematic yet flexible way (for example, if turbidity exceeds 10% of background, reduce operating speed to reduce sediment resuspension).

### **1.6.3 Initial evaluation**

For MPRSA and CWA, an initial evaluation is conducted to determine whether the DM is suitable for placement. This initial evaluation begins with an examination of existing information to see whether a technical determination can be made or additional information will be required. If the available LOE are sufficient, biological testing and other assessments may not be needed.

The initial evaluation consists of four steps:

1. Evaluate readily available information (for example, from previous evaluation reports, DEVOID tool, pollution incident reports) and technical determinations.
2. Determine whether the DM may be excluded from further testing requirements (see Table 1-1; guidance provided in DEMAND tool).
3. Analyze physical and chemical characteristics of representative samples for comparison with prior data and available sediment quality guidelines (from previous evaluation reports, DEVOID tool).

4. Frame the evaluation, considering possible beneficial uses for the DM (for example, whether COPC were identified in previous evaluations).

Sediments meeting certain criteria may be excluded from further testing because they have minimal environmental risk.<sup>26</sup> If material satisfies the requirements for an exclusion, the basis for this exclusion must be documented in the project record or in the DEMAND tool report.

In the initial evaluation process, readily available information is collected to inform the technical determination. Such information includes previously collected physical, chemical, and biological data. If site conditions, receptors and pathways remain unchanged, previously conducted technical determinations and evaluations may still be representative for a project. Establishing suitability based on these earlier technical determinations and evaluations may include a comparison of current bulk sediment chemistry with results of previously collected data and the application of models (see Section 4.5) for the evaluation of theoretical bioaccumulation potential to any measured bioaccumulative constituents.

Sediment quality guidelines (SQGs), defined as “numerical chemical concentrations intended to be either protective of biological resources, or predictive of adverse effects to those resources, or both” (Wenning and Ingersoll 2002, 5), can be helpful as screening values in the initial evaluation (Berry, Rubinstein, et al. 2003). However, sediment chemistry data alone are generally not sufficient for establishing potential toxicity to aquatic organisms.

If insufficient site information is available, the initial evaluation may involve sampling to gather information on the sediment’s physical and chemical properties. These data are important, as the evaluation process under both CWA and MPRSA includes a comparison of these DM characteristics to existing sediment at the designated placement site.

---

26. See, for example, those outlined in 40 C.F.R. 227.13(b) for MPRSA or 40 C.F.R. 230.60(c) and (d) for CWA.

**Table 1-1. Exclusions from testing under the Marine Protection, Research, and Sanctuaries Act (MPRSA) and the Clean Water Act (CWA)  
(language as appears in regulations).**

| Exclusions from testing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MPRSA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | CWA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>40 CFR 227.13(b): Dredged material which meets the criteria set forth in the following paragraphs (1), (2), or (3) of this section is environmentally acceptable for ocean dumping without further testing under this section:</p> <p>Dredged material is composed predominantly of sand, gravel, rock, or any other naturally occurring bottom material with particle sizes larger than silt, and the material is found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels; or</p> <p>Dredged material is for beach nourishment or restoration and is composed predominantly of sand, gravel or shell with particle sizes compatible with material on the receiving beaches; or</p> <p>When:</p> <p>The material proposed for dumping is substantially the same as the substrate at the proposed disposal site; and</p> <p>The site from which the material proposed for dumping is to be taken is far removed from known existing and historical sources of pollution so as to provide reasonable assurance that such material has not been contaminated by such pollution.</p> | <p>40 CFR 230.60(c): Where the discharge site is adjacent to the extraction site and subject to the same sources of contaminants, and materials at the two sites are substantially similar, the fact that the material to be discharged may be a carrier of contaminants is not likely to result in degradation of the disposal site. In such circumstances, when dissolved material and suspended particulates can be controlled to prevent carrying pollutants to less contaminated areas, testing will not be required.</p> <p>40 CFR 230.60(d): Even if the § 230.60(b) evaluation (previous tests, the presence of polluting industries and information about their discharge or runoff into waters of the U.S., bioinventories, etc.) leads to the conclusion that there is a high probability that the material proposed for discharge is a carrier of contaminants, testing may not be necessary if constraints are available to reduce contamination to acceptable levels within the disposal site and to prevent contaminants from being transported beyond the boundaries of the disposal site, if such constraints are acceptable to the permitting authority and the Regional Administrator, and if the potential discharger is willing and able to implement such constraints.</p> |

Data collected for an initial evaluation may include sampling and analysis for information about physical or chemical characteristics of the sediment. Physical attributes can be used to determine whether the sediment is excluded from further testing. Chemical attributes characterized during the initial evaluation can be compared to previous characterizations or used to screen testing needs for evaluating the pathways in subsequent analyses.

DM evaluations typically include an evaluation of the following potential exposure pathways, as indicated in Figure 1-2:

1. Water-column impacts—Collection of sediment samples for analysis of toxicological and chemical attributes important to understanding the release of contaminants from the solid phase to the suspended-particulate and aqueous phases during discharge and subsequent impacts to water-column organisms. Data produced from such samples may include chemical concentrations in sediment, organic carbon content, DM elutriate toxicity, and elutriate chemistry.
2. Benthic impacts—Collection of sediment samples for analysis of toxicological and chemical attributes important to understanding the direct toxicity of chemicals to benthic organisms. Chemical concentrations measured during the initial evaluation can be compared to applicable SQGs. Relevant data may include chemical concentrations, organic carbon content, and sediment toxicity to benthos.
3. Bioaccumulation impacts—Collection of sediment samples for analysis of attributes important to understanding the bioaccumulation of chemicals in benthic organisms and may be used to predict theoretical bioaccumulation potential. Data produced from such samples may include chemical concentrations, organic carbon content, and chemical concentrations in organisms exposed to sediment samples as well as an understanding of potential benthic receptors and potential food web interactions at the proposed placement site.

## **2 Supplemental Tools: Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) and Dredging Evaluation Visualization, Organization and Integration Database (DEVOID)**

### **2.1 Description and purpose of the software applications**

The 2022 versions of the DEMAND and DEVOID tools are independent but complimentary tools intended to be used together. The DEMAND tool can be used for initial project planning and documentation as well as recording decisions made during the dredging evaluation process. The DEVOID tool facilitates examination of historic information (for example, prior dredging evaluations) to support the initial evaluation (Section 1.6.3) and management decisions prompted within the DEMAND tool. For the DEVOID tool to be valuable, its associated database must be populated with the most recent dredging evaluations of the location(s) of interest.

### **2.2 Acquisition of the applications**

The DEMAND and DEVOID applications may be obtained by downloading them from the Dredging Operations and Environmental Research (DOER) website (<https://doer.el.erdcdren.mil/tools.html>) or contacting the authors. At the time this report was written, an alpha-tested version was available. Prospective users should periodically check the link or contact the authors to determine whether newer versions have completed development.

### **2.3 Running the applications**

A DEMAND and DEVOID application installation and user guide is described in Section 7.

### **2.4 Remainder of technical report**

The following sections provide general guidance for considerations and analyses encountered when using the DEMAND and DEVOID tools. The sections on sampling, water-column evaluation, sediment toxicity, and bioaccumulation assessment inform the user of considerations and procedures in greater detail than provided within the DEMAND tool.

### 3 Sampling and Analysis Logistics

While planning and executing sampling are critical phases to a successful dredging evaluation, these are outside the scope of this technical report and the purview of the DEMAND and DEVOID tools. A general, non-comprehensive overview of important logistical considerations for the planning, collection, and analysis of site water and sediment samples is provided for a basic understanding. Field mobilization is an expensive part of dredging evaluations, and the intensity of a sampling effort should be commensurate with the amount of data needed to provide an appropriate level of confidence in the results and conclusions. Prior to sampling efforts, it is critical to clearly define the data quality objectives for relevant pathways and end points identified in the project conceptual model (see Figure 1-2 for typical pathways and end points).

It is strongly recommended that a written plan for sediment sampling and analyses be prepared and provided to the appropriate federal and state agencies for coordination prior to sampling, where practical. This coordination can reduce the chance of having to repeat costly procedures and can facilitate keeping projects on schedule. Since mobilization is expensive and remobilization to the site is undesirable, the test material collected should be sufficient to allow all possible analyses and contingencies (that is, material can be archived and later disposed if not needed). Maximum allowable and recommended sample and organism holding times as well as the exigencies of resampling should be given careful consideration.

New data should supplement existing data and should only be collected after a review of readily available data is performed. Existing data can aid the layout of DM management units (DMMUs) and further sampling locations for pathway testing. Sampling for initial evaluation may be performed in a separate operation from subsequent sampling for pathways testing. However, because of the costs associated with mobilization and demobilization, it may be advisable to have a single collection effort (that is, collecting all the material that may be potentially required for a full evaluation) as a cost-saving measure should additional data need to be generated. Discrete samples (that is, samples collected from individual locations not composited into a management unit) can be analyzed under quick-turn analysis to inform subsequent compositing and evaluation as required. The initial data analysis may be conducted to verify that no

change in conditions has occurred, which would support use of existing data and evaluations.

Important considerations prior to and during field collection are listed below:

1. Prepare a QAPP or SAP for review by stakeholders.
2. Consider data quality objectives (DQOs).
3. Consider a robust sampling design and representative DMMUs, discrete sampling locations, and compositing and testing plan.
4. Consider sampling depths relevant to shoaling.
5. Consider sufficient sediment and water volumes to cover all subsequent evaluations and potential reanalysis to avoid expense of remobilization.
6. Consider selection and collection of a relevant (for example, location to disposal site, physical characteristics, background contamination levels) comparative reference sediment for the project DMMUs.
7. Consider the physical characterization of the sediment required for analysis, interpretation and to populate necessary dilution modeling parameters.
8. Consider required or project specific COPC lists for analytical chemistry based on local industry and use.
9. Consider required or discretionary biological testing needs, including water-column (sediment elutriate) effects bioassays, whole sediment toxicity tests (bedded sediment) and if determination of COPC bioaccumulation potential is needed. May also consider test organism selection according to their compatibility with the test material (that is, whether they inhabit, for example, sandy sediments, clays).

### **3.1 Reference sediments**

Reference sediment is used in evaluating the benthic effects of DM. For solid-phase toxicity and bioaccumulation tests, reference sediment provides a point of comparison against which effects of DM can be compared.

A reference sediment point of comparison relative to a DM being evaluated for open-water placement is consistent with the basic application, meaning, and intent of the CWA Section 404(b)(1) guidelines.<sup>27</sup> These guidelines contain testing and evaluation procedures

---

27. 33 U.S.C. § 1344(b)(1).

that require “comparing sediment at the dredging site with sediment at the disposal site,” both in terms of chemical and biological characteristics, which are directed at site specification.<sup>28</sup>

Reference sediment should be representative of sediment at the disposal site in the absence of disposal activity. Because subsequent discharges at a disposal site could conceivably affect the point of comparison, use of a reference sediment unaffected by previous discharges of DM should adequately reflect contaminant-related predisposal conditions in most cases. The reference sediment comparison is designed to assess the potential impacts of a proposed discharge relative to the ambient conditions of the water body of the proposed disposal site. Therefore, for the testing and evaluation of DM, this technical report will employ reference sediment as the point of comparison, because it provides a characteristic basis for predicting biologically meaningful contaminant-related benthic impacts resulting from the discharge of DM.

### **3.2 Collection of reference sediment**

Reference sediment collection should

- obtain physical characteristics, including grain size, as similar as practicable to the DM proposed for placement and the sediment at the disposal site;
- avoid areas in the immediate vicinity of, including depositional zones of, spills, outfalls, or other significant sources of contaminants; and
- be carried out as close as practicable to, and subject to the same hydrologic influences as, the placement site, but removed from areas subject to sediment migration of previous dredged-sediment discharges.

It may be necessary to use more than one reference sediment. If it is not possible to locate a reference sediment with physical characteristics similar to the DM proposed for open-water placement, tests should use organisms that are not sensitive to these differences.

---

28. 40 C.F.R. § 230.61(c)(1).

### **3.3 Reference sediment sampling approaches**

Three potential reference sediment sampling approaches, as discussed in the following sections, are recommended, because they allow for statistically valid comparisons.

#### **3.3.1 Reference point approach**

This approach is used when the placement site is known to be sufficiently homogeneous in terms of physical characteristics such that a single reference location is representative of the placement site. A single reference location is sampled, and the sediment is tested concurrently with the DM. Bulk chemistry or bioassay data on the reference sediment sample are compared to those on the DM proposed to be discharged.

#### **3.3.2 Reference area approach**

This approach is used when the placement site is known to be heterogeneous, and more than one reference location needs to be sampled to adequately characterize the placement site. Several reference locations are sampled, and a composite of all the sediments is tested concurrently with the DM. Bulk chemistry or bioassay data on the reference sediment composite sample are compared to those on the DM proposed to be discharged.

#### **3.3.3 Periodic reference approach**

This approach could be used when it is not desirable or possible to sample reference sediment each time that the DM is to be tested or when the test results on a given reference sediment are gauged to be unreliable. Bulk chemistry or bioassay data generated on reference sediments over time can be used to develop guidance values and associated confidence bounds. These data can be compared to the results on the DM proposed to be discharged for decision-making.

## **4 Testing and Assessment of the Water Column**

This section outlines procedures to evaluate contaminant impacts to the water column resulting from DM discharge at the aquatic disposal location. Placement or disposal of DM in open water may result in contaminant release into the water column and potential exposure of pelagic biota (organisms that dwell in the water column; Figures 1-2 and 1-3). The placement or disposal site is the primary concern for assessing impacts to pelagic communities. Testing and assessment as described should proceed until a technical determination can be reached for the water column.

### **4.1 Discharge of DM into the water column**

DM is discharged into the water column as individual discrete loads (for example, material barges and hopper dredges) or a continuous flow (for example, pipeline and side-casting hopper dredges). Dissolved contaminants partition between the carrier or captured water and DM particles during transport. The discharge of DM is commonly described in three phases: convective descent through the water column, dynamic collapse on the bottom, and long-term passive transport and diffusion (Johnson and Schroeder 1993). On release, the sediment descends as a discrete discharge or jet, which grows as it entrains ambient fluid. In 60 ft of water, this convective descent phase is typically completed in a few seconds. During descent, a portion of the extremely fine fraction and fluid with dissolved contaminants may be stripped and released to the water column. Once the material reaches the bottom or becomes neutrally buoyant, the material cloud or jet collapses and spreads horizontally, stripping additional material and releasing additional fine-grained solids and fluid as the discharge rapidly densifies on the sediment bed. The resulting clouds of stripped solids and fluid are then subject to turbulent diffusion and passive transport by local currents, becoming progressively more dilute.

Since suspended DM and associated contaminants are expected to exist as a discernible plume for a short time, the potential for exposure of organisms to the plume in the water column (Figures 1-2 and 1-3) is acute (short in duration) compared to longer-term (chronic) exposures

considered in the evaluations of benthic and bioaccumulation impacts. The potential for and magnitude of exposure will depend on the nature of the placement operation (for example, discrete barge or hopper discharge), continuous pipeline discharge, or placement directly on or near the bottom. For instance, for mechanical dredging operations, there may be little entrained water, and much of it may be tied up in DM clumps and not released to the water column. Hydraulic dredging operations, however, may release or exchange virtually all of the water in the DM.

## 4.2 Evaluation of impacts to the water column

Figure 4-1 provides the basic testing and assessment procedure to make a technical determination about the suitability of open-water discharge without unacceptable risk to the water column. An initial evaluation (Section 1.6.3) is first conducted to determine whether a technical determination can be reached using existing information. If a technical determination cannot be made during the initial evaluation, samples are collected and analyzed to perform detailed testing and evaluation. The evaluation approach outlined in this chapter uses two LOE to assess the risk to the pelagic environment (Figure 4-2).

The first LOE is compliance with National Water Quality Criteria (WQC) or State Water Quality Standards (WQS).<sup>29</sup> Sections 4.5–4.6 outline both desktop screening procedures and laboratory testing for evaluation of WQC and WQS compliance.

Figure 4-1. Bioassay testing.

MPRSA—required unless technical determination is made during initial evaluation (for example, meets exclusionary criteria)

CWA—informative for management decisions when there are COPCs without WQC and WQS and multiple COPCs are present for which COPCs are a concern

---

29. 40 C.F.R. § 230.10(b)(1).

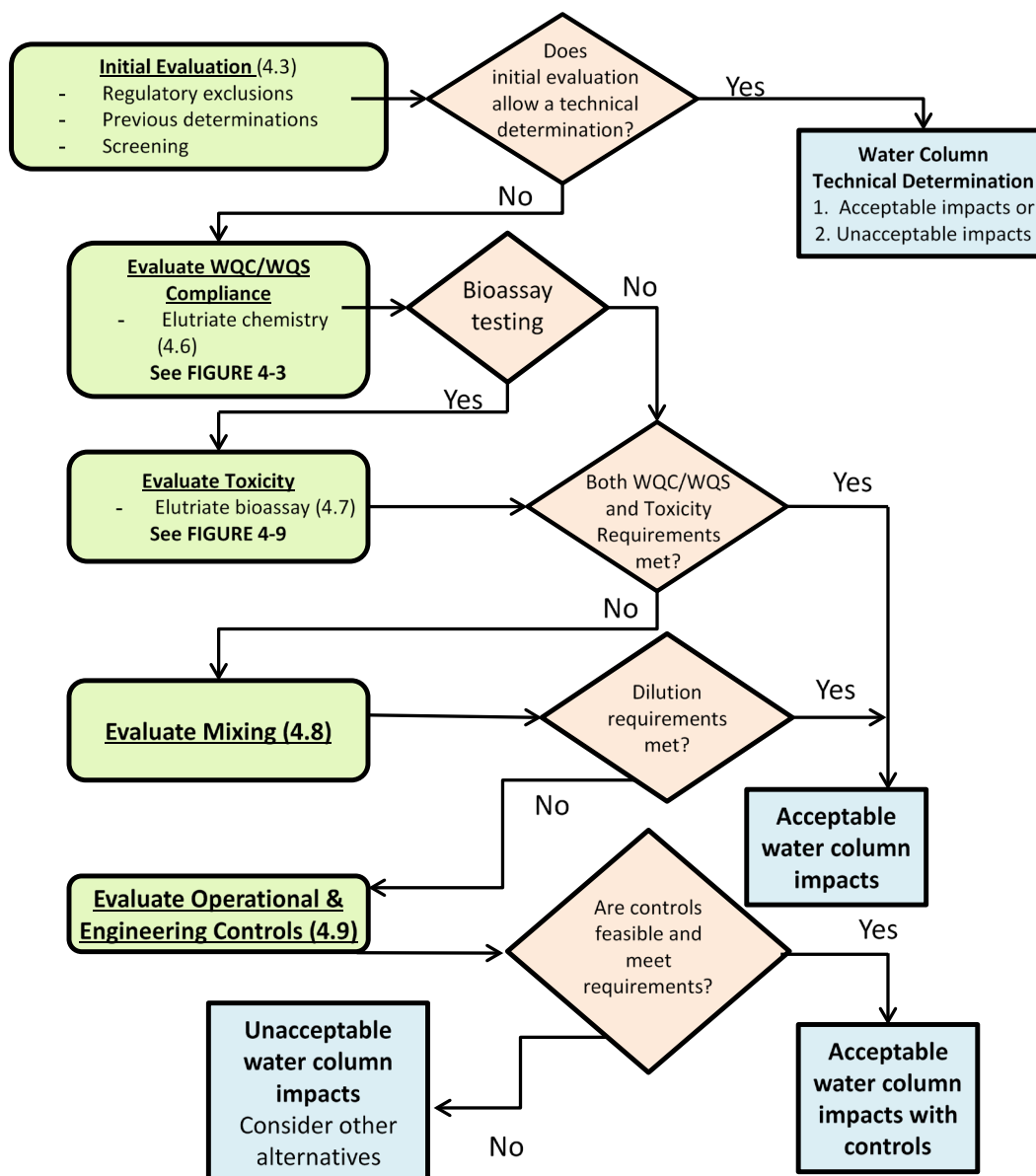
The second LOE is determination of water-column toxicity, as evaluated by elutriate bioassays detailed in Section 4.7.1. Under current regulatory guidelines, whether a determination can be made using one LOE or both are required depends on jurisdiction. Criteria for evaluation of permit applications for ocean dumping by the MPRSA specifies that both WQC and water-column toxicity (that is, biological testing) be evaluated for compliance, whereas guidelines for Section 404(b)(1) of the CWA requires WQC and WQS compliance and suggests the use of water-column bioassays only when deemed of value by the permitting authority.<sup>30</sup> When toxicity testing is required (MPRSA) or deemed useful for informing management decisions (CWA), comparison to WQC and WQS and toxicity tests may be performed in parallel. Both LOEs include consideration of dilution by mixing with the ambient water column. Numerical mixing models are available to quantify the necessary dilution required to meet both compliance criteria (Section 4.8). If dilution requirements are met (that is, sufficient mixing is determined such that WQC and WQS and, if needed, toxicity criteria will not be exceeded), a technical determination can be made that the discharge is acceptable relative to the potential for water-column impacts. Regardless of this result, benthic and bioaccumulation impacts should still be evaluated (Sections 3 and 4, respectively).

Failure to meet water-column compliance does not necessarily indicate the open-water placement cannot be performed. If compliance with either WQC and WQS or water-column toxicity is not demonstrated without restrictions, management alternatives such as operational or engineering controls (Section 4.9) can be used to reduce the risks. Controls typically result in a change in equipment size, dredging methods, placement methods and location, or mixing conditions such as velocity and can be evaluated by changes to the mixing model rather than laboratory procedures. If feasible controls cannot be identified, or compliance cannot be demonstrated, other placement alternatives will have to be considered.

---

30. 40 C.F.R. § 230.61(b)(2)(ii).

Figure 4-2. Water-column evaluation process. (Accessible version in Appendix A.3.)



### 4.3 Water-column pathway initial evaluation

As discussed in Section 1.6.3, the initial evaluation of the water-column pathway seeks to reach a technical determination using existing information. Regulatory exclusionary criteria should first be consulted to determine whether the sediment can be deemed environmentally acceptable without further testing. Section 1.6.3 also summarizes the exclusion criteria for both MPRSA and CWA; supplementary guidance is available in the DEMAND tool.

If regulatory exclusionary criteria are not met, a conceptual model should be developed for the water-column pathway—specifically, for the discharge alternative under consideration. Details specific to the nature of the discharge, the disposal site, and receptors are needed to fully understand the exposure scenario. This model should include how the material will be dredged, how and where the material will be released in the water column, nature of currents at the disposal site, and distance to disposal site boundaries.

All reasonably available existing information should be assembled to provide evidence as to potential adverse impacts to the water column, including (1) previously and presently collected physical, chemical, and biological data for the proposed site to be dredged and discharged; (2) previously collected water-column testing data and associated water-column evaluations; (3) information about the source of the material to be discharged to identify potential COPC; (4) nearby site data; and (5) information that might indicate changing site conditions (for example, spills, new discharges, floods, storms).

If the initial evaluation for the water column shows a lack of water-column toxicity according to the two LOE (compliance with WQC and WQS or bioassay results, or both), previous technical determinations should be considered for applicability to the current evaluation. For annual or episodic dredging, reevaluation may not be necessary if there are no significant changes in sediment composition, site conditions, discharge methods, or regulations. Any changes may be determined by a comparison of the physical and chemical characteristics of the proposed material to be dredged with previous characterizations of materials for which technical determinations were made. Screening methods (Section 4.5) can aid in comparing the characterizations for differences in potential adverse water-quality impacts. If significant changes have not occurred, the results of the previous technical determination may still be valid, contingent on USEPA and USACE concurrence.

If a technical determination cannot be made using previous evaluations, a determination may be made by comparing existing information to criteria or screening guidelines. To evaluate compliance with WQC and WQS, water-column concentrations can be estimated using bulk sediment concentrations. Section 4.5 presents the desktop screening approach.

If the initial evaluation does not result in a technical determination, a more rigorous water-column evaluation will proceed as detailed in the following sections.

#### **4.4 Water-quality criteria (WQC) and water-quality standards (WQS)**

An evaluation of potential impacts to the water column must determine that the concentration of contaminants will remain below national WQC and applicable state WQS (for aquatic life protection) after dissolved contaminants from the DM mix and disperse. Chemical concentrations below WQC and WQS are considered safe for aquatic organisms and protective of ecosystem health, according to toxicity tests in controlled settings under highly conservative conditions.

For many contaminants, WQC and WQS are derived for both acute and chronic effects (Figure 4-3). Determination of which criterion is applicable depends on exposure time. According to the (EPA-OWEP 1991), the term *chronic* defines a stimulus that continues for a relatively long period of time. Chronic is considered a relative term depending on the life span of an organism, often one-tenth of the life span or more. Organisms should be able to tolerate exposure to concentrations at or below acute criteria for a brief time with little to no impact and can be exposed indefinitely at or below chronic criteria without chronic effects (EPA-OWEP 1991).

Chronic exposure to DM discharges in the water column are not common for open-water placement operations. Discrete discharges (for example, most barge or hopper operations) result in a plume that is quickly diluted as it entrains water during descent, spreads during collapse on the sediment bed, diffuses from the source, mixes with ambient water, and is transported with the current. Thus, the water column at a given location is affected only for short periods of time, and acute WQS and WQC are therefore appropriate for comparison. Pipeline operations for open-water placement have intermittent discharges that may be continuous for periods of several hours, generating a plume in the water column, where there could be longer-term exposure of sessile or other organisms that do not avoid the plume. Continuous exposure of organisms for periods deemed chronic exposures may warrant the use of chronic WQC and WQS.

Figure 4-3. Consideration of relative effects and modes of toxic action.

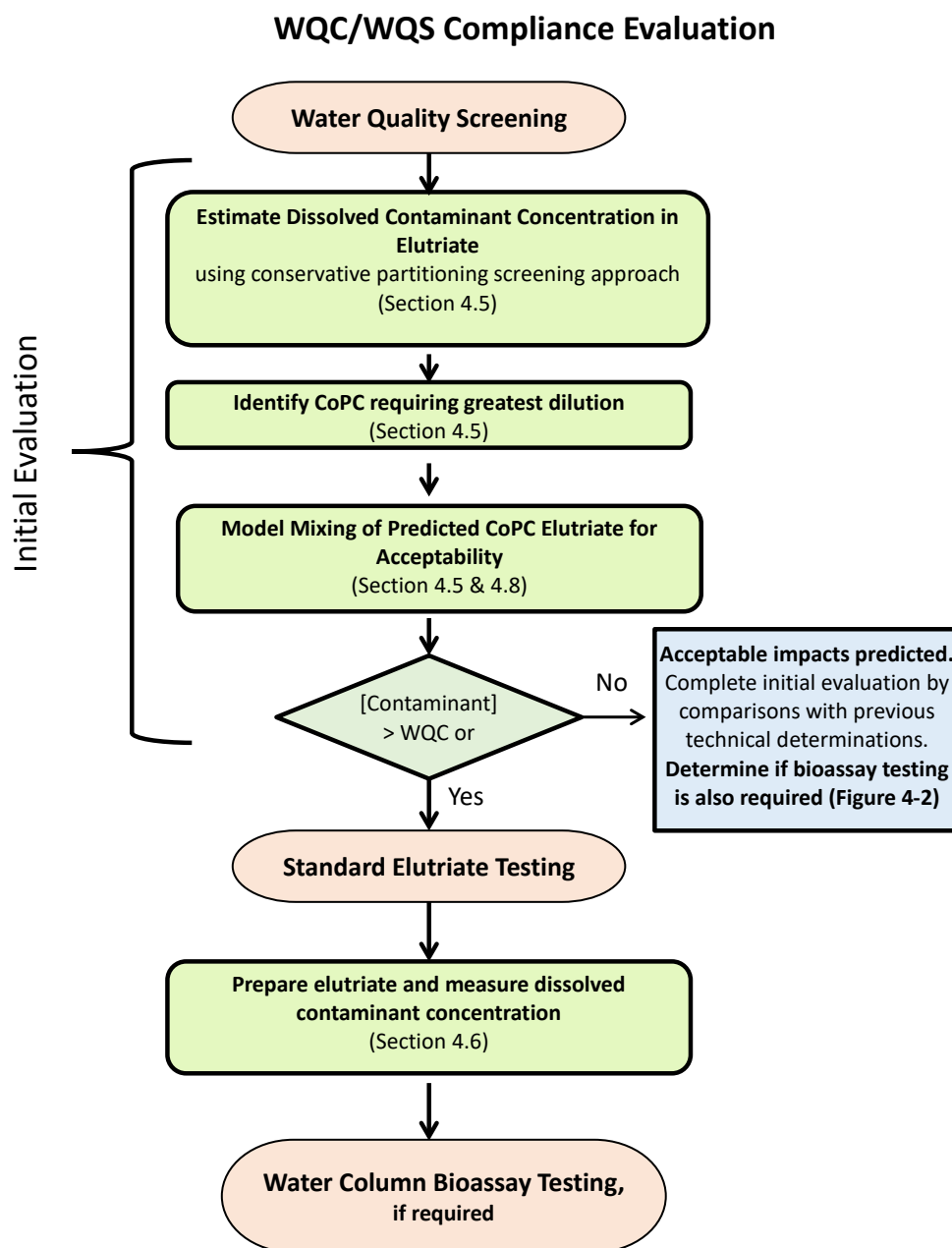
To determine the potential level of concern regarding interactive effects, consider the number and classes of contaminants that may be exceeded and the relative degree of exceedance. Interactive effects may be synergistic (the resulting effect is greater than the sum of the effects stemming from individual contaminants) or antagonistic (the resulting effect is less than the sum of the effects stemming from individual contaminants). Chemicals of the same class may have the same mechanism of toxicity and are more likely to elicit additive effects. In cases where several contaminants in the DM and water concentrations after mixing are close to WQC and WQS—especially if they are the same class of contaminants—synergistic effects may be considered. If there is a potential for synergistic effects, or if there are COPCs without applicable WQC and WQS, toxicity should also be evaluated using elutriate bioassays (Section 4.7), as required by the MPRSA.

An important factor in predicting adverse effects on organisms are based on exposure to a given concentration over a period of time. Yet, it is apparent that water-column concentrations are not constant with respect to space and time. It may therefore be necessary to apply an average concentration over a particular time frame and area of influence. The USEPA recommends an averaging period of one hour for acute criteria and four days for chronic criteria (EPA-OW 2002b). State WQS may specify different averaging periods. For contaminants that are shown to exceed WQS and WQC, but typically do not persist in the water column for long periods of time (that is, because of volatilization or degradation), it may be advisable to seek a waiver.

Comparison to WQC and WQS may be insufficient to fully evaluate the risk associated with exposure to DM contaminants released to the water column. Making a determination solely based on compliance with WQC and WQS is not adequate when (1) there are COPC that do not have WQC and WQS; or (2) multiple COPC are present that have potential to induce synergistic effects (Figure 4-3). In either case, it is recommended (and currently required under MPRSA) to perform elutriate toxicity tests to further assess toxicity potential (Figure 4-4). This additional toxicity-

potential testing may involve a conservative screening approach (Section 4.5), which, if insufficient for supporting a decision, may be followed by a chemical analysis of COPC concentrations (in the laboratory) of the liquid phase (DM standard elutriate), as described in Section 4.6. Stakeholders may discuss use of analytical chemistry and toxicity test results as LOEs to inform a final management decision.

Figure 4-4. Evaluation of water-quality criteria (WQC) and water-quality standards (WQS) compliance. (Accessible version available in Appendix A.4.)



## 4.5 Desktop screening to estimate concentrations considering partitioning

The first step to evaluate WQC and WQS compliance can be employed during the initial evaluation. This desktop screening approach is applied to conservatively estimate contaminant release into the water column.

The partitioning-based screening approach estimates the maximum water-column concentration of contaminants resulting from partitioning between the DM solids and their pore water or slurry water during open-water disposal, considering the concentrations of solids and contaminants. The approach is based on conservative partitioning assumptions informed by conservative design and operating principles for open-water disposal. Prior to dredging, contaminants are in a state of equilibrium between sediment particles and pore water, such that there is a constant ratio ( $K_d$ ) of the contaminant concentration adsorbed on the particles to the dissolved concentration in the pore water. The equilibrium constant,  $K_d$ , is a function of organic carbon content and the organic carbon partition coefficient ( $K_{oc}$ ). Upon dredging, additional carrier water is entrained, which mixes (to an extent) with the pore water. While the carrier water dilutes the original pore water, additional contaminants are stripped from the particles as the slurry reaches a new equilibrium. The dissolved concentration in the slurry can be calculated based on  $K_d$ . However, equilibrium is unlikely to be achieved during the short period between dredging and disposal, therefore the assumption of equilibrium provides a conservative boundary condition. This screening procedure is available for evaluating open water disposal that involves both mechanically dredged and hydraulically dredged or offloaded sediments (Schroeder et al. 2006).

The partitioning approach uses the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS; available at <https://dots.el.erdcdren.mil/models5.html>) screening tool for execution of calculations (ERDC-EL 2023). Equations for performing the calculations manually also are available (Schroeder et al. 2006). Project-specific information regarding disposal methods, initial mixing, and DM properties is entered in the appropriate cells of the spreadsheet. The evaluation uses these data and conservative default values for contaminant properties to calculate a predicted maximum concentration for the contaminants prior to mixing with ambient water. Required dilution is calculated by comparison with national WQC or state WQS. Mixing models (Section 4.8) can then be used

to determine whether the required dilution can be achieved at the site. Note that the model need only be run for the contaminant that requires the greatest dilution. If the conservative estimate of this contaminant concentration is shown to meet the WQC and WQS, all other contaminants requiring less dilution will also meet the WQC and WQS. Likewise, if the predicted concentrations are below WQC and WQS prior to mixing, no dilution is necessary and there is no need to model mixing.

The partitioning and dilution calculations will result in one of the following outcomes:

- When the water-column concentrations of listed COPCs are predicted to be less than applicable WQC and WQS after initial mixing at the relevant time and location, all contaminants have applicable WQC and WQS, and there is no concern about interaction of contaminants, no further water-column evaluations to demonstrate WQC and WQS compliance are necessary. Under the CWA, compliance with WQC and WQS provides sufficient WOE to show that the discharge will not result in water-column toxicity. The DM is suitable for discharge without additional management options. Under the MPRSA, however, elutriate bioassays are also required to provide another LOEs for water-column toxicity.
- When the water-column concentrations of listed COPCs are predicted to be less than applicable WQC and WQS after initial mixing at the relevant time and location, but either some COPCs do not have WQC and WQS for comparison or there are concerns about contaminant interaction, there is remaining uncertainty with regard to whether the discharge will result in water-column toxicity. Therefore, it is recommended (and currently required under MPRSA) that elutriate bioassays be conducted to further assess water-column toxicity.
- The water-column concentrations of one or more dissolved contaminants are predicted to exceed applicable WQC and WQS and the required dilution is not achievable by initial mixing. In this case, because of the conservative nature of the evaluation, it is still uncertain whether water-column impacts will result. Elutriate chemistry testing is recommended to refine predicted contaminant concentrations to make a determination regarding water-quality impacts. Although operational or engineering controls could be considered at this point, it is likely more practical and cost-effective to use measured

concentrations from the liquid phase as well as elutriate bioassays to further assess water-column toxicity.

## 4.6 Comparison of the liquid phase to WQC and WQS

When the screening-level evaluation of sediment chemistry and comparison to WQC and WQS are insufficient to determine whether disposal of DM will result in adverse effects to the water column, laboratory testing is needed to provide more accurate water-column concentrations. The standard elutriate test (SET) generates an aqueous extract (elutriate) considered representative of the liquid component of the DM prior to mixing. In this procedure, concentrations of freely dissolved chemicals released from DM are simulated by elutriate testing and measured (rather than estimated as in the screening-level approach).

Procedures are given below for conducting the SET and evaluating the results. The same SET preparation procedure is also used for preparing elutriates to evaluate toxicity (Section 4.7).

### 4.6.1 Elutriate preparation

Several types of elutriate tests are available for various purposes. These include the modified elutriate test (MET) or effluent elutriate test (EET) for point discharges from confined disposal operations (USACE 2003), the dredging elutriate test (DRET) for releases at the site of dredging from dredging operations (DiGiano et al. 1995), and the SET, which most commonly applies to the evaluation of an open-water discharge at a placement site. The following procedure for elutriate preparation, as described in 40 CFR § 227.32, generates elutriate for both dissolved chemical analysis (liquid phase only) and toxicity analysis (suspended particulate phase, which includes the liquid phase).<sup>31</sup> The CWA does not provide specific procedures regarding elutriate evaluations.

Water collected from the dredging site is recommended for the preparation of sediment elutriates. Stakeholders may discuss use of laboratory water if more logistically feasible. Dredging site water should be used to prepare elutriates as soon as possible but no longer than four weeks after collection.<sup>32</sup> Guidance for proper storage, handling, and

---

31. 40 C.F.R. § 227.32(b)(1).

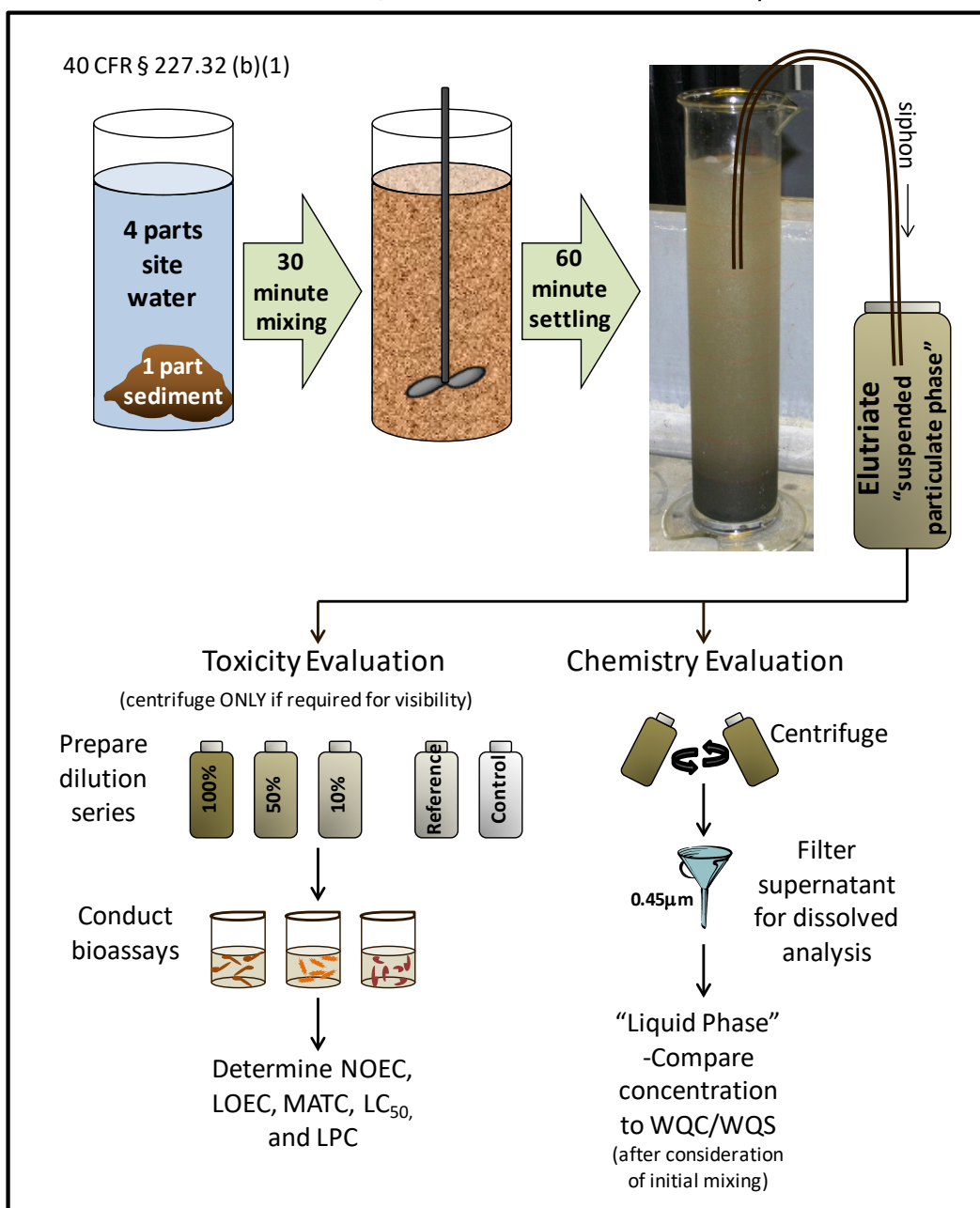
32. The dredging site water should be analyzed for contaminants within two weeks of collection.

manipulation of sediment (for example, homogenization) is available (EPA-OST 2001). Sufficient elutriate should be prepared for the chemical analyses (including matrix spike and duplicate analyses as required by analytical procedures), and for the water-column toxicity tests if needed. Note that large amounts of elutriate (for example, 15 to 40 L) may be needed for analytical chemistry and bioassay testing with some species. If multiple batches of the same elutriate are prepared to meet volume requirements, these batches must be composited prior to analysis.

A SET is prepared by subsampling the thoroughly homogenized DMMU composite sample. Sediment may be homogenized with a mechanical mixer or other approved method. Alternative methods may be required for relatively dry sediments, sands, or clays. The DM and unfiltered dredging site water are combined in a sediment-to-water volumetric ratio of 1:4 at room temperature ( $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ), ideally by volumetric displacement (Figure 4-5). The mixture is stirred vigorously for 30 minutes. At 10-minute intervals, the mixture should be visually inspected and manually stirred to ensure complete mixing and continual suspension of all solid-phase material. After the 30-minute mixing period, the sediment-water suspension is allowed to settle for one hour. The supernatant is carefully siphoned off without disturbing or incorporating the settled material. This elutriate (liquid phase and the material remaining in suspension following the settling period) is defined as the 100% suspended particulate phase that would be used for bioassays (note that centrifugation may be recommended for CWA jurisdiction evaluations comparing to WQC and WQS). If the supernatant (suspended particulate phase) represents less than 40% of the total volume, centrifuging the entire mixture (supernatant and settled solids) may be considered to increase elutriate yields. The elutriate should be split into separate aliquots for chemical analysis and, if needed, toxicity testing.

The portion of elutriate targeted for chemical analyses should be centrifuged to remove particulate to facilitate filtration. The centrifuged supernatant is filtered ( $0.45\ \mu\text{m}$ ) to obtain the liquid phase elutriate prior to chemical analysis of dissolved contaminants.

Figure 4-5. Elutriate preparation procedure. (NOEC—no observable effect concentration; LOEC—lowest observable effect concentration; MATC—maximum allowable toxicant concentration; LC<sub>50</sub>—median lethal concentration.)



In general, elutriates prepared for toxicity tests are not centrifuged. However, if the suspension is too turbid after 60 minutes' settling for test organism observations, the supernatant may be centrifuged until the suspension is clear enough for the organisms to be visible in the testing chamber (for example, 1,500× *g* for 15 minutes; repeat for additional 15 minutes or increase speed to 3,000× *g* only if necessary); note that the objective of centrifugation for bioassays is to reduce turbidity for the

purposes of organism observation, not to completely remove particles from suspension. Centrifugation is not recommended when turbidity is lower than 50 nephelometric turbidity units (NTU).

#### **4.6.2 Chemical analysis of elutriate for determining compliance with WQC and WQS**

Chemical analysis of the liquid phase of the standard elutriate allows direct comparison to applicable WQC and WQS. Note that the contaminant requiring the greatest dilution as previously calculated from bulk sediment chemistry (Section 4.5) may not be the same as the contaminant requiring the greatest dilution to achieve compliance as calculated from standard elutriate tests, due to differences in hydrophobicity, solubility, and affinity for the sediment particles. The dilution,  $D$ , which would be required to meet the WQC and WQS should be determined for all of the contaminants detected during chemical analysis of elutriate for which there are WQC and WQS using the following equation:

$$D = \frac{(C_e - C_{wq})}{(C_{wq} - C_{ds})}, \quad (1)$$

where

- $D$  = dilution to meet WQC and WQS,
- $C_e$  = concentration of the dissolved contaminant in the standard elutriate in micrograms per liter ( $\mu\text{g/L}$ ),
- $C_{wq}$  = applicable WQC or WQS in micrograms per liter ( $\mu\text{g/L}$ ), and
- $C_{ds}$  = background concentration of the contaminant at the discharge site in micrograms per liter ( $\mu\text{g/L}$ ).

The  $C_{ds}$  should be obtained by sampling the placement site or according to previously collected chemistry information obtained from the discharge site. When  $C_{ds}$  is reported as nondetect in the chemical analysis and the method detection limit is higher than  $C_{wq}$ ,  $C_{ds}$  should be reported as 0.5  $C_{wq}$ . When  $C_{ds}$  is reported as nondetect in the chemical analysis and the method detection limit is lower than  $C_{wq}$ ,  $C_{ds}$  should be reported as 0.5 times the method detection limit.

If the constituent concentration in the elutriate ( $C_e$ ) is less than  $C_{wq}$ , no calculation is necessary, since no dilution is required and DM elutriate is already in compliance with WQC and WQS. The  $C_e$  may be reported as a nondetect value when the concentration is lower than the method detection limit. In this case, assume that  $C_e$  is equal to the lowest level of detection or, if lower, the predicted concentration from partitioning screening.

Once the elutriate concentrations are determined, and the contaminant requiring the greatest dilution is identified, a numerical mixing model is used to determine whether WQC and WQS are exceeded outside the mixing zone or mixing period. After consideration of the elutriate water-quality information and consideration of initial mixing, one of the following scenarios exists:

- Water-column concentrations of COPCs are predicted to be less than applicable WQC and WQS after initial mixing at the relevant time and location, COPCs have applicable WQC and WQS, and there is no concern about interaction of contaminants. Unacceptable risks in the water column are not expected according to WQC and WQS compliance, and no further water-column assessment is necessary to demonstrate compliance with criteria. Under CWA regulations, WQC and WQS compliance is sufficient to make a determination regarding water-column impacts; therefore, no further water-column assessment would be necessary, and it is not necessary to implement additional management options. However, under the MPRSA, toxicity evaluation is also required to make a determination.
- Available WQC and WQS are not exceeded, but WQC and WQS are not available for one or more of the COPCs identified for the project, or there is concern about interactive effects. While no further water-column evaluations are necessary to demonstrate WQC and WQS compliance, information is not sufficient to reach a decision regarding water-column impacts. In this case, conduct elutriate toxicity testing to generate the data needed to support a decision.
- Water-column concentrations of one or more contaminants are expected to exceed applicable WQC and WQS after consideration of initial mixing at the relevant time and location. If disposal is occurring in an impaired water body, see the following section (Section 4.6.3) to determine whether the discharge is acceptable. Otherwise, evaluate management actions to prevent exceedances by increasing dilution.

Management alternatives are typically assessed using the mixing models. If toxicity testing is also required, the greatest level of dilution required to meet both WQC and WQS and toxicity requirements is determined. If management actions cannot yield sufficient dilution, the DM is not considered suitable for open-water disposal.

#### **4.6.3 Disposal in impaired systems**

There may be placement sites where the ambient discharge site water concentration ( $C_{ds}$ ) of a constituent is greater than  $C_{wq}$ . In these cases, discharge is occurring in an impaired water body, and water-quality criteria at the placement site cannot be achieved by dilution. If the concentration of the dissolved contaminant in the standard elutriate is higher than the WQC or WQS but lower than the background concentration of the contaminant at the discharge site (that is,  $C_e > C_{wq}$  and  $C_e < C_{ds}$ ), it should be deemed acceptable (discharge of elutriate would not further degrade the water body).

If the concentration of the dissolved contaminant in the standard elutriate is higher than the WQC or WQS and higher than the background concentration of the contaminant at the discharge site (that is,  $C_e > C_{wq}$  and  $C_e > C_{ds}$ ), dilution to WQC or WQS is not possible, and further degradation of the system may occur. However, direct contaminant releases to the water column from discharge in open water pose short-term impacts, may yield insignificant increases in water-column concentration at the edge of the disposal site, and are not likely to significantly degrade the system, while benthic impacts are potentially long term and may contribute to system degradation. The acceptability of discharge should be evaluated by a comparative risk assessment. Consult the USACE and USEPA regional office about local policy.

### **4.7 Evaluation of impacts using biological testing**

The objective of water-column toxicity tests is to directly determine the potential impact of a sediment elutriate on organisms in the water column and the dilution necessary to reduce risk to an acceptable level. During elutriate toxicity tests, organisms are exposed to elutriates prepared using dredging site water and sediment. The resulting elutriate may then be diluted with water from the discharge site, laboratory water, or other approved water (Section 4.7.2). Organisms are then exposed to the dilution series. When sufficient toxicity is observed, calculation of a no

observable effect concentration (NOEC), lowest observable effect concentration (LOEC), median lethal concentration (LC<sub>50</sub>), or median effective concentration (EC<sub>50</sub>), where applicable, is performed to provide an estimate of the acute effect (Section 4.7.3). These results are used to determine a limiting permissible concentration (LPC) to evaluate whether concentrations of contaminants after mixing and dilution comply with the MPRSA or CWA requirements for open-water disposal (Section 4.7.6). The MPRSA states that the LPC is determined by multiplying a concentration that is acutely toxic by an application factor (AF). Calculation of the LPC is not specified under the CWA, and specific methods are subject to regional approval. Below is a procedural overview of the evaluation of elutriate toxicity:

1. Prepare sediment elutriate.
2. Perform elutriate toxicity tests.
3. Determine the LPC if acute toxicity is observed; otherwise, the DM is not expected to result in water-column toxicity.
4. Model mixing of the DM (Section 4.8) to determine whether dilution is sufficient to meet the LPC.
5. If dilution is not sufficient, evaluate operational or engineering controls to manage water-column risk.
6. As further discussed in Section 4.7.4, the evaluation procedure may depend on whether ammonia is expected to influence toxicity.

#### **4.7.1 Evaluation of elutriate toxicity to water-column receptors**

Elutriate toxicity testing may be required under the MPRSA and necessary under the CWA for projects in the absence of applicable WQC and WQS for COPCs or because of concerns about interactive toxic effects of the contaminant mixture. Any water-column toxicity data generated for a project should be made available to relevant USEPA regions and USACE districts for compiling into a widely available database (for example, USACE district websites) to more easily locate existing information to make decisions about the need for analytical and biological testing in future projects. Elutriate toxicity tests directly evaluate the acute toxicity of DM by exposing relevant, standard water-column organisms (Figure 4-6) to the elutriate prepared with dredging site water and sediment. Test organisms are exposed in the laboratory for 48 or 96 hours, depending on the selected test method. The organisms are examined at the end of the test, and sometimes at specified intervals during the test, to determine

whether the test material is producing a predefined biological effect (for example, significant mortality).

Figure 4-6. Elutriate toxicity bioassay setup.



#### 4.7.2 Preparation of elutriate dilutions

The elutriate is prepared as described in the preceding section (Section 4.6.1) in sufficient volume for toxicity testing. Dilutions of the elutriate are needed if acute toxicity<sup>33</sup> is observed in the undiluted (100%) elutriate to provide data suitable for conducting statistical analysis and establishment of an NOEC. Thus, three concentrations (for example, 100%, 50%, and 10%) of the prepared elutriate are typically used in toxicity tests. Greater dilution (for example, 1% elutriate) may be required for some elutriate waters or for very sensitive test species; it may be more cost effective to include dilutions upfront to avoid the need to repeat a bioassay. Alternative dilution concentrations are allowed, but the concentrations must bracket the  $EC_{50}$  and allow calculation of an NOEC.

Dilution water must not be stressful to test organisms and is used to simulate dilution at the placement site. It may not be logistically feasible to collect water from the placement site. Therefore, laboratory-reconstituted water, clean natural water, or other approved water may be used. Table 4-1 summarizes use of different types of water in elutriate toxicity testing. It is

---

33. Defined as reduction in the test end point that is at least 10% reduced (20% for development tests) and statistically significantly different from the reference condition.

recommended that the dilution water be approved prior to conducting testing. To properly evaluate the test results, organisms are also exposed to the dilution water. It is recommended that the water used to prepare the elutriate also be tested (without DM) for comparison (that is, determine baseline effects on organisms). The dilution water is used as the comparative control for statistical analysis and acceptability determinations.

**Table 4-1. Summary of media used in elutriate toxicity testing. Testing of each medium is required as a treatment in biological testing unless otherwise specified.**

| Application                                                                  | Test medium                                                                                                                                                                   |
|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Elutriate preparation                                                        | DM or sediment (1 part);<br>Dredging site water or other approved water (4 parts)                                                                                             |
| Water for elutriate dilution                                                 | Disposal site water, laboratory reconstituted water, clean natural water, or other approved water                                                                             |
| Water for elutriate dilution                                                 | For toxicity test specific organism performance acceptability criteria                                                                                                        |
| Reference water (0% treatment) for statistics                                | Dilution water (above)                                                                                                                                                        |
| Negative control (for reference toxicant test assessment of organism health) | Culture or holding water (often laboratory reconstituted water or clean natural water). May also be used as the approved dilution water.                                      |
| Comparative reference (recommended)                                          | Elutriate preparation water (if different from the dilution water)                                                                                                            |
| Reference toxicant test                                                      | A reference chemical is diluted into water (typically the control water) to generate an LC <sub>50</sub> or EC <sub>50</sub> , or both, to compare to historic control charts |

### 4.7.3 Test organisms, assessment end points, and test methods

Organisms selected for elutriate toxicity testing should be species recommended by ASTM International (West Conshohocken, Pennsylvania) and the USEPA, as appropriate, while best representing the pelagic communities at the placement site. Current MPRSA language requires testing of three sensitive marine organisms representing (1) phytoplankton or zooplankton, (2) crustacean or mollusk, and (3) fish. Under the CWA, two species representing different taxonomic groups are recommended. Table 4-2 lists test organisms for which sufficiently developed toxicity testing protocols and interpretative guidance exist. Other regionally important species may also be considered, on USEPA and USACE approval.

Appropriate species for water-column toxicity testing are listed in Table 4-2. If testing of other (for example, regionally important) species is desired, those species should be appropriately sensitive, share characteristics of the standard species listed, and be preapproved by USACE and the USEPA. For evaluations including a large number of elutriate treatments (for example, greater than six) that are suspected to cause minimal water-column toxicity, the elutriate toxicity evaluation may first be performed with the 100% elutriate, only, for logistical reasons. However, if statistically significant toxicity is observed, it is necessary to repeat the elutriate test using dilution series to calculate toxicological end points. If this strategy is employed, the testing laboratory should be cognizant of the dredging site water holding time of four weeks from sample collection. The recommended acute toxicity test duration (Table 4-2) is 48 hours for plankton and 96 hours for fish and mysid shrimp (Figures 4-7 and 4-8). References to organism-specific USEPA and ASTM bioassay procedures are provided in Table 4-2.

To measure overall test performance and organism health, it is necessary to run a laboratory performance control concurrently with test treatments, with water from the same source as that in which the animals were held or cultured in prior to testing (Table 4-1). The performance control should be the same as the dilution water control if that water is used for the elutriate dilution. If less than acceptable mean survival or normal embryonic development occurs in the control (Table 4-2 for specific criteria), as defined in the procedures for proper conduct of that test, the test must be

repeated.<sup>34</sup> If the dilution water is different than the control water, an additional bioassay treatment testing the dilution water should be conducted simultaneously to determine whether any toxicity is attributable to the dilution water (that is, 0% elutriate). The number of replicate exposure chambers per treatment (typically five), is provided in standard bioassay test methods. It may also be appropriate on a case-specific basis to test the elutriate preparation (dredging site) water to ensure it does not induce toxicity. Finally, reference toxicant tests should be conducted to relate organism sensitivity to historical ranges using control charts of the same reference toxicant. If ammonia is expected to be a cause of toxicity, it may be practical to also test ammonia (for example, as ammonium chloride) as a reference toxicant (see Section 4.7.4).

A nonexhaustive summary of requirements to meet test acceptability includes the following:

- Acceptable negative control survival (see specific bioassay methods)
- Water-quality parameters within specified ranges (see specific bioassay methods)
- Reference toxicant results within control chart limits
- Generation of a NOEC concentration; testing must be repeated with additional lower elutriate concentrations (for example, addition of 1%) if significant responses observed in all concentrations (for example, 100%, 50%, 25%, 12%) are initially evaluated

---

34. If control acceptability criteria are not met but there is little impact in the undiluted elutriates, then stakeholders should be contacted to determine whether the test results can be accepted.

Figure 4-7. Embryos of the marine bivalve *Mytilus galloprovincialis* (top left), embryo of the sea urchin *Arbacia punctulata* (top right), freshwater cladoceran *Daphnia magna* (bottom left), and mysid *Americamysis bahia* (bottom right).

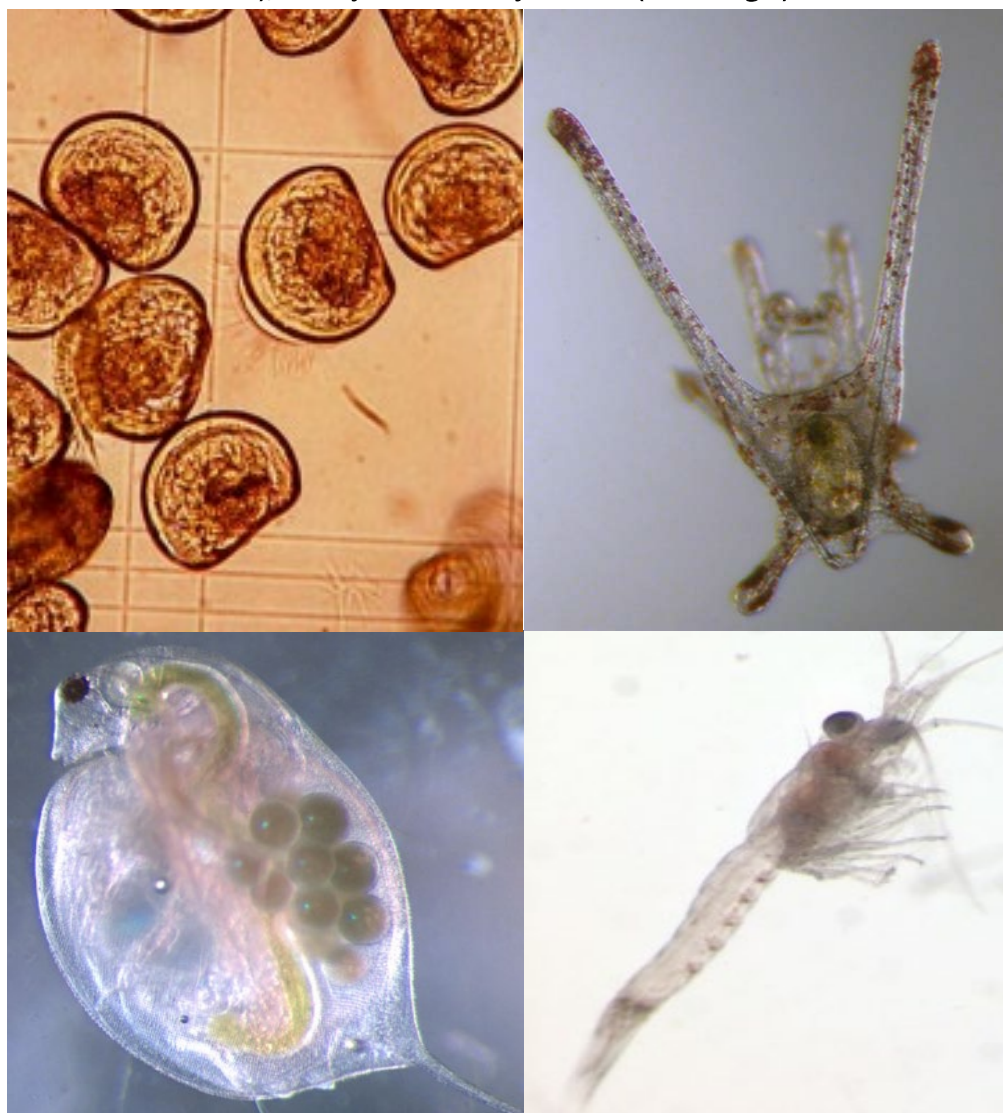


Figure 4-8. Larva of the freshwater fish *Pimephales promelas* (left) and of the marine and the estuarine fish *Menidia beryllina* (right).

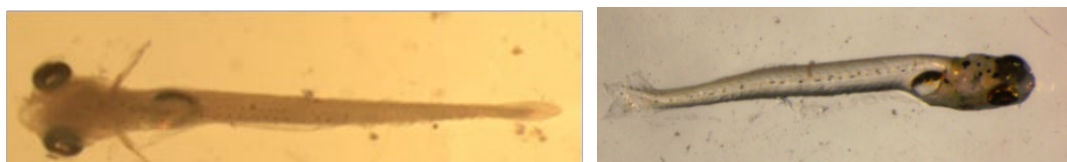


Table 4-2. Test species and recommended methods routinely used for elutriate toxicity testing.

| Species                                                          | Taxonomic group                              | Habitat and feeding strategy                                       | Test duration and end points                       | Reference      |
|------------------------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------|----------------------------------------------------|----------------|
| <b>Freshwater</b>                                                |                                              |                                                                    |                                                    |                |
| <i>Ceriodaphnia dubia</i>                                        | Cladoceran                                   | Zooplankton (filter feeder)                                        | 48 h, survival                                     | EPA-OW (2002a) |
| <i>Daphnia magna</i>                                             | Cladoceran                                   | Zooplankton (filter feeder)                                        | 48 h, survival                                     | EPA-OW (2002a) |
| <i>Daphnia pulex</i>                                             | Cladoceran                                   | Zooplankton (filter feeder)                                        | 48 h, survival                                     | EPA-OW (2002a) |
| <i>Oncorhynchus mykiss</i>                                       | Fish                                         | Pelagic larva (predator)                                           | 48 h or 96 h, survival                             | EPA-OW (2002a) |
| <i>Pimephales promelas</i>                                       | Fish                                         | Pelagic larva (predator)                                           | 48 h or 96 h, survival                             | EPA-OW (2002a) |
| <b>Marine and estuarine</b>                                      |                                              |                                                                    |                                                    |                |
| <i>Americamysis bahia</i><br>(formerly <i>Mysidopsis bahia</i> ) | Invertebrate crustacean                      | Pelagic larva (<24 h)<br>Juvenile (1–5 d)<br>(predator)            | 48 h, survival<br>48 h or 96 h, survival           | EPA-OW (2002a) |
| <i>Holmesimysis costata</i>                                      | Invertebrate crustacean                      | Pelagic larva (<24 h)<br>Juvenile (1–5 d)<br>(predator)            | 48 h, survival<br>48 h or 96 h, survival           | EPA-OW (2002a) |
| <i>Crassostrea gigas</i><br>and <i>C. virginica</i>              | Zooplankton<br>(larval form only)<br>bivalve | Pelagic larvae of hard-<br>bottom benthic adults,<br>filter feeder | Typically 48 h, embryo<br>survival and development | ASTM (2004)    |
| <i>Mercenaria mercenaria</i>                                     | Zooplankton<br>(larval form only)<br>bivalve | Pelagic larvae of hard-<br>bottom benthic adults,<br>filter feeder | Typically 48 h, embryo<br>survival and development | ASTM (2004)    |
| <i>Mytilus edulis</i>                                            | Zooplankton<br>(larval form only)<br>bivalve | Pelagic larvae of hard-<br>bottom benthic adults,<br>filter feeder | Typically 48 h, embryo<br>survival and development | ASTM (2004)    |

Table 4-2 (cont.). Test species and recommended methods routinely used for elutriate toxicity testing.

| Species                                                               | Taxonomic group                              | Habitat and feeding strategy                                | Test duration and end points                    | Reference                                                                   |
|-----------------------------------------------------------------------|----------------------------------------------|-------------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------------|
| <b>Marine and estuarine</b>                                           |                                              |                                                             |                                                 |                                                                             |
| <i>Arbacia punctulata</i>                                             | Zooplankton<br>(larval form only)<br>bivalve | Pelagic larvae of hard-bottom benthic adults, filter feeder | Typically 48 h, embryo survival and development | (ASTM 2004)                                                                 |
| <i>Dendraster excentricus</i>                                         | Zooplankton<br>(larval form only)<br>Bivalve | Pelagic larvae of hard-bottom benthic adults, filter feeder | Typically 48 h, embryo survival and development | (ASTM 2004)                                                                 |
| <i>Lytechinus pictus</i>                                              | Zooplankton<br>(larval form only)<br>Bivalve | Pelagic larvae of hard-bottom benthic adults, filter feeder | Typically 48 h, embryo survival and development | (ASTM 2004)                                                                 |
| <i>Strongylocentrotus purpuratus</i>                                  | Zooplankton<br>(larval form only)<br>bivalve | Pelagic larvae of hard-bottom benthic adults, filter feeder | Typically 48 h, embryo survival and development | (ASTM 2004)                                                                 |
| <i>Acartia</i> spp.<br><i>Pseudodiaptomus</i> spp.                    | True zooplankton                             | Holo zooplankton                                            | 48 h, survival                                  | (Kennedy et al. 2016; Kennedy et al. 2019; Rabalais et al. 2018; ECCC 2019) |
| <i>Cyprinodon variegatus</i>                                          | Fish                                         | Pelagic larva, predator                                     | 48 h or 96 h, survival                          | (EPA-OW 2002a)                                                              |
| <i>Menidia beryllina</i><br><i>M. menidia</i><br><i>M. peninsulae</i> | Fish                                         | Pelagic larva, predator                                     | 48 h or 96 h, survival                          | (EPA-OW 2002a)                                                              |

#### 4.7.4 Toxicity from ammonia

##### 4.7.4.1 General considerations

Ammonia is a naturally occurring constituent in sediments resulting from the diagenesis of organic material. The un-ionized fraction of ammonia (UIA), or  $\text{NH}_3$ , is generally more toxic relative to the ammonium ( $\text{NH}_4^+$ ) ion (EPA-OW 1999; EPA-ERL 1989).<sup>35</sup> The UIA fraction is contingent on the pH, temperature, and salinity of the test water; the relative fraction of UIA increases in direct proportion to increases in solution pH and temperature (salinity is less influential). Generally, ammonia is more toxic in freshwater than in saltwater, and fish are more sensitive to ammonia than invertebrates (Miller et al. 1990) and references within). A notable exception is that bivalve and echinoderm larvae used in the development test are extremely sensitive to ammonia (Carr and Chapman 1995; Carr, Chapman, Presley, et al. 1996; Byrne et al. 2008; Carr, Chapman, Howard, et al. 1996). For specific levels of sensitivity, see (Kennedy et al. 2015; Kennedy et al. 2017; Melby et al. 2018b). Thus, the embryo development bioassays may not be desirable for use by districts and regions that do not consider ammonia as a COPC, as these tests are extremely sensitive to ammonia (Kennedy et al. 2015; Kennedy et al. 2017). Alternatively, copepods have been shown to be highly sensitive to many COPCs but less sensitive to ammonia (Kennedy et al. 2019). The fish (for example, *Menidia beryllina*, *Pimephales promelas*) survival end point is also sensitive to ammonia (Kennedy et al. 2015) and is likely adequate for determining potential for toxicity; a determination of whether echinoderm or bivalve larvae are expected to be present at the disposal site should be considered when selecting species. Since sufficiently high ammonia concentrations to cause toxicity in elutriate bioassays are common, correct identification of ammonia as the sole causative agent of toxicity is useful in determining project-specific contaminants and appropriate AFs for nonpersistent contaminants. Ammonia toxicity in elutriate testing is further described by (Kennedy et al. 2015), who include discussion of relative species sensitivity to ammonia.

---

35. For a full list of the spelled-out forms of the chemical elements used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 265, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

#### 4.7.4.2 Identifying ammonia toxicity

To determine the utility of employing methods to identify ammonia as the toxicity driver, it is informative to measure the total ammonia, pH, and salinity in the sediment pore water prior to elutriate preparation (by centrifuging the sediment and extracting the porewater) and in the elutriate water immediately following preparation. The calculated UIA can be compared to the ammonia tolerance levels of the selected test organisms. Methods exist to identify ammonia as a causative agent of observed toxicity in water-column bioassays (Kreitinger et al. 2017; Melby et al. 2018a). When ammonia is a COPC, toxicity testing of the ammonia-reduced elutriate is supplemental information and does not replace standard testing of the unmodified elutriate. When ammonia is not a COPC, the ammonia-reduced (purged) elutriate may be used as the primary test for decisions so long as sufficient analytical chemistry confirmation is available to demonstrate purging methods do not remove other COPCs.

Methods for removing ammonia from water are described in several publications (Burgess 2000; Melby et al. 2018b; Burgess et al. 2003; Burgess et al. 2004). Specific methods are also available for sediment elutriate toxicity testing (Melby et al. 2018b; Kreitinger et al. 2017). Ammonia can be removed from the prepared elutriate via zeolite column, sorption to the alga *Ulva*, pH modifications and aeration, or sediment purging. However, these methods have potential drawbacks that must be considered when interpreting data. Zeolite and *Ulva* bind some metals (Burgess et al. 2003; Burgess et al. 2004), and zeolite has reduced efficacy at removing ammonia in saltwater. While an auxiliary treatment with EDTA (ethylenediamine tetraacetic acid, which complexes metals but not ammonia) can be conducted in tandem, the inferred conclusion can only indicate whether the concentration of ammonia is high enough to induce mortality.

Manipulative pH treatments involve adding a base to increase the pH and volatilize ammonia from solution (for example, pH = 10 in the presence or absence of aeration), with subsequent acid addition to reduce the pH to a level acceptable for the test organisms of choice. Increasing pH may decrease the bioavailability of metals (if present) through mechanisms such as flocculation, precipitation, and speciation. Bioassays with toxicity comparisons of the same elutriate water with less aggressive pH modifications (for example, pH 6.5 versus 9.0) may be informative, since

ammonia toxicity increases with higher pH while metal toxicity decreases. Use of pH modifications in water toxicity identification evaluations is described by (EPA-ERL 1991). Aeration by itself may reduce ammonia without affecting metal concentrations, but reduction may take days to weeks, which conflicts with the requirement to use elutriates in bioassays within 24 hours of preparation. Aeration may also volatilize other volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs), reducing toxicity. It may also be useful to perform reference toxicity tests using ammonia so that direct comparisons can be made between ammonia measured in the elutriate water and the exposure response of the same batch of test organisms exposed only to ammonia.

#### **4.7.5 Reporting and interpretation of water-column toxicity results**

The following information should be reported for elutriate toxicity results:

- test initiation date and time
- scientific name of the test species
- source of the test species
- conditions of collection or culture site
- collection and shipping dates
- number of organisms in each treatment at the start of the test
- number of organisms alive at each observation period, if applicable
- number of organisms recovered alive or in normal health from each chamber at the end of the test
- additional information including water quality (that is, means, variation, and ranges for dissolved oxygen, pH, salinity or conductivity, temperature, ammonia) and any behavioral or other abnormalities
- acceptable survival in the laboratory control
- results of reference toxicity test and associated control charts

##### *4.7.5.1 Interpretation of elutriate toxicity test results*

Toxicity tests are interpreted by comparing the level of impact to the measurement end point (for example, survival, development) in the 100% elutriate and dilution treatments, including the dilution water, and the control.

Figure 4-9 provides an overview of how to analyze elutriate toxicity test results. Briefly, if the test end point is reduced by less than 10% (20% for development tests; (Carr and Biedenbach 1999) or if no statistical

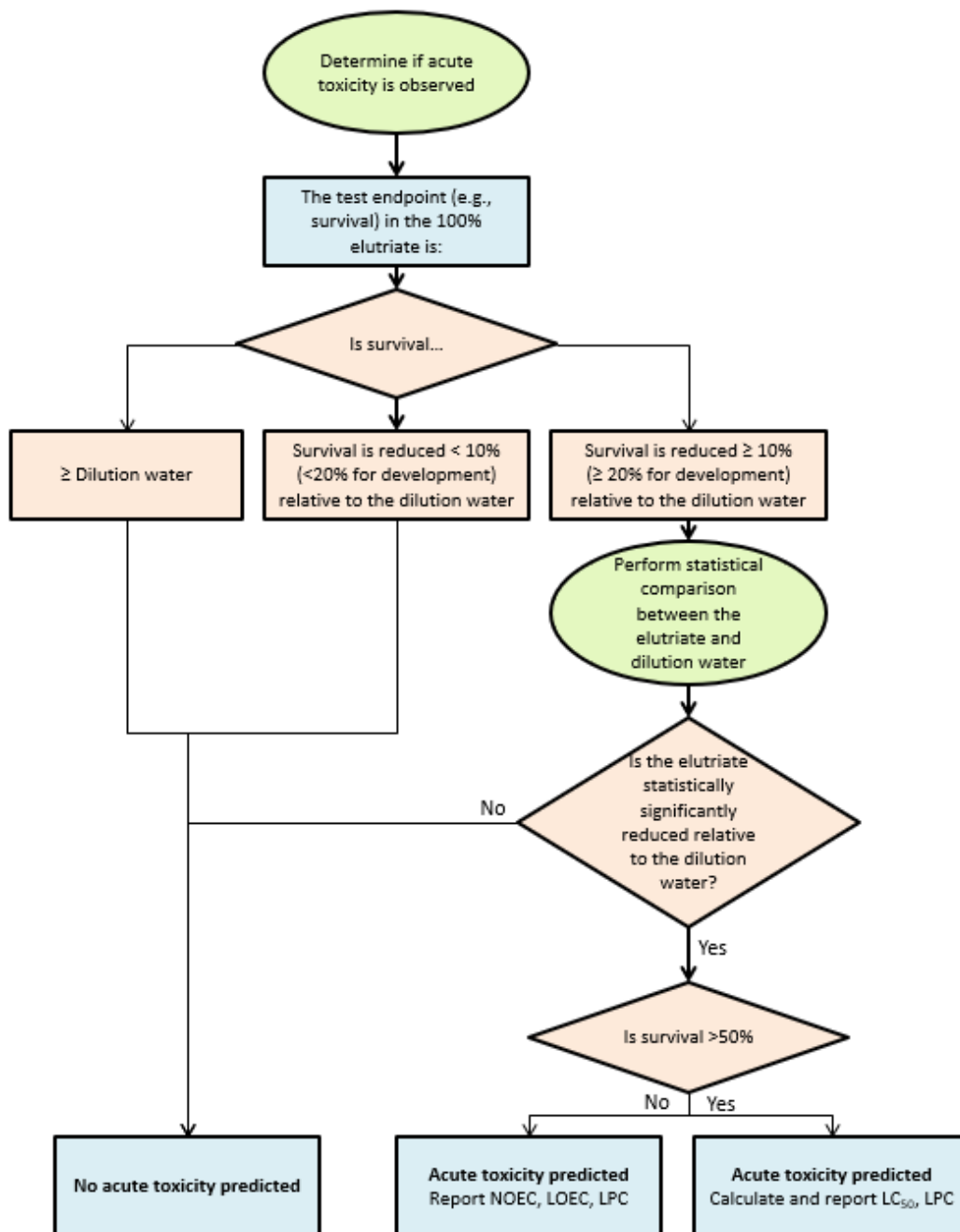
difference is observed in the undiluted (100%) elutriate, no acute toxicity is predicted, and no further evaluation is needed. However, if the end point is reduced by at least 10% (20% for development tests) and is statistically significantly reduced, acute toxicity is predicted, and further evaluation is required to generate appropriate toxicity metrics (for example,  $LC_{50}$ , LOEC, NOEC) to determine the LPC to compare to modeled concentrations at the placement site.

Possible outcomes of toxicity testing, including cases where low or no toxicity is observed, and subsequent steps are summarized in Table 4-3 and discussed below. When no acute toxicity is observed in the undiluted elutriate (that is, no statistical difference relative to the dilution water), then the discharge activity can proceed.

If the test end point is statistically reduced but the reduction is less than a median effect (for example, less than 50% mortality), then the 100% elutriate concentration can conservatively be used to determine the LPC (that is, 100% elutriate AF). Alternatively, a  $LC_{50}$  can be extrapolated (above 100%) from the exposure response curve using a logistical approach if a  $LC_{50}$  must be generated to determine the LPC. Other methods to generate an LPC may be considered (Clarke et al. 2002), such as simply applied a no effect concentration.

If the test end point is reduced beyond a median effect (for example, greater than 50% mortality) then appropriate, test specific, regression-based toxicity metrics should be generated: a lethal median effect concentration ( $LC_{50}$ ) value for survival tests, or median effects end point ( $EC_{50}$ ) value for alternative end points.

Figure 4-9. Flowchart for determining toxicological end points for an elutriate toxicity test. Test end points may then be related to the limiting permissible concentration (LPC) using Figure 4-10.(Accessible version in Appendix A.5.)



#### 4.7.5.2 Interpretation and use of toxicological end points

For dredging methods that are expected to result in acute water-column exposure (for example, barge, hopper), the directly measured NOEC value from the acute toxicity tests provides a protective value. Since the NOEC is by definition one of the arbitrarily selected test treatments, the maximum allowable toxicant concentration (MATC) may also be used to determine the toxicity threshold in evaluations under the CWA (Clarke et al. 2002), although this is inherently a higher concentration than the NOEC and thus less conservative. However, under the MPRSA,<sup>36</sup> the LPC is defined as the product of a concentration inducing acute toxicity (for example, LOEC, LC<sub>50</sub>) and an appropriate AF (see Section 4.7.6).

For dredging methods expected to result in chronic water-column exposure (for example, continuous pipeline discharge), a chronic protective value may be appropriate for evaluations under both the CWA and MPRSA. When toxicity is sufficient to generate a LC<sub>50</sub> value, the AF multiplied by the LC<sub>50</sub> approach is employed. The default AF or defensible alternative for specific chemical classes (see Kennedy et al. 2015) can be employed to provide the appropriate level of chronic protection specific to the elutriate being evaluated.

---

36. 40 C.F.R. § 227.27.

Table 4-3. Possible test outcomes, data interpretation, actions.

| Test outcome                                                                                                                                                                | Interpretation                 | LC <sub>50</sub> or EC <sub>50</sub>                                  | Action                                                                     | Toxicity criteria to use in model |                                                                                                                     |                                                                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                             |                                |                                                                       |                                                                            | CWA                               |                                                                                                                     | MPRSA                                                                                                               |
|                                                                                                                                                                             |                                |                                                                       |                                                                            | Short-term discharge (≤48 h)      | Longer-term discharge (>48 h)                                                                                       | Various durations                                                                                                   |
| Unacceptable control (and site water) survival                                                                                                                              | Unacceptable test <sup>†</sup> | n/a                                                                   | Repeat bioassay <sup>a</sup>                                               | n/a                               | n/a                                                                                                                 | n/a                                                                                                                 |
| High toxicity in all elutriate concentrations tested (no NOEC observed in any test concentration; e.g., 100%, 50%, 10%)                                                     | Unusable results               | Cannot be calculated by interpolation                                 | Repeat bioassay with lower elutriate concentrations tested (e.g., 10%, 1%) | n/a                               | n/a                                                                                                                 | n/a                                                                                                                 |
| 50% effect was bracketed by elutriate concentrations tested and a NOEC is obtained                                                                                          | Acute toxicity predicted       | Can be calculated by interpolation                                    | Model initial mixing to determine compliance                               | LPC = no effect concentration     | Determine LPC by multiplying LC <sub>50</sub> /EC <sub>50</sub> by AF                                               | LPC = no effect concentration or determine by multiplying LC <sub>50</sub> /EC <sub>50</sub> by AF                  |
| Effect in 100% elutriate treatment is significantly greater than in dilution water but is less than 50%; NOEC and LOEC obtained but no LC <sub>50</sub> or EC <sub>50</sub> | Acute toxicity predicted       | Cannot be calculated (i.e., is greater than 100% elutriate treatment) | Model initial mixing to determine compliance                               | LPC = no effect concentration     | LPC = no effect concentration or conservatively determine by multiplying LC <sub>50</sub> or EC <sub>50</sub> by AF | LPC = no effect concentration or conservatively determine by multiplying LC <sub>50</sub> or EC <sub>50</sub> by AF |
| Effect is lower in treatments than in dilution water                                                                                                                        | No acute toxicity predicted    | No need to calculate                                                  | DM passes without mixing, therefore no need to model initial mixing        | n/a                               | n/a                                                                                                                 | n/a                                                                                                                 |
| Effect is less than 10% reduced relative to the dilution water                                                                                                              | No acute toxicity predicted    | No need to calculate                                                  | DM passes without mixing, therefore no need to model initial mixing        | n/a                               | n/a                                                                                                                 | n/a                                                                                                                 |
| Effect is not significantly greater in treatments than in dilution water                                                                                                    | No acute toxicity predicted    | No need to calculate                                                  | DM passes without mixing, therefore no need to model initial mixing        | n/a                               | n/a                                                                                                                 | n/a                                                                                                                 |

Note: EC<sub>50</sub>—median effect concentration; CWA—Clean Water Act; MPRSA—Marine Protection, Research, and Sanctuaries Act; AF—application factor; DM—dredged material.

<sup>a</sup> If survival is high in the 100% elutriates, stakeholders should be consulted to determine whether the test results can still be used.

#### **4.7.6 Determining the limiting permissible concentration (LPC)**

##### *4.7.6.1 Defining the LPC*

This section provides guidance for appropriately determining the LPC using data from acute elutriate toxicity tests when toxicity is observed. Under MPRSA regulations the LPC of the liquid phase of a material is defined as

(1) that concentration of a constituent which, after allowance for initial mixing as provided in § 227.29, does not exceed applicable marine water-quality criteria [WQC]; or, when there are no applicable marine water-quality criteria [WQC],

(2) that concentration of waste or dredged material [DM] in the receiving water which, after allowance for initial mixing, as specified in § 227.29, will not exceed a toxicity threshold defined as 0.01 of a concentration shown to be acutely toxic to appropriate sensitive marine organisms in a bioassay carried out in accordance with approved EPA procedures.<sup>37</sup>

However, regulations clearly allow use of alternative AFs.<sup>38</sup> Determination of the LPC may be flexible under CWA.

The elutriate toxicity evaluation employs acute duration (48–96 hour duration) toxicity tests that generate LC<sub>50</sub>, EC<sub>50</sub>, NOEC, LOEC, or MATC values, expressed as a percentage of the elutriate. For CWA disposal operations that are defined as short-term exposures (for example, hopper, barge placement of DM), an AF is not necessary to calculate the LPC; an applicable no effect concentration (for example, NOEC, probabilistic determination, LC<sub>50</sub>) generated from the acute bioassays may serve as the LPC provided that the most sensitive stage is tested and no further protective factors should be necessary (see Table 4-3). This approach is further described by (Clarke et al. 2002).

---

37. 40 C.F.R. § 227.27(a).

38. 40 C.F.R. § 227.27(a)(3).

When acute toxicity is observed in bioassays for a discharge that is longer term (under the CWA) or if the disposal operation is under the MPRSA (any duration), an AF approach is employed to determine a safe toxicity threshold (that is, the LPC), since median effect concentrations ( $LC_{50}$ ,  $EC_{50}$ ) and LOECs inherently indicate adverse impact.

#### 4.7.6.2 Selection of an application factor (AF)

Selection of the AF has strong influence on the LPC and, in turn, if there is toxicity in the elutriate bioassays, a strong influence on whether the DM passes the water-column toxicity evaluation (Fava et al. 1984). The National Academy of Science (NAS) Water Quality Derivation Document (NAS-NAE CWQC 1972) recommended a general AF of 0.01 as a default to estimate a safe chronic exposure concentration to a chemical from acute toxicity data for compounds with a half-life greater than eight weeks; this factor was adopted by 40 CFR § 227.27.<sup>39</sup> The AF of 0.01 is similar to safety factors of 100:1 used in mammalian toxicity to determine acceptable daily intake levels for food for applying animal test data to humans (FDA 2000).<sup>40</sup>

Use of AFs other than 0.01 are acceptable when scientifically defensible.<sup>41</sup> The 0.01 AF multiplier is not contaminant specific and when applied to an acute median effects value (for example,  $LC_{50}$ ), the resulting LPC is expected to be protective of longer-term, chronic exposure. Thus, the duration of time that the DM remains in the water column should also be considered (see Table 4-3). While AFs are sparingly referenced in the literature, acute-to-chronic ratios (ACRs) are more common. The AF is the inverse of the ACR (Mount 1977; Kenaga 1982; Giesy and Graney 1989); the ACR is the quotient of the acute  $LC_{50}$  and chronic NOEC (or MATC). AFs and ACRs are more relatable to specific chemical classes within a test species (Kenaga 1982); AFs and ACRs are less likely to be relatable between different species of test organisms, especially when comparing fish to invertebrates or for chemicals with different modes of action (Mount 1977); thus, there is generally a large variability in AF and ACR values in the literature (Mount 1977; Verma et al. 1981; Giesy and Graney 1989). (Kennedy et al. 2015) provide a detailed description on the range of

---

39. 40 C.F.R. § 227.27(a)(2).

40. That is, one one-hundredth of the maximum amount shown to be without harm to animals; 21 C.F.R. § 170.22. <https://www.govinfo.gov/content/pkg/CFR-2021-title21-vol3/pdf/CFR-2021-title21-vol3-sec170-22.pdf>.

41. 40 C.F.R. § 227.27(a)(3).

ACRs and AFs for different contaminants and the shortcomings of a universal, default AF.

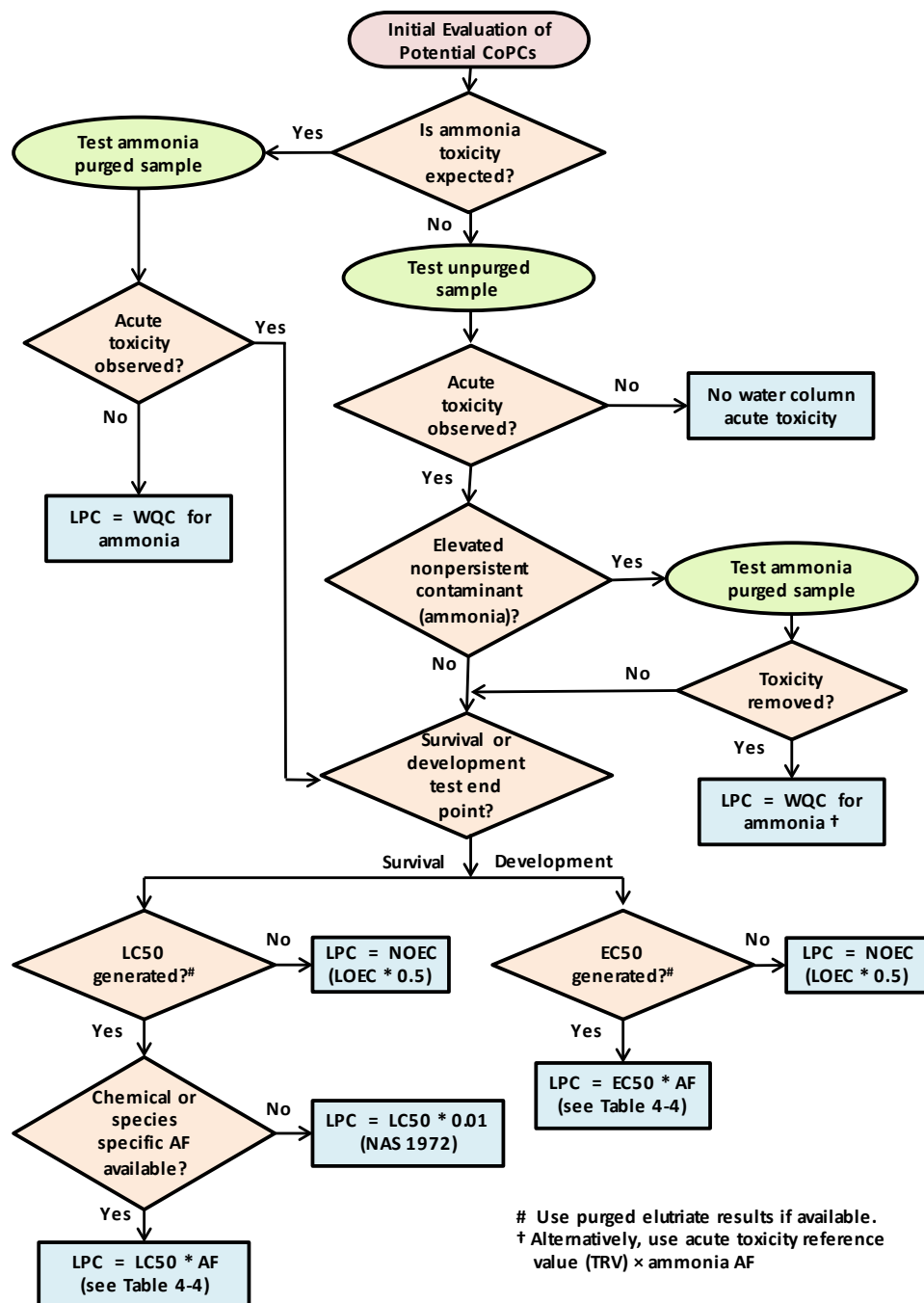
The following section considers the process for determining the LPC when the contaminant driving the toxicity is nonpersistent (for example, ammonia, sulfides) and when the toxicological end point is a measure other than survival (for example, development). Figure 4-10 provides direct guidance for determining the LPC under these different scenarios, while Table 4-4 provides a nonexhaustive list of alternative AFs.

#### 4.7.6.2.1 Persistent versus nonpersistent contaminants

Alternative AFs are more appropriate for toxicity driven by nonpersistent contaminants (for example, ammonia, sulfides). For example, an AF for ammonia toxicity of 0.1 has literature support (Thurston et al. 1986; Thurston et al. 1983), and it is generally accepted that less-restrictive AFs (0.05–0.1) should be applied to nonpersistent chemicals (NAS-NAE CWQC 1972; Fava et al. 1984; EPA-OW and USACE 1991; EPA-OW and USACE-OCRD 1998; Lloyd and Orr 1969; Brown et al. 1969). Nonpersistent chemicals are generally defined to have a half-life of less than eight weeks (NAS-NAE CWQC 1972).

When ammonia is not a COPC and present at concentrations expected to cause toxicity (that is, greater than NOEC; Kennedy et al. 2015; Melby et al. 2018b), laboratory methods to reduce or identify ammonia specific toxicity should be considered to support use of higher AFs or nonpersistent contaminant management interpretations and options. Supplemental ammonia reduced (purged) bioassays may be performed (in addition to the unmodified elutriates) to provide a LOE if it is the main driver of toxicity (if observed in the bioassays). See Section 4.7.4 for guidance on determining ammonia toxicity using bioassays. When toxicity testing provides an acceptable LOE that a nonpersistent contaminant is the cause of toxicity, either the applicable WQC (for example, for ammonia; recommended) or the contaminant-specific AF (Table 4-4) multiplied by the acutely toxic value (for example, LC<sub>50</sub>, 100% elutriate) should be used to determine the LPC, as summarized in Figure 4-10.

Figure 4-10. When acute toxicity is observed, this figure provides the process to determine the LPC, with consideration to the type of contaminant causing the toxicity and the type of toxicological end point assessed (AF—application factor; NAS 1972—NAS-NAE CWQC 1972). (Accessible version available in Appendix A.6.).



#### 4.7.6.2.2 Type of test end point: survival versus development

The type of toxicological end point (that is, survival versus development) is important for determining a relevant and appropriate LPC. The MPRSA requires elutriate toxicity testing using three marine species: a fish, a

crustacean or mollusk, and a planktonic species. While cladocerans fill the plankton requirement for freshwater testing, available test protocols for marine species are subject to interpretation. Marine organisms that are plankton for their entire life cycle are appropriate, including copepods, rotifers, and mysids (Kennedy et al. 2016). Recently, acute methods for copepods were developed (Rabalais et al. 2018) and validated (Kennedy et al. 2019) that are appropriate for marine elutriate testing.

In certain US regions, embryonic development tests using echinoderms or bivalves were historically used to fill the marine zooplankton requirement. Although embryonic development tests are considered acute methods (ASTM 2001, 2012), they are unlike the acute survival tests in that they use a much more sensitive, embryonic development end point (including cell division, which is adversely affected by small, suspended sediment loads). These embryo development tests are extremely sensitive to and confounded by very low levels of ammonia (Kennedy et al. 2017), which is ubiquitous in elutriates (Kennedy et al. 2015), and therefore not an optimal testing procedure to determine the effects of more persistent chemicals in elutriate waters. The 48-hour embryonic development end point is fundamentally different than the acute survival end point historically used to develop AFs; this end point is the development of an embryo to a viable swimming larva, which is used to calculate an  $EC_{50}$ , where 50% of the organisms fail to develop normally. The green book (EPA-OW and USACE 1991) does not mention applying a 0.01 factor to an  $EC_{50}$  value. Further, (EPA-OW and USACE-OCR 1998) indicate that “the 0.01 factor is intended for acute mortality data (e.g., relating acute to chronic toxicity) and not for more subtle effects such as abnormalities, growth, or reproduction, including  $EC_{50}$ ” and that the “historic application factor [AF] was largely a matter of ‘best professional judgment’ by the NAS” (11-7, citing NAS-NAE CWQC 1972). Thus, using an ACR of 100 ( $AF = 0.01$ ) is not appropriate or applicable to  $EC_{50}$  embryonic development data (Kennedy et al. 2015). Embryonic development is the most sensitive life stage, with subsequent juvenile and adult life stages being substantially more tolerant. Consequently, a no effect concentration from this test represents the most relevant and defensible LPC (Kennedy et al. 2015). Table 4-4 and recent publications discuss potential alternative AFs for the development test, especially when the suspected toxicity relates to elevated ammonia concentrations (Kennedy et al. 2015; Kennedy et al. 2017).

Table 4-4. Nonexhaustive list of alternative AFs that provide protection from chronic exposure. Additional alternative AFs can be found in Kennedy et al. (2015).

| Type of AF             | Chemical                               | Organism                   | AF<br>(1 / ACR) | Source                                           |
|------------------------|----------------------------------------|----------------------------|-----------------|--------------------------------------------------|
| Default: persistent    | General                                | —                          | 0.01            | NAS-NAE CWQC (1972)                              |
| Default: nonpersistent | General                                | —                          | 0.05 to 0.1     | NAS-NAE CWQC (1972)                              |
| 90th percentile        | General                                | —                          | 0.01            | Länge et al. (1998)                              |
| 90th percentile        | Metals,<br>organometals,<br>pesticides | —                          | 0.01            | Länge et al. (1998);<br>Raimondo et al. (2007)   |
| 90th percentile        | Aromatic<br>hydrocarbons               | —                          | 0.05            | Länge et al. (1998)                              |
| Mean                   | Ammonia                                | —                          | 0.14            | Diamond et al. (1993)                            |
| Species specific       | Ammonia                                | <i>Pimephales promelas</i> | 0.11            | Thurston et al. (1983;<br>Thurston et al. (1986) |
| Species specific       | Ammonia                                | <i>Americamysis bahia</i>  | 0.14            | Miller et al. (1990)                             |
| Species specific       | Ammonia                                | <i>Menidia beryllina</i>   | 0.05            | Miller et al. (1990)                             |
| Species specific       | Ammonia                                | <i>Mytilus</i> spp.        | 0.2             | Kennedy et al. (2016;<br>Kennedy et al. (2017)   |

#### 4.7.7 Water-column toxicity assessment

The water-column toxicity assessment will result in a determination of either an LPC or *no water-column toxicity*. The evaluation for each organism may result in a different determination. If an LPC is generated, a mixing evaluation is needed to determine whether sufficient dilution is predicted to achieve the LPC. Note that the mixing evaluation is only required for the lowest LPC.

The results of water-column toxicity testing acceptable toxicity threshold (or LPC) support the evaluation of the potential impacts of DM on the pelagic community. One of four conclusions can be drawn from the water-column toxicity tests:

1. The elutriate toxicity tests indicate no toxicity in the 100% DM elutriate relative to the dilution water. Therefore, the DM is not predicted to be acutely toxic to water-column organisms. It is not necessary to implement additional management options.
2. The mixing model indicates concentrations within the water column, after allowance for initial mixing, do not exceed (1) the acceptable toxicity threshold (LPC) at and beyond the boundaries of the site at any time or inside the site after four hours for disposal operations under the MPRSA or (2) outside the mixing zone for disposal operations under the CWA.

Therefore, the DM is predicted not to be acutely toxic to water-column organisms. It is not necessary to implement additional management options.

3. The modeled concentration of the liquid phase of a DM, after allowance for initial mixing, does exceed (1) the acceptable toxicity threshold (LPC) either outside the site at any time or inside the site after four hours, or both, for disposal operations under the MPRSA or (2) outside the mixing zone for disposal operations under CWA. Therefore, the DM is predicted to be acutely toxic to water-column organisms without additional management actions during placement operations. In this case, design and evaluate additional management actions to modify disposal operations (for example, decrease barge size, change dredging method, change disposal method or discharge rate, limit disposal to certain hydrodynamic conditions) so that the acceptable toxicity threshold is met.
4. Otherwise, if the LPC is exceeded and management actions are not shown to sufficiently dilute the water-column concentrations, the DM under evaluation will not be found suitable for open-water disposal.

Recall that the toxicity evaluation yields only one LOE, and WQC and WQS compliance must also be met. Conversely, the results of the toxicity evaluation should be interpreted in context with measured analytical chemistry values for the COPC as a WOE approach in management decisions.

## 4.8 Initial mixing and the numerical mixing models

Both the CWA and MPRSA recognize the occurrence of natural mixing and associated dilution. Unless criteria are met at the point of discharge (as estimated by screening, measurement of elutriate, or toxicity bioassays), dilution will be factored in to determine whether criteria are met or exceeded at the point of compliance. For application of dilution, it is important to understand how each regulation defines initial mixing. As defined by the MPRSA, initial mixing is the dispersion or diffusion of liquid, suspended particulate, and solid phases of a discharge, which occurs within four hours after disposal.<sup>42</sup> Applicable WQC and WQS and water-column toxicity must be met for the entire water column, including within the mixing zone, after four hours of initial mixing. Under the MPRSA, the mixing zone is defined as the placement site itself.<sup>43</sup> Under

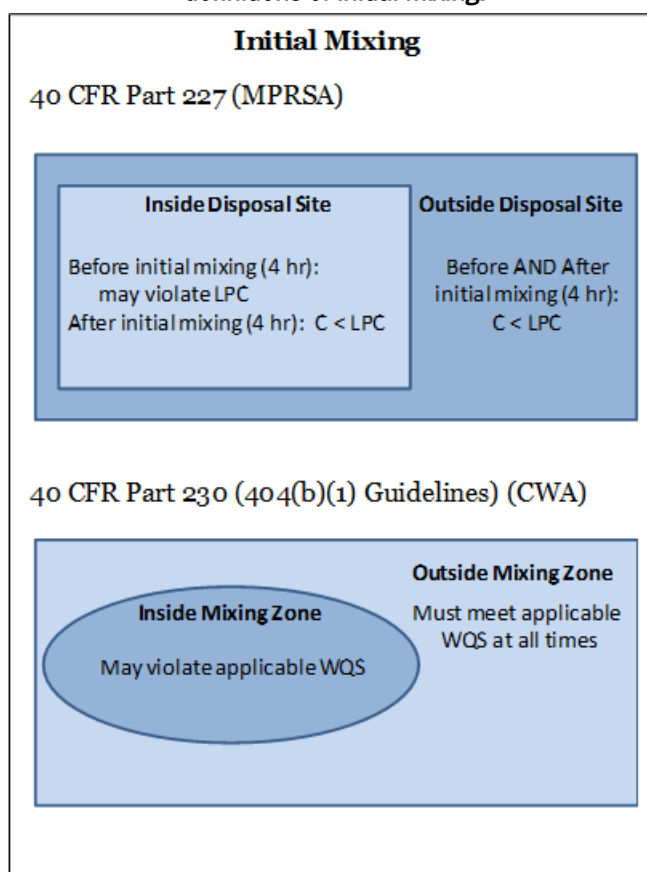
---

42. 40 C.F.R. § 227.29(a).

43. 40 C.F.R. § 227.29(a).

the CWA, a mixing zone is defined as a finite volume of water serving as a zone of dilution in the vicinity of a discharge point where receiving water may not meet quality standards or other requirements otherwise applicable to the receiving water.<sup>44</sup> CWA criteria for determining the acceptability of a proposed mixing zone are specified in the regulations.<sup>45</sup> Under both the MPRSA and CWA, specific criteria for water quality and water-column toxicity must be met outside of the mixing zone at all times (Figure 4-11). Application of a mixing zone by different states and at individual sites can be highly variable.

Figure 4-11. Comparison of Marine Protection, Research and Sanctuaries Act (MPRSA) and Clean Water Act (CWA) definitions of *initial mixing*.



While the permit or disposal site boundary defines the allowable mixing zone, the actual dilution occurring within that zone will depend on site conditions and placement operations. A numerical mixing model estimates the concentration of contaminants in the water column after

44. 40 C.F.R. 230.3(m).

45. 40 C.F.R. 230.11(f)(2).

disposal as a function of time and location. Mixing calculations describe the spatial and temporal limits within which the discharge will comply with the WQC and WQS and toxicity. If these limits are within the established mixing zone limits, there is no unacceptable adverse environmental effect. If these limits exceed the established mixing zone limits, there is potential for an associated adverse effect.

Table 4-5 provides a summary of potential mixing models. The short-term FATE (STFATE) model is typically used to evaluate the initial mixing of a discharge in open water systems when disposal occurs as a discrete discharge from a barge or a hopper dredge. Continuous discharges of DM from pipelines are typically modeled with the disposal from a continuous discharge (DIFCD), continuous discharge FATE (CDFATE), Dredging Cornell Mixing Zone Expert System (D-CORMIX), or Cornell Mixing Zone Expert System–General Tools Sediment (CORMIX-GTS) models. Personal computer versions and example applications are available (ERDC 2023). Typical data needed to run the models include information about the DM (volume, grain size, water content), the discharge site (water depth, current velocity, water density, stratification), and the discharge operation (dredge type, bin dimensions, vessel speed).

When no other means of estimation are feasible, the MPRSA provides an alternate method for calculating dilution. The liquid and suspended particulate phases are “assumed to be evenly distributed . . . over a column of water bounded on the surface by the release zone and extending to the ocean floor, thermocline, or halocline if one exists, or to a depth of 20 meters, whichever is shallower.”<sup>46</sup> The release zone is defined as “the area swept out by the locus of points constantly 100 meters from the perimeter of the conveyance engaged in dumping activities, beginning at the first moment in which dumping is scheduled to occur and ending at the last moment” and “shall not exceed the total surface area of the [placement site].”<sup>47</sup>

---

46. 40 C.F.R. § 227.29(b)(1).

47. 40 C.F.R. § 227.28.

Table 4-5. Summary of discharge types, hydrodynamic conditions, and applicable models and methods for evaluation of initial mixing.

| Type of discharge | Characteristics of discharge | Near-field effects | Applicable model or technique                                                                                                                                                                                                        | Model hydrodynamics                                  |
|-------------------|------------------------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| Barge             | Discrete                     | Strong             | STFATE                                                                                                                                                                                                                               | Steady, nonuniform                                   |
| Hopper            | Semidiscrete                 | Moderate           | STFATE                                                                                                                                                                                                                               | Steady, nonuniform                                   |
| Pipeline          | Continuous                   | Moderate           | <ul style="list-style-type: none"> <li>• AdH</li> <li>• CDFATE</li> <li>• CORMIX</li> <li>• D-CORMIX<sup>a</sup></li> <li>• DIFCD</li> <li>• Dilution Volume Method</li> <li>• EFDC</li> <li>• CORMIX-GTS</li> <li>• TABS</li> </ul> | Steady, uniform unsteady, nonuniform steady, uniform |

Note: STFATE— short-term FATE; AdH—Adaptive Hydraulics; CDFATE— continuous discharge FATE; CORMIX— Cornell Mixing Zone Expert System; D-CORMIX—Dredging Cornell Mixing Zone Expert System; DIFCD— Disposal from a continuous discharge; EFDC—Environmental Fluid Dynamics Code; CORMIX-GTS—Cornell Mixing Zone Expert System—General Tools Sediment; TABS—TABS Analysis Software Package, US Army Corps of Engineers, Vicksburg, Mississippi.

<sup>a</sup> D-CORMIX has not been developed and verified for national application. However, the fundamental processes contained in D-CORMIX are applicable for continuous pipeline discharges, and this model is currently under investigation for future use.

It is only necessary to perform the mixing evaluation for the toxicity LPC or contaminant requiring the greatest dilution. Because mixing and dilution is highly dependent on a number of factors, an iterative process will probably be necessary to balance achievable dilution with operating constraints. The steps below suggest a process for evaluating mixing with respect to operating constraints:

1. Run the model with worst-case current conditions (high velocity to determine the distance that the plume travels before meeting the LPC and low velocity to determine the maximum time required to meet the LPC) discharging at different locations (distances to the mixing zone or placement site boundary) to define acceptable (unrestricted) placement zones that meet water-quality restrictions (dilution required to meet LPC and WQC and WQS). Determine whether there is sufficient dilution capacity within the unrestricted placement zone to accommodate the planned DM placement.
2. Evaluate placement zones for a range of current conditions to define allowable placement zones for specified current conditions.

3. Evaluate mixing with respect to operational controls (Section 4.9) to determine whether specific operating conditions will provide sufficient dilution.

## **4.9 Operational and engineering controls**

Operational and engineering controls are considered when the water-column evaluation indicates a need to reduce exposures below levels of concern. Strategies that can be employed to reduce risks associated with dissolved contaminants include reducing water column dissolved concentrations by increasing dilution and mixing or by treatment by adsorption or degradation (not commonly implemented).

Operational controls include actions that the site manager or operator can implement when placing the material, such as scheduling the placement for optimum site conditions, spreading the release in a cross-current direction, or controlling the rate and location of placement. Engineering controls require a physical construction technology, such as reducing the barge size or changing the dredging method to reduce the volume of water in the DM, or modification of the site design to reduce environmental risk to acceptable levels, such as amendments to treat dissolved contaminants.

When considering operational and engineering controls, the CM will need to be revised to incorporate these controls. Quantifying the effectiveness of these techniques generally requires modeling to compare concentrations with and without a control. Elutriate testing will generally not need to be repeated, but rather the mixing model (for example, STFATE or CDFATE) will be reevaluated to incorporate different equipment or operations. The models may not be able to accommodate some controls, in which case laboratory data or pilot evaluations may be necessary to predict performance.

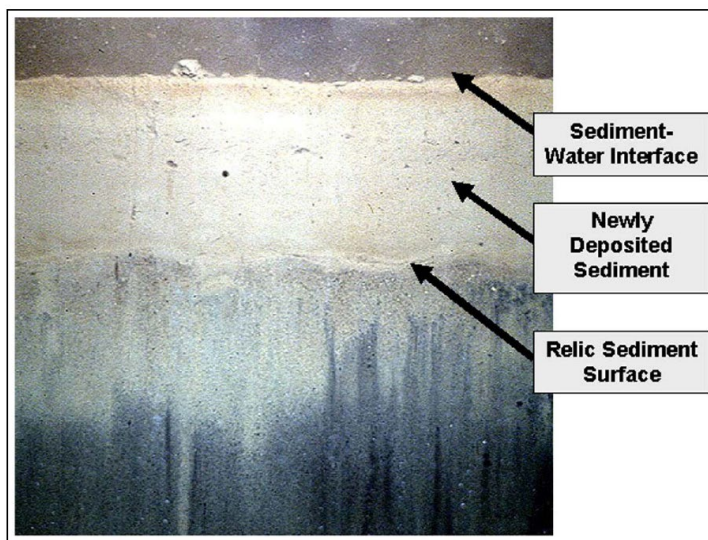
## **5 Assessment of Potential for Benthic Toxicity**

This section identifies procedures to evaluate potential contaminant effects of DM placement on benthic organisms (Figures 1-1 and 1-2). In addition to identifying evaluation procedures, this section outlines methods to generate and interpret toxicity test results and provides guidance for using other LOEs for evaluating potential contaminant impacts to benthos for use towards achieving a technical determination.

The benthos is the community of organisms that inhabit sediment or are closely associated with sediment. Generally speaking, benthic organisms live in or on bottom substrate in aquatic ecosystems. Many benthic species are critical to aquatic ecosystems because they comprise a major food source for fish and other wildlife. A single or a sequence of DM placement events will often result in a layer of newly deposited sediment (Figure 5-1). Most benthic organisms live in the top 10 cm of sediment and maintain some connection to the sediment-water interface for ventilation and feeding (Miller et al. 2002; Teal et al. 2008).

Contaminants in DM can be directly toxic to benthic organisms that survive placement events and those that colonize the newly deposited sediment at the placement site. Direct effects may occur via uptake of contaminants from sediment or sediment pore water, followed by a toxic response associated with the chemical exposure.

Figure 5-1. A vertical cross-sectional image showing an overburden approximately 5 cm thick that resulted from open-water discharge of DM in Corpus Christi Bay, Texas. (Reproduced from Wilber et al. 2005, 2. Public domain.)



## 5.1 Overview of the evaluation of potential for benthic toxicity

Sediment toxicity testing as the primary line of evidence provides the basic testing and assessment procedure to make a technical determination as to the suitability for open water discharge without unacceptable risk to the benthos (Figure 5-2). The complexities inherent to the potential of sediment to cause toxicity to sediment-dwelling organisms necessitate relying on multiple LOEs, within an overall WOE approach, to reach conclusions about the contaminant risks posed. Assessment and decision frameworks according to WOE are designed to lead to conclusions supported by a preponderance of evidence using information supplied from multiple, separate LOEs, including physical, chemical, and biological data (Linkov et al. 2012; Moore et al. 1998; Linkov et al. 2009; Linkov et al. 2011).

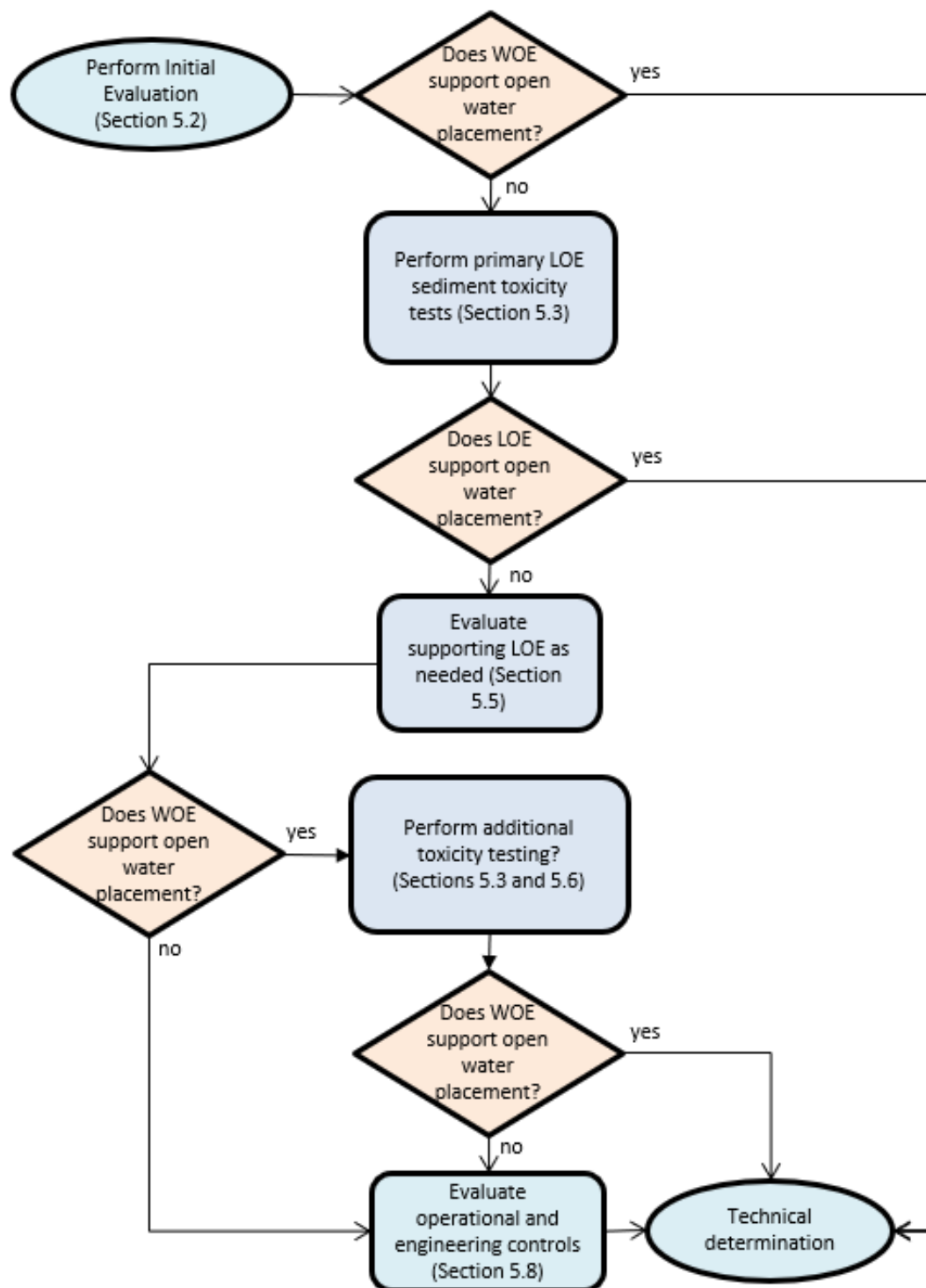
For assessing the potential impact of contaminants on sediment biota, evaluation of toxicity according to measurement of lethal toxicity is the primary LOE. The complex matrix of DM places limitations on the use of chemical analytical methods alone for estimating the bioavailability and the toxicity of contaminants present. The impact of contaminants on sediment biota depends on their bioavailability (that is, the extent to which they can be taken up by sediment-dwelling organisms), so assessment of the risks of sediment contaminants should include direct

assessment of their bioavailability. Toxicity tests improve on chemical measurements because they integrate the effects of multiple contaminants and provide an empirical assessment of bioavailability. By exposing relevant organisms under controlled conditions to samples of the actual sediment to be dredged and measuring lethal effects in the test organisms, confident conclusions about potential for benthic toxicity are typically reached. However, the observation of significant biological effects, even decreased survival, does not necessarily indicate that DM-associated contaminants are the cause of observed effects. Therefore, other LOEs should be evaluated to determine whether they support the conclusion obtained.

Acute sediment toxicity tests have been shown to be adequately responsive to legacy contaminants and are the primary choice for evaluating DM for open-water placement. Guidance for conducting whole-sediment 10-day toxicity tests to assess lethal effects is provided in Section 5.3.

Chronic sublethal testing should be used only on rare occasions where evaluation of chronic responses is deemed appropriate because of the particular contaminant evaluated or other specific circumstance that could be addressed with a longer exposure. Challenges with the use of chronic sublethal toxicity tests include decreased responsiveness in the lethality end point because of feeding and water exchange (that is, marine and estuarine chronic test methods) and higher probability of test failure because of the extended exposure time. In addition, the lack of interpretive guidance beyond statistical significance (for example, magnitude of response) for the chronic test end points makes data interpretation difficult. Additionally, for certain species (for example, *Leptocheirus plumulosus*) data have shown 10-day acute lethality end points to be generally as responsive indicators of contaminant impacts as chronic sublethal measures of growth or reproduction (Kennedy et al. 2009). Guidance for conducting whole-sediment toxicity tests to assess chronic effects on survival and sublethal effects is provided in Section 5.4.

Figure 5-2. Illustration of the weight-of-evidence (WOE) approach for determining benthic impacts of DM prior to open-water placement. (Accessible version available in Appendix A.7.)



### 5.1.1 Supporting lines of evidence (LOEs)

Supporting LOEs provide additional information for use in a WOE approach when evaluating the conclusions obtained from sediment toxicity testing (that is, primary LOE). Although they can provide additional weight to support the conclusions obtained from toxicity tests, they cannot be used to negate the results of a toxicity test where they do not support the conclusion reached. However, the weight provided by evaluation of supporting LOEs can be used to steer the study toward additional toxicity testing that can be used as the primary LOE (for example, conduct additional testing using a different species that is more tolerant to the grain size characteristics of the sediment). An overview of supporting LOEs is provided below and guidance for their use is provided in Section 5.5.

The first supporting LOE evaluated should be focused on assessing the potential for toxicity to the benthos by comparing sediment concentrations of chemicals of potential concern with applicable SQGs using available data or data obtained from additional sampling. SQGs are intended to provide insight as to whether benthic toxicity is expected from exposure to contaminants present in sediments. The approach for assessing potential for benthic toxicity using sediment chemistry and their comparison to SQGs is described in Sections 5.2.2 and 5.5.1. An SQG evaluation may allow a technical determination during the initial evaluation or support the conclusions obtained in the toxicity test or could indicate that unknown contaminants or noncontaminant factors are the cause of the observed toxicity.

Growing evidence shows that sediment porewater concentration of contaminants represents the highly bioavailable fraction and thus is a good indicator of bioavailability (Lotufo, Michalsen, et al. 2022). Concentrations of contaminants in sediment pore water, either predicted using equilibrium partitioning or measured (preferable) can be compared to toxicity information or benchmarks using water exposures for predicting lethality in sediment exposures. This approach is described in Section 5.5.2.

Concentrations of contaminants in invertebrates exposed to dredged and reference sediment in laboratory bioaccumulation tests (Section 6) may be compared to concentrations associated with adverse effects and serve as a supporting LOE for determining chemically derived effects.

The influence of noncontaminant factors should also be considered when evaluating the results obtained from a toxicity test. Toxicity from factors such as grain size, salinity, ammonia, and sulfides can be falsely attributed to sediment contaminants. If noncontaminant factors are suspected as the cause of the observed mortality in toxicity testing, then additional toxicity testing or specialized testing such as a toxicity identification evaluation (TIE; see Section 5.1.2) could be considered.

Benthic community structure studies are also recommended in most of the sediment quality assessments conducted under a WOE approach but, because of the physical disturbance of dredging operations and ship traffic, information about benthic community structure at the placement site is of little value when evaluating the potential impact of contaminants of DM on sediment biota.

### **5.1.2 Sediment toxicity identification evaluation (TIE)**

In some cases, determining the cause of toxicity can be important. For example, knowing the class of contaminant that is driving the observed toxicity may provide information that can be used to help direct and focus engineering solutions for sediment isolation and containment. A TIE would be useful where toxicity is observed but there is no clear indication as to the potential cause according to sediment chemistry information. In this situation the cause of toxicity could be produced from a contaminant that was not included in the sediment chemistry analysis or from a noncontaminant factor. In most cases a Phase I TIE (EPA-ORD 2007) is appropriate. This phase of the TIE process can identify contaminants to three classes: (1) ammonia (2) metals and (3) organics. It can also help isolate the cause of toxicity to a noncontaminant factor if no reduction in toxicity is observed from elimination of these three contaminant classes.

## **5.2 Initial evaluation of potential for biological effects**

The initial evaluation is used to determine whether a technical determination can be achieved without additional efforts (Section 1.6.3). Conditions that are recognized in the regulatory framework as exclusion from further testing are also described in Section 1.6.3. If it is determined that an exclusion from further testing applies to the DM, the evaluation of potential contaminant impacts to benthos described in this section becomes unnecessary. This section provides guidance for the use of chemical SQGs as an LOE for achieving a technical determination without

generating biological testing data. This section also provides a detailed description of the suitability and application of previous benthic toxicity evaluations towards achieving a technical determination concerning potential contaminant impacts to benthos without conducting new sediment toxicity testing.

### **5.2.1 Use of previous technical determinations or evaluations**

The ongoing nature of many navigational dredging projects and environmental programs at the national and local scale have generated many sources of information about sediment, contaminants, and risk that may be relevant to prospective dredging projects. Data developed from previous dredging projects may be a valuable source for evaluating a new dredging project.

Efforts to collect toxicity, bioaccumulation, and other biological data may be avoided when high-quality biological data already exist. Existing data may be used in place of new data, provided the data meet quality criteria. Therefore, before embarking on new biological testing efforts, existing data should be assessed to determine whether they can provide sufficient information for achieving a technical determination, generally in consort with a screening evaluation using sediment chemistry.

Prior to using data from previous dredging projects, their suitability and quality should be thoroughly evaluated. Specific data evaluation procedures may exist at the regional level, but in their absence, case-by-case judgments must be made. The quality of existing biological data is determined by their applicability and relevance to the CM (Section 1.5.1), especially when determining whether risks to relevant receptors have been addressed sufficiently. If previous benthic toxicity testing has been conducted, and the results of that testing (1) are applicable to material under consideration and (2) satisfy the applicable testing requirements (MPRSA or CWA), then the results of the previous testing may be used in the initial evaluation to determine whether the sediment under consideration meets the MPRSA criteria or Section 404(b)(1) guidelines. Even if previous testing results are determined to be insufficient for the proposed DM, the information gathered in this evaluation may be used in subsequent analyses, such as selection of test species.

Many factors influence the length of time that previous testing data are valid, such as changes in land-use patterns, site conditions, analytical

methods, and relative levels of potential risk. Some sites undergo repeated maintenance navigational dredging. Such areas are often characterized by a routine and rapid accumulation of freshly deposited sediment that is relatively homogeneous.

The proposed DM is sufficiently similar physically and chemically to previously tested material and the risk potential may be assumed relatively constant, if (1) watershed conditions remain fairly constant, (2) the evaluation finds no new pollution sources (or spills), (3) new COPCs are not identified during initial characterization, and (4) the concentrations of COPCs remain relatively unchanged. In these situations, qualified existing biological testing data, preferably generated no more than three years prior<sup>48</sup> that demonstrates that placement of DM is not expected to result in unacceptable benthic effects, may be used in lieu of new testing.

### **5.2.2 Benthic toxicity screening evaluation using sediment chemistry**

Chemical benchmarks, such as chemical SQGs, have been used to gauge the degree to which sediment is contaminated with chemicals and to estimate the potential for toxicity to benthic invertebrates (Wenning and Ingersoll 2002). The use of SQGs to assess potential for benthic toxicity should include an adequate understanding for the intent of the guidelines (whether they were intended to predict toxicity or the absence of toxicity) and what effects they were designed to assess.

SQGs that relate the potential for adverse effects on sediment-dwelling organisms have been derived using both mechanistic (often referred to as *theoretical*) and empirical approaches. Mechanistic SQGs are based on equilibrium partitioning theory and apply to selected classes of contaminants, primarily divalent metals and several types of nonionic organic compounds (Berry, Burgess, Hansen, DiToro, DeRosa, et al. 2003; Berry, Burgess, Hansen, DiToro, Bell, et al. 2003; Hansen et al. 2003; Hansen et al. 2005; Burgess et al. 2008). Although these models are useful for describing contaminant bioavailability and evaluating the potential of specific chemicals to cause sediment toxicity, each individual mechanistic SQG approach is applicable only to specific contaminant types (Burgess et al. 2013). In addition, measurements of some of the parameters needed to apply these guidelines (for example, sediment acid volatile sulfides [AVS]

---

48. Older data may be acceptable providing it can be clearly demonstrated that the data are of good quality and that there has been no significant change in site conditions.

and simultaneously extracted metals [SEM]; AVS-SEM ratios) are methodologically challenging and carry great uncertainty regarding accuracy (Hammerschmidt and Burton Jr. 2010; McQueen et al. 2016).

Empirical approaches to deriving SQGs are based on statistical analyses of collected chemical and biological effects data in whole sediments (Long et al. 1995a; DelValls et al. 2004; Wenning and Ingersoll 2002). They are fundamentally statistical methods that provide no basis for assuming any cause-and-effect relationship between a COPC and a biological response. Empirical approaches are better suited than mechanistic approaches to predicting toxicity in sediments where a diverse mixture of contaminants, rather than a single contaminant or a single class of contaminants, may pose a concern and collectively contribute to toxicity. Because DM is typically a complex mixture and because of their simple application, empirical SQGs are preferred for the evaluation of potential contaminant impacts to benthos.

Empirical SQGs are derived from statistical association of matched sediment chemistry and biological effects data. Examples of empirical SQG approaches for the marine environment include effects range low and effects range median (ERL and ERM) (Long et al. 1995a), and the threshold effects level and probable effects level (TEL and PEL) (Macdonald et al. 1996). The narrative intent of lower-level empirical guidelines (for example, ERL and TEL) is to predict when acute toxicity is unlikely to occur. The upper empirical guidelines (for example, ERM and PEL) are intended to indicate when an increased probability of observing toxic effects is evident, as the number of individual contaminant upper-level guidelines exceeded increases as the likelihood that the sediment is toxic also increases. Consensus guidelines, which aggregate several different SQGs having a similar narrative intent (for example, median effect), are a further development of the empirical approach. Marine consensus SQGs have been developed for some constituents, including metals, PCBs, and PAHs (MacDonald et al. 2000; Swartz 1999; Vidal and Bay 2005). Freshwater consensus SQGs for nonionic organic compounds and metals were proposed by (MacDonald et al. 2000. (MacDonald et al. 2000).

While empirical SQGs are a tool for comparing the concentrations of individual contaminants to guideline values, DM are typically contaminated with complex mixtures of chemicals and only rarely by a

single substance. An assessment tool for determining the potential effects of contaminant mixtures in sediments uses empirical SQGs to derive SQG quotients (SQGQs). Quotients are derived by dividing the concentrations of chemicals or class summation concentration in the sediment by the respective SQG value for each chemical for which individual SQGs were derived. A value greater than one indicates the chemical concentration in that sample exceeded its respective SQG. The mean SQGQ (mSQGQ) is obtained by calculating the mean of the resulting individual SQGQs for a list of chemicals or class summation concentration. The result is a single, unitless, effect-based index of the relative degree of contamination that can provide a basis for determining the likelihood that a sediment sample would be toxic to sediment-dwelling organisms.

#### *5.2.2.1 Calculation of mean sediment quality guideline quotient (mSQGQ) for estuarine and marine sediments*

The approach adopted by (Iannuzzi et al. 2008) is recommended to derive mSQGQ for marine and estuarine dredged and reference sediments. The SQGs used are the ERM values derived for NOAA with data from multiple marine and estuarine sites in the United States and Canada (Long et al. 1995a). ERMs for 12 chemicals and chemical groups listed in Table 5-1 are used to derive the mean ERM quotient (ERMQ). Nickel is not used in the calculation because of the low degree of reliability associated with it (Long and MacDonald 1998; Long et al. 1998). PAH individual compounds and PCB congeners are combined into groups. Following (Long et al. 1995b), PAHs are divided into two categories (low-molecular-weight PAHs [L-PAHs] and high-molecular-weight PAHs [H-PAHs]). Individual PCB congeners are summed into a measure of total PCBs. For each dredged or reference sediment, concentrations of individual chemicals are normalized to their respective ERM value to derive a concentration or ERM quotient; the normalized values are then averaged to generate the mean ERMQ following (Long et al. 1995b).

**Table 5-1. Effects range median values (ERMs) for use in deriving effects range median quotients (ERMQs).**

| <b>Chemicals</b>                  | <b>ERM</b>   |
|-----------------------------------|--------------|
|                                   | <b>mg/kg</b> |
| Arsenic                           | 70           |
| Cadmium                           | 9.6          |
| Chromium                          | 370          |
| Copper                            | 270          |
| Lead                              | 218          |
| Mercury                           | 0.71         |
| Silver                            | 3.7          |
| Zinc                              | 410          |
| <b>Chemical class</b>             | <b>µg/kg</b> |
| Low-molecular weight PAH (L-PAH)  | 3,160        |
| High molecular weight PAH (H-PAH) | 9,600        |
| Total DDT (six isomers)           | 46.1         |
| Total PCBs                        | 180          |

#### 5.2.2.2 Calculation of mSQGQ for freshwater sediments

The approach described in (Ingersoll et al. 2001) is used to derive mSQGQ for freshwater dredged and reference sediments. The SQGs used are the consensus-based probable effect concentration (PEC) guidelines (MacDonald et al. 2000). The consensus-based PECs are intended to define the concentrations of sediment-associated contaminants above which adverse effects on sediment-dwelling organisms are likely to be observed. Individual PCB congeners are summed into a measure of total PCBs; likewise, individual PAH compounds (that is, anthracene, fluorene, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene) are summed into a measure of total PAHs. The p'p and the o'p congeners of DDE are summed into a measure of total DDE. Only ten reliable PECs (Table 5-2) are used in calculating the mean PEC quotient (PEC-Q; arsenic, cadmium, chromium, copper, lead, nickel, zinc, total PAHs, total PCBs, and sum DDE). For each dredged or reference sediment, concentrations of individual chemicals are normalized to their respective PEC value to derive a concentration or PEC-Q; then the normalized values are averaged to generate the mean PEC-Q. Half of the reporting limit is used as a proxy concentration for a sample in which the concentration of a chemical is less than its reporting limit, which, in turn,

is less than the corresponding PEC. If the reporting limit is greater than the PEC, that chemical is not to be included in the calculation of PEC-Qs.

**Table 5-2. Probable effect concentrations (PECs) for use in deriving PEC quotients (PEC-Q).**

|                | PEC    |
|----------------|--------|
| Chemicals      | mg/kg  |
| Arsenic        | 33.0   |
| Cadmium        | 4.98   |
| Chromium       | 111    |
| Copper         | 149    |
| Lead           | 128    |
| Mercury        | 1.06   |
| Nickel         | 48.6   |
| Zinc           | 459    |
| Chemical class | µg/kg  |
| Total PAH      | 22,800 |
| Total PCBs     | 676    |
| Sum DDE        | 81.9   |

#### 5.2.2.3 Conclusion on potential for benthic toxicity using sediment chemistry

For marine and estuarine sediments, (Long and MacDonald 1998; Long et al. 1998) assigned a contamination classification according to the values of the mean ERMQ. The categories of *uncontaminated* (mean ERMQ < 0.1), *slightly contaminated* (0.1 < ERMQ < 0.5), *moderately contaminated* (0.5 < mean ERMQ < 1.5), or *highly contaminated* (mean ERMQ > 1.5) were associated with increasing probabilities of toxicity as observed in a meta-analysis of a nationwide database. No similar classification system is available for freshwater sediments using PEC-Qs. Since consensus-based PECs are intended to define the concentrations of sediment-associated contaminants above which adverse effects on sediment-dwelling organisms are likely to be observed, mean PEC-Q < 0.1 is also expected to indicate a classification of slightly contaminated.

When the mean ERMQ or mean PEC-Q is less than 0.1, or no contaminant concentrations exceed its corresponding ERL and TEL, the DM is unlikely to cause unacceptable adverse effects and should be considered environmentally acceptable without further testing. If COPCs for which SQGs do not exist were identified, SQGs do not provide sufficient basis to

determine environmental acceptability, so biological testing data should be used in consort to chemistry data to achieve a factual determination.

### **5.3 Primary LOE for assessing potential for benthic toxicity: sediment toxicity tests measuring acute survival**

It is widely recognized that a variety of sediment toxicity tests can provide direct and quantifiable evidence of adverse impacts to benthos (Lotufo et al. 2014). When applied to dredged and reference sediment samples, these tests measure the combined effects of all bioavailable contaminants in the test samples that typically include some degree of chemical interaction among sediment contaminants (for example, ASTM 2008a; EPA-ORD et al. 2001). Survival is widely accepted as an indicator of sediment quality, and lethal effects are expected to effectively predict the viability of populations under field conditions (McGee et al. 1999; Ferraro and Cole 2002). Acute lethality tests are relatively inexpensive and generally provide easily interpretable results in a short period. Measurement of lethality alone is considered adequate for the benthic impact assessment of DM (Steevens et al. 2008).

Sediment toxicity tests (Figure 5-3) are conducted by exposing laboratory-reared or field-collected benthic invertebrates, typically juveniles or subadults, to sediment under controlled laboratory conditions for 10 days, after which the organisms are recovered to assess survival (ASTM 2008a, 2008b, 2010; EPA-ORD et al. 2001). Unacceptable adverse impacts are determined by a statistical and response magnitude comparison of the survival end-point measurements of the DM exposed organisms to end-point measurements from organisms exposed to reference sediment. References to organism-specific USEPA and ASTM bioassay procedures are provided in Table 5-3.

Figure 5-3. Laboratory whole-sediment sediment toxicity testing set up for a 10-day amphipod test (*left*) and a 10-day midge test (*right*) using a water-delivery apparatus.



### 5.3.1 Control and reference sediment

It is important to clearly distinguish between control and reference sediments in the context of testing for benthic impacts. Reference sediment is used in evaluating the benthic effects of DM and is described in Section 3.1. Results of solid-phase toxicity and bioaccumulation tests using reference sediment provide a point of comparison against which effects of DM can be compared.

Control sediment is a sediment essentially free of contaminants routinely used to assess the acceptability of a test. This sediment is used to confirm the health of the test animals and the acceptability of the test conditions.

### 5.3.2 Species Selection

Under the MPRSA, benthic toxicity evaluation tests are to be performed with appropriate sensitive benthic marine organisms of two or more species

that together represent filter-feeding, deposit-feeding, and burrowing characteristics. These organisms shall be chosen from among the species that are most sensitive for each type they represent, and that are documented in the scientific literature and accepted

by [US]EPA as being reliable test organisms to determine the anticipated impact on the site.<sup>49</sup>

Testing of more than one species is recommended. The use of two or more species with different life-history strategies provides a wider range of varying species sensitivities and biological end-point responses, which results in a higher level of environmental protection than can be achieved with testing only a single species.

Test organisms of different species exhibit different sensitivities to the physical and chemical composition of sediments (Anderson et al. 1998; Giesy et al. 1990; Hickey and Martin 1995; Phipps et al. 1995; Watts and Pascoe 2000; Weinstein and Sanger 2003; Milani et al. 2003; Word et al. 1989; Gentile et al. 1988). To account for this variation, test species representing different taxonomic groups (for example, an amphipod and a polychaete) should be selected where possible.

Test organisms for the evaluation of potential effects of DM on benthic infauna should be

- highly responsive to contaminants;
- exhibit low responsiveness to noncontaminant factors (for example, sediment grain size, pore water ammonia);
- included in a developed test method (for example, USEPA, USACE, ASTM);
- available year-round for collection or purchase.

Selection of a species that is indigenous to the placement site or a surrogate of an indigenous species is desirable.

The key species most commonly used in freshwater and marine 10-day sediment toxicity tests are presented below, and their habitats and feeding strategies are summarized in Table 5-3.

---

49. 40 C.F.R. 227.27(d).

Table 5-3. Summary of standard benthic and epibenthic toxicity tests.

| Species                                               | Taxonomic group      | Habitat and feeding strategy                                                      | Reference                                                 |
|-------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------|
| <b>Marine</b>                                         |                      |                                                                                   |                                                           |
| <i>Ampelisca abdita</i>                               | Amphipod             | Filter and deposit-feeder, tube builder                                           | EPA-ORD (1994); ASTM 2008b)                               |
| <i>Eohaustorius estuarius</i>                         |                      | Deposit feeder, free burrower                                                     |                                                           |
| <i>Rhepoxynius abronius</i>                           |                      | Deposit feeder, predator, free burrower                                           |                                                           |
| <i>Leptocheirus plumulosus</i> (marine and estuarine) | Amphipod             | Deposit feeder, filter and suspension feeder, nonpermanent tube builder, burrower | EPA-ORD (1994); ASTM (2008b)                              |
| <i>Neanthes arenaceodentata</i>                       | Polychaete           | Deposit feeder, tube builder, burrower                                            | ASTM (2007)                                               |
| <i>Americamysis bahia</i>                             | Shrimp               | Filter feeder and deposit feeder                                                  | No standard guidance available; see Kennedy et al. (2009) |
| <b>Freshwater</b>                                     |                      |                                                                                   |                                                           |
| <i>Hyalella azteca</i>                                | Amphipod             | Deposit feeder and burrower                                                       | EPA-ORD (2000); ASTM 2010                                 |
| <i>Chironomus dilutus</i>                             | Insect (midge larva) | Deposit feeder and burrower                                                       | EPA-ORD (2000); ASTM (2010)                               |

- Marine organisms—Commonly used species in whole-sediment tests include the sediment-burrowing amphipods *Ampelisca abdita*, *Leptocheirus plumulosus*, *Eohaustorius estuaries*, and *Rhepoxynius abronius*; the mysid *Americamysis bahia*; and the infaunal tube-building polychaete *Neanthes arenaceodentata*. Standardized test methods are available for most test organisms (Table 5-3). *Leptocheirus plumulosus*, *Neanthes arenaceodentata*, and *Americamysis bahia* are available year-round as a cultured species from aquatic vendors. *Ampelisca abdita*, *Eohaustorius estuaries*, and *Rhepoxynius abronius* are usually field collected.
- Freshwater organisms—the two most commonly used test species are the amphipod *Hyalella azteca* and the midge *Chironomus dilutus* (formerly *C. tentans*). Standardized methods are available for both species (Table 5-3).
- Alternatives—The mysid shrimp *Americamysis bahia* can also be used, although it is an intermittent burrower and therefore has limited interaction with the sediment. The use of *A. bahia* is recommended where the use of amphipods and polychaetes is not appropriate; for

example, when amphipods are unable to burrow because of the physical nature of the sediment.

Potential influence of sediment noncontaminant factors should be considered when selecting test species. For example, the species selected should be tolerant of the grain size, pore-water salinity, and ammonia concentrations of the sediment. Other noncontaminant factors that cannot be addressed through species selection, such as presence of indigenous organisms, can also affect testing results. Examples of noncontaminant factors include the following:

- Grain size—Organisms such as amphipods may be impaired physically by finer-grained sediments rich in clay or silt, even to the point of mortality. Consult available tolerance limits for grain size for the organisms being considered for dredge sediment toxicity testing (ASTM 2008b, 2010). If grain sizes are outside or near the limits of the optimal range for the test organism, consult guidance (ASTM 2008b, 2010) to determine a more appropriate test organism for the grain size encountered in the DM. Ideally, make sure that physicochemical characteristics of the dredged and reference sediments are within tolerance limits of the selected test organism (Word et al. 2005).
- Salinity—Marine invertebrates have specific salinity ranges and tolerances. Testing species outside their salinity range may produce unacceptable test results (ASTM 2008b). Measure, monitor, and adjust pore-water and overlying water salinity during sediment toxicity tests to maintain target salinity levels.
- Ammonia—Ammonia is a naturally occurring, labile, transient, nonpersistent, nonbioaccumulative compound in sediments, produced by the degradation of organic material. Ammonia is generally not a COPC during open-water placement of DM, because natural dilution processes minimize its toxic effects (Jones and Lee 1988; Moore et al. 1997). However, in cold storage and in confined laboratory toxicity tests, excessive nutrients and organic carbon in sediment can result in toxic concentrations of ammonia in sediment pore water and overlying water. Bulk pore-water ammonia measurements should be conducted on sediment prior to test initiation to determine whether ammonia levels are high enough to elicit toxicity in the test species chosen for dredge sediment evaluations. If the pore-water ammonia concentrations are below species specific values provided in Table 5-4 for marine and estuarine species, or below 20 mg/L for freshwater

species, then toxicity due to ammonia would not be expected. If the ammonia levels exceed the guidance value, then ammonia toxicity is possible.

If the pore-water ammonia concentrations are above species-specific values, procedures to reduce ammonia levels prior to sediment toxicity test initiation can be employed. Ammonia chemistry surrogate test chambers should be included with the test exposure chambers explicitly for measuring pore-water ammonia levels at test initiation and test termination.

To measure ammonia levels during testing and to ensure ammonia does not increase over the course of the toxicity test, chemistry surrogate chambers should be set up for test sediments even if bulk pore-water ammonia levels were below guidance values. A minimum of two surrogate chambers are required for each sediment (Day 0 and test termination). Additional surrogate chambers should be set up if ammonia levels are high enough to expect reduction procedures to take several successive days. Information obtained during bulk sediment pore-water ammonia measurement can provide guidance on the number of surrogate chambers required.

Surrogate chambers should be terminated for each sediment at the beginning of the toxicity test (Day 0), prior to addition of organisms, to determine initial pore-water ammonia levels. If ammonia levels are below species-specific values provided Table 5-4 for marine and estuarine species, or below 20 mg/L for freshwater species, then test initiation can proceed normally. If they exceed the guidance values, then up to twice daily water-volume exchanges and aeration to saturation should be used to reduce the ammonia concentrations.

**Table 5-4. General acceptability ranges for ammonia in recommended marine sediment toxicity tests.**

| Species                         | Total ammonia (mg/L; pH 7.7) | UIA <sup>a</sup> (mg/L; pH 7.7) |
|---------------------------------|------------------------------|---------------------------------|
| <i>Leptocheirus plumulosus</i>  | <60                          | <1.4                            |
| <i>Ampelisca abdita</i>         | <30                          | <0.5                            |
| <i>Rhepoxynius abronius</i>     | <30                          | <0.5                            |
| <i>Eohaustorius estuaris</i>    | <60                          | <1.0                            |
| <i>Americamysis bahia</i>       | <50                          | <0.8                            |
| <i>Neanthes arenaceodentata</i> | <50                          | <0.8                            |
| All freshwater species          | <20                          | <0.5                            |

Note: These values serve as general guidance only and should not be interpreted as predictive values that determine bioassay outcomes.

Source: Values were directed from various sources (EPA-OW and USACE-OCRD 1998; Melby et al. 2018b; Kennedy et al. 2015; EPA-ORD 1994, 2000) and contract laboratories (for example, EcoAnalysts, Brian Hester, pers. comm., 2022).

<sup>a</sup> UIA—Un-ionized ammonia; UIA was calculated from total ammonia using the specific pH and test method specific temperature and salinity.

Pore-water ammonia should be measured in a surrogate chamber each day until the concentration falls below the appropriate species-specific level, at which time the test can be initiated by adding organisms. If ammonia reduction is not feasible or the target level cannot be reached through ammonia-reduction procedures, then TIE approaches for determining the relative contribution of ammonia to the overall toxicity can be conducted (Section 5.6). Organisms should be added to the chemistry surrogate chambers to be terminated at the end of the toxicity test to account for organism influence on ammonia concentrations. Some other confounding factors include the following:

- **Hydrogen sulfide**—Hydrogen sulfide occurs naturally in anoxic marine sediment and may co-occur with ammonia (Postma et al. 2002; Lapota et al. 2000; USACE-SAD and EPA-R4 2008). Tube-building benthic invertebrates typically circulate oxygenated water through their burrows, thus reducing exposure to pore-water hydrogen sulfide (Sims and Moore 1995). Sieving or homogenization of the sediment, or both, followed by test chamber aeration procedures commonly used in laboratory toxicity tests, typically eliminate sulfide as a confounding factor.

- Indigenous organisms—Presence of indigenous organisms can affect test results by competing for space and food and by preying on test organisms. Methods for addressing indigenous organisms can be found in “Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual” (EPA 823-B-01-002; EPA-OST 2001).

If noncontaminant factors are suspected and their effects are not properly mitigated using the approaches recommended above, additional toxicity testing may be necessary.

### **5.3.3 Sediment toxicity test interpretation**

Determining that DM could potentially pose an environmentally significant response in benthic invertebrates involves meeting two conditions:

1. Survival of benthic invertebrates exposed to DM must be at least 10 percentage points lower (20 points for estuarine and marine amphipods) than that of invertebrates exposed to reference sediments
2. Differences between the mean test and mean reference sediment toxicity test results must be statistically significant

Once sediment toxicity testing results are complete, the absolute percentage difference in survival is determined as the difference in mean percentage of mortality between test and reference sediment treatments. Differences in lethal effects of less than 10% or 20% (estuarine and marine amphipods) described above are considered environmentally insignificant as these differences are within the bounds of typical analytical and natural variability (Suter et al. 2000).

For sediments where survival exceeds the 10% or 20% (estuarine and marine amphipods) criteria, the survival results from DM exposures are statistically compared to reference sediment. These comparisons identify sediments where survival is statistically lower than observed in reference sediment.

### **5.3.4 Statistical analysis of survival data**

One-tailed statistical comparisons are performed to identify sediments where survival is statistically lower than observed in reference sediment.

Specific guidance and procedures for conducting statistical analyses of survival data can be found in (EPA-ORD 1994; EPA-ORD et al. 2001; EPA-ORD 2000; EPA-OW and USACE-OCRDR 1998). When conducting means comparison testing, special consideration should be given to the type I error ( $\alpha$ ) that is controlled by the means comparison procedure. For most DM evaluations, controlling the comparison-wise (pairwise) type I error rate rather than the experiment-wise type I error rate is the appropriate choice since DM placement decisions are made independently for each dredge site regardless of how many sites are compared to the same reference (EPA-OW and USACE-OCRDR 1998).

#### **5.4 Primary LOE for assessing potential for benthic toxicity: sediment toxicity tests measuring chronic survival and sublethal end points**

Acute sediment toxicity tests measuring lethality have been demonstrated to be adequately responsive to legacy contaminants and are the primary choice for evaluating dredge sediment for open-water placement.

Whole sediment chronic and sublethal testing is conducted in a similar manner to 10-day testing but is, in some cases, of longer duration. Chronic-sublethal tests include sublethal end points that are believed to be more sensitive indicators of sediment impairment. Chronic-sublethal tests are generally considered to be more responsive than traditional acute approaches, since the test is conducted for a longer duration and the test is initiated with a younger and generally more sensitive life stage. As such, a chronic-sublethal test may detect toxicity that would be missed in an acute exposure. However, sublethal end point data are typically highly variable among replicates, which lead to low statistical power and therefore low responsiveness relative to the acute end point, potentially leading to high uncertainty in decision-making (Steevens et al. 2008; Kennedy et al. 2009). As with acute tests, the observation of significant biological effects is not necessarily indicative of a cause-and-effect relationship with contaminants in the sediment.

Chronic-sublethal tests should only be used as a primary LOE on rare occasions when evaluation of chronic responses is deemed appropriate because of the particular contaminant evaluated or other specific circumstances that could be addressed with a longer exposure. For example, if a contaminant is known to produce a delayed toxic effect that

occurs outside the bounds of a standard acute test, then a chronic test may be appropriate.

Selection of appropriate chronic end points is also important. The biological end point data generated from sediment toxicity testing that can be interpreted as posing a strong biological relationship to adverse impacts on the viability of populations (that is, effects on survival) carry more weight in decision-making than sublethal effects. End points presenting a tenuous or ill-defined relationship to population viability (for example, molecular responses) are not used for decision-making.

Challenges with the use of chronic-sublethal toxicity tests include increased costs, decreased responsiveness in the lethality end point due to feeding and water exchange (that is, not necessarily more responsive than acute tests), loss of discriminatory power due to the variability of sublethal end points, increased complexity and difficulty in performing the test, higher rate of failures in meeting performance criteria, and susceptibility to noncontaminant factors.

Because of the lack of interpretive guidance for chronic-sublethal tests and acute tests with sublethal end points, judgments about the biological and ecological relevance of the chronic survival and sublethal end points measured must be made before considering the use of those data to make decisions regarding the potential for unacceptable benthic impacts of the DM. Decisions should not be made using statistical significance alone. Additional ecologically relevant and scientifically defensible interpretive guidance (for example, minimum response magnitude) must be developed before using a toxicity test employing chronic survival or sublethal end points in the decision-making process for open-water placement.

Chronic toxicity tests are generally run for 28 days, but longer tests may be required to measure reproductive end points. Species selection, influence of confounding factors are the same as described for acute tests. Standard chronic-sublethal tests are provided in Table 5-5.

Table 5-5. Summary of chronic and chronic-sublethal toxicity tests.

| Species                         | Taxonomic group      | Test duration    | End points measured | Reference    |
|---------------------------------|----------------------|------------------|---------------------|--------------|
| <b>Marine and estuarine</b>     |                      |                  |                     |              |
| <i>Leptocheirus plumulosus</i>  | Amphipod             | 28 days          | Survival and growth | ASTM (2008b) |
| <i>Neanthes arenaceodentata</i> | Polychaete           | 20 days; 28 days | Survival and growth | ASTM (2007)  |
| <b>Freshwater</b>               |                      |                  |                     |              |
| <i>Hyalella azteca</i>          | Amphipod             | 10 days; 28 days | Survival and growth | ASTM (2010)  |
| <i>Chironomus dilutus</i>       | Insect (midge larva) | 10 days; 20 days | Survival and growth | ASTM (2010)  |

## 5.5 Supporting LOEs for assessing potential for benthic toxicity

Including supporting LOEs in a WOE approach provides additional information that can be used to evaluate lethality data obtained in the primary LOE evaluation of a toxicity test. The additional information can provide weight supporting the conclusions of the primary LOE or may provide evidence suggesting other causes of toxicity (for example, noncontaminant effect). Supporting LOEs carry less weight than the primary LOE (that is, lethality) and cannot be used to negate the results of a toxicity test where they do not support the conclusion reached. Yet, the information provided by evaluation of supporting LOEs can be used to direct the study toward additional toxicity testing (for example, grain size identified as a noncontaminant factor can lead to using a different species that is more tolerant of that grain size for testing). The additional toxicity testing can then be used as the primary LOE for decision-making. Evaluation of sediment and porewater chemistry, tissue residue levels and noncontaminant effects are examples of other LOEs.

### 5.5.1 Benthic toxicity evaluation using sediment chemistry

Empirical SQGs have typically been derived from databases of sediment chemistry (using concentrations of specific contaminants) and observed biological effects. Empirical SQGs and their use as an assessment tool for determining the potential effects of contaminant mixtures in DM is described in Section 5.2.2. This relatively simple approach is recommended for using sediment chemistry to derive an additional LOE

for assessing potential for benthic toxicity and can be complemented with approaches described by (Burgess et al. 2013) using mechanistic SQGs.

### **5.5.2 Benthic toxicity evaluation using porewater chemistry**

Mechanistic SQGs predict the concentration of hydrophobic organic contaminants in sediment pore water using concentrations of contaminants in bulk sediment and organic carbon, comparing these values to toxicity information or benchmarks according to water exposures (Burgess et al. 2013). The high uncertainty associated with predicting concentrations of hydrophobic organics in pore water can be avoided by actual measurement of concentrations in sediment pore water (Gschwend et al. 2011). Measured concentrations of hydrophobic organics in pore water can then be compared to relevant benchmarks, such as toxicity data or other effects benchmarks (Burkhard et al. 2017).

Mechanistic SQGs were developed to predict the toxicity of metals in sediment using their concentration in the pore water. However, the ability to directly measure interstitial metal concentrations is technically challenging and expensive (Burgess et al. 2013).

#### *5.5.2.1 Evaluation of hydrophobic organic compounds pore-water chemistry data*

Empirical measurement of contaminants in sediment pore water is challenging, and few standardized methods are widely available. For organics, conventional pore-water extraction or passive reservoir sampling methods that rely on extremely large water volumes (often liters) are not practicable. Moreover, these approaches suffer from incomplete water-phase separation, sorption, or evaporative losses during sample preparation as well as interference from contaminants associated with colloids and dissolved organic carbon, despite best efforts (for example, centrifugation, filtering) to account for these artifacts (Lu et al. 2014). Thus, while these approaches may be more useful for evaluating toxicity than concentrations of contaminants in bulk sediment, direct pore-water measurements are not perfect and may not always indicate truly bioavailable fractions.

Recent advances in measurement technology have enabled the freely dissolved contaminant concentration ( $C_{\text{free}}$ ) in pore water to be quantitatively inferred from the diffusion of contaminants from sediment

pore water to solid materials (passive samplers) placed in contact with the sediment. Solid-state passive samplers for organics include solid-phase microextraction (SPME) fibers, polyethylene (PE) strips, polyoxymethylene (POM) strips, and other devices (Lydy et al. 2014; Lu et al. 2014). The use of SPME in determination of PAHs in sediment pore water has recently been established (ASTM 2011). An overview of approaches for estimating  $C_{\text{free}}$  for sediment samples in the laboratory are provided in the references (Burgess et al. 2012; Ghosh et al. 2014; Jonker et al. 2020).

Once  $C_{\text{free}}$  data are obtained and compiled,  $C_{\text{free}}$  is then compared to toxicity benchmarks. Appropriate toxicity benchmarks are the final chronic value (FCV) used to derive WQC. However, because of the stringent data requirements for the development of WQC, sufficient data are not always available to derive an FCV, and a secondary chronic value (SCV) or other water-only value may need to be used (Burgess et al. 2013; Burkhard et al. 2017). (Di Toro et al. 1991) demonstrated the similarity in sensitivities of pelagic and benthic organisms, supporting the use of FCVs, SCVs, and potentially other water-only data for predicting toxicological effects in the sediments. Conventional and narcosis chronic water-only toxicity values were compiled by (Burgess et al. 2013). When toxicity benchmarks are not exceeded in sediment pore water for a particular contaminant or class of contaminants, it can be ruled out as a causative agent of toxicity. For chemicals occurring in mixtures, toxic units can be used to evaluate toxicity (Burgess et al. 2013; Burgess et al. 2008; Berry, Burgess, Hansen, DiToro, Bell, et al. 2003).

#### 5.5.2.2 *Evaluation of metal pore-water chemistry data*

A standard approach exists for the evaluation of a mixture of the metals cadmium, copper, lead, nickel, silver, and zinc in sediment pore water (Burgess et al. 2013; Hansen et al. 2005); these metals are common sediment contaminants known to be toxic to benthic organisms (Burgess et al. 2013). Several approaches, such as centrifugation, dialysis, filtration, squeezing, and other methods have traditionally been used to separate the interstitial water from the solid phase for subsequent chemical analysis of metals. Traditional methods to extract pore water for metals analysis, including dialysis samplers, may lead to major artifacts that result in a high degree of uncertainty in estimating the true pore-water concentration of bioavailable metal (Lu et al. 2014; Peijnenburg et al. 2014; Zhang and Davison 1995). Methods using passive samplers provide improved

estimates of bioavailable metal concentrations. Diffusion gradient in thin-film gels (DGT) is a sampling technique that has been used frequently in the study of metals bioavailability in sediments (Lu et al. 2014; Peijnenburg et al. 2014). However, DGTs only provide estimates of concentration of bioavailable metals under specific conditions (Peijnenburg et al. 2014) and the use of DGT ex situ measurements of the bioavailable metals were not useful for predicting benthic toxicity in some studies (for example, Zhang et al. 2019) and therefore should only be used to estimate metal pore-water concentration for predicting toxicity. However, recent methodological developments for microcosm in situ applications for using DGT probes to measure bioavailable metal fluxes provided robust prediction of benthic toxicity (Xie et al. 2021). Therefore, until the DGT technology is further developed and validated, the use of dialysis samplers to obtain samples of interstitial water as described by (Hansen et al. 2005) is recommended. Interstitial water should be analyzed for the metals cadmium, copper, lead, nickel, silver, and zinc by routine atomic spectrochemical techniques appropriate for environmental waters (Hansen et al. 2005).

Sediments containing a mixture of cadmium, copper, lead, nickel, silver, and zinc should not cause direct toxicity to benthic organisms if the sum of the dissolved pore-water concentrations for each of those metals divided by their respective WQC FCV is less than or equal to 1.0. Metal toxicity additivity is assumed. This basic concept was expanded to include the influence of organic carbon on metal bioavailability. The recommended procedures for using this approach are provided by (Hansen et al. 2005) and (Burgess et al. 2013).

A complementary equilibrium partitioning approach for estimating bioavailable metals with the goal of predicting whether sediments may be toxic is widely used (Burgess et al. 2013; Hansen et al. 2005). In sediments, cadmium, copper, lead, nickel, silver, and zinc should not cause direct toxicity to benthic organisms if AVS concentration exceeds the summed concentration of SEM for those metals. Detailed procedures for using this approach are provided by (Hansen et al. 2005) and (Burgess et al. 2013).

### **5.5.3 Evaluation of bioaccumulation data to infer potential for effects to the benthos**

Concentrations of contaminants in invertebrate test organisms exposed to DM in laboratory bioaccumulation tests (Section 2) often comprise an influential LOE for determining chemically derived effects. The concentration of a chemical in tissue may be considered a toxicological dose directly related to toxic effects, especially for organic contaminants (McCarty et al. 2011; McCarty and Mackay 1993). Tissue concentrations may be less useful for metals that are physiologically regulated, such as copper and zinc.

Evaluation of bioaccumulation data for predicting toxicity involves comparison of concentrations of contaminants in test invertebrates exposed to dredged and reference sediment to critical body residues (CBRs). CBRs are concentrations associated with adverse effects and are usually derived in single-chemical or single-chemical-class (for example, PCBs) experiments under controlled laboratory conditions. CBR information is obtained from previously conducted experiments as reported in the scientific literature or in USACE's Environmental Residue-Effects Database (ERDC-EL 2017).

Evaluation of bioaccumulation test results using the CBR approach can reduce uncertainty when attempting to determine the cause of toxic effects (for example, see Sappington et al. 2011). Contaminants with tissue concentrations below their corresponding CBR are unlikely toxicity drivers. However, the presence of a chemical in tissues at concentrations above a CBR value does not necessarily indicate that the sediment is likely to result in toxicity or establish the cause of toxic effects. Rather, exceedance of CBR values generally indicates that further evaluation is needed.

If it is unlikely that lethality was due to contaminants suspected as causative agents of toxicity because their steady-state concentrations as determined in the bioaccumulation evaluation are lower than their CBR for lethality, then stressors other than contaminants might be driving the response.

#### **5.5.4 Influence of noncontaminant-related causes of toxicity**

When evaluating the results of toxicity tests, it is important to determine whether noncontaminant factors contribute to the observed response. The observation of significantly decreased survival in a toxicity test does not necessarily indicate that dredged-sediment-associated contaminants are the cause of the observed effects. Factors (for example, grain size, ammonia) other than sediment-associated contaminants can affect biotic responses during exposure to sediment. Discussion regarding the influence of noncontaminant factors is provided in Section 5.3.2.

If a noncontaminant factor is suspected as a possible cause of toxicity observed in the primary LOE toxicity test, then an alternative testing approach can be considered. For example, if ammonia levels exceeded the tolerance limits for the species tested and ammonia is suspected as a cause of the observed toxicity, then ammonia reduction procedures can be employed or an alternate species tolerant of the ammonia levels encountered could be selected for toxicity testing. The results from this test can then be used as the primary LOE for decision-making.

Where the extent of influence for a noncontaminant factor is unknown, specialized testing methods and procedures (for example, TIEs, pore-water and sediment chemistry) can be used to help pinpoint whether the observed toxicity is contaminant related or possibly related to a noncontaminant effect.

### **5.6 Whole-sediment TIE**

Whole-sediment TIEs are used to identify the causes of toxic effects in sediment-quality evaluations (Burgess et al. 2011). In DM evaluations, they are primarily used for establishing cause of toxicity or in evaluating cause and effect relationships (for example, evaluating the influence of confounding factors). The TIE process involves a combination of chemical manipulation and whole-organism toxicity testing (Burgess et al. 2011; Ho and Burgess 2008). Each chemical manipulation removes or ameliorates the bioavailability of a particular class of contaminants. For example, in sediment in which either ammonia or organic contaminants (for example, PAHs) are suspected causes of observed toxicity, one subsample is treated with activate carbon (for example, coconut charcoal) to reduce organic chemical bioavailability, while another subsample is treated with an adsorbent material (for example, zeolite) to reduce ammonia. If toxicity is

significantly reduced after the zeolite treatment (but not after the coconut charcoal treatment), it is likely the adverse effects originally observed in the DM are related to ammonia. Conversely, if toxicity is significantly reduced in the coconut charcoal treatment (but not the zeolite treatment), the cause of the effects is likely related to organic contaminants. A TIE is conducted in three phases with increasing resolution as to causality with each phase. Phase I identifies causality to chemical class (that is, organics, metals or ammonia). Phase II identifies specific compounds causing toxicity. Phase III confirms the toxic agents identified in the previous two phases (Burgess et al. 2011). Costs increase with each phase of a TIE.

A TIE is useful in a cause-and-effect evaluation for situations when the cause of toxicity is not clear from sediment chemistry and whole-sediment testing. For example, if whole sediment toxicity indicates that sediments are toxic, but sediment chemistry does not identify a contaminant as the likely cause of the observed toxicity, a TIE can be used to determine whether toxicity is due to a contaminant not measured during sediment chemistry or due to a noncontaminant factor. A TIE can also provide information for determining appropriate DM management options. For example, if multiple contaminants are present in sediment that has been deemed toxic, knowing which contaminant is the primary cause of toxicity can focus the engineering design efforts to deal primarily with that contaminant, potentially reducing sediment management costs.

In most cases a Phase I TIE is the appropriate choice for evaluation of DM. A Phase I TIE should be conducted as described by (EPA-ORD 2007). A Phase I TIE can be interpreted as shown in Table 5-6.

Table 5-6. Interpretation of a Phase I toxicity identification evaluation (TIE) toxicity test results.

| Amendment target                            | Significant decrease in toxicity observed? |                                          |                                        |                                                                                          |
|---------------------------------------------|--------------------------------------------|------------------------------------------|----------------------------------------|------------------------------------------------------------------------------------------|
|                                             | Result 1                                   | Result 2                                 | Result 3                               | Result 4                                                                                 |
| Ammonia<br>(for example, zeolite)           | Yes                                        | No                                       | No                                     | No                                                                                       |
| Organics<br>(for example, activated carbon) | No                                         | Yes                                      | No                                     | No                                                                                       |
| Metals<br>(for example, anionic resin)      | No                                         | No                                       | Yes                                    | No                                                                                       |
| Interpretation of results                   | Ammonia<br>primary cause<br>of toxicity    | Organics<br>primary cause<br>of toxicity | Metals<br>primary cause<br>of toxicity | Toxicity due to<br>noncontaminant factor<br>or contaminant not<br>targeted by amendments |

The ability to identify the source of toxicity to contaminant class is relatively easy when a sediment is contaminated primarily with a high level of a single contaminant class such as PCBs, PAHs, pesticides, and metals. In many cases there is co-occurrence of contaminants at various levels, resulting in mixture-influenced toxicity. In these cases it becomes more difficult to determine which class of contaminant is the cause of toxicity, since the toxicity of one can mask the toxicity of the other. One approach for evaluating mixture toxicity is to use a blend of amendments. For example, if chemistry analysis shows high levels of PAHs and metals, then a blend of activated carbon and anionic resin can be added as a treatment level to determine whether PAHs and metals are acting together to produce toxicity. The presence of unusual toxicants or biological factors, both anthropogenic and naturally occurring, can influence the results of a Phase I TIE test. There are a number of naturally occurring environmental toxicants in aquatic environments (for example, organic acids, algal blooms) that may result in toxicity to macroinvertebrates but would not be identified in TIE testing. Although the specific cause of toxicity may not be identified in these cases, it is possible that a Phase I TIE could eliminate classes of contaminants as the cause if toxicity is not reduced in the amended sediment for that particular contaminant class.

## 5.7 Integration of LOEs and decision-making

The use of a WOE approach for decisions on open-water placement of DM requires careful consideration and evaluation of the primary and other LOEs available. The biological end point of survival used in sediment toxicity tests is used as the primary LOE in a WOE approach since it

provides direct and quantifiable evidence of adverse impacts to benthos (Lotufo et al. 2014). Lethality has a strong biological relationship to the viability of organism populations. Therefore, significant lethality is indicative of a high probability of an adverse population-level effect. Because of this strong relationship, survival as the primary LOE carries more weight (greater than 50%) than other LOEs and is used as the primary factor in a WOE approach evaluation for determining suitability for open-water placement.

The WOE for decision-making is obtained by evaluating the primary LOE in the context of other LOEs available. Although other LOEs cannot be used to negate the results obtained from the primary LOE (that is, lethality) due to its weight, they can provide additional WOE that can be used to support the results obtained from the sediment toxicity test or direct the study toward additional toxicity testing that can be used as the primary LOE.

For example, a toxicity test where interpretive guidance indicates adverse impacts, coupled with sediment (SQG) and pore-water or tissue chemistry indicating that toxicity would be expected, provides strong WOE that unacceptable impacts are likely to occur from open-water sediment placement. Alternatively, a toxicity test where interpretive guidance indicates no adverse impacts, coupled with sediment (SQG) and tissue chemistry indicating that toxicity would not be expected, provides strong WOE that environmental impacts are not likely to occur from open-water sediment placement. In these cases, the other LOEs support the findings of the toxicity test or primary LOE.

In cases where interpretive guidance from a toxicity test indicates adverse impacts, but sediment (SQG) and pore-water or tissue chemistry indicate that toxicity would not be expected and a noncontaminant factor (for example, grain size, total organic carbon, ammonia) is suspected to be influencing survival results, the WOE suggests that the toxicity test used as the primary LOE may not be the best indicator of contaminant-driven toxicity. In these cases an alternative testing approach may be appropriate. For example, additional steps to decrease ammonia or other noncontaminant confounding factors could be employed or, in the case of grain-size tolerance issues, a different test species with greater grain-size tolerance could be used in the sediment toxicity test to generate a new primary LOE. A TIE could be useful in this situation to help determine

whether the effects observed are driven by contaminants or a noncontaminant factor.

## **5.8 Operational and engineering controls**

Operational and engineering controls are considered when the evaluation of potential for benthic toxicity indicates a need to reduce exposure to DM following placement. Operational controls include actions that the site manager or operator can implement during or following placement of the material, such as scheduling the placement of lower-quality sediment prior to placement of higher-quality sediment to improve the quality of the biologically active layer.

Engineering controls require a physical construction technology or modification of the site design to reduce environmental risk to acceptable levels, such as amending the sediment to reduce desorption, lateral confinement, and capping.

## 6 Assessment of Potential for Contaminant Impacts Resulting from Benthic Bioaccumulation

### 6.1 Scope of a bioaccumulation evaluation

The main focus of a DM bioaccumulation evaluation is to examine the potential for adverse effects to fish, wildlife, or humans that may indirectly accumulate contaminants from DM (Figure 1-2). In the context of DM placement in aquatic systems, exposure to contaminants occurs via food webs that include consumption of benthic invertebrates that have accumulated contaminants from sediment at the placement site.

The assessment of bioaccumulation begins with consideration of the CM to verify that exposure pathways for bioaccumulative chemicals in DM to fish, aquatic wildlife, terrestrial wildlife, or humans is present at the placement site and will persist for a time period sufficient to pose a risk of adverse effects. The generic exposure pathway includes benthic invertebrates colonizing and inhabiting the *upper* sediment layer of the placement site and that are consumed by fish or wildlife that visit the placement site. The general pattern for infaunal distribution, whether in freshwater, estuarine, or marine environments, is that the greatest numbers of organisms occur within 2 to 5 cm of the sediment surface, with very few numbers of organisms being found deeper than 20 cm (Bosworth and Thibodeaux 1990).

Figure 6-1 provides the basic testing and assessment procedure to make a technical determination on the potential for contaminant impacts caused by benthic bioaccumulation. Simply determining that contaminants in DM are present or bioaccumulate in benthic organisms in laboratory exposures is not evidence of the potential for adverse effects to receptors of concern. When significant bioaccumulation of contaminants in fish, wildlife, or humans is expected, the relationship between contaminants in these receptors and the potential for unacceptable adverse effects must be adequately evaluated to assess risks.

The risks of adverse effects to benthic invertebrates from contaminants, including those that tend to bioaccumulate, is adequately evaluated using benthic toxicity testing and associated LOEs and should not be the focus of

the bioaccumulation evaluation. Although contaminants may release to the water column during DM placement, most bioaccumulative contaminants are highly hydrophobic, and, as a result, a biologically significant release to the water column from DM placement is highly unlikely. Moreover, the limited spatial and temporal nature of this release and dispersion of the material in the water column greatly decrease the potential for the bioaccumulation of contaminants in pelagic organisms. Further, suspended-particulate-phase bioaccumulation testing is not required under the CWA or MPRSA.

Figure 6-1. Decision-making process for the evaluation of bioaccumulation of contaminants from DM. Consider each dredged material management unit (DMMU) for each contaminant of potential concern (COPC) and cycle through this chart until all COPC are addressed (that is, repeat this process for each COPC). (Accessible version available in Appendix A.8.)

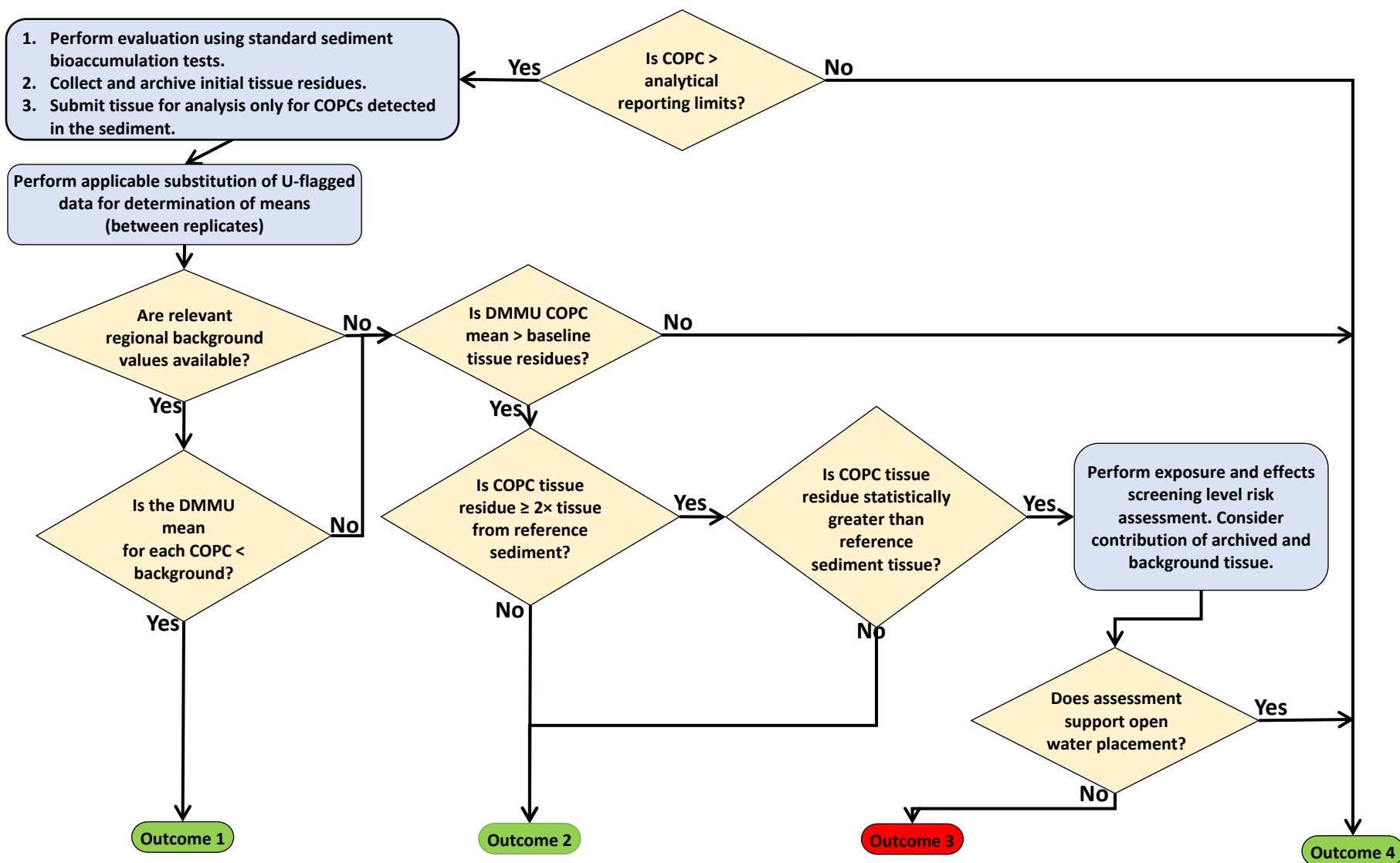
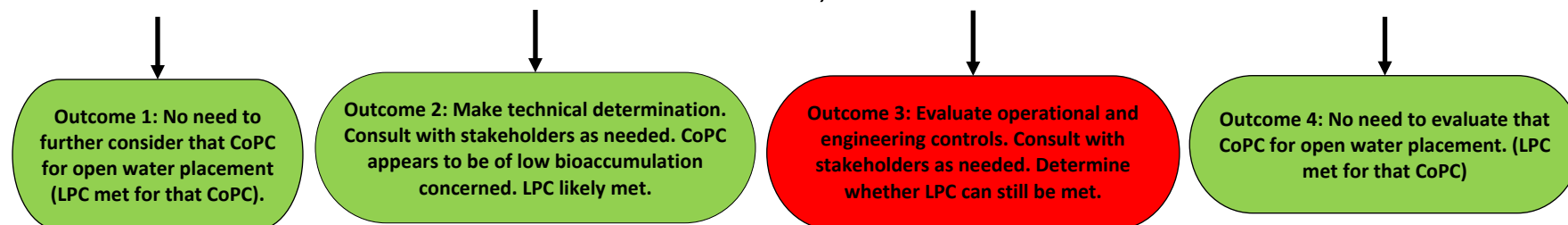


Figure 6-1 (cont.). Decision-making process for the evaluation of bioaccumulation of contaminants from DM. Consider each dredged material management unit (DMMU) for each contaminant of potential concern (COPC) and cycle through this chart until all COPC are addressed (that is, repeat this process for each COPC).



## 6.2 Chemicals with bioaccumulation potential

The scope of a bioaccumulation evaluation should not include all measurable chemicals detected in DM. Most chemicals with propensity to bioaccumulate and biomagnify are non-ionic (that is, hydrophobic) organic contaminants (ASTM 2019; Gobas et al. 2009). Hydrophobic organic contaminants with low octanol-water partition coefficients (that is,  $\log K_{OW} < 5$ ) will not magnify from food to consumer owing to a high rate of chemical elimination (Gobas et al. 1999) and are unlikely to bioaccumulate significantly in aquatic systems (Mackay and Fraser 2000) and therefore should be excluded from the bioaccumulation potential evaluation. Metals that form organic complexes such as selenium and mercury share many attributes with bioaccumulative non-ionic chemicals when uptake is from diet, not dissolved exposure, and are therefore also of concern. Methylmercury produced in nearshore sediments accounts for a significant fraction of mercury in primary producers that bioaccumulates at higher trophic levels (Hammerschmidt et al. 2004). It is well established that selenium bioaccumulates in food webs principally through dietary exposure (Presser and Luoma 2010). A bioaccumulation evaluation of DM should always include the following substances, when they are among the contaminants present in the sediment:

- PCBs—PCBs can be measured as PCB Aroclors or individual PCB congeners. Evaluation of bioaccumulation should be performed on the basis of total PCBs (sum of Aroclors or congeners). PCB congener analysis (rather than Aroclor analysis) is recommended. Guidance for handling of nondetects in multiple tissue replicates is available in (USACE-SAD and EPA-R4 2008).
- Organochlorine (OC) pesticides—OC pesticides include many legacy pesticides (for example, DDTs, chlordane, and dieldrin, as measured using USEPA Method 8080; (for example, DDTs, chlordane, and dieldrin, as measured using USEPA Method 8080; EPA 1986a), most of which have multiple forms (that is, 4,4' or 2,4'-DDT, DDDs, DDEs).
- Methylmercury—Methylmercury is the methylated, bioaccumulative form of mercury. Bioaccumulation evaluation should be performed for methylmercury as measured using USEPA Method 1631 (EPA-OST 1999), not total or inorganic mercury.
- Selenium—Selenium should be evaluated as total selenium as measured using USEPA Method 7740 (EPA 1986b). While the organic form of selenium is most relevant to bioaccumulation assessments,

there are no standardized methods for measuring organic selenium in sediment, therefore the standardized method for total selenium is recommended.

The above list does not include two classes of bioaccumulative hydrophobic organic contaminants: dioxins and furans, and polybrominated diphenyl ethers (PBDEs). DM bioaccumulation evaluation for these chemical classes should be evaluated when sediment concentrations are considered elevated, relative to reference concentrations of the placement site, or if there is evidence of local or regional concerns, such as fish advisories, regionally established thresholds, or Section 303(d) listings because of these chemicals.<sup>50</sup>

A bioaccumulation potential assessment for DM should not routinely include PAHs, tributyltin (TBT), or metals (for example, cadmium, lead, arsenic, silver, nickel, zinc, copper). PAHs and TBT are effectively biotransformed by higher-trophic-level species into constituents of less concern (Veltman et al. 2006; Wan et al. 2007; Hu et al. 2006). Because organisms situated at a high trophic level have the ability to rapidly metabolize or reduce the assimilation of PAHs, a trend of PAH biodilution with increasing trophic level has been reported for freshwater and marine food webs (for example, Broman et al. 1990; Nakata et al. 2003; Wan et al. 2007; Takeuchi et al. 2009; Huang et al. 2014). For marine food webs, absence of biomagnification or biodilution of TBT has been reported (Takahashi et al. 1999; Hu et al. 2006; Fortibuoni et al. 2013), but biomagnification of TBT has also been shown (Fortibuoni et al. 2013). Some metals have limited bioavailability (for example, lead) and uptake of other physiologically regulated metals (for example, copper, zinc) is limited, with bioaccumulation in most species correlating poorly with environmental exposure (Luoma and Rainbow 2005; Cardwell et al. 2013; Gao et al. 2021), therefore lowering the potential for bioaccumulation via predation on the benthos. For these substances, the primary concern arises from direct toxicity to organisms in contact with the sediment, not via the benthic bioaccumulation and trophic transfer pathway (Section 1).

---

50. Federal Water Pollution Control Act Amendments of 1972 § 303(d), 33 U.S.C. § 1313(d)(1)(D). (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap26.pdf>.

### 6.3 Initial evaluation of bioaccumulation potential

If bioaccumulative contaminants are detected in sediment and bioaccumulation exposure pathways are assumed to be complete, an assessment of bioaccumulation potential should follow the decision-making process described in Figure 6-1.

The initial evaluation is used to determine whether a technical determination can be achieved without additional efforts (Section 1.6.3). Conditions that are recognized in the regulatory framework as exclusions from further testing are described in Section 1.6.3. If it is determined that an exclusion from further testing applies to the DM, the evaluation of potential contaminant impacts caused by benthic bioaccumulation described in this chapter becomes unnecessary.

If bioaccumulative contaminants are detected in sediment and a technical determination on the basis of exclusion from further testing was not achieved, a screening assessment using sediment chemistry data is conducted. Concentrations in sediment proposed for placement are compared to concentrations in reference sediment. For organic contaminants or methylmercury, concentrations are first normalized to organic carbon. If concentrations in the DM are greater, an evaluation of bioaccumulation potential is conducted using laboratory sediment testing. A 1.5 factor difference between the concentration in sediment proposed for placement and concentrations in reference sediment is recommended as a biologically meaningful difference below which an evaluation of bioaccumulation potential using laboratory sediment testing should be considered unnecessary. The 1.5 factor was selected according to the variability in replicate bioaccumulation data derived from laboratory exposures using common test species (for example, (Kennedy et al. 2010; Linkov et al. 2001; Van Geest et al. 2010; McQueen et al. 2020; Lotufo, Biedenbach, et al. 2022)). Moreover, because of the relatively high variability associated with measuring bioaccumulation from sediment, it is recommended that bioaccumulation experiments be designed to detect a two-fold difference between tissue residues in the test and reference sediments (ASTM 2019). Therefore, exposure to sediments with less than a factor of 1.5 difference in the concentrations of bioaccumulative contaminants is not expected to result in meaningful differences in tissue residue between treatments.

This step can be omitted if sediment chemistry data are unavailable or if prior data or the CM indicates concentrations of bioaccumulative chemicals in the DM are likely to be elevated relative to reference sediment chemistry.

In some cases, historical studies at or near the area to be dredged or the placement site may provide relevant information regarding benthic bioaccumulation or body residues in invertebrates. If historical bioaccumulation testing or tissue residue information is determined to be of sufficient quality, these data can be adopted as an alternative to conducting bioaccumulation testing as part of the initial evaluation (Section 1.6.3).

## **6.4 Bioaccumulation testing**

Bioaccumulation testing consists of obtaining sediment that will be dredged and sediment from a reference location (Section 5.3.1), exposing laboratory organisms to the samples in a laboratory setting, and measuring concentrations of contaminants in the organisms after a predetermined exposure period.

Laboratory bioaccumulation tests (Figure 6-2) are generally conducted by exposing infaunal organisms to sediment under controlled conditions for a predetermined period of time, after which the organisms are separated from the sediment to directly measure the concentration of contaminants in their tissues. (ASTM 2019) provides more information about bioaccumulation tests, including experimental design. Important test considerations are discussed in this section.

Figure 6-2. Laboratory whole-sediment bioaccumulation testing set up for a 28-day *Macoma nasuta* test. Note that the *lower right* image shows clams immediately following addition to the tanks; clams should be completely buried within 24 hours.



#### 6.4.1 Bioaccumulation test species

Desired characteristics of bioaccumulation test species include the following:

- readily available year-round
- relatively free of contamination
- burrow in sediments and ingest sediment for feeding
- sufficiently robust to tolerate handling and exposure to DM and reference sediments under laboratory conditions
- of sufficient size to provide adequate tissue mass for chemical analysis (pooling multiple individuals is also acceptable)
- related phylogenetically or ecologically to important species at the placement site (for example, related to relevant resident prey species)

Table 6-1 provides a list of recommended species for use in freshwater and marine sediment bioaccumulation testing. (ASTM 2019) provides general information about bioaccumulation tests, a list and description of basic characteristics of test species used in laboratory sediment bioaccumulation testing, and experimental design. Specific guidance for recommended bioassay procedures is provided by (EPA-OW and USACE-OCR D 1998; USACE-SAD and EPA-R4 2008).

Table 6-1. Suitable species for use in benthic bioaccumulation tests.

| Species                                      | Taxonomic group | Feeding strategy                    |
|----------------------------------------------|-----------------|-------------------------------------|
| <b>Freshwater</b>                            |                 |                                     |
| <i>Lumbriculus variegatus</i> <sup>a</sup>   | Oligochaete     | Subsurface deposit feeder           |
| <i>Corbicula fluminea</i>                    | Bivalve         | Filter feeder                       |
| <b>Marine and estuarine</b>                  |                 |                                     |
| <i>Macoma nasuta</i>                         | Bivalve         | Surface deposit feeder              |
| <i>Macoma balthica</i>                       | Bivalve         | Subsurface deposit feeder           |
| <i>Alitta virens</i>                         | Polychaete      | Subsurface deposit-feeder, omnivore |
| <i>Hediste diversicolor</i>                  | Polychaete      | Surface deposit-feeder              |
| <i>Nephtys caecoides</i>                     | Polychaete      | Subsurface deposit feeder           |
| <i>Leptocheirus plumulosus</i> <sup>a</sup>  | Amphipod        | Subsurface deposit feeder           |
| <i>Neanthes arenaceodentata</i> <sup>a</sup> | Polychaete      | Subsurface deposit feeder           |

<sup>a</sup> Species that are typically obtained from laboratory cultures. All other species are field collected.

Test organisms should be selected on the basis of their relative tolerance to contaminants and their body size. The number of test organisms must be sufficient to recover enough tissue at the end of the exposure for proper chemical analysis. For assessing bioaccumulation, adequate tissue biomass and the ability to ingest sediments are more important than taxon sensitivity. Although advances in microscale testing methods (Jones et al. 2006; Valente et al. 2006; Millward et al. 2007) that determine contaminant concentrations with less tissue mass than previous methods has led to the opportunity for using smaller infaunal species such as amphipods and smaller polychaetes in bioaccumulation tests (Millward et al. 2005; Janssen et al. 2010; Sanders et al. 2018; Sinche et al. 2019), these typically only supply enough volume for one extraction and analysis, so additional replicates may be necessary for multiple analyses.

Some annelid species are commonly selected for bioaccumulation tests because they are intimately and continuously associated with the sediment, ingest sediment directly, are easily reared and handled in the laboratory, and can be exposed to a wide variety of sediment types (sandy or fine grained). Thus, the use of annelids in testing generally provides a conservative assessment of contaminant bioavailability and bioaccumulation potential (ASTM 2019; Van Geest et al. 2010). Commonly used annelids include the freshwater oligochaete *Lumbriculus variegatus* and the marine polychaete *Alitta virens* (Figure 6-3; ASTM 2019). Another species routinely used for bioaccumulation testing is the marine clam *Macoma nasuta* (Figure 6-3; ASTM 2019). In addition to the above

recommended species, the marine and estuarine clams *Macoma balthica* and *Yoldia limatula* and the polychaetes *Hediste diversicolor* and *Nephtys caecoides* are considered suitable candidates. All the above species are field collected, except for *L. variegatus*, which is easily cultured in the laboratory. A list and description of basic characteristics of test species used in laboratory sediment bioaccumulation testing is presented by (ASTM 2019).

Figure 6-3. The freshwater oligochaete *Lumbriculus variegatus* (left), the marine polychaete *Alitta virens* (center), and the marine and estuarine clam *M. nasuta* (right).



The oligochaete *L. variegatus* should always be used to assess the potential bioaccumulation of contaminants from freshwater DM. If testing with two species is desired, the freshwater benthic mussel *Corbicula fluminea* is considered a suitable test species. Species for use with marine and estuarine sediment should be selected from those in Table 6-1. *A. virens* and *M. nasuta*, the species historically most routinely used for bioaccumulation testing, should be selected when possible.

#### 6.4.2 Bioaccumulation steady state

Duration of the bioaccumulation test influences the amount of contaminant accumulated by test organisms. Accumulation of contaminants in the tissues generally follows an asymptotic curve where tissue concentration increases with exposure time, approaching a steady state body residue expected to be comparable to that for similar organisms exposed to DM at a placement site.

The current scientific consensus is that 28 days is appropriate for most bioaccumulation test organisms to accumulate concentrations of most contaminants to levels that are within 20% of steady-state levels (ASTM 2019). However, time-series experiments have demonstrated that steady

state is not reached in 100% of all 28-day tests with all species and bioaccumulative contaminants due to variability associated with sediment type, test conditions, organism conditions, chemical measurement variability and other experimental artifacts (ASTM 2019; Kennedy et al. 2010; Burkhard et al. 2012).

To enable 28-day bioaccumulation test results to reflect potential bioaccumulation following DM placement, the following data rules apply for standard 28-day test results:

- Concentrations of organic chemicals in bivalve species (for example, *M. nasuta*) should be multiplied by a factor of three (on the basis of recent evaluations of bioaccumulation test data, (Burkhard et al. 2012; Kennedy et al. 2010; ASTM 2019). If site-specific correction factors are available (such as those by (Kennedy et al. 2010) for New York harbor), these should be used in place of three.
- The correction factor can be omitted if steady-state concentrations in bivalve species are derived using longer or multiple-time series tests, typically referred to as *steady-state bioaccumulation tests* according to (ASTM 2019) procedures. This advanced bioaccumulation testing will result in increased test costs, because it requires additional sample material and longer (for example, 56-day) tests for some contaminants. Steady-state bioaccumulation tests are strongly recommended for sites where concentrations of bioaccumulative contaminants in sediment are high, as the use of conservative correction factors may indicate adverse risks to wildlife or human health while increasing the uncertainty associated with the evaluation.
- 28-day tissue concentrations of organic chemicals in species other than bivalves are assumed to approximate steady state and need no correction (that is, correction factor of one).
- 28-day tissue concentrations of methylmercury (or other organometals or metals) are assumed to approximate steady state and need no correction (that is, correction factor of one).

#### **6.4.3 Procedures for termination of bioaccumulation tests**

Organisms that ingest sediment (for example, oligochaetes, polychaetes, and bivalves) are likely to contain sediment within their digestive tracts on the termination of a bioaccumulation test. The chemicals associated with this ingested sediment have not truly been bioaccumulated into tissue and may contain chemical forms that are not biologically available (ASTM

2019). To avoid extracting this portion of chemicals during the analysis of tissues, digestive tracts of the animals should be emptied or removed prior to preserving and preparing the tissues for chemical analysis. Ingested sediment removal should occur immediately after termination of the exposure period using standard laboratory test procedures in which animals are either dissected or maintained in sediment-free test chambers for a period of time to allow their digestive tracts to void the ingested sediment. Additional detail can be found in (ASTM 2019).

The best procedure is to excise the digestive tract to exclude undigested sediment from chemical analysis. Removal of the gut is practical with large bivalves, such as *Macoma nasuta* (Kennedy et al. 2010), and gut content extrusion has been applied to polychaetes (Kennedy et al. 2010; Millward et al. 2005); however, either other test organisms are not large enough for this to be practical or the practice is too labor intensive. Such organisms are allowed to void the material by passing it through their gut. This process can be facilitated by various methods, including placing organisms in clean water (test media) and potentially including some material (for example, clean sand, fines) for organisms that cannot passively void their guts. Organisms are held in separate aquaria in clean, sediment-free water for up to 24 hours to allow purging to occur. To minimize the possibility of loss of contaminants from tissues, purging for longer periods is not recommended. Purging for 6 hours was recommended for *L. variegatus* (Mount et al. 1999; Millward et al. 2005; Farrar et al. 2011) and should be used for that species as well as *N. caecoides* and *L. plumulosus*. A purging period of 24 hours is recommended for the larger invertebrates *C. fluminea*, *M. nasuta*, *M. balthica*, *A. virens*, and *N. arenocodonta*. At the conclusion of this purging period, organisms are sacrificed for chemical analysis.

#### **6.4.4 Analysis of organism tissue**

Analytical protocols to quantify contaminant concentrations in sediment and tissue are specified in USEPA SW-846 methods (EPA 1997), although in some cases more than one method may be available for measuring a particular contaminant. For example, individual PCB congeners can be quantified according to either USEPA 8082A (EPA-OW 2000) or USEPA 1668 (EPA-OW 1997) methods. PCB analytical methods vary depending on whether the test results are to be reported as total PCBs, one or more PCB Aroclor mixtures, or individual PCB congeners.

In addition to analyzing for COPCs, it is recommended that lipid content of test organisms be measured at test initiation and termination for all exposed organisms (for example, DM, reference, and control). Measurement of lipid content permits an assessment of organism health at test initiation and over the course of the exposure. If lipid content remains relatively constant or increases over the course of the exposure, it is an indication that sufficient food was available and animals were not unduly stressed during the exposure. A statistically significant decrease in lipid content over the course of the test may be an indication of potential stress or starvation. This comparison can be coupled with observations regarding the burrowing or feeding activity of organisms to determine whether they are being exposed to the test material. In cases where lipid content decreases significantly or it is suspected that organisms are not feeding from the test materials, consideration may be given to repeating the test with appropriate modifications. Further, lipid content measurements permit the calculation of site-specific biota-sediment accumulation factors (BSAFs), which may be useful in future assessments at that site (Burkhard et al. 2012).

## **6.5 Bioaccumulation test data preparation**

Data from bioaccumulation tests include the concentration of contaminants in the DM, reference sediment, and the exposed test organisms. Before bioaccumulation data can be interpreted for decision-making purposes, any analytical data provided by the laboratory that are below detection limit or require summation must be converted to an appropriate form for statistical analysis and hypothesis testing.

## **6.6 Bioaccumulation test data interpretation**

### **6.6.1 Comparison of bioaccumulation test data to reference conditions**

Contaminant tissue concentrations in organisms exposed to the DM are statistically compared to contaminant tissue concentrations measured in organisms exposed to the reference sediment.

Loss of contaminant tissue residues in reference invertebrates can sometimes occur (particularly in sandy materials with low organic content), resulting in lower concentrations in reference exposed invertebrates after 28 days relative to their initial tissue concentration. This loss may lead to statistical differences between invertebrates exposed

to reference sediment and those exposed to DM that are not a consequence of bioaccumulation but rather as a result of differences in the kinetics of depuration of the initial body burden. For this reason, it is recommended that invertebrates from the same batch used in the bioaccumulation test be archived and frozen so that they may be analyzed in the event there are significant differences between reference-sediment-exposed and dredged-sediment-exposed organisms to confirm that bioaccumulation has occurred. If no bioaccumulation occurred (that is, the initial tissue concentration is similar to or greater than the measured 28-day tissue concentrations), no further evaluation is required. If bioaccumulation has occurred in the dredged-sediment-exposed organisms but not in the reference-sediment-exposed organisms, then the higher of the reference invertebrate tissue concentrations at exposure termination or the initial body burden should be used in the statistical comparison with invertebrates exposed to DM.

Statistical procedures for comparison of tissue residues in reference and DM exposed organisms are described by (ASTM 2019). Statistical significance should not be used as the sole LOE to determine whether the bioaccumulation potential poses unacceptable risks. Consideration of the magnitude difference between bioaccumulation from DM and reference material, or *MOD*, should be a relevant element of the evaluation (McQueen et al. 2020). Considering the *MOD* is advantageous, as it allows the practitioner to account for uncertainty related to inherent variability of the test in the interpretation of statistically significant bioaccumulation results. Establishing a minimum *MOD* to determine a meaningful level of bioaccumulation relative to reference sediment is highly desirable and has been recently proposed (McQueen et al. 2020). According to (ASTM 2019), the lack of consensus concerning what constitutes an acceptable minimum difference supports adopting a bioaccumulation testing protocol to detect a two-fold difference between tissue residues in the DM test and the reference sediment test. A two-fold difference is considered sufficient to determine the potential for ecological and human health concerns. Therefore, contaminant concentrations in test organisms must be more than twice the levels found in the same organisms exposed to reference sediments to be considered as a *biologically* meaningful difference within the context of the bioaccumulation evaluation of DM. Data sets with *MODs* less than two were considered by (McQueen et al. 2020) to be within the inherent variability range of the methods associated with laboratory sediment bioaccumulation testing. Results from an

interlaboratory evaluation of variability in sediment bioaccumulation tests (Lotufo, Biedenbach, et al. 2022) corroborate the use of MOD of two as a minimum relative threshold when applying MOD as an LOE in delineating an appropriate level of bioaccumulation relative to reference sediment warranting further evaluation.

The following decision rules are recommended:

- If mean contaminant concentrations in the tissues of invertebrates exposed to the DM are not statistically greater than those exposed to reference sediment (or concentrations of benthic organisms collected directly from reference areas outside the placement site), or greater by less than a factor of two, further evaluation is not needed. The placement of DM in the aquatic environment is not expected to result in unacceptable risks of adverse effects to human and ecological receptors compared to the reference area as a result of bioaccumulation.
- If mean contaminant concentrations in the tissues of invertebrates exposed to the DM are statistically significantly greater than those exposed to reference sediment or are greater than those in benthic organisms representing the placement site, and the magnitude of the difference is greater by at least a factor of two, further evaluation is needed, or the DM is considered unacceptable for aquatic placement without management options.

#### **6.6.2 Evaluation of potential effects using bioaccumulation modeling**

The bioaccumulation evaluation calls for a detailed assessment of potential effects to higher-trophic-level organisms only if the preceding steps fail to resolve the nature and extent of potential aquatic life exposure to contaminants in the DM. Using a detailed CM for the site, a modeling-based, potential-effects evaluation should be performed. The use of the Bioaccumulation Risk Assessment Modeling System (BRAMS), an executable program that can be used to calculate potential human health and ecological risks due to bioaccumulation of sediment-associated contaminants, is recommended. BRAMS contains three separate tools that use separate equations and inputs to calculate risks: Trophic Trace (TT), the Bioaccumulation Evaluation Screening Tool (BEST), and FishRand (FR). These tools and associated guidance documents can be obtained from <https://dots.el.erdcdren.mil/models5.html>.

For human health risk assessments, consider the following:

- If risk estimates are at or below risk or hazard thresholds (generally a hazard quotient [HQ] of 1 and cancer risk of  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$ , depending on relevant regulatory guidelines), unacceptable adverse effects derived from DM placement are not expected.
- If risk estimates are above risk or hazard thresholds (generally HQ of 1 and cancer risk of  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$ , depending on relevant regulatory guidelines), unacceptable adverse effects derived from DM placement are possible. At this point, it may be prudent to evaluate key uncertainties of the human health risk assessment.

For ecological risk assessments, consider the following:

- If risk estimates are at or below risk or hazard thresholds (HQ of 1), unacceptable adverse effects derived from DM placement are not expected.
- If risk estimates are above risk or hazard thresholds (HQ of 1), unacceptable adverse effects derived from DM placement are possible. At this point, it may be prudent to evaluate key uncertainties of the ecological risk assessment.

## 7 DEMAND and DEVOLD Application User's Guide

### 7.1 DEMAND tool

The DEMAND Application is designed to guide a DM program manager, risk assessor, or laboratory technician through a dredging evaluation. The application provides step-by-step procedures for planning and executing a dredging evaluation so that workers new to dredging evaluations consider the most relevant evaluation requirements (for example, what and when to test) and document rationale for decisions and communication with stakeholders. The application is particularly useful for stakeholder decision documentation so that the same conversations and decisions are not continuously revisited (a waste of time and monetary resources) the next time a harbor or location is evaluated.

The DEMAND Application was developed by the USACE ERDC Environmental Laboratory and the Information Technology Laboratory. It is a containerized application using a microservice-based software architecture. The microservices consist of a proxy server, a NextJS web server, a Go API server, and a MySQL database. This architecture allows for segmented logic implementations and increased portability by using the Docker platform for software deployment. The only software dependencies needed to run the DEMAND Application are Docker and 7-Zip.

#### 7.1.1 Installation of docker desktop

Docker is the underlying software infrastructure that powers the DEMAND Application. Docker is freely available in the USACE Software Application Portal managed by ACE-IT.

An ACE-IT technician will be needed to install the Docker Desktop application on a USACE-managed workstation because of the elevated privileges required. During the installation process, ensure the following requirements are met:

- The machine supports virtualization.
- The Microsoft hypervisor client Hyper-V is enabled on the machine.
- The current user account is listed in the `docker-users` group.

Once the installation has completed. Start the Docker Desktop application. On a Windows machine, Docker can be started by searching for the Docker Desktop application and clicking it. After several seconds, a Docker window will appear on the user's desktop.

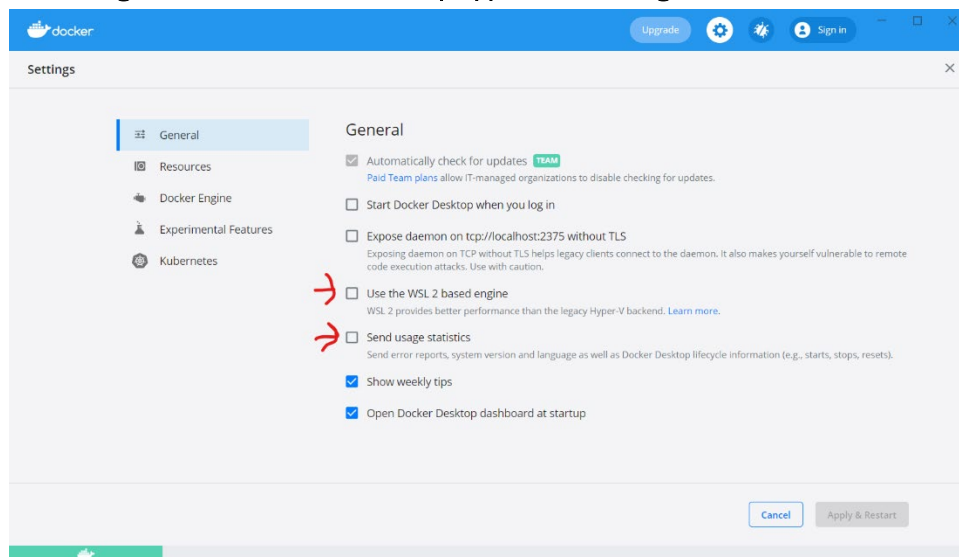
After first installation of the Docker Desktop application, some of the default settings will need to be changed to ensure that the application successfully starts and performs. To start the process of changing the default settings, click on the Settings icon (the gear icon) at the top of the Docker Desktop application (Figure 7-1).

Figure 7-1. The Docker Desktop Application Settings icon.



Clicking this icon will open the settings screen of the Docker Desktop application. Click on the General tab to the left of the settings screen (Figure 7-2).

Figure 7-2. The Docker Desktop Application Settings-General section.

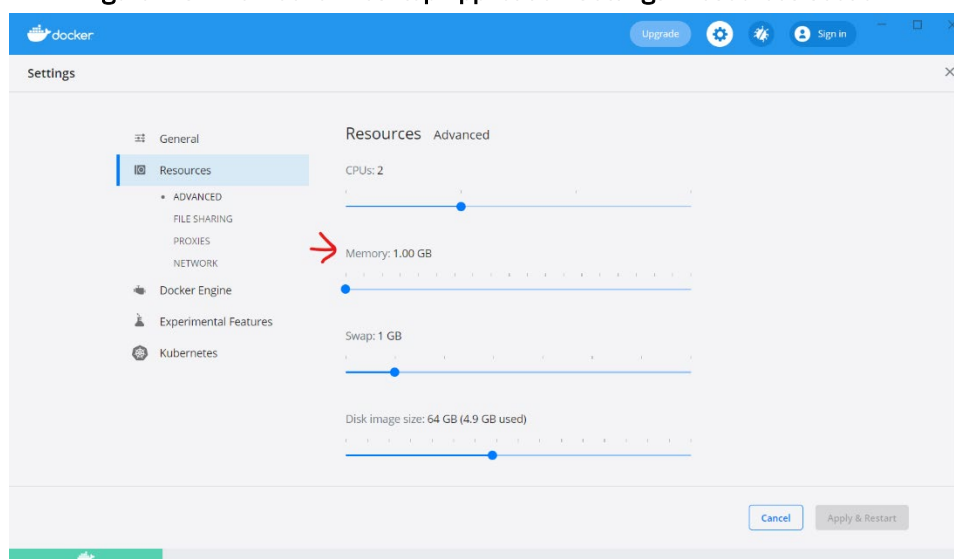


Ensure that the *Use the WSL 2 based engine* and the *Send usage statistics* options are unchecked (Figure 7-3). After ensuring that those options are unchecked, click on the Resources tab to the left of the settings screen. The Resources tab is directly under the General tab.

In the ADVANCED section of the Resources tab, for the Memory section, allocate the memory down to 1.00 GB (Figure 7-3). When the resources and checkboxes are unchecked, press the Apply & Restart button to the lower right of the window. This will restart the Docker Desktop application.

When the Docker status light at the bottom of the window is green, Docker is ready for usage.

Figure 7-3. The Docker Desktop Application Settings–Resources section.



### 7.1.2 Installation of the DEMAND application

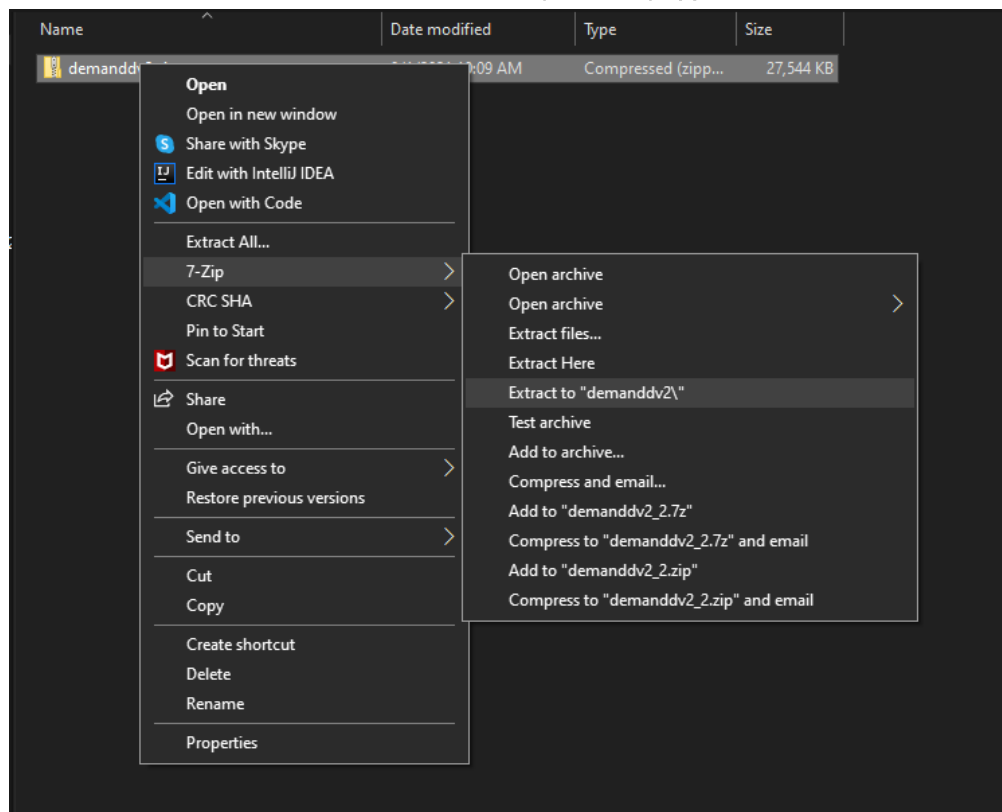
The DEMAND Application is packaged and distributed using the 7-Zip format and tool. In order for the application to function correctly, it must be unzipped using the 7-Zip tool. The application can be unpackaged anywhere on the machine the user can access. Please note that because of information assurance requirements and restrictions, the application may not function on all systems.

To unzip the application, 7-Zip must be installed on the user's machine. 7-Zip can be downloaded from <https://www.7-Zip.org/download.html>, or it may be already installed on the machine depending on IT standards and practices of the organization. The picture below demonstrates how to extract the DEMAND Application using 7-Zip.

To extract the application (Figure 7-4), complete the following steps:

1. Right-click on the file that was downloaded or distributed to the machine.
2. Move the mouse cursor down to the 7-Zip menu selection. *Note:* Not all machines will have this selection.
3. Move the mouse cursor over to the submenu and move the cursor down to the Extract to “demandv2\” choice and left-click the highlighted menu option. This filename may be different because of management and distribution practices.
4. Once the DEMAND Application is extracted, open the newly created folder to view the contents. The extracted folder contains several subfolders and files.
5. In order to successfully install the DEMAND Application, the Docker runtime (version greater than or equal 3.1) must be installed on the machine. Once Docker is installed, ensure that the Docker runtime is running. On a Windows machine, Docker can be started by searching for the Docker Desktop application and clicking it. After several seconds, a Docker window will appear on the user’s desktop.
6. Once the Docker runtime has started, click on the `install.bat` file in the extracted folder. Depending on the configuration of the machine, the .bat extension may not be visible. Clicking on this file starts the build process for the microservice containers and may take several minutes due to network connection speeds. In the event an error occurs, please refer to the user guide included in the application folder.

Figure 7-4. Guidance for extracting the Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) application.

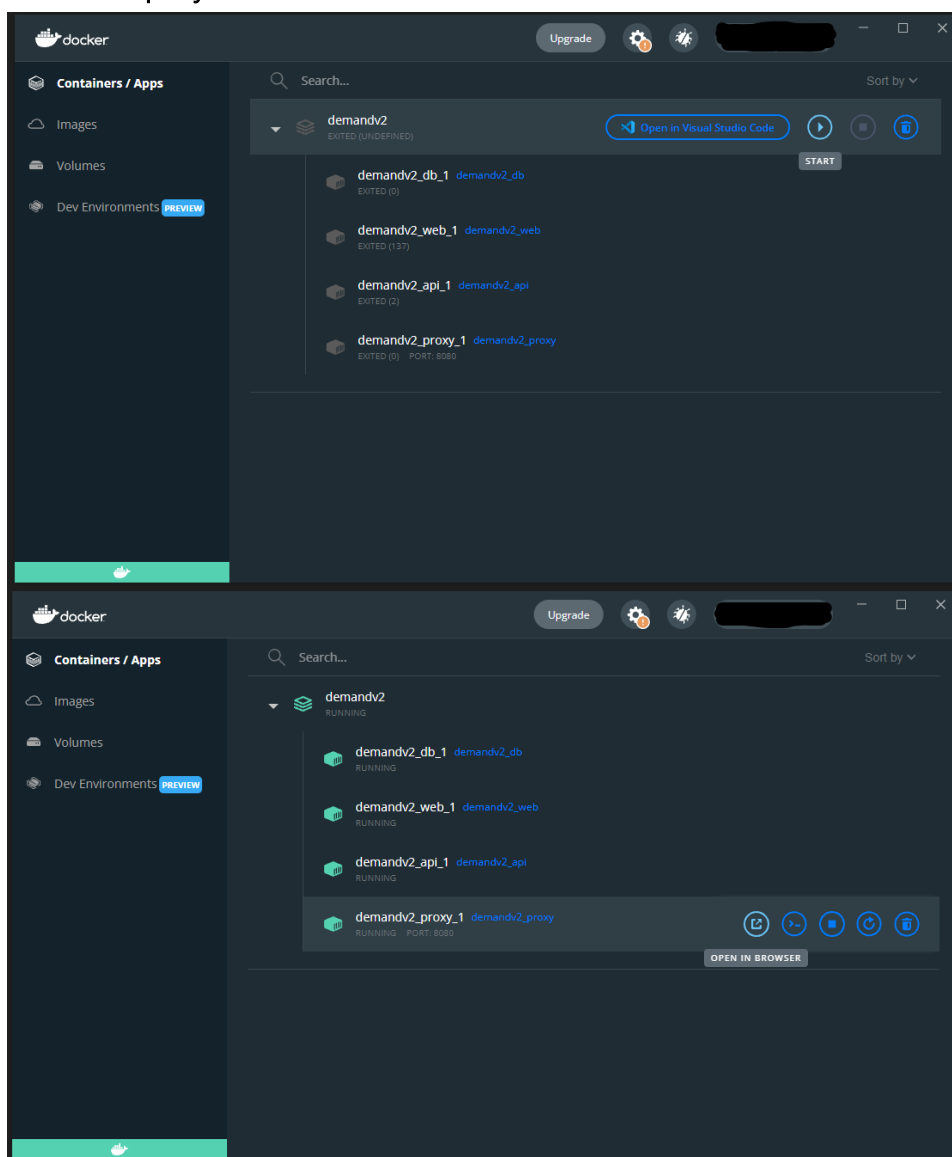


### 7.1.3 Running the DEMAND application

To start the DEMAND Application, ensure that Docker runtime is enabled. This can be done on a Windows machine by starting the Docker Desktop application. In the Docker Desktop application, in the Containers / Apps tab, the DEMAND Application should be registered. If the DEMAND Application tab is grayed out, the DEMAND Application must be started by clicking on the START button to the right of the tab. When the tab is all green, click the Expand arrow to the left of the DEMAND Application tab to reveal the different DEMAND containers (Figure 7-5).

Highlight, or mouseover, the proxy container tab. The proxy container tab will have a button signaling that a web browser can be opened to reveal the application. Click this button, and the DEMAND Application will be opened in the machine's default web browser. The DEMAND Application was built to be run in modern (as of 2022) web browsers.

Figure 7-5. *Top*, Docker Desktop command window listing the DEMAND Application. *Top*, highlights how the containerized DEMAND Application is started. *Bottom*, the proxy container with the OPEN IN BROWSER button selected.



### 7.1.4 Using the DEMAND application

The DEMAND Application is designed to guide a researcher through a dredging evaluation and use a step-wise approach to the evaluation.

#### 7.1.4.1 Starting screen

The application starts on the Starting Screen (Figure 7-6) and directs the user to start, import, or continue a dredging assessment.

Figure 7-6. Starting screen.



#### 7.1.4.2 New dredging operation screen

If a new dredging assessment is desired, the user should click on the Start a New Dredging Assessment button. This will bring up the New Dredging Operation screen (Figure 7-7). At this screen, the user will enter relevant information regarding the dredging operation. When all information is entered, the user will click on the Submit button at the bottom of the screen and be taken to the Home screen.

Figure 7-7. New Dredging Operation screen.

DEMAND | New

localhost:3000/project/new

ERDC

Dredging Evaluation Management, Analysis and Networked Documentation

### New Dredging Operation

USACE Division  
Great Lakes and Ohio River Division

USACE District  
Buffalo District

Project Harbor \*

Project Year \*  
2000

Project Description

SUBMIT

### 7.1.4.3 Home screen

The Home screen (Figure 7-8) gives an overview of the current assessment. Here, the user can view the project's checklist for final reporting capabilities, generate a project report, generate a project COPC report, or delete the project.

Figure 7-8. Home screen.



Before performing the assessment, the user should click on the Continue to Add DMMUs button on the Home screen. Clicking this button will take the user to the DMMUs screen.

#### 7.1.4.4 DMMUs screen

On the DMMU screen (Figure 7-9), the user can populate the different DMMUs associated with the project. Here, the user specifies the name of the DMMU, the estimated cubic yards of the DMMU, and if the DMMU is the reference or disposal site. Once information is entered, the user can click Submit to save the DMMU entry to the project. When all DMMUs are entered, the user can click the Add COPC button at the bottom of the screen. Clicking this button will take the user to the COPC screen.

Figure 7-9. DMMU screen.

The screenshot displays the 'DMMU' screen within the 'Maumee' application. The interface includes a navigation bar at the top with links for 'Starting Screen', 'Home', 'DMMUs', 'CoPCs', and 'Credits'. The main content area is divided into two sections. On the left, the 'New DMMU' form contains instructions and input fields for 'New DMMU Name' (with 'DMMU 2' entered), 'Estimated Volume (cu yd)' (with '35000' entered), and a checkbox for 'Is Reference Sediment / Disposal Site?'. A 'Submit' button is located below these fields. On the right, a table titled 'DMMUs' lists existing entries: 'Reference / Disposal Site - Disposal Site' and 'Dmmu 1', each with a close button (X). At the bottom of the screen, a message states 'When all DMMUs have been submitted. Click below to continue to CoPC Selection.' with an 'Add CoPCs' button.

| DMMUs                                     |   |
|-------------------------------------------|---|
| Reference / Disposal Site - Disposal Site | X |
| Dmmu 1                                    | X |

#### 7.1.4.5 Contaminants of potential concern (COPCs) screen

On the COPC screen (Figure 7-10), the user populates each DMMU with Contaminants of Potential Concern relevant to the project at hand. When all COPC are entered, the user can click the Review COPC for DMMUs button at the bottom of the page and be taken back to the Home screen.

To start the DMMU analysis, click on the Review This DMMU button (Figure 7-11) under the DMMU subsection on the Home screen (Figure 7-8). This will start the analysis process for that specific DMMU. Reference and Disposal Site may be indicated (via check box) but are not eligible for review.

Figure 7-10. COPCs screen.

**Contaminants of Potential Concern**

Select the relevant pathway(s) and their associated contaminants of potential concern (CoPC).

When all CoPC selections are complete, return to the "Home" screen for DMMU Analysis and Review

**Disposal Site**

**Sediment**

**Nutrients** **Clear Selection** ☐ Select All

☐ Ammonia ☐ Total Kjeldahl Nitrogen (TKN)

☐ Total Phosphorous

**Add a New CoPC**

**Oil and Grease** **Clear Selection** ☐ Select All

☐ Oil and Grease

Figure 7-11. Populated DMMU with COPCs.

The screenshot shows the DEMAND application interface. At the top, there is a browser window with the address bar showing 'localhost:3000/project'. Below the browser window, there is a table of COPCs (Contaminants of Potential Concern) with three columns. The table contains the following rows:

|                     |                    |                 |
|---------------------|--------------------|-----------------|
| 2,4'-DDD            | 2,4'-DDE           | 2,4'-DDT        |
| 4,4'-DDD            | 4,4'-DDE           | 4,4'-DDT        |
| Aldrin              | Cyanide            | Dieldrin        |
| Endosulfan I        | Endosulfan II      | Endrin          |
| Heptachlor          | Heptachlor epoxide | Oxychlordane    |
| Toxaphene           | alpha-Chlordane    | cis-Nonachlor   |
| gamma-BHC (Lindane) | gamma-Chlordane    | trans-Nonachlor |

Below the table, there is a section titled 'Dmmu 1'. It contains a paragraph of text: 'Review project DMMUs and associated CoPC lists. To make changes, click on "DMMUs" or "CoPCs" on the menu bar. To start analysis, click on the "Review this DMMU" button. You will need to repeat this process for subsequent DMMUs.'

Below the text, there is a button labeled 'Review This DMMU'.

Below the button, there is a section titled 'Sediment'. It contains a table of COPCs (Contaminants of Potential Concern) with three columns. The table contains the following rows:

|                     |                    |                 |
|---------------------|--------------------|-----------------|
| 2,4'-DDD            | 2,4'-DDE           | 2,4'-DDT        |
| 4,4'-DDD            | 4,4'-DDE           | 4,4'-DDT        |
| Aldrin              | Cyanide            | Dieldrin        |
| Endosulfan I        | Endosulfan II      | Endrin          |
| Heptachlor          | Heptachlor epoxide | Oxychlordane    |
| Toxaphene           | alpha-Chlordane    | cis-Nonachlor   |
| gamma-BHC (Lindane) | gamma-Chlordane    | trans-Nonachlor |

Below the table, there is a button labeled 'View History'.

### 7.1.5 Go back

The DEMAND Application provides limited ability to return to previously selected nodes and questions in the evaluation process.

If a user needs to go back to a previous node, the Go Back button should be pressed until the desired node is encountered.

### 7.1.6 Save functionality

All information for the dredging assessment is automatically stored locally on the user's workstation.

### 7.1.7 Print report functionality

The current (2022) alpha version of DEMAND allows all decisions nodes, responses to questions, decision documentation and limited data entered to be exported as a PDF report (Figure 7-12). Such reports can serve as the permanent record of a dredging evaluation project that can be archived and later reviewed prior to conducting subsequent dredging evaluations for the same location or harbor.

Figure 7-12. Example of a project-specific report generated by the application (earlier version shown).



**DEMANDD**

**PROJECT SUMMARY**

|                     |                                     |
|---------------------|-------------------------------------|
| USACE DIVISION      | Great Lakes and Ohio River Division |
| USACE DISTRICT      | Buffalo District                    |
| PROJECT HARBOR      | Cleveland                           |
| PROJECT YEAR        | 1970                                |
| PROJECT DESCRIPTION | 404 evaluation                      |

Generated on: September 22, 2021

**DMMU(s)**

DMMU-1

Is this new work or O&M dredging?  
O&M

Consult with stakeholders

Identify Available Management Option: aquatic or upland (incl disposal and/or beneficial use)  
Aquatic

Documentation: What is the regulatory jurisdiction of this material?  
MPRSA

Was the material tested in the past 5-10 years?  
No

Develop new QAPP -> consensus with stakeholders -> make sure measurement endpoints met DQO before use in decision making

Collect material and generate new sediment data for exclusionary/confirmatory analysis.

Perform exclusionary/confirmatory analysis using the newly generated data

Is/was the sediment fines <= 10%?  
No

Is the material new work (e.g., pre-pleistocene clay)?  
No

Refine previous CoC list and proceed to planning and analysis (consider each exposure pathway (water, sediment toxicity, bioaccumulation)).

**Continue Analysis**

Refine previously established CoC list and proceed to planning and analysis for open water placement/disposal

Can the DM be excluded from reduced testing (based on historic information)?  
No

Is there a path for beneficial use?  
No

Collect sufficient material for all testing requirements (logistical cost savings)

Perform grain size (confirmatory) analysis

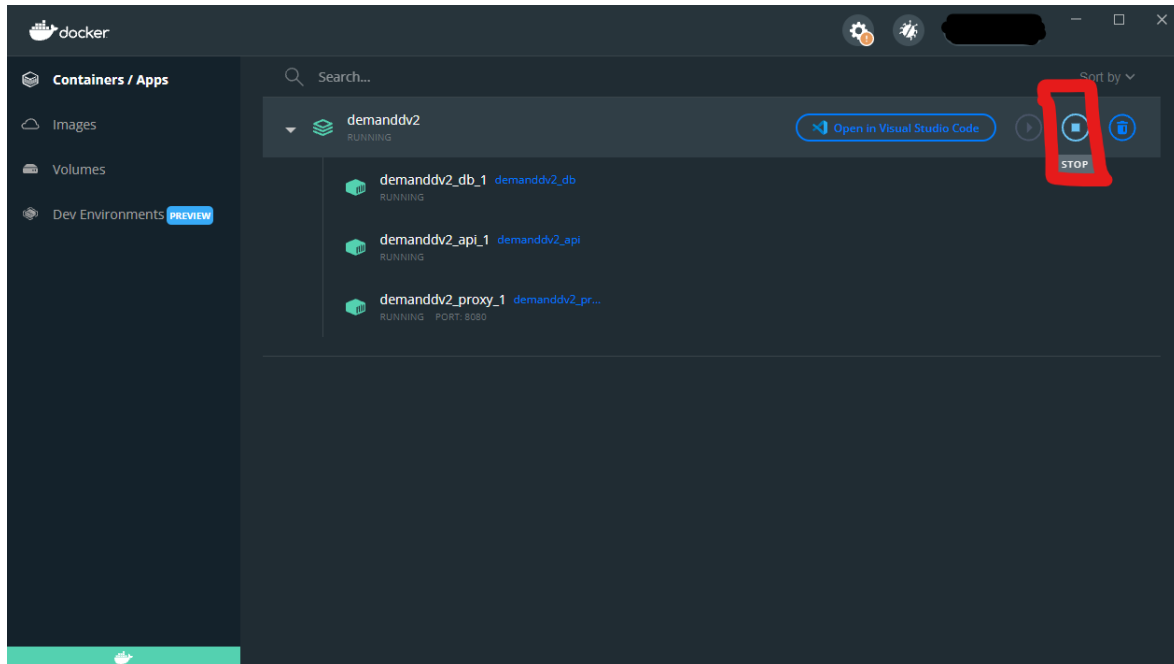
Can the DM be excluded based on new data?  
No

## 7.2 Stopping the DEMAND application

When the DEMAND Application is no longer needed, the application must be closed out of the browser window and stopped in the Docker Desktop Application.

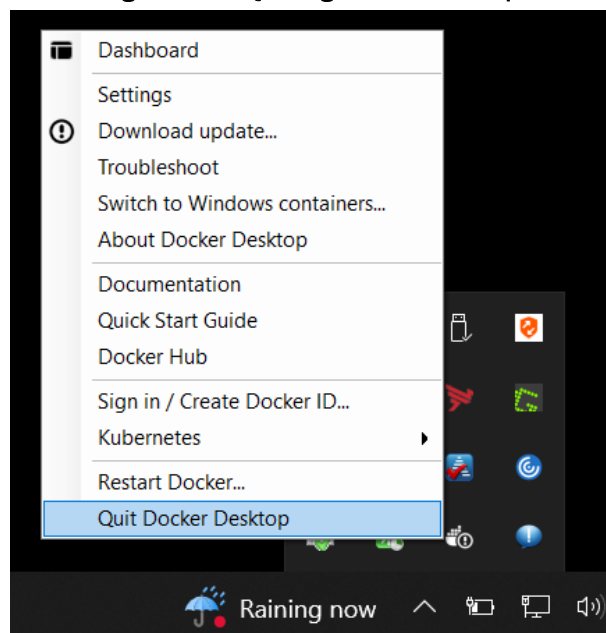
To stop the DEMAND Application, press the STOP button in the Docker Desktop Application (Figure 7-13). The STOP button is located directly to the right of the START button used in the earlier starting step. After pressing the STOP button, all entries under the DEMAND Application will be grayed out.

Figure 7-13. STOP Button.



Once all containers have stopped, close out of the Docker Desktop Application and click on the arrow at the lower right of the Windows Desktop. This will reveal hidden icons on the user's toolbar, and the Docker icon will be included in those icons. Mouseover the Docker icon and right click the icon. Click on the Quit Docker Desktop entry to stop the Docker runtime on the machine (Figure 7-14).

Figure 7-14. Quitting Docker Desktop.



### 7.3 DEVOID tool

The DEVOID tool is a data visualization application (Figure 7-15). The application mines a dredging database file represented within a Microsoft Excel spreadsheet. The DEVOID tool was written using the R programming language and packaged using the 7-Zip compression software.

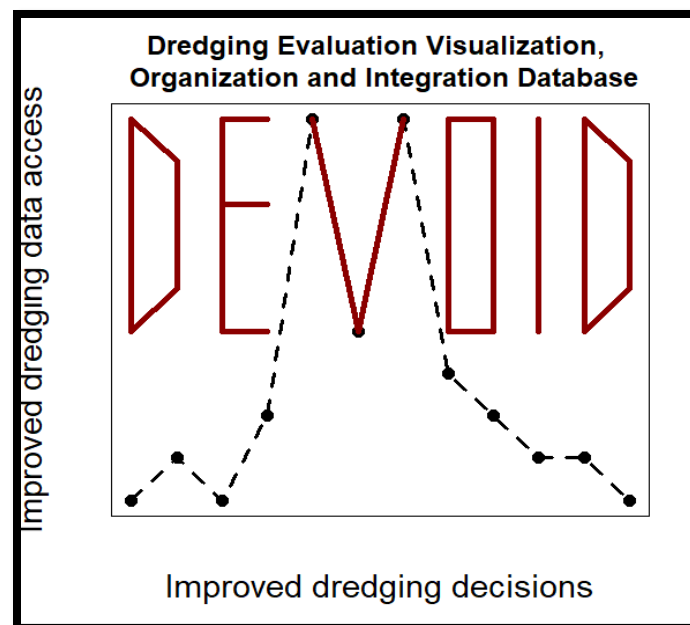
The DEVOID Version 1.0 was developed jointly by the Environmental Laboratory and the Information Technology Laboratory of the Engineer Research and Development Center. Points of contact are

Al Kennedy  
*Environmental Laboratory Project Manager*  
[Alan.J.Kennedy@usace.army.mil](mailto:Alan.J.Kennedy@usace.army.mil)

David W. Moore, PhD  
*Research Biologist*  
[David.W.Moore@usace.army.mil](mailto:David.W.Moore@usace.army.mil)

Trent May  
*Information Technology Laboratory Lead Developer*  
[Trent.C.May@usace.army.mil](mailto:Trent.C.May@usace.army.mil)

Figure 7-15. Dredging Evaluation Visualization, Organization and Integration Database (DEVOID) program logo.



### 7.3.1 Installation of the DEVOID application

The DEVOID Application is packaged through the 7-Zip compression software.

To unpackage the application (Figure 7-16), complete the following steps:

1. Navigate to the folder where the compressed package is stored in the file manager window.
2. Right-click on the compressed package and select 'Extract to devoid\' under the 7-Zip submenu. This filename may be different due to management and distribution practices.

### 7.3.2 Running the DEVOID application

The preferred method for running the DEVOID Application is through the RStudio application. RStudio is a development environment for the R programming language and is available for download at <https://www.rstudio.com/>. Alternatively, for USACE personnel, R software, RStudio, RShiny and other associated software are currently (as of March 2022) available on the software portal (<https://app-portal.usace.army.mil/esd/Home>). The core R software (titled *R for Windows 4.0.3* in the App Portal as of March 2022) and RStudio (titled *RStudio Version 1.4.1717* in the App Portal as of March 2022) must be downloaded and installed separately.

Start a new session of RStudio by clicking on the RStudio desktop application, then open the project with RStudio as shown below (Figure 7-16). Select File in the top menu bar (Figure 7-17), then Open Project... This will open the Windows file manager. Navigate to the directory where the DEVOID Application was unpackaged.

Figure 7-16. Launching of the RStudio application.

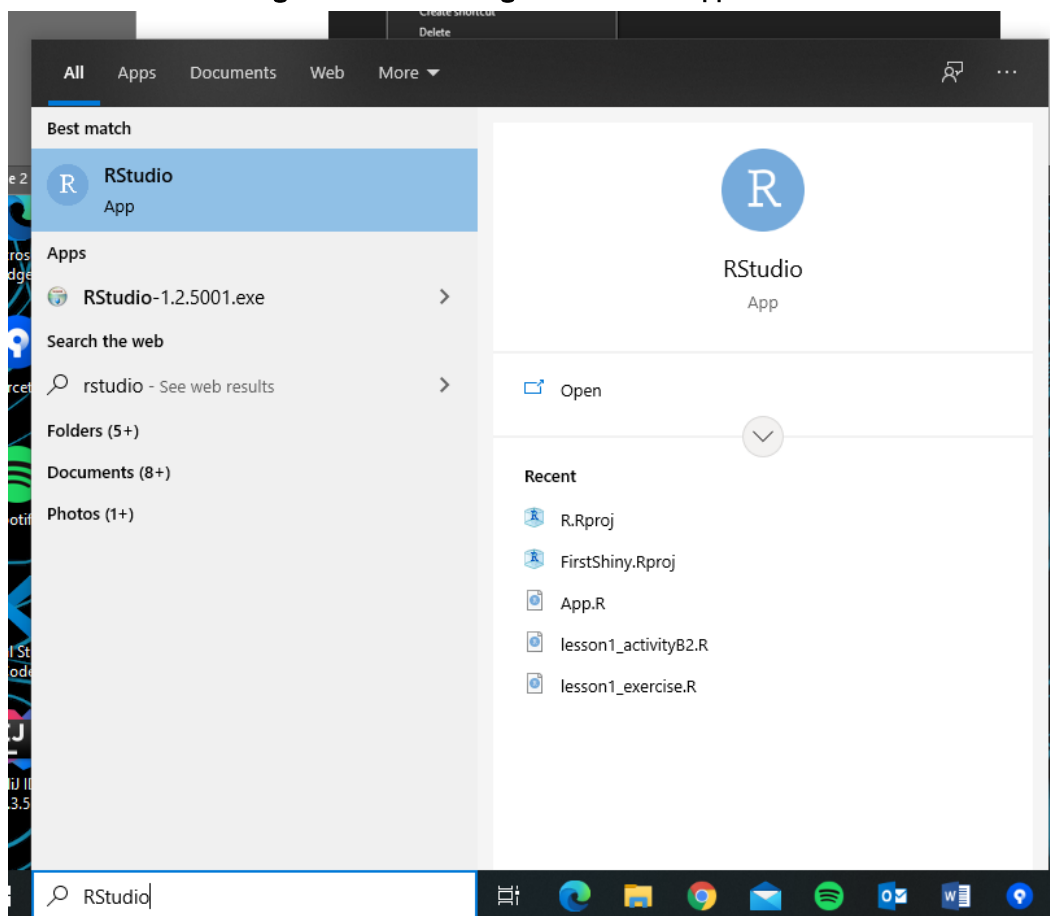
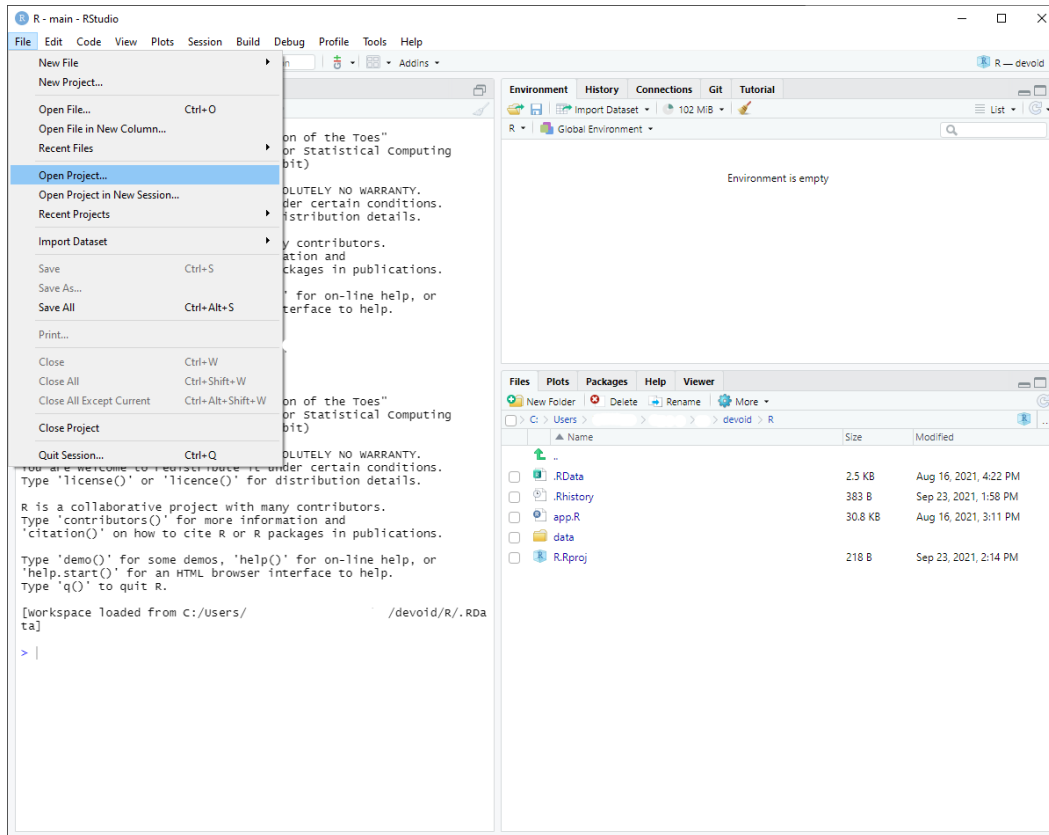
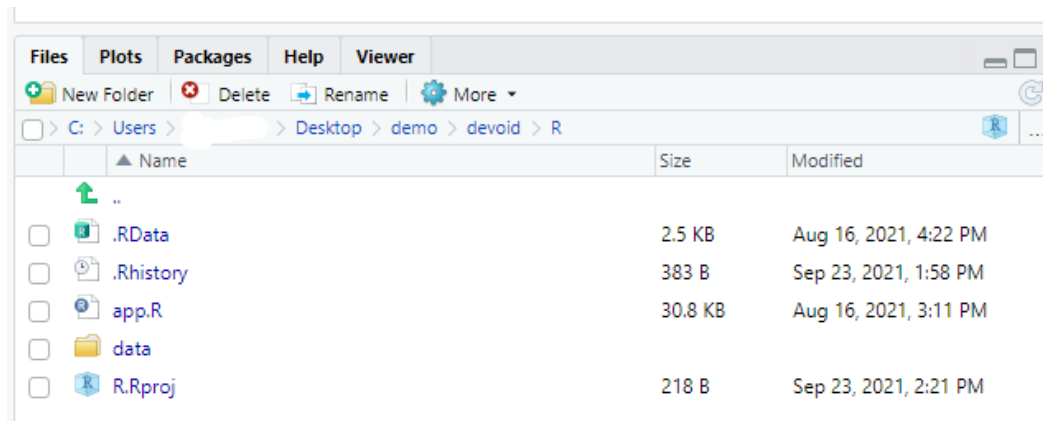


Figure 7-17. Open the DEVOID project.



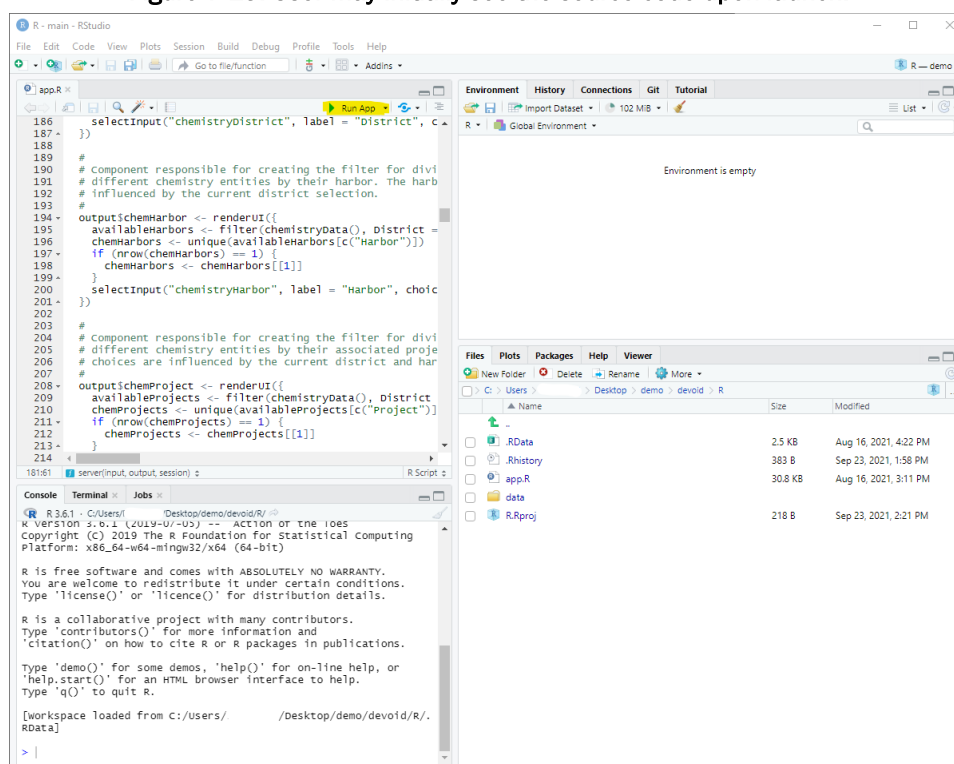
Navigate to the `R` directory of the unpackaged application and click the `R` file. Depending on the system configuration of the machine, the file's extension (`.Rproj`) may or may not be shown. This will open the project in RStudio. Once the project is loaded, in the Files tab of the window to the lower right of the screen, click on the `app.R` file (Figure 7-18).

Figure 7-18. Loading the source code.



The application's source code will appear in the left window of the screen. At this screen, click on the Run App button (highlighted in Figure 7-19) at the top of the window. Rstudio will then check for installed packages which may take 30–60 seconds.

Figure 7-19. User may initially see the source code upon launch.



A new window will open with the DEVOID application ready for user interaction (Figure 7-20). The DEVOID application may be run by selecting all code (Ctrl + A) and followed by simultaneously pressing Ctrl + Enter. It may take several seconds for the code to run and the data to upload into the tool. An example of output produced by the program is shown in Figure 7-21.

Figure 7-20. Opening screen of the DEVOID application.

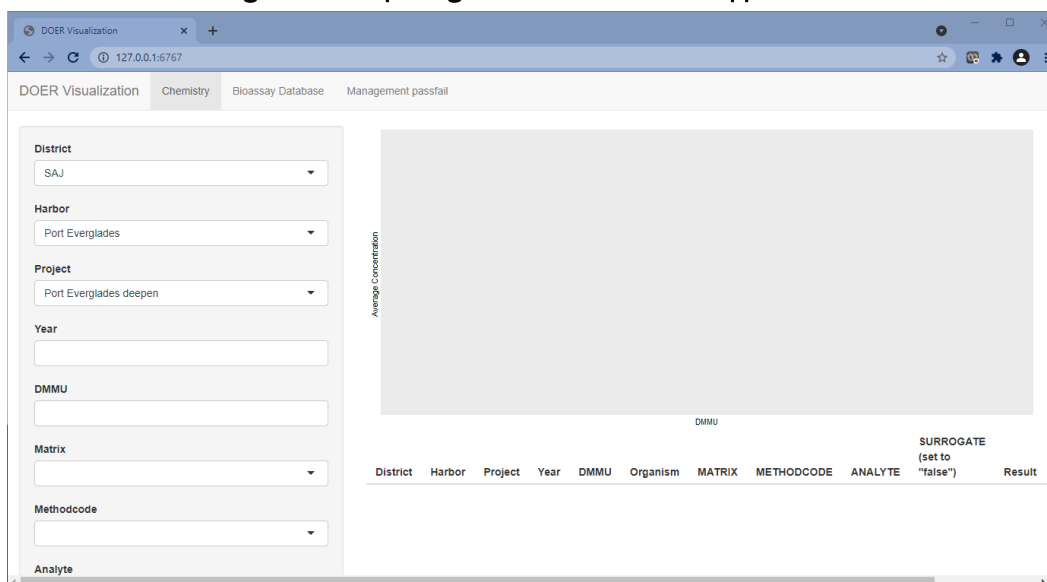
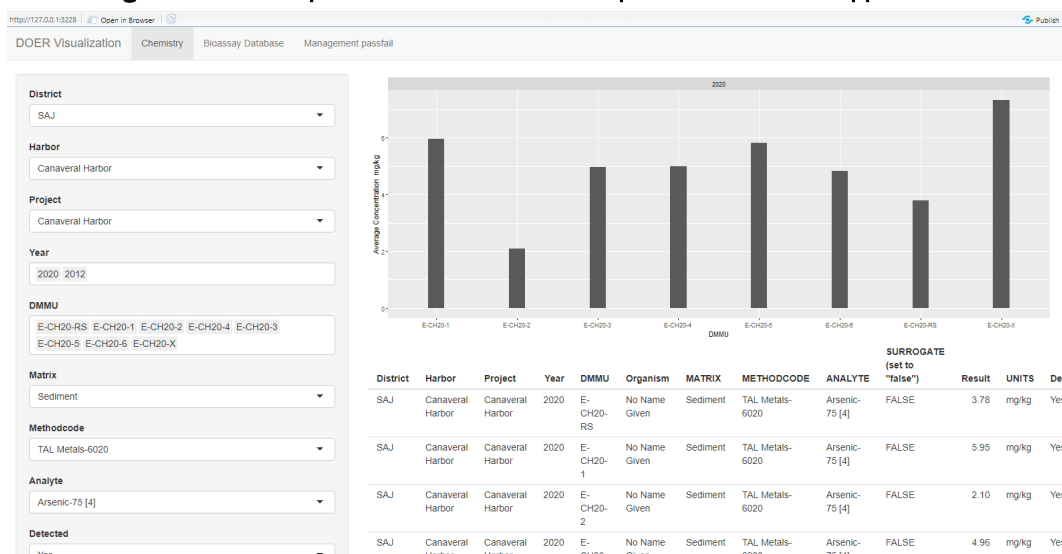


Figure 7-21. Example of data visualization output for the DEVOID application.



### 7.3.3 Using the DEVOID application

The DEVOID application displays information from a Microsoft Excel spreadsheet located in the data folder of the DEVOID application directory. The file is titled Dredging database and is required for use of the application. Should the file be altered with a name or location change, the DEVOID application will not function.

The Dredging database file consists of three required worksheets titled Chemistry, Bioassay Database, and Management pass/fail. If these sheets

are not located in the database file, the DEVOID application will not function. Each datasheet is represented by a tab located at the top of the application. By clicking on a certain tab, the data contained within its respective sheet will be populated in the window for further analysis and review. The sheets can be queried through respective data fields that correspond to the different columns in the sheet. By inputting selections into the selection fields, the data is retrieved and displayed (Figure 7-21).

In the Chemistry menu, the tool provides a rapid and user-guided way to view trends in dredging evaluation chemical data by USACE district, harbor, project, year, DMMU, environmental matrix (that is, water, sediment, tissue) and analyte. The drop down menus can be used in any order, but it is most logical to work from top to bottom. Multiple projects, project years and DMMUs may be visualized simultaneously by making individual selections from the applicable drop-down menus (Figure 7-20).

In the Bioassay Database and Management passfail menus, a similar selection process may be made. The Bioassay Database menu enables visualization of the bioassay end point results for various test species, and the Management passfail menu allows the user to view whether DMMUs passed or failed toxicity or bioaccumulation testing, as well as corresponding reasons for failure and subsequent management decisions (for example, volume restriction).

#### *7.3.3.1 Application interface fields*

The DEVOID Application allows a user to visualize information regarding data from different dredging evaluations and tests. The information is displayed in both chart and tabular forms. The information tables below describe the different fields available. The following tables summarize each menu bar function and whether multiple selections can be made (Tables 7-1 and 7-2).

Table 7-1. Chemistry.

| Field      | Description                                                            | Multiselect <sup>a</sup> |
|------------|------------------------------------------------------------------------|--------------------------|
| District   | USACE district with jurisdiction over the performed evaluation         | No                       |
| Harbor     | Location where the evaluation was done                                 | No                       |
| Project    | Specific project associated with the evaluation                        | No                       |
| Year       | The year the project was conducted                                     | Yes                      |
| DMMU       | The DMMU tested                                                        | Yes                      |
| Matrix     | The matrix associated with the DMMU (that is, water, sediment, tissue) | No                       |
| Methodcode | The associated analytical methodcode                                   | No                       |
| Analyte    | The associated analyte                                                 | No                       |
| Detected   | Was the analyte detected?                                              | No                       |

<sup>a</sup> To trigger multiselect, click in the selection box after initial criteria is selected and select the next criteria for evaluation.

Table 7-2. Bioassay database.

| Field         | Description                                                    | Multiselect <sup>a</sup> |
|---------------|----------------------------------------------------------------|--------------------------|
| District      | USACE district with jurisdiction over the performed evaluation | No                       |
| Project       | Specific project associated with the evaluation                | No                       |
| Year          | The year the project was conducted                             | Yes                      |
| DMMU          | The DMMU tested                                                | Yes                      |
| Test Type     | The test type conducted                                        | No                       |
| Treatment     | The treatment studied                                          | Yes                      |
| Concentration | The concentration that was used                                | Yes                      |
| Test Species  | The species tested                                             | Yes                      |

<sup>a</sup> To trigger multiselect, click in the selection box after initial criteria is selected and select the next criteria for evaluation.

### 7.3.3.2 Data document schema definitions

The application is designed to parse and display data based on the Dredging database file (described earlier in this section) located in the `data` directory of the R folder in the unpackaged application. Sheets within the Dredging database file may be edited, however the file must retain the name of Dredging database and remain a Microsoft Excel file. The required sheets of Chemistry, Bioassay Database, and Management passfail must be present in the workbook along with the columns listed as required in the tables above. The data present in those columns must match the schema as presented in the tables.

## 8 Summary

This technical report provides stakeholders in DM management decisions a modern update to guidance documents published in 1991 and 1998. The final section provides a user's guide for new supplemental software available in 2022. This technical report provides more robust considerations for assessment of DM for open-water disposal decisions than provided within the tool; the software and report may be used in concert, depending on user needs.

## References

- Act of March 3, 1899. 2021. 33 U.S.C. §§ 401, 403–404, 406–409, 411, 413–15. <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap9.pdf>.
- Anderson, Brian S., John W. Hunt, Bryn M. Phillips, Shirley Tudor, Russell Fairey, John Newman, H. Max Puckett, Mark Stephenson, Edward R. Long, and Ronald S. Tjeerdema. 1998. "Comparison of Marine Sediment Toxicity Test Protocols for the Amphipod *Rhepoxynius abronius* and the Polychaete Worm *Nereis (Neanthes) arenaceodentata*." *Environmental Toxicology and Chemistry* 17 (5): 859–66. <https://doi.org/10.1002/etc.5620170513>.
- ASTM (American Society for Testing and Materials International). 2001. *Standard Guide for Conducting in-Situ Field Bioassays with Marine, Estuarine, and Freshwater Bivalves*. ASTM E2122-01. West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E2122-01>.
- ASTM (American Society for Testing and Materials International). 2004. *Standard Guide for Conducting Static Acute Toxicity Tests Starting with Embryos of Four Species of Saltwater Bivalve Molluscs*. ASTM E724-98(2004). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E0724-98>.
- ASTM (American Society for Testing and Materials International). 2007. *Standard Guide for Conducting Sediment Toxicity Tests with Marine and Estuarine Polychaetous Annelids*. ASTM E1611-00(2007). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1611-00R07>.
- ASTM (American Society for Testing and Materials International). 2008a. *Standard Guide for Designing Biological Tests with Sediments*. ASTM E1525-02(2008). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1525-02R0>.
- ASTM (American Society for Testing and Materials International). 2008b. *Standard Test Method for Measuring the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Invertebrates*. ASTM E1367-03(2008). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1367-03R23>.
- ASTM (American Society for Testing and Materials International). 2010. *Standard Test Method for Measuring the Toxicity of Sediment-Associated Contaminants with Freshwater Invertebrates*. ASTM E1706-05(2010). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1706-05R10>.

- ASTM (American Society for Testing and Materials International). 2011. *Standard Test Method for Determination of Parent and Alkyl Polycyclic Aromatics in Sediment Pore Water Using Solid-Phase Microextraction and Gas Chromatography/Mass Spectrometry in Selected Ion Monitoring Mode*. ASTM D7363-11. West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/D7363-11>.
- ASTM (American Society for Testing and Materials International). 2012. *Standard Guide for Conducting Static Acute Toxicity Tests with Echinoid Embryos*. ASTM E1563-98(2012). West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1563-98R12>.
- ASTM (American Society for Testing and Materials International). 2019. *Standard Guide for Determination of the Bioaccumulation of Sediment-Associated Contaminants by Benthic Invertebrates*. West Conshohocken, PA: American Society for Testing and Materials International. <https://doi.org/10.1520/E1688-19>.
- Berry, Walter J., Robert M. Burgess, David J. Hansen, Dominic M. DiToro, Heidi E. Bell, Mary C. Reiley, Frank E. Stancil Jr., Christopher S. Zarba, David R. Mount, and Robert L. Spehar. 2003. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Dieldrin*. Edited by Robert M. Burgess. EPA/600/R-02/010. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30002J14.PDF>.
- Berry, Walter J., Robert M. Burgess, David J. Hansen, Dominic M. DiToro, Laurie D. DeRosa, Heidi E. Bell, Mary C. Reiley, et al. 2003. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Endrin*. Edited by Robert M. Burgess. EPA/600/R-02/009. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30002IYW.PDF>.
- Berry, Walter, Norman Rubinstein, Brian Melzian, and Brian Hill. 2003. *The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review*. AED-02-103. Internal Report. Narragansett, RI: Environmental Protection Agency–Office of Research and Development. <https://archive.epa.gov/epa/sites/production/files/2015-10/documents/sediment-appendix1.pdf>.
- Bosworth, Weldon S, and Louis J Thibodeaux. 1990. "Bioturbation: A Facilitator of Contaminant Transport in Bed Sediment." *Environmental Progress* 9 (4): 211–17. <https://doi.org/10.1002/ep.670090414>.
- Bridges, Todd S., Walter J. Berry, Stefano Della Sala, Philip B. Dorn, Stephen J. Ells, Thomas H. Gries, D. Scott Ireland, et al. 2005. "A Framework for Assessing and Managing Risks from Contaminated Sediments." In *Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments*, edited by Richard J. Wenning, Graeme E. Batley, Christopher G. Ingersoll and David W. Moore, 227–66. Pensacola, FL: Society of Environmental Toxicology and Chemistry (SETAC) Press.

- Broman, Dag, Carina Näuf, Ivar Lundbergh, and Yngve Zebühr. 1990. "An In Situ Study on the Distribution, Biotransformation and Flux of Polycyclic Aromatic Hydrocarbons (PAHs) in an Aquatic Food Chain (Seston-*Mytilus edulis* L.-*Somateria mollissima* L.) from the Baltic: An Ecotoxicological Perspective." *Environmental Toxicology and Chemistry: An International Journal* 9 (4): 429–42. <https://doi.org/10.1002/etc.5620090404>.
- Brown, VM, DHM Jordan, and BA Tiller. 1969. "The Acute Toxicity to Rainbow Trout of Fluctuating Concentrations and Mixtures of Ammonia, Phenol and Zinc." *Journal of fish biology* 1 (1): 1–9. <https://doi.org/10.1111/j.1095-8649.1969.tb03837.x>.
- Burgess, Robert M. 2000. "Characterizing and Identifying Toxicants in Marine Waters: A Review of Marine Toxicity Identification Evaluations (TIEs)." *International Journal of Environment and Pollution* 13 (1-6): 2–33. <https://doi.org/10.1504/IJEP.2000.002308>.
- Burgess, Robert M., Walter J. Berry, David R. Mount, Gerald T. Ankley, D. Scott Ireland, Dominic M. Di Toro, David J. Hansen, et al. 2008. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Compendium of Tier 2 Values for Nonionic Organics*. EPA/600/R-02/016. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=60000MUK.PDF>.
- Burgess, Robert M., Walter J. Berry, David R. Mount, and Dominic M. Di Toro. 2013. "Mechanistic Sediment Quality Guidelines Based on Contaminant Bioavailability: Equilibrium Partitioning Sediment Benchmarks." *Environmental Toxicology and Chemistry* 32 (1): 102–14. <https://doi.org/10.1002/etc.2025>.
- Burgess, Robert M., Kay T. Y. Ho, Adam D. Biales, and Werner Brack. 2011. "Recent Developments in Whole Sediment Toxicity Identification Evaluations: Innovations in Manipulations and Endpoints." In *Effect-Directed Analysis of Complex Environmental Contamination*, edited by Werner Brack, 19–40. Berlin, Germany: Springer-Verlag. [https://doi.org/10.1007/978-3-642-18384-3\\_2](https://doi.org/10.1007/978-3-642-18384-3_2).
- Burgess, Robert M., Susan B. Kane Driscoll, Robert J. Ozretich, David R. Mount, and Mary C. Reiley. 2012. *Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Procedures for the Determination of the Freely Dissolved Interstitial Water Concentrations of Nonionic Organics*. EPA/600/R-02/012. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100G7G6.PDF>.
- Burgess, R. M., M. C. Pelletier, K. T. Ho, J. R. Serbst, S. A. Ryba, A. Kuhn, M. M. Perron, P. Raczelowski, and M. G. Cantwell. 2003. "Removal of Ammonia Toxicity in Marine Sediment TIEs: A Comparison of *Ulva lactuca*, Zeolite and Aeration Methods." *Marine Pollution Bulletin* 46 (5): 607–18. [https://doi.org/10.1016/S0025-326X\(03\)00038-9](https://doi.org/10.1016/S0025-326X(03)00038-9).

- Burgess, R. M., M. M. Perron, M. G. Cantwell, K. T. Ho, J. R. Serbst, and M. C. Pelletier. 2004. "Use of Zeolite for Removing Ammonia and Ammonia-Caused Toxicity in Marine Toxicity Identification Evaluations." *Archives of Environmental Contamination and Toxicology* 47 (4): 440–47. <https://doi.org/10.1007/s00244-004-4003-3>.
- Burkhard, Lawrence P., Jon A. Arnot, Michelle R. Embry, Kevin J. Farley, Robert A. Hoke, Masaru Kitano, Heather A. Leslie, et al. 2012. "Comparing Laboratory- and Field-Measured Biota-Sediment Accumulation Factors." *Integrated environmental assessment and management* 8 (1): 32–41. <https://doi.org/10.1002/ieam.218>.
- Burkhard, Lawrence P, David R Mount, and Robert M Burgess. 2017. *Developing Sediment Remediation Goals at Superfund Sites Based on Pore Water for the Protection of Benthic Organisms from Direct Toxicity to Non-Ionic Organic Contaminants*. EPA/600/R-15/289. Washington, DC: Office of Research and Development National Human and Environmental Effects Research Laboratory. <https://semspub.epa.gov/work/HQ/100000539.pdf>.
- Byrne, Maria, Diana J. Oakes, John K. Pollak, and Edwina Laginestra. 2008. "Toxicity of Landfill Leachate to Sea Urchin Development with a Focus on Ammonia." *Cell Biology and Toxicology* 24: 503–12. <https://doi.org/10.1007/s10565-008-9099-1>.
- Cardwell, Rick D., David K. DeForest, Kevin V. Brix, and William J. Adams. 2013. "Do Cd, Cu, Ni, Pb, and Zn Biomagnify in Aquatic Ecosystems?" In *Reviews of Environmental Contamination and Toxicology Volume 226*, edited by David M. Whitacre, 101–22. New York: Springer Science+Business Media. [https://doi.org/10.1007/978-1-4614-6898-1\\_4](https://doi.org/10.1007/978-1-4614-6898-1_4).
- Carr, R Scott, Duane C Chapman, Cynthia L Howard, and James M Biedenbach. 1996. "Sediment Quality Triad Assessment Survey of the Galveston Bay, Texas System." *Ecotoxicology* 5 (6): 341–64. <https://doi.org/10.1007/BF00351951>.
- Carr, Robert Scott, and James M. Biedenbach. 1999. "Use of Power Analysis to Develop Detectable Significant Criteria for Sea Urchin Toxicity Tests." *Aquatic Ecosystem Health and Management* 2 (4): 413–18. <https://doi.org/10.1080/14634989908656979>.
- Carr, Robert Scott, and Duane C. Chapman. 1995. "Comparison of Methods for Conducting Marine and Estuarine Sediment Porewater Toxicity Tests-Extraction, Storage and Handling Techniques." *Archives of Environmental Contamination and Toxicology* 28 (1): 69–77. <https://doi.org/10.1007/BF00213971>.
- Carr, R. S., D. C. Chapman, B. J. Presley, J. M. Biedenbach, L. Robertson, P. Boothe, R. Kilada, T. Wade, and P. Montagna. 1996. "Sediment Porewater Toxicity Assessment Studies in the Vicinity of Offshore Oil and Gas Production Platforms in the Gulf of Mexico." *Canadian Journal of Fisheries and Aquatic Sciences* 53, no. 11 (November): 2618–28. <https://doi.org/10.1139/f96-218>.

- Clarke, Joan U., Paul R. Schroeder, and Jeffery A. Steevens. 2002. *Selecting Tier Iii Water Column Toxicity Standards for CDF Discharges: Statistical Alternatives*. ERDC Technical Notes Collection. ERDC/TN EEDP-04-33. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8913>.
- Coastal Zone Management Act of 1972. 2021. 16 U.S.C. §§ 1451–67. <https://www.govinfo.gov/content/pkg/USCODE-2021-title16/pdf/USCODE-2021-title16-chap33.pdf>.
- Corps of Engineers Dredged Material Permits. 1977. 40 C.F.R.. § 225. <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part225.pdf>.
- Criteria for the Evaluation of Permit Applications for Ocean Dumping of Materials. 1977. 40 C.F.R.. § 227. <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part227.pdf>.
- Criteria for the Management of Disposal Sites for Ocean Dumping. 1977. 40 C.F.R.. § 228. <https://www.govinfo.gov/content/pkg/CFR-2021-title40-vol27/pdf/CFR-2021-title40-vol27-part228.pdf>.
- Definition of Navigable Waters of the United States. 1986. 33 C.F.R.. § 329. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part329.pdf>.
- Definitions of Waters of the United States. 1986. 33 C.F.R.. § 328. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part328.pdf>.
- DelValls, T.A., A. Andres, M.J. Belzunce, J.L. Buceta, M.C. Casado-Martinez, R. Castro, I. Riba, J.R. Viguri, and J. Blasco. 2004. “Chemical and Ecotoxicological Guidelines for Managing Disposal of Dredged Material.” *TrAC Trends in Analytical Chemistry* 23, no. 10–11 (November–December): 819–28. <https://doi.org/10.1016/j.trac.2004.07.014>.
- Di Toro, Dominic M., Christopher S. Zarba, David J. Hansen, Walter J. Berry, Richard C. Swartz, Christina E. Cowan, Spyros P. Pavlou, Herbert E. Allen, Nelson A. Thomas, and Paul R. Paquin. 1991. “Technical Basis for Establishing Sediment Quality Criteria for Nonionic Organic Chemicals Using Equilibrium Partitioning.” *Environmental Toxicology and Chemistry* 10, no. 12 (December): 1541–83. <https://doi.org/10.1002/etc.5620101203>.
- Diamond, Jerome M., Donald G. MacKler, William J. Rasnake, and David Gruber. 1993. “Derivation of Site-Specific Ammonia Criteria for an Effluent-Dominated Headwater Stream.” *Environmental Toxicology and Chemistry* 12, no. 4 (April): 649–58. <https://doi.org/10.1002/etc.5620120406>.
- DiGiano, Francis A., Cass Timothy Miller, and Jeyong Yoon. 1995. *Dredging Elutriate Test (Dret) Development*. Contract Report D-95-1. Vicksburg, MS: US Army Engineer Waterways Experiment Station. <https://hdl.handle.net/11681/4736>.

- ECCC (Environment and Climate Change Canada). 2019. *Biological Test Method: Reference Method for Determining Acute Lethality Using Acartia Tonsa*. Reference Method STB 1/RM/60. Ottawa, CA: Environment and Climate Change Canada–Development and Applications Unit. <https://publications.gc.ca/pub?id=9877223&sl=0>.
- Endangered Species Act of 1973. 2021. 16 U.S.C. §§ 1531–44. <https://www.govinfo.gov/content/pkg/USCODE-2021-title16/pdf/USCODE-2021-title16-chap35.pdf>.
- Enforcement. 1986. 33 C.F.R.. § 326. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part326.pdf>.
- EPA (Environmental Protection Agency). 1986a. *Organochlorine Pesticides and Polychlorinated Biphenyls by Gas Chromatography*. Method 8080 [Deleted from SW-846 1998]. Washington, DC: Environmental Protection Agency. [https://www.epa.gov/sites/default/files/2019-06/documents/chapter\\_four\\_update\\_vi\\_12-11-2018.pdf](https://www.epa.gov/sites/default/files/2019-06/documents/chapter_four_update_vi_12-11-2018.pdf).
- EPA (Environmental Protection Agency). 1986b. *Selenium (Atomic Absorption, Furnace Technique)*. Method 7740. Washington, DC: Environmental Protection Agency. [https://www.nemi.gov/methods/method\\_summary/5239/](https://www.nemi.gov/methods/method_summary/5239/) [direct download available at [https://www.nemi.gov/methods/method\\_pdf/5239/](https://www.nemi.gov/methods/method_pdf/5239/)].
- EPA (Environmental Protection Agency). 1997. “The SW-846 Compendium.” Method SW-846. Washington, DC: Environmental Protection Agency. <https://www.epa.gov/hw-sw846/sw-846-compendium>.
- EPA (Environmental Protection Agency). 1998. *Guidelines for Ecological Risk Assessment*. Washington, DC: Environmental Protection Agency–Risk Assessment Forum. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30004XFR.PDF>.
- EPA-ERL (Environmental Protection Agency–Environmental Research Laboratory). 1989. *Ambient Water Quality Criteria for Ammonia (Saltwater)-1989 [Ambient Aquatic Life Water Quality Criteria for Ammonia (Salt Water)]*. Narragansett, RI: Environmental Protection Agency–Environmental Research Laboratory. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=00001N64.PDF>.
- EPA-ERL (Environmental Protection Agency–Environmental Research Laboratory). 1991. *Methods for Aquatic Toxicity Identification Evaluations: Phase I Toxicity Characterization Procedures*. 2nd ed. EPA/600/6-9 1/003. Duluth, MN: Environmental Protection Agency–Environmental Research Laboratory. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=300011NY.PDF>.

EPA-GLNPO, and USACE-LRD (Environmental Protection Agency–Great Lakes National Program Office and US Army Corps of Engineers–Great Lakes and Ohio River Division). 1998. *Great Lakes Dredged Material Testing and Evaluation Manual*. Prepared by Dennis Anderson, Gary Ankley, Mark Barath, Patricia Boone, John Dorkin, Al Fenedick, Steve Garbaciak, et al. Cincinnati, OH: US Army Corps of Engineers–Great Lakes and Ohio River Division. <https://www.lre.usace.army.mil/Portals/69/docs/GreatLakesInfo/docs/Great%20Lakes%20Dredging%20Team/Publications/1998-usace-dredged-material-testing-manual-all.pdf?ver=fgMpeFqcg03hhqHDpyE7YQ%3d%3d>.

EPA-ORD (Environmental Protection Agency–Office of Research and Development). 1994. *Methods for Assessing the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Amphipods*. Narragansett, RI: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=300032A9.PDF>.

EPA-ORD (Environmental Protection Agency–Office of Research and Development). 2000. *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*. 2nd ed. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30003SBA.PDF>.

EPA-ORD (Environmental Protection Agency–Office of Research and Development). 2007. *Sediment Toxicity Identification Evaluation: Phases I, II, and III Guidance Document*. Edited by Kay T. Ho, Robert M. Burgess, and David R. Mount. EPA/600/R-07/080. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1003GR1.PDF>.

EPA-ORD, EPA-OST, and ERDC (Environmental Protection Agency–Office of Science and Technology, Environmental Protection Agency–Office of Research and Development, US Army Engineer Research and Development Center–Waterways Experiment Station). 2001. *Method for Assessing the Chronic Toxicity of Sediment-Associated Contaminants with *Leptocheirus Plumulosus**. EPA 600/R-01/020. Newport, OR: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30002GRK.PDF>.

EPA-OST (Environmental Protection Agency–Office of Science and Technology). 1999. *Method 1631, Revision B: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Absorption Fluorescence Spectrometry*. EPA 821-R-99-005. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=40001E02.PDF>.

EPA-OST (Environmental Protection Agency–Office of Science and Technology). 2001. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*. EPA-823-B-01-002. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20003PLT.PDF>.

- EPA-OW (Environmental Protection Agency–Office of Water). 1997. *Method 1668: Toxic Polychlorinated Biphenyls by Isotope Dilution High Resolution Gas Chromatography/High Resolution Mass Spectrometry*. EPA-821-R-97-001. Method 1668. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=200036PX.PDF>.
- EPA-OW (Environmental Protection Agency–Office of Water). 1999. *1999 Update of Ambient Water Quality Criteria for Ammonia*. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=2000303L.PDF>.
- EPA-OW (Environmental Protection Agency–Office of Water). 2000. *Method 8082A: Polychlorinated Biphenyls (PCBs) by Gas Chromatography*. Method 8082A. Revision 1, November 2000. Washington, DC: Environmental Protection Agency–Office of Water. [https://www.nemi.gov/methods/method\\_summary/9356/](https://www.nemi.gov/methods/method_summary/9356/) [direct download available at [https://www.nemi.gov/methods/method\\_pdf/9356/](https://www.nemi.gov/methods/method_pdf/9356/)].
- EPA-OW (Environmental Protection Agency–Office of Water). 2001. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20003PLT.PDF>.
- EPA-OW (Environmental Protection Agency–Office of Water). 2002a. *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*. 5th ed. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1008IOL.PDF>.
- EPA-OW (Environmental Protection Agency–Office of Water). 2002b. *National Recommended Water Quality Criteria: 2002*. Washington, DC: Environmental Protection Agency–Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1005EQ.PDF>.
- EPA-OW and USACE (Environmental Protection Agency–Office of Water and US Army Corps of Engineers). 1991. *Evaluation of Dredged Material Proposed for Ocean Disposal: Testing Manual*. EPA 503/8-91/001. Washington, DC: Environmental Protection Agency–Office of Water. [https://www.epa.gov/sites/default/files/2015-10/documents/green\\_book.pdf](https://www.epa.gov/sites/default/files/2015-10/documents/green_book.pdf).
- EPA-OW and USACE. 2004 [1992]. *Evaluating Environmental Effects of Dredged Material Management Alternatives—A Technical Framework*. EPA842-B-92-008 Revised. Washington, DC: Environmental Protection Agency–Office of Water. [https://www.epa.gov/sites/default/files/2015-09/documents/2004\\_08\\_20\\_oceans\\_regulatory\\_dumpdredged\\_framework\\_techframework.pdf](https://www.epa.gov/sites/default/files/2015-09/documents/2004_08_20_oceans_regulatory_dumpdredged_framework_techframework.pdf).
- EPA-OWEP (Environmental Protection Agency–Office of Water Enforcement and Permits). 1991. *Technical Support Document for Water Quality-Based Toxics Control*. Washington, DC: Environmental Protection Agency–Office of Water Enforcement and Permits. <https://purl.access.gpo.gov/GPO/LPS45586>.

EPA-R6, USACE-SWG, and USACE-MVN (Environmental Protection Agency–Region 6, US Army Corps of Engineers–Galveston District, and US Army Corps of Engineers–New Orleans District). 2003. *Regional Implementation Agreement: For Testing and Reporting Requirements for Ocean Disposal of Dredged Material Off the Louisiana and Texas Coasts under Section 103 of the Marine Protection, Research and Sanctuaries Act*. Dallas, TX: Environmental Protection Agency–Region 6. <https://www.epa.gov/sites/default/files/2017-02/documents/r6ria.pdf>.

ERDC-EL (US Army Engineer Research and Development Center–Environmental Laboratory). 2017. ERED: Environmental Residue-Effects Database. US Army Engineer Research and Development Center–Environmental Laboratory. <https://ered.el.erdcdren.mil/>.

ERDC-EL (US Army Engineer Research and Development Center–Environmental Laboratory). 2023. “Dredged Material Disposal Management Models.” US Army Engineer Research and Development Center–Environmental Laboratory. <https://dots.el.erdcdren.mil/products.cfm?Topic=model&Type=drmat>.

Factors to Be Considered in the Evaluation of Army Corps of Engineers Dredging Projects Involving the Discharge of Dredged Material into Waters of the US and Ocean Waters. 1988. 33 C.F.R.. § 336. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part336.pdf>.

Farrar, J. Daniel, Guilherme R. Lotufo, and Jerre G. Sims. 2011. *Development of a Bioaccumulation Test Method with the Amphipod Leptocheirus plumulosus*. ERDC Technical Notes Collection. ERDC TN-DOER-R15. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8664>.

Fava, James A., Wayne L. McCulloch, James J. Gift, and William J. Rue. 1984. “Evaluation of the Limiting Permissible Concentration Concept in Ocean Dumping Assessments.” In *OCEANS ’84 Conference Record*, 10–12 September 1984, Washington, DC, 1:996–1001. New York: Institute of Electrical and Electronics Engineers. <https://doi.org/10.1109/OCEANS.1984.1152215>.

FDA (Food and Drug Administration). 2000. Guidance for Industry and Other Stakeholders: Redbook 2000; Toxicological Principles for the Safety Assessment of Food Ingredients. Revised 2007. College Park, MD: Office of Food Additive Safety in the Center for Food Safety and Applied Nutrition. <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-and-other-stakeholders-redbook-2000>.

Federal Water Pollution Control Act Amendments of 1972 § 303(d). 2021. 33 U.S.C. § 1313(d)(1)(D). <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap26-subchapIII-sec1313.pdf>.

Federal Water Pollution Control Act of 1948. 2021. 33 U.S.C. §§ 1251–389. <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap26.pdf>.

- Ferraro, Steven P., and Faith A. Cole. 2002. "A Field Validation of Two Sediment-Amphipod Toxicity Tests." *Environmental Toxicology and Chemistry* 21, no. 7 (July): 1423–37. [https://doi.org/10.1897/1551-5028\(2002\)021<1423:afvots>2.0.co;2](https://doi.org/10.1897/1551-5028(2002)021<1423:afvots>2.0.co;2).
- Fortibuoni, Tomaso, Seta Noventa, Federico Rampazzo, Claudia Gion, Malgorzata Formalewicz, Daniela Berto, and Saša Raicevich. 2013. "Evidence of Butyltin Biomagnification Along the Northern Adriatic Food-Web (Mediterranean Sea) Elucidated by Stable Isotope Ratios." *Environmental Science & Technology* 47, no. 7 (March): 3370–77. <https://doi.org/10.1021/es304875b>.
- Gao, Yongfei, Ruyue Wang, Yanyu Li, Xuebin Ding, Yueming Jiang, Jianfeng Feng, and Lin Zhu. 2021. "Trophic Transfer of Heavy Metals in the Marine Food Web Based on Tissue Residuals." *Science of the Total Environment* 772 (June): 145064. <https://doi.org/10.1016/j.scitotenv.2021.145064>.
- General Regulatory Policies*. 1986. 33 C.F.R.. § 320. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part320.pdf>.
- Gentile, John H., Gerald G. Pesch, James L. Lake, Paul P. Yevich, Gerald E. Zarogian, P. Rogerson, John F. Paul, et al. 1988. *Synthesis of Research Results: Applicability and Field Verification of Predictive Methodologies for Aquatic Dredged Material Disposal*. TECHNICAL REPORT D-88-5. Vicksburg, MS, and Narragansett, RI: US Army Corps of Engineers–Waterways Experiment Station and US Environmental Protection Agency–Environmental Research Laboratory. <https://hdl.handle.net/11681/6426>.
- Ghosh, Upal, Susan Kane Driscoll, Robert M. Burgess, Michiel T. O. Jonker, Danny Reible, Frank Gobas, Yongju Choi, et al. 2014. "Passive Sampling Methods for Contaminated Sediments: Practical Guidance for Selection, Calibration, and Implementation." *Integrated Environmental Assessment and Management* 10, no. 2 (April): 210–23. <https://doi.org/10.1002/ieam.1507>.
- Giesy, John P., and Robert L. Graney. 1989. "Recent Developments in and Intercomparisons of Acute and Chronic Bioassays and Bioindicators." In *Environmental Bioassay Techniques and Their Application*, edited by M. Munawar, G. Dixon, C.I. Mayfield, T. Reynoldson, and M.H. Sadar, 21–60. *Developments in Hydrobiology* 54. Springer Science+Business Media: Dordrecht, Netherlands. [https://doi.org/10.1007/978-94-009-1896-2\\_3](https://doi.org/10.1007/978-94-009-1896-2_3).
- Giesy, John P., Cornell J. Rosiu, Robert L. Graney, and Mary G. Henry. 1990. "Benthic Invertebrate Bioassays with Toxic Sediment and Pore Water." *Environmental Toxicology and Chemistry: An International Journal* 9, no. 2 (February): 233–48. <https://doi.org/10.1002/etc.5620090214>.
- Gobas, Frank APC, Watze de Wolf, Lawrence P Burkhard, Eric Verbruggen, and Kathleen Plotzke. 2009. "Revisiting Bioaccumulation Criteria for POPs and PBT Assessments." *Integrated Environmental Assessment and Management* 5, no. 4 (October): 624–37. [https://doi.org/10.1897/IEAM\\_2008-089.1](https://doi.org/10.1897/IEAM_2008-089.1).

- Gobas, Frank APC, Watze de Wolf, Lawrence P Burkhard, Eric Verbruggen, and Kathleen Plotzke. 2009. "Revisiting Bioaccumulation Criteria for POPs and PBT Assessments." *Integrated Environmental Assessment and Management* 5 (4): 624–37. [https://doi.org/10.1897/IEAM\\_2008-089.1](https://doi.org/10.1897/IEAM_2008-089.1).
- Gschwend, Philip M, John K MacFarlane, Danny D Reible, X Lu, Steven B Hawthorne, David V Nakles, and Timothy Thompson. 2011. "Comparison of Polymeric Samplers for Accurately Assessing PCBs in Pore Waters." *Environmental Toxicology and Chemistry* 30, no. 6 (June): 1288–96. <https://doi.org/10.1002/etc.510>.
- Hammerschmidt, Chad R., and G. Allen Burton Jr. 2010. "Measurements of Acid Volatile Sulfide and Simultaneously Extracted Metals Are Irreproducible among Laboratories." *Environmental Toxicology and Chemistry* 29, no. 7 (July): 1453–56. <https://doi.org/10.1002/etc.173>.
- Hammerschmidt, Chad R., William F. Fitzgerald, Carl H. Lamborg, Prentiss H. Balcom, and Pieter T. Visscher. 2004. "Biogeochemistry of Methylmercury in Sediments of Long Island Sound." *Marine Chemistry* 90, no. 1–4 (November): 31–52. <https://doi.org/10.1016/j.marchem.2004.02.024>.
- Hansen, David J., Dominic M. DiToro, Walter J. Berry, Warren S. Boothman, Robert M. Burgess, Gerald T. Ankley, David R. Mount, et al. 2005. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver and Zinc)*. EPA/600/R-02/011. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1008GZA.PDF>.
- Hansen, David J., Dominic M. DiToro, Joy A. McGrath, Richard C. Swartz, David R. Mount, Robert L. Spehar, Robert M. Burgess, et al. 2003. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures*. EPA/600/R-02/013. Washington, DC: Environmental Protection Agency–Office of Research and Development. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=30006D0D.PDF>.
- Hickey, Christopher W., and Michael L. Martin. 1995. "Relative Sensitivity of Five Benthic Invertebrate Species to Reference Toxicants and Resin-Acid Contaminated Sediments." *Environmental Toxicology and Chemistry: An International Journal* 14, no. 8 (August): 1401–9. <https://doi.org/10.1002/etc.5620140817>.
- Ho, Kay T., and Robert M. Burgess. 2008. "Marine Sediment Toxicity Identification Evaluations (TIEs): History, Principles, Methods, and Future Research." In *Contaminated Sediments*, edited by Tarek .A. Kassim , and Dami Barceló, 75–95. Berlin, Germany: Springer-Verlag. [https://doi.org/10.1007/698\\_5\\_108](https://doi.org/10.1007/698_5_108).
- Hu, Jianying, Huajun Zhen, Yi Wan, Junmin Gao, Wei An, Lihui An, Fen Jin, and Xiaohui Jin. 2006. "Trophic Magnification of Triphenyltin in a Marine Food Web of Bohai Bay, North China: Comparison to Tributyltin." *Environmental Science and Technology* 40 (10): 3142–47. <https://doi.org/10.1021/es0514747>.

- Huang, Lei, Sergei M. Chernyak, and Stuart A. Batterman. 2014. "PAHs, Nitro-PAHs, Hopanes, and Steranes in Lake Trout from Lake Michigan." *Environmental Toxicology and Chemistry* 33, no. 8 (August): 1792–801. <https://doi.org/10.1002/etc.2620>.
- Iannuzzi, Timothy J., Tina N. Armstrong, Edward R. Long, Jacqueline Iannuzzi, and David F. Ludwig. 2008. "Sediment Quality Triad Assessment of an Industrialized Estuary of the Northeastern USA." *Environmental Monitoring and Assessment* 139, no. 1-3 (April): 257–75. <https://doi.org/10.1007/s10661-007-9832-x>.
- Ingersoll, C. G., D. D. MacDonald, N. Wang, J. L. Crane, L. J. Field, P. S. Haverland, N. E. Kemble, R. A. Lindskoog, C. Severn, and D. E. Smorong. 2001. "Predictions of Sediment Toxicity Using Consensus-Based Freshwater Sediment Quality Guidelines." *Archives of Environmental Contamination and Toxicology* 41, no. 1 (May): 8–21. <https://doi.org/10.1007/s002440010216>.
- IWR (Institute for Water Resources). 2012. *U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels*. Washington, DC: US Army Corps of Engineers–Institute for Water Resources. [https://www.iwr.usace.army.mil/Portals/70/docs/portwaterways/rpt/June\\_20\\_U.S.\\_Port\\_and\\_Inland\\_Waterways\\_Preparing\\_for\\_Post\\_Panamax\\_Vessels.pdf](https://www.iwr.usace.army.mil/Portals/70/docs/portwaterways/rpt/June_20_U.S._Port_and_Inland_Waterways_Preparing_for_Post_Panamax_Vessels.pdf).
- Janssen, Elisabeth M. L., Marie-Noële Croteau, Samuel N. Luoma, and Richard G. Luthy. 2010. "Measurement and Modeling of Polychlorinated Biphenyl Bioaccumulation from Sediment for the Marine Polychaete *Neanthes Arenaceodentata* and Response to Sorbent Amendment." Special issue, *PCB Sources, Exposures, Toxicities. Environmental Science and Technology* 44, no. 8 (April): 2857–63. <https://doi.org/10.1021/es901632e>.
- Johnson, Billy H., and Paul R. Schroeder. 1993. *Numerical Disposal Modeling*. ERDC Technical Notes Collection. Technical Note DRP-1-02. Vicksburg, MS: US Army Engineer Waterways Experiment Station. <https://hdl.handle.net/11681/4960>.
- Jones, R Anne, and G Fred Lee. 1988. "Toxicity of Us Waterway Sediments with Particular Reference to the New York Harbor Area." In *Chemical and Biological Characterization of Sludges, Sediments, Dredge Spoils and Drilling Muds, ASTM Stp 976*, edited by James. J. Lichtenberg, F. A. Winter, Cornelius. I. Weber, and Larry Fradkin, 403–17. Philadelphia: American Society for Testing and Materials (ASTM). <https://doi.org/10.1520/STP26725S>.
- Jones, Robert P., Rod N. Millward, Richard A. Karn, and Allyson H. Harrison. 2006. "Microscale Analytical Methods for the Quantitative Detection of PCBs and PAHs in Small Tissue Masses." *Chemosphere* 62, no. 11 (March): 1795–805. <https://doi.org/10.1016/j.chemosphere.2005.07.027>.
- Jonker, Michiel T. O., Robert M. Burgess, Upal Ghosh, Philip M. Gschwend, Sarah E. Hale, Rainer Lohmann, Michael J. Lydy, Keith A. Maruya, Danny Reible, and Foppe Smedes. 2020. "Ex Situ Determination of Freely Dissolved Concentrations of Hydrophobic Organic Chemicals in Sediments and Soils: Basis for Interpreting Toxicity and Assessing Bioavailability, Risks and Remediation Necessity." *Nature Protocols* 15, no. 5 (April): 1800–28. <https://doi.org/10.1038/s41596-020-0311-y>.

- Keil, Karen G., Trudy J. Estes, Joseph P. Kreitinger, Guilherme R. Lotufo, Richard A. Price, Burton C. Suedel, Michael W. Habberfield, et al. 2022. *Environmental Evaluation and Management of Dredged Material for Beneficial Use*. ERDC/EL TR-22-9. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://dx.doi.org/10.21079/11681/45024>.
- Kenaga, Eugene E. 1982. “Predictability of Chronic Toxicity from Acute Toxicity of Chemicals in Fish and Aquatic Invertebrates.” *Environmental Toxicology and Chemistry* 1, no. 4 (November): 347–58. <https://doi.org/10.1002/etc.5620010410>.
- Kennedy, Alan J., Thomas W. Biber, Lauren R. May, Guilherme R. Lotufo, J. Daniel Farrar, and Anthony J. Bednar. 2019. “Sensitivity of the Marine Calanoid Copepod *Pseudodiaptomus pelagicus* to Copper, Phenanthrene, and Ammonia.” *Environmental Toxicology and Chemistry* 38, no. 6 (June): 1221–30. <https://doi.org/10.1002/etc.4397>.
- Kennedy, Alan J., James H. Lindsay, James M. Biedenbach, and Ashley R. Harmon. 2017. “Life Stage Sensitivity of the Marine Mussel *Mytilus edulis* to Ammonia.” *Environmental Toxicology and Chemistry* 36, no. 1 (January): 89–95. <https://doi.org/10.1002/etc.3499>.
- Kennedy, Alan J., Guilherme Lotufo, Jennifer G. Laird, and John D. Farrar. 2016. *Dredged Material Evaluations: Review of Zooplankton Toxicity Test Methods for Marine Water Quality Evaluations*. ERDC Technical Notes Collection. ERDC TN-DOER-R24. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/20276>.
- Kennedy, Alan J., Guilherme R. Lotufo, and Jeffery A. Steevens. 2015. *Review of Dredged Elutriate Application Factors: Relevance to Acute-to-Chronic Protection, Contaminant, and Endpoint Specificity*. ERDC/EL TR-15-10. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://hdl.handle.net/11681/7035>.
- Kennedy, Alan J., Guilherme R. Lotufo, Jeffery A. Steevens, and Todd S. Bridges. 2010. *Determining Steady-State Tissue Residues for Invertebrates in Contaminated Sediment*. ERDC/EL TR-10-2. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://hdl.handle.net/11681/6925>.
- Kennedy, Alan J., Jeffery A. Steevens, Guilherme R. Lotufo, John D. Farrar, Mark R. Reiss, Roy K. Kropp, Jon Doi, and Todd S. Bridges. 2009. “A Comparison of Acute and Chronic Toxicity Methods for Marine Sediments.” *Marine Environmental Research* 68, no. 3 (January): 118–27. <https://doi.org/10.1016/j.marenvres.2009.04.010>.
- Kreitinger, Joseph P., J. Daniel Farrar, and Guilherme R. Lotufo. 2017. *Application of Toxicity Identification and Evaluation Procedures for Dredged Material Management*. ERDC Technical Notes Collection. ERDC TN-DOER-R25. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://doi.org/10.21079/11681/21208>.

- Länge, Reinhard, Thomas H. Hutchinson, Norbert Scholz, and John Solbé. 1998. "Analysis of the Ecetoc Aquatic Toxicity (Eat) Database Ii - Comparison of Acute to Chronic Ratios for Various Aquatic Organisms and Chemical Substances." *Chemosphere* 36, no. 1 (January): 115–27. [https://doi.org/10.1016/S0045-6535\(97\)10024-8](https://doi.org/10.1016/S0045-6535(97)10024-8).
- Lapota, David, Debbie Duckworth, and Jack Q. Word. 2000. *Confounding Factors in Sediment Toxicology*. White paper. San Diego, CA: SPAWAR Systems Center. <https://www.clu-in.org/download/contaminantfocus/sediments/testing-sediments-confound.pdf>.
- Linkov, Igor, Susan Cormier, Joshua Gold, F. Kyle Satterstrom, and Todd Bridges. 2012. "Using Our Brains to Develop Better Policy." *Risk Analysis: An International Journal* 32, no. 3 (March): 374–80. <https://doi.org/10.1111/j.1539-6924.2011.01683.x>.
- Linkov, Igor, Drew Loney, Susan Cormier, F. Kyle Satterstrom, and Todd Bridges. 2009. "Weight-of-Evidence Evaluation in Environmental Assessment: Review of Qualitative and Quantitative Approaches." *Science of the Total Environment* 407, no. 19 (September): 5199–205. <https://doi.org/10.1016/j.scitotenv.2009.05.004>.
- Linkov, Igor, Katherine E von Stackelberg, Dmitriy Burmistrov, and Todd S Bridges. 2001. "Uncertainty and Variability in Risk from Trophic Transfer of Contaminants in Dredged Sediments." *Science of the Total Environment* 274, no. 1–3 (July): 255–69. [https://doi.org/10.1016/S0048-9697\(01\)00747-1](https://doi.org/10.1016/S0048-9697(01)00747-1).
- Linkov, Igor, Paul Welle, Drew Loney, Alex Tkachuk, Laure Canis, J. B. Kim, and Todd Bridges. 2011. "Use of Multicriteria Decision Analysis to Support Weight of Evidence Evaluation." *Risk Analysis: An International Journal* 31, no. 8 (August): 1211–25. <https://doi.org/10.1111/j.1539-6924.2011.01585.x>.
- Lloyd, R., and Lydia D. Orr. 1969. "The Diuretic Response by Rainbow Trout to Sub-Lethal Concentrations of Ammonia." *Water Research* 3, no. 5 (May): 335–44. [https://doi.org/10.1016/0043-1354\(69\)90086-4](https://doi.org/10.1016/0043-1354(69)90086-4).
- Long, Edward R., L. Jay Field, and Donald D. MacDonald. 1998. "Predicting Toxicity in Marine Sediments with Numerical Sediment Quality Guidelines." *Environmental Toxicology and Chemistry* 17, no. 4 (April): 714–27. <https://doi.org/10.1002/etc.5620170428>.
- Long, Edward R., and Donald D. MacDonald. 1998. "Recommended Uses of Empirically Derived, Sediment Quality Guidelines for Marine and Estuarine Ecosystems." *Human and Ecological Risk Assessment* 4 (5): 1019–39. <https://doi.org/10.1080/10807039891284956>.
- Long, Edward R., Donald D. Macdonald, Sherri L. Smith, and Fred D. Calder. 1995. "Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments." *Environmental management* 19 (January): 81–97. <https://doi.org/10.1007/BF02472006>.

- Lotufo, Guilherme R., James M. Biedenbach, J. Daniel Farrar, Michael K. Chanov, Brian W. Hester, C. Ryan Warbritton, Jeffery A. Steevens, Jenifer M. Netchaev, Anthony J. Bednar, and David W. Moore. 2022. "Interlaboratory Comparison of Three Sediment Bioaccumulation Tests." *Environmental Toxicology and Chemistry* 41, no. 5 (May). <https://doi.org/10.1002/etc.5300>.
- Lotufo, Guilherme R., G. Allen Burton, Gunther Rosen, and John W. Fleeger. 2014. "Assessing Biological Effects." In *Processes, Assessment and Remediation of Contaminated Sediment*, edited by Danny D. Reible, 131–75. SERDP and ESTCP Remediation Technology Monograph Series 6. New York: Springer. [https://doi.org/10.1007/978-1-4614-6726-7\\_6](https://doi.org/10.1007/978-1-4614-6726-7_6).
- Lotufo, Guilherme R., Mandy M. Michalsen, Danny D. Reible, Philip M. Gschwend, Upal Ghosh, Alan J. Kennedy, Kristen M. Kerns, et al. 2022. "Interlaboratory Study of Polyethylene and Polydimethylsiloxane Polymeric Samplers for Ex Situ Measurement of Freely Dissolved Hydrophobic Organic Compounds in Sediment Porewater." *Environmental Toxicology and Chemistry* 41, no. 8 (August): 1885–902. <https://doi.org/10.1002/etc.5356>.
- Lu, Xiaoxia X., Yongseok Hong, and Danny D. Reible. 2014. "Assessing Bioavailability of Hydrophobic Organic Compounds and Metals in Sediments Using Freely Available Porewater Concentrations." In *Processes, Assessment and Remediation of Contaminated Sediments*, edited by Danny D. Reible, 177–96. SERDP ESTCP Environmental Remediation Technology 6. New York: Springer. [https://doi.org/10.1007/978-1-4614-6726-7\\_7](https://doi.org/10.1007/978-1-4614-6726-7_7).
- Luoma, Samuel N., and Philip S. Rainbow. 2005. "Why Is Metal Bioaccumulation So Variable? Biodynamics as a Unifying Concept." *Environmental Science and Technology* 39 (7): 1921–31. <https://doi.org/10.1021/es048947e>.
- Lydy, Michael J., Peter F. Landrum, Amy M. P. Oen, Mayumi Allinson, Foppe Smedes, Amanda D. Harwood, Huizhen Li, Keith A. Maruya, and Jingfu Liu. 2014. "Passive Sampling Methods for Contaminated Sediments: State of the Science for Organic Contaminants." *Integrated environmental assessment and management* 10, no. 2 (April): 167–78. <https://doi.org/10.1002/ieam.1503>.
- Macdonald, Donald D., R. Scott Carr, Fred D. Calder, Edward R. Long, and Christopher G. Ingersoll. 1996. "Development and Evaluation of Sediment Quality Guidelines for Florida Coastal Waters." *Ecotoxicology* 5:253–78. <https://doi.org/10.1007/BF00118995>.
- MacDonald, Donald D., Lisa M. Dipinto, Jay Field, Christopher G. Ingersoll, Edward R. Lvong, and Richard C. Swartz. 2000. "Development and Evaluation of Consensus-Based Sediment Effect Concentrations for Polychlorinated Biphenyls." *Environmental Toxicology and Chemistry* 19, no. 5 (May): 1403–13. <https://doi.org/10.1002/etc.5620190524>.
- Mackay, D., and A. Fraser. 2000. "Bioaccumulation of Persistent Organic Chemicals: Mechanisms and Models." *Environmental Pollution* 110, no. 3 (December): 375–91. [https://doi.org/10.1016/S0269-7491\(00\)00162-7](https://doi.org/10.1016/S0269-7491(00)00162-7).

- Marine Protection, Research, and Sanctuaries Act of 1972. Pub. L. No. 92-532, 86 Stat. 1052. <https://www.govinfo.gov/content/pkg/STATUTE-86/pdf/STATUTE-86-Pg1052.pdf>.
- McCarty, LS, PF Landrum, SN Luoma, JP Meador, AA Merten, BK Shephard, and AP Van Wezel. 2011. "Advancing Environmental Toxicology through Chemical Dosimetry: External Exposures Versus Tissue Residues." Special issue, *Tissue Residue Approach Special Series. Integrated Environmental Assessment and Management* 7, no. 1 (January): 7–27. <https://doi.org/10.1002/ieam.98>.
- McCarty, Lynn S., and Donald Mackay. 1993. "Enhancing Ecotoxicological Modeling and Assessment. Body Residues and Modes of Toxic Action." *Environmental Science and Technology* 27, no. 9 (September): 1718–28. <https://doi.org/10.1021/es00046a001>.
- McGee, Beth L., Daniel J. Fisher, Lance T. Yonkos, Gregory P. Ziegler, and Steve Turley. 1999. "Assessment of Sediment Contamination, Acute Toxicity, and Population Viability of the Estuarine Amphipod *Leptocheirus plumulosus* in Baltimore Harbor, Maryland, USA." *Environmental Toxicology and Chemistry* 18, no. 10 (October): 2151–60. <https://doi.org/10.1002/etc.5620181006>.
- McQueen, Andrew D., Ciera M. Kinley, Kyla J. Iwinski, Alyssa J. Calomeni, and John H. Rodgers. 2016. "Effects of Acid Volatile Sulfides (AVS) from Na<sub>2</sub>S-Amended Sediment on *Hyalella azteca*." *Water, Air, and Soil Pollution* 227 (April):158. <https://doi.org/10.1007/s11270-016-2849-4>.
- McQueen, Andrew D., Guilherme R. Lotufo, Scott W. Pickard, Andrew M. Lenox, David W. Moore, Katherine von Stackelberg, and Burton C. Suedel. 2020. "Evaluation of Dredged Sediment for Aquatic Placement: Interpreting Contaminant Bioaccumulation." *Environmental Monitoring and Assessment* 192 (April):277. <https://doi.org/10.1007/s10661-020-8236-z>.
- Melby, Nicolas L., Alan J. Kennedy, J. Daniel Farrar, Anthony J. Bednar, David W. Moore, and Wade Lehmann. 2018. *Toxicity Reduction (and Identification) Evaluation for Dredging Evaluations: Methods for Whole Sediment Elutriate Bioassays*. ERDC Technical Notes Collection. ERDC/TN DOER-R26. Vicksburg, MS: US Army Engineer Research and Development Center. <https://dx.doi.org/10.21079/11681/28467>.
- Milani, Danielle, Trefor B. Reynoldson, Uwe Borgmann, and Jurek Kolasa. 2003. "The Relative Sensitivity of Four Benthic Invertebrates to Metals in Spiked-Sediment Exposures and Application to Contaminated Field Sediment." *Environmental Toxicology and Chemistry* 22, no. 4 (April): 845–54. <https://doi.org/10.1002/etc.5620220424>.
- Miller, D. C., S. Poucher, J. A. Cardin, and D. Hansen. 1990. "The Acute and Chronic Toxicity of Ammonia to Marine Fish and a Mysid." *Archives of Environmental Contamination and Toxicology* 19:40–48. <https://doi.org/10.1007/BF01059811>.

- Miller, D.C., S.L. Poucher, and L. Corio. 2002. "Determination of Lethal Dissolved Oxygen Levels for Selected Marine and Estuarine Fishes, Crustaceans, and a Bivalve." *Marine Biology* 140, no. 2 (February): 287–96. <https://doi.org/10.1007/s002270100702>.
- Millward, Rod N., Todd S. Bridges, Upal Ghosh, John R. Zimmerman, and Richard G. Luthy. 2005. "Addition of Activated Carbon to Sediments to Reduce PCB Bioaccumulation by a Polychaete (*Neanthes arenaceodentata*) and an Amphipod (*Leptocheirus plumulosus*)." *Environmental Science and Technology* 39 (8): 2880–87. <https://doi.org/10.1021/es048768x>.
- Millward, Rod, Robert Jones, Richard Karn, and Allyson Harrison. 2007. *A Microscale Approach for the Quantitative Detection of PCBs and PAHs in Small Tissue Masses*. ERDC Technical Notes Collection. ERDC TN-DOER-T9. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8682>.
- Moore, David W., Todd S. Bridges, and Jerome J. Cura. 1998. *Dredging/Dredged Material Management Risk Assessment*. ERDC Technical Notes Collection. Technical Note DOER-R1. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8661>.
- Moore, David W., Todd S. Bridges, Brian R. Gray, and B. Maurice Duke. 1997. "Risk of Ammonia Toxicity During Sediment Bioassays with the Estuarine Amphipod *Leptocheirus plumulosus*." *Environmental Toxicology and Chemistry* 16, no. 5 (May): 1020–27. <https://doi.org/10.1002/etc.5620160523>.
- Mount, David R., Timothy D. Dawson, and Lawrence P. Burkhard. 1999. "Implications of Gut Purging for Tissue Residues Determined in Bioaccumulation Testing of Sediment with *Lumbriculus variegatus*." *Environmental Toxicology and Chemistry* 18, no. 6 (June): 1244–49. <https://doi.org/10.1002/etc.5620180625>.
- Mount, Donald I. 1977. *Recent Advances in Fish Toxicology: A Symposium*. Ecological Research. EPA 600/3-77-085. Corvallis, OR: Environmental Protection Agency–Environmental Research Laboratory. <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100F2IX.PDF?Dockey=P100F2IX.PDF>.
- Nakata, Haruhiko, Yasufumi Sakai, Takashi Miyawaki, and Akira Takemura. 2003. "Bioaccumulation and Toxic Potencies of Polychlorinated Biphenyls and Polycyclic Aromatic Hydrocarbons in Tidal Flat and Coastal Ecosystems of the Ariake Sea, Japan." *Environmental Science and Technology* 37 (16): 3513–21. <https://doi.org/10.1021/es021083h>.
- NAS-NAE CWQC (National Academy of Sciences–National Academy of Engineering Committee on Water Quality Criteria). 1972. *Water Quality Criteria, 1972*. EPA-R-3-73-033. Washington, DC, <https://nepis.epa.gov/Exe/ZyPDF.cgi/2000XOYT.PDF?Dockey=2000XOYT.PDF>.
- National Environmental Policy Act of 1970. 2021. 42U.S.C. §§ 4321–47. <https://www.govinfo.gov/content/pkg/USCODE-2021-title42/pdf/USCODE-2021-title42-chap55-sec4321.pdf>.

Nationwide Permit Program. 1991. 33 C.F.R. § 330. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part330.pdf>.

Operation and Maintenance of Army Corps of Engineers Civil Works Projects Involving the Discharge of Dredged or Fill Material into Waters of the U.S. or Ocean Waters. 1988. 33 C.F.R. § 335. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part335.pdf>.

Peijnenburg, Willie JGM, Peter R Teasdale, Danny Reible, Julie Mondon, William W Bennett, and Peter GC Campbell. 2014. "Passive Sampling Methods for Contaminated Sediments: State of the Science for Metals." *Integrated Environmental Assessment and Management* 10, no. 2 (April): 179–96. <https://doi.org/10.1002/ieam.1502>.

Permits for Dams and Dikes in Navigable Waters of the United States. 1986. 33 C.F.R. § 321. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part321.pdf>.

Permits for Discharges of Dredged or Fill Material into Waters of the United States. 1986. 33 C.F.R. § 323. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part323.pdf>.

Permits for Ocean Dumping of Dredged Material. 1986. 33 C.F.R. § 324. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part324.pdf>.

Permits for Structures or Work in or Affecting Navigable Waters of the United States. 1986. 33 C.F.R. § 322. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part322.pdf>.

Phipps, G. L., V. R. Mattson, and G. T. Ankley. 1995. "Relative Sensitivity of Three Freshwater Benthic Macroinvertebrates to Ten Contaminants." *Archives of Environmental Contamination and Toxicology* 28:281–86. <https://doi.org/10.1007/BF00213103>.

Postma, J. F., S. de Valk, M. Dubbeldam, J. L. Maas, M. Tonkes, C. A. Schipper, and B. J. Kater. 2002. "Confounding Factors in Bioassays with Freshwater and Marine Organisms." *Ecotoxicology and Environmental Safety* 53, no. 2 (October): 226–37. <https://doi.org/10.1006/eesa.2002.2195>.

Practice and Procedure. 1988. 33 C.F.R. § 337. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part337.pdf>.

Presser, Theresa S, and Samuel N Luoma. 2010. "A Methodology for Ecosystem-Scale Modeling of Selenium." *Integrated Environmental Assessment and Management* 6, no. 4 (October): 685–710. <https://doi.org/10.1002/ieam.101>.

Processing of Department of the Army Permits. 1986. 33 C.F.R. § 325. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part325.pdf>.

- Public Hearings. 1986. 33 C.F.R. § 327. <https://www.govinfo.gov/content/pkg/CFR-2021-title33-vol3/pdf/CFR-2021-title33-vol3-part327.pdf>.
- Rabalais, Lauren K., Jennifer G. Laird, Alan J. Kennedy, John D. Farrar, Guilherme R. Lotufo, and James M. Biedenbach. 2018. *Acute Toxicity Testing and Culture Methods for Calanoid Copepods in Water Column (Elutriate) Toxicity Evaluations*. ERDC/EL TR-18-7. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://doi.org/10.21079/11681/27968>.
- Raimondo, Sandy, Brian J. Montague, and Mace G. Barron. 2007. “Determinants of Variability in Acute to Chronic Toxicity Ratios for Aquatic Invertebrates and Fish.” *Environmental Toxicology and Chemistry* 26, no. 9 (September): 2019–23. <https://doi.org/10.1897/07-069R.1>.
- Sanders, James P., Natasha A. Andrade, Charles A. Menzie, C. Bennett Amos, Cynthia C. Gilmour, Elizabeth A. Henry, Steven S. Brown, and Upal Ghosh. 2018. “Persistent Reductions in the Bioavailability of PCBs at a Tidally Inundated *Phragmites australis* Marsh Amended with Activated Carbon.” *Environmental Toxicology and Chemistry* 37, no. 9 (September): 2496–505. <https://doi.org/10.1002/etc.4186>.
- Sappington, Keith G., Todd S Bridges, Steven P Bradbury, Russell J Erickson, A Jan Hendriks, Roman P Lanno, James P Meador, David R Mount, Mike H Salazar, and Doug J Spry. 2011. “Application of the Tissue Residue Approach in Ecological Risk Assessment.” Special issue, *Tissue Residue Approach Special Series. Integrated Environmental Assessment and Management* 7, no. 1 (January): 116–40. <https://doi.org/10.1002/ieam.116>.
- Schroeder, Paul, Trudy Estes, and Susan Bailey. 2006. *Screening Evaluations for Upland Confined Disposal Facility Effluent Quality*. ERDC Technical Notes Collection. ERDC TN-DOER-R11. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8670>.
- Section 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material. 1980. 40 C.F.R. § 320. <https://www.govinfo.gov/content/pkg/CFR-2018-title40-vol27/pdf/CFR-2018-title40-vol27-part230.pdf>.
- Sims, Jerre G., and David W. Moore. 1995. *Risk of Pore Water Ammonia Toxicity in Dredged Material Bioassays*. Miscellaneous Paper D-95-3. Vicksburg, MS: US Army Engineer Waterways Experiment Station. <https://hdl.handle.net/11681/2996>.
- Sinche, Federico L., Guilherme R. Lotufo, Peter Landrum, and Michael J. Lydy. 2019. “Can Tenax Extraction Be Used as a Surrogate Exposure Metric for Laboratory-Based Bioaccumulation Tests Using Marine Sediments?” *Environmental Toxicology and Chemistry* 38, no. 6 (June): 1188–97. <https://doi.org/10.1002/etc.4398>.

- Steevens, Jeffery, Alan Kennedy, Daniel Farrar, Cory McNemar, Mark R. Reiss, Roy K. Kropp, Jon Doi, and Todd Bridges. 2008. *Dredged Material Analysis Tools; Performance of Acute and Chronic Sediment Toxicity Methods*. ERDC/EL TR-08-16. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://hdl.handle.net/11681/6880>.
- Suter, Glenn W., II, Rebecca A. Efroymson, Bradley E. Sample, and Daniel S. Jones. 2000. *Ecological Risk Assessment for Contaminated Sites*. Boca Raton, FL: CRC Press. <https://doi.org/10.1201/9780367802707>.
- Swartz, Richard C. 1999. “Consensus Sediment Quality Guidelines for Polycyclic Aromatic Hydrocarbon Mixtures.” *Environmental Toxicology and Chemistry* 18, no. 4 (April): 780–87. <https://doi.org/10.1002/etc.5620180426>.
- Takahashi, S., S. Tanabe, I. Takeuchi, and N. Miyazaki. 1999. “Distribution and Specific Bioaccumulation of Butyltin Compounds in a Marine Ecosystem.” *Archives of Environmental Contamination and Toxicology* 37:50–61. <https://doi.org/10.1007/s002449900489>.
- Takeuchi, Ichiro, Noriko Miyoshi, Kaoruko Mizukawa, Hideshige Takada, Tokutaka Ikemoto, Koji Omori, and Kotaro Tsuchiya. 2009. “Biomagnification Profiles of Polycyclic Aromatic Hydrocarbons, Alkylphenols and Polychlorinated Biphenyls in Tokyo Bay Elucidated by  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  Isotope Ratios as Guides to Trophic Web Structure.” *Marine Pollution Bulletin* 58, no. 5 (May): 663–71. <https://doi.org/10.1016/j.marpolbul.2008.12.022>.
- Teal, L. R., M. T. Bulling, E. R. Parker, and M. Solan. 2008. “Global Patterns of Bioturbation Intensity and Mixed Depth of Marine Soft Sediments.” *Aquatic Biology* 2 (June): 207–18. <https://doi.org/10.3354/ab000052>.
- Thurston, Robert V., Rosemarie C. Russo, Elizabeth L. Meyn, Richard K. Zajdel, and Charlie E. Smith. 1986. “Chronic Toxicity of Ammonia to Fathead Minnows.” *Transactions of the American Fisheries Society* 115, no. 2 (March): 196–207. [https://doi.org/10.1577/1548-8659\(1986\)115%3C196:CTOATF%3E2.0.CO;2](https://doi.org/10.1577/1548-8659(1986)115%3C196:CTOATF%3E2.0.CO;2).
- Thurston, Robert V., Rosemarie C. Russo, and Glenn R. Phillips. 1983. “Acute Toxicity of Ammonia to Fathead Minnows.” *Transactions of the American Fisheries Society* 112, no. 5 (September): 705–11. [https://doi.org/10.1577/1548-8659\(1983\)112%3C705:ATOATF%3E2.0.CO;2](https://doi.org/10.1577/1548-8659(1983)112%3C705:ATOATF%3E2.0.CO;2).
- USACE (US Army Corps of Engineers). 1987. *Confined Disposal of Dredged Material*. Engineering Manual 1110-2-5027. Washington, DC: US Army Corps of Engineers. <https://apps.dtic.mil/sti/citations/ADA403449>.
- USACE (US Army Corps of Engineers). 2003. *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore, or Upland Confined Disposal Facilities — Testing Manual*. ERDC/EL TR-03-1. Vicksburg, MS: US Army Engineer Research and Development Center–Environmental Laboratory. <https://hdl.handle.net/11681/7038>.

- USACE (US Army Corps of Engineers). 2012. *The U.S. Waterway System: Transportation Facts and Information*. Alexandria, VA: US Army Corps of Engineers–Navigation and Civil Works Decision Support Center. <https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/1419/>.
- USACE (US Army Corps of Engineers). 2018. *Section 408 – Interim Changes for Immediate Implementation and Future Policy Revisions*. Memorandum. 12 January 2018. Washington, DC: US Army Corps of Engineers. <https://usace.contentdm.oclc.org/digital/collection/p16021coll11/id/2005/>.
- USACE-NAN and EPA-R2 (US Army Corps of Engineers–New York District and Environmental Protection Agency–Region 2). 2016. *Guidance for Performing Tests on Dredged Material Proposed for Ocean Disposal*. New York: Environmental Protection Agency–Region 2. [https://www.epa.gov/sites/default/files/2016-10/documents/r2\\_rtm-april\\_2016.pdf](https://www.epa.gov/sites/default/files/2016-10/documents/r2_rtm-april_2016.pdf).
- USACE-NWS, EPA-R10, WADNR, and WADE (US Army Corps of Engineers–Seattle District, Environmental Protection Agency–Region 10, Washington State Department of Natural Resources, and Washington State Department of Ecology). 2018. *Dredged Material Evaluation and Disposal Procedures User Manual*. Prepared by USACE-NWS–Dredged Material Management Office. Seattle, WA: US Army Corps of Engineers–Seattle District. <https://usace.contentdm.oclc.org/digital/collection/p16021coll11/id/3788>.
- USACE-SAD and EPA-R4 (US Army Corps of Engineers–South Atlantic Division and Environmental Protection Agency–Region 4). 2008. *Southeast Regional Implementation Manual (SERIM): Requirements and Procedures for Evaluation of the Ocean Disposal of Dredged Material in Southeastern U.S. Atlantic and Gulf Coast Waters*. EPA 904-B-08-001. Atlanta, GA: Environmental Protection Agency–Region 4. [https://www.epa.gov/sites/default/files/2016-05/documents/r4\\_serim\\_final\\_august\\_2008.pdf](https://www.epa.gov/sites/default/files/2016-05/documents/r4_serim_final_august_2008.pdf).
- Valente, Raymond M., Donald C. Rhoads, Peggy L. Myre, Lorraine B. Read, and Drew A. Carey. 2006. *Evaluation of Field Bioaccumulation as a Monitoring Tool*. DV-2006-002. DAMOSVision, Contract No. W912WJ-05-D-0001. Concord, MA: US Army Corps of Engineers–New England District. <https://www.nae.usace.army.mil/portals/74/docs/DAMOS/TechReports/169.pdf>.
- Van Geest, Jordana L., David G. Poirier, Paul K. Sibley, and Keith R. Solomon. 2010. “Measuring Bioaccumulation of Contaminants from Field-Collected Sediment in Freshwater Organisms: A Critical Review of Laboratory Methods.” *Environmental Toxicology and Chemistry* 29, no. 11 (November): 2391–401. <https://doi.org/10.1002/etc.326>.
- Verma, S. R., I. P. Tonk, and R. C. Dalela. 1981. “Determination of the Maximum Acceptable Toxicant Concentration (MATC) and the Safe Concentration for Certain Aquatic Pollutants.” *Acta Hydrochimica et Hydrobiologica* 9 (3): 247–54. <https://doi.org/10.1002/ahch.19810090303>.

- Vidal, Doris E., and Steven M. Bay. 2005. "Comparative Sediment Quality Guideline Performance for Predicting Sediment Toxicity in Southern California, USA." *Environmental Toxicology and Chemistry* 24, no. 12 (December): 3173–82. <https://doi.org/10.1897/04-656R.1>.
- Wan, Yi, Xiaohui Jin, Jianying Hu, and Fen Jin. 2007. "Trophic Dilution of Polycyclic Aromatic Hydrocarbons (PAHs) in a Marine Food Web from Bohai Bay, North China." *Environmental Science and Technology* 41, no. 9 (May): 3109–14. <https://doi.org/10.1021/es062594x>.
- Watts, M. M., and D. Pascoe. 2000. "A Comparative Study of *Chironomus riparius* Meigen and *Chironomus tentans* Fabricius (Diptera: Chironomidae) in Aquatic Toxicity Tests." *Archives of Environmental Contamination and Toxicology* 39, no. 3 (September): 299–306. <https://doi.org/10.1007/s002440010108>.
- Weinstein, John E., and Denise M. Sanger. 2003. "Comparative Tolerance of Two Estuarine Annelids to Fluoranthene under Normoxic and Moderately Hypoxic Conditions." *Marine Environmental Research* 56, no. 5 (December): 637–48. [https://doi.org/10.1016/S0141-1136\(03\)00047-3](https://doi.org/10.1016/S0141-1136(03)00047-3).
- Wenning, Richard J., and Christopher G. Ingersoll, eds. 2002. *Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments: Executive Summary Booklet of a SETAC Pellston Workshop, 17–22 August 2002, Fairmont, MT.* Pensacola, FL: Society of Environmental Toxicology and Chemistry. [https://www.cerc.usgs.gov/pubs/sedtox/wg0\\_setac\\_sqg\\_summary.pdf](https://www.cerc.usgs.gov/pubs/sedtox/wg0_setac_sqg_summary.pdf).
- Wilber, D. H., W. Brostoff, D. G. Clarke, and G. L. Ray. 2005. *Sedimentation: Potential Biological Effects of Dredging Operations in Estuarine and Marine Environments*. ERDC Technical Notes Collection. ERDC TN-DOER-E20. Vicksburg, MS: US Army Engineer Research and Development Center. <https://hdl.handle.net/11681/8751>.
- Word, Jack Q., William W. Gardiner, and David W. Moore. 2005. "Influence of Confounding Factors on SQGs and Their Application to Estuarine and Marine Sediment Evaluations." In *Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments*, edited by Richard J. Wenning, Graeme E. Batley, Christopher G. Ingersoll, and David W. Moore, 633–86. Pensacola, FL: Society of Environmental Toxicology and Chemistry.
- Word, Jack Q., Jeffrey A. Ward, Betsy Brown, Brian D. Walls, and Sandy Lemlich. 1989. "Relative Sensitivity and Cost of Amphipod Bioassays." *OCEANS '89 2: Ocean Pollution*, 467–73, 18–21 September, Seattle, WA. Piscataway, NJ: Institute of Electrical and Electronic Engineers. <https://doi.org/10.1109/OCEANS.1989.586771>.
- Xie, Minwei, Stuart L. Simpson, Jianyin Huang, Peter R. Teasdale, and Wen-Xiong Wang. 2021. "In Situ DGT Sensing of Bioavailable Metal Fluxes to Improve Toxicity Predictions for Sediments." *Environmental Science and Technology* 55, no. 11 (June): 7355–64. <https://doi.org/10.1021/acs.est.0c07670>.

Zhang, Hao, and William Davison. 1995. "Performance Characteristics of Diffusion Gradients in Thin Films for the in Situ Measurement of Trace Metals in Aqueous Solution." *Analytical Chemistry* 67, no. 19 (October): 3391–400. <https://doi.org/10.1021/ac00115a005>.

Zhang, Yanfeng, Jinxi Yang, Stuart L. Simpson, Yuanyuan Wang, and Lingyan Zhu. 2019. "Application of Diffusive Gradients in Thin Films (DGT) and Simultaneously Extracted Metals (SEM) for Evaluating Bioavailability of Metal Contaminants in the Sediments of Taihu Lake, China." *Ecotoxicology and Environmental Safety* 184, no. 30 (November): 109627. <https://doi.org/10.1016/j.ecoenv.2019.109627>.

## Appendix A

This appendix includes plaintext versions of Figures 1-1, 1-3, 4-2, and 4-4.

### A.1 Plaintext version of Figure 1-1

1. Source; orange
  - a. Dredged Material; Go to 2a, 2b, or 2c; orange oval
2. Pathways; yellow
  - a. Water column; Go to 3a or 3b; yellow rectangle
  - b. Direct Benthic; Go to 3c; yellow rectangle
  - c. Indirect Benthic (Trophic Transfer); Go 3d; yellow rectangle
3. Receptors; green
  - a. Aquatic Invertebrates; Go to 3b
  - b. Pelagic Fish
  - c. Benthic Invertebrates
  - d. Benthic Invertebrates
    - i. Pelagic Fish; Go to 3d(ii) or 3d(iii)
    - ii. Piscivorous Fish and Wildlife; Go to 3d(iii)
    - iii. Humans

### A.2 Plaintext version of Figure 1-3

1. Source: Dredged Sediment; Go to Step 2a, Step 2b, or Step 2c
2. Potential Exposure Pathways
  - a. Water Column; Go to Step 3a

- b. Bottom Sediment; Go to Step 3b
  - c. Bottom Sediment; Go to Step 3c
- 3. Potential Receptors
  - a. Phytoplankton, Zooplankton, Pelagic Fish; Go to Step 4a or Step 4b
  - b. Benthic Invertebrates; Go to Step 3c, Step 4c, or Step 4d
  - c. Pelagic Fish, Humans; Go to Step 4e
- 4. Testing
  - a. Acute Toxicity; Go to Step 5a
  - b. Sublethal Toxicity; Go to Step 5a
  - c. Acute Toxicity; Go to Step 5c
  - d. Sublethal Toxicity; Go to Step 5c
  - e. Bioaccumulation of Contaminants; Go to Step 5d
- 5. Weight-of-Evidence (WOE) Evaluation
  - a. Assess Toxicity of Surface Water or Elutriate using Multiple Lines of Evidence; Go to Step 5b
  - b. Integrate Lines of Evidence into WOE Evaluation; Go to Step 6
  - c. Assess Toxicity of Sediment using Multiple Lines of Evidence; Go to Step 5b
  - d. Assess Trophic Transfer of Contaminants integrating Multiple Lines of Evidence into WOE; Go to Step 5c
- 6. Technical Determination; blue rectangle

- a. Aquatic Discharge Acceptable With or Without Controls; Go to Step 7a
  - b. Aquatic Discharge Not Acceptable based on Existing Information; Go to Step 7b
- 7. Project Implementation and Management
  - a. Proceed with Dredging Project after Instituting Engineering and/or Operational Controls, as Needed
  - b. Collect Additional Data to Support Technical Determination (Iterate)

### **A.3 Plaintext version of Figure 4-2**

- 1. Initial Evaluation (4.3); green rectangle
  - a. Regulatory exclusions
  - b. Previous determinations
  - c. Screening
- 2. Does initial evaluation allow a technical determination?; orange diamond
  - a. Yes: Water Column Technical Determination; blue rectangle
    - i. Acceptable impacts or
    - ii. Unacceptable impacts
  - b. No: Go to Step 3
- 3. Evaluate WQS/WQS Compliance; green rectangle
  - a. Elutriate chemistry (4.6)
  - b. See Figure 4-3

4. Bioassay testing; orange diamond
  - a. No: Go to Step 6
  - b. Yes: Go to Step 5
5. Evaluate Toxicity; green rectangle
  - a. Elutriate bioassay (4.7)
  - b. See Figure 4-9
6. Both WQC/WQS and Toxicity Requirements met?; orange diamond
  - a. Yes: Acceptable water column impacts; blue rectangle
  - b. No: Go to Step 7
7. Evaluate Mixing (4.8); green rectangle
8. Dilution requirements met?; orange diamond
  - a. Yes: Acceptable water column impacts; blue rectangle
  - b. No: Go to Step 9
9. Evaluate Operational & Engineering Controls (4.9); green rectangle
10. Are controls feasible and meet requirements?; orange diamond
  - a. Yes: Acceptable water column impacts with controls; blue rectangle
  - b. No: Unacceptable water column impacts, Consider other alternatives; blue rectangle

#### **A.4 Plaintext version of Figure 4-4**

Note for accessible version: brackets part of original figure.

1. Water Quality Screening; orange oval
2. Initial Evaluation
  - a. Estimate Dissolved Concentration Contaminants in Elutriate; green rectangle
    - i. using conservative partitioning screening approach (Section 4.5)
  - b. Identify CoPC requiring greatest dilution (Section 4.5) ; green rectangle
  - c. Model Mixing of Predicted CoPC Elutriate for Acceptability (Section 4.5 & 4.8); green rectangle
  - d. [Contaminant] >WQC or; green diamond
    - i. No: Acceptable impacts predicated. Complete initial evaluation by comparisons with previous technical determinations. Determine if bioassay testing is also required (Figure 4-2); blue rectangle
    - ii. Yes: Go to Step 3
3. Standard Elutriate Testing; orange oval
4. Prepare elutriate and measure dissolved contaminant concentration (Section 4.6); green rectangle
5. Water Column Bioassay Testing, if required; orange oval

## **A.5 Plaintext version of Figure 4-9**

Note for accessible version: text in brackets not part of original figure; text in brackets represents additional information to help guide readers through the flowchart.

1. Determine if acute toxicity is observed: Compare endpoint (e.g., survival) in 100% elutriate to endpoint in dilution water; orange oval
2. Survival?; green irregular hexagon
  - a. Survival  $\geq$  Dilution water: Go to Step 6a
  - b. Survival is reduced  $< 10\%$  ( $< 20\%$  for development) relative to the dilution water: Go to Step 6a
  - c. Survival is reduced  $\geq 10\%$  ( $\geq 20\%$  for development) relative to the dilution water: Go to Step 3
3. Perform statistical comparison between the elutriate and dilution water; yellow rectangle
4. Is the elutriate statistically significantly reduced relative to the dilution water?; green irregular hexagon
  - a. No: Go to Step 6a
  - b. Yes: Go to Step 5
5. Is survival  $> 50\%$ ?; green irregular hexagon
  - a. No: Go to Step 6b
  - b. Yes: Go to Step 6c
6. [Step 6]
  - a. No acute toxicity predicted; blue rectangle
  - b. Acute toxicity predicted: Report NOEC, LOEC, LPC; blue rectangle
  - c. Acute toxicity predicted: Calculate and report  $LC_{50}$ , LPC; blue rectangle

## A.6 Plaintext version of Figure 4-10

Note for accessible version: text in brackets not part of original figure; text in brackets represents additional information to help guide readers through the flowchart.

1. Initial evaluation of Potential CoPCs; orange oval
2. Is ammonia toxicity expected?; green irregular hexagon
  - a. Yes: Go to Step 3a
  - b. No: Go to Step 3b
3. [Step 3]
  - a. Test ammonia; Go to Step 4a; yellow oval
  - b. Test unpurged; Go to Step 4b; yellow oval
4. [Step 4]
  - a. Acute toxicity observed?; green irregular hexagon
    - i. No: LPC = WQC for ammonia; blue rectangle
    - ii. Yes: Go to Step 5
  - b. Acute toxicity observed from purged sample?; green irregular hexagon
    - i. No: Use LPC based on elutriate testing; blue rectangle
    - ii. Yes: Go to Step 5
5. Survival or development test endpoint?; green irregular hexagon
  - a. Survival: Go to Step 6a
  - b. Development: Go to Step 6b

6. [Step 6]
  - a. LC50 generated?; green irregular hexagon
    - i. No: LPC = 100% Elutriate; blue rectangle
    - ii. Yes: Go to Step 7
  - b. EC50 generated?; green irregular hexagon
    - i. Yes: LPC = NOEC
    - ii. No: LPC = 100% Elutriate
7. Chemical or species specific AF available?; green irregular hexagon
  - a. Yes:  $LPC = LC_{50} * AF$  (see Table 4-4)
  - b. No:  $LPC = LC_{50} * 0.01$  (NAS 1972)

\* Use purged results when available.

† Alternatively acute toxicity reference value (TRV) X ammonia AF

## **A.7 Plaintext version of Figure 5-2**

1. Perform Initial Evaluation (Section 5.2); blue oval
2. Does WOE support open water placement?; orange irregular hexagon
  - a. Yes: Go to Step 10
  - b. No: Go to Step 3
3. Perform primary LOE sediment toxicity tests (Section 5.3); blue rectangle
4. Does primary LOE support open water placement?; orange irregular hexagon

- a. Yes: Go to Step 10
  - b. No: Go to Step 5
- 5. Evaluate supporting LOE as needed (Section 5.5); blue rectangle
- 6. Does WOE support open water placement?; orange irregular hexagon
  - a. Yes: Go to Step 7
  - b. No: Go to Step 9
- 7. Perform additional toxicity testing? (Sections 5.3 and 5.6); blue rectangle
- 8. Does WOE support open water placement?; orange irregular hexagon
  - a. Yes: Go to Step 10
  - b. No: Go to Step 9
- 9. Evaluate operational and engineering controls; green rectangle (Section 5.8) [Go to Step 10]
- 10. Technical determination; blue oval

## **A.8 Plaintext version of Figure 6-1**

Note for accessible version: text in brackets not part of original figure; text in brackets represents additional information to help guide readers through the flowchart.

- 1. Is CoPC in sediment > analytical reporting limits?; yellow diamond
  - a. Yes: Go to Step 2
  - b. No: Go to Step 11d (Outcome 4)

2. (1) Perform evaluation using standard sediment bioaccumulation tests. (2) Collect and archive initial tissue residues. (3) Submit tissue for analysis only for CoPCs detected in the sediment., Go to Step 3; blue rectangle
3. Perform applicable substitutions of U-flagged data for determination of means (between replicates), Go to Step 4; blue rectangle
4. Are relevant regional background values available?; yellow rectangle
  - a. Yes: Go to Step 6
  - b. No: Go to Step 5
5. Is DMMU CoPC mean > baseline tissue residues?; yellow diamond
  - a. Yes: Go to Step 7
  - b. No: Go to Step 11d (Outcome 4)
6. Is the DMMU mean for each CoPC < background?; yellow diamond
  - a. Yes: Go to Step 11a (Outcome 1)
  - b. No: Go to Step 5
7. Is CoPC tissue residue  $\geq 2 \times$  tissue from reference sediment?; yellow diamond
  - a. Yes: Go to Step 8
  - b. No: Go to Step 11b (Outcome 2)
8. Is CoPC tissue residue statistically greater than reference sediment tissue?; yellow diamond
  - a. Yes: Go to Step 9

- b. No: Go to Step 11b (Outcome 2)
- 9. Perform exposure and effects screening level risk assessment. Consider contribution of archived and background tissue., Go to Step 10; blue rectangle
- 10. Does risk assessment support open water placement?; yellow diamond
  - a. Yes: Go to Step 11d (Outcome 4)
  - b. No: Step Step 11c (Outcome 3)
- 11. [Step 11]
  - a. Outcome 1: No need to further consider that CoPC for open water placement (LPC met for that CoPC).; green oval
  - b. Outcome 2: Make technical determination. Consult with stakeholders as needed. CoPC appears to be of low bioaccumulation concerned. LPC likely met.; green oval
  - c. Outcome 3: Evaluate operational and engineering controls. Consult with stakeholders as needed. Determine whether LPC can still be met.; red oval
  - d. Outcome 4: No need to evaluate that CoPC for open water placement. (LPC met for that CoPC); green oval

## Abbreviations

|            |                                                                          |
|------------|--------------------------------------------------------------------------|
| ACR        | Acute-to-chronic ratio                                                   |
| AF         | Application factor                                                       |
| ASTM       | ASTM International (formerly American Society for Testing and Materials) |
| AVS        | Acid volatile sulfides                                                   |
| BSAF       | Biota-sediment accumulation factor                                       |
| CBR        | Critical body residues                                                   |
| CDFATE     | Continuous discharge FATE                                                |
| CFR        | Code of Federal Regulations                                              |
| CM         | Conceptual model                                                         |
| COPC       | Contaminant of potential concern                                         |
| CORMIX     | Cornell Mixing Zone Expert System                                        |
| CORMIX-GTS | Cornell Mixing Zone Expert System—General Tools Sediment                 |
| CWA        | Clean Water Act                                                          |
| D-CORMIX   | Dredging Cornell Mixing Zone Expert System                               |
| DEMAND     | Dredging Evaluation Management, Analysis and Networked Documentation     |
| DEVOID     | Dredging Evaluation Visualization, Organization and Integration Database |
| DGT        | Diffusion gradient in thin-film gels                                     |
| DIFCD      | Disposal from a continuous discharge                                     |
| DM         | Dredged material                                                         |

|                  |                                                                                           |
|------------------|-------------------------------------------------------------------------------------------|
| DMMU             | Dredged material management unit                                                          |
| DOER             | Dredging Operations and Environmental Research Program                                    |
| DQO              | Data quality objective                                                                    |
| DRET             | Dredging elutriate test                                                                   |
| EC <sub>50</sub> | Median effect concentration                                                               |
| EET              | Effluent elutriate test                                                                   |
| EPA              | United States Environmental Protection Agency; see also USEPA                             |
| ERL              | Effects range low                                                                         |
| ERM              | Effects range medium                                                                      |
| ERMQ             | Effects range medium quotient                                                             |
| FCV              | Final chronic value                                                                       |
| HQ               | Hazard quotient                                                                           |
| ITM              | Inland testing manual                                                                     |
| LC <sub>50</sub> | Median lethal concentration                                                               |
| LOE              | Line of evidence                                                                          |
| LOEC             | Lowest observable effect concentration                                                    |
| LPC              | Limiting permissible concentration                                                        |
| MATC             | Maximum allowable toxicant concentration                                                  |
| MET              | Modified elutriate test                                                                   |
| MOD              | Magnitude difference between bioaccumulation from dredged material and reference material |
| MPRSA            | Marine Protection, Research, and Sanctuaries Act                                          |

---

|       |                                          |
|-------|------------------------------------------|
| mSQGQ | Mean sediment quality guideline quotient |
| NAS   | National Academy of Sciences             |
| NEPA  | National Environmental Policy Act        |
| NOEC  | No observable effect concentration       |
| NTU   | Nephelometric turbidity unit             |
| OC    | Organochlorine                           |
| OTM   | Ocean testing manual                     |
| PBDE  | Polybrominated diphenyl ether            |
| PE    | Polyethylene                             |
| PEC   | Probable effect concentration            |
| PEC-Q | Probable effect concentration quotient   |
| PEL   | Probable effects level                   |
| POM   | Polyoxymethylene                         |
| QAPP  | Quality assurance project plan           |
| RIA   | Regional implementation agreement        |
| RIM   | Regional implementation manual           |
| SAP   | Sampling and analysis plan               |
| SCV   | Secondary chronic value                  |
| SEM   | Simultaneously extracted metals          |
| SET   | Standard elutriate test                  |
| SPME  | Solid-phase microextraction              |
| SQG   | Sediment quality guideline               |
| SQGQ  | Sediment quality guideline quotient      |

---

|        |                                    |
|--------|------------------------------------|
| STFATE | Short-term FATE                    |
| SVOC   | Semivolatile organic compound      |
| TBT    | Tributyltin                        |
| TEL    | Threshold effects level            |
| TIE    | Toxicity identification evaluation |
| UIA    | Un-ionized ammonia                 |
| USACE  | US Army Corps of Engineers         |
| USEPA  | US Environmental Protection Agency |
| UTM    | Upland testing manual              |
| VOC    | Volatile organic compound          |
| WOE    | Weight of evidence                 |
| WQC    | Water-quality criteria             |
| WQS    | Water-quality standard             |

# REPORT DOCUMENTATION PAGE

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|---------------------------|-------------------------|
| <b>1. REPORT DATE</b><br>May 2023                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    | <b>2. REPORT TYPE</b><br>Final      |     | <b>3. DATES COVERED</b><br><table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none;"><b>START DATE</b><br/>FY19</td> <td style="width: 50%; border: none;"><b>END DATE</b><br/>FY22</td> </tr> </table> |                                   | <b>START DATE</b><br>FY19 | <b>END DATE</b><br>FY22 |
| <b>START DATE</b><br>FY19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>END DATE</b><br>FY22            |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>4. TITLE AND SUBTITLE</b><br>Advances in Dredged Material Evaluations for Inland and Ocean Aquatic Placement: Modernized Processes and Supportive Tools                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>5a. CONTRACT NUMBER</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    | <b>5b. GRANT NUMBER</b>             |     | <b>5c. PROGRAM ELEMENT</b>                                                                                                                                                                                                          |                                   |                           |                         |
| <b>5d. PROJECT NUMBER</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    | <b>5e. TASK NUMBER</b>              |     | <b>5f. WORK UNIT NUMBER</b>                                                                                                                                                                                                         |                                   |                           |                         |
| <b>6. AUTHOR(S)</b><br>Alan J. Kennedy, David W. Moore, J. Daniel Farrar, Guilherme R. Lotufo, Burton C. Suedel, Susan E. Bailey, Paul R. Schroeder, Paige M. Krupa, Taylor E. Rycroft, and Trent C. May                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br>US Army Engineer Research and Development Center (ERDC)<br>Environmental Laboratory (EL)<br>3909 Halls Ferry Road<br>Vicksburg, MS 39180-6199<br><br>US Army Engineer Research and Development Center (ERDC)<br>Information Technology Laboratory (ITL)<br>3909 Halls Ferry Road<br>Vicksburg, MS 39180-6199                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    |                                     |     | <b>8. PERFORMING ORGANIZATION REPORT NUMBER</b><br>ERDC TR-23-6                                                                                                                                                                     |                                   |                           |                         |
| <b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br>US Army Engineer Research and Development Center (ERDC)<br>Environmental Laboratory (EL)<br>3909 Halls Ferry Road<br>Vicksburg, MS 39180-6199                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |     | <b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>                                                                                                                                                                                             |                                   |                           |                         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |     | <b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>                                                                                                                                                                                       |                                   |                           |                         |
| <b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b><br>Distribution Statement A. Approved for public release: distribution is unlimited.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>13. SUPPLEMENTARY NOTES</b><br>Project 19-11, "Dredging Evaluation Management, Analysis and Networked Documentation (DEMAND) Tool," Dredging Operations and Environmental Research (DOER) Program; Civil Direct—Funding Account Code RT19-11, AMSCO Code 089500                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>14. ABSTRACT</b><br><p>As part of the US Army Corps of Engineers' mission to evaluate and move dredged material (DM) to maintain navigation channels, environmental evaluation of the prospective material is required by the Code of Federal Regulations. While existing guidance manuals provide useful guidance to DM regulators, they are over 30 years old and not reflective of the latest science. However, efforts to update procedures and publish the documents individually or as a combined dredging manual have been thus far unsuccessful. These issues, coupled with a lack of consistent reporting and decision documentation, lead to delays arising from challenges addressing project-specific issues not clearly covered within the existing guidance, revisiting previously resolved issues or negotiating disputes between permitting authorities. This technical report provides a path toward modernization of the environmental compliance aspects of DM evaluation guidance in part through software executables guiding the management and decision process and through a structured, evidence-based approach. The value added is an updated approach to DM testing and evaluation decisions.</p> |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>15. SUBJECT TERMS</b><br>Dredging; Dredging spoil--Evaluation; Dredging spoil--Management; Environmental management; Environmental policy--Compliance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |     |                                                                                                                                                                                                                                     |                                   |                           |                         |
| <b>16. SECURITY CLASSIFICATION OF:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    |                                     |     | <b>17. LIMITATION OF ABSTRACT</b>                                                                                                                                                                                                   |                                   |                           |                         |
| <b>a. REPORT</b><br>Unclassified                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>b. ABSTRACT</b><br>Unclassified | <b>c. THIS PAGE</b><br>Unclassified | SAR |                                                                                                                                                                                                                                     | <b>18. NUMBER OF PAGES</b><br>185 |                           |                         |
| <b>19a. NAME OF RESPONSIBLE PERSON</b><br>Alan J. Kennedy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    |                                     |     | <b>19b. TELEPHONE NUMBER (include area code)</b><br>(601) 634-3344                                                                                                                                                                  |                                   |                           |                         |