

Environmental Surveillance and Monitoring Program for Dredging and Sediment Management Projects

Design and Implementation Procedures

Jean-René Michaud

Innovation, Monitoring and Industrial sectors
Environmental Protection Branch
Environment Canada – Quebec Region

June 2000



Environment
Canada

Environnement
Canada

Canada

NOTE TO READERS

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. For further information on this guide and the recommendations contained in it, please contact:

Environment Canada
Environmental Protection Branch
Innovation, Monitoring and Industrial sectors
105 McGill, 4th floor
Montreal, Quebec
H37 2E7
Tel.: (514) 283-9274

This publication should be cited as follows:

Michaud, Jean-René (2004). *Environmental Surveillance and Monitoring Programs for Dredging and Sediment Management Projects. Design and Implementation*. Environment Canada, Environmental Protection Branch, Quebec Region, Innovation, Monitoring and Industrial sectors. 227 p.

Published by authority of the Minister of the Environment
© Minister of Public Works and Government Services Canada 2004
Catalogue No. En153-108/2004E
ISBN: 0-662-35733-7

Production Team

Coordination

René Rochon

Research and writing

Jean-René Michaud

Translation

Elizabeth Sanborn

Editing

Jacqueline Grekin

Acknowledgments

This guide was prepared in collaboration with a number of departments. We want to thank the following individuals for their suggestions during the preparation of this document and their comments on the various preliminary versions:

Environment Canada

Caroll Bélanger, Intervention and Restoration Section
Michel Chevalier, Eco-Technology Innovation Section
Alain Latreille, Intervention and Restoration Section
Serge Lemieux, Environmental Assessment Division
Serge Lepage, St. Lawrence Centre
Marc Provencher, Marine Environment Protection Section

Fisheries and Oceans Canada

Daniel Hardy, Regional Oceans and Environment
Francine Richard, Technical Services Branch
Gordon Walsh, Regional Oceans and Environment

Public Works and Government Services Canada

Yves Lavergne, Real Property Services

Ministère de l'Environnement du Québec

Gilles Brunet, Direction des projets en milieu hydrique
Hélène Gouin, Service de la faune aquatique
Pierre Michon, Direction des projets en milieu hydrique

Foreword

This document is intended to assist proponents and project managers in designing and implementing environmental surveillance and monitoring programs (ESMPs) for dredging and sediment management projects. While its basic objectives, theoretical concepts and practical suggestions are generally applicable, the examples of environmental surveillance and monitoring programs presented must be adapted for specific projects. Indeed, it is virtually impossible to propose programs that are applicable to the broad range of possible projects and environmental conditions. Consequently, the recommendations and suggestions given here, especially in terms of the parameters analysed and the frequency of analysis, are presented merely as examples and should not be considered strict guidelines applicable to every project. They must be adapted and improved by the professionals and managers responsible, to the best of their ability, on the basis of the environmental problems at a given site and the specific characteristics of the project.

The present document summarizes the various concepts and information required for the preparation of coherent environmental monitoring and surveillance programs. Produced in the context of Phase III of the St. Lawrence Vision 2000 Action Plan, it represents a first effort and a useful reference source for the preparation of a general guide governing the development of programs of this kind intended for proponents of marine engineering projects who carry out dredging operations or who are responsible for sound sediment management.

Avant-propos

Ce document vise à aider les promoteurs et les gestionnaires dans la conception et la mise en œuvre de programmes de surveillance et de suivi environnemental (PSSE) de projets de dragage et de gestion des sédiments. Si les objectifs généraux et les notions théoriques ainsi que les suggestions pratiques s'appliquent de façon générale, il reste que les exemples de programmes de surveillance et de suivi de projets présentés doivent être adaptés à chaque cas. Il s'avère en effet presque impossible de proposer des programmes applicables à toutes les gammes de projets et de conditions environnementales. De ce fait, les recommandations et suggestions formulées, en particulier en ce qui concerne les paramètres analysés et la fréquence d'analyse, ne sont présentées qu'à titre indicatif et ne doivent pas être considérées comme des directives strictes et applicables à tous les projets. Elles doivent être adaptées et améliorées au meilleur du jugement des professionnels et des gestionnaires, en fonction de la problématique environnementale du site et des particularités du projet.

Le présent document est une synthèse des diverses notions et informations nécessaires à la préparation de programmes articulés et cohérents de surveillance et de suivi environnemental. Rédigé dans le cadre des travaux de la phase III du Plan d'action Saint-Laurent, maintenant désignée par Saint-Laurent Vision 2000, il constitue un effort préalable et une source de référence des plus utiles en vue de préparer un guide général régissant l'élaboration de tels programmes pour le bénéfice des promoteurs de projets de génie maritime qui entreprennent des travaux de dragage ou qui ont à effectuer une saine gestion des sédiments.

Abstract

Sediment dredging and management projects often have adverse impacts on the environment. An environmental surveillance and monitoring program (ESMP) is therefore normally required to verify the applicability and effectiveness of the mitigation measures and to ensure compliance with the various environmental protection statutes and regulations. The aim of the ESMP is also to permit better knowledge, understanding and measurement of the true environmental impacts of a project. Ultimately, it can lead to the identification of new mitigation and compensation measures and the improvement of good environmental practices. The present document is intended to assist project proponents and managers in designing and applying programs of this kind.

Chapter 1 presents the contextual framework of the report, its target objectives and methodological approach. Chapter 2 discusses the objectives, guidelines and theoretical elements generally associated with the process of designing and implementing ESMPs for sediment dredging and management projects. The chapters that follow describe the proposed approach in detail. Chapter 3 examines the design process, Chapter 4 implementation, Chapter 5 dissemination of the results, and Chapter 6 looks at the process of reviewing or updating an ESMP. Schematic diagrams, figures and tables illustrate the sequence of activities involved in each phase, the main information required and the results anticipated at each stage. The conclusions and recommendations arising from the implementation of an ESMP are presented in Chapter 7.

In the appendices, readers will find useful information for designing and implementing an ESMP, including conceptual models of the impacts of dredging and sediment management activities and contaminated sediment remediation projects, as well as the mitigation measures that may have to be considered and tested for effectiveness in the design and implementation of these projects.

Résumé

Les projets de dragage et de gestion des sédiments ont souvent des impacts sur l'environnement qui pourraient parfois s'avérer négatifs. Un programme de surveillance et de suivi environnemental (PSSE) est donc habituellement requis pour vérifier l'applicabilité et l'efficacité des mesures d'atténuation et s'assurer que la réalisation de tels projets respecte les différentes législations et réglementations en matière de protection de l'environnement. Un PSSE vise également à mieux connaître, comprendre et mesurer les impacts environnementaux réels d'un projet. Ultiment, il peut permettre d'identifier de nouvelles mesures d'atténuation et de compensation et contribuer à améliorer les bonnes pratiques environnementales. Ce document est destiné à aider les promoteurs et les gestionnaires de projets à concevoir et à appliquer un tel programme.

Le chapitre 1 présente le cadre contextuel du rapport, les objectifs visés et la démarche méthodologique. Le chapitre 2 énonce les objectifs, les principes directeurs et discute des éléments théoriques généralement associés à la démarche de conception et de mise en œuvre d'un PSSE applicable à des projets de dragage et de gestion des sédiments. Les chapitres suivants décrivent en détail l'approche proposée. Le chapitre 3 traite ainsi de la démarche de conception, le chapitre 4, de la mise en œuvre, le chapitre 5, de la diffusion des résultats alors que le chapitre 6 a trait à la révision ou l'actualisation d'un PSSE. Des schémas, figures et tableaux illustrent la séquence des activités prévues à chaque phase, les principaux renseignements requis et les résultats attendus à chaque étape. Les conclusions et les recommandations qui découlent de cette démarche de mise en œuvre d'un PSSE sont présentées dans le chapitre 7.

Le lecteur trouvera en annexes des renseignements qui pourront l'aider lors de la conception et la mise en œuvre d'un PSSE. Il est notamment question des modèles conceptuels d'impact des activités de dragage et de gestion des sédiments et des projets de restauration de sédiments contaminés, ainsi que des mesures d'atténuation dont il faudra au besoin tenir compte lors de la conception et de la réalisation de ces projets et voir à mesurer leur efficacité.

Table of content

PRODUCTION TEAM	III
ACKNOWLEDGMENTS	IV
FOREWORD	V
AVANT-PROPOS	VI
ABSTRACT	VII
RÉSUMÉ	VIII
LIST OF FIGURES	XIII
LIST OF TABLES	XV
LIST OF ABBREVIATIONS	XVIII
1 INTRODUCTION	1
1.1 Context	1
1.2 Objectives	2
1.3 Methodological Approach	3
1.4 Principal Definitions	3
2 PRESENTATION OF OVERALL APPROACH	6
2.1 Objectives of an ESMP	6
2.2 Guidelines	7
2.3 Relationship between Environmental Assessment and an ESMP	12
2.4 ESMP Management System	15
2.4.1 Responsibilities for Program Implementation	15
2.4.2 Management Mechanism	16
2.4.3 Preparation of a Financial Assessment	17
2.5 Proposed Approach	17
3 DESIGN OF AN ENVIRONMENTAL SURVEILLANCE AND MONITORING PROGRAM	20

3.1	Formulation of General and Specific Objectives (Step 1)	21
3.2	Identification of Environmental Components Requiring Surveillance (Step 2)	29
3.3	Formulation of the Testable Impact Hypotheses (Step 3)	30
3.3.1	Identification of the Impact Mechanisms to be Considered	30
3.3.2	Development of Conceptual Impact Models	33
3.3.3	Establishment of the Scientific and Spatial/Temporal Boundaries	33
3.3.4	Determination of the Action or Control Thresholds	34
3.3.5	Development of the Testable Impact Hypotheses	38
3.4	Design of the Sampling Plan and Selection of Analysis Methods (Step 4)	43
3.4.1	Selection of the Surveillance and Monitoring Parameters	43
3.4.2	Definition of the Quality Assurance and Quality Control (QA/QC) Program	51
3.4.3	Selection of the Measurement Tools	53
3.4.4	Design of the Sampling Plan	61
3.4.5	Identification and Selection of Data Analysis and Interpretation Methods	68
3.5	Design of the Action Plan (Management Options and Response Measures) (Step 5)	73
3.6	Identification of the Other Specific Components of the Project Requiring Surveillance (Step 6)	82
4	IMPLEMENTATION OF AN ENVIRONMENTAL SURVEILLANCE AND MONITORING PLAN (STEP 7)	84
4.1	Identification of the Mechanisms for Communicating the Results and the Decision-making System	84
4.2	Preparation of Specifications for the Surveillance and Monitoring Program	86
4.3	Tendering and Selection of Consultant for Program Implementation	86
4.4	Employee Awareness and Training Program	86
4.5	Sampling, Analysis and Inspection of Operations	86
4.6	Interpretation and Communication of Results	87
4.7	Implementation of Response Measures	87
5	DISSEMINATION OF THE RESULTS	88
5.1	Preparation of the Final Report (Step 8)	88
5.2	Dissemination of the Report (Step 9)	89

6 PERIODIC PROGRAM REVIEW (STEP 10)	92
7 CONCLUSIONS AND RECOMMENDATIONS	94
7.1 Conclusions	94
7.2 Recommendations	94
REFERENCES	96
APPENDIX A GLOSSARY	111
APPENDIX B STATUTES, REGULATIONS, POLICIES, GUIDELINES AND GUIDES POTENTIALLY APPLICABLE TO DREDGING AND CONTAMINATED SEDIMENT REMEDIATION PROJECTS	131
B.1 Federal Statutes and Regulations	131
B.2 Quebec Statutes and Regulations	134
B.3 Municipal By-laws	136
B.4 Policies	137
B.5 Guidelines	138
B.6 Guidelines (Criteria)	139
B.7 Guides	140
APPENDIX C CONCEPTUAL IMPACT MODELS FOR DREDGING AND SEDIMENT MANAGEMENT ACTIVITIES	143
C.1 Identification of the Impact Mechanisms to be Monitored	144
C.2 Developing Conceptual Impact Models	155
C.3 Conceptual Models for Cumulative Impacts	163
C.4 Formulation of Impact Hypotheses: Examples	164
APPENDIX D RECOMMENDED READING	174
D.1 Quality Assurance and Control Programs	174
D.2 A. Measurement Tools for Physical, Chemical and Biological Parameters	175
D.2. B Measurement Tools for Secure Aquatic Containment of Contaminated Sediments	175

D.3	Publications on Elements to be Considered in Designing a Sampling Plan to Monitor Physico-chemical and Biological Impacts	176
D.4	Publications on Good Environmental Practices	177
APPENDIX E	STATISTICAL FORMULAE FOR CALCULATING NUMBER OF SAMPLES	180
APPENDIX F	MITIGATION MEASURES FOR REMEDIATION PROJECTS	183
F.1	Contaminated Sediment Remediation Scenarios	183
F.2	Contaminant Migration Mechanisms in Sediment Remediation Projects	184
F.3	Mitigation Measures to Minimize Contaminant Migration in Sediment Remediation Projects	184
INDEX		205

List of Figures

1	Example of a tiered ESMP for an aquatic dredged material disposal site	11
2	Activities involved in the design and implementation of an environmental surveillance and monitoring program (ESMP)	19
3	Formulation of environmental surveillance and monitoring objectives (Step 1)	23
4	Example of objectives applicable to a tiered ESMP for an ocean dredged material disposal site	27
5	Formulation of testable impact hypotheses (Step 3)	32
6	Design of the sampling plan and selection of analysis methods (Step 4)	45
7	Flowchart of a possible approach to the use of bioassays in the assessment and monitoring of sediment remediation projects	56
8	Environmental discharges to be monitored in a conventional contaminated sediment treatment system	67
9	Flowchart for considering causes of variance between predicted and actual effects	70
10	Design of the action plan and identification of other project components requiring surveillance (Steps 5 and 6)	74
11	Example of a decision tree applicable to the action plan of a tiered ESMP for a dredging and open-water disposal site	78
12	Implementation of the environmental surveillance and monitoring program (Step 7)	85
13	Preparation of the surveillance and monitoring report and dissemination of the results (Steps 8 and 9)	90
Figures in Appendices		
C1	Example of an environmental impact assessment matrix for dredging and sediment management projects	145

C2a	Contaminant migration pathways associated with mechanical dredging	146
C2b	Contaminant migration pathways associated with hydraulic dredging	146
C3a	Contaminant migration pathways associated with open-water disposal	147
C3b	Contaminant migration pathways associated with shoreline disposal	147
C4a	Contaminant migration pathways associated with confined disposal in shallow water	148
C4b	Contaminant migration pathways associated with confined disposal in deep water	149
C5a	Contaminant migration pathways associated with confined disposal in shallow water with lateral containment	150
C5b	Contaminant migration pathways associated with disposal in a waterway with lateral containment	151
C6	Contaminant migration pathways associated with upland confined disposal	152
C7	Contaminant migration pathways associated with a contaminated sediment treatment facility	152
C8	Procedure used in the standard elutriate test	158
C9	Mathematical models developed in the U.S. to predict water quality following aquatic or upland sediment disposal or containment	159
C10	Models recommended for use in Canada to simulate sediment transport following aquatic disposal of dredged material	161
C11	Example of a matrix illustrating sources of cumulative impacts on the marine environment of the Southern California Bight	165

List of Tables

1	Key technological, environmental and economic issues associated with the implementation of ESMPs for dredging and sediment management projects	24
2	List of environmental components to be monitored in ESMPs for dredging and sediment management projects	31
3	Reference criteria or thresholds for various environmental components applicable to ESMPs for dredging and sediment management projects	36
4	Examples of thresholds for assessing the environmental performance of dredging equipment	37
5	Examples of action thresholds for aquatic dredged material disposal	39
6	Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for dredging sites, open-water disposal sites or aquatic or upland containment or treatment sites for contaminated sediments	42
7	Sample list of physico-chemical and biological parameters applicable to ESMPs for ocean dredged material disposal in Canada	46
8	Sample list of physico-chemical and biological parameters for use in characterization in ESMPs for ocean dredged material disposal sites in the United States	47
9	Sample list of parameters for use in monitoring effluent quality in upland sediment containment sites in the United States	48
10	Monitored components and methods of monitoring the physico-chemical parameters required by the Ministère de l'Environnement du Québec for use in ESMPs for secure landfills	49
11	Analytical physico-chemical parameters for sediment treatability testing performed in the context of the ARCS program	51
12	List of points to be documented in a comprehensive quality assurance project plan	53
13	Techniques and measurement tools for environmental monitoring of aquatic dredged material disposal sites	54
14	Examples of analytical technologies for contaminant screening	57
15	Screening tests used by the USEPA/USACE to assess sediment contamination in the Great Lakes	59

16	Batteries of microbioassays used to assess contaminated freshwater sediments	60
17	Sampling program used to assess innovative dredging technologies for sediment management in Ontario's Welland Canal	64
18	Possible conclusions arising from sediment quality analysis using the triad approach	72
19	Examples of management options or mitigation measures applicable to ESMPs for dredging and sediment management projects	75
20	Standard emergency measures plan	76
21	Example of an action plan applicable to tiered ESMPs for aquatic dredged material disposal sites in the United States	80
22	Example of an action plan applicable to a tiered ESMP for aquatic contaminated sediment capping projects in the United States	81
23	List of good environmental practices to be monitored in ESMPs for dredging and sediment management projects	83
24	Sample checklist for reviewing an ESMP	93

Tables in Appendices

C1	Comparison of the risks to the environment and human health associated with various methods of confining contaminated sediments	153
C2	Contaminant migration mechanisms associated with <i>in situ</i> remediation technologies	154
C3	Principal contaminant migration mechanisms associated with dredging and contaminated sediment management projects	155
C4	Availability and reliability of techniques for estimating contaminant losses associated with dredging and sediment management projects	162
C5	Availability and reliability of techniques for estimating contaminant losses associated with pretreatment and confined disposal facilities for contaminated sediments	163
C6	Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for dredging sites	166
C7	Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for open-water dredged material disposal sites	168
C8	Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for aquatic dredged material containment sites	170

C9	Examples of protection objectives, testable questions and impact hypotheses applicable to ESMPs for upland dredged material disposal sites	171
C10	Examples of protection objectives, testable questions and impact hypotheses applicable to ESMPs for contaminated sediment treatment projects	173
F1	Contaminated sediment remediation scenarios	184
F2	Examples of mitigation measures for reducing contaminant migration associated with <i>in situ</i> remediation of contaminated sediments	186
F3	Examples of mitigation measures for reducing contaminant migration associated with the excavation of contaminated sediments	187
F4	Examples of mitigation measures for reducing contaminant migration associated with the transport of contaminated sediments	189
F5	Examples of mitigation measures for reducing contaminant migration associated with the pretreatment of contaminated sediments	192
F6	Examples of mitigation measures for reducing contaminant migration associated with the treatment of contaminated sediments	194
F7	Examples of mitigation measures for reducing contaminant migration from the aqueous, solid and gaseous residues generated by most sediment treatment technologies	196
F8	Examples of mitigation measures for reducing contaminant migration associated with the disposal of pretreatment and treatment residues	198
F9	Mitigation measures for other environmental problems associated with the operation of a permanent contaminated-sediment treatment centre	201
F10	Mitigation measures for closure and post-closure maintenance, environmental surveillance and monitoring of a contaminated-sediment treatment site	204

List of Abbreviations

ARCS	Assessment and Remediation of Contaminated Sediments
ATP	Adenosine triphosphate
AVS	Acid volatile sulphide
BOD	Biological oxygen demand
CCG	Canadian Coast Guard
CCME	Canadian Council of Ministers of the Environment
CEAA	<i>Canadian Environmental Assessment Act</i>
COD	Chemical oxygen demand
DFO	Department of Fisheries and Oceans Canada (Fisheries and Oceans Canada)
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EC	Environment Canada
ESMP	Environmental Surveillance and Monitoring Program
FTU	Formazin turbidity units
IMO	International Maritime Organization
MEF	Ministère de l'Environnement et de la Faune du Québec
MENV	Ministère de l'Environnement du Québec (new name)
MENVIQ	Ministère de l'Environnement du Québec (former name)
MUC	Montreal Urban Community (former name, now City of Montreal)
NH ₃	Ammonia
NO ₂ +NO ₃	Nitrites and nitrates
NRC	National Research Council
NWPA	<i>Navigable Waters Protection Act</i>
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PIANC	Permanent International Association of Navigation Congresses
QA	Quality assurance
QC	Quality control
SEM	Simultaneously extracted metals
SLC	St. Lawrence Centre
SOPs	Standard Operating Procedures
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VSS	Volatile suspended solids

1 Introduction

1.1 Context

Since the early 1980s, Environment Canada – Quebec Region, in collaboration with other partners,¹ has published a number of documents that offer dredging-project managers and contractors up-to-date summaries of the current state of knowledge in this area with a view to improving equipment and working methods and thus minimizing environmental impacts, perhaps even helping to improve the environment.

These documents have dealt with the following areas:

- Environmental problems associated with dredging operations and the disposal of dredged material (EC 1980, 1994a; Rochon 1985; Rochon and Sarazin 1987);
- Quality and volume of materials dredged from the St. Lawrence over the past 25 years (SLC 1993a);
- Sediment dynamics and contamination of the St. Lawrence (Loiselle et al. 1997);
- Sediment sampling and storage methods (Rochon and Chevalier 1987; EC 1994b);
- Methods for chemical characterization (SLC 1992a);
- Interim criteria for quality assessment of St. Lawrence River sediment (SLC 1992b);
- Environmental assessment methods (EC 1985);
- Legislative framework for sediment management in Quebec (SLC 1993b);
- Use of microscale bioassays to predict and monitor freshwater sediment toxicity (EC 1997a; Côté et al. 1998a; 1998b);
- Selection of good operating practices for dredging equipment (SLC 1992c);
- Assessing and selecting treatment technologies for contaminated sediment (SLC 1993b); and
- Assessment protocol of the applicability of ore-processing technologies to treat contaminated soil, sediment and sludge (EC 1998a).

1 Ministère de l'Environnement du Québec, Public Works and Government Services Canada, Fisheries and Oceans Canada.

However, there still remained a need for a tool that could be used in the development of the environmental surveillance and monitoring programs (ESMPs) required for most dredging and dredged material management projects. These programs ensure that the projects will comply with environmental protection legislation. They also permit better knowledge and understanding of the true impacts of these projects, the identification of new environmental protection measures, impact reduction at the source and the improvement of good environmental practices.

1.2 Objectives

The major challenge was to propose an ESMP that was sufficiently flexible and adaptable to the specific characteristics of each site, while being detailed enough to allow users to develop a program that could be adapted to specific projects.

This document describes:

1. The objectives, principles and theoretical framework for analysis and assessment of dredging and sediment management projects.
2. The stages in the design and implementation of an ESMP for maximum practical, economic, environmental and scientific impact.
3. Pragmatic means of integrating these theoretical concepts in a comprehensive approach, including their practical application in the design and implementation of an ESMP.
4. Detailed studies and reference documents on ESMPs developed and recommended by environmental protection agencies for the surveillance and monitoring of dredging sites, freshwater or ocean dredged material disposal sites, and aquatic, shoreline or upland containment sites for contaminated sediments and for sediment treatment.

1.3 Methodological Approach

The managers of the various federal and provincial departments involved in the assessment and monitoring of dredging and site remediation projects were consulted prior to the preparation of this document to determine their environmental surveillance and monitoring needs for projects performed in the Great Lakes and on the St. Lawrence River.

The ESMPs proposed in various reports on the impacts of dredging and remediation projects were analysed, together with documents published by Environment Canada in other regions of the country and guides for monitoring ocean disposal and wastewater projects.

In addition, the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE) and European organizations involved in similar projects were consulted to identify other useful reference documents. The review was completed by a computerized bibliographic keyword search of specialized documentary databases and a systematic search of the Internet.

1.4 Principal Definitions

Definitions of an environmental surveillance and monitoring program (ESMP) found in the literature or in various environmental statutes often differ. For instance, an environmental monitoring program, as defined by the *Canadian Environmental Assessment Act* (CEAA), is a program for verifying the accuracy of the environmental assessment of a project and determining the effectiveness of any measures taken to mitigate the adverse environmental effects of the project.

In contrast, the Dredged Material Assessment Framework (DMAF) adopted by the Contracting Parties to the *London Convention* of 1972 (LC72), to which Canada is a signatory and which is designed to ensure that potential adverse impacts of any ocean disposal activities are minimized and that adequate surveillance is provided for early detection and mitigation of these impacts, defines surveillance as a measurement of:

1. Compliance with permit requirements; and
2. Condition (and changes in condition) of the receiving area in order to assess the impact hypothesis upon which the permit was approved.

In the first definition, environmental monitoring relates to both effects and compliance while, in the second definition, monitoring is included in the term surveillance. To clarify matters for the reader, the following definitions, adapted from the guidelines of the Ministère de l'Environnement du Québec specified in section 31.2 of the *Environment Quality Act* (MEF 1997b), have been used in the present document.

Dredging and sediment management activities – Activities including the excavation, transport and aquatic, shoreline or upland disposal of sediments. In the case of contaminated sediments, these activities include all applicable remediation technologies: *in situ* treatment, dredging and offsite treatment or aquatic, shoreline or upland containment.

Environmental monitoring – Scientific approach used to monitor the evolution of certain components of the natural and human environments affected by the implementation of the project to permit verification of the accuracy of the predictions and impact assessments and prompt response to the failure of mitigation or compensation measures or to any further disturbance of the environment.

Environmental surveillance – Surveillance of the implementation of construction or operational activities to ensure compliance with the environmental measures contemplated in the impact study, including mitigation measures, the conditions established in the authorization orders and certificates, and the requirements arising out of the relevant statutes and regulations.

Environmental impacts – All positive and negative impacts, direct or indirect, on the environment during the preparation, construction and operation stages of the project and, where applicable, the cumulative, synergistic and irreversible impacts associated with the implementation of the project.

Mitigation measures – Measures designed to mitigate the impacts and ensure optimal integration of the project within the environment. These measures include actions, works and corrective or additional measures performed at various stages in the implementation of the project to eliminate negative impacts or to reduce their intensity.

Compensation measures - Measures designed to compensate for the inevitable residual impacts on the biotic environment or on the citizens and communities affected. Losses of aquatic or wetland habitats must be offset by the creation or improvement of equivalent habitats. Compensation measures may also include possible re-use of the equipment or temporary facilities for public or community purposes.

Definitions of the other technical and scientific terms used in this document appear in the Glossary at the end of this document (Appendix A).

2 Presentation of Overall Approach

This chapter presents the objectives, guidelines and theoretical elements generally associated with the development and implementation of environmental surveillance and monitoring programs (ESMPs) for all types of dredging and sediment management projects.

2.1 Objectives of an ESMP

The advantage of using an ESMP is that any uncertainty as to the effectiveness of mitigation measures and/or the accuracy of impact predictions can generally be avoided. Some uncertainty may arise in situations where the project involves a new or unproven technology, where an otherwise familiar or routine project is proposed for a new or unfamiliar environmental setting, or where potential cumulative effects are of concern to the authorities and/or the public (EC 1994c).

An ESMP is generally designed to achieve one or more of the following objectives:

1. Verify, over a given period of time, the accuracy of predictions of anticipated impacts on valued ecosystem components, particularly those presenting some risk or uncertainty in the impact study.
2. Verify the adequacy and effectiveness of the measures taken to mitigate the anticipated adverse impacts.
3. Ensure compliance with the conditions established in the authorization orders and certificates, and the requirements of the relevant statutes and regulations.
4. Help the proponent to react rapidly if a mitigation or compensation measure proves ineffective or in the event of an unanticipated impact, and to take more appropriate measures or further measures to mitigate or compensate for impacts not anticipated in the impact study.
5. Improve the predictive capability of subsequent environmental assessments.
6. Contribute indirectly to the improvement of equipment, mitigation and protection measures and good environmental practices.

2.2 Guidelines

Environmental surveillance and monitoring programs must be based on principles or rules of good practice aimed at precise objectives. According to the Canadian Environmental Assessment Agency (EC 1994c) and Fisheries and Oceans Canada (EC 1992a), an ESMP should:

1. Have objectives aimed at determining the effectiveness of mitigation measures in protecting valued ecosystem components and/or the accuracy of predicted effects on valued ecosystem components.
2. Permit the collection of information on valued ecosystem *components* at the proposed development site (baseline conditions).
3. Be designed so that the results can be used to detect possible *spatial and temporal variations* in the effects on the study area.
4. Focus on a *set of indicators of the state of health of the environment* that will reveal whether or not the project is having a significant effect on valued ecosystem components. These environmental indicators, which are used to detect and quantify the adverse effects on valued ecosystem components, should be measurable using a well established methodology.

The variables, parameters and ecological indicators to be used in surveillance should be chosen on the basis of the following criteria:

- a) relevance to the detection/quantification of adverse or likely adverse effects on the resource that is to be protected;
- b) availability of a well established methodology having appropriate levels of sensitivity, accuracy and precision;
- c) amenability to consistent scientific evaluation and interpretation with a high degree of confidence.

It is also important that these criteria be:

- measurable
- indicative of the valued ecosystem components
- sensitive to the valued ecosystem components
- standardized
- appropriate to the spatial and temporal scale of disturbance/pollution
- naturally low in variability
- appropriate to the impact mechanism
- relevant to a broad range of applications

- consistent with temporal dynamics
- useful in identifying the potential cause
- ideally, readily understood by non-specialist stakeholders (EC 1994c)

Because of the complexity of ecosystems, it is impossible to use ecological indicators that apply to all the valued ecosystem components selected. Consequently, it is important to select the ecological indicators that are the most representative and easiest to measure.

In addition, in order to derive maximum benefit from the human and financial resources allocated to the ESMP, it is important that the variables selected for measurement target the truly significant issues and those that can in fact provide information on the nature and degree of change in the environmental components.

These variables normally include resources of intrinsic importance (e.g., economically important or threatened species), indicators capable of rapidly recognizing the existence of a problem (e.g., variables that respond rapidly to stress), sensitive indicators (e.g., variables that provide an indication of the stresses on complex ecosystems) and variables with high levels of redundancy (e.g., variables generally representative of the behaviour of a large number of parameters) (NRC 1990).

5. Be *scientifically rigorous* and based on testable impact hypotheses regarding the effects of the project on valued ecosystem components.
6. Include *precise decision points* and *continue* until the initial hypotheses regarding the project's effects can be supported or refuted.
7. Include *several sampling campaigns* covering a period of time compatible with the impact hypotheses or sufficient to permit examination of the effectiveness of the mitigation measures.
8. Be based on a *rigorous, a priori statistical design*.
9. Have *quality control and quality assurance* procedures.

Any QA/QC program must be based on previously established data quality objectives (DQOs) and must target the following objectives:

- a) produce good quality analytical data using recognized standard sampling techniques;
- b) reflect the natural spatial and temporal variability of the ecological indicators;
- c) be sensitive to sampling and analytical errors;

- d) be sensitive to sample contamination and to the presence of extreme values due to the natural or specific conditions of the sources of disturbance;
- e) provide complete documentation and ensure the reliability (unassailability) of all data;
- f) expedite data assessment and acceptance.

Quality assurance programs consist of a range of internal and external practices of an administrative and technical nature designed to ensure that the data produced by ESMPs are of known quality (precision, accuracy, detection limits, reproducibility, etc.) and that they are appropriate for the proposed use. Quality control is an internal aspect of quality assurance and consists of assessing and measuring data quality and taking corrective measures if it fails to meet the objectives.

To be effective, quality assurance must begin as soon as planning begins on the ESMP. In this way, the level of uncertainty associated with obtaining the required information can be balanced against the cost of obtaining the data. Quality assurance must continue to be an integral component of monitoring systems from implementation through interpretation and dissemination of the data and information produced by the ESMP. The need for quality assurance and control programs increases with the complexity of the measurement program and the number of stakeholders and/or laboratories involved (NRC 1990).

ESMPs must be based on a sound statistical sampling plan in which all data are subject to quality assurance and control. A solid statistical basis is required to determine whether a change observed in one variable or indicator is within the range of natural variations or whether it is in fact caused by a project activity.

- 10. Offer a good *cost-benefit ratio*.
- 11. Be *open-ended and flexible* enough to permit the inclusion of new or improved monitoring techniques and to reflect the results of previous ESMPs.
- 12. Be *manageable* in terms of requirements and deadlines.

Among the other conditions required for success, Fredette et al. (1986; 1990a) recommend that an ESMP:

- 1. Be “prospective” rather than “retrospective” in nature: for instance, the predicted biological impacts must be determined *a priori* and the thresholds at which physical, biological and chemical changes become unacceptable must be explicitly specified in advance.

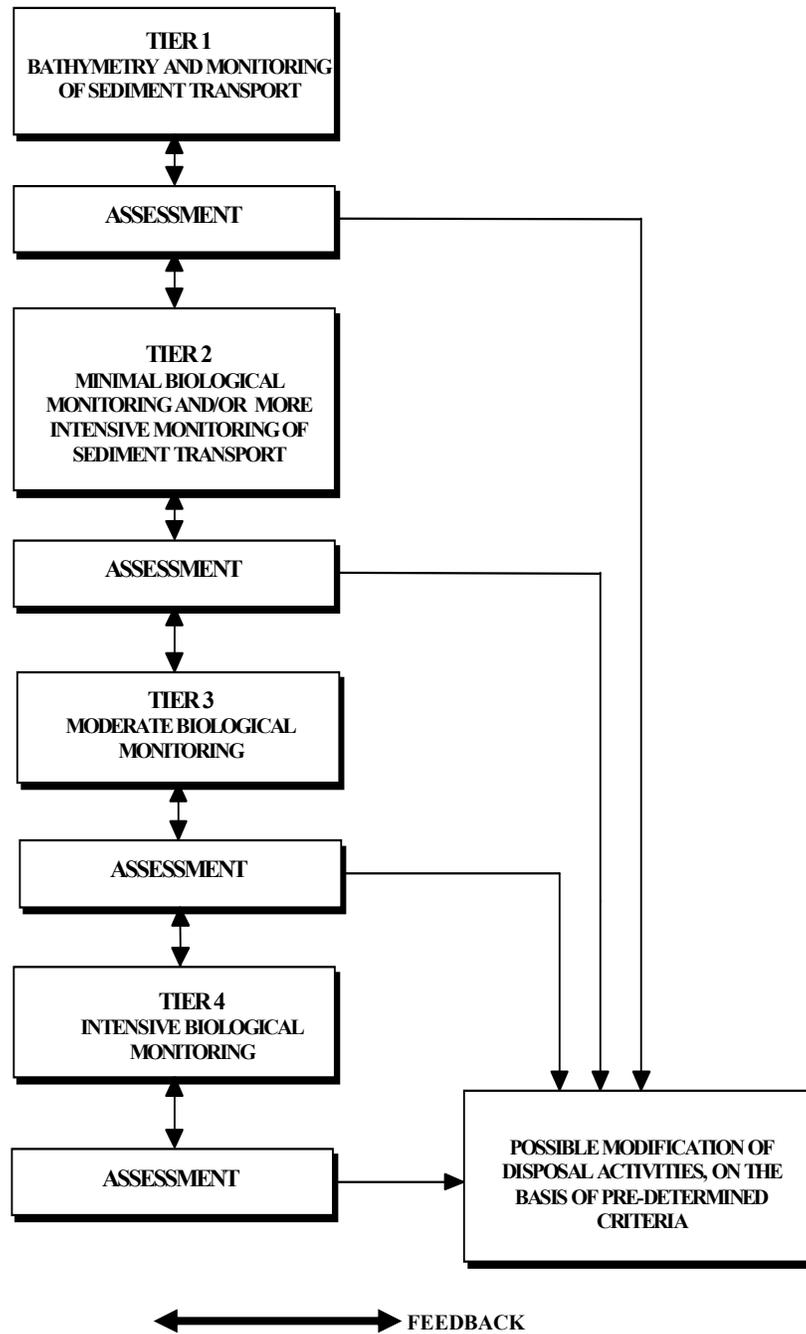
2. Be based on null impact hypotheses and unacceptable environmental thresholds defined in 1 and be designed accordingly.
3. Have multiple levels or tiers (e.g., Tier 1: physical analyses; Tier 2: chemical analyses; Tier 3: biological analyses), each with its own specific thresholds, null impact hypotheses, sampling and analysis programs and response measures to be implemented if these thresholds are exceeded. Figure 1 illustrates a sample four-tier ESMP for an aquatic dredged material disposal site. In Tier 1, only bathymetry and sediment transport are monitored. In Tier 2, more intensive monitoring of sediment transport is accompanied by minimal monitoring of biological parameters. Tiers 3 and 4 are distinguished simply by the number of biological components and/or parameters to be monitored.
4. Be designed by a multidisciplinary committee.

In addition, for all environmental assessments performed by Canadian federal authorities, section 16 (1) of the *Canadian Environmental Assessment Act* (CEAA) requires the explicit consideration of **cumulative environmental effects**. Dredging projects that may result in cumulative effects, for example, might involve the construction of new port facilities to meet industrial needs;² multiple small-scale dredging projects spread over a number of years;³ or a large-scale dredging project to accommodate large ships and deep draft tankers.⁴

² For example, the combined effects on air quality attributable to an increase in marine, road and rail traffic and the establishment of new industries.

³ For example, the combined effects on wildlife habitat losses or alterations attributable to dredging, alterations of the hydrosedimentary environment and boat pollution.

⁴ For example, the combined effects on erosion of the St. Lawrence shoreline and islands attributable to alterations of the hydrosedimentary environment and increased traffic and ship size.



Source: Pequegnat et al. (1990).

Figure 1 Example of a tiered ESMP for an aquatic dredged material disposal site

While the specific requirements for monitoring cumulative effects in follow-up programs will depend on the project proposal and the environmental context in which it is to proceed, certain principles should nonetheless be taken into account in developing an ESMP. Special considerations include:

1. Identifying a baseline or reference condition that incorporates the environmental effects of previous development and the predicted effects of proposed projects;
2. Identifying indicators capable of providing an integrated assessment of ecosystem health that reflects the structure and key functions of the ecosystem (productivity, diversity, etc.);
3. Developing conceptual models of the potential interactions between multiple stressors or sources of similar stress; and
4. Assessment of the potential for incremental (additive) effects, especially any effects that may be propagated through ecological pathways (EC 1994c).

2.3 Relationship between Environmental Assessment and an ESMP

The *Canadian Environmental Assessment Act* (CEAA) applies when a federal authority:

- proposes a project;
- provides financial assistance to enable the project to be carried out (including funding, loan guarantees or tax advantages specific to the project);
- grants an interest in land (sale, gift) to enable the project to be carried out;
- issues a permit or licence to enable the project to be carried out in whole or in part.

The CEAA's definition of a project includes two types of activities: first, a physical work, and secondly, any proposed physical activity not relating to a physical work. By default, all physical works are subject to the CEAA, with the exception of those described in the *Exclusion List*. Dredging is listed in the Inclusion List, and is therefore, under the terms of the Act, a project of the kind generally requiring an environmental assessment, unless the project is to be carried out in response to an emergency in order to prevent damage to property or the

environment or to protect public health or safety. Dredging operations associated with the construction or modification of marine infrastructure (works) may require a comprehensive study.

In addition to this CEAA requirement, an environmental assessment will also be required because dredging normally involves either a permit under the *Navigable Waters Protection Act* (NWPA) or Part VI of CEPA (disposal at sea) or an authorization to alter fish habitat or to permit the deposit of deleterious substances under the *Fisheries Act*.

The environmental assessment, which must be performed as early as possible in the planning stages of the project subject to the CEAA, includes, briefly, two distinct approaches: screening and comprehensive study. **Screening**, the scope of which is dependent on the nature and magnitude of the project, must include a consideration of the following factors:

- the environmental effects of the project (including any cumulative effects and the environmental effects of malfunctions and accidents);
- the significance of the effects;
- public comments on the project;
- the technically and economically feasible mitigation measures. An ESMP may also be required or recommended to the responsible authority to verify the effectiveness of the mitigation measures.

When a **comprehensive study**, which is generally referred to a mediator or review panel, is required because of potentially significant impacts on the environment, it must include a consideration of the same factors and, in addition:

- the purpose of the project;
- technically and economically feasible alternative means of carrying out the project and the environmental effects of any such means;
- the need for, and **requirements of, a monitoring or “follow-up” program (in the CEAA, “follow-up program” means a program for verifying the accuracy of the environmental assessment of a project, and/or determining the effectiveness of the mitigation measures); as noted in Chapter 1 – Introduction, while the terminology is different, the ESMP presented in this document meets the requirements of the CEAA;**

- the capacity of renewable resources that are likely to be significantly affected by the project to meet the needs of the present and those of the future (sustainable development).

When the dredging and sediment management project is not subject to federal jurisdiction, the Quebec *Environment Quality Act* (EQA) provides for two forms of environmental assessment:

- ***Environmental assessment*** under section 22, which requires the proponent to submit an environmental assessment of the project (detailed description of the project and evaluation of its effects on the environment) in order to obtain a certificate of authorization. The public is not consulted. For instance, an application for authorization must be submitted for any aquatic dredging or backfilling project, regardless of its area or volume.
- ***Environmental impact assessment statement***, under section 31.1, which requires the proponent to submit an environmental impact assessment statement in order to obtain an authorization certificate. This impact statement is made public if the public so requests, and public hearings are held under the authority of the *Bureau d'audiences publiques sur l'environnement* (BAPE); an environmental impact assessment must be conducted for works in an aquatic environment that extend a distance of 300 metres or more or over an area of 5000 m² or more.

The environmental impact assessment statement for a dredging project should generally include:

- the context of the project;
- a description of the receiving environment;
- a description of the project and any possible variations;
- an analysis of the impacts of the variation(s) selected;
- an accident risk management program;
- **an environmental surveillance and monitoring program (ESMP).**

ESMPs are thus an integral part of environmental impact assessment procedures at both the federal and Quebec (impact assessment statement) levels, and are designed essentially to verify and structure the implementation of decisions made in the context of these procedures. While these procedures provide direction for ESMPs, ESMPs in turn offer information that is of use in improving these impact assessment procedures.

2.4 ESMP Management System

2.4.1 Responsibilities for Program Implementation

The ESMP is normally drawn up by the project proponent on the basis of the requirements of the departments responsible for environmental protection, and in consultation with the other departments concerned. Responsibility for implementation of environmental surveillance and monitoring activities also lies with the proponent, who must inform government authorities of the individuals or consultants assigned to perform them. The proponent must also indicate how long it expects surveillance to continue if the mitigation measures prove effective and adequate, and the form and timetable for submission of the ESMP to the departments concerned. The responsible authority is required to inform the public of the proposed surveillance and monitoring program and of its results.

As is often the case in environmental matters, the implementation of a project may involve a number of federal agencies. A single project may thus have a number of responsible federal authorities that must work together to determine how the responsibilities for environmental assessment and implementation of the process are to be shared. In the event of a disagreement, the Canadian Environmental Assessment Agency may advise the federal authorities on their shared responsibilities and how those responsibilities are to be met.

The CEAA allows the responsible federal authority to delegate the screening or comprehensive study, or the development and implementation of an ESMP to another federal or provincial government agency, or to a private firm, but permits no delegation of its decision-making authority with respect to the exercise of the responsibility (project implementation, financial assistance, land transfers, authorization or permits).

Environment departments may provide the proponents with technical and scientific advice on the design, implementation and interpretation of the results of the ESMP. The Quebec Ministère de l'Environnement may verify the implementation and effectiveness of ESMPs and their compliance with the environmental authorizations issued to the project. It may also ensure the applicability and effectiveness of mitigation measures and of possible compensation measures (e.g., measures to replace fish habitat losses) proposed in environmental impact statements. At

the federal level, the responsible authority is required to ensure the implementation and effectiveness of the ESMP.

2.4.2 Management Mechanism

In the development and implementation of an ESMP, it is essential that all stakeholders devote the time and effort required at both the financial level and in terms of their expertise in design, implementation and data synthesis, interpretation and dissemination to ensure that the efforts and funds invested are used to compile data and information of value to all participants (NRC 1990).

It is important that the proponent designate an individual to develop data collection and management systems at the initial ESMP design stage. This individual must also provide for mechanisms for decision-making in the event that it becomes necessary to redesign the program, review the mitigation measures or even suspend work temporarily.

According to the Canadian Environmental Assessment Agency (EC 1994c), at a minimum, an ESMP must include the following management systems and/or mechanisms:

- an administration system for planning, design and coordination;
- a data collection system for sampling, quality assurance and control;
- a system and mechanisms for making decisions regarding the measures to be taken if the results of the monitoring program suggest problems and concerning program redesign or modification of mitigation measures;
- a computer system for data storage, retrieval, analysis and dissemination; and
- mechanisms for periodic review of the ESMP to ensure that the established objectives, questions and hypotheses are still relevant and of maximum utility to managers and decision makers.

Given that the ultimate goal of monitoring is to produce information that is useful to managers and decision-makers, dialogue between scientists responsible for designing monitoring programs and the users of monitoring information is essential. These interactions give decision-makers and managers an understanding of the limitations of monitoring and at the same time provide the technical experts who design monitoring programs with an understanding of what questions should be answered (NRC 1990).

2.4.3 Preparation of a Financial Assessment

A detailed financial assessment must be performed when the ESMP is still in the development stage, since this can have a significant influence on its design and implementation.

In addition to overall administration and coordination costs, an ESMP includes at least six major cost elements:

1. Program design costs
2. Field sampling programs
3. Laboratory analyses
4. Operation and maintenance costs associated with information management
5. Quantitative analysis and reporting; and
6. Communication and liaison with the proponent and environment departments (EC 1994c).

2.5 Proposed Approach

The overall approach proposed in this document is patterned after that recommended by a U.S. committee based on reflections on the role of environmental monitoring and surveillance programs in the marine environment (NRC 1990). It also builds on recommendations set out in an unpublished document prepared by the Canadian Environmental Assessment Agency (EC 1994c).

As illustrated in Figure 2, the design and implementation of an ESMP involves 10 steps, grouped in four phases:

1. Design
2. Performance
3. Dissemination of results
4. Review or updating

Figure 2 also shows the feedback points in the proposed approach. The feedback points are designed to ensure that the information produced by the ESMP can be used on a continuing basis to review the objectives, clarify the environmental components and impact hypotheses, and improve the sampling and analysis program. They also permit regular

assessment of the appropriateness of the mitigation and/or compensation measures in light of the scientific, logistic and financial constraints identified during implementation of an ESMP. The following chapters describe the anticipated objectives, activities and results associated with each of the 10 steps involved in the implementation of an ESMP.

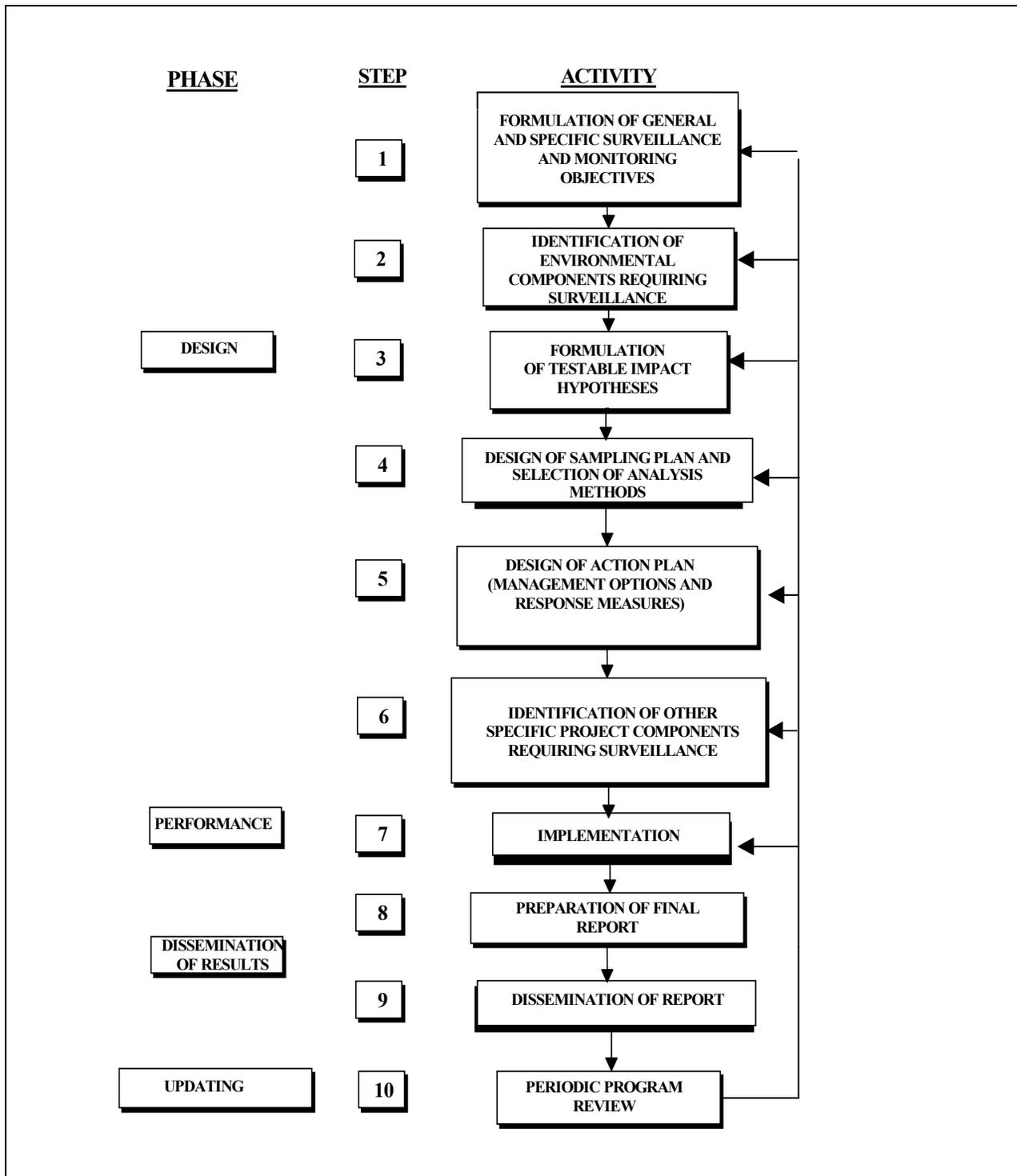


Figure 2 Activities involved in the design and implementation of an environmental surveillance and monitoring program (ESMP)

3 Design of an Environmental Surveillance and Monitoring Program

In designing an ESMP, it is essential to answer the following questions, adapted from the International Maritime Organization (IMO 1992).

1. What are the objectives of the ESMP?
2. What testable effect/impact hypotheses will be used to achieve the objectives?
3. What measurements can be used to confirm or reject the hypotheses?
4. What standards must the measurements meet to confirm the hypotheses (precision, accuracy, detection limits, reproducibility)?
5. At what levels, sites and frequency must these measurements be performed?
6. Have measures been taken to guarantee the quality of the data and are statistical methods available to verify the reliability of any conclusion with respect to the alterations or impacts produced?
7. How should the data be processed or interpreted for confirmation of the hypotheses and with respect to the achievement of the objectives?
8. What response measures can be implemented in the event that the null impact hypotheses are rejected?
9. Who will be responsible for implementing the response measures?
10. To whom will the results of the ESMP be submitted and reported?

The systematic approach to ESMP design suggested in Figure 2 is based on the tiered approach proposed by Fredette et al. (1986; 1990a; 1990b) for physical and biological monitoring of aquatic dredged material disposal sites.

Each tier or level requires, at the outset, the definition of objectives, the identification of the environmental components requiring surveillance, the identification of thresholds for action, the formulation of testable impact hypotheses, the development of a data sampling and collection plan and the design of an action plan for implementation in the event the ESMP results fail to comply with the predefined thresholds.

This “prospective” rather than “retrospective” approach avoids the need for implementing very complex and often very costly ESMPs when the results of the first step or tier in the surveillance process confirm the null impact hypotheses (Zeller and Wastel 1986). If, on the other hand, the results refute the null impact hypotheses, the ESMP must be able to inform the managers of the possibility that the project will result in unanticipated unacceptable adverse effects, and that rapid implementation of corrective measures is required to avoid these undesirable impacts, which may be confirmed by an ESMP at a higher level of analysis.

3.1 Formulation of General and Specific Objectives (Step 1)

The first and probably the most important step in the design of an ESMP is the formulation of general and specific program objectives.

To determine the protection objectives and the priority orientations of the ESMP, it is important to have, from the outset, a detailed knowledge of the project activities likely to produce impacts on the environment, as well as a thorough knowledge of the environment affected by the project, in order to define the sensitive resources and uses in the area affected by the operations.

As noted in chapter 2, this is precisely the objective of the environmental assessments required by both the federal (*Canadian Environmental Assessment Act*) and the provincial (*Environment Quality Act*) legislation. To assist proponents in planning and implementing the impact statement, the federal government has prepared reference documents in the form of guidelines or reference guides for projects of all types (Canadian Environmental Assessment Agency 1992; 1994; Cumulative Effects Assessment Working Group 1997), or more specifically for dredging or aquatic dredged material disposal projects (EC 1980, 1985). The Quebec Ministère de l'Environnement et de la Faune also publishes general guidelines (MEF 1997a) for the implementation of impact studies or more specific guidelines for dredging (MEF 1997b) or port construction projects (MEF 1997c).

It is generally up to the consultants responsible for performing the environmental assessments and the proponents to determine the objectives of the ESMP, which are then submitted to the environmental protection authorities for approval and improvement, if they see

fit. These objectives may also be ratified by environmental groups, local communities, industry representatives and professional associations during the subsequent consultation process and/or public hearings. Figure 3 illustrates the general objectives of an ESMP.

Apart from these general objectives, managers must also consider the key technological, environmental and economic issues involved in dredging and sediment management projects (see Table 1). These issues arise largely from the fears and concerns raised by the public and by environmental protection and public health authorities.

In addition to using ESMPs to ensure that projects are carried out in accordance with the various statutes relating directly or indirectly to environmental protection (Appendix B1), managers may define other specific objectives for certain projects authorized under certain conditions, and they may set them out in the permit or authorization certificate. These conditions may be dictated by the scope of the project (e.g., authorized dredging volumes, hourly dredging rate, etc.) or may be conditional on the application of corrective or mitigation measures and/or specific mitigation measures (e.g., installation of protective curtains near the dredge or sensitive areas, compensation measures for habitat losses caused by residual impacts not eliminated by the mitigation measures).

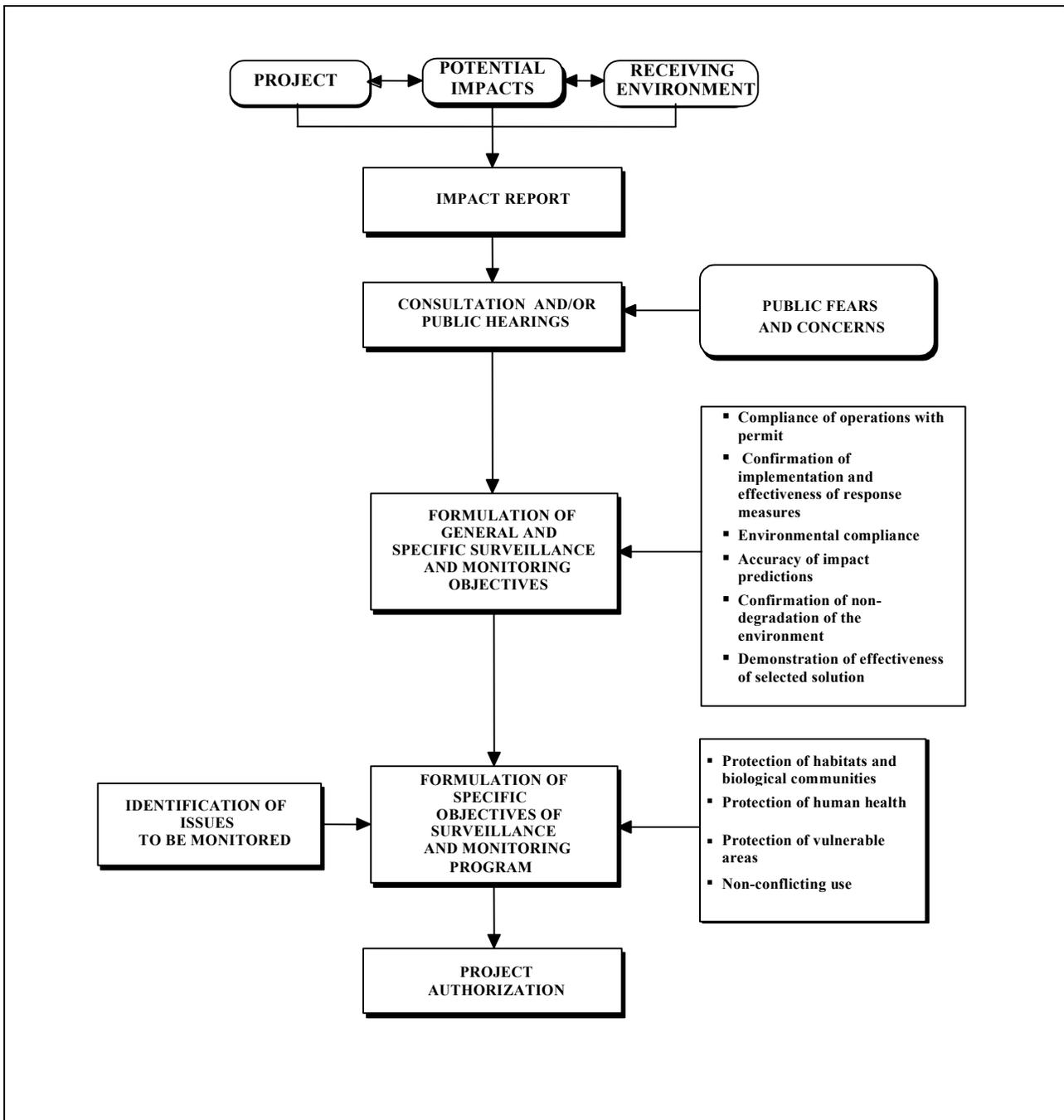


Figure 3 Formulation of environmental surveillance and monitoring objectives (Step 1)

Table 1**Key technological, environmental and economic issues associated with the implementation of ESMPs for dredging and sediment management projects**

Project	Issues		
	Technological*	Environmental**	Economic***
DREDGING	<ul style="list-style-type: none"> - Interference with navigation - Optimal dredge performance in terms of % solids - Productivity rate vs environmental performance 	<ul style="list-style-type: none"> - Resuspension of sediments in the water column - Resuspension and redissolution of contaminants - Risk of contamination of remediated sediments 	<ul style="list-style-type: none"> - Overdredging - Underdredging - Performance
TRANSPORT	<ul style="list-style-type: none"> - Interference with navigation - Watertightness of equipment 	<ul style="list-style-type: none"> - Sediment losses during transshipment and transport - Risks to health/safety of workers and/or the public - Nuisances for local populations (noise, odours, dust, etc.) 	<ul style="list-style-type: none"> - Minimize transfer points
OPEN-WATER DISPOSAL	<ul style="list-style-type: none"> - Interference with navigation - Location of disposal area - Stability of deposits 	<ul style="list-style-type: none"> - Physical degradation of sediment quality - Chemical degradation of sediment quality - Burial of benthic organisms - Risks to health/safety of workers and/or the public - Loss of biodiversity - Transport of suspended solids outside the boundaries of the disposal area - Habitat destruction or adverse effects on aquatic and avian fauna - Conflicts with other water uses 	<ul style="list-style-type: none"> - Long-term capacity of the disposal site - Long-term costs of the ESMP - Costs of compensation measures for fish habitat loss
AQUATIC CONTAINMENT	<ul style="list-style-type: none"> - Quality of capping materials - Material placement methods - Long-term stability 	<ul style="list-style-type: none"> - Resuspension of contaminants during operations - Long-term environmental effectiveness - Risks to health/safety of workers - Risk of contamination of the food chain 	<ul style="list-style-type: none"> - Volume of capping materials - Long-terms costs of the ESMP - Costs of compensation measures for fish habitat loss

Table 1 (Continued)

Project	Issues		
	Technological*	Environmental**	Economic***
SHORELINE OR COASTAL DISPOSAL/CONTAINMENT	<ul style="list-style-type: none"> - Retention capacity of the water-sediment-contaminant mixture - Dike impermeability and stability - Quality of sealing materials 	<ul style="list-style-type: none"> - Risks of surface water contamination - Risks of groundwater contamination - Risks of ambient air contamination - Contamination of plant species and terrestrial and avian fauna - Conflicts with other forms of land use - Nuisances for local populations (noise, odours, dust, visual aspects) 	<ul style="list-style-type: none"> - Long-term capacity of the disposal site - Long-term costs of the ESMP - Costs of compensation measures for fish habitat loss
REMEDIATION OR TREATMENT	<ul style="list-style-type: none"> - Treatment effectiveness - Compatibility of the components of the treatment system 	<ul style="list-style-type: none"> - Fate of contaminants in the different matrices (water, air, residues and sediments) - Risks to health/safety of workers - Risks to public health - Long-term effectiveness of remediation operations 	<ul style="list-style-type: none"> - Environmental cost-benefit ratio - Treatment costs - Costs of residue disposal - Costs related to pre- and post-treatment of liquid and solid wastes and air emissions - Short- and long-term costs of the ESMP

* For all projects, ESMPs are generally designed to ensure compliance with the operations authorized in the permit or authorization certificate and the implementation and effectiveness of the mitigation and compensation measures set out by the proponent.

** For all projects, ESMPs are generally designed to ensure compliance with all statutes and regulations relating to environmental protection, to ensure that the project minimizes impacts on the environment and that the measured impacts correspond to the predicted impacts.

*** For all projects, ESMPs may also include monitoring and accounting of project costs.

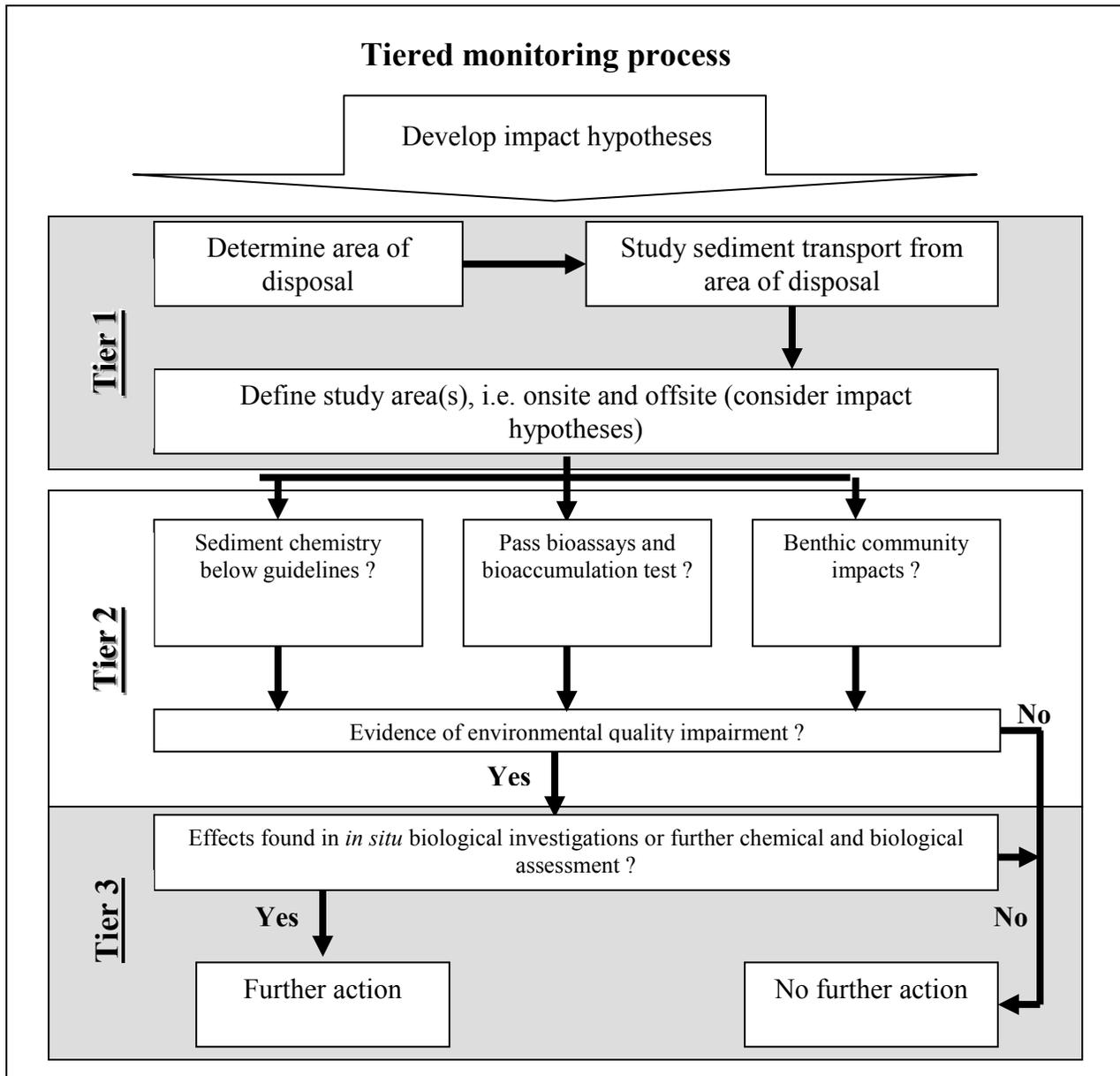
Environmental protection and public health authorities may also request, on occasion, that the ESMP concentrate on the measurement of certain specific parameters in an effort to expand scientific knowledge or because of uncertainty with respect to the anticipated results. For example, the Department of Fisheries and Oceans (DFO) has required environmental monitoring of fish occurring at a new dredged material disposal site. While such a requirement is uncommon, it may be justified either by an environmental problem relating specifically to a given species of fish or by commercial or recreational exploitation of the resource. Monitoring the use of the site by fish is limited in terms of sampling effort and statistical significance. However, it may provide an integrated picture of the impacts created by dredging and aquatic disposal of dredged material, including the disturbances associated with the use of equipment, temporary increases in turbidity, the burial of benthic organisms or alterations in depth, granulometry or currents.

Examples of the specific objectives that may be associated with an ESMP are provided in the *National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites* (Chevrier and Topping 1998).

These specific objectives can be formulated in relation to the following five goals:

1. Prevent adverse effects on biota.
2. Prevent habitat destruction and unacceptable impacts on fish and fisheries.
3. Protect human health (contamination of edible fish, shellfish and crustacean species).
4. Protect sensitive areas.
5. Prevent conflicts with other legitimate uses of the sea.

It should be noted that, in a tiered ESMP (organized in tiers or steps), the objectives must be adapted for each tier or level (see Figure 4). For instance, in the surveillance and monitoring of an ocean dredged material disposal site, the objective of physical surveillance (Tier 1) is to define the disposal site, study the accumulation of dredged material in the area of deposition and document evidence of sediment transport from the disposal site. The objective is the long-term fate of the deposited materials.



Source: Chevrier and Topping 1998.

Figure 4 Example of objectives applicable to a tiered ESMP for an ocean dredged material disposal site

As indicated in Figure 4, the second level or tier of surveillance involves simultaneous chemical and biological assessments. Chemical surveillance is used to measure

chemical concentrations in the sediments, while biological surveillance focuses on laboratory toxicity and bioaccumulation tests, and on surveys of benthic communities. If the data collected indicate a deterioration in the environmental quality of the study area, the third tier of the ESMP may be required, including additional chemical and biological assessments, a study of the site's long-term stability or *in situ* biological measurements (Chevrier and Topping 1998).

It has been noted that determination of the objectives of an ESMP must take into account the effects and cumulative impacts of human activities and natural phenomena on the environment and natural resources. In practice, however, it is often difficult to detect and document cumulative effects attributable to multiple sources or isolated events. In addition, in certain regions, the data from environmental monitoring programs is difficult to interpret because of natural spatio-temporal variations in the resources and contaminants (NRC 1990).

Since there is no single standard method of assessing cumulative effects, the Canadian Environmental Assessment Agency has published a guide that illustrates why and how practitioners (proponents, consultants, government agencies) have used certain methods or approaches to consider cumulative environmental effects of projects (Cumulative Effects Assessment Working Group 1997). For example, Appendix C3 presents a conceptual model of a matrix tool that offers a good starting point for the development of ESMP objectives that take cumulative impacts into consideration.

3.2 Identification of Environmental Components Requiring Surveillance (Step 2)

Environmental components requiring surveillance are normally dictated by the objectives of the ESMP defined in Step 1. These objectives themselves arise from the environmental assessment used to identify, as accurately as possible, the environmental components likely to be affected by implementation of the project.

The results of the environmental assessment of a project are generally summarized in an impact matrix that permits rapid visualization of the environmental components requiring environmental surveillance and monitoring (see Appendix C, Figure C1).

To facilitate the identification of these components for the purposes of an ESMP, it is recommended that they be classified in three categories (physical, chemical and biological), bearing in mind that the selection of the biological components (or processes) to be monitored is directly dependent on the project's impacts on the physical or chemical components (or processes) (Palermo et al. 1992).

This classification normally provides the basis for the development of a tiered ESMP. For instance, in most cases, if the sediments to be dredged or eliminated are uncontaminated, tier 2 focuses on the measurement of biological changes and tier 3 on the measurement of social and economic changes. In the case of contaminated sediments, the ESMP must focus first on the measurement of physical changes (tier or level 1), secondly on the measurement of chemical changes (tier 2), then on the measurement of biological changes (tier 3) and finally on the measurement of socio-economic changes (tier 4). Using this approach, chemical changes (tier 2) are monitored only if the tier 1 results confirm that the project results in undesirable or unanticipated physical impacts; similarly, biological monitoring (tier 3) or socio-economic monitoring (tier 4) is undertaken only if the ESMP demonstrates physical or chemical impacts at an unanticipated level.

For example, during dredging and open-water disposal of dredged material, the excavation and disposal of sediments normally result in their resuspension (physical processes). The contaminants trapped in the sediments can thus be released into the water column (chemical processes), creating impacts on aquatic habitats and communities (biological processes). Table 2 lists the physical, chemical and biological components requiring surveillance for dredging and sediment management projects.

3.3 Formulation of the Testable Impact Hypotheses (Step 3)

This step requires prior knowledge of the potentially problematic activities involved in the project and the mechanisms by which they affect the environmental components identified in step 2. In addition, conceptual impact models must be developed, scientific and spatial/temporal boundaries identified, and thresholds determined (Figure 5).

3.3.1 Identification of the Impact Mechanisms to be Considered

Identification of the impact mechanisms to be considered requires, first, a knowledge of the project activities and their interaction with all components of the environment. The impact mechanisms can be identified by means of an impact matrix that can serve as a checklist, conceptual schematics or summary tables illustrating the principal mechanisms of contaminant migration (see Appendix C.1).

Table 2

List of environmental components to be monitored in ESMPs for dredging and sediment management projects

Components	Disposal/containment					Pre-treatment	Treatment
	Dredging	Transport	Open-water	Shoreline	Upland		
Physical							
Bathymetry	x		x				
Hydrodynamic conditions			x	x			
Sediment granulometry			x			x	
Turbidity	x		x	x	x		
Suspended solids	x	x	x	x	x		
Sedimentary environment	x		x				
Noise level	x	x		x	x	x	x
Sediment losses		x				x	
Drainage				x	x		
Material quality			x	x	x		
Chemical							
Ambient air quality	x*	x*		x*	x*	x	x
Sediment quality	x*		x			x	x
Soil quality				x	x	x	
Surface water quality	x		x	x	x		
Groundwater quality				x*	x*	x	
Vegetation quality	x						
Edible species quality			x*				
Wastewater quality					x	x	x
Atmospheric emission quality					x	x	x
Material quality			x	x	x		
Residue quality						x	x
Biological							
Benthic density/diversity			x				
Toxicity	x*		x*	x*			x
Bioaccumulation in biota			x*		x*		
Bioaccumulation in plants				x*	x*		
Animal and plant species			x	x	x		
Habitats			x	x	x		

* In the presence of contaminated sediments.

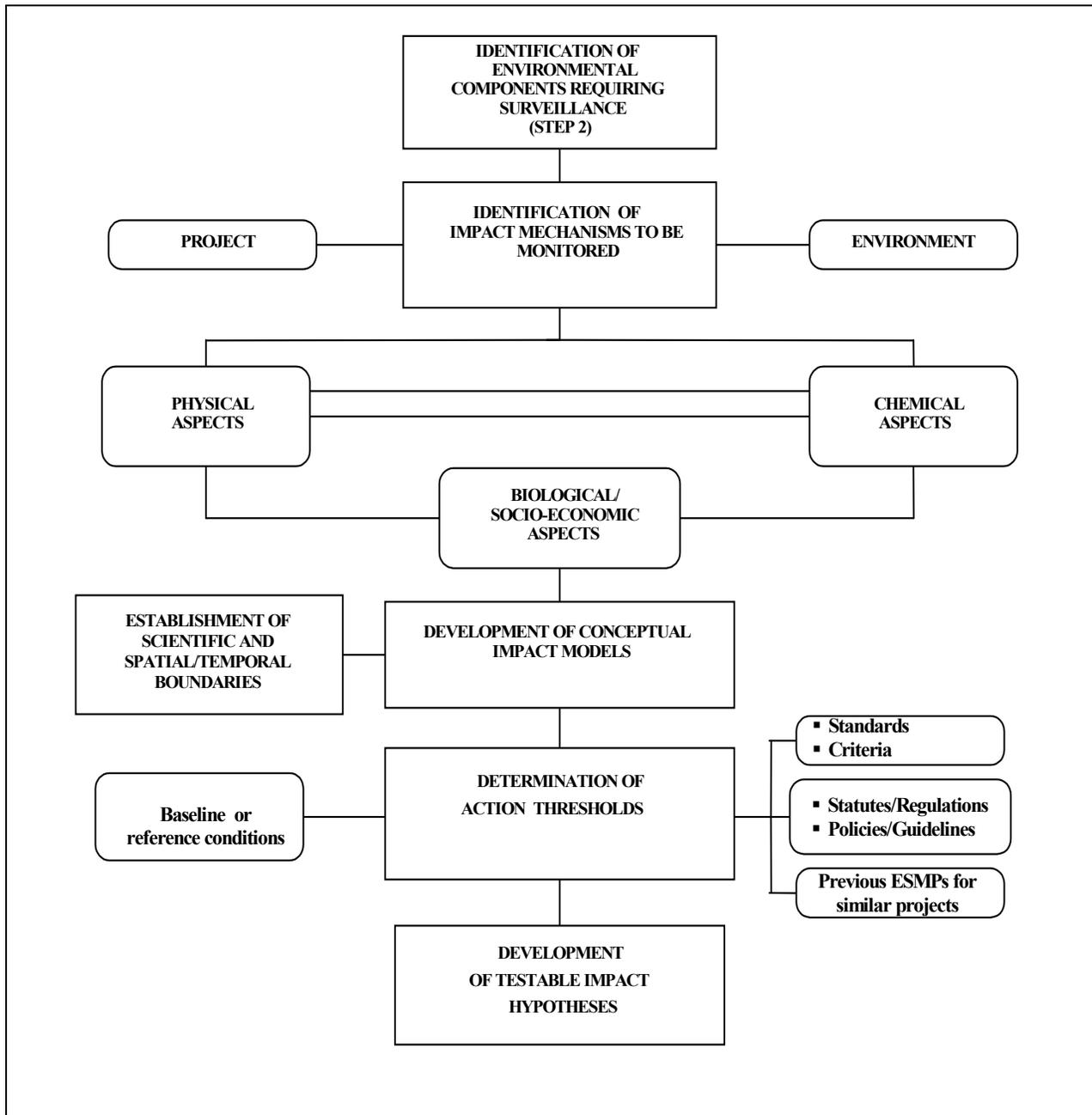


Figure 5 Formulation of the testable impact hypotheses (Step 3)

3.3.2 Development of Conceptual Impact Models

It is important to note that the design of sampling plans or programs for any ESMP will be based on hypotheses and predictions regarding the probable responses of the environmental components to disturbances. Predictions of the potential effects or impacts and of the effectiveness of the mitigation measures must be based on clearly expressed conceptual models of the cause-and-effect relationships, both direct and indirect.

A conceptual model describes the links between the resources at risk, the physical, chemical and biological parameters of the ecosystems and the anticipated changes attributable to the project or to natural causes. The resulting understanding of the situation makes it possible to formulate testable questions and impact hypotheses for assessment (NRC, 1990).

Depending on the objectives of the ESMP, the scientific knowledge and the level of precision required, the conceptual models of the projects' potential effects can be presented in a number of forms: laboratory simulation tests, mathematical models, qualitative statements based on historical information on the effects of similar projects, ecological theories or professional judgment. Appendix C.2 provides information on the most common conceptual models.

3.3.3 Establishment of the Scientific and Spatial/Temporal Boundaries

In designing an ESMP, it is important to be aware of the scientific and spatial/temporal boundaries of the conceptual impact models used. Examples of boundaries that contribute to the sampling design of a monitoring program include:

- Administrative boundaries deriving from political, social or economic factors;
- Project boundaries deriving from the spatial and temporal extent of the project or perturbation under study;
- Scientific boundaries deriving from our relatively limited knowledge of the physical, chemical and biological processes involved; and
- Technical boundaries deriving from limits on capabilities to predict or measure ecological change and/or ecosystem processes (NRC, 1990).

Establishing appropriate space and time boundaries is particularly important in developing the sampling design for monitoring studies for several reasons:

- First, the majority of parameters (e.g., water quality) or variables (e.g., turbidity) that could be measured by monitoring programs vary on space and time scales. No single set of boundaries is adequate for all parameters and all variables;
- Second, events that occur over large areas typically can only be perceived over long periods and vice versa;
- Third, spatial and temporal variations in the natural environment can easily confound the interpretation of monitoring results (NRC 1990).

3.3.4 Determination of the Action or Control Thresholds

To ensure effective intervention in the course of operations, action or control thresholds must be previously established for each of the parameters and variables included in the ESMP. These thresholds are normally determined by the baseline conditions or standards, criteria and guidelines associated with environmental protection legislation and regulations and by the other issues identified by the consultation and public hearing processes and by government concerns (Figure 5).

Maintenance, capital or cleanup dredging operations and sediment management projects are governed by statutes and regulations and by guidelines and policies relating to environmental protection, navigable waters, valued aquatic habitats and species, fish fauna and habitat, and migratory birds. These are listed in Appendix B. These statutes, regulations, policies and guidelines may apply to environmental protection in general or, more specifically, to contaminated sediment treatment projects. The latter are also governed by legislation and guidelines relating to air quality, wastewater and solid or hazardous waste management, and the handling, transport and storage of hazardous materials.

The *Environmental Criteria for Dredging and Spoil Management: A Review of Canadian Regulatory Requirements* (Canadian Coast Guard 1990), the *Legislative Framework for Sediment Management in Quebec* (SLC 1993b) and the *Code de conformité environnementale* (DFO 1997) present the obligations and requirements arising from the administrative and legal provisions applicable to dredging and sediment management projects.

The thresholds applicable to each of the environmental components likely to be affected by a dredging and sediment management project can be established on the basis of these statutes, policies and guidelines (see Table 3).

Baseline conditions at work sites and reference stations are also frequently used to establish thresholds, either in the absence of fixed standards or criteria for certain parameters, or when the baseline conditions for certain parameters already reflect physical/chemical degradation of the environment (e.g., extensive sediment contamination by heavy metals) or biological degradation (e.g., low abundance and/or diversity of biological communities).

Baseline conditions provide equally important information on the natural variations in the physical, chemical and biological parameters of a given site and permit measurement of the actual changes attributable to the project.

The thresholds will be used to determine what constitute acceptable or unacceptable effects in the course of the operations and whether to continue or halt operations and implement pre-established response measures. Note that the definition of what is considered an acceptable or unacceptable impact is often established on the basis of the best professional judgment of those involved in the project and the results of the public consultation process. In addition to the technical aspects and operational feasibility of the project, social, political and economic factors must be considered as well. The resulting decision is not carved in stone and may change, for example, in the light of the results of subsequent ESMPs, technological innovations and improvements or changes in the legislation and regulations.

Table 3

Reference criteria or thresholds for various environmental components applicable to ESMPs for dredging and sediment management projects

Environmental component	Criteria/thresholds
Sediments	<ul style="list-style-type: none"> - Interim Criteria for Quality Assessment of St. Lawrence River Sediment (SLC 1992b) - Canadian Sediment Quality Guidelines (EC 1995c) - National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites (Chevrier and Topping 1998) - Granulometry similar to reference stations
Surface water	<ul style="list-style-type: none"> - Critères de qualité pour les divers usages de l'eau (MENVIQ 1990a, rev. 1992) - Canadian Water Quality Guidelines (CCME 1989, rev. 1990) - % increase over reference stations
Groundwater	<ul style="list-style-type: none"> - Criteria applicable to groundwater decontamination, Soil Protection and Contaminated Sites Rehabilitation Policy (MEF 1998). - Interim Canadian Environmental Quality Criteria for Contaminated Sites (CCME 1991a)
Drinking water	<ul style="list-style-type: none"> - Drinking water/raw water standards (<i>Drinking Water Regulation</i>, RRQ, 1981, c. Q-2, r. 4.1). - Technological limitations of the filtration station
Wildlife/Vegetation	<ul style="list-style-type: none"> - Diversity/abundance in relation to reference stations - Toxicity (scale) or in relation to reference stations - Bioaccumulation
Edible species	<ul style="list-style-type: none"> - Guidelines on chemical contamination of fish (Health Canada)
Air	<ul style="list-style-type: none"> - Ambient air standards (<i>Regulation Respecting the Quality of the Atmosphere</i>, RRQ, c. Q-2, r. 20) - <i>By-law Pertaining to Air Purification</i> (MUC By-law 90)
Soil	<ul style="list-style-type: none"> - Generic criteria for soil, Soil Protection and Contaminated Sites Rehabilitation Policy (MEF 1998) - Interim Canadian Environmental Quality Criteria for Contaminated Sites (CCME 1991a)
Workplace	<ul style="list-style-type: none"> - Exposure standards/doses (<i>Regulation Respecting the Quality of the Work Environment</i>, RRQ, c. S-2.1, r. 15)
Acoustic environment	<ul style="list-style-type: none"> - Maximum noise levels and zoning
Wastewater	<ul style="list-style-type: none"> - Standards for wastewater disposal in stormwater, combined and domestic sewer systems (MENVIQ Regulation Respecting Wastewater Disposal in Sewer Systems in Municipality X and MUC <i>By-law 87</i>)
Solid waste	<ul style="list-style-type: none"> - Leachate standards from the <i>Regulation Respecting Solid Waste</i> (RSW) (RRQ, c. Q-2, r. 14)
Atmospheric waste	<ul style="list-style-type: none"> - Standards for atmospheric emissions (<i>Regulation Respecting the Quality of the Atmosphere</i>, RRQ, c. Q-2, r. 20 and <i>By-law Pertaining to Air Purification</i>, MUC <i>By-law 90</i>)

Table 4 presents examples of thresholds for dredging sites as defined by Environment Canada to assess the environmental performance of new dredging equipment for demonstration projects in tests performed in connection with the Great Lakes Action Plan (Buchberger 1993; Milles 1995; Pelletier 1994a, 1994b, 1994c).

Table 4
Examples of thresholds for assessing the environmental performance of dredging equipment

Parameter	Criteria or thresholds
Turbidity	- Must not exceed bottom levels by more than 30% 25 m away from the dredge*
Suspended solids	- Must not exceed bottom concentrations by more than 25 mg/L 25 m away from the dredge when these concentrations are below 100 mg/L* - Must not exceed bottom concentrations by more than 10% 25 m away from the dredge when these concentrations are above 100 mg/L*
Total organic content	- Must be between 4 and 27 mg/L 25 m away from the dredge - Must not exceed bottom concentrations by more than 30% when these concentrations are above 27 mg/L
Spillage and leakage	- Maintain minimum freeboard of 1 m in barges or scows used for transport - Ensure watertightness of barges, scows or truck bodies before transport to the disposal or treatment site
Extraction efficiency	- Maintain a solid-liquid ratio of at least 30% by volume
Effluent quality	- Maximize concentrations of excavated solids - Possible mechanical or chemical removal of suspended sediments from liquid sludge mixtures - Possible treatment of effluents from the disposal site
Extraction rate	- Adjust the extraction rate to allow sediment decantation at the disposal site so that the effluent meets provincial water quality standards - Adjust the extraction rate to the capacity of the equipment or facilities used for transport, storage, disposal or treatment of the dredged sediments

Source: Buchberger (1993).

* These thresholds were established to assess the environmental performance of new dredging equipment. Standard dredging operations normally use less stringent thresholds (e.g., 1.5 times ambient concentrations).

The general operational and performance criteria verified on site included measurements of turbidity, suspended solids, total organic carbon, percentage of solids in the water-sediment mixture and monitoring of spillage, leakage, effluent quality and dredge performance.

Table 5 presents examples of action thresholds used in the surveillance and monitoring of aquatic dredged material disposal sites. These thresholds may be based on reference concentration levels for analysis of the metals and chemicals present in the sediments, or criteria indicating the success or failure of the bioassays performed on the sediments. As this table indicates, these thresholds may also relate to levels that confirm or refute the null impact hypothesis for the disposal site (defined below) with respect to changes in sediment granulometry, benthic productivity and contaminant concentrations in benthic species and other elements of the food chain.

3.3.5 Development of the Testable Impact Hypotheses

Once the impact mechanisms have been identified and the thresholds determined, testable impact hypotheses can be formulated for the different environmental components. For example, since ESMPs must pose precise questions on a project's potential effects on the elements of the ecosystem, they must be based on impact hypotheses describing the current state of our knowledge on the cause-and-effect relationships between the activities involved in the project and the elements of the ecosystem.

An impact hypothesis consists of a series of statements linking the activities involved in a project to their possible effects on the elements of the ecosystem and includes definitions of the following three elements:

1. Project activities: activities that could have effects on the environment.
2. Valued ecosystem components: elements that are affected by the activities or, in the case of an ecological indicator, elements that measure the effect.
3. Linkages: set of statements that describe the mechanisms by which project activities are linked to valued ecosystem components (EC 1994c).

Table 5
Examples of action thresholds for aquatic dredged material disposal

Criteria	Parameters and reference levels	Interpretation
Reference screening levels for chemicals in sediments (EC 1996a; 1997b)	<ul style="list-style-type: none"> - Cadmium: 0.6 ppm (dry weight) - Mercury: 0.75 ppm (dry weight) - Total PCBs: 0.1 ppm (dry weight) - Total PAHs: 2.5 ppm (dry weight) 	<ul style="list-style-type: none"> - If the observed values are below the screening level, the disposal site sediments are considered harmless for the parameter measured. - If the observed values are above the screening level, further assessment will be required, including bioassays to determine sediment quality.
Concerning bioassays, interim pass-fail criteria employed to determine toxic effects (EC 1996a; 1997b)	<ul style="list-style-type: none"> - An acute toxicity test using marine or estuarine amphipods (the end point is lethality) - A toxicity test using a photoluminescent bacteria, the Microtox® solid-phase test (the end point is significant reduction in bioluminescence) - A fertilization assay using echinoids (the end point is significant reduction in fertilization) 	<ul style="list-style-type: none"> - Failure occurs when test sediment survival is at least 20% lower than reference sediment survival. - Failure occurs when the concentration of the sample that is estimated to cause 50% inhibition of light production by the bacteria after 5 min of exposure is less than 1000 ppm. - Failure occurs when a decrease in fertilization of at least 25% is observed between the test sediment and control water.
Null impact hypothesis (Pequegnat et al. 1990)	<ul style="list-style-type: none"> - The granulometry outside the disposal site remains unchanged following disposal of the sediments 	<ul style="list-style-type: none"> - An increase of more than 15% in fine sediment particle composition is unacceptable if they produce adverse effects on sensitive aquatic organisms.

Table 5 (Continued)

Criteria	Parameters and reference levels	Interpretation
Null impact hypothesis (Continued)	- The disposal of dredged sediments generally results in an increase in benthic productivity at the disposal site compared to ambient conditions, because of the presence of assimilable organic substances in the dredged sediments	- A reduction of 25% or more in the productivity of benthic organisms within a reasonable period of time following disposal should trigger further analyses.
	- Benthic species show no significant increase in contaminant concentrations in their tissues compared to ambient conditions	- An increase in the concentration of priority contaminants in the tissues of predator species should trigger a review of the disposal activities.
	- The predator species at the top of the food chain show no evidence of bioaccumulation of the problem contaminants	- An increase in the concentration of priority contaminants in the tissues of predator species to a level equivalent to or exceeding the recommended standards for human consumption should lead to discontinuation of sediment disposal and capping of the sediments.

An example of an *impact hypothesis* for a dredging project would be:

“Dredging and sediment transport will result in contaminant resuspension in the water column in amounts sufficient to result in degradation of the chemical quality of the sediments in downstream areas.”

This impact hypothesis permits the formulation of a *null impact hypothesis*, such as:

“Dredging and sediment transport will not result in contaminant resuspension in the water column in amounts sufficient to result in degradation of the chemical quality of the sediments in downstream areas.”

These impact hypotheses are generally based on the environmental assessment (or the review performed in connection with the application for a permit or authorization certificate), in which each of the objectives of the ESMP is reflected or expressed in the form of *testable impact hypotheses*. For example, if the ESMP has been developed for an ocean dredged material disposal site, these hypotheses generally relate to conflicts with other legitimate uses of the sea, habitat destruction and unacceptable impacts on fish and fisheries, the protection of sensitive areas, acute or chronic effects on the marine biota typical of the ecosystem at the disposal site and chemical contamination of edible fish, shellfish and crustacean species (Chevrier and Topping 1998).

Table 6 presents examples of objectives, testable questions and impact hypotheses applicable to ESMPs for dredging sites, open-water disposal sites or aquatic or upland containment or treatment sites for contaminated sediments. More detailed examples of impact hypotheses are presented in Appendix C.4. These examples are based on the publications of Environment Canada (Chevrier and Topping 1998; EC, 1993a), Mann et al. (1995a, 1995b), Germano et al. (1994) and Fredette et al. (1990a). These hypotheses, in addition to helping identify the variables to be monitored, are also useful in demonstrating the value of ESMPs to stakeholders and the public.

Table 6

Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for dredging sites, open-water disposal sites, or aquatic or upland containment or treatment sites for contaminated sediments

Program objectives	Testable questions	Testable impact hypotheses
<i>Dredging site</i>		
01. Prevent adverse effects on biota (flora and fauna)	<p>Q1. Will dredging and sediment transport result in contaminant resuspension in the water column, and will this resuspension result in possible contaminant uptake by aquatic organisms?</p> <p>Q2. During dredging and sediment transport, can aquatic organisms absorb contaminants in concentrations high enough to create risks to human health?</p>	H1. Dredging and sediment transport will not result in contaminant uptake by harvested species to levels beyond those having no potential effect on human health.
<i>Outside the designated open-water disposal site</i>		
01. Prevent habitat destruction and effects on fish and fisheries	Q1. Are the deposited sediments likely to be transported outside the designated open-water disposal site and to result in possible degradation of the chemical quality of the sediments in the affected area and consequently in habitat degradation?	H1. Disposal of the dredged sediments will not result in transport of these sediments outside the designated disposal site; the chemical quality of the sediments in the outside area should not change nor alter the habitats.
<i>Aquatic containment of contaminated sediments</i>		
01. Containment by capping with clean materials effectively isolates the benthic populations from the contaminated sediments	Q1. Are contaminant concentrations in the tissues of the benthic populations at the containment site higher than those in ambient areas?	H1. The contaminant concentrations in the tissues of resident benthic populations are no higher than those observed in the same species in ambient areas.
<i>Upland disposal site</i>		
01. Prevent potential effects on human health	Q1. Could disposal of the contaminated sediments result in contaminant uptake by plants and animals likely to pose risks to human health?	H1. Upland disposal of the contaminated sediments will not result in degradation of the chemical quality of the soil and groundwater at the disposal site, contaminant uptake by plants and animals nor ensuing potential effects on human health.
<i>Treatment of contaminated sediments</i>		
01. Demonstrate the environmental performance of the selected treatment technology	Q1. Does the selected technology permit isolation or destruction of the contaminants and thus upland disposal or reclamation?	H1. The selected technology isolates or destroys the contaminants to levels below the concentrations defined in the MEF <i>Soil Protection and Contaminated Sites Rehabilitation Policy</i> and can thus be used for the remediation of aquatic environments.

3.4 Design of the Sampling Plan and Selection of Analysis Methods (Step 4)

Following identification of the processes and environmental components requiring monitoring (section 3.2) and formulation of the impact hypotheses for each of these components (section 3.3), a sampling plan can be designed and analysis methods selected. Figure 6 indicates the steps involved.

3.4.1 Selection of the Surveillance and Monitoring Parameters

The sampling parameters selected for ESMPs must establish a direct link between the impact hypotheses and the information required for management. The guidelines for selection of the variables or parameters and ecological indicators are presented in section 2.2.

For chemical and biological parameters, and to a lesser extent for physical parameters, it is the baseline conditions found at the work sites and reference stations (e.g., types of contaminants, types of biological communities present) that normally determine the chemical and biological parameters over which it is most important to exercise surveillance.

While it is impossible to establish a list of parameters for analysis that is applicable to all ESMPs, it may be useful to consult the lists of physico-chemical and biological parameters recommended by government authorities for specific dredging and sediment management projects. For instance, for monitoring water quality in new dredging equipment demonstration projects on the Great Lakes, Environment Canada (Buchberger 1993; Milles 1995; Pelletier 1994a, 1994b, 1994c) has recommended monitoring the following physico-chemical parameters before, during and after the demonstration operations:

- pH;
- conductivity;
- oil and grease, metals and priority organic compounds;
- total dissolved solids (TDS), total suspended solids (TSS);
- volatile suspended solids (VSS);
- total phosphorus (TP), ammonia (NH₃), total Kjeldahl nitrogen (TKN);
- nitrites and nitrates (NO₂+ NO₃);

- total organic carbon (TOC);
- chemical oxygen demand (COD), biological oxygen demand (BOD) and dissolved oxygen (DO).

Table 7 lists the steps and sampling parameters from the principal monitoring program recommended by Environment Canada in the *National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites* (Chevrier and Topping 1998).

In the same context, Table 8 lists the physico-chemical and biological parameters for use in characterization in ESMP projects for ocean dredged material disposal sites in the United States.

These parameters are designed to characterize the degree of contamination of the water column, sediments and biological communities at each underwater disposal site and in the reference areas before and after disposal of the dredged material, and the impact on the diversity and productivity of the biological communities present (Pequegnat et al. 1990).

Table 9 presents a list of the parameters recommended by the USACE for monitoring effluent quality at upland dredged sediment containment facilities. Some parameters are measured systematically (e.g., concentration of suspended solids), while others (e.g., dissolved oxygen) are measured only occasionally or only when metallic or organic compounds are present in the sediments to be dredged.

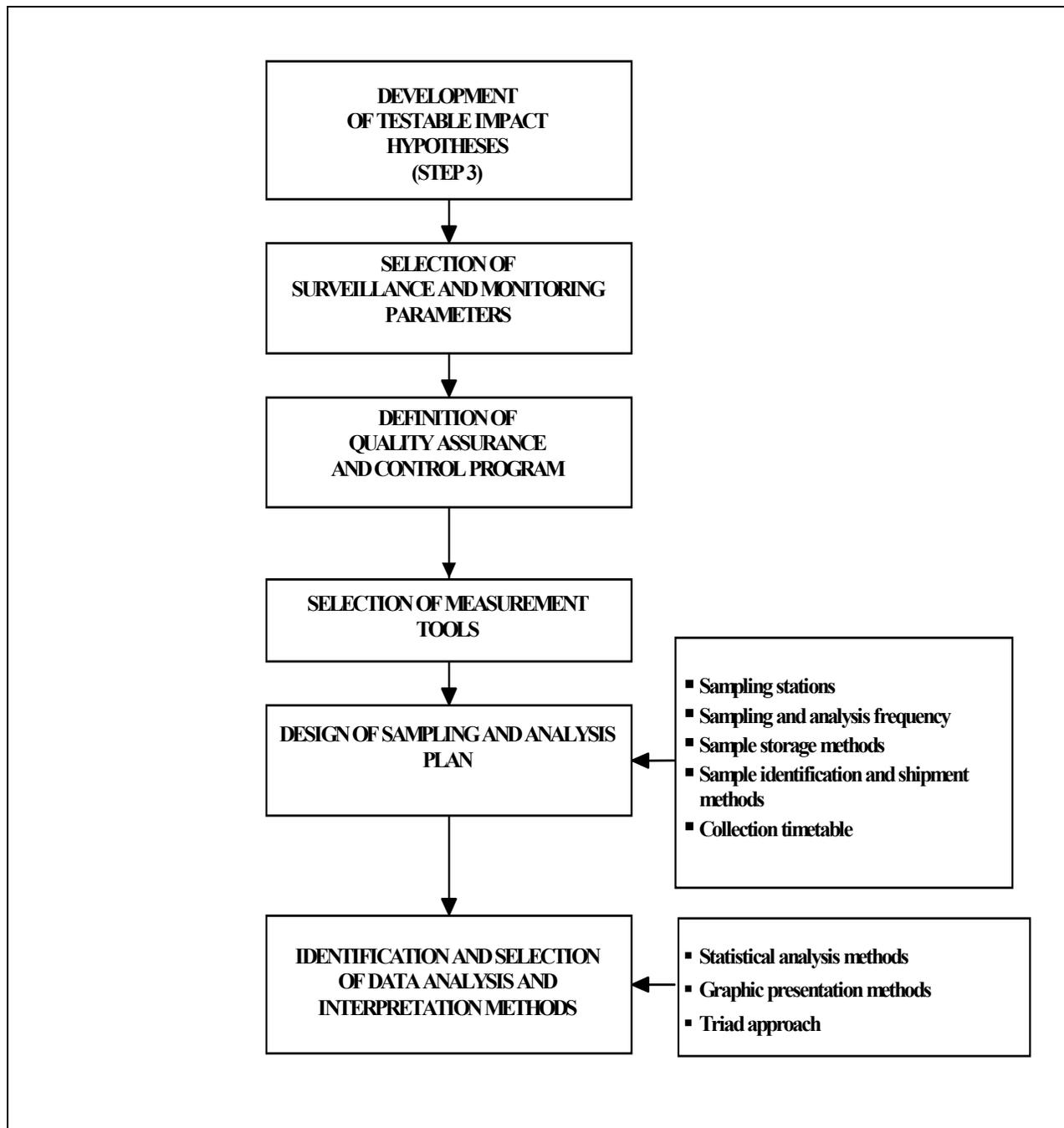


Figure 6 Design of the sampling plan and selection of analysis methods (Step 4)

Table 7
Sample list of physico-chemical and biological parameters applicable to ESMPs for ocean dredged material disposal in Canada

Type/objectives	Parameters
<i>Physical assessment</i>	
Collection of geological and physical data for determining the area of disposal, delineating the disposal site boundaries, studying the accumulation of dredged material within the area of disposal and documenting evidence of sediment transport from the ocean disposal site	<ul style="list-style-type: none"> - Bathymetry - Sediment granulometry - Sonar or other types of imaging to verify the predictions of the sediment transport models
<i>Chemical assessment</i>	
Sediment chemistry (measurement of certain chemicals and trends)	<ul style="list-style-type: none"> - Cadmium - Mercury - PCBs - Total PAHs - Low molecular weight PAHs - High molecular weight PAHs - Total organic carbon - Other parameters requiring Tier 1 examination to permit interpretation of the results of the toxicity tests
<i>Biological assessment</i>	
All assessments involving field or laboratory studies of living organisms	<ul style="list-style-type: none"> - Bioaccumulation in benthic organisms (USEPA Protocol) - Toxicity assessed by means of a battery of at least three bioassays - <i>In situ</i> measurements of the exoenzyme activity of the bacterial community - Survey of benthic communities (families)
Further biological surveillance and monitoring	<ul style="list-style-type: none"> - Variables capable of integrating effects at the community level - Monitoring of caged mussels, assays of residues in tissues and condition indicator - Survey of benthic communities (species) - Study of populations specific to a given environment - Microbial counts

Source: Adapted from Chevrier and Topping (1998).

Table 8
Sample list of physico-chemical and biological parameters for use in characterization in ESMPs for ocean dredged material disposal sites in the United States

Parameters	Site characterization
<i>Water column characteristics</i>	
Temperature/Salinity/Depth	All stations
Dissolved oxygen	All stations
Turbidity	All stations
Contaminants	Central stations and one upstream station
Dissolved mercury, cadmium, lead and copper	
High molecular weight hydrocarbons	
PCBs	
Chlorinated pesticides	
Current	Centre of site (to be repeated during monitoring)
<i>Sediment characteristics</i>	
Bathymetry	Site and vicinity
Granulometry and presence of debris	All cores from the meiofauna sampling stations and the first two cores from the benthic macroinvertebrate measurement stations
Total organic carbon	
Metals: mercury, cadmium, lead, copper	All stations
High molecular weight hydrocarbons	All stations
PCBs	
Chlorinated pesticides	
<i>Biological characteristics</i>	
Benthic macroinvertebrates	All stations
Meiofauna	All stations
Macroepifauna	3 stations (1 inside the site and 2 outside)
Bioaccumulation in tissues (2 species for mercury, cadmium, lead, copper, PCBs, hydrocarbons and pesticides)	
Bioaccumulation	
Introduced species	
Indigenous species (analysis of muscles for the contaminants listed above and liver for enzymes – optional)	

Source: Pequegnat et al. (1990).

Table 9**Sample list of parameters for use in monitoring effluent quality in upland sediment containment sites in the United States**

Category	Parameters*	Problem
Physical and physical/chemical	<ul style="list-style-type: none"> - Temperature - Suspended solids (SS) - Dissolved oxygen (DO) - pH - Turbidity 	<ul style="list-style-type: none"> Rarely Always Rarely Rarely Always
Nutrients	<ul style="list-style-type: none"> - Total organic carbon (TOC) - Ammonia (NH₃) - Nitrates (NO₃) - Phosphates (PO₄) 	All, if these elements are present in the sediments at problem levels
Metals**	<ul style="list-style-type: none"> - Iron (Fe) - Manganese - Nickel - Zinc (Zn) - Cadmium (Cd) - Chromium (Cr) 	All, if these elements are present in the sediments at problem levels
Organic compounds**	<ul style="list-style-type: none"> - Polychlorinated biphenyls (PCBs) - Polycyclic aromatic hydrocarbons (PAHs) - Pesticides 	All, if these elements are present in the sediments at problem levels

Source: Adapted from Thackson and Palermo (1988).

* All parameters specified in the authorization certificates and permits.

** All other contaminants potentially present.

When contaminated dredged material is to be deposited in a specially designed secure landfill, Table 10 presents the ESMP components and parameters that are to be reported on a regular basis to the Ministère de l'Environnement du Québec for the entire period of site operation.

Table 10

Monitored components and methods of monitoring the physico-chemical parameters required by the Ministère de l'Environnement du Québec for use in ESMPs for secure landfills

Monitored components	Monitoring methods
Condition of gates and fences	Physical integrity
Physical movement of landfill cells	Detection of possible settlement of buried materials capable of causing damage, particularly to the underground drainage system, using settlement plates in the cap material
Effectiveness of the secondary collection system (drainage system used to recover liquids migrating between the two geoliners)	<p>Pumping tests performed on installation of the upper cell base liner</p> <p>Regular pumping and analysis of the liquids recovered and disposal in accordance with existing statutes and regulations</p>
Effectiveness of the primary collection system (drainage system used to recover leachate accumulating in the cell base)	<p>Pumping tests of the leachate collection system.</p> <p>Regular pumping and analysis of the leachate to limit liquids to 30 cm above the upper liner and disposal in accordance with existing statutes and regulations</p>
Ground and surface water quality	<p>Quality control system around the perimeter of the site to permit sampling, analyses, flow measurements and piezometric level measurements</p> <p>For each geological unit within the groundwater saturation zone, the monitoring system should include:</p> <ul style="list-style-type: none"> - a reference piezometer located hydraulically upstream from the site that will not be affected by possible pollutant migration; - at least 3 piezometers located hydraulically downstream and very close to the secure landfill site, to detect any impact by the site on the water table; and - at least 3 piezometers further downstream to monitor any possible migration of the pollution flow. <p>The parameters are listed in the Appendix to the reference document.</p> <p>Piezometric level monitoring and sampling, analysis of ground and surface water throughout the entire period of operation.</p>

Table 10 (Continued)

Monitored components	Monitoring methods
Atmospheric emissions	<p>Monitoring of dust and odours, by air samplers located throughout the site on the basis of the prevailing winds, during grading and excavation operations and handling of contaminated soils and wastes.</p> <p>Sampling, analysis and treatment of gaseous emissions from the system used to collect and remove gases from the closed cells.</p> <p>The parameters analysed are dependent on the contaminants present in the wastes and contaminated soils.</p>
General inspection of the landfill site	Verification of the condition of existing infrastructure on the landfill site (fence, access route, drainage ditch, etc.) and the condition of the cell surface.

Source: Adapted from MEF (1996).

Table 11 shows a sample list of parameters that may require surveillance and monitoring in a contaminated-sediment treatment project. It includes those recommended by the USEPA for demonstration projects involving innovative contaminated-sediment treatment technologies performed within the context of the Assessment and Remediation of Contaminated Sediments (ARCS) program for Great Lakes sediments (USEPA 1994c, 1994d, 1994e, 1994f) and by the USACE (1993, 1994).

Table 11**Analytical physico-chemical parameters for sediment treatability testing performed in the context of the ARCS program**

Parameter	Untreated sediments	Treated solids	Water residual	Oil residual
Total solids	x	x		
Volatile solids	x	x		
Oil and grease	x	x	x	x
Metals ^a	x	x	x ^b	x
Polychlorinated biphenyls ^c	x	x	x ^b	x
Polycyclic aromatic hydrocarbons ^d	x	x	x ^b	x
Total organic carbon	x	x	x ^b	x
Total cyanide	x	x	x	x
Total phosphorus	x	x	x	x
pH	x	x	x	x
Biochemical oxygen demand			x	x
Total suspended solids			x	x
Conductivity			x	x
Leachate toxicity	x	x		

Source: USEPA (1994b).

- a Metals analysed were arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and selenium.
- b Both particle-bound and dissolved components should be analysed (for assessments of subsequent treatment).
- c Total polychlorinated biphenyls (PCBs), measured as Aroclors. Congener-specific analyses are more appropriate if treatment goals are established for individual congeners, or where the treatment process significantly alters Aroclor patterns (e.g., bioremediation).
- d Individual and total of 16 Priority Pollutant List polycyclic aromatic hydrocarbons (PAHs).

3.4.2 Definition of the Quality Assurance and Quality Control (QA/QC) Program

In any program involving the sampling and analysis of contaminated sediments and soils, and perhaps particularly in the case of ESMPs attempting to confirm null project impact hypotheses, quality assurance (QA) and quality control (QC) programs are essential.

To ensure the effectiveness of ESMPs and of QA/QC programs, it is important not only that the guidelines set out in section 2.2 be taken into account in their design, but that field and laboratory personnel be fully informed about the tasks to be performed and that the entire sampling and analysis program be based on Standard Operating Procedures (SOPs). Environment Canada's reference guides should be consulted in this regard (1994b, 1995a).

In addition, written protocols explaining the approach to be followed in performing each task must be developed for sampling, sample analysis and data processing. While activities are often planned more or less independently, they are nonetheless interrelated. Their objectives must therefore be familiar to all ESMP participants. The protocols can also be a source of information for those participating in these joint efforts.

To ensure that the data produced are properly documented to permit a clear assessment of the results, the Canadian Council of Ministers of the Environment (CCME), in its *Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites, Volume 1* (CCME 1993a), suggests a comprehensive quality assurance project plan. Table 12 lists some of the points to be documented in such a plan. In addition to detailing the requirements relating to quality assurance and quality control, the project plan should describe the quality assurance activities required to achieve the data quality objectives, and must indicate how data precision, accuracy, representativeness, completeness, comparability and compatibility will be assessed.

The CCME document (1993a) cited above constitutes an excellent reference work on the objectives and content of quality assurance and quality control (QA/QC) programs for each phase of an ESMP. Other documents more specific to QA/QC programs relating to sediment sampling and analysis may also be consulted (see Appendix D.1).

Table 12**List of points to be documented in a comprehensive quality assurance project plan**

1	Project description
2	Project organization and delegation of responsibilities
3	Quality assurance objectives (data precision, accuracy, completeness, integrity and comparability)
4	Sampling and sample handling methods
5	Sample custody, transport, preservation and storage
6	Calibration methods and frequency
7	Experimental design and analysis method
8	Reference and quality control standards
9	Reference documentation
10	Data reduction, validation, verification and presentation
11	Internal quality control audits
12	Preventive maintenance methods and timetable
13	Specific methods for routine assessment of quality control
14	Corrective measures
15	Quality assurance reports submitted to the Branch
16	References

3.4.3 Selection of the Measurement Tools

The measurement tools used in an ESMP must permit a rapid and reliable response to ensure rapid intervention.

Table 13 presents a list of the tools for measurement of the physical, chemical and biological parameters normally used in ESMPs for dredging and aquatic disposal of dredged material. Appendix D.2 lists a number of excellent reference works on the operating principles, advantages and limitations of these various tools, as well as USACE documents on the recommended tools for projects involving aquatic containment of contaminated sediments.

Table 13

Techniques and measurement tools for environmental monitoring of aquatic dredged material disposal sites

Parameters	Techniques	Equipment
Physical parameters	- Navigation and positioning equipment	- Electronic systems (Miniranger, Trisponder, Loran-C) - Optical methods (theodolite, sextant, radar) - Satellite positioning system (GPS, SATNAV)
	- Bathymetry and bottom configuration	- Depth sounder - Side-scan sonar - Sub-bottom profilers - Sediment profiling camera (SPC)
	- Sediment sampling	- Surface samplers (grab samplers) - Depth samplers (corers)
	- Remote data collection on site conditions	- Sediment profiling camera (SPC) - Video camera - Other tools for <i>in situ</i> measurement of the physical properties of the materials at the disposal site (granulometry, density, pore pressure, shear forces, compaction rate, etc.)
	- Measurement of waves and currents	- Current meters - Seabed drifters
Chemical parameters	- Gradients or changes in contaminant distribution at the disposal site	- Surface samplers (grab samplers) - Depth samplers (corers)
	- Water quality	- Water column samplers - Acoustic methods - Turbidity monitors - Suspended solids monitors
Biological parameters	- Fish and shellfish sampling	- Nets (other dragnets, seines) - Various types of traps (anchored gill net, hoop net, fyke nets, etc.)
	- Benthic infauna and submergent vegetation	- Traps, grab samplers, box corers, etc.
	- Toxicity	- Water column and sediment samples for toxicity tests

Sources: Adapted from Fredette et al. (1990a, 1990b) and EC (1994b).

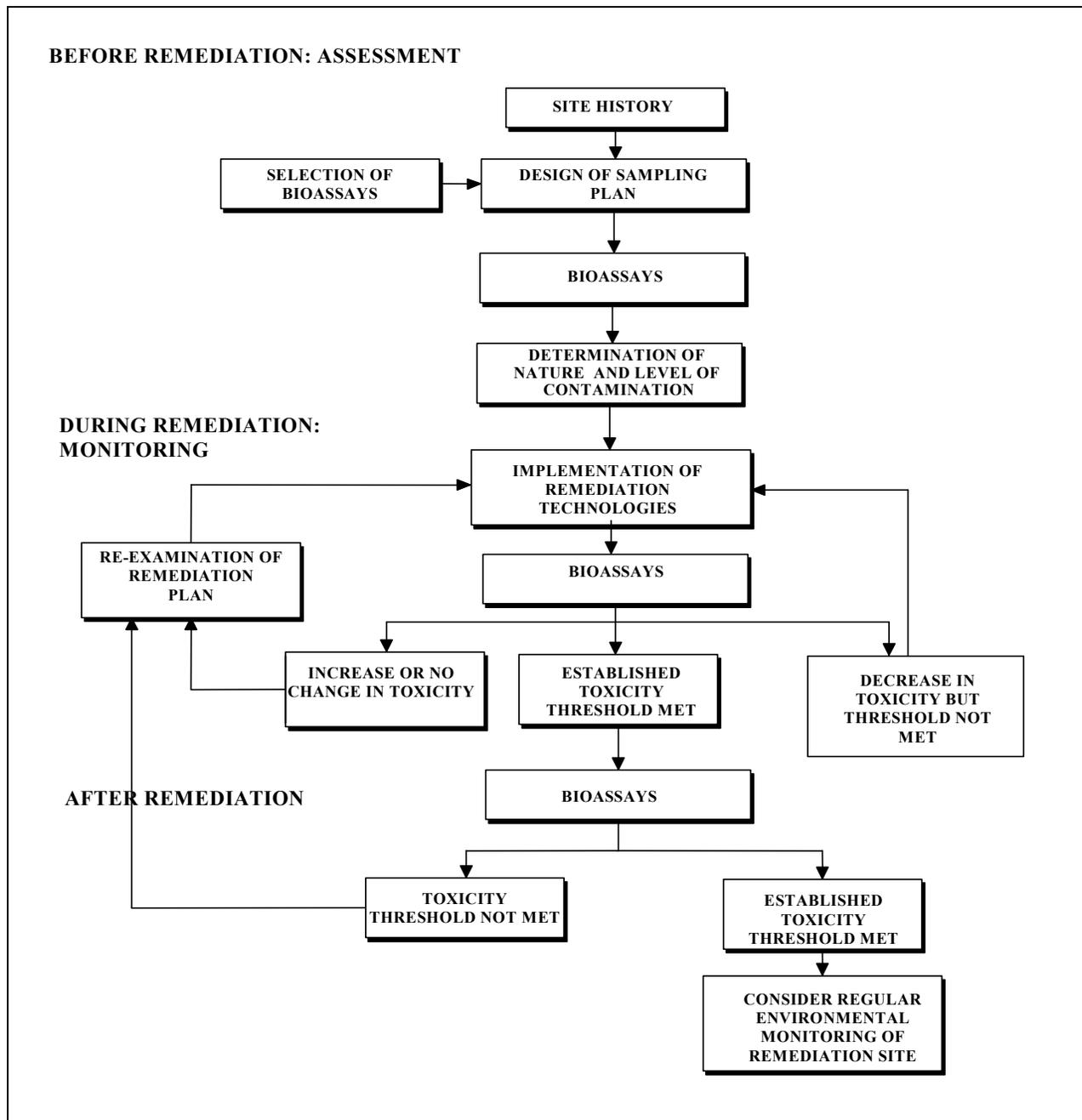
Moreover, because of the inherent limitations of physico-chemical analyses, including their inability to take into account inter-contaminant synergy, bioassays are increasingly being used as a complement to these analyses to measure the impacts associated with the dredging, treatment and containment of contaminated sediment (EC, 1997a).

Figure 7 illustrates how bioassays are used in planning and monitoring remediation projects. For example, bioassays can help to assess the risks associated with areas showing higher contaminant concentrations. During and after sediment treatment, they can be used in conjunction with chemical analyses to demonstrate the short- and long-term effectiveness of remediation operations.

In terms of monitoring the quality of atmospheric emissions and liquid and solid treatment wastes, the tools for measuring the effectiveness of the processes are well known and highly developed, having been in use for many years. Some permit direct, continuous readings for a number of parameters, to facilitate monitoring of the processes and to demonstrate the compliance of the wastes with existing environmental protection standards.

Samples of inputs and outputs of the overall process and the intermediate solid effluents from the various pieces of equipment included in the complete treatment system are normally composite samples, collected using spatulas or containers, then stored and shipped to the laboratory.

New measurement and detection tools will be developed in the years to come. As Table 14 indicates, analytical technologies that permit direct screening in the field are already available; these include infrared and photoluminescence detectors, portable X-ray fluorescence (XRF) units, portable gas chromatographs, portable mass spectrometers, immunoassay kits, colorimetric test kits (chemical kits) and biosensors, which are still under development and progressing rapidly. These screening technologies are described in the glossary in Appendix A.



Source: Keddy et al. (1995).

Figure 7 Flowchart of a possible approach to the use of bioassays in the assessment and monitoring of sediment remediation projects

Table 14
Examples of analytical technologies for contaminant screening

Technology	
<i>Soils, sediments and sludges</i>	
Geophysical characteristics of soil and bedrock	<i>In situ</i> geophysical tests, drilling technologies; core barrel sensors; seismic reflection/refraction
Buried objects and anomalies in the subsoil	Georadar; infrared monitors or detectors; high-frequency electromagnetic sensors; electromagnetic subsoil measurement technologies; mobile electromagnetic geophysical instruments
Benzene, toluene, ethylbenzene and xylene (BTEX)	Colorimetric test kits; immunoassay kits; laser-induced fluorescence; cone penetrometer; portable gas chromatograph; portable mass spectrometer
Explosives	Colorimetric test kits; immunoassay kits; portable gas chromatographs; portable mass spectrometer
Mercury	Immunoassay kits; laser-induced fluorescence; cone penetrometer
Pentachlorophenol (PCP)	Immunoassay kits; laser-induced fluorescence; cone penetrometer
Pesticides	Immunoassay kits
Polychlorinated biphenyls (PCBs)	Colorimetric test kits; immunoassay kits; portable gas chromatograph; portable mass spectrometer
Polycyclic aromatic hydrocarbons (PAHs)	Colorimetric test kits; immunoassay kits; portable gas chromatograph; portable mass spectrometer; soil gas analysers; chemical reaction indicators; biodetectors
Total petroleum hydrocarbons (TPHs)	Colorimetric test kits; immunoassay kits; laser-induced fluorescence; cone penetrometer; infrared monitors
VOCs, SVOCs, dioxins, furans	Portable gas chromatograph; portable mass spectrometer

Table 14 (Continued)

Technology	
<i>Ground and surface water, and leachates</i>	
Buried objects	Georadar; infrared monitors; high-frequency electromagnetic sensors; electromagnetic subsoil measurement technologies; mobile electromagnetic geophysical instruments
Metals	X-ray analysers; biosensors
PAHs	Immunoassay kits
Pesticides	Immunoassay kits; portable gas chromatograph; portable mass spectrometer; chemical reaction indicators
PCBs	Colorimetric test kits; immunoassay kits; portable gas chromatograph; portable mass spectrometer
BTEX	Colorimetric test kits; immunoassay kits; portable gas chromatograph; portable mass spectrometer
VOCs, SVOCs	Portable gas chromatograph; portable mass spectrometer
<i>Soil gases</i>	
VOCs, SVOCs, PCBs, pesticides, dioxins, furans	Portable gas chromatograph; portable mass spectrometer; soil gas analyzers

Screening tests permit the assessment of large numbers of samples for subsequent laboratory analysis, if required. Properly performed, field screening makes it possible to acquire numerous data efficiently and economically, either by rapidly delineating the problem area to be assessed (e.g., to determine the extent of the contamination) or by assessing the effectiveness of the remediation operations (e.g., to determine the thickness of the sediment layer to be removed). Once the area to be assessed or decontaminated has been delineated by means of screening tests or techniques, an appropriate sampling strategy can then confirm and characterize the screening results more precisely (CCME 1993a).

According to Sommerfeld (1995), the efficacy of environmental monitoring programs can be increased tenfold through the simple use of immunoassay technology. For example, if 100 samples can be screened in this way for every 10 samples collected and analysed by standard means, the results of the monitoring program will have greater reliability and validity since the sample size is statistically more representative.

A number of screening tests have been studied by the USEPA in the context of the Assessment and Remediation of Contaminated Sediments (ARCS) program to clean up contaminated sediments in the Great Lakes (USEPA 1994). Table 15 lists the new tools tested in this connection.

Table 15
Screening tests used by the USEPA/USACE to assess sediment contamination in the Great Lakes

Method	Parameters
Immunoassays*	PCBs (0.1 to 5 ppm) Halogenated pesticides PAHs Other organic compounds
Fluorometry	Total PAHs
Infrared spectroscopy	Total hydrocarbons (1 to 10 ppm)
Thin-layer chromatography	Semi-volatile organic compounds (1 to 10 ppm)
X-ray fluorescence	Metals (100 to 1000 ppm)
Rapid bioassays: Microtox™ , Daphnia IQ™ , Rotifera	Chronic toxicity

Source: USEPA (1994a).

* Boldface indicates screening tests recommended by the USEPA/USACE.

Other newly developed contaminant screening tests and analytical tools (supercritical fluid extraction, immunoassays, solid-phase microextraction, rapid extraction and fluorescence detection, microwave-assisted digestion and energy-dispersive X-ray fluorescence) have been assessed for near real time monitoring of contaminated soil remediation projects (EC 1995a; ASL et al. 1995). This project has demonstrated that these tests, described in the Glossary in Appendix A, can considerably reduce the time and costs of the operations required for the characterization and remediation of contaminated sites.

In addition, Environment Canada has financed a major three-year study to develop and test a battery of microbioassays for freshwater sediment toxicity assessment (EC 1997a; Beak International Inc. 1998; Côté et al. 1998a, 1998b). Table 16 shows the two batteries of microbioassays proposed on the basis of this study.

Table 16

Batteries of microbioassays used to assess contaminated freshwater sediments

	Trophic level	Bioassays	Fraction
Battery 1 (screening)	Primary producers	- Algal solid-phase study	Whole sediments
	Decomposers	- ATP tests	Whole sediments
	Include physical/chemical analysis of different parameters (e.g., TOC, granulometry, metals, PAHs, PCBs, NH ₃ , SEM and AVS) of whole sediments		
Battery 2 (confirmation)	Primary consumers	- Conventional bioassay (<i>H. Azteca</i> and/or <i>C. Riparius</i> survival) - Tamonotoxkit ^{F™} or Daphtoxkit ^{F™}	Whole sediments Pore water
	Secondary consumers	- Hydra tests	Interstitial water
	Decomposers	- Microtox® (acute toxicity)	Pore water
		- SOS Chromotest [™]	Pore water

Source: Beak International Inc. (1998).

The first battery, which is designed for toxicity screening of aquatic organisms in direct contact with the sediments, may be useful in optimizing sediment and water sampling programs involving characterization, dredging or remediation operations. If the sediments prove toxic and/or contain high levels of contaminants, the second battery is used for further analysis. The user's guide prepared by Beak International Inc. (1998) in collaboration with the Analytical Chemistry and Toxicology Section of the St. Lawrence Centre indicates the circumstances under which either of these batteries of microbioassays should be used in the management of contaminated sediments and how the results are to be interpreted.

3.4.4 Design of the Sampling Plan

The sampling design is the central element in Step 4 of the design methodology. It specifically defines which questions will be assessed and how spatial and temporal variations associated with different sources of disturbance will be measured.

As indicated in Figure 6, designing the sampling plan involves the following steps:

- Selecting the sampling stations (including reference areas);
- Determining the number of samples required for each variable;
- Establishing sampling frequency;
- Selecting field and laboratory analysis methods;
- Identifying sample storage methods;
- Selecting sampling equipment and procedures, as well as sample identification, packaging and shipment methods.

The scope of the sampling program is obviously dependent, first, on the nature and volume of the sediments to be dredged, the duration of the operations and the technologies used to perform the operations, and, secondly, on the sensitivity of the receiving environment. In addition, selection of the analysis methods must be an integral part of the sample planning process because it influences the sampling protocol and the sample volume required to measure the target substances at the established detection levels and the selection of sample containers and storage techniques (CCME 1993a).

In many ESMPs (e.g., in the case of sediment remediation projects), it is not always possible to collect preoperational data or to establish baseline conditions before an impact has occurred. In such cases, statistical comparisons are made between data distributions at different measuring stations in the study area and those at reference areas (NRC 1990).

It is usually easy to locate appropriate *reference stations to define the baseline conditions of physical or chemical components or parameters*. For example, changes in surface or ground water quality are measured at one or two stations located hydraulically upstream and downstream from the area of the operations. Air quality is assessed at two to four stations, located if possible on the periphery, outside the area affected by the operations.

The situation is quite different when selecting *reference stations for biological components*. For instance, to measure the impacts of dredged material disposal on biological communities, the DAMOS (Disposal Area Monitoring System) program, the environmental surveillance and monitoring program for ocean disposal sites on the east coast of Maine, recommends sampling at least three reference stations at each disposal site. These reference stations are chosen on the basis of the following factors (Germano et al. 1994):

1. The reference stations should have had the same biological community structure as the disposal site (determined by a baseline survey).
2. The reference stations should have had a similar sediment type as the disposal site. The reference stations should show no physical or chemical evidence of historical disposal of dredged material or other wastes.
3. The reference stations and disposal mound should be located within comparable water depths and as near to one another as possible without subjecting the reference stations to the possibility of contamination by disposal operations or post-disposal transport. This can be done by locating the reference station at a position that is offset from the major downstream transport direction(s) of the disposal site.

For *monitoring dredging sites*, water quality sampling stations may be required near sensitive areas, such as drinking water intakes, identified by the impact study, in addition to measuring stations within the plume and one upstream reference station unaffected by the operations. For example, Table 17 summarizes the sampling program used by Environment Canada to assess the environmental performance of new dredging equipment used in the restoration of Ontario's Welland Canal. In addition to identifying the departments involved in the ESMP, the table specifies the action thresholds, the number and location of the sampling stations, the type of samples, the sampling frequency and the physico-chemical parameters requiring systematic monitoring.

As in the case of aquatic disposal site monitoring, the *stations selected for monitoring water quality near the dredge* must undergo sampling before operations begin. This is necessary to determine the natural variability of the parameters studied, particularly during meteorological and hydrodynamic conditions conducive to resuspension in the water column or during periods of heavy ship traffic.

For *monitoring ocean dredged material disposal sites*, Environment Canada's *Interim Monitoring Guidelines for Ocean Disposal* (EC 1993a), the principles of which apply to freshwater disposal site monitoring as well, recommend that the following elements be taken into consideration in the sampling plan:

- Most aquatic disposal site monitoring requires a spatial control (reference site) and a temporal control (baseline information from the disposal site). In addition, some monitoring should occur in areas immediately adjacent to the disposal site. As previously noted, the reference area should have oceanographic, geochemical and biological conditions similar to the disposal site and/or offsite areas under investigation.

Table 17

Sampling program used to assess innovative dredging technologies for sediment management in Ontario's Welland Canal

Monitoring program	Suspended solids	Contaminant mass	Turbidity plume
Required by	OMNR and DFO to protect fisheries	OMOEE to protect the water column from contaminant input	Environment Canada to determine the impact of dredging on water quality
Limiting criteria (thresholds)	TSS <10 % above baseline conditions, or 25 mg/L	Downstream turbidity <80 FTU (formazin units) more than upstream turbidity	TSS <25 mg/L more than baseline conditions 25 m from the dredge
Number and location of sampling stations	2 stations: 1 100 m upstream 1 100 m downstream	3 stations: 1 100 m upstream 1 100 m downstream 1 inside the protective screen (all located 10 to 15 m from shoreline/bank)	3 stations inside the protective screen: 1 10 m upstream from the dredge 1 10 m downstream from the dredge 1 near the dredgehead
Sample type and sampling frequency	2 composite samples per day at each station (consisting of one sample collected above the bottom, at mid-depth and near the surface and one at ¼, ½ and ¾ the width of the canal)	1 composite sample per day at each station, collected by an automatic sampler (1 sample every 15 minutes during dredging)	1 sample per performance test
Parameters of interest	Turbidity, TSS	Dissolved oxygen, temperature, pH, conductivity, turbidity, oil and grease, BOD, COD, DOC, PT, NH ₃ , NO ₃ + NO ₂ , TKN, 24 metals measured by plasma emission spectrometry, TDS, VSS and TSS	Turbidity, TSS

Source: Milles (1995).

OMNR : Ontario Ministry of Natural Resources
DFO : Fisheries and Oceans Canada
OMOEE : Ontario Ministry of the Environment and Energy

- Sediment transport models (see Appendix C) will help to define the initial area of deposition used to determine the boundaries of the ocean disposal site and thus contribute to the design of the environmental surveillance and monitoring program. Geological studies are useful as well in confirming the predictions, while historical data help to define the boundaries of existing disposal sites.
- For each ocean disposal site, the number of samples required and the design of the optimal sampling plan may also be determined on the basis of pilot environmental monitoring studies, existing historical data and statistical methods of analysis.
- Once again, it is essential that temporal variability be taken into consideration in the design of the sampling program, for example, when samples must be collected every year at a precise time of the year, or to establish time series when long-term changes are of a matter of concern.

It is often difficult to determine the number of samples to be collected at each station because the number is proportional to the spatial or temporal heterogeneity of the variable to be measured. Statistical analyses require a minimum of three replicate samples to establish the mean and standard deviation. From 10 to 20 may be required to measure impacts on biological communities, depending on the processes or communities concerned.

For *aquatic, shoreline or upland containment* operations, the choice of the parameters and stations to be sampled is dependent on the contaminant migration pathways. Each potential source and each environment receiving contaminant losses (see Appendix C) should ideally be monitored with respect to the source (e.g., liquid effluent from upland containment facilities) and/or the receiving environment (e.g., ground water), depending on whether physical, chemical or biological processes are involved.

For the *treatment of contaminated sediments*, all sources of atmospheric emissions and discharges of wastewater or solid residues should be monitored as well, together with reference stations for the quality of ambient air and surface and ground water likely to be influenced by the operations. As illustrated in Figure 8, all components of a conventional treatment system are capable of generating gaseous, liquid or solid discharges.

In the case of an ESMP for *contaminated sediment demonstration and treatment projects*, additional sampling points are normally required to assess the fate of the contaminants (water, air, soil, sorbent media), establish mass balances or demonstrate the effectiveness of treatment systems or pollution control equipment.

Because of the number of sampling stations, the wide range of contaminants (heavy metals and organic compounds) and the corresponding costs of analysis, the samples to be analysed are generally collected once or twice a day and consist of subsamples collected every hour or two, depending on the stability of the treatment processes used. For proven technologies, the requirements in terms of the number of stations and sampling frequency are generally considerably lower.

The reader is referred to Appendix D.3 for the publications listing the elements to be considered in the design of sampling plans for monitoring the physical and biological impacts of dredging and of aquatic and upland disposal sites, as well as sediment treatment projects.

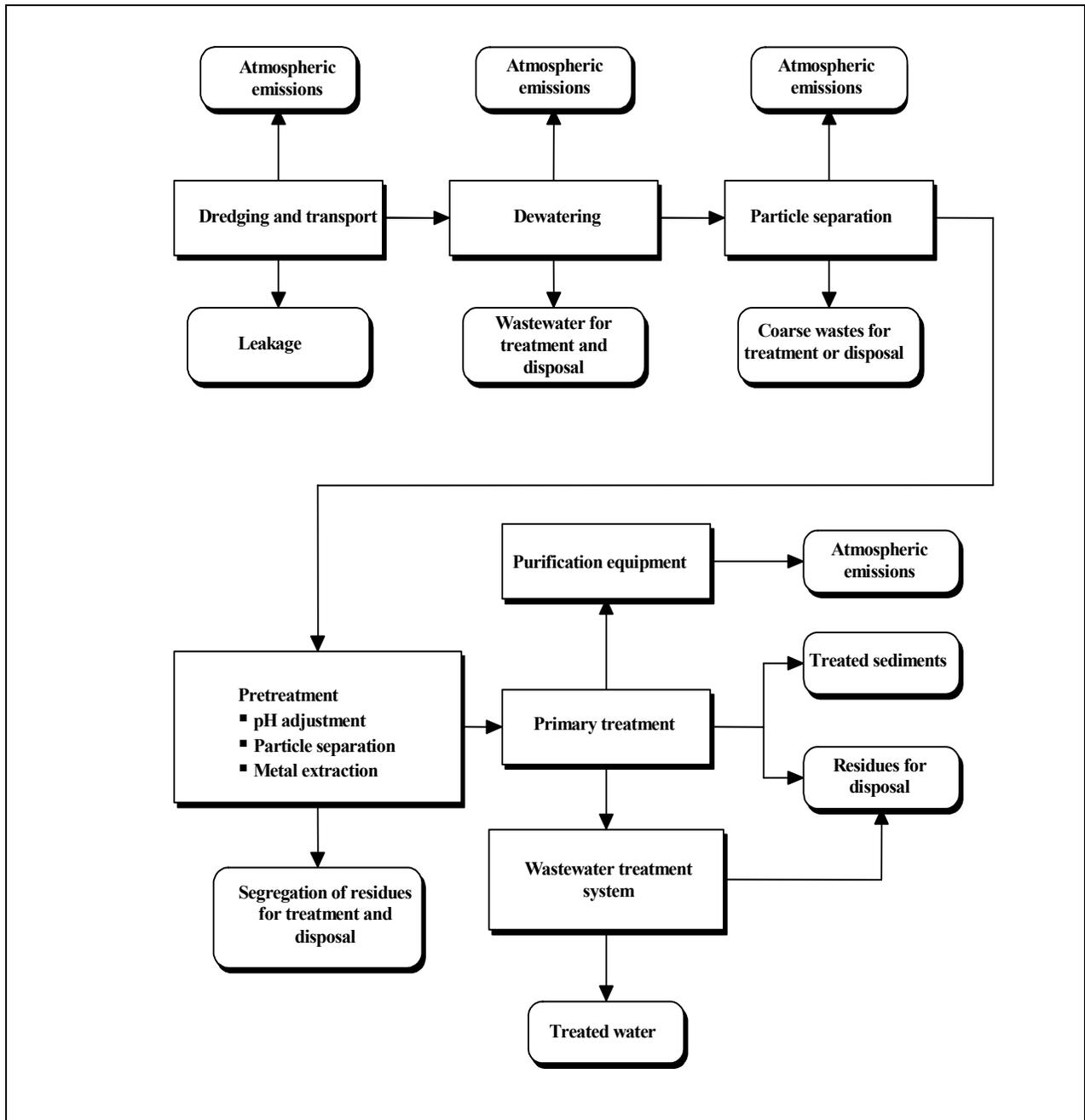


Figure 8 Environmental discharges to be monitored in a conventional contaminated sediment treatment system

3.4.5 Identification and Selection of Data Analysis and Interpretation Methods

Before embarking on the identification and selection of methods of data analysis and interpretation, it is important to implement a number of processes and protocols to ensure that the data produced by the ESMPs are credible. The management aspects of a QA program for data quality are described in detail in a document published the Canadian Council of Ministers of the Environment (CCME 1993a):

- Data recording and documentation, including data custody and data transfer reports;
- Validation of data completeness and representativeness;
- Verification of data quality (adequacy, representativeness, validity);
- Data handling, particularly data rounding and treatment of significant figures;
- Data transmission, particularly electronic transmission;
- Data evaluation, particularly interpretation, recording and preparation of laboratory reports.

In addition, since the raw data collected in an ESMP frequently do not directly address public concerns or the information needs of decision makers, they must be processed, synthesized and organized on the basis of the program's objectives.

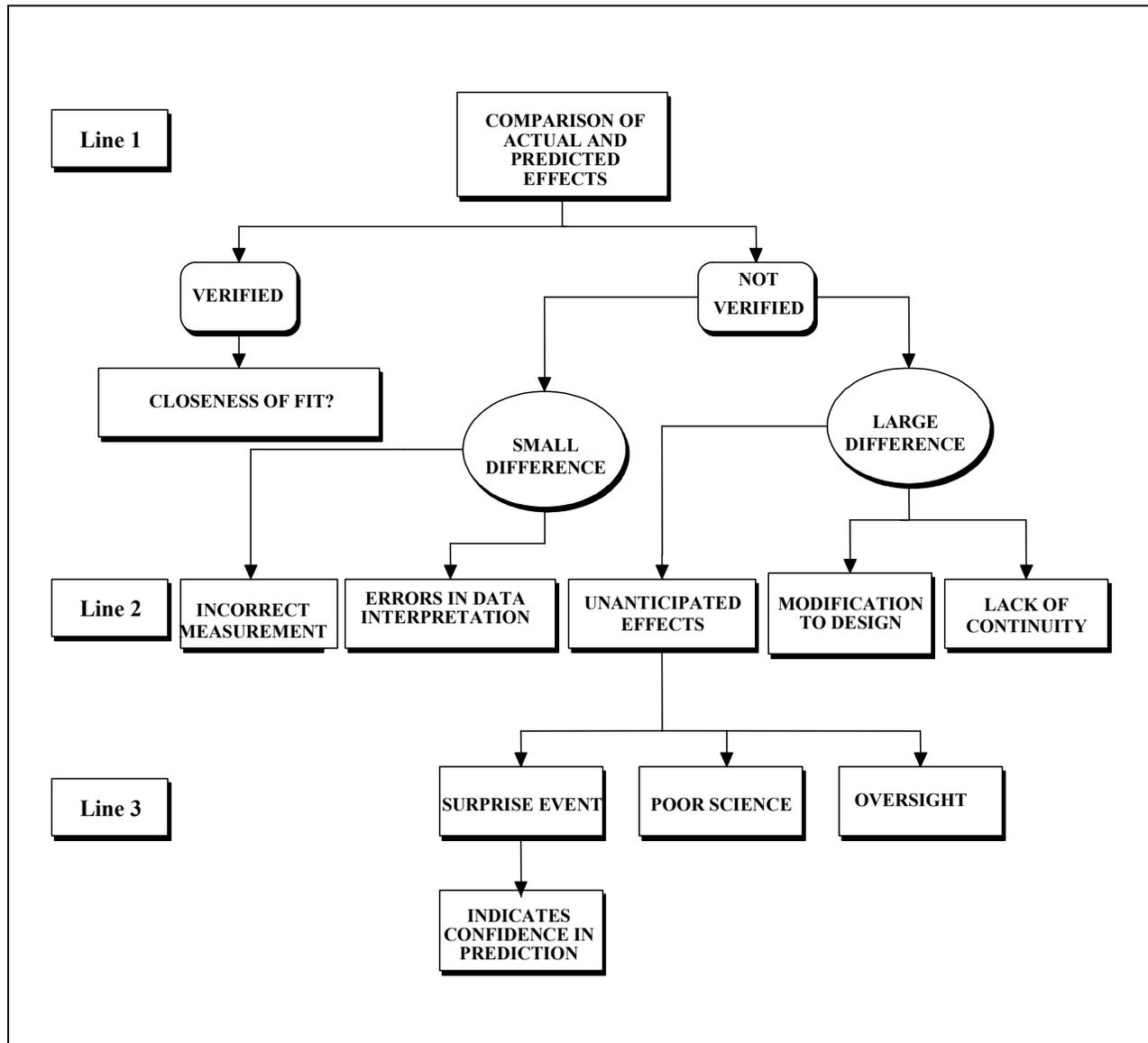
For example, measurements of contaminant concentrations in the water or sediments near a discharge are not, in and of themselves, useful information. The data must be analysed and mapped in order to identify patterns and trends. They must then be combined with additional data (e.g., background levels, transport processes and flux rates) to define exposure or combined with the results of studies of pollutant transport and effects research (e.g., bioassay experiments) to assess the risks to and consequences for aquatic organisms and human health.

One way to ensure the utility of the information obtained is to use a phased analysis approach. This approach involves collecting data early in the monitoring program and using them to develop and, if necessary, refine routine analysis methods, classify the data into spatial and temporal components, determine the adequacy of the sampling design and methods, define the status of its relationship to historical conditions and develop a preliminary understanding of links between components and processes (NRC 1990).

When identifying and selecting methods for interpretation and analysis of the results, it is important to remember that the purpose of the analysis is to determine the extent to which the predictions being tested are either substantiated or refuted on the basis of data provided by ESMP. For the analysis of numerical data sets, acceptable statistical methods are most likely to be appropriate, e.g., Student's t-tests, ANOVA (analysis of variance) and chi-square tests. The various methods of statistically analysing the results generated by ESMPs are described in the following reference documents: Green (1979); Fredette et al. (1990b); USEPA/USACE (1994; 1991); Mann et al. (1995a; 1995b). Appendix E presents a summary of the statistical formulae normally used to determine the number of samples required for these statistical methods.

To explain the likely causes of variance between predicted and actual effects during data analysis, Davies and Sadler (1990), in a document entitled *Post-Project Analysis and the Improvement of Guidelines for Environmental Monitoring and Audit*, prepared for Environment Canada, propose the probable-cause flowchart illustrated in Figure 9. Thus, Line 1 represents the comparison of actual and predicted effects as having two possible outcomes: either the predictions are verified by empirical data or they are not. When predictions are verified, an attempt may be made to establish some measure of the "extent" of verification, i.e. the closeness of fit or accuracy of prediction. It may also be possible to convert this measure to a threshold level, below which predictions are deemed not to be verifiable by empirical data.

Line 2 of Figure 9 suggests five possible reasons why environmental impact predictions may not be verified by empirical observation, depending on whether the differences observed are small (incorrect measurement during monitoring activities, or errors in data interpretation or prediction) or large (lack of continuity in personnel, changes or modifications to project or monitoring program design, or an unanticipated or unpredicted event). Finally, if an unanticipated or unpredicted event occurs, Line 3 suggests three reasons why this may be the case.



Source: Adapted from Davies and Sadler (1990).

Figure 9 Flowchart for considering causes of variance between predicted and actual effects

As noted by Davies and Sadler (1990), this figure is not intended to provide a procedure for the analysis of environmental impact predictions. Rather, it suggests, in the form of a flow chart, a number of possible outcomes that could help explain the possible variance between observed effects of a project and those effects predicted during the ESMP.

Data from sediment sampling programs and ESMPs must often be analysed and interpreted in terms of chemical, toxicological and biological quality. This can be done by means of a triad, or three-pronged, approach (Sediment Quality Triad), as proposed by Chapman et al. (1987; 1992), Chapman (1986; 1989) and the USEPA (1992a). Table 18 illustrates how the results of chemical, toxicological and biological analyses can be generally interpreted.

For instance, when the ESMPs indicate that the project results in a decline in sediment chemical quality, increased toxicity and degradation of biological communities, it can be concluded that the project has real impacts on the environment. On the other hand, if the ESMP results demonstrate non-degradation of the chemical, toxicological and biological quality of the sediments, it is easier to conclude that the project generates no environmental impacts. When the results of the chemical, toxicological and biological analyses are contradictory, Table 18 proposes possible explanations for consideration.

This triad approach is being used to an increasing extent by Environment Canada to interpret the results of ESMPs for ocean dredged material disposal sites. For example, it was first used in Quebec for analysis and interpretation of the ESMP data for the Grande Entrée disposal site (Magdalen Islands) (St-Laurent et al. 1999).

Table 18**Possible conclusions arising from sediment quality analysis using the triad approach**

Variables used in the triad approach to assessing sediment quality			
Sediment contamination	Sediment toxicity	Alteration of benthic communities	Possible conclusions
+	+	+	Strong evidence that pollution is causing environmental degradation
-	-	-	Strong evidence that environmental degradation is not caused by pollution
+	-	-	The contaminants are probably not bioavailable
-	+	-	Unmeasured chemical substances or other conditions may be causing environmental degradation
-	-	+	The alteration is probably not caused by toxic chemical contamination
+	+	-	Chemicals are causing stress on the environment
-	+	+	Unmeasured chemicals are causing toxicity that is resulting in environmental degradation
+	-	+	Non-bioavailable chemical substances or alterations are not caused by the toxicity of the chemicals

Sources: USEPA (1992a, 1994a).

+ = Measured differences between tested and control samples or samples from reference stations.

- = No measured differences between tested and control samples or samples from reference stations.

3.5 Design of the Action Plan (Management Options and Response Measures) (Step 5)

If the results of the ESMP demonstrate that the project is causing effects beyond the established action thresholds and that the null impact hypotheses are therefore not refuted, it is important that the proponents/managers have a previously determined action plan defining the criteria for action in each case and describing in detail the response measures and procedures for rapid implementation.

As indicated in Figure 10, the action plan may include the adoption of a more extensive ESMP to confirm or disprove the concerns, the implementation of response or mitigation measures or even the temporary suspension of operations.

Table 19 presents examples of management options or mitigation measures to reduce contaminant production and migration at dredging sites, aquatic disposal or containment sites and upland containment facilities. It will be noted that a number of measures are available to reduce the concentrations of suspended solids and contaminants in the water column at dredging and aquatic or upland disposal sites. For upland sediment disposal, containment or treatment, a number of measures can be used to reduce contaminant concentrations in gaseous, liquid and solid emissions and the risks of migration in air, soil and groundwater and thus to limit the pathways by which natural and human environments are exposed to the contaminants. Other mitigation measures that can be used to reduce the risks of contaminant migration in sediment remediation projects are listed in Appendix F.

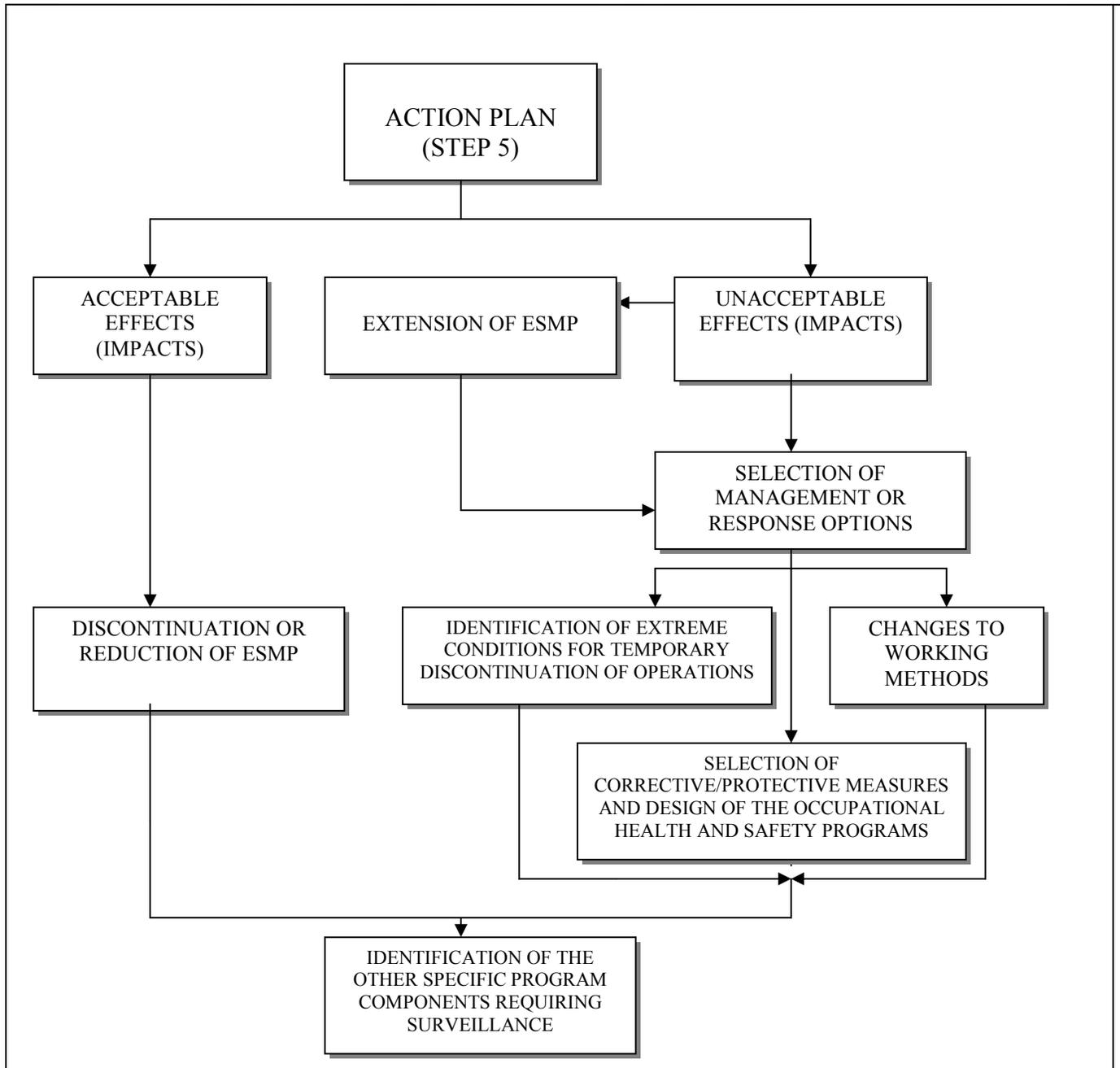


Figure 10 Design of action plan and identification of other project components requiring surveillance (Steps 5 and 6)

Table 19

Examples of management options or mitigation measures applicable to ESMPs for dredging and sediment management projects

Contaminant migration pathway	Management options – Mitigation measures
<p><i>Water column</i> Reduction of concentrations of resuspended and redissolved solids and contaminants, and reduction of transport by current advection</p>	<p><u>Dredging/transport</u></p> <ol style="list-style-type: none"> 1. Limit operations to favourable points in the tidal/hydrological cycle. 2. Reduce time and rate of dredging operations. 3. Reduce depth of cut. 4. Optimize cutterhead speed with pump power. 5. Increase suction pump power. 6. Install an impermeable cover near the cutterhead. 7. Improve gaskets on mechanical grab samplers, barges or discharge pipelines and on buckets, cars or tankers used to transport dredged material. 8. Install protective screens/curtains (watertight liners, sheet piling, bubble curtains) at the work site or near sensitive areas. 9. Prohibit use of overflow when filling barges/scows. <p><u>Open-water disposal/containment</u></p> <ol style="list-style-type: none"> 1. Limit operations to favourable points in the tidal/hydrological cycle. 2. Reduce the volume of materials per discharge. 3. Install submerged diffusers on discharge pipelines. 4. Cap contaminated sediments with clean materials. 5. Load sediments on barges/scows in geotextile bags. 6. Consider the use of barges/scows in place of discharge pipelines. <p><u>Upland disposal/containment</u></p> <ol style="list-style-type: none"> 1. Reduce hydraulic flows of deposited materials. 2. Add flocculants or physical barriers to improve sedimentation. 3. Check the operation or installation of physical/chemical effluent treatment systems.
<p><i>On land</i> Reduction of contaminant concentrations in gaseous, liquid and solid wastes; reduction of risks of contaminant migration in air, soil, groundwater and sewer systems, and reduction of pathways of exposure for natural and human environments</p>	<p><u>Upland disposal/containment</u></p> <ol style="list-style-type: none"> 1. Maintain water cover over sediments or keep surface layer wet throughout the containment period. 2. Improve dike impermeability. 3. Cap contaminated sediments with clean materials or install watertight liners. 4. Plant vegetation screens or erect earthen berms around the disposal site. <p><u>Treatment of contaminated sediments</u></p> <ol style="list-style-type: none"> 1. Reduce treated flows. 2. Ensure that all sources of gaseous, liquid and solid wastes are recovered and directed to the treatment equipment. 3. Ensure that the equipment is operating properly in accordance with the manufacturer's specifications. 4. Add further treatment systems. 5. Review the selection of technological components for the entire treatment process.

In addition to these response and monitoring measures, ESMPs must include occupational health and safety programs and emergency plans. The occupational health and safety programs must specify the requirements regarding the use of safety helmets, safety boots, safety goggles, masks, self-contained breathing apparatus, gloves and hazardous materials suits. In addition, devices to monitor individual exposure to certain chemicals or to chemical concentrations in the ambient air may also be required (CCME 1993a). The document entitled *The Inspector's Guide – A Field Guide for Environment Canada Inspectors* (1996b) lists some good examples of safety measures for sample-collection personnel.

The emergency measures plan should be designed to identify the principal responses to be considered in the event of an incident or accident and specify the mechanisms for transmitting the alert and how these mechanisms fit in with the emergency plans of the municipalities concerned. Table 20 presents the standard emergency measures plan proposed by the Quebec Ministère de l'Environnement (MEF 1997a; 1997b).

Table 20

Standard emergency measures plan

-
- Description of accident scenarios used for planning: consequences, probability of occurrence, areas affected, etc.
 - Description of various possible and probable situations involving risks of minor accidents confined to the project site.
 - Emergency information: names, addresses and telephone numbers of persons in authority, list of available equipment, site plans, assembly points, list of safety equipment.
 - Company emergency response structure and decision-making mechanisms.
 - Protective measures for populations that may be affected.
 - Effective alarm and evacuation procedures for populations that may be affected, in cooperation with the municipal and government agencies concerned.
 - Emergency measures updating and review program.
-

Sources: Adapted from MEF (1997a; 1997b).

The instructions contained in the emergency plan should be an integral part of the training program for employees on all sites. All of the materials required for immediate action in the event of an incident, as listed in the emergency plan, should be readily available on site. Copies of the emergency plan should be distributed to all relevant agencies that may be called to the site (police, fire department, etc.).

In planning these response measures, it is important to ensure that they are technically, logistically and economically feasible, and that they can be implemented rapidly or replaced by alternative scenarios if necessary.

Project proponents should therefore structure their action plans in the form of decision trees or summary tables clearly identifying the sampling programs, decision points and measures to be taken during operations in the event of non-compliance with the action thresholds or null impact hypotheses.

Figure 11 presents an example of a decision tree applicable to the action plan of a tiered ESMP for a dredging or open-water dredged material disposal site. For instance, if the physical parameters measured in tier 1 indicate that the pre-established thresholds have been exceeded, the proponent must correct the situation by implementing appropriate mitigation measures; if these are not effective, a more detailed ESMP (tier 2) must be implemented to avoid potential chemical or toxicological impacts. If the results of the microbioassays demonstrate potential toxicity, the proponent may continue the analysis to determine whether it is confirmed by toxicity analyses performed by means of a battery of standard bioassays (tier 3). For each level of analysis, the decision tree indicates the points at which the proponent must decide to discontinue the operations, implement mitigation measures or consider reducing or increasing the sampling frequency, for example, and/or the number of parameters to be monitored in the ESMP.

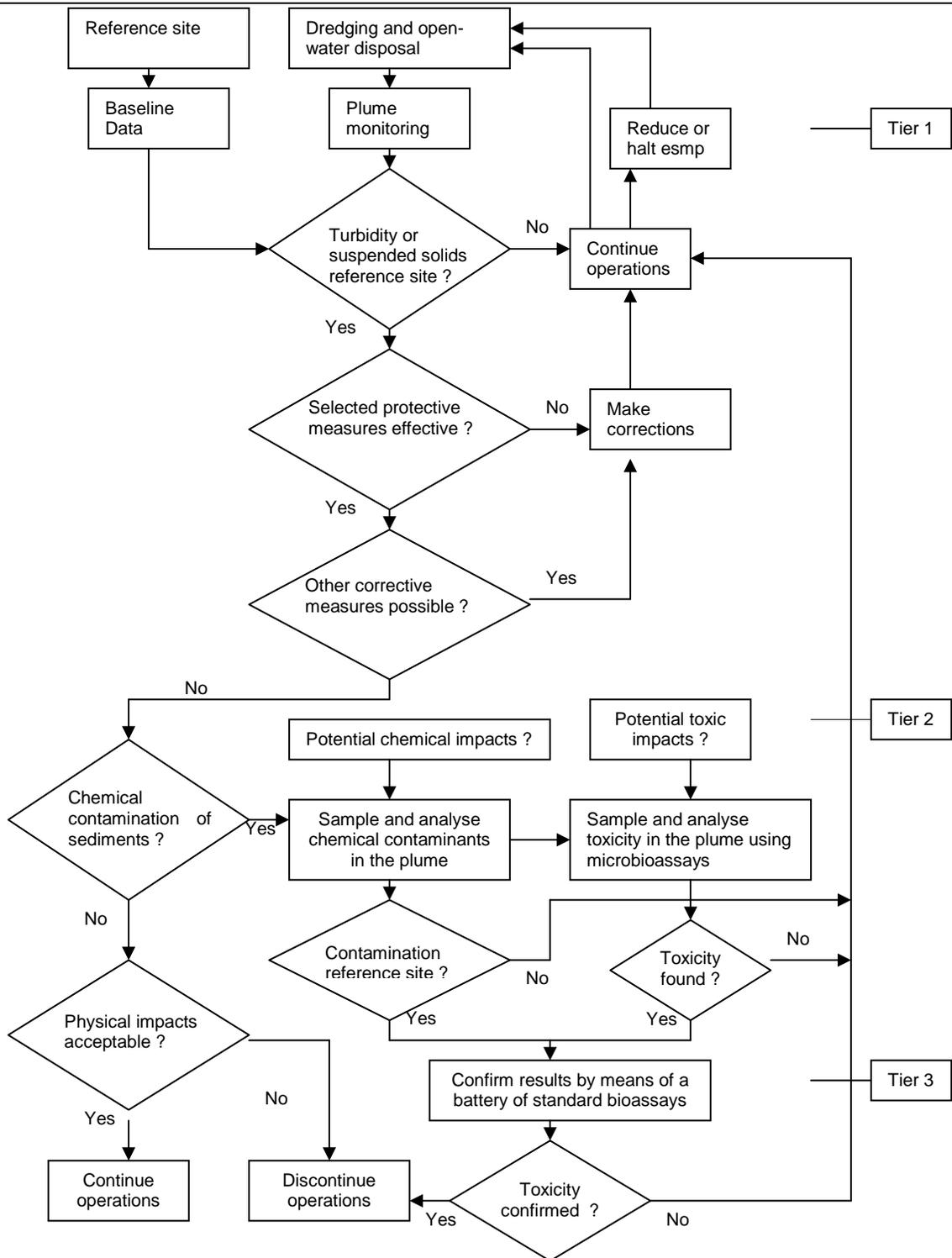


Figure 11 Example of a decision tree applicable to the action plan of a tiered ESMP for a dredging and open-water disposal site

Tables 21 and 22 respectively present examples of decision trees in the form of summary tables for use with a tiered ESMP for a dredged material disposal site and an aquatic contaminated material containment site. These tables identify the sampling programs for each level of analysis, the sampling frequency, the action thresholds and the action to be taken if the results of the ESMP indicate that these levels have or have not been exceeded. More detailed examples of management options for aquatic disposal sites are presented by Fredette et al. (1990a).

These decision trees or tables may be posted in strategic locations to inform all stakeholders of the activities and mitigation or management measures included in the action plan.

Table 21

Example of an action plan applicable to tiered ESMPs for aquatic dredged material disposal sites in the United States

Monitoring strategy	Monitoring frequency	Predefined threshold for action	Management options	
			Threshold not exceeded	Threshold exceeded
Dredged material/Site material = SAND/SAND		Sensitive resource nearby = No		
TIER 1 - Bathymetry, coarse grid	Following disposal annually	- Mound height within 1.5 m of forming a navigation hazard	- Discontinue monitoring - Continue monitoring at same tier	- Move/rotate disposal points within site
TIER 2 - Bathymetry, fine grid	Annually	- Mound height within limits of navigation hazard	- Continue monitoring at lower tier	- Move up one monitoring tier - Use dispersed disposal
TIER 3 - Bathymetry, fine grid	Biannually	- Mound forms definite navigation hazard		- Limit quantity of material - Move/redredge material - Cease site use
Dredged material/Site material = SAND/SAND		Sensitive resources nearby = Yes, clam bed		
TIER 1 - Bathymetry, coarse grid - Current meter	Following disposal annually	1) Mound height within 1.5 m of forming a navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Predominant currents in direction of clam bed	- Discontinue monitoring - Continue monitoring at same tier - Continue monitoring at lower tier	- Move up one monitoring tier - Move/rotate disposal points within site - Use dispersed disposal - Limit quantity of material
TIER 2 - Bathymetry, fine grid (incl. clam bed) - Current meter - Grab samples on mound and clam bed - Grabs/cores/penetrometer to map mound fringe and accumulation in clam bed (sand tough to penetrate)	Biannually	1) Mound at limit of navigation hazard and/or 2) Increase in fine sediment content of clam bed approaches hazard level and/or 3) Rate of sand accretion in clam bed approaches limit of recovery from burial		- Change timing of disposal - Move/redredge material - Construct underwater containment berm - Cease site use
TIER 3 - Bathymetry, fine grid (incl. clam bed) - Current meter - Sample clam population - Grabs/cores/penetrometer to map fringe of mound and accumulation in clam bed (sand tough to penetrate)	Biannually	1) Mound forms definite navigation hazard and/or 2) Clam mortality imminent from fine sediment increase and/or 3) Clam mortality imminent from burial		

Source: Fredette et al. (1990).

Table 22

Example of an action plan applicable to a tiered ESMP for aquatic contaminated sediment capping projects in the United States

Monitoring strategy*	Monitoring frequency	Predefined threshold for action	Management options	
			Threshold not exceeded	Threshold exceeded
TIER 1				
<ul style="list-style-type: none"> - Bathymetry - Sub-bottom profiles - Side-scan sonar - Sediment profile camera - Surface grab samples - Cores - Water samples 	Pre-, post-placement, annually	<ul style="list-style-type: none"> - Mound within 1.5 m of forming a navigation hazard - Cap thickness decreases 0.15 m - Contaminant exceeds limit in sediment or water sample 	<ul style="list-style-type: none"> - Continue to monitor at the same tier - Move up one monitoring tier - Discontinue monitoring 	<ul style="list-style-type: none"> - Go to next tier - Stop using site - Increase cap thickness
TIER 2				
<ul style="list-style-type: none"> - Bathymetry - Sub-bottom profiles - Side-scan sonar - Sediment profile camera - Cores - Water samples - Consolidation instrument 	Biannually	<ul style="list-style-type: none"> - Cap thickness decreases 0.30 m - Contaminant exceeds limit in sediment or water sample 	<ul style="list-style-type: none"> - Continue to monitor at same tier - Move up one monitoring tier 	<ul style="list-style-type: none"> - Go to next tier - Replace cap material - Increase cap thickness - Stop using site
TIER 3				
<ul style="list-style-type: none"> - Bathymetry - Sub-bottom profiles - Side-scan sonar - Sediment profile camera - Consolidation instrument - Surface grab samples - Cores - Water samples - Tissue samples from target aquatic organisms 	Monthly to biannually	<ul style="list-style-type: none"> - Cap thickness decreases 0.30 m - Contaminant exceeds limit in sediment or water sample - Contaminant exceeds limit in tissue of target organisms 	<ul style="list-style-type: none"> - Continue to monitor at same tier - Move up one monitoring tier 	<ul style="list-style-type: none"> - Replace cap material - Increase cap thickness - Stop using site - Change cap sediment - Redredge and remove contaminated sediments

Source: Palermo et al. (1992).

* Consult the study on baseline conditions at the disposal site, the Advisory Committee and the impact report to define the physico-chemical and biological components of the monitoring program.

3.6 Identification of the Other Specific Components of the Project Requiring Surveillance (Step 6)

In addition to the implementation of a sampling and analysis plan, most ESMPs must provide for the surveillance and monitoring of certain specific components of the project (e.g., the scope and timetable of operations, methods of residue management), equipment operation (e.g., used oil management methods, condition of the equipment, watertightness of transport equipment) or the environment (bank or dike erosion, interference with commercial navigation or recreational boating, specific meteorological conditions, etc.).

These specific components requiring surveillance are listed in tables that may serve as checklists of good environmental practices to be adopted in connection with ESMPs. These good practices may be general in nature and applicable to all activities of a dredging and sediment management project (e.g., ensure that the selected equipment is compatible with the nature and scope of the operations). Others will be more specific to dredging sites (e.g., verify the proper operation of the dredge positioning systems), disposal sites (e.g., monitor the quality of the deposited materials) or treatment sites (e.g., monitor the effectiveness of the atmospheric emission collection and treatment systems) (see Table 23).

In addition to the mitigation measures and good environmental practices presented in Tables 19 and 23 respectively, the reader is advised to consult the documents listed in Appendix D.4 and the tables in Appendix F.

Table 23**List of good environmental practices to be monitored in ESMPs for dredging and sediment management projects**

Project components	Good environmental practices
General	<ol style="list-style-type: none"> 1. Ensure that the selected equipment is compatible with the nature and scope of the operations. 2. Ensure that the equipment is properly maintained and operated by qualified personnel. 3. Verify the watertightness of the equipment used for sediment excavation, transport, storage and treatment. 4. Ensure that workers use adequate protective equipment. 5. Verify the implementation of programs for workers: environmental awareness and training, occupational health and safety. 6. Verify the implementation of emergency measures plans. 7. Ensure adequate signage of work areas. 8. Ensure that access to the work site is properly controlled. 9. Keep a detailed log of all operations. 10. Ensure that operations do not interfere with other land and water uses. 11. Maintain an effective system of communication between all work areas.
Dredging	<ol style="list-style-type: none"> 1. Verify the proper operation of the dredge and transport barge/scow positioning systems. 2. Verify the proper operation of the instruments for monitoring extraction and water-sediment mixing during dredging operations. 3. Ensure that barges are not filled to maximum capacity. 4. Monitor the bathymetry frequently at the dredging site to avoid under- or overdredging.
Aquatic disposal or containment	<ol style="list-style-type: none"> 1. Monitor the quality and quantity of the deposited materials. 2. Monitor the bathymetry frequently to avoid exceeding site capacity. 3. Ensure that disposal sites are clearly defined, marked and observed.
Upland disposal or containment	<ol style="list-style-type: none"> 1. Monitor the quality and quantity of the deposited materials. 2. Verify the impermeability of the dikes and impermeable liners. 3. Monitor the condition of ditches for collecting and diverting natural drainage water from the site. 4. Monitor the effectiveness of the effluent treatment station. 5. Ensure that the transport equipment is decontaminated before leaving the disposal areas. 6. Ensure that the water used to wash the transport equipment is collected, monitored and, if necessary, treated before being discharged into the environment.
Treatment	<ol style="list-style-type: none"> 1. Monitor the effectiveness of the atmospheric emission collection and treatment systems. 2. Monitor the effectiveness of the wastewater collection and treatment systems. 3. Monitor the watertightness of the liquid, sludge and solid handling and storage systems. 4. Ensure that the transport equipment is decontaminated before leaving the treatment areas. 5. Ensure that the water used to wash the transport equipment is collected, monitored and, if necessary, treated before being discharged into the environment. 6. Ensure that the quality and quantity of the substances (liquids, solids and sludges) are monitored before final disposal.

4 Implementation of an Environmental Surveillance and Monitoring Plan (Step 7)

As soon as the ESMP is approved by the responsible authorities, work can begin on its implementation (Step 7), which consists of seven activities: Identification of the mechanisms for communicating the results and the decision-making system; Preparation of the specifications for the surveillance and monitoring program; Tendering and selection of the consultant for program implementation; Employee awareness and training program; Sampling, analysis and inspection of the operations; Interpretation and communication of the results; and Implementation of the response measures (see Figure 12).

4.1 Identification of the Mechanisms for Communicating the Results and the Decision-making System

In order to ensure that the selected response measures can be rapidly implemented if the ESMP identifies impacts at levels beyond the acceptable thresholds, it is important that the mechanisms for communicating the results and the decision-making system be established in advance and, if necessary, posted in critical locations before operations begin.

These communication and decision-making systems should indicate clearly *who* is responsible for reporting the results, *how*, *when* and *to whom* they will be reported and especially, who will have the authority to order implementation of the proposed response measures. Since these measures may extend to temporary or permanent discontinuation of the operations, it is important that the chain of command be predetermined and approved by all stakeholders (proponents, contractors, consultants, departments).

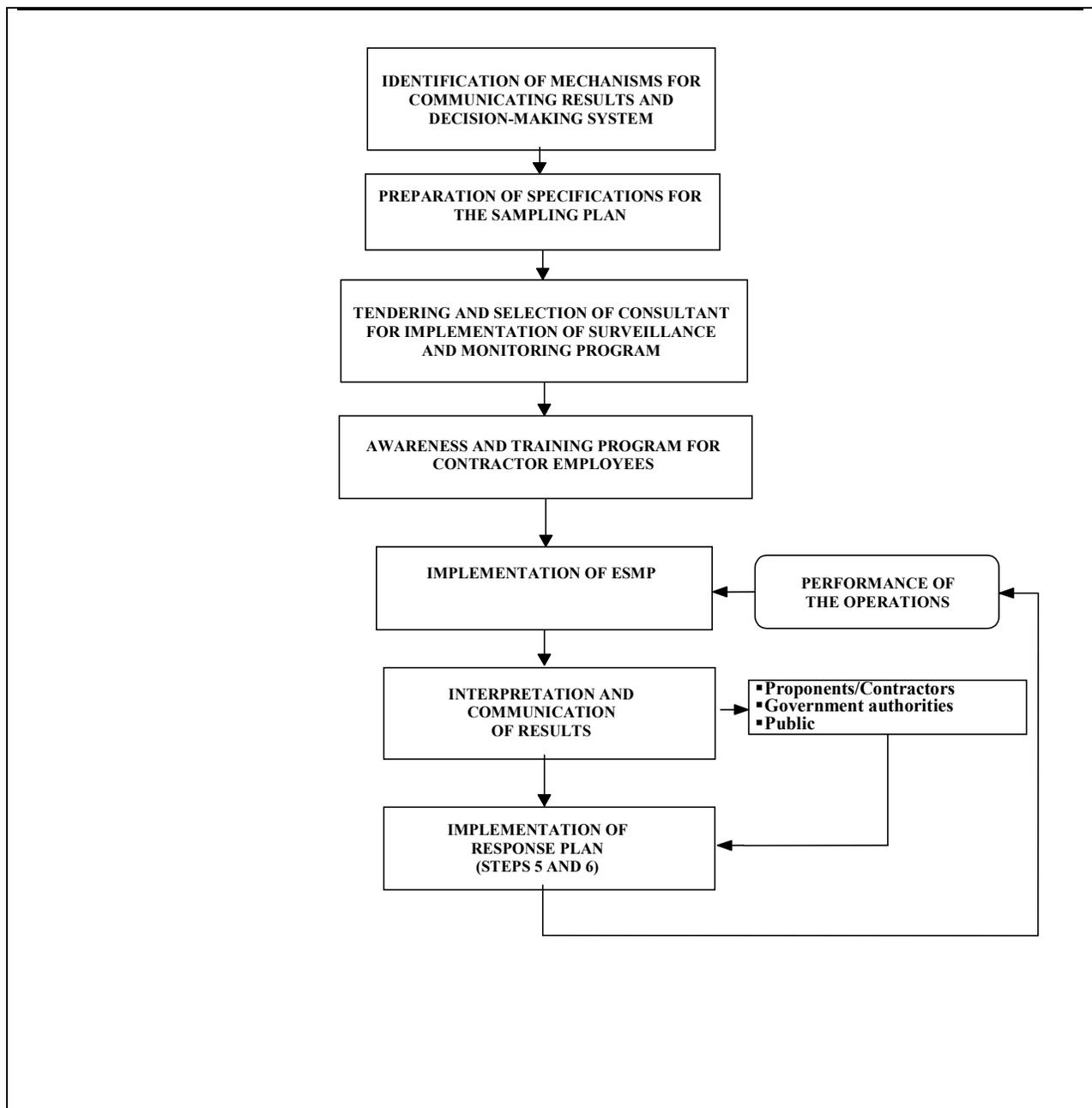


Figure 12 Implementation of the environmental surveillance and monitoring program (Step 7)

4.2 Preparation of Specifications for the Surveillance and Monitoring Program

Once all the steps and components of the ESMP have been developed and all the requirements of the sampling and analysis plan defined in detail, specifications can be developed for the tender call to the consultants who will be responsible for implementing the ESMP on behalf of the proponents.

4.3 Tendering and Selection of Consultant for Program Implementation

After calling for tenders, the proponent will select the consultant it considers best qualified on the basis of the expertise and experience of its personnel, the proposed methods and the costs of implementing the ESMP as defined in the specifications.

4.4 Employee Awareness and Training Program

Before beginning operations, it is important that the consultant responsible for implementing the ESMP develop an awareness and training session for all operators and employees of the contractors and subcontractors selected to perform the work.

All the requirements and response measures will be presented and the responsibilities of each of the stakeholders will be described to ensure rapid and effective application of the proposed action plan. The consultant will use this session to inform employees of the potential impacts of the project and the importance of ensuring environmental protection through the use of good environmental practices in all phases of the operations.

4.5 Sampling, Analysis and Inspection of Operations

When all of the above steps have been completed, the operations and activities of the surveillance and monitoring program may begin.

4.6 Interpretation and Communication of Results

As soon as the results of the analyses performed on site or by outside laboratories are available, they must be interpreted and communicated rapidly to all stakeholders (proponent, contractors, government authorities and, in some cases, the public). To facilitate a rapid review of these results, it is important that they be presented graphically or in some other visual form that indicates at a glance whether or not the project has produced readings that exceed the unacceptable impact thresholds and whether the null impact hypotheses are confirmed.

4.7 Implementation of Response Measures

As indicated in Figure 12 and described in Section 3.5, possible response measures generally include: temporary discontinuation of the operations to review working methods; implementation of specific mitigation measures; or modifications to the ESMP itself (e.g., a reduction or increase in sampling frequency or the introduction of a more detailed sampling and analysis plan).

It is important that, throughout the operations, the consultant responsible for implementing the ESMP keep a log of project data, meteorological conditions, any anomalies observed and response measures implemented.

5 Dissemination of the Results

5.1 Preparation of the Final Report (Step 8)

The report preparation stage is an important element of the ESMP because the report must describe the ESMP in detail, from the rationale for its existence to the results and their interpretation. If necessary, the report must include recommendations on tightening or relaxing the mitigation or environmental protection methods or on improving the effectiveness of the environmental assessment methods. In addition, the information contained in the report will facilitate the design and implementation of future ESMPs.

In preparing the reports, it is important to bear in mind that the results of monitoring programs should be disseminated to a range of audiences and at several technical levels. Monitoring programs that produce only technical reports summarizing data and scientific findings are not likely to show the public or decision makers that they provide information essential to better environmental protection or management decisions. In fact, information obtained from an ESMP can only aid management when it is delivered to managers and decision makers in a usable, accessible form (NRC 1990).

Since ESMPs are based on testable impact hypotheses that are designed to be as realistic as possible, it is important to realize that monitoring is limited in terms of its ability to quantify changes and to identify their causes. The reality of imperfect knowledge about marine systems means that monitoring should be used as an opportunity to increase and refine our knowledge of them. Data and information derived from ESMPs should be used to check, validate and refine the assumptions, models and understandings on which the ESMP was based (NRC 1990).

Environmental surveillance and monitoring reports must clearly indicate the links that exist between the impact hypotheses arising from the permit application review, on the one hand, and the objectives and results of the ESMPs, on the other. They must also present information on the parameters selected for analysis, the surveillance and monitoring tools, the sampling plan and the methods of data analysis and interpretation. In addition, they must clearly indicate the results

used to determine whether the permit conditions have been met and whether the hypotheses advanced in the course of the permit application review and the federal or provincial environmental assessment procedures are accurate and sufficient to ensure environmental protection. Figure 13 illustrates the typical content of a surveillance and monitoring report.

5.2 Dissemination of the Report (Step 9)

Because of the significance of these reports to a number of stakeholders and the general public, it is important that the environmental surveillance and monitoring reports on dredging and sediment remediation projects be published by the project proponents or environmental organizations.

Groups with a particular interest in the publication of these reports include: regulatory agencies, which can use the results to improve the standards, regulations and guidelines for impact studies; project proponents, who can use them to improve the design and implementation of their projects; and environmental assessment practitioners, who will generally benefit from a better understanding of the predictive capabilities of the various methods and techniques used in environmental planning and management.

It is for this reason that Environment Canada – Quebec Region (1994a), in collaboration with the Ontario Region, has published a document entitled *Environmental Impacts of Dredging and Sediment Disposal*. This report reviews the results of the ESMPs for a dozen dredging projects performed in the Great Lakes or on the St. Lawrence River between 1983 and 1992 and involving open-water or upland disposal of dredged material. The results demonstrate that these projects have produced very limited or negligible impacts on the environmental components monitored.

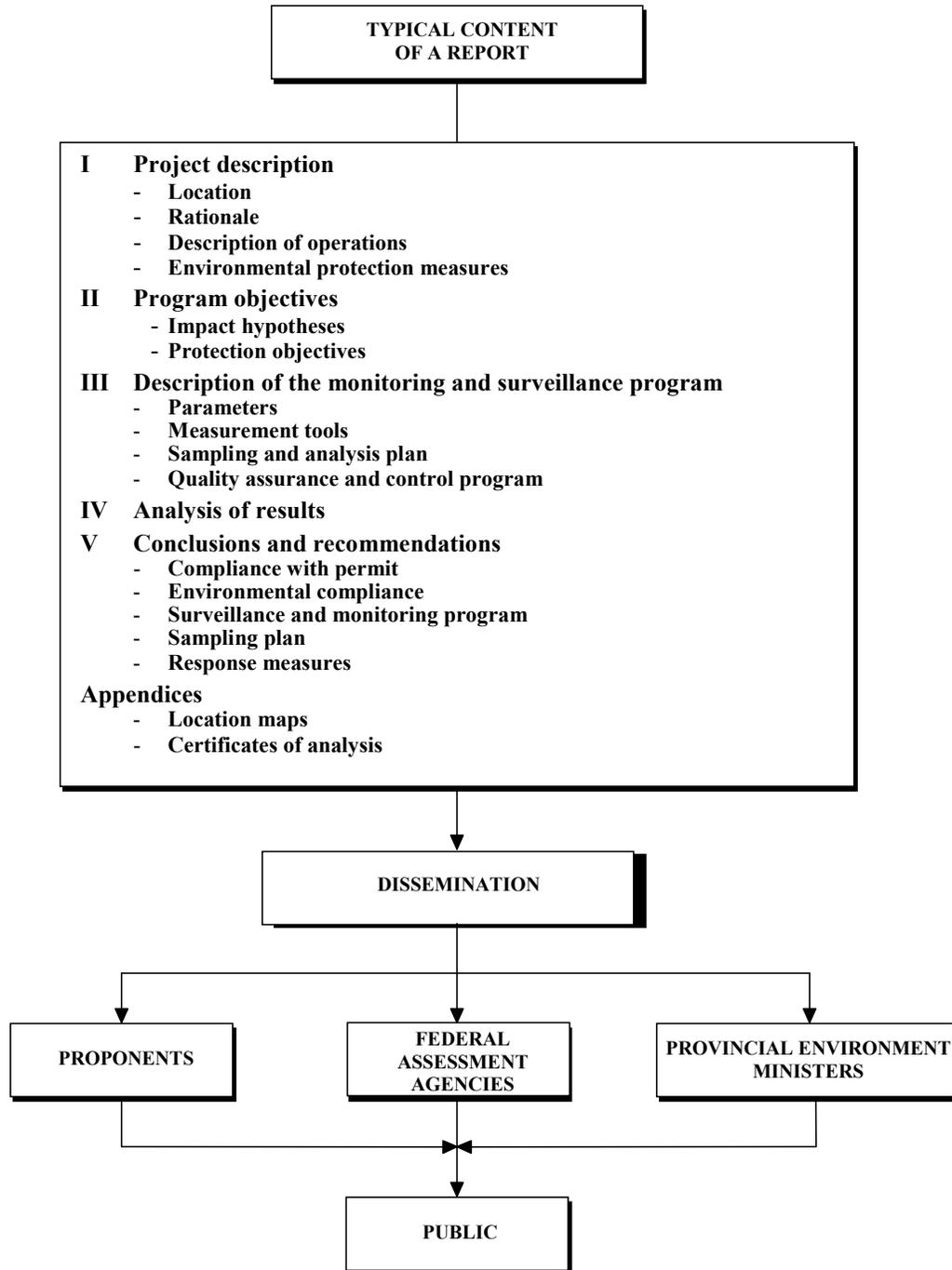


Figure 13 Preparation of the surveillance and monitoring report and dissemination of the results (Steps 8 and 9)

Every year since 1995, the Marine Environment Division of Environment Canada has published the results of ESMPs carried out in connection with ocean dredged material disposal projects and reported the results both nationally and internationally through a National Compendium (EC, 1995c; 1997b). The National Compendium provides valuable information to clients and other interested parties on the environmental surveillance and monitoring operations conducted. It is also submitted annually to the International Maritime Organization to meet Canada's treaty obligations under the *London Convention 1972 (LC72)* and its *1996 Protocol*.

6 Periodic Program Review (Step 10)

The results of an ESMP must be reviewed at regular intervals to determine whether to continue with it in its original form or to reassess its objectives, the impact hypotheses, the procedures or tools used in the sampling plan, the analysis methods, the mitigation measures included in the action plan, etc.

Periodic reviews of ESMPs (Step 10) are essential to ensure that they are fulfilling their role, that is, that the projects are being carried out in compliance with the various applicable regulations and with the conditions established by the permits or authorization certificates, that the impact hypotheses arising out of the permit application review are accurate and, finally, that the proposed mitigation measures and permit conditions are sufficient to ensure adequate protection of the environment.

Periodic reviews of ESMPs also make it possible to determine the state of our knowledge on the actual impacts of projects, to identify research and development requirements for better surveillance and monitoring tools, and to develop or improve mitigation measures.

Table 24 provides a sample checklist that can be used for *a posteriori* assessment of an ESMP to determine whether these steps and activities are adequate or appropriate and thus to suggest and determine the priority of recommended improvements for future ESMPs.

Table 24

Sample checklist for reviewing an ESMP

PROJECT TITLE:	
PROPONENT:	
DATE:	LOCATION:

#	ESMP STEPS	PRIORITY	ADEQUATE	INAPPROPRIATE	NEEDS IMPROVEMENT	RECOMMENDATIONS
1	Objectives of the ESMP					
	. Issues to be monitored					
	. General objectives					
	. Specific objectives					
2	Environmental components					
	. Physical					
	. Chemical					
	. Biological					
3	Testable impact hypotheses					
	. Thresholds					
	. Impact hypotheses					
	. Null impact hypotheses					
4	Sampling and analysis program					
	. Parameters					
	. Measurement tools					
	. QA/QC program					
	. Selection or number of stations					
	. Sampling frequency					
	. Sampling methods					
	. Analysis methods					
5	Action plan					
	. Control and mitigation measures					
	. Health and safety program					
	. Emergency measures program					
	. Good environmental practices					
6	Implementation					
	. Selection of consultant					
	. Selection of laboratory					
	. Communication mechanisms					
	. Sampling specifications					
	. Awareness/training program					
	. Interpretation of results					
	. Dissemination of results					
7	Other					

7 Conclusions and Recommendations

7.1 Conclusions

Environmental surveillance and monitoring programs are designed essentially to ensure 1) that dredging and sediment management projects are carried out in compliance with the various statutes and regulations in the area of environmental protection; 2) the effectiveness of the mitigation measures; 3) the accuracy of the impact predictions; and 4) that they are carried out with minimal environmental impact.

The preceding chapters have demonstrated, among other things, that if ESMPs are to achieve the desired results, they must be designed to meet very specific objectives and be based on principles or rules of good practice to ensure that the data obtained are associated with recognized and readily interpretable environmental protection indicators.

ESMPs must be designed in steps and tiers around testable impact hypotheses based on a detailed knowledge of the activities involved in the project and the mechanisms of impact on all the environmental components likely to be affected by the project. In addition, each step or tier of the ESMP must have its own sampling and analysis plan and its own mitigation and management measures as part of an action plan to be implemented in the event the program results fail to meet the thresholds for action.

7.2 Recommendations

It is recommended that the principal results of environmental surveillance and monitoring reports on dredging and contaminated sediment remediation projects be made available to all stakeholders and to the public. In this way, they help to ensure a better understanding of the impact mechanisms and true impacts of these projects on the environment and thus to improve the mitigation measures and good environmental practices.

Rapid-response tools must also be developed to measure physical, chemical and biological parameters and existing tools improved to facilitate the technological and economic implementation of ESMPs.

Finally, it is important that every ESMP be subject to periodic review at regular intervals to determine whether to continue with it in its original form or to reassess its objectives, the testable impact hypotheses formulated, the procedures and tools used in the sampling plan, the analysis methods, and the mitigation measures and good environmental practices included in the action plan.

References

- Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME). 1997. *Détection et caractérisation appliquées aux sites pollués - Investigations géophysiques et mesures des polluants sur site*. Direction de l'industrie, ADEME Éditions, Angers, France.
- ASL Analytical Services Laboratories, Wastewater Technology Centre and Grace Dearborn Ltd. 1995. *Enhanced Bioremediation and Near Real Time Monitoring of Contaminated Soils*. Report prepared by the British Columbia Ministry of the Environment, Lands and Parks and Environment Canada as part of the Development and Demonstration of Site Remediation Technology Program (DESRT Program).
- Averett, D.E. and N.R. Francingues. 1994. Sediment Remediation: An International Review. In *Proceedings of Dredging '94*. ASCE, Lake Buena Vista, FL, 596-604.
- Averett, D.E., B.D. Perry, E.J. Torrey and J.A. Miller. 1990. *Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Miscellaneous Paper EL-90-25.
- Averett, D.E. and M.J. Otis. 1988. *New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives-Report 12: Executive Summary*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report EL-88-15.
- Beanlands, G.E. and P.N. Duinker. 1983. *An Ecological Framework for Environmental Impact Assessment in Canada*. Institute for Resource and Environmental Studies, Published in Cooperation with the Federal Environmental Assessment Review Office, Hull, Quebec.
- Brannon, J.M. and T.E. Myers. 1994. Leachate Testing and Evaluation for Freshwater Sediment. In *Proceedings of Dredging '94*. ASCE, Lake Buena Vista, FL, 737-746.
- Brannon, J.M., J.C. Pennington, D. Gunnison, and T.E. Myers. 1990. *Comprehensive Analysis of Migration Pathways (CAMP): Contaminant Migration Pathways at Confined Dredged Material Disposal Facilities*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Miscellaneous Paper D-90-5.
- Buchberger, C. 1993. Environment Canada demonstrations, remedial technologies for the removal of contaminated sediment in the Great Lakes. *Terra et Aqua*, 50: 3-12.
- Canadian Coast Guard. 1990. *Environmental Criteria for Dredging and Spoil Management: A Review of Canadian Regulatory Requirements*. Report prepared for Transport Canada, Waterways Development Division, by Lavalin Environnement, Montreal.
- Canadian Environmental Assessment Agency. 1994. *Reference Guide to the Canadian Environmental Assessment Act: Addressing Cumulative Environmental Effects*. Hull, Quebec.

- Canadian Environmental Assessment Agency. 1992. *Reference Guide to the Canadian Environmental Assessment Act: Determining Whether A Project is Likely to Cause Significant Adverse Environmental Effects*. Hull, Quebec.
- CCME – Canadian Council of Ministers of the Environment. 1993a. *Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites, Volume I: Main Report*. Canadian Council of Ministers of the Environment, Report CCME EPC-NCS62E.
- CCME. 1993b. *Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites, Volume II: Analytical Method Summaries*. Report by the Canadian Council of Ministers of the Environment EPC-NCS66E.
- CCME. 1991a. *Review and Recommendations for the Interim Canadian Environmental Quality Criteria for Contaminated Sites*. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba, Scientific Series; Study No. 197.
- CCME. 1991b. *National Guidelines for the Landfilling of Hazardous Waste*. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba, Report CCME-WM/TRE-028E.
- CCME. 1989, rev. 1990. *Canadian Water Quality Guidelines*. Water Quality Guidelines Task Force. Canadian Council of Ministers of the Environment, Environment Canada, Ottawa.
- Chapman, P.M. 1989. Current approaches to developing sediment quality criteria. *Environ. Toxicol. Chem.* 8: 589-599.
- Chapman, P.M. 1986. Sediment quality criteria from the sediment quality triad: An example. *Environ. Toxicol. Chem.* 5: 957-964.
- Chapman, P.M., E.A. Power and G.A. Burton Jr. 1992. Integrative assessment in aquatic ecosystems. In *Sediment Toxicity Assessment*, edited by G.A. Burton, Jr., Lewis Publishers, Boca Raton, FL.
- Chapman, P.M., R.N. Dexter and E.R. Long. 1987. Synoptic measures of sediment contamination, toxicity and infaunal community structure (the sediment quality triad) in San Francisco Bay. *Mar. Ecol. Prog. Ser.* 37: 75-96.
- Chevrier, A. and P.A. Topping. 1998. *National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites*. Environment Canada, Marine Environment Division.
- Clausner, J.E. and D.A. Nelson. 1989. Physical monitoring guidelines for dredged material placement sites. *Dredging, Technology, Environmental Mining, Proceedings of WOODCON XII, XIIth World Dredging Congress, May 2-5, Orlando, Florida*.

- Contaminated Sites Management Working Group. 1997. *Site Remediation Technologies: A Reference Manual*. Prepared by Water Technology International Corporation, Burlington, Ontario, Canada.
- Côté, C. 1998. *Développement et validation d'une batterie micro-bioanalytique multitrophique pour sédiments dulcicoles*. Final report of a research project prepared for Environment Canada, Environmental Protection Branch by Beak International Inc., Montreal.
- Côté, C., C. Blaise, J.R. Michaud, L. Ménard, S. Trottier, F. Gagné, and R. Lifshiz. 1998a. Comparisons between microscale and whole sediment assays for freshwater sediment toxicity assessment. *Environmental Toxicology and Water Quality* 13: 93-110.
- Côté, C., C. Blaise, J. Schroeder, M. Douville, and J.R. Michaud. 1998b. Investigating the adequacy of selected micro-Scale bioassays to predict the toxic potential of freshwater sediments through a tier process. Submitted to the *Water Quality Research Journal*.
- Cullinane, M.J., D.E. Averett, R.A. Shafer, J.W. Male, C.L. Truitt, and M.R. Bradbury. 1986. *Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions. Puget Sound Dredged Disposal Analysis*. U.S. Army Corps of Engineers, Seattle District, Seattle, WA.
- Cumulative Effects Assessment Working Group. 1997. *Cumulative Effects Assessment Practitioners Guide*. Working paper prepared by Axys Environmental Consulting Ltd. for the Canadian Environmental Assessment Agency, Hull, Quebec.
- Davies, M. and B. Sadler. 1990. *Post-Project Analysis and the Improvement of Guidelines for Environmental Monitoring and Audit*. Environment Canada, Environmental Assessment Division, Environmental Protection Series, Report EPS 6/FA/1.
- Décontam Inc. 1995. *Final Report on the On-site Demonstration of the AOSTRA-Taciuk Technology*. Report submitted to the Research Coordination Branch of the Quebec Ministère de l'Environnement et de la Faune and to the Technology Development Section, Environmental Protection Branch, Environment Canada.
- DFO. 1998a. *Decision Framework for the Determination and Authorization of Harmful Alteration, Disruption and Destruction of Fish Habitat*. Fisheries and Ocean Canada, Public Works and Government Services Canada. Ottawa.
- DFO. 1998b. *Habitat Conservation and Protection Guidelines*. Developed from the Policy for the Management of Fish Habitat (1986). Second Edition. Ottawa.
- DFO. 1997a. *Code de conformité environnementale: Obligations réglementaires et d'éthique*. Service des installations, Secteur de conformité environnementale.
- DFO. 1997b. *What the Law Requires (Fish Habitat Conservation and Protection)*. Ottawa.
- DFO. 1986. *Fish Habitat Management Policy*. Ottawa.

- DiGiano, F.A., C.T. Miller, and J. Yoon. 1995. *Dredging Elutriate Test (DRET) Development*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Contract Report D-95-1.
- DiGiano, F.A., C.T. Miller, and J. Yoon. 1993. Predicting Release of PCBs at the Point of Dredging. *American Society of Civil Engineers, Journal of Environmental Engineering*, 119 (1): 72-89.
- EC – Environment Canada. 1998a. *Assessment Protocol of the Applicability of Ore-Processing Technologies to Treat Contaminated Soil, Sediment and Sludge*. Data Sheet, St. Lawrence Technologies, St. Lawrence Vision 2000.
- EC 1998b. *Guide for the Management of Hazardous Materials and Waste and Environmental Emergencies at Federal Facilities in Quebec*. Environmental Protection Branch, Pollution Prevention and Environmental Emergencies, Quebec Region.
- EC. 1997a. *Contaminated Sediment: Development and Validation of Toxicity Screening Essays for Freshwater Sediments*. Data Sheet, St. Lawrence Technologies, St. Lawrence Vision 2000.
- EC. 1997b. *1996 National Compendium Monitoring at Ocean Disposal Sites*. Marine Environmental Division, Hull, Quebec.
- EC. 1996a. *1996-97 Discussion Paper on Ocean Disposal and Cost Recovery*. Disposal at Sea Program, Marine Environment Division, Toxics Pollution Prevention Directorate, Environmental Protection Service.
- EC. 1996b. *The Inspector's Guide - A Field Guide for Environment Canada Inspectors*. Office of Enforcement, Environmental Protection Service.
- EC. 1995a. *Near Real Time Monitoring of Contaminated Soils*. Data sheet, Demonstration and Evaluation of Site Remediation Technology (DESRT) Program. Project carried out by ASL Analytical Laboratories.
- EC. 1995b. *A Sampling Manual and Reference Guide for Environment Canada Inspectors*. Office of Enforcement, Environmental Protection Service, Environment Canada.
- EC. 1995c. *1995 National Compendium Monitoring at Ocean Disposal Sites*. Marine Environment Division, Hull, Quebec.
- EC. 1995d. *Interim Sediment Quality Guidelines*. Soil and Sediment Quality Section, Guidelines Division, Ecosystem Conservation Directorate Evaluation and Interpretation Branch, Ottawa, Ontario.
- EC. 1994a. *Environmental Impacts of Dredging and Sediment Disposal*. Document prepared by Les Consultants Jacques Bérubé Inc. for the Technology Development Section, Environmental Protection Branch, Quebec and Ontario Regions. Catalogue No.: En 153-39/1994E.

- EC. 1994b. *Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing*. Report EPS 1/RM/29.
- EC. 1994c. *Environmental Effects Monitoring in Environmental Assessment*. Unpublished report prepared by Robert R. Everitt, Environmental and Social Systems Analysts, and edited by the Environmental Assessment Branch, Environment Canada and the Federal Environmental Assessment and Review Office.
- EC. 1994d. *Guidelines on Biological Monitoring – Addenda* Environment Canada, Marine Environment Division, Hull, Quebec.
- EC. 1993a. *Interim Monitoring Guidelines for Ocean Disposal*. Environment Canada, Marine Environment Division, Hull, Quebec.
- EC. 1993b. *Biological Test Method: Acute Test for Sediment Toxicity Using Marine or Estuarine Amphipods*. Prepared by the Method Development and Application Section, Environmental Technology Centre, Ottawa. Report EPS 1/RM/26, with modifications added in December 1992.
- EC. 1993c. *Biological Test Method: Toxicity Test Using Luminescent Bacteria (Photobacterium Phosphoreum)*. Prepared by Method Development and Application Section, Environmental Technology Centre, Ottawa. Report EPS 1/RM/24, with modifications added in November 1992.
- EC. 1993d. *Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars)*. Prepared by Method Development and Application Section, Environmental Technology Centre, Ottawa. Report EPS 1/RM/27, with modifications added in December 1992.
- EC. 1992a. *Aquatic Environmental Effects Monitoring Requirements*. Department of Fisheries and Oceans, Report no. EPS 1/RM/8.
- EC. 1985. *Guide pour l'examen environnemental préalable des projets de dragage et de génie maritime dans le Saint-Laurent*. Conservation and Protection, Report En21-50/1985.
- EC. 1980. *Guide relatif au dragage et à l'élimination des sédiments contaminés dans le Saint-Laurent. Volume 1*. Prepared by Roche Ltée.
- Francingues, N.R. and D.E. Averett. 1988. *New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives, Report 1, Study Overview*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report EL-88-15, Report 1.
- Francingues, N.R., M.R. Palermo, C.R. Lee, and R.K. Peddicord. 1985. *Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Miscellaneous Paper D-85-1.
- Fredette, T.J., D.A. Nelson, J.E. Clausner, and F.J. Anders. 1990a. *Guidelines for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites*. U.S. Army

- Engineer Waterways Experimental Station, Vicksburg, MS. Technical Report D-90-12.
- Fredette, T.J., D.A. Nelson, D.A. Miller-Way, J.A. Adair, J.A. Sotler, J.E. Clausner, E.B. Hand, and F.J. Anders. 1990b. *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Technical Report D-90-11.
- Fredette, T.J., G. Anderson, B.S. Payne, and J.D. Lunz. 1986. Biological monitoring of open-water dredged material disposal sites. In *Proceedings, IEEE Oceans'86 Conference, Washington, DC*, 764-769.
- Germano, J.D., D.C. Rhoads, and J.D. Lunz. 1994. *An Integrated, Tiered Approach to Monitoring and Management of Dredged Material Disposal Sites in the New England Region*. Report prepared by Science Applications International Corporation (SAIC) for the U.S. Army Corps of Engineers, New England Division, Disposal Area Monitoring Systems (DAMOS) Contribution No. 87.
- Green, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists*. John Wiley and Sons, Toronto, Ontario.
- Hodgins, D.O. and J.R. Harper. 1994. *Technical Guidelines for Physical Monitoring At Ocean Disposal Sites*. Final Report prepared for Environment Canada, Hull, by Seaconsult Marine Research Ltd. and Coastal and Ocean Resources Inc.
- IJC – International Joint Commission. 1988. *Options for the Remediation of Contaminated Sediments in the Great Lakes*. Report submitted to the Great Lakes Water Quality Board by the Subcommittee and its Remedial Options Group, International Joint Commission Great Lakes Regional Office, Windsor, Ontario.
- IMO – International Maritime Organization. 1992. *Guidelines for the Assessment of Wastes or other Matter that may be Considered for Dumping, London Convention 1972 – Annex 4*.
- Johnson, B.H. 1990. *User's Guide for Models of Dredged Material Disposal in Open Water*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report D-90-5.
- Jones, R.A. and G.F. Lee. 1978. *Evaluation of the Elutriate Test as a Method of Predicting Contaminant Release during Open-Water Disposal of Dredged Sediments and Environmental Impacts of Open-Water Dredged Material Disposal Vol. I: Discussion*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report D-78-45.
- Kan, G., F. Dumouchel, P. Hennigar, and H. Quon. 1996. *Analytical Quality Assurance/Quality Control Guidelines for the National Ocean Dumping Program*. Preliminary report prepared by Environment Canada, Environmental Conservation Branch, Pacific and Yukon Region, Quebec Region and Atlantic Region.

- Keddy, C., Greene, J.C., and M.A. Bonnell. 1995. *Application of Recommended Whole Organism Bioassays in the Assessment of Contaminated Sites in Canada*. Prepared for the Canadian Council of Ministers of the Environment (CCME) Subcommittee on Environmental Quality Criteria for Contaminated Sites, National Contaminated Sites Remediation Program.
- Loiselle, C., G R. Fortin, S. Lorrain, and M. Pelletier. 1997. *Dynamics and Contamination of St. Lawrence River Sediment*. Environment Canada – Quebec Region, St. Lawrence Centre, Montreal, Quebec. St. Lawrence Update, thematic report on the St. Lawrence River.
- Mann, G.S., C.A. McPherson, B.C. Sander, and N.A. Sloan. 1995a. *Technical Guidance on Biological Monitoring for Ocean Disposal: Final Report*. Report prepared for Environment Canada, Hazardous Waste Management, Hull, Quebec by EVS Environmental Consultants, North Vancouver, BC.
- Mann, G.S., C.A. McPherson, B.C. Sander, and N.A. Sloan. 1995b. *Technical Guidance on Biological Monitoring for Ocean Disposal: Sample Data Analyses*. Report prepared for Environment Canada, Hazardous Waste Management, Hull, Quebec by EVS Environmental Consultants, North Vancouver, BC.
- May, B., Pabst, D., and S. McDowell. 1994. Dioxin Capping Management and Monitoring Program: Design and Implementation. In *Proceedings of Dredging '94, ASCE, Lake Buena Vista, FL*, 1027-1036.
- MEF – Ministère de l'Environnement et de la Faune du Québec. 1998. *Politique de protection des sols et de réhabilitation des terrains contaminés*. Direction des politiques du secteur industriel, Service des lieux contaminés.
- MEF. 1997a. *Guide de réalisation d'une étude d'impact sur l'environnement*. Direction de l'évaluation environnementale des projets industriels et en milieu hydrique.
- MEF. 1997b. *Directive pour la réalisation d'une étude d'impact sur l'environnement d'un projet de dragage, de creusement ou de remblayage en milieu hydrique*. Direction de l'évaluation environnementale des projets industriels et en milieu hydrique.
- MEF. 1997c. *Directive pour la réalisation d'une étude d'impact sur l'environnement d'un projet de port ou de quai*. Direction de l'évaluation environnementale des projets industriels et en milieu hydrique.
- MEF. 1996. *Lignes directrices pour le traitement de sols contaminés par biodégradation, bioventilation ou volatilisation*. Direction des politiques du secteur industriel, Service des lieux contaminés, Publications du Québec.
- MEF. 1995. *Lieux d'enfouissement sécuritaire : guide d'implantation et de gestion de lieux d'enfouissement de sols contaminés*. Direction des politiques du secteur industriel, Service des lieux contaminés, Publications du Québec.

- MEF and Centre d'expertise en analyse environnementale du Québec. 1997. *Liste des méthodes d'analyse relatives à l'application des règlements découlant de la Loi sur la qualité de l'environnement. Règlement sur les matières dangereuses*. First edition.
- MENVIQ - Ministère de l'Environnement du Québec. 1990a, rév. 1992. *Critères de qualité de l'eau*. Service d'évaluation des rejets toxiques et Direction de la qualité des cours d'eau. Report EMA88-09.
- MENVIQ. 1990b. *Guide des méthodes de conservation et d'analyse des échantillons d'eau et de sol*. Direction des laboratoires.
- MENVIQ. 1988. *Guide standard de caractérisation des terrains contaminés*. Direction des substances dangereuses.
- Milles, P. 1995. Sediment and water quality monitoring as part of the Welland River pilot-scale sediment removal demonstration. In *Proceedings of Sediment Remediation 95, Windsor, Canada, May 8-10, 1995*. Acres International Limited.
- Moore, D.W. 1994. Quality assurance and quality control in laboratory bioassays of dredged material. In *Proceedings of Dredging '94, ASCE, Lake Buena Vista, FL*, 728-736.
- Myers, T.E. 1990. *Preliminary Guidelines and Conceptual Framework for Comprehensive Analysis of Migration Pathways (CAMP) of Contaminated Dredged Material*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Effects of Dredging Program, Technical Note EEDP-06-11.
- Myers, T.E., D.D. Reible, M.R. Palermo, T.J. Olin, D.E. Averett, and S.G. McCutcheon. 1996. *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments*. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL. EPA905-R96-001.
- Myers, T.E., J.M. Brannon, and C.B. Price. 1992. *Recent Developments in Leachate Testing and Evaluations*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Miscellaneous Paper D-92-2.
- Myers, T.E. and J.M. Brannon. 1991. *Technical Considerations for Applications of Leach Tests to Sediments and Dredged Material*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Effects of Dredging Program, Technical Note EEDP-002-15.
- NRC – National Research Council. 1990. *Managing Troubled Waters. The Role of Marine Environmental Monitoring*. National Academy Press. Washington, DC.
- Palermo, M.R. 1994. Placement techniques for capping contaminated sediments. In *Proceedings of Dredging '94, ASCE, Lake Buena Vista, FL*, 1111-1121.
- Palermo, M.R. 1991a. *Design Requirements for Capping*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Dredging Research Technical Notes DRP-5-03.

- Palermo, M.R. 1991b. *Site Selection for Capping*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Dredging Research Technical Notes DRP-5-04.
- Palermo, M.R. 1991c. *Equipment and Placement Techniques for Capping*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Dredging Research Technical Notes DRP-5-05.
- Palermo, M.R. 1988. *Field Evaluations of the Quality of Effluent from Confined Dredged Material Disposal Areas*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report D-88-1.
- Palermo, M.R. 1986. *Development of a Modified Elutriate Test for Estimating the Quality Effluent from Dredged Material Disposal Areas*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report D-86-4.
- Palermo, M.R., S. Maynard, J. Miller, and D. Reible. 1998. *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments*. Great Lakes National Program Office, Chicago, IL. EPA 905-B96-004.
- Palermo, M.R., T. Fredette, and R.E. Randall. 1992. *Monitoring Considerations for Capping*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Dredging Research Technical Notes DRP-5-07.
- Palermo, M.R. and V.R. Pakow. 1988. *New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives, Report 10, Evaluation of Dredging Control Technology*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report EL-88-15, Report 10.
- Parametrix, Inc. 1990. *Standards for Confined Disposal of Contaminated Sediments-Development Documentation*. Prepared jointly with Odgen Beeman and Associates Inc., Hart-Crowler Inc., Science Applications International Corp., Pacific Groundwater Group, Janet N. Knox Inc. for Washington State Department of Ecology.
- Pelletier, J.-P. 1994a. *Toronto Harbour Contaminated Sediment Removal Demonstration: The Bio-Assay Results and the Chemical and Physical Characteristics of Parliament Street Slip Sediment*. Environment Canada, Protection Branch, Ontario Region. Remediation Technologies Program.
- Pelletier, J.-P. 1994b. *Toronto Harbour Contaminated Sediment Removal Demonstration: Report on the Water Quality Monitoring Program*. Environment Canada, Protection Branch, Ontario Region. Remediation Technologies Program.
- Pelletier, J.-P. 1994c. *Hamilton Harbour Contaminated Sediment Removal Demonstration: Report on the Water Quality Monitoring Program*. Environment Canada, Protection Branch, Ontario Region. Remediation Technologies Program.

- Pequegnat, W.E., B.J. Gallaway, and T.D. Wright. 1990. *Revised Procedural Guide for Designation Surveys of Ocean Dredged Material Disposal Sites*. Report prepared by the Department of the Army, U.S. Army Corps of Engineers, Washington, DC. Technical Report D-90-8.
- Permanent International Association of Navigation Congresses (PIANC). 1996. *Handling and Treatment of Contaminated Dredged Material From Ports and Inland Waterways, Vol. I*. Report of PIANC PTC 1 Working Group No. 17.
- Poindexter-Rollings, M. 1989. *Monitoring Dredged Material Consolidation and Settlement at Aquatic Disposal Sites*. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. Environmental Effects of Dredging Technical Notes EEDP-01-5.
- Rochon, R. 1985. *Problems Associated With Dredging Operations on the St. Lawrence*. Environment Canada, Environmental Protection Service, Report EPS 4/MA/1.
- Rochon, R. and L. Sarazin. 1987. *Technical Guide to the Environmental Screening of Dredging Projects and Marina Developments in Eastern Canada*. Environment Canada, Conservation and Protection, Quebec Region and Ontario Region.
- Rochon, R. and M. Chevalier. 1987. *Échantillonnage et conservation des sédiments en vue de la réalisation des projets de dragage*. Environment Canada, Conservation and Protection, Quebec Region.
- Schroeder, P.R. and M.R. Palermo. 1990. *The Automated Dredging and Disposal Alternatives Management Systems (ADDAMS)*. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Effects of Dredging Technical Note EEDP-06-12.
- Scheffner, N.W., M.M. Thevenot, J.R. Tallent, and J.M. Masson. 1995. *LTFATE: A Model to Investigate the Long-term Fate and Stability of Dredged Material Disposal Sites-Users Guide*. U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report DRP-95-1.
- SLC – St. Lawrence Centre. 1993a. *Qualité des sédiments et bilan des dragages sur le Saint-Laurent*. Prepared by Lucie Olivier and Jacques Bérubé, Technology Development Branch. Cat. No. En 153-12/1993F.
- SLC. 1993b. *Legislative Framework of Sediment Management in Quebec*. Prepared by Jacques Bérubé Consultants Inc. for the Technology Development Branch. Cat. No. En 153-29/1993E.
- SLC. 1993c, rev. 94. *Guide to Assessing and Selecting Treatment Technologies for Contaminated Sediment*. Prepared by Jean-René Michaud, Technology Development Branch, Cat. No. En 40-450/1993E.
- SLC. 1992a. *Methods Manual for Sediment Characterization*. Prepared jointly by Environment Canada and the Ministère de l'Environnement du Québec, Montreal, Québec.

- SLC. 1992b. *Interim Criteria for Quality Assessment of St Lawrence River Sediment*. Prepared jointly by Environment Canada and the Ministère de l'Environnement du Québec.
- SLC. 1992c. *Guide to Selecting and Operating Dredging Equipment and Related Practices*. Prepared in collaboration with Public Works Canada and the Quebec Ministère de l'Environnement and produced by Jacques Bérubé Consultants Inc.. Cat. No.: En 40-438/1992E.
- SLC. 1990. *Équipements et méthodes de dragage recommandés sur le fleuve Saint-Laurent*. Final report prepared by Lavalin Environnement and Sanexen for Environment Canada.
- Sommerfeld, A. 1995. Field testing kits using immunoassay technology to improve monitoring program results. *Hazardous Materials Management, June/July*.
- St-Laurent, D., R. Chabot, M. Provencher, M. Douville, and C. Côté. 2000. *Suivi environnemental au dépôt D des déblais de dragage du chenal de la Grande Entrée, Îles de la Madeleine, Québec (1997)*. Cat. No. EN37-127/2000F. Prepared by Environnement Canada – Quebec Region, Environmental Protection Branch in cooperation with Beak International Inc., Montreal, Quebec.
- Thackson, E.L. and M.R. Palermo. 1988. *General Guidelines for Monitoring Effluent Quality from Confined Dredged Material Disposal Areas*. Environmental Effects of Dredging Technical Notes EEDP-04-9. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS.
- Truitt, C.L. 1987a. *Engineering Considerations for Subaqueous Dredged Material Capping – Background and Preliminary Planning*. Environmental Effects of Dredging Technical Notes EEDP-01-3. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS.
- Truitt, C.L. 1987b. *Engineering Considerations for Capping Subaqueous Dredged Material Deposits-Design Concepts and Placement Techniques*. Environmental Effects of Dredging Technical Notes EEDP-01-4. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS.
- Truitt, C.L. 1986. *The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring*. Technical Report D-86-2. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS.
- USACE – U.S. Army Corps of Engineers. 1994. *Quality Assurance/Quality Control (QA/QC) Guidance for Laboratory Dredged Material Bioassays*. Waterways Experiment Station, Seattle, WA.
- USACE. 1987a. *Dredged Material Beneficial Uses*. Engineer Manual 1110-2-5026. U.S. Army Corps of Engineers, Washington, DC..
- USACE. 1987b. *Confined Disposal of Dredged Material*. Engineer Manual 1110-2-5027. U.S. Army Corps of Engineers, Washington, DC.

- USACE. 1986. *Upland Animal Bioassays of Dredged Material*. Environmental Effects of Dredging Technical notes, EEDP-02-2. U.S. Army Engineer Waterways Experiment Station.
- USACE. 1985. *Plant Bioassay of Dredged Material*. Environmental Effects of Dredging Technical Notes, EEDP-02-1. U.S. Army Engineer Waterways Experiment Station.
- USACE. 1983. *Dredging and Dredged Material Disposal*. Engineer Manual 1110-2-5025. U.S. Army Corps of Engineers, Washington, DC.
- USACE Buffalo District. 1994. *Pilot-Scale Demonstration Thermal Desorption for the Treatment of Ashtabula River Sediments*. EPA905-R94-021. Prepared for the U.S. Environmental Protection Agency and the Great Lakes National Program Office, Chicago, IL.
- USACE Buffalo District. 1993. *Pilot-Scale Demonstration Thermal Desorption for the Treatment of Buffalo River Sediments*. EPA905-R93-005. Prepared for the U.S. Environmental Protection Agency and the Great Lakes National Program Office, Chicago, IL.
- USEPA. 1995. *QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations – Chemical Evaluations*. EPA 823-B-95-001. Published by the U.S. Environmental Protection Agency, Office of Water.
- USEPA. 1994a. *ARCS Assessment Guidance Document*. EPA905-B94-002. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1994b. *ARCS Remediation Guidance Document*. EPA905-B94-003. U.S. Environmental Protection Agency and the Great Lakes National Program Office, Chicago, IL.
- USEPA. 1994c. *Assessment and Remediation of Contaminated Sediments (ARCS) Program Pilot-Scale Demonstration of Solvent Extraction for the Treatment of Grand Calumet River Sediments*. EPA905-R94-003. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1994d. *Assessment and Remediation of Contaminated Sediments (ARCS) Program Pilot-Scale Demonstration of Thermal Desorption for the Treatment of Ashtabula River Sediments*. EPA905-R94-021. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1994e. *Assessment and Remediation of Contaminated Sediments (ARCS) Program Bench-Scale Evaluation of SoilTech's Anaerobic Thermal Process Technology on Contaminated Sediments from the Buffalo and Great Calumet Rivers*. EPA905-R94-009. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1994f. *Assessment and Remediation of Contaminated Sediments (ARCS) Program Pilot-Scale Demonstration of Thermal Desorption for the Treatment of Ashtabula River*

- Sediments*. EPA905-R94-021. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1993a. *Assessment and Remediation of Contaminated Sediments (ARCS) Program Pilot-Scale Demonstration of Thermal Desorption for the Treatment of Buffalo River Sediments*. EPA905-R94-005. U.S. Environmental Protection Agency and Great Lakes National Program Office, Chicago, IL.
- USEPA. 1993b. *Selecting Remediation Techniques for Contaminated Sediment*. Office of Water, Office of Science and Technology, Washington, D.C. and Office of Research and Development, Cincinnati, Ohio.
- USEPA. 1993c. *Guidance Manual: Bedded Sediment Bioaccumulation Test*. EPA/600/R-93/183. U.S. Environmental Protection Agency.
- USEPA. 1992a. *Sediment Classification Methods Compendium*. EPA-823-R006. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- USEPA. 1992b. *Quality Assurance Management Plan for the Assessment and Remediation of Contaminated Sediments (ARCS) Program*. U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV.
- USEPA. 1992c. *Guide for Conducting Treatability Studies under CERCLA: Solvent Extraction, Interim Guidance*. EPA 540/R-92/016a. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC.
- USEPA. 1991. *Test Methods for Evaluating Solid Waste- Physical/Chemical Methods*. Revised Methods, Third Edition, U.S. Environmental Protection Agency, Washington, DC.
- USEPA. 1988a. *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. Interim Final*. EPA 540//G-89/004, OSWER Directive 9355.3-01. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC.
- USEPA. 1988b. *Guidance for Conducting Treatability Studies under CERCLA*. EPA 540/2-89/058. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.
- USEPA/USACE. 1998. *Great Lakes Dredged Material Testing and Evaluation Manual*. Final Draft. U.S. Environmental Protection Agency Regions 2, 3 and 5, Great Lakes National Program Office and U.S. Army Corps of Engineers, Great Lakes and Ohio River Division.
- USEPA/USACE. 1995. *QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations-Chemical Evaluations*. EPA 823-B95-001. U.S. Environmental Protection Agency, Washington, DC and U.S. Army Corps of Engineers.
- USEPA/USACE. 1994. *Evaluation of Dredged Material Proposed for Discharge in Inland Waters and Near Coastal Waters-Inland Testing Manual*. EPA-823-B-94-002. U.S.

- Environmental Protection Agency, Washington, DC and U.S. Army Corps of Engineers.
- USEPA/USACE. 1992. *Evaluating Environmental Effects of Dredged Material Management Alternatives - A Technical Framework*. EPA-842-B-92-008. U.S. Environmental Protection Agency, Washington, DC and U.S. Army Corps of Engineers.
- USEPA/USACE. 1991. *Evaluation of Dredged Material Proposed for Ocean Disposal (Testing Manual)*. EPA-503/8/91/001. Office of Water, U.S. Environmental Protection Agency, Washington, DC.
- Wright, D.G. and G.E. Hopky. 1998. *Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters*. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 2107.
- Zeller, R.W. and T.A. Wastel. 1986. Tiered ocean disposal monitoring will minimize data requirements. In *Proceedings, IEEE Oceans'86 Conference, Washington, DC*, 1004-1009.

Appendices

Appendix A Glossary

Absorption: Penetration of a substance into a solid or liquid body.

Action plan: Program permitting rapid and effective implementation of all necessary response measures in the event of an emergency. Plan of measures to be taken in response to unforeseen events or accidents. In an ESMP, set of monitoring, mitigation, management or response measures required in the course of operations to limit or reduce the physico-chemical, biological and human impacts of dredging and sediment management activities. The action plan may also include the expansion or reduction of an ESMP. Emergency plans and occupational, health and safety plans are integral parts of an action plan.

Activated carbon: Plant carbon treated to produce a large specific surface area. Used to adsorb materials that impart a taste, odour or colour to water and to absorb excess chlorine from disinfected water. The commercial product may be granular or powdered.

Advection: Transport of energy (thermal) or matter (chemical) by physical displacement of a heat transfer medium (air or water). Advection is often the dominant mechanism, compared, for example, to diffusion (chemical) or radiation (thermal).

Algal solid-phase test: The algal solid-phase test measures the inhibition of esterase activity in the algae *Selenastrum capricornutum* by the contaminants present in a sediment sample. An aliquot part of fluorescein diacetate (FDA) is added to a suspension of algae and sediments. The esterases present in the algae cleave the ester bond of the FDA, releasing the fluorescein. This fluorescent substance will remain in cells with good membrane integrity. The intensity of the fluorescence is measured by flux cytometry. This luminous intensity will be greater in healthy algae.

Aquatic containment: Underwater disposal in a site that is not only capped but also protected laterally by its location in a depression on the bottom or in the shelter of underwater dikes, to avoid dispersion of the material on the bottom.

Aquatic ecosystem: Aquatic system, including wetlands (see definition), providing habitat for interacting plant and animal communities and populations.

Assessment by a review panel: According to the CEAA, an environmental assessment that is conducted by a review panel established pursuant to s. 33 and that includes a consideration of the factors required to be considered under ss. 16(1) and (2).

- ATP test:** The ATP test determines the viability of the microbial biomass in a sediment sample on the basis of the cell's adenosine triphosphate (ATP) content. An aliquot part of sediments is filtered and the microbial cells are lysed to release their ATP. Luciferase and luciferin are then added to the suspension and the luminescence produced by the luciferin-luciferase-ATP reaction is measured. The quantity of light emitted reflects the microbial biomass of the sample.
- Baseline conditions:** Baseline conditions existing prior to implementation of the project and used as a reference point in an environmental surveillance and monitoring program.
- Battery of bioassays:** Set of bioassays used to assess the toxicity of a given sample.
- Bedrock:** Geological term used to describe undisturbed rock on the surface of the earth.
- Benthic:** Term used to describe the environment at the bottom of oceans or lakes and the organisms or materials found in that environment.
- Benthic macrofauna:** Benthic organisms readily visible to the naked eye.
- Benthic microfauna:** Benthic organisms not readily visible to the naked eye.
- Benthos:** All aquatic organisms living on or in the bottom of oceans or lakes.
- Bioaccumulation:** Constantly increasing retention of a substance in the tissues of an organism throughout its life (as the bioconcentration factor constantly increases).
- Bioassay:** (*Syn.: Toxicity test, biological assay*) a) Technique for assessing the biological impact of a substance contained in water by observing the changes in a biological activity. b) Test in which a given concentration of a substance is placed in contact with given organisms to assess the substance's toxic effects on them.
- Biochemical oxygen demand (BOD):** Test used to measure the quantity of oxygen consumed by microorganisms during biological oxidation of the organic matter present in water, under given physical, chemical and biological conditions. The concentration of oxygen dissolved in a waterway or lake is one of the principal criteria of the degree of pollution.
- Bioconcentration:** Retention of a substance in the tissues of an organism at a concentration greater than that in the ambient environment, at a given point in the life of the organism.
- Biodegradable:** Term used to describe a substance or product that can be completely decomposed by living organisms.
- Biological process:** Process by which the vital activities of bacteria and other microorganisms, in their search for nourishment, break down complex organic compounds into simple, stabler substances.
- Biological treatment:** Treatment process that uses microorganisms to break down the toxic contaminants of wastes into less toxic compounds.
- Biosensors:** Biosensors are analytical systems made up of a biological sensing element (bioreceptor) and a transducer that transforms the biological signal into a

measurable electrical signal. Biosensors that use the affinity of complex molecular structures for specific molecules may be:

- enzymatic,
- antibodies,
- microbial.

Transducers use various techniques, including photometry (inhibition of bacterial luminescence), electrochemistry, piezoelectricity or calorimetry.

Bioturbation: Transformation or degradation of sediments as a result of the activities of fossorial organisms.

Bottom sediments: Materials similar to soil, primarily minerals and natural organic substances, which are permanently under or in contact with water, in the tidal zone, or periodically submerged for periods long enough to permit the development of benthic communities.

Capital dredging: Dredging in ports and inland navigable waterways to widen or deepen existing channels or basins, or to create new ones (initial dredging).

Capping: Precisely controlled placement of contaminated dredged material in an open-water disposal site, following by capping with an isolating layer of clean materials.

Carcinogenic: Term used to describe substances that cause the development of cancer in a living organism.

Characterization: Precise identification of the distinctive elements of a substance, environment or process.

Chemical treatment: Treatment process that modifies the chemical structure of the toxic contaminants of wastes to reduce their toxicity, mobility or volume.

Chlorinated organic compound: Organic hydrocarbon containing one or more chlorine atoms. Typical compounds: HCB, HCH, dieldrin, DDT, PCB.

Clean technology: Technology involving a new, less polluting production process, recovery of lost raw material and recycling back into the manufacturing process, or use of wastes as the raw material in a secondary production.

Cleanup: With respect to contaminated bottom sediments, disposal or mitigation of the effects of contamination by treatment, immobilization, extraction or other operations.

Cleanup dredging: Dredging in navigable waterways and ports for the specific purpose of pollution control.

Cleanup technologies: Technologies used to treat the wastes from a process by means of the treatment of atmospheric emissions, wastewater or wastes themselves. Unlike clean technologies, these technologies are inserted at the end of the process.

- CO (carbon monoxide):** Odourless, colourless, tasteless gas produced by incomplete combustion of carbon compounds (e.g., automobile exhaust). In the body, it binds with the hemoglobin in the blood, reducing the efficiency of oxygen transport from the lungs to the tissues. Carbon monoxide is thus capable of inducing hypoxia (lack of oxygen). A significant source of carbon monoxide is direct or passive exposure to cigarette smoke.
- Colorimetric test kit:** This term covers all measurement techniques involving the use of colorimetry. The principle consists of using a reagent on a liquid sample obtained directly from the subsurface environment or extracted from the soil to cause a chemical reaction, which is emphasized by staining. The results are determined by visual comparison, by measuring light absorption (photometry) or, more simply, without a reagent, by a specific electrode.
- Compensation:** DFO's *Policy for the Management of Fish Habitat* defines compensation as: "the replacement of natural habitat, increase in the productivity of existing habitat, or maintenance of fish production by artificial means in circumstances dictated by social and economic conditions, where mitigation techniques and other measures are not adequate to maintain habitats for Canada's fisheries resources."
- Compensation may occur either on site or remote from the project site in the order of preference listed in the Habitat Policy and *Habitat Conservation and Protection Guidelines*. Any instruction, action, intervention, construction or undertaking to offset an unmitigated reduction in productive capacity in order to satisfy the no net loss guiding principle can be considered compensation.
- Composite sample:** Sample obtained by combining materials from more than one sample or subsample.
- Comprehensive study list:** According to the CEAA, a list of all projects or classes of projects that have been prescribed pursuant to regulations made under paragraph 59(d).
- Confined disposal facility (CDF):** Structured unit for the containment of dredged material. It consists of dikes or any analogous structure delineating a disposal site, located on land, above any nearby water bodies, in which the materials removed by dredging from the ambient water are isolated during disposal.
- Conservation goal:** DFO's *Policy for the Management of Fish Habitat* describes conservation goals as follows: "The first goal of the Habitat Policy is to maintain the current productive capacity of fish habitats supporting Canada's fishery resources, such that fish suitable for human consumption may be produced. The Conservation Goal is implemented using the no net loss guiding principle."
- Containment:** Corrective actions involving the construction of physical barriers to prevent contaminant migration in various matrices. Placement of contaminated sediments or dredged material in a confined upland or near-shore disposal site, with dikes or similar structures to isolate the materials from the ambient water, water bodies, surface water and groundwater during disposal.

Contaminant: A body contained in water, air or any other medium that is not part of its normal composition and that gives it a harmful quality.

According to the Quebec Environment Quality Act (EQA), the condition of the environment when a pollutant is present.

According to the EQA, solid, liquid or gaseous waste from industrial, commercial or farming activities, rubbish, household garbage, waste oil, demolition debris, pathological waste, carcass of animals, motor vehicle wrecks, used tires, radioactive waste, empty containers and waste material of any kind other than mine tailings.

According to the EQA, a contaminant or a mixture of several contaminants present in the environment in a concentration or in a quantity greater than the permissible level determined by regulation of the Government, or whose presence in the environment is prohibited by regulation of the Government.

According to the EQA, a solid, liquid or gaseous matter, a microorganism, a sound, a vibration, rays, heat, an odour, radiation or a combination of any of them likely to alter the quality of the environment in any way.

Core: Sediment sample collected by means of a coring device.

Coring device: Device used to collect a column of sediments (core), which is then analysed to reveal the chronological or vertical distribution of its physical and chemical characteristics.

Criminal liability: Criminal liability serves a punitive purpose, to restrain antisocial behaviour in situations explicitly defined by the law. The offence must be proven beyond a reasonable doubt.

Cumulative environmental effects: According to the Canadian Environmental Assessment Agency, changes to the environment that are caused by an action in combination with other past, present and future human actions.

Cutterhead: Mechanical unit mounted on the suction pipeline of a hydraulic dredge, used to dislodge sediments by rotary movement and permit suction of the dredged material.

Data quality objectives (DQOs): Previously defined criteria applicable to the data used in a study or the results of the study, to ensure that they are of acceptable quality to meet the needs of the program.

Decomposers: Microorganisms that mineralize or transform the organic matter produced by other organisms.

Destruction of fish habitat: DFO's *Policy for the Management of Fish Habitat* describes the destruction of fish habitat as: "any permanent change of fish habitat that renders it completely unsuitable for future production of fish, regardless of the means employed in causing the change (e.g., by removal, infilling, blockage, etc.)."

- Dioxins:** Group of approximately 75 chemicals of the chlorinated dibenzo-*p*-dioxin family, including 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, which is generally considered the most toxic.
- Dispersion:** Spreading of a substance through a system (soil, water, air) by means of a transport mechanism or other mechanism.
- Disruption of fish habitat:** DFO's *Policy for the Management of Fish Habitat* describes disruption of fish habitat as follows: "any change to fish habitat occurring for a limited period that reduces its capacity to support one or more life processes of fish."
- Dissolved solids:** Materials dissolved in natural or wastewater.
- Dredged material:** Materials excavated or dredged from the bottom.
- Dredged material disposal:** In this report, this expression is used to describe any discharge of dredged material in a country's inland waters, as a result of intentional dumping in open water, escape of materials from unconfined sites (beach nourishment or other forms of re-use), losses from a confined disposal site (effluents, surface runoff, percolation) or overflows from scows, hopper dredges or other transport vessels.
- Echo sounder:** Device transmitting acoustic (e.g., ultrasonic) pulses, which are reflected back off the bottom, making it possible to determine the depth of the water by measuring the time lag between transmission and reception.
- Ecological impact:** Examination of the possibility of studying and anticipating the effects of a proposed activity on the qualities or elements of the ecosystem concerned (Canadian Environmental Assessment Agency).
- Ecology:** Science that studies the relationships of living organisms with one another and with the environment in which they live.
- Ecosystem:** Ecological unit of the biosphere, consisting of living animals and plants (biocenosis) and inert elements (biotope). Ecosystems are thus functional dynamic systems of the biosphere, in which living species act as both producers and consumers within food chains.
- Ecotoxicity:** Ability of a substance to cause toxic effects, not only on living species but also on their organization, their relationships with inanimate materials, and their relationships with one another (biological imbalances). The ecotoxicity of a substance is related in particular to its long-term toxic effects.
- Effluent:** In the case of dredged material, decantation water (backflow) from a confined disposal site as a result of infilling or the disposal of dredged material.
- Elutriate:** Aqueous solution obtained following the addition of water to a solid substance or unconsolidated material (e.g., sediments, tailings, drilling mud, dredged material) by agitation of the mixture, followed by centrifugation, filtration or decantation of the supernatant.

Elutriation: Operation consisting of washing dispersed or suspended granular or muddy materials in water, followed by decantation and disposal of the supernatant. This operation can be repeated several times until the desired result is obtained.

Energy-dispersive X-ray fluorescence spectrometry (EDXRF): This technique involves irradiating the soil matrix using X-rays to excite the metals in the contaminants. The radiation emitted by fluorescence of the metallic species is used to characterize and assay the metals present in the soil.

Environment: Set of natural (physical, chemical, biological) and cultural (sociological) conditions capable of affecting living organisms and human activities.

According to the EQA, the environment refers to the water, atmosphere and soil or a combination of any of them or, generally, the ambient milieu with which living species have dynamic relations.

According to the CEAA, the set of conditions and natural components of the Earth, including:

- a) land, water and air, including all layers of the atmosphere;
- b) all organic and inorganic matter as well as living organisms; and
- c) the interacting natural systems that include components referred to in paragraphs (a) and (b).

Environmental assessment: According to the CEAA, an assessment of the environmental effects of a project that is conducted in accordance with this Act and the regulations.

Environmental components: Elements of the natural environment. These normally include the following elements: air, water, soil, topography, vegetation, animals, fish and birds.

Environmental effects: According to the CEAA, any change that a project may cause in the environment, including any effect of any such change on health and socio-economic conditions, on physical and cultural heritage, on the current use of lands and resources for traditional purposes by aboriginal persons, or on any structure, site or thing that is of historical, archaeological, paleontological or architectural significance, and any change to the project that may be caused by the environment, whether any such change occurs within or outside Canada.

Environmental impacts: Radical positive or negative change in the quality of human life (health and welfare) as a result of an alteration of the environment, including the quality of the ecosystem on which human survival depends.

Evaporation: Passage of water from the liquid to the gaseous state, from the exposed surface of water or soil.

Exclusion list: According to the CEAA, a list of all projects or classes of projects that have been prescribed pursuant to regulations made under paragraph 59(c).

Exoenzyme activity of the bacterial community: Degradation and transport of organic molecules in bacterial cells by means of extracellular enzymes. The level of enzyme activity may be influenced by ambient environmental conditions and is used as a biological indicator. Exoenzyme activity may be measured on site or by means of a laboratory toxicity test (using fluorometric measurement of fluorescent compounds following degradation of an analogous substrate incorporated in the tested sediments).

Extraction: Action taken on a chemical compound to separate out its constituents through the use of a solvent (acid, base, etc.).

Federal authority: According to the CEAA,

(a) A Minister of the Crown in right of Canada;

(b) An agency of the Government of Canada or other body established by or pursuant to an Act of Parliament that is ultimately accountable through a Minister of the Crown in right of Canada to Parliament for the conduct of its affairs;

(c) Any department or departmental corporation set out in Schedule I or II to the *Financial Administration Act*; and

(d) Any other body that is prescribed pursuant to regulations made under paragraph 59(e).

Flammable: Readily ignited.

Food chain: (*Syn.: trophic chain*) Succession of plant and animal populations that feed on one another in a given order. There are several levels: producers; primary, secondary and tertiary consumers; and decomposers.

Freshwater: Relating to fresh water.

Furans: Family of products similar in composition and toxicity to dioxins.

Georadar: This method involves using an antenna to transmit pulses (bursts) of radar waves (50 MHz to several GHz) into the subsoil. These are partially reflected at the boundaries between electrically contrasting materials (conductivity and dielectric constant) and the reflected wave is picked up by the receiving antenna. The absorbency (water, clay) or reflective quality (metal, masonry) of the surfaces makes it possible to differentiate objects from the subsoil.

GPS (Global Positioning System): Relatively new navigation system based on satellite data. Developed by the American army, it can provide continuous readings of the user's position.

Grab sampler: Device used to collect sediment. Generally consists of a pair of jaws that close on the sediment, or a bucket that rotates and cuts into the sediment on touching the bottom.

Groundwater: Generic term used to describe the water found below the surface of the soil. Groundwater accounts for the great majority of freshwater reserves.

Habitat: Area or environment in which a specific type of fauna or flora lives. The habitat provides the organism concerned with everything it needs to survive. Typical

coastal habitats include beaches, marshes, rocky shores, bottom sediments, mud banks and water itself.

Harmful alteration of fish habitat: DFO's *Policy for the Management of Fish Habitat* describes harmful alteration of fish habitat as: "any change to fish habitat that reduces its long-term capacity to support one or more life processes of fish but does not permanently eliminate the habitat."

Hazardous material (substance): Material or substance that, because of its properties (e.g., corrosivity, flammability, toxicity, radioactivity, etc.), presents a danger to the health, safety or physical integrity of a worker or the environment; the associated risks may be eliminated or reduced through special handling and disposal techniques.

Heavy metals: Term used to describe metals that have relatively high atomic weights, such as chromium, nickel, cadmium, lead, silver, gold, mercury, bismuth, copper, etc., and can be precipitated by hydrosulphuric acid. In the soluble state, they are often toxic. Heavy metals can accumulate throughout the food chain.

Hydra test: The hydra test measures the lethal and sublethal effects of liquids on the hydra, *Hydra attenuata*. Three adult organisms are placed in plate wells in the presence of the sample to be studied. Over a 48- to 96-hour exposure period, survival and the morphological changes occurring in the tentacles and body are noted daily and compared to those found in the control group.

Hydrocarbon (H_xC_y): Organic compound consisting of carbon and hydrogen. Petroleum is a natural mixture of hydrocarbons and other organic compounds.

Immiscible: Term used to describe two or more liquids that separate into two or more phases following intimate mixture.

Immunoassay techniques: Techniques using highly selective antigen-antibody interactions and sensitive enzymatic reactions to obtain analytical results.

Immunoassays: Immunoassays are based on the specific recognition of antigens (the substance to be detected) by antibodies, high molecular weight molecules secreted by living immune systems. The method operates as follows: a support (test plate or tube) contains a known quantity of antibodies. The solution to be analysed is placed in contact with the support. The antibodies in the support bind to the antigens contained in this solution (target molecules). Depending on the concentration of antibodies in the solution, varying numbers of antibodies remain unbound after this first operation. The solution to be analysed is rinsed and a final solution of artificially labelled antigens (contained in the kit) is poured on the support. This makes it possible to label all the unbound antibodies. A third operation is then performed to bring about a reaction, for assay purposes, in the labelled antigens bound to the support, by means of colorimetry, photoluminescence or visual assessment.

Impact hypothesis: According to the Canadian Environmental Assessment Agency: a set of statements that link project activities to potential effects on ecosystem components.

***In situ* treatment:** Physical, biological, thermal or chemical process used to treat contaminated matrices (soils, sludges, groundwater, sediments) on site without excavation.

Incineration: Destruction of organic wastes from household garbage, sewage sludge, industrial wastes, etc., by burning.

Industrial effluents: Liquids discharged into water or gaseous emissions. Solids or liquids not discharged into water are described as industrial wastes/residues.

Inorganic: Generic term used to describe certain chemical elements. In general, they do not burn and contain carbon only in non-combustible form. Not composed of living matter.

Inorganic matter: Chemical substances of mineral origin.

Interested party: According to the CEAA, any person or body having an interest in the outcome of the environmental assessment for a purpose that is neither frivolous nor vexatious.

Interim measures: Management measures, such as limitation of access to the site or surveillance of the approaches to the site, implemented in the period following the identification of a potential sediment contamination problem and prior to cleanup operations on the bottom of the waterway.

Leachate: Water or any other liquid likely to contain soluble materials such as organic salts and minerals dissolved (leached) from solid materials.

Leaching: a) removal in solution of certain contaminants from a substance placed in contact with a liquid that acts as a solvent (often water). In a landfill, wastes are leached primarily by rainwater.
b) removal of solid elements from waste by a solvent. In a landfill, wastes are leached primarily by rainwater.

Lethal: Capable of causing death in exposed organisms.

Loran (Long-range Radio Navigation): Widely used navigation system used to determine the position of hyperbolas by measuring the time lag between the reception of signals from fixed, synchronized transmitting stations.

Loran C: Loran navigation system operating in the 100 to 110 kHz band.

Luminescence: Emission of light by a living organism as a result of metabolic activities.

Maintenance dredging: Dredging to maintain navigable depths in navigation channels.

Management measures (options): Measures or actions deemed necessary to limit or reduce the chemical or physical effects of dredging or dredged material disposal activities.

- Mediation:** According to the CEAA, an environmental assessment that is conducted with the assistance of a mediator appointed pursuant to s. 30 and that includes a consideration of the factors required to be considered under ss. 16(1) and (2).
- Microbioassay:** Miniaturized bioassay that requires few samples and is rapid and relatively inexpensive.
- Microorganism:** Very small organism, plant or animal, invisible or barely visible to the naked eye.
- Microwave digestion techniques:** Techniques using commercial microwave sources to heat and rapidly digest contaminated soils.
- Mineralization:** Decomposition of organic matter into mineral compounds.
- Miniranger:** Electronic positioning system using microwaves.
- Mitigation:** According to the CEAA, the disposal, reduction or control of the adverse environmental effects of a project, including restitution for any damage to the environment caused by such effects through replacement, remediation, compensation or any other means.
- DFO's *Policy for the Management of Fish Habitat* defines mitigation as: "actions taken during the planning, design, construction and operation of works and undertakings to alleviate potential adverse effects on the productive capacity of fish habitats." Under the guidelines relative to section 35(2), the term mitigation also designates measures designed to preserve habitat or to prevent any residual impacts to habitat at the project site or any damage indirectly caused by the project. Mitigation measures may thus include a wide range of activities (e.g., project redesign or relocation, definition of timing windows for the work, selection of construction or operation methods) designed to avoid or minimize changes in habitat characteristics and thus to limit the impacts on fish habitat productivity.
- Mobility:** Ability of substances to detach themselves from their original support or medium as a result of physical or chemical processes.
- Mutagen:** Any substance or effect that modifies genetic characteristics or produces genetic material.
- Natural resources:** Generic term used to describe all the natural products, ecosystems, abiotic elements and equilibria that make up the Earth, together with the various forms of natural energy.
- Neutralization:** Chemical reaction between H^+ and OH^- ions, accompanied by the formation of water molecules.
- No net loss:** DFO's *Policy for the Management of Fish Habitat* defines no net loss as: "a working principle by which the department strives to balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further

reductions to Canada's fisheries resources due to habitat loss or damage may be prevented.” The principle of no net loss is fundamental to the conservation objective of the Policy for the Management of Fish Habitat.

Non-renewable natural resources: All natural resources existing in limited quantities and vulnerable to exhaustion at the current rate of consumption.

NO_x (nitrogen oxides): Nitrogen oxides are a family of contaminants frequently found in air presenting photochemical pollution (e.g., Los Angeles smog). Nitrogen dioxide (NO₂) is a lung irritant.

Nuisance: Term used to describe both a cause (pollutant, noise, odour) and an effect (pollution, annoyance).

Ocean disposal: Disposal of substances at sea, in an estuary or in fresh water.

Ocean disposal site: Area in which disposal of a substance or waste at sea is authorized under conditions established by a valid ocean disposal permit.

Organic: Term used to describe chemical compounds having a carbon base, generally combustible. Relating to living beings.

Organic matter: Chemical substances of animal or plant origin or, more accurately, having a carbon base. This category includes most carbon compounds; most organic materials are combustible and many are volatile.

Organochlorine: Term used to describe a synthetic organic chemical substance, derived from chlorine molecules and used for various purposes: insecticides, pesticides (e.g., DDT), fungicides, refrigerants, etc. Organochlorines are generally toxic and persistent.

Oxidation: Chemical process that may consist of oxygen fixation (combustion), hydrogen loss (H₂S to S) or an increase in valence (transformation of a ferrous compound to a ferric compound).

Ozone: Gas resulting from the condensation of oxygen into a molecule having the formula O₃. Ozone is a powerful oxidant with bactericidal and virucidal properties.

PCBs: Generic name for polychlorinated biphenyls, organic compounds consisting of phenol compounds and atoms of chlorine.

Penetrometry using detectors: Adaptation of the penetrometer, a geotechnical investigative tool, for use in various detection tests. A hollow rod, equipped with a penetrating tip and protected by tubing of the same diameter as the tip, is hydraulically driven into the soil. At regular intervals, the tubing is raised several centimetres, thus exposing the detector. The detector may also be in permanent contact with the soil.

Three types of detectors are currently being tested:

- fibre optic photoluminescence detector,
- XRF detector,
- resistivity probe.

Pesticides: Generic term used to describe industrially synthesized compounds used as pest control products, including pesticides, particularly organochlorine compounds: herbicides, fungicides and insecticides.

pH: Measurement of the acidity or alkalinity of a solution or soil; the negative logarithm of the H^+ concentration.

Photoluminescence detectors: This technique makes use of the ability of certain molecules to emit photoluminescence (fluorescence or phosphorescence) when illuminated by a light source of a given wavelength (UV to Visible). The excitation source consists of a pulsed or continuous xenon lamp or a laser source.

Physical treatment: Treatment process that modifies the physical structure of the contaminants in wastes to reduce their toxicity, mobility or volume.

Physico-chemical characterization: Analysis of sediments or pore water to determine physico-chemical properties or components (e.g., pH, granulometric distribution, concentration of major ions, ion exchange capacity, redox potential, salinity and ammonia content, total organic carbon and total volatile sulphides).

Pollutant: A substance or body that contaminates an environment. Physical, chemical or biological agent that adversely affects the natural balance.

Pollution: Contamination of a natural environment as a result of direct or indirect human introduction of toxic substances. Action of polluting, that is, of introducing an undesirable substance into an environment. Degradation of an environment as a result of the introduction of a pollutant.

Polycyclic aromatic hydrocarbons (PAHs): Hydrocarbons having carbon atoms arranged in two or more rings.

Pore water: Generic expression used to describe the water found in the pores of surface soil or sediments from the bottom of a waterway.

Potential fishery: DFO's *Policy for the Management of Fish Habitat* describes potential fishery as: "a fish stock or fish population capable of supporting a subsistence, commercial or recreational fishery but which is not currently being exploited."

ppb (parts per billion): Number of parts per billion, expressed as a mass percentage.

ppm (parts per million): Number of parts per million, expressed as a mass percentage.

Precipitation: Chemical action by which a substance in solution is isolated from its solvent and deposited on the bottom.

- Pretreatment:** First step in the treatment of sewage, sediments, etc., involving screening, crushing or, in some cases, grit removal, to prepare the water and sediments for further treatment.
- Primary consumer:** Term used to describe an animal organism that obtains nourishment from plants.
- Productive capacity:** DFO's *Policy for the Management of Fish Habitat* defines productive capacity as: "the maximum natural capacity of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend."
- Project:** According to the CEAA, any proposed construction, maintenance, modification, decommissioning, abandonment, or other undertaking in relation to a physical work, or any proposed physical activity not relating to a physical work that is prescribed or is within a class of physical activities that is prescribed pursuant to regulations made under paragraph 59(b).
- Proponent:** According to the CEAA, the person, body, federal authority, or government that proposes a project.
- Quality assurance program:** Duplication of some or all laboratory analyses to ensure the desired levels of precision and reproducibility.
- Quality control program:** Duplication of some chemical analyses (generally by an independent external laboratory) to estimate the overall quality of the results obtained and to determine, if necessary, what changes are required to achieve or maintain the desired levels of quality.
- Radar (Radio Detection And Ranging):** Navigation system using reflected electromagnetic radiation to determine the speed and location of a target.
- Rapid extraction and fluorescence detection of PAHs:** This technique uses high-temperature rapid extraction, followed by analysis by means of a two-pump liquid chromatography system combined with a fluorescence detector, to perform rapid, sensitive and partially selective assays of the PAHs present in contaminated soils.
- Reactive:** A compound is reactive if it tends to react spontaneously and violently with ambient water or air.
- Reclamation, reuse:** Creation of added value through the use of dredged sediments, by processing or by the reuse of disposal or fill sites.
- Recovery:** Separation of certain products or materials from wastes for reuse, reutilization or recycling.
- Recycling:** Reintroduction of a recovered material into the production cycle from which it was initially produced. Paper can be recycled, as can steel (in the form of scrap steel) and glass (in the form of scrap glass, or cullet).

- Reduction:** Application of more effective techniques that are less wasteful of raw materials (e.g., use of china coffee cups in place of Styrofoam or paper cups) and improvement of internal measures to prevent spillage.
- Regeneration:** Treatment designed to restore the original qualities of a contaminated or used product, so that it can be used for the same purpose (e.g., regeneration of plastic).
- Renewable natural resources:** All natural resources considered inexhaustible because of their constant renewal (e.g., solar energy).
- Residue:** Material remaining after a chemical or physical operation or transformation. By-product of an industrial process that is of no commercial value but can be used for other purposes (energy, fill, raw material for another industry, etc.).
- Responsible authority:** According to the CEAA, a federal authority that is required pursuant to subsection 11(1) to ensure that an environmental assessment of the project is conducted.
- Resuspension:** New mixture of sediments and pollutants with water as a result of storms, currents, organisms and human activities, such as dredging.
- Reuse:** New use, in its existing condition, of a recovered product or material for a purpose analogous to its original use (e.g., returnable packaging).
- Reutilization:** Use of a recovered material in a production cycle other than the one from which it was initially produced (e.g., incorporation of glass wastes in paving materials, production of acoustic tiles from recovered paper and rubber).
- Risk:** Measurement of the probability and severity of an adverse effect on health, material goods or the environment.
- Runoff:** Liquid fraction from dredged material or surface drainage due to precipitation in confined disposal facilities.
- Sand:** Non-cohesive type of soil, consisting of particles between 0.06 mm and 2 mm in diameter.
- Sanitary landfill:** Site used for the disposal of solid wastes.
- SATNAV:** (from SATellite NAVigation) Relatively inexpensive navigation system that provides worldwide but discontinuous coverage. It uses information from geostationary satellites and other data sources to determine a position.
- Saturated zone:** 1) Portion of the subsoil where air or gas cannot exist as distinct phases; all interstitial spaces are therefore filled with water (which may contain air or gas in solution or in bubble form).
2) Zone in which the interstitial spaces of soil or the fissures in rock are filled with water at greater than atmospheric pressure. In an unconfined aquifer formation, the water table represents the upper boundary of the saturated zone.
- Screening report:** According to the CEAA, a report that summarizes the results of a screening.

- Secondary consumer:** Heterotrophic organism that obtains nourishment from primary consumers.
- Sediments:** Layer of materials from any source, rock, organic or volcanic matter, transported by water from the place of origin to the site of deposition. In waterways, sediments are alluvial materials transported by suspension or as bedload.
- Semi-volatile (compound):** Substance that changes readily to the vapour phase at temperatures between 110°C and 250°C. While these compounds form vapours at lower temperatures, they do so in negligible quantities.
- Sextant:** Double-reflecting optical instrument used to determine latitude and longitude, normally by measuring the angular distance of a star above the horizon.
- Silt:** Type of soil having cohesive properties, consisting of particles between 0.002 mm and 0.006 mm in diameter.
- Sludge:** General term designating the residues from water purification or treatment, occurring in the form of mud or muck with a high water content, deposited on the bottom of sedimentation basins.
- Social impact:** According to the Canadian Environmental Assessment Agency, identification of the environmental qualities or components that are of concern to the public and/or professionals and require assessment on a priority basis.
- Soil gas:** Vapour or gas found in the interstitial spaces of the unsaturated zone.
- Solidification/stabilization:** Treatment techniques that immobilize sediments and their contaminants by the addition of solid and/or liquid reagents. They may be designed simply to impede the physical mobility of the contaminants or, more ambitiously, to fix them by means of a reaction that modifies their chemical nature.
- Solid-phase micro-extraction (SPME):** This method has been studied as an alternative method of characterizing volatile aromatic hydrocarbons (BETEX) in contaminated soils. BETEX are extracted from the soil using a fused silica fibre; this is then removed and the analytes are thermally desorbed in the injector of a gas-phase chromatograph.
- Solids:** All materials, dissolved or undissolved, volatile or non-volatile, present in sewage or water supply systems.
- Sonar (Sound Navigation And Ranging):** Communication or positioning system based on the underwater reflection and propagation energy of acoustic signals.
- Sorption:** Physical or chemical adsorption or absorption.

Specific detector (gas chromatography): Gas chromatography combines a gas separation column technique and detection at the column outlet. The gas separation column technique permits separation of the gases on the basis of their molecular size, using the property of differential retention as a gaseous mixture passes through a capillary column or a column packed with a retentive substance. As they exit the column, the gases pass in succession through the detector. The detectors used on portable chromatographs are:

- total detectors (flame ionization);
- total detectors (photoionization).

Specific detector (infrared): A small pump feeds the gas into the measurement chamber, where a ray of infrared light passes through it from a source via an interferometer. A detection unit measures light absorption over the entire infrared spectrum. The modulated signal produced by selective absorption of the gas is converted by mathematical transformation (Fourier transform) into an absorption spectrum.

Specific detector (mass spectrometry): Mass spectrometry (MS), alone or in combination with gas chromatography (GC/MS), is one of the most reliable methods for volatile and semi-volatile pollutants. The sample is first introduced into an ionization chamber where the molecules are broken down according to a characteristic pattern specific to each substance. The ions thus formed are accelerated by means of a magnetic field, then separated on the basis of mass in a quadrupole. The multiplied photo signal provides a recognizable spectrum for comparison with the standards contained in a database. The effectiveness of the system can be enhanced by combination with the chromatographic technique.

Specific detector (X-ray fluorescence): The sample is placed under low X-radiation (Cm 244 or Am 241). The radiation photons collide with the atomic cloud of the atom, thus creating vacancies in the internal orbits. The outer electrons fill these voids by migrating into the internal orbit, where they emit X-radiation. The photons produced by X-fluorescence are counted over a given period and classified by a multichannel analyser on the basis of their energy. This produces a characteristic spectrum for the sample, which is then compared with a bank of standards. Selection of the source makes it possible to target an appropriate portion of the spectrum. Existing devices have sufficient memory to permit the measurement of a number of chemical elements and/or matrix standards.

Spill: Any accidental or deliberate discharge into the environment, of short duration, likely to create an environmental nuisance.

Stabilization: Process used to reduce the hazardous potential of a waste physically or chemically by converting the toxic contaminants to a less mobile or reactive form.

Study area: The study site and its vicinity (that is, any area likely to influence the study site), which require surveillance or assessment.

- Subaqueous capping:** Capping of contaminated sediments in an underwater disposal site with a layer of clean, or less contaminated, materials. May be performed in a natural depression or a previously prepared excavation.
- Sublethal:** Having an adverse effect on exposed organisms but not directly causing their death.
- Sulphates:** Generic term for salts having sulphate as the anion. Sulphates are natural products or are formed by the action of sulphuric acid.
- Supercritical fluid extraction (SFE):** In this technique, solvents such as carbon dioxide and nitrous oxide in the supercritical state are used to extract polycyclic aromatic hydrocarbons and chlorinated phenols from contaminated soils.
- Suspended solids (SS):** Materials that can be deposited or removed by filtration.
- Sustainable development:** Set of practices promoting the development of resources to meet the needs of the present, without compromising the ability of future generations to meet their own needs.
- According to the CEAA, sustainable development means development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.
- Synergy:** Effect of the combination of two or more agents such that their combined effect is greater than the sum of their individual effects.
- Tendering:** Invitation to a number of firms with the capacity to carry out a project to prepare offers for a clearly defined set of project tasks.
- Theodolite:** Telescope used in surveying for accurate measurement of horizontal and vertical angles.
- Thermal treatment:** Treatment process designed to oxidize hazardous organic substances into carbon dioxide and water.
- Total detectors (flame ionization):** A small pump feeds the gas into the measurement chamber, where it is ionized in the presence of oxygen from the air and an injected combustible gas: hydrogen. The ions produced then pass into an artificial electrical field where they generate a current proportional to the gas concentration. The signal is linked in particular to the proportion of hydrogen atoms in the gas molecule.
- Total detectors (photoionization):** A small pump feeds the gas into the measurement chamber, where it is ionized by the energy flux from a lamp. The ions produced generate a measureable electrical current. The compounds are ionized (detected) only if their ionization potential is similar to or lower than the energy of the lamp used.
- Total organic carbon (TOC):** Measurement of the quantity of carbon in a sample originating entirely from organic matter. This test is performed by burning the sample and measuring the carbon dioxide produced.

- Toxic substance:** Substance capable of causing death, disease, behavioural anomalies, cancer, genetic mutations, physiological or reproductive anomalies or physical deformities in any organism or its offspring or capable of becoming toxic as a result of concentration in the food web or in combination with other substances.
- Toxicity:** Capacity of a substance to change or disrupt the functions of a living organism, resulting in adverse effects, the most serious of which is the death of the organism. The toxicity of a substance is dependent on concentration and length of exposure. There are two types of toxicity: acute (short-term) and chronic (long-term).
- Toxicity tests:** Experiment to determine the effect of a material or substance on a population of a given species of experimental organisms under given conditions. This normally measures either the proportion of organisms affected or the degree of the effect observed following exposure to a given test substance (e.g., a sample of sediments, pore water or elutriate).
- Treatability tests (studies):** Laboratory or *in situ* tests of treatment technologies, required for a detailed assessment of their technical, economic and environmental feasibility.
- Treatment system:** Complete treatment process, including pre-treatment, primary treatment, treatment of residues and other wastes (atmospheric emissions, liquid and solid effluents) from the treatment and post-treatment processes. In some cases, these treatment systems include technologies capable of effectively treating inorganic as well as organic contaminants.
- Trisponder:** Electronic positioning system using microwaves.
- Turbidity:** Characteristic of water that is not transparent.
- Unsaturated zone:** Zone located below the surface (normally above the saturated zone), where gaseous, aqueous and solid phases coexist. Ordinarily the zone closest to the surface.
- Valued ecosystem components:** Each of the environmental attributes or components considered important by the proponent, public, scientists and governments participating in an assessment process. Cultural values as well as scientific concerns may be used as criteria to assess the importance of these components.
- Volatile organic compounds (VOCs):** Any carbon compound, with the exception of carbon oxides, metal carbides, carbonates and cyanides, likely to be found in the atmosphere at ambient pressure and temperature (e.g., organic solvents, light hydrocarbons). The definition of a volatile organic compound often includes references to specific sampling and analysis methods (e.g., MUC, U.S. Environmental Protection Agency).
- Volatility:** Tendency to change into the vapour phase. Chemicals having low vapour pressures have high volatility.

Waste disposal: Term used to describe all operations involving the storage, sorting, collection, transport and treatment of wastes to produce substances that can be either returned to the natural environment without adverse effects, or reintroduced into the economic cycle for reuse or recycling.

Waste reclamation: Any treatment of wastes that gives them a positive economic value in terms of energy or recovery of raw materials.

Waste treatment: Set of operations performed on wastes to reduce their potential harmfulness to the environment or to facilitate their handling, transport or reclamation.

Wastes: Residues, materials, substances or debris discarded following production, manufacture or use.

Water table: Ground water; in simple hydrogeological situations, the water table corresponds to the upper surface of the ground water.

Appendix B Statutes, Regulations, Policies, Guidelines and Guides Potentially Applicable to Dredging and Contaminated Sediment Remediation Projects

B.1 Federal Statutes and Regulations

Legislation	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
<i>Canada Labour Code</i>	X	X	X	LC
- Canada Occupational Safety and Health Regulations			X	LC
- Aviation, Marine, On Board Trains, Oil and Gas Occupational Safety and Health Regulations			X	LC
<i>Canadian Environmental Protection Act (CEPA)</i>	X	X	X	EC
- Federal Registration of Storage Tank Systems for Petroleum Products and Allied Petroleum Products on Federal Lands or Aboriginal Lands Regulations			X	EC
- Storage of PCB Material Regulations		X	X	EC
- Federal Mobile PCB Treatment and Destruction Regulations			X	EC
- PCB Waste Export Regulations		X	X	EC
- Fuels Information Regulations, No. 1			X	EC
- Export and Import of Hazardous Wastes Regulations		X	X	EC
- Ocean Dumping Regulations, 1988	X			EC
- Contaminated Fuel Regulations			X	EC
- New Substances Notification Regulations			X	EC

B.1 Federal Statutes and Regulations (Continued 1)

Legislation	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
<i>Canadian Environmental Assessment Act (CEAA)</i>	X	X	X	CEAA/FA
- Regulations Respecting the Coordination by Federal Authorities of Environmental Assessment Procedures and Requirements	X	X	X	CEAA
- Comprehensive Study List Regulations	X	X	X	CEAA
- Exclusion List Regulations	X	X	X	CEAA
- Inclusion List Regulations	X			CEAA
- Law List Regulations	X	X	X	CEAA
<i>Explosives Act</i>	X	X		NRCan
- Explosives Regulations	X	X		NRCan
<i>Hazardous Products Act</i>			X	NRCan
- Hazardous Products Regulations			X	HC
<i>Transportation of Dangerous Goods Act, 1992 (TDGA)</i>			X	TC
- Transportation of Dangerous Goods Regulations (TDGR)		X	X	TC
<i>Hazardous Materials Information Review Act</i>			X	HC
- Hazardous Materials Information Review Regulations			X	HC
<i>Navigable Waters Protection Act (NWPA)</i>	X			DFO and CCG
<i>Fisheries Act</i>	X	X	X	DFO
- Fishery (General) Regulations	X	X		DFO
- Marine Mammal Regulations	X			DFO

B.1 Federal Statutes and Regulations (*Continued 2*)

Legislation	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
<i>Migratory Birds Convention Act, 1994</i>	X	X		EC
- Migratory Birds Regulations	X	X		EC
- Migratory Bird Sanctuary Regulations	X	X		EC
<i>Plant Protection Act</i>				AAFC
- Plant Protection Regulations		X		AAFC
<i>Health of Animals Act</i>		X		AAFC
- Health of Animals Regulations		X		AAFC
<i>Canada Shipping Act</i>				TC
- Ship-source Oil Pollution Fund Regulations	X			TC
- Garbage Pollution Prevention Regulations	X			TC
- Air Pollution Regulations	X			TC
- Oil Pollution Prevention Regulations	X			TC
- Response Organizations and Oil Handling Facilities Regulations	X			TC
- Dangerous Chemicals and Noxious Liquid Substances Regulations	X			TC
- Pollutant Discharge Reporting Regulations, 1995	X			TC
Workplace Hazardous Materials Information System (WHMIS)			X	HC

B.2 Quebec Statutes and Regulations

Legislation	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
<i>Highway Safety Code</i>		X	X	MTQ
- Transport of Dangerous Substances Regulation			X	MTQ
<i>Environment Quality Act</i>	X	X	X	MENV
- Regulation Respecting Environmental Impact Assessment and Review	X	X	X	MENV
- Regulation Respecting the Application of the <i>Environment Quality Act</i>	X	X	X	MENV
- Regulation Respecting Wastewater Disposal Systems for Isolated Dwellings			X	MENV
- Regulation Respecting Solid Waste		X	X	MENV
- Regulation Respecting Hazardous Materials			X	MENV
- Regulation Respecting the Quality of the Atmosphere		X	X	MENV
- Regulation Respecting Underground Waters		X	X	MENV
- Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains (Order-in-Council 103-96)		X		MENV
<i>Act Respecting the Conservation and Development of Wildlife</i>	X	X	X	MENV
- Regulation Respecting Wildlife Habitats	X	X	X	MENV
<i>Act Respecting the Use of Petroleum Products</i>				MRN
- Petroleum Products Regulation			X	MRN
<i>Act Respecting Pressure Vessels</i>			X	CSST
<i>Act Respecting Explosives</i>	X	X		MRN
- Regulation Respecting the <i>Act Respecting Explosives</i>	X	X		MRN
Workplace Hazardous Materials Information System (WHMIS)			X	CSST

B.2 Quebec Statutes and Regulations (*Continued*)

Legislation	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
<i>Act Respecting Occupational Health and Safety</i>				CSST
- Regulation Respecting the Quality of the Work Environment	X	X	X	CSST
- Regulation Respecting Industrial and Commercial Establishments			X	CSST
- Safety Code for the Construction Industry	X	X	X	CSST
- Regulation Respecting Information on Controlled Products			X	CSST

B.3 Municipal By-laws

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Municipal by-laws		X	X	Municipalities
By-law Pertaining to Air Purification (<i>By-law 90</i>)		X	X	VdM
By-law Respecting Wastewater Disposal in Sewer Systems and Waterways (<i>By-law 87</i>)		X	X	VdM

ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
CEAA	Canadian Environmental Assessment Agency
CSST	Commission de la santé et sécurité au travail
DFO	Fisheries and Oceans Canada
EC	Environment Canada
FA	Federal authorities
HC	Health Canada
LC	Labour Canada
MENV	Quebec Environment Department
MRN	Quebec Department of Natural Resources
MTQ	Quebec Department of Transport
NRCan	Natural Resources Canada
TC	Transport Canada
VdM	Ville de Montréal

B.4 Policies

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Soil Protection and Contaminated Sites Rehabilitation Policy (June 1998)		X	X	MENV
Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments (April 1976)		X	X	EC
Incinération des déchets solides non dangereux, projet de règlement (August 1989)			X	EC
Groundwater Protection and Conservation Policy (August 1996, revised June 1997)		X	X	MENV
Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains (1996)		X	X	MENV
Policy for the Management of Fish Habitat (1986)	X			DFO
Federal Policy on Wetland Conservation (1991)	X	X	X	EC

B.5 Guidelines

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Lignes directrices pour la caractérisation des sédiments	X			MENV
Priority Substances List 2	X	X	X	MENV
National Guidelines for the Landfilling of Hazardous Wastes (1991)		X	X	CCME
National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites (1998)	X			EC
Directive pour la réalisation d'une étude d'impact sur l'environnement d'un projet de port ou de quai (1997)	X			MENV
Guidance Document on the Management of Contaminated Sites in Canada (1997)	X	X		CCME
Lignes directrices pour le traitement des sols par biodégradation, bioventilation ou volatilisation (1991)			X	MENV
Guidelines for the Use of Explosives In or Near Canadian Fishing Waters (1998)	X			DFO
Guidelines for Reporting Incidents Involving Dangerous Goods, Harmful Substances and/or Marine Pollutants	X			CCG
National Guidelines on Physical-Chemical-Biological Treatment of Hazardous Waste (1989)			X	CCME
Technical Guidelines for Aboveground Storage Tank Systems Containing Petroleum Products			X	EC
Standards for Oil Handling Facilities Oil Pollution Emergency Plans	X	X	X	EC
Lignes directrices pour l'application de mesures d'atténuation des impacts de travaux en milieu côtier sur les mammifères marins du Saint-Laurent	X			DFO
Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments		X	X	EC

B.6 Guidelines (Criteria)

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Interim Criteria for Quality Assessment of St. Lawrence River Sediment (1992)	X	X	X	EC/MENV
Canadian Interim Sediment Quality Guidelines (1995)	X			EC
Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (1995)	X			CCME
Review and Recommendations for Canadian Interim Environmental Quality Criteria for Contaminated Sites (1991)		X	X	CCME
Development of Canadian Marine Environmental Quality Guidelines (1992)	X			EC
Guidelines for Canadian Drinking Water Quality (1995)	X	X	X	CCME
Méthode de calcul des objectifs environnementaux de rejet pour les contaminants du milieu aquatique	X	X	X	MENV
Règlement relatif aux rejets dans les réseaux d'égouts de la municipalité (Guide proposed by the Ministère de l'Environnement du Québec to municipalities)		X	X	MENV/ Municipalities
Assainissement atmosphérique: le bruit communautaire	X	X	X	MENV

B.7 Guides

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Responsible Authorities Guide – <i>Canadian Environmental Assessment Act</i>	X	X	X	CEAA
Legislative Framework for Sediment Management in Quebec (1993)	X	X	X	EC
Environmental Impacts of Dredging and Sediment Disposal (1994)	X	X		EC/MENV
Guide relatif au dragage et à l'élimination des sédiments contaminés dans le fleuve Saint-Laurent (1980)	X	X	X	EC
Guide pour un examen préalable des projets de dragage et de génie maritime dans le Saint-Laurent (1985)	X	X	X	EC
Cumulative Effects Assessment Practitioner's Guide	X	X	X	CEAA
Guide to Selecting and Operating Dredging Equipment and Related Practices	X	X	X	EC/MENV
Guide to Assessing and Selecting Treatment Technologies for Contaminated Sediment (1993)			X	EC
Review of Whole Organism Bioassays for Assessing the Quality of Soil, Freshwater Sediment, and Freshwater in Canada (1994)	X	X	X	EC
Lieux d'enfouissement sécuritaire: guide d'implantation et de gestion de lieux d'enfouissement de sols contaminés (1995)		X	X	MENV
Dangerous Goods - Guide to Initial Emergency Response (1992)			X	CANUTEC
Canadian Coastal Environments, Shoreline Processes, and Oil Spill Cleanup	X			EC
Guide de gestion des matières et déchets dangereux et des urgences environnementales dans les installations fédérales au Québec (1998)			X	EC
Guidelines for the Notification and Testing of New Substances			X	EC
Code of Practice for Used Oil Management in Canada (August 1989)			X	CCME
Manual for the Management of Wastes Containing PCBs (September 1989)			X	CCME

B.7 Guides (Continued 1)

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Users' Guide to Hazardous Waste Classification (1993)			X	EC
Users' Guide to the Hazardous Waste Manifest (1993)		X	X	EC
Users' Guide to the Hazardous Waste Export/Import Notice (1993)		X	X	EC
User's Guide to Implementation: Export and Import of Hazardous Wastes Regulations (1993)		X	X	EC
A Framework for Ecological Risk Assessment at Contaminated Sites in Canada: Review and Recommendations	X	X	X	EC
Répertoire de guides techniques d'intervention en environnement	X	X	X	EC
Used Oil Management in Canada: Existing Practices and Alternatives (August 1989)			X	CCME
Response Techniques for the Cleanup of Sinking Hazardous Materials (1989)	X			EC
Guide d'entreposage des déchets dangereux et gestion des huiles usées (1985)		X	X	MENV
Périmètre de protection autour des ouvrages de captage des eaux souterraines		X	X	MENV
National Fire Protection Code (1990)			X	FC
Pesticide Management Code (May 1989)		X	X	MENV
Environmental Code of Practice for Aboveground Storage Tank Systems Containing Petroleum Products (August 1994)				
Federal Policy on Wetland Conservation Implementation Guide for Federal Land Managers (1996)		X		EC
Guide pour l'évaluation des impacts sur les oiseaux (1997)	X	X		DFO
Technical Guidance Document for Aquatic Environmental Effects Monitoring Related to Federal Fisheries Act Requirements (1993)	X			DFO

B.7 Guides (Continued 2)

	Open-water dredging and disposal	Upland disposal	Treatment	Responsibility
Guide d'évaluation des impacts potentiels de différents projets en relation avec les habitats du poisson (1992)	X	X		DFO
Guide d'évaluation environnementale en regard du poisson et de son habitat: aménagement hydroélectrique, routes et infrastructures d'accès		X	X	DFO
Guide d'évaluation environnementale en regard du poisson et de son habitat (1993)	X			DFO

ABBREVIATIONS

CANUTEC	Canadian Transport Emergency Centre
CCG	Canadian Coast Guard
CCME	Canadian Council of Ministers of the Environment
CEAA	Canadian Environmental Assessment Agency
DFO	Fisheries and Oceans Canada
EC	Environment Canada
FC	Fire Commissioner of Canada
MENV	Ministère de l'Environnement du Québec

Appendix C Conceptual Impact Models for Dredging and Sediment Management Activities

The environmental impacts generally associated with dredging and sediment management relate to sediment excavation, transport and aquatic or upland disposal. While some may permanently affect the environment, most are temporary and local.

With respect to the physical environment, the impacts of dredging and sediment disposal activities are felt primarily on water quality: increased turbidity, higher concentrations of suspended solids, dispersion of contaminants and, in certain very specific cases, increased chemical oxygen demand (COD), reduced concentration of dissolved oxygen, dispersion of nutrients, etc. Dredging also affects the physical characteristics of excavation or disposal sites through alteration of the bottom or of hydrodynamic conditions and bathymetry.

Dredging and disposal activities can also affect the components of the biological environment, either directly by destroying fish habitat, burying or disturbing benthic fauna and shellfish areas or suffocating fish eggs and larvae, or indirectly by temporarily modifying the characteristics of aquatic or riparian habitats or exposing organisms to toxic substances in the dredged sediments.

The disturbance of water quality and alteration of physical characteristics can in turn affect various components of the human environment, including recreational sites and activities, water intakes, commercial and recreational fishing, agriculture, navigation, etc. Finally, the presence and activity of dredging and disposal equipment may temporarily conflict with certain human or biological activities.

Depending on the processes used, contaminated sediment remediation projects may lead not only to contaminant losses during dredging and transport, but to atmospheric emissions and discharges of wastewater and solid wastes that, if not controlled and treated, may result in a deterioration of environmental quality and risks to human health.

Obviously, all these potential repercussions and impacts on the natural environment and on human beings are not invariably associated with every dredging and sediment management project. One of the earliest environmental assessment tools, used since the mid-1970s to identify the environmental components likely to be affected by the various activities involved in a project, is an impact matrix as illustrated in Figure C1. As noted in Chapter 3, this impact matrix can also be very useful in an ESMP for rapid visualization of the components requiring particular surveillance and monitoring.

C.1 Identification of the Impact Mechanisms to be Monitored

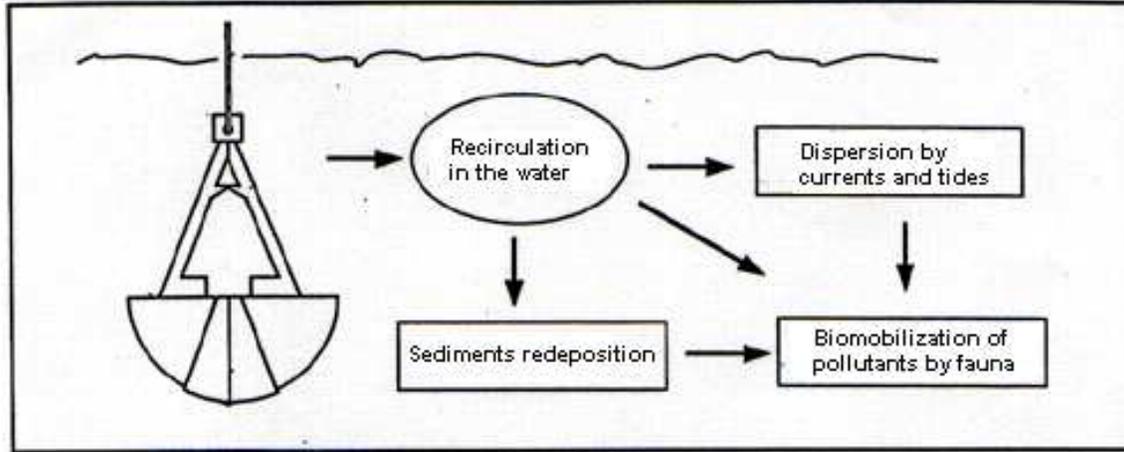
Identification of the impact mechanisms to be monitored requires, first, a knowledge of the activities involved in the project and their possible interactions with all the components of the environment, as illustrated in the impact matrix (Figure C1).

Conceptual diagrams illustrating the principal mechanisms of contaminant migration are also useful in visualizing these impacts. Figures C2 to C6 present examples of diagrams for possible contaminant losses associated with mechanical dredging (Figure C2a), hydraulic dredging (Figure C2b), open-water disposal (Figure C3a), shoreline disposal (Figure C3b), confined disposal in shallow water (Figure C4a), confined disposal in deep water (Figure C4b), disposal in shallow water with lateral containment (Figure C5a), disposal in a stream with lateral containment (Figure C5b), and disposal in an upland confined disposal facility (Figure C6). Figure C7 presents the possible pathways of contaminant migration or loss associated with a contaminated sediment treatment facility.

		<i>Environmental Components</i>																							
		PHYSICAL				CHEMICAL				BIOLOGICAL					SOCIO-ECONOMIC										
PROJECT COMPONENTS	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.		
	BATHYMETRY	HYDRODYNAMICS	SEDIMENTOLOGY	DRAINAGE	EROSION	SEDIMENT QUALITY	AIR QUALITY	SURFACE WATER QUALITY	SOIL QUALITY	GROUNDWATER QUALITY	AQUATIC FAUNA AND HABITAT	AVIAN FAUNA AND HABITAT	TERRESTRIAL FAUNA AND HABITAT	RIPARIAN FAUNA AND HABITAT	RECREATIONAL ACTIVITIES	HERITAGE AND PROTECTED AREAS	COMMERCIAL FISHING	LAND USE	LANDSCAPE AESTHETICS	QUALITY OF LIFE	WATER INTAKES	ARTESIAN WELLS	HUMAN HEALTH		
A. SEDIMENT EXCAVATION																									
B. DYNAMITING																									
C. SHIPPING																									
D. OVERLAND TRANSPORT																									
E. OPEN-WATER DISPOSAL																									
F. SHORELINE DISPOSAL																									
G. UPLAND DISPOSAL																									
H. TREATMENT AREA																									
I. PRETREATMENT																									
J. SEDIMENT STORAGE																									
K. CHEMICAL STORAGE																									
L. TREATMENT																									
M. POST-TREATMENT																									
N. RESIDUE STORAGE																									
O. RESIDUE DISPOSAL																									
P. EQUIPMENT TRAFFIC																									
Q. DEMOBILIZATION/ DECONTAMINATION																									

Note: The blanks represent potential impacts.

Figure C1 Example of an environmental impact assessment matrix for dredging and sediment management projects



Source: Parametrix, 1990.

Figure C2a Contaminant migration pathways associated with mechanical dredging

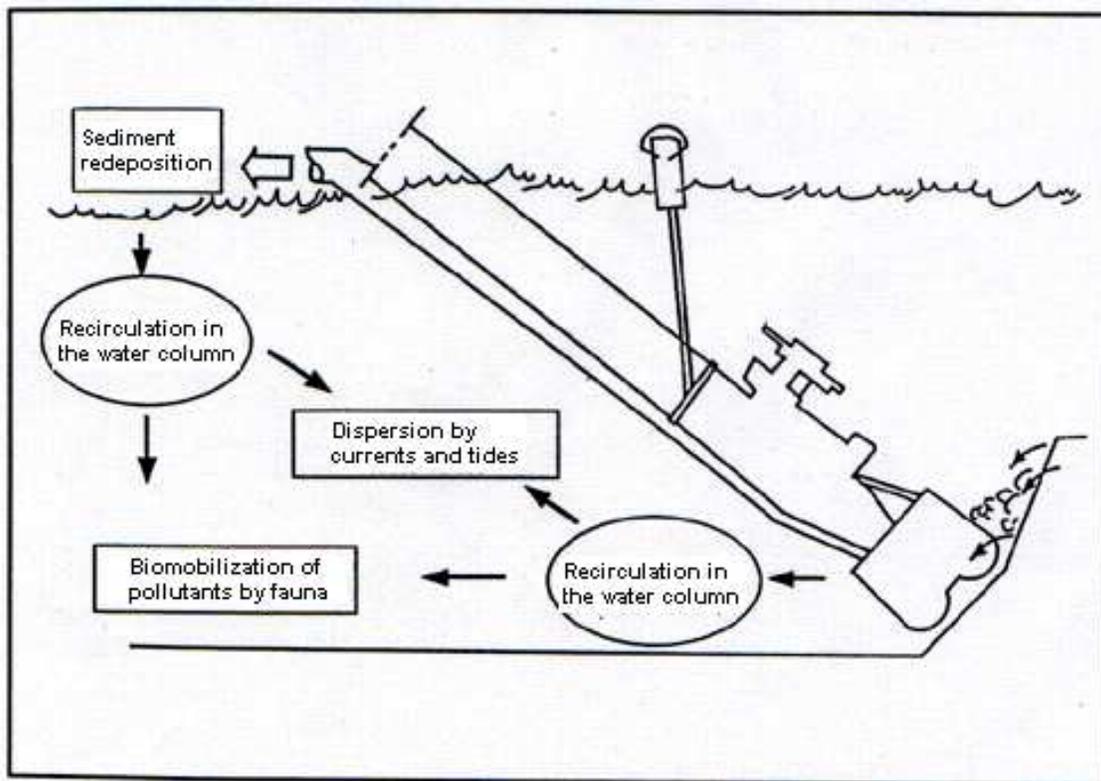


Figure C2b Contaminant migration pathways associated with hydraulic dredging

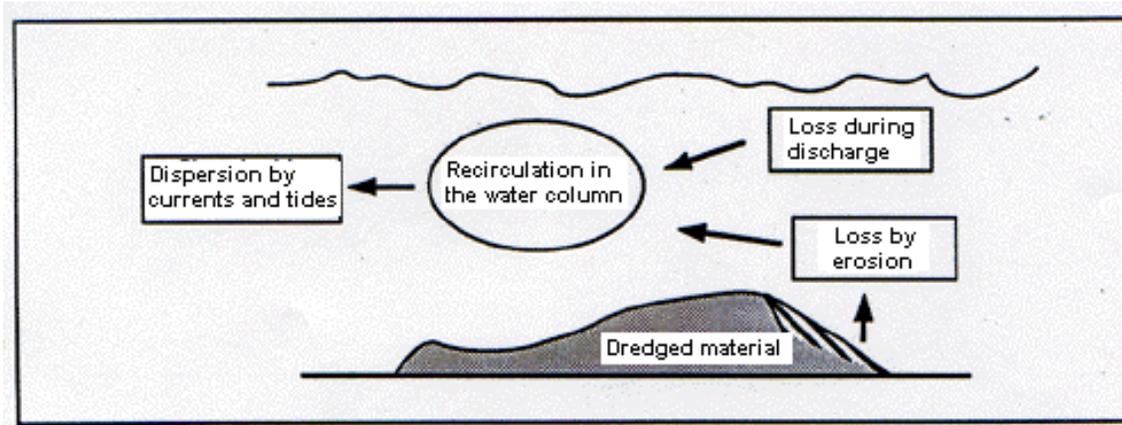
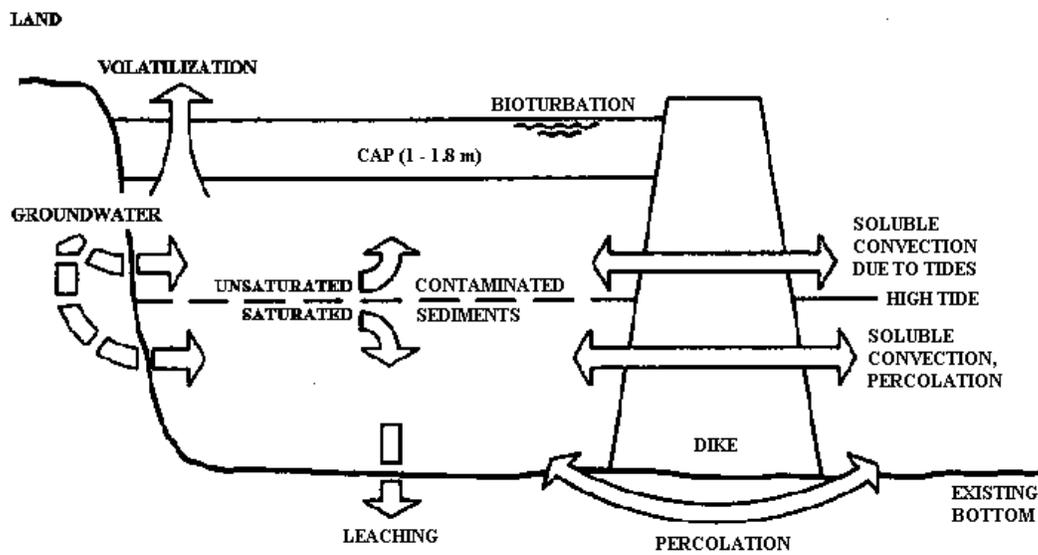
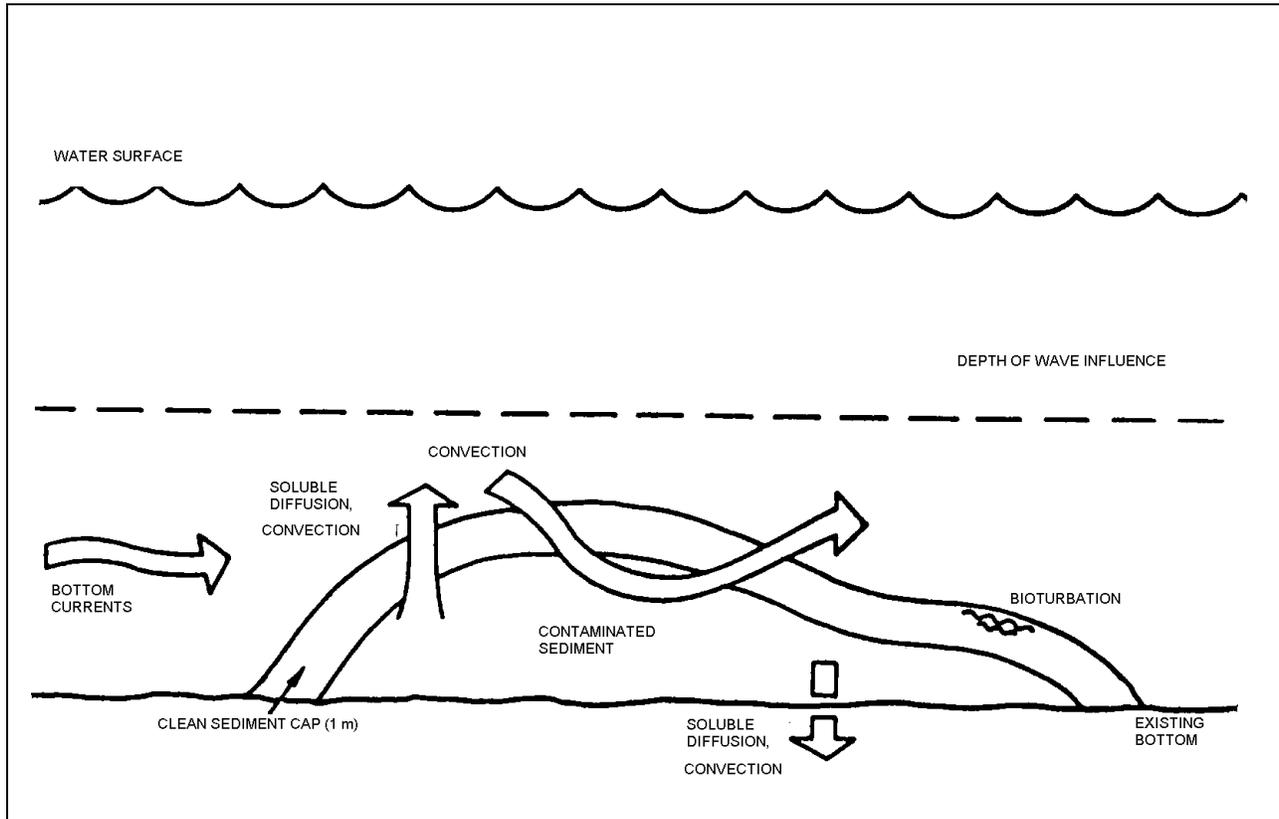


Figure C3a Contaminant migration pathways associated with open-water disposal



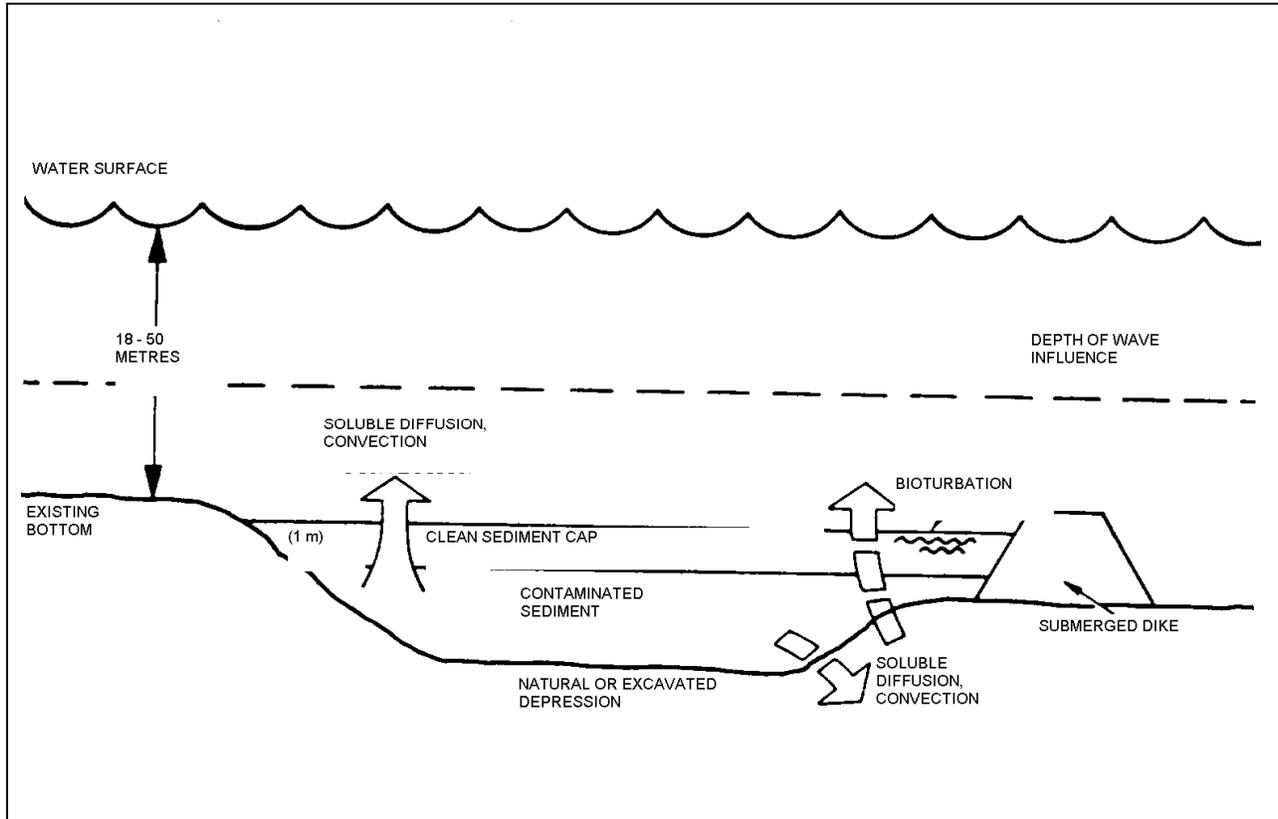
Source: Cullinane et al. (1986).

Figure C3b Contaminant migration pathways associated with shoreline disposal



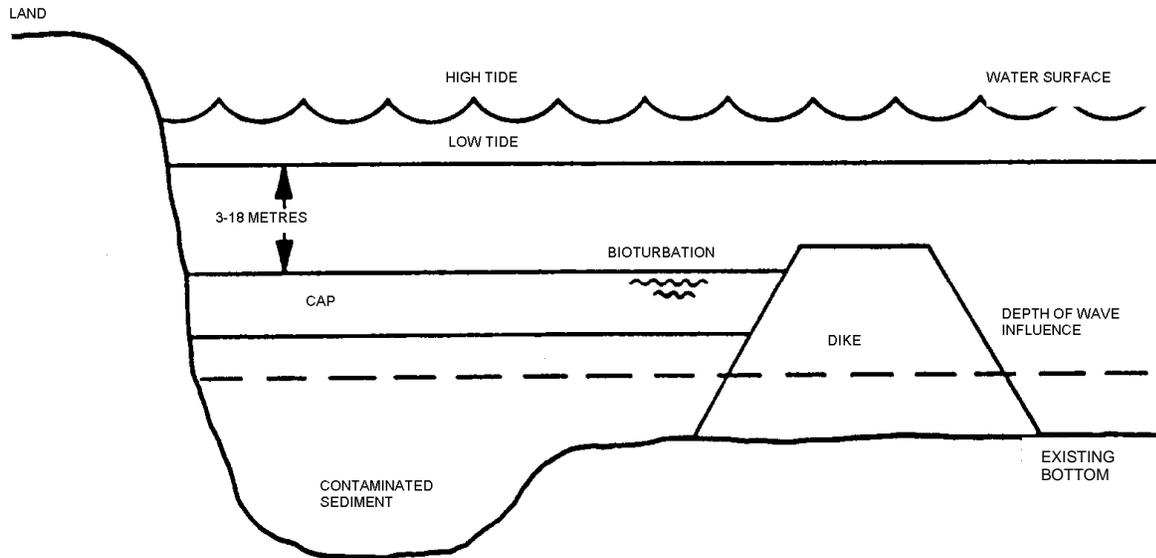
Source: Cullinane et al. (1986).

Figure C4a Contaminant migration pathways associated with confined disposal in shallow water



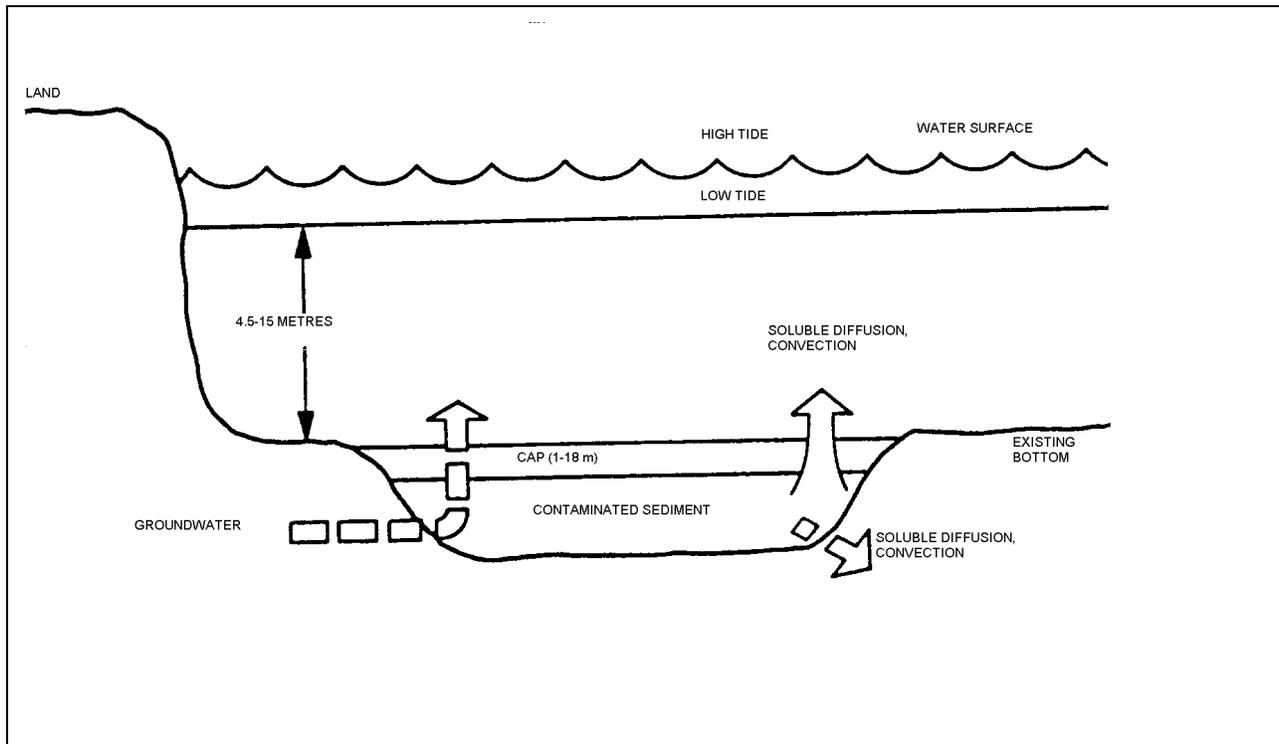
Source: Cullinane et al. (1986).

Figure C4b Contaminant migration pathways associated with confined disposal in deep water



Source: Cullinane et al. (1986).

Figure C5a Contaminant migration pathways associated with confined disposal in shallow water with lateral containment



Source: Cullinane et al. (1986).

Figure C5b Contaminant migration pathways associated with disposal in a waterway with lateral containment

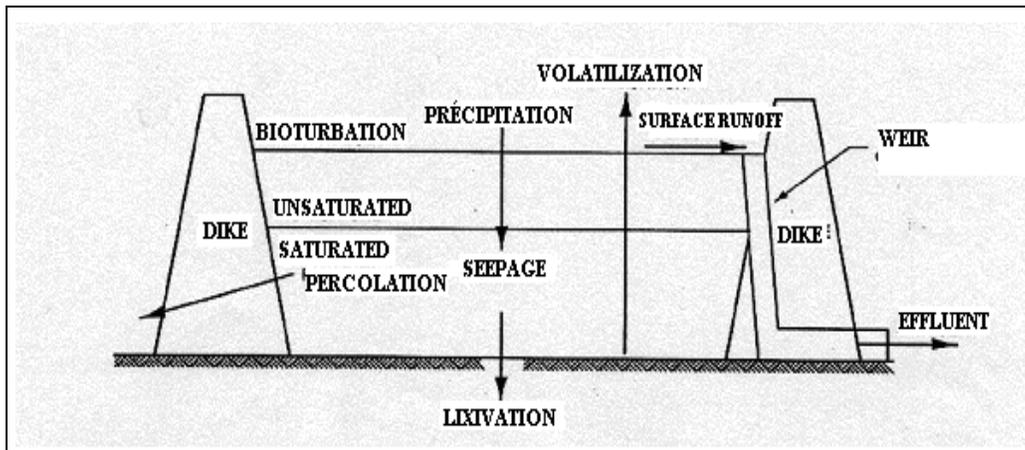


Figure C6 Contaminant migration pathways associated with upland confined disposal

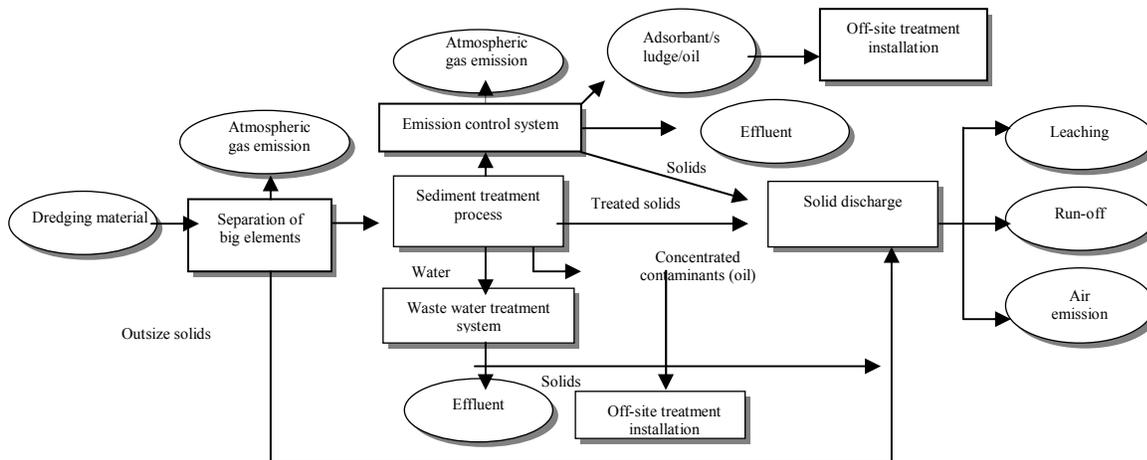


Figure C7 Activities associated with an off-site contaminated sediment remediation project or stages in an off-site contaminated sediment remediation project

The next step is to classify these mechanisms in terms of environmental and human health risks. For example, Table C1 identifies the environmental and human health risks associated with the various methods of sediment confinement in aquatic, shoreline and upland

environments. For each method, this table indicates the significance of the geochemical effects on contaminant mobilization, the range of options available for control and a qualitative assessment of the resulting risks to the environment and human health. It should be noted, however, that the qualitative risk assessment presented in this table is not valid for all containment projects since it varies with the scope of the project and the particular vulnerability of the receiving environment.

Table C1

Comparison of the risks to the environment and human health associated with various methods of containing contaminated sediments

Method of containment	Geochemical effects on contaminant mobilization	Significance of transport Mechanisms	Control options available	Risks to the environment and human health*
Aquatic capping	Low	Diffusion: high Convection: moderate Bioturbation: variable Erosion: moderate	Few	Low because of dilution (risks to resources)
Upland containment	High	Diffusion: low Convection: moderate Volatilization: high Bioturbation: variable Erosion: low	Many	Vary with contaminants (risks to human health)
Shoreline containment	High in unsaturated environments Moderate in saturated environments	Diffusion: high Convection: high Volatilization: high Bioturbation: variable Erosion: low	Varying	Moderate (risks to human health and resources)

Source: Cullinane et al. (1996).

* This assessment may vary with the scope of the project and the sensitivity of the receiving environment.

A table of this kind is useful in designing an ESMP. While few options are available for controlling contaminant transport mechanisms in aquatic capping projects, it will be noted, on the other hand, that the possibilities of contaminant mobilization are generally low. The risks to

the environment and human health are thus considered generally low, particularly in view of the dilution factor offered by the aquatic environment in the event of contaminant redissolution. In contrast, the table indicates that, with upland containment, a number of mechanisms can result in contaminant mobilization. However, since numerous control options are available, the risks to the environment and human health vary from low to high depending on the nature of the contaminants and the effectiveness of the control measures. Shoreline containment occupies a position midway between the other two approaches.

Similarly, Table C2 lists the principal mechanisms of contaminant loss associated with aquatic capping, containment and *in situ* treatment of contaminated sediments. In the case of capping and treatment, short-term contaminant losses are linked to the resuspension of sediments in the water column, and long-term losses to the mechanisms of diffusion, bioturbation and erosion. In the case of containment, losses are believed to be dependent on seepage and possible long-term leaching of the contaminants trapped in the sediments.

Table C2

Contaminant migration mechanisms associated with *in situ* remediation technologies

Technology	Contaminant migration mechanism
<i>In situ</i> capping	<ul style="list-style-type: none"> - Resuspension/advection during placement of cap - Long-term diffusion/advection - Long-term bioturbation - Long-term erosion
<i>In situ</i> containment	<ul style="list-style-type: none"> - Resuspension during construction - Loss during dewatering/filling - Long-term seepage/leaching
<i>In situ</i> treatment	<ul style="list-style-type: none"> - Resuspension during treatment - Long-term diffusion - Long-term bioturbation - Long-term erosion

Source: USEPA (1994b).

Once the impact mechanisms have been identified and classified, it becomes possible to identify the contaminant migration pathways in the sediments, air, surface water, soils, groundwater and food chain requiring environmental surveillance and monitoring. Table C3 lists these principal contaminant migration mechanisms or pathways for all components of a dredging,

disposal and contaminated sediment management project. The reader is invited to consult Myers et al. (1996), USEPA/USACE (1992), Myers (1990), Brannon et al. (1990) and Parametrix (1996) for detailed descriptions of these migration mechanisms.

Table C3

Principal contaminant migration mechanisms associated with dredging and contaminated sediment management projects

Mechanisms/ Migration pathways	Project components							
	Containment					Treatment		
	Dredging	Transport	Open-water	Shoreline	Upland	Pre-treatment	Treatment	Post-treatment
Sources								
Atmospheric emissions						X	X	X
Fugitive dust					X		X	X
Liquid wastes				X	X	X	X	X
Leakage	X	X	X	X	X	X	X	X
Solid wastes	X					X	X	X
Accidental spillage		X				X	X	X
Mechanisms								
Resuspension in the water column	X	X	X	X				
Direct discharge into the water column		X	X					
Surface runoff				X	X	X	X	
Subsurface seepage				X	X	X	X	X
Volatilization	X	X		X	X	X		
Wind transport		X		X	X	X	X	X
Pathways								
Direct contact	X	X		X	X	X	X	X
Absorption/ Bioaccumulation by plants				X	X			
Absorption/ Bioaccumulation by animals			X	X	X			

C.2 Developing Conceptual Impact Models

It is important to recognize that the sampling designs of all monitoring programs are based on assumptions and predictions about likely responses to perturbation.

Consequently, predictions about effects or potential impacts and the effectiveness of the mitigation measures should be based on conceptual models that specify cause-and-effect relationships, and they should be stated clearly. Implicit assumptions should be avoided because their consequences are frequently not evident either to the designers or the users of monitoring data (NRC 1990).

In their study of impact assessment methods, Beanlands and Duinker (1983, cited in NRC 1990) provide a particularly good example of the difference between nebulous questions and those that are truly useful in a surveillance and monitoring program. For instance, a nebulous question such as, “What are the impacts of a proposed dam on the fish resources of the river?” fails to help focus the sampling design because it does not ask, “What impacts and which fish resources are of concern?” To provide decision makers with truly useful information, the question should be, “What percentage of the Arctic char spawning habitat would be lost given a 0.5 m reduction in the water level of the river in the month of September?”

A conceptual model describes the linkages between the resources at risk; the physical, chemical and biological attributes of the ecosystems; and human and natural causes of change. The resulting understanding permits testable questions and impact hypotheses to be clearly stated and ultimately evaluated (NRC 1990).

Depending on the objectives of the ESMP, the scientific knowledge and the level of precision required, conceptual models of the projects’ potential impacts may take a variety of forms: laboratory simulations, mathematical models, qualitative statements based on historical information on the effects of similar projects, ecological theories or professional judgment.

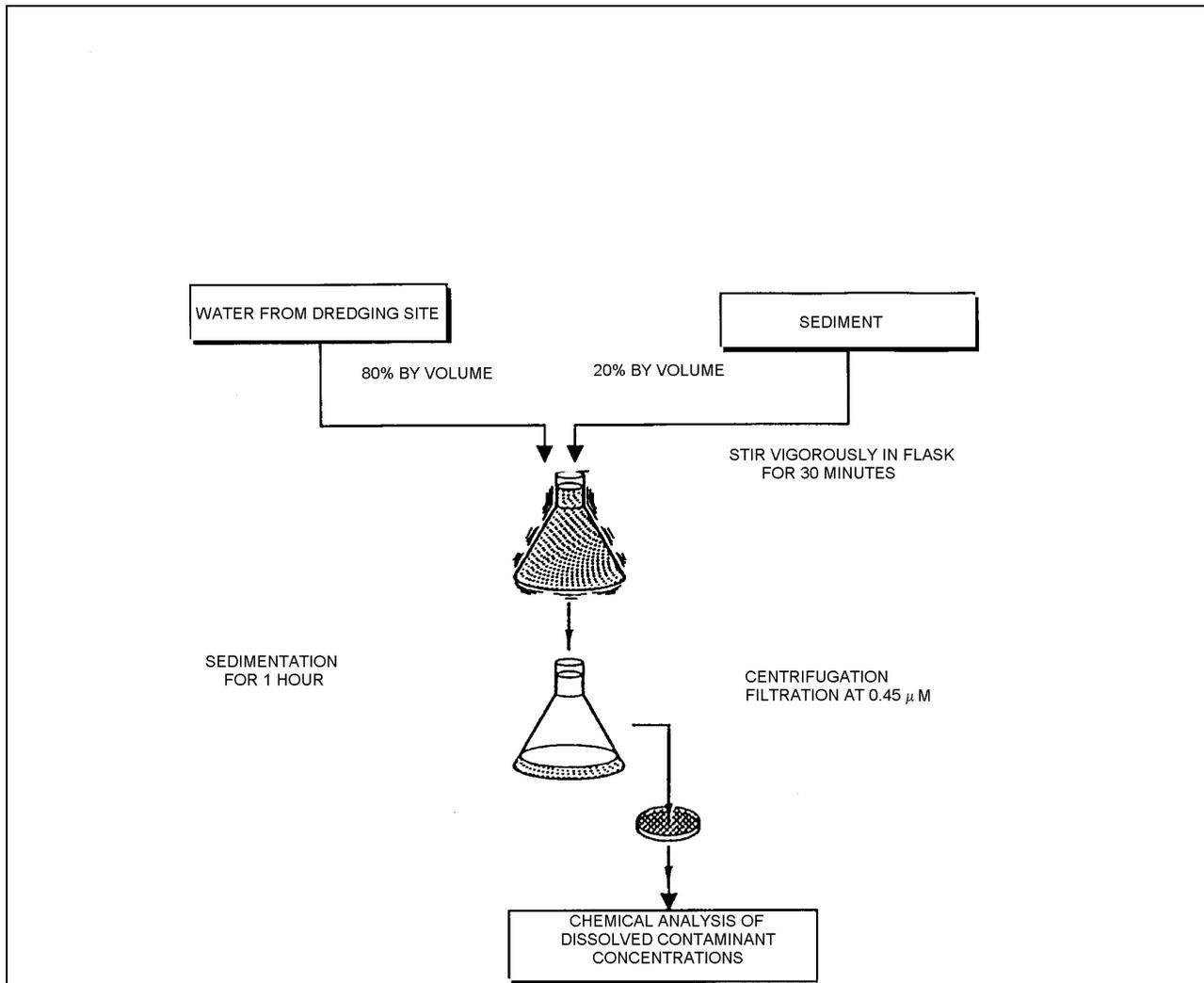
The most common conceptual impact models are those related to the impacts of a project on water quality. According to Myers et al. (1996), they may be empirical or deterministic in nature. In the empirical approach, statistical analyses are performed to establish correlations between the laboratory and field data, while the deterministic approach uses mathematical models based on the physical and chemical laws that govern and control environmental processes.

A well-known empirical model for simulating the impacts of dredging and aquatic disposal of dredged material is the standard elutriate test (Figure C8) developed in the United States in the early 1970s (Jones and Lee 1978). This test to predict contaminant dissolution was

developed to compare the results with the applicable water quality criteria or to develop an appropriate representative medium for the measurement of contaminant toxicity (bioassays) in the water column (USEPA/USACE 1991; 1994a; 1994b). This elutriate test was then adapted to simulate impacts at dredging sites (DiGiano et al. 1993; 1995).

Laboratory tests (modified elutriate tests and sedimentation tests) are also available to predict the water quality of effluents from upland disposal sites (USEPA/USACE 1994a; Myers et al. 1996; 1992; Palermo 1986; 1988; Brannon and Myers 1994; Myers and Brannon 1991). There are also bioassays to assess the toxicity created by the uptake of contaminants by plants and animals (USEPA/USACE 1992; USACE 1985; 1986). In Canada, studies of contaminant bioaccumulation by aquatic organisms and toxicological studies using a battery of bioassays are also recommended for monitoring ocean dredged material disposal sites (Mann et al. 1995a; 1995b; EC 1994d; 1992a; 1992b; 1992c; 1993b; 1993c; 1993d).

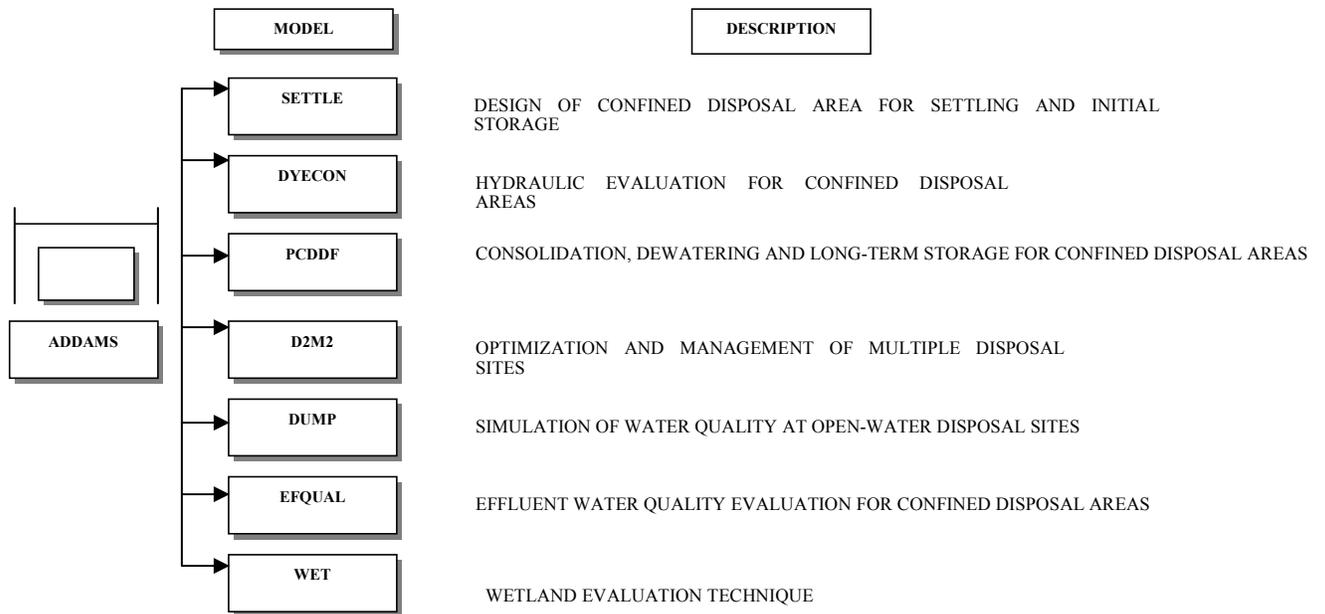
Despite the limitations of the mathematical models used in the deterministic approach, they are often applied to the development and management of ESMPs because they consolidate the state of the knowledge in a single system and permit quantitative predictions. However, it is important to recognize their limitations since their predictions are not infallible.



Source: Myers et al. (1996).

Figure C8 Procedure used in the standard elutriate test

The best known mathematical models are those developed to predict the concentrations of suspended solids and contaminants that may be released as a result of aquatic or upland disposal of dredged material. The U.S. Army Corps of Engineers (USACE) uses seven models to facilitate the design and management of disposal sites (see Figure C9). These models are integrated in the PC-based ADDAMS (Automated Dredging and Disposal Alternatives Management System) software system.



ADDAMS Automated Dredging and Disposal Alternatives Management System
 SETTLE Suspended Solids Retention and Initial Storage Requirements
 DYECON Determination of Hydraulic Retention Time and Efficiency of Confined Disposal Facilities
 PCDDF Primary Consolidation and Desiccation of Dredged Fill for Determining Long-Term Storage Requirements
 D2M2 Dredged Material Disposal Management Model
 DUMP Dump Scows, Hopper Dredges or Pipelines
 EFQUAL Effluent Quality
 WET Wetland Evaluation Technique

Source: Schroeder and Palermo (1990).

Figure C9 Mathematical models developed in the U.S. to predict water quality following aquatic or upland sediment disposal or containment

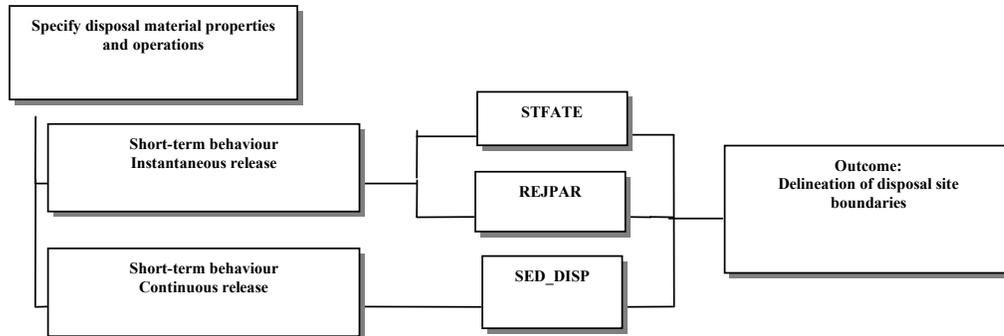
These models are also very useful in the design, optimization and management of aquatic, shoreline and upland disposal or containment sites. They make it possible to determine the water quality parameters requiring particular short- and long-term surveillance and monitoring within the context of an ESMP.

Descriptions of these models, their advantages and limitations and the data required for their use are presented in documents from the USEPA/USACE (1994; 1994b; 1991; 1992) and the USACE (Scheffner et al. 1955; Johnson 1990; Schroeder and Palermo 1990).

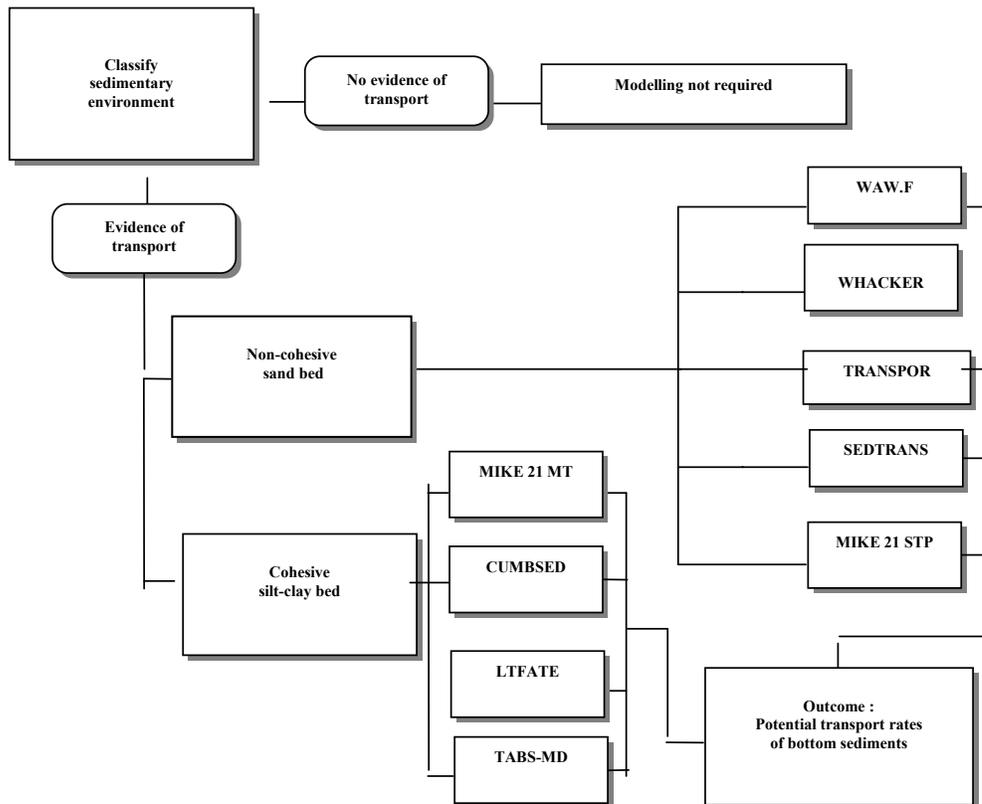
Figure C10 indicates the principal sediment transport models recommended for use in Canada to simulate the behaviour of dredged material following aquatic disposal (area subject to sediment resuspension) and ocean disposal (vulnerability of deposited materials to transport by waves and currents).

Dispersion models like ADDAMS are useful for predicting the contaminant concentrations present in dredged material and dissolved and suspended in water, the time required for these materials to reach the bottom, and the radius and direction of the plume formed by dredged material. Figure C9 shows that different transport models can be used to forecast the initial area of the deposition zone on the basis of the characteristics of the materials (cohesive or non-cohesive sediments) and the hydrosedimentary environment of the disposal site, all useful data in preparing an ESMP.

1. Short-term behaviour (disposal)



2. Behaviour and long-term fate



Source: Hodgins and Harper (1994).

Figure C10 Models recommended for use in Canada to simulate sediment transport following aquatic disposal of dredged material

Theoretical bases and descriptions of the models used in Canada to prepare ESMPs for aquatic dredged material disposal sites are presented in *Technical Guidelines for Physical Monitoring At Ocean Disposal Sites* (Hodgins and Harper 1994).

As part of the Great Lakes cleanup program (Assessment and Remediation of Contaminated Sediments – ARCS), Myers et al. have conducted a detailed critical review of the various laboratory tests or models developed to quantify contaminant losses for all phases of a contaminated sediment management project involving either containment or *in situ* or offsite treatment (Tables C4 and C5).

Table C4 shows that the techniques for estimating contaminant losses during sediment treatment are reliable and relatively easy to use (treatability test). However, for the other components of management projects, such as dredging losses, the tests are relatively unreliable and somewhat difficult to perform.

Table C4

Availability and reliability of techniques for estimating contaminant losses associated with dredging and sediment management projects

Component or alternative	Availability	Reliability	Ease of use
<i>In situ</i> capping	Yes	Moderate	Difficult
Open-water disposal/capping	Yes	Moderate	Difficult
Dredging	Yes	Low	Moderately difficult
Transport	No	-	-
Containment	Yes	Variable	Moderately difficult
Treatment	Yes	High	Simple
No action	Yes	High	Very difficult

Source: Myers et al. (1996).

Table C5 shows that the existing tests are very reliable and relatively simple to use for estimating contaminant losses from upland containment sites through effluents or runoff. The situation is very different for certain other phenomena, including contaminant losses as a result of volatilization during storage of the materials. The estimation techniques are unreliable and difficult to use.

Table C5**Availability and reliability of techniques for estimating contaminant losses associated with pretreatment and confined disposal facilities for contaminated sediments**

Migration pathways	Availability	Reliability	Ease of use
Effluent		High	Difficult
- Hydraulic	Yes		
- Mechanical	No		
Leaching	Yes	Moderate	Moderate
Volatilization	Yes	Low	Difficult
Runoff	Yes	High	Simple

Source: Myers et al. (1996).

C.3 Conceptual Models for Cumulative Impacts

The literature suggests a number of different approaches for defining ESMP objectives with respect to the cumulative effects associated with multiple projects in a given region. Figure C11 presents a sample matrix that can be used to summarize the various possible interactions among the sources of disturbance and the valued components of an ecosystem. The columns represent the cumulative impacts on each of the valued environmental components, while the rows illustrate the impacts of the sources of disturbance on the valued environmental components.

Even though the analysis underlying Figure C11 was qualitative and was based on incomplete understanding, this model provides an effective starting point for developing monitoring objectives, including the selection of specific resources, impacts and changes that should be monitored (NRC 1990).

Since there is no single standard method for assessing cumulative effects, the Canadian Environmental Assessment Agency (CEAA) has published a guide that uses examples to illustrate why and how practitioners (proponents, consultants, government agencies) have used certain methods or approaches to take the cumulative environmental effects of their projects into consideration (Cumulative Effects Assessment Working Group 1997).

C.4 Formulation of Impact Hypotheses: Examples

As we saw in Chapter 3, impact hypotheses can be formulated once the impact mechanisms and thresholds have been identified for the various environmental components likely to experience impacts. Examples of possible impact hypotheses applicable to ESMPs for dredging sites, open-water disposal sites, aquatic or upland contaminated sediment containment sites and treatment projects are also presented.

Other examples of impact hypotheses are given in the following tables for ESMPs relating to dredging sites (Table C6), open-water dredged material disposal sites (Table C7), aquatic dredged material containment sites (Table C8), upland dredged material containment sites (Table C9) and, finally, offsite contaminated sediment treatment projects (Table C10).

Sources of disturbance	Valued ecosystem components													
	Microheterotrophs	Phytoplankton	Zooplankton	Soft-bottom benthos	Hard-bottom benthos	Kelp beds	Wetlands and estuaries	Commercial shellfish	Pelagic fish	Demersal fish	Fish eggs and larvae	Marine mammals	Marine birds	Human health
Storms	☐ ³			☐ ²	☐ ²	■ ¹	☐ ²							☐ ³
El Niño	■ ³	■ ²	■ ²	☐ ³	☐ ³	■ ¹	☐ ³	?	☐ ²	☐ ³		☐ ³	☐ ²	
Upwelling		■ ²	■ ²			■ ¹			■ ²	?	■ ²		☐ ²	
Basin flushing	☐ ³			■ ³						☐ ³				
Mass sediment flows	☐ ³			■ ³						☐ ³				
Blooms/invasions				☐ ¹		☐ ¹			☐ ³	☐ ³				
Diseases						☐ ³		☐ ¹		☐ ³		?		
Ecological interactions	■ ²	■ ²	■ ²	☐ ²		■ ²	☐ ³	☐ ²	☐ ³		☐ ³	?	☐ ³	
Power plants						☐ ¹	☐ ³		☐ ³		☐ ³			
Wastewater outfalls	☐ ³	☐ ³		■ ¹		☐ ³		☐ ³		☐ ²	?	☐ ³	☐ ²	☐ ³
Dredging				☐ ¹		☐ ³	☐ ²							
River flow and stormwater runoff	?	?				☐ ²				?				☐ ³
Commercial fishing						☐ ¹		■ ²	☐ ³	☐ ³		☐ ¹	☐ ¹	☐ ³
Sport fishing								☐ ²		☐ ²		☐ ³		☐ ³
Marine commerce and boating							■ ¹					☐ ³	☐ ¹	
Habitat loss and alteration						☐ ¹	■ ¹					☐ ²	☐ ¹	
Oil spills	☐ ³						☐ ³				?	?	☐ ¹	☐ ³
Oil seeps														
Atmospheric input	☐ ³	☐ ³	☐ ³								☐ ³			☐ ³

POTENTIAL INFLUENCE: ■ Controlling ☐ Major ☐ Moderate ☐ Some
ASSESSMENT RELIABILITY: ¹ High ² Moderate ³ Low
? Some evidence for impact but further study needed
☐ Blank: no impact.

Source: National Research Council (1990).

Figure C11 Example of a matrix illustrating sources of cumulative impacts on the marine environment of the Southern California Bight

Table C6

Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for dredging sites

Program objectives	Testable questions	Testable impact hypotheses
Dredging site		
<i>O1.</i> Prevent adverse effects on biota (fauna and flora).	<i>Q1.</i> Will dredging and sediment transport result in contaminant resuspension in the water column?	<i>H1.</i> Dredging and sediment transport will not result in contaminant resuspension in the water column at the dredging site in amounts sufficient to cause contaminant uptake by aquatic organisms or ensuing effects on that biota.
<i>O3.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q2.</i> Will this resuspension result in the risk of contaminant uptake by aquatic organisms?	<i>H2.</i> Dredging and sediment transport will not result in contaminant uptake by harvested species or ensuing potential effects on human health.
	<i>Q3.</i> Will this contaminant uptake result in adverse effects on aquatic organisms?	
	<i>Q4.</i> Does this contaminant uptake by harvested species pose a risk to human health?	
Downstream from the dredging site		
<i>O1.</i> Prevent adverse effects on biota.	<i>Q5.</i> Are the contaminants resuspended during dredging likely to be transported downstream and to result in degradation of the chemical quality of the sediments in sensitive areas?	<i>H3.</i> Dredging and sediment transport will not result in contaminant resuspension in the water column in amounts sufficient to cause degradation of the chemical quality of the sediments in downstream areas or contaminant uptake by aquatic organisms or effects on that biota.
<i>O3.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q7.</i> Will this resuspension result in contaminant uptake by aquatic organisms and harmful effects on that biota?	<i>H4.</i> Dredging and sediment transport will not result in contaminant uptake by harvested species or ensuing potential effects on human health.
	<i>Q8.</i> Will this resuspension result in contaminant uptake by harvested species likely to pose a risk to human health?	
	<i>Q9.</i> Will this resuspension result in degradation of the water quality in downstream areas and threaten the water quality at drinking water intakes?	
<i>O4.</i> Protect sensitive areas (intakes, important aesthetic, cultural and historic values or values of specific scientific or biological interest).		<i>H5.</i> Dredging and sediment transport will not result in degradation of the water quality in downstream areas and will not threaten the water quality at drinking water intakes.

Table C6 (Continued)

Program objectives	Testable questions	Testable impact hypotheses
Downstream from the dredging site		
O2. Prevent habitat destruction and effects on fish and fisheries.	Q10. Will dredging and sediment transport result in sediment resuspension in the water column in amounts sufficient to cause the destruction of a <u>protected</u> habitat or to have adverse effects on the protected elements?	H6. During dredging and transport, the resuspended sediments will not reach any <u>habitat/sensitive habitat/area of potential use conflict</u> through water column transport, in amounts sufficient to be bring about their destruction or to be harmful to the protected elements.
O5. Prevent use conflicts between the disposal site and recreational areas, shipping lanes and areas of the seafloor having engineering uses (mining, cables, desalination or energy conversion sites).	Q11. Is this sediment resuspension likely to affect a fishery and result in harmful effects on certain species of fish?	H7. During dredging and transport, the resuspended sediments will not reach any fishing area through water column transport, in amounts sufficient to cause adverse effects on certain species of fish.
	Q12. Is this sediment resuspension likely to disturb recreational activities or conflict with other uses of the water bottom?	H8. During dredging and transport, the resuspended sediments will not affect any recreational activity or conflict with other uses of the water bottom.

Table C7

Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for open-water dredged material disposal sites

Program objectives	Testable questions	Testable impact hypotheses
Disposal site		
<i>O1.</i> Prevent adverse effects on biota.	<i>Q1.</i> Will disposal of the dredged material result in degradation of the chemical quality of the sediments at the disposal site?	<i>H1.</i> Disposal of the dredged material will not result in degradation of the chemical quality of the sediments at the disposal site, contaminant uptake by the protected aquatic organisms or ensuing effects on that biota.
<i>O3.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q2.</i> Will disposal of the dredged material result in the risk of contaminant uptake from the sediments by the protected aquatic organisms?	<i>H2.</i> Aquatic disposal of the dredged material will not result in contaminant uptake by harvested species or ensuing potential effects on human health.
	<i>Q3.</i> Will this contaminant uptake result in adverse effects on the protected aquatic organisms?	
	<i>Q4.</i> Is disposal of the dredged material likely to result in contaminant uptake by harvested species that may pose a risk to human health?	
Outside the designated disposal site		
<i>O1.</i> Prevent adverse effects on biota	<i>Q5.</i> Is the deposited dredged material likely to be transported outside the designated open-water disposal site?	<i>H3.</i> Disposal of the dredged material will not result in sediment transport outside the designated disposal site, degradation of the chemical quality of the sediments in the affected area, contaminant uptake by the protected aquatic organisms or adverse effects on that biota.
<i>O3.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q6.</i> Is this resuspension likely to result in the risk of degradation of the chemical quality of the sediments in the affected area?	
<i>O4.</i> Protect sensitive areas (important aesthetic, cultural and historic values or values of particular scientific or biological interest).	<i>Q7.</i> Is this resuspension likely to result in the risk of contaminant uptake by the protected aquatic organisms and adverse effects on that biota?	<i>H4.</i> Aquatic disposal of the dredged material will not result in contaminant uptake by harvested species or ensuing potential effects on human health.
	<i>Q8.</i> Are the deposited dredged materials likely to result in contaminant uptake by harvested species that may pose a risk to human health?	

Table C7 (Continued)

Program objectives	Testable questions	Testable impact hypotheses
Disposal site		
O2. Prevent habitat destruction and effects on fish and fisheries.	Q9. Will disposal of the dredged material result in destruction of fish habitat or adverse effects on the protected elements through water column transport?	H5. During initial disposal, the dredged material will not reach any protected element through water column transport, in amounts sufficient to be of concern in relation to their destruction or adverse effects on the protected elements.
	Q10. Are these transported sediments likely to affect a fishery?	H6. During initial disposal, the dredged material will not reach any fishing area through water column transport, in amounts sufficient to cause adverse effects on certain species of fish.
Outside the designated disposal site		
O2. Prevent habitat destruction and effects on fish and fisheries.	Q11. Will resuspension, erosion and transport of the deposited dredged material occur in amounts sufficient to cause the destruction of fish habitat or adverse effects on protected elements in sensitive areas?	H7. The deposited dredged material will not reach any protected habitat or sensitive areas through resuspension, erosion and sediment transport, in amounts sufficient to cause their destruction or adverse effects on the protected elements.
O4. Protect sensitive areas (important aesthetic, cultural and historic values or values of particular scientific or biological interest).		
O5. Prevent conflicts between use of the disposal site and recreational areas, navigation routes and aquatic or sea floor areas used for technical purposes (mines, cables, desalination or energy conversion facilities).	Q12. Will resuspension, erosion and transport of the deposited dredged material occur in amounts sufficient to cause conflicts with recreational areas or with other uses of the water bottom?	H8. Resuspension, erosion and transport of the deposited dredged material will not occur in amounts sufficient to cause conflicts with recreational areas or with other uses of the water bottom.

Table C8

Examples of objectives, testable questions and impact hypotheses applicable to ESMPs for aquatic dredged material containment sites

Program Objectives	Testable Questions	Testable Impact Hypotheses
Confined disposal site		
<i>O1.</i> Demonstrate the effectiveness of the technique of capping contaminated dredged material with clean materials.	<i>Q1.</i> Evidence of contaminant migration or diffusion through the cap materials?	<i>H1.</i> Analyses of the cap materials demonstrate that there has been no contaminant migration or diffusion from the contaminated dredged material into the cap materials.
<i>O2.</i> Demonstrate that the thickness of the cap layer is maintained.	<i>Q2.</i> Evidence of a reduction in the thickness of the cap layer over the contaminated dredged material caused by the hydrosedimentary environment?	<i>H2.</i> The hydrosedimentary environment of the disposal site does not cause erosion of the cap layer over the contaminated dredged material.
<i>O3.</i> Demonstrate that the technique of capping contaminated dredged materials effectively isolates the contaminated materials from the benthic populations.	<i>Q3.</i> Are the concentrations of contaminants in the tissues of benthic populations at the containment site higher than those in adjacent areas?	<i>H3.</i> The concentrations of contaminants in the tissues of resident benthic populations are no higher than those observed in the same species in adjacent areas.
Outside the designated capping site		
<i>O4.</i> Prevent adverse effects on biota.	<i>Q4.</i> Are the sediments and contaminants resuspended during disposal of the contaminated dredged material and placement of the cap materials likely to be transported downstream and to result in degradation of the physical/chemical quality of the sediments in the affected area?	<i>H4.</i> Disposal of the contaminated dredged materials and placement of the cap materials will not result in sediment transport outside the designated disposal site, degradation of the physical/chemical quality of the sediments in the affected area or in sensitive areas, contaminant uptake by the protected aquatic organisms, or effects on that biota.
<i>O5.</i> Prevent habitat destruction and effects on fish and fisheries.		
<i>O6.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q5.</i> Are the suspended sediments and transported contaminants likely to result in the risk of contaminant uptake by protected aquatic organisms and effects on that biota?	<i>H5.</i> Disposal of the contaminated dredged material and placement of the cap materials will not result in habitat destruction or contaminant uptake by harvested species, or ensuing potential effects on human health.
<i>O7.</i> Protect sensitive areas (important aesthetic, cultural and historic values or values of particular scientific or biological interest).		
	<i>Q6.</i> Are the suspended sediments and transported contaminants likely to result in habitat destruction or contaminant uptake by harvested species that may pose a risk to human health?	

Table C9

Examples of protection objectives, testable questions and impact hypotheses applicable to ESMPs for upland dredged material disposal sites

Program objectives	Testable questions	Testable impact hypotheses
Disposal site		
<i>O1.</i> Prevent adverse effects on biota.	<i>Q1.</i> Will upland disposal of the dredged material result in the dispersion of contaminants in drainage ditches around the disposal site?	<i>H1.</i> Upland disposal of the dredged material will not result in concentrations of suspended solids or contaminants in drainage ditches around the disposal site, beyond the standards or criteria established in the permit or authorization certificate.
<i>O2.</i> Prevent potential effects on human health.	<i>Q2.</i> Are the deposited dredged materials likely to permit leaching into the groundwater of contaminants that may pose risks to human health?	<i>H2.</i> The design and control measures established for the disposal site prevent leaching of contaminants into the groundwater below the disposal area.
	<i>Q3.</i> Are the deposited dredged materials likely to result in plant and animal uptake of contaminants that may pose a risk to human health?	<i>H3.</i> Upland disposal of the dredged materials will not result in degradation of the chemical quality of the soils at the disposal site, contaminant uptake by plants/animals, or ensuing potential effects on human health.
	<i>Q4.</i> Are the deposited dredged materials likely to result in emission into the atmosphere of contaminants that may pose a risk to human health (workers)?	<i>H4.</i> The design and mitigation measures established for the disposal site ensure effective protection of workers during the operations.

Table C9 (Continued)

Program objectives	Testable questions	Testable impact hypotheses
Outside the designated disposal site		
<i>O1.</i> Prevent adverse effects on biota.	<i>Q5.</i> Do the concentrations of suspended solids or contaminants in the effluent from the disposal site comply with the standards or criteria established in the permit or authorization certificate?	<i>H5.</i> Upland disposal of the dredged materials will not result in concentrations of suspended solids or contaminants in the effluent from the disposal site, beyond the standards or criteria established in the permit or authorization certificate.
<i>O2.</i> Prevent habitat destruction and effects on fish and fisheries.		
<i>O3.</i> Prevent potential effects on human health (contamination of edible fish, shellfish and crustacean species).	<i>Q6.</i> Are the deposited dredged materials likely to permit leaching into the soils around the disposal site of contaminants that may pose a risk to human health or be harmful to the habitat or to local terrestrial and avian fauna?	<i>H6.</i> The design and mitigation measures established for the disposal site ensure effective protection of surrounding soils, wildlife habitats and health of local populations.
<i>O4.</i> Protect sensitive areas (important aesthetic, cultural and historic values or values of particular scientific or biological interest).	<i>Q7.</i> Are the deposited sediments likely to permit leaching into the groundwater around the disposal site of contaminants that may pose a risk to human health?	<i>H7.</i> The design and mitigation measures established for the disposal site prevent leaching of contaminants into the groundwater around the disposal area.
	<i>Q8.</i> Will upland transport and disposal of the dredged material create nuisances (dust, noise, traffic) for local populations?	<i>H8.</i> The design and mitigation measures established for the disposal site minimize nuisances for local populations.
	<i>Q9.</i> Are the deposited dredged materials likely to result in emission into the atmosphere of contaminants that may pose a risk to the health of local residents?	<i>H9.</i> The deposited dredged materials do not result in emission into the atmosphere of contaminants that may pose a risk to the health of local residents.

Table C10

Examples of protection objectives, testable questions and impact hypotheses applicable to ESMPs for contaminated sediment treatment projects

Program objectives	Testable questions	Testable impact hypotheses
<i>O1.</i> Demonstrate the environmental performance of the treatment technology selected.	<i>Q1.</i> Does the selected technology permit extraction or destruction of the contaminants from the sediments, and thus upland disposal or reclamation?	<i>H1.</i> The technology selected permits extraction or destruction of the contaminants to the levels defined in the MEF Soil Protection and Contaminated Sites Rehabilitation Policy, and thus upland disposal or reclamation.
<i>O2.</i> Compliance with the permit or authorization certificate.	<i>Q2.</i> Does the technology reduce the mobility, toxicity or volume of the contaminants in the sediments?	<i>H2.</i> The technology reduces the mobility, toxicity or volume of the contaminants in the sediments.
<i>O3.</i> Prevent potential adverse effects on the natural environment or on human health.	<i>Q3.</i> Does the selected technology permit extraction or destruction of the contaminants from the sediments, and thus aquatic disposal or reclamation?	<i>H3.</i> The selected technology permits extraction or destruction of the contaminants to the levels defined in the <i>Interim Criteria for Quality Assessment of St. Lawrence River Sediment</i> , and thus aquatic disposal or reclamation.
<i>O4.</i> Demonstrate the effectiveness of the control and mitigation measures in minimizing contaminant losses at all phases of the contaminated sediment remediation operations.	<i>Q4.</i> Do all components of the contaminated sediment remediation project comply with the requirements of the environmental authorizations and the other environmental protection legislation?	<i>H4.</i> Dredging and treatment of the contaminated sediments comply with the requirements of the authorization certificate and the other environmental protection legislation.
	<i>Q5.</i> Are the control and mitigation measures established in the contaminated sediment remediation project sufficient to minimize contaminant losses into the environment (water, air, soil) and risks to the natural and human environment?	<i>H5.</i> The control and mitigation measures established in the contaminated sediment remediation project are sufficient to minimize contaminant losses into the environment (water, air, soil) and risks to the natural and human environment.

Appendix D Recommended Reading

D.1 Quality Assurance and Control Programs

- *Evaluation of Dredged Material Proposed for Discharge in Inland and Near Coastal Waters: Inland Testing Manual* (USEPA/USACE 1994a).
- *Evaluation of Dredged Material Proposed for Ocean Disposal: Testing Manual* (USEPA/USACE 1991).
- *Great Lakes Dredged Material Testing and Evaluation Manual* (USEPA/USACE 1998).
- *Sediment Classification Methods Compendium* (USEPA 1992a).
- *QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations - Chemical Evaluations* (USEPA/USACE 1995).
- *ARCS Assessment Guidance Document* (USEPA 1994a).
- *Quality Assurance Project Plan for GLNPO: Assessment and Remediation of Contaminated Sediment Technology Demonstration Support* (USEPA 1992b; 1993a; 1994c; 1994d; 1994e; 1994f).
- *Programme d'assurance et de contrôle de qualité liés à un projet de démonstration d'une unité de désorption thermique* (Décontam 1995).
- *Methods Manual for Sediment Characterization* (SLC 1992a).
- *Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing* (EC 1994b).
- *Analytical Quality Assurance/Quality Control Guidelines for the National Ocean Dumping Program* (Kan et al. 1996).
- *Quality Assurance and Quality Control in Laboratory Bioassays of Dredged Material* (Moore 1994; USACE 1994).

D.2 A. Measurement Tools for Physical, Chemical and Biological Parameters

- *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette et al. 1990a; 1990b).
- *Technical Guidelines for Physical Monitoring at Ocean Disposal Sites* (Hodgins and Harper 1994).
- *Technical Guidelines on Biological Monitoring for Ocean Disposal* (Mann et al. 1995a).
- *Revised Procedural Guide for Designation Survey of Ocean Dredged Material Disposal Sites* (Pequegnat et al. 1990).
- *Détection et caractérisation appliquées aux sites pollués - investigations géophysiques et mesures des polluants sur site* (Ademe 1997).

D.2. B Measurement Tools for Secure Aquatic Containment of Contaminated Sediments

- *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (Palermo et al. 1998).
- *Monitoring Considerations for Capping* (Palermo et al. 1992).
- *Monitoring Dredged Material Consolidation and Settlement at Aquatic Disposal Sites* (Poindexter-Rolling 1989).
- *Physical Monitoring Guidelines for Dredged Material Placement Sites* (Clausner and Nelson 1989).
- *Tiered Ocean Disposal Monitoring Will Minimize Data Requirements* (Zeller and Wastel 1984).

D.3 Publications on Elements to be Considered in Designing a Sampling Plan to Monitor Physico-chemical and Biological Impacts

U.S. approaches recommended by the USEPA and/or the U.S. Army Corps of Engineers

- *Evaluation of Dredged Material Proposed for Ocean Disposal: Testing Manual* (USEPA/USACE 1991).
- *Evaluation of Dredged Material Proposed for Discharge in Inland and Near Coastal Waters: Inland Testing Manual* (USEPA/USACE 1994a).
- *Great Lakes Dredged Material Testing and Evaluation Manual* (USEPA/USACE 1994b).
- *Guidelines for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette et al. 1990a).
- *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette et al. 1990b).
- *Revised Procedural Guide for Designation Surveys of Ocean Dredged Material Disposal Sites* (Pequegnat et al. 1990).
- *General Guidelines for Monitoring Effluent Quality from Confined Dredged Material Disposal Areas* (Thackson and Palermo 1988).
- *Guide for Conducting Treatability Studies* (USEPA 1988a; 1998b; 1992c).
- *Sediment Classification Methods Compendium* (USEPA 1992a).
- *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods* (USEPA 1991).

Canadian approaches recommended by Environment Canada and the Ministère de l'Environnement du Québec

- *Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites* (CCME 1993a; 1993b).
- *Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing* (EC 1994b).
- *A Sampling Manual and Reference Guide for Environment Canada Inspectors* (EC 1995b).
- *Methods Manual for Sediment Characterization* (SLC 1992b).

D.3 (Continued)

- *Guide des méthodes de conservation et d'analyse des échantillons d'eau et de sol* (MENVIQ 1990b).
- *National Guidelines for Monitoring Dredged and Excavated Material at Ocean Disposal Sites* (Chevrier and Topping 1998).
- *Interim Monitoring Guidelines for Ocean Disposal* (Environment Canada 1993a; 1994c).
- *Technical Guidelines for Physical Monitoring at Ocean Disposal Sites* (Hodgins and Harper 1994).
- *Technical Guidance on Biological Monitoring for Ocean Disposal* (Mann et al. 1995a; 1995b).
- *Procédure d'évaluation des caractéristiques des déchets solides et boues pompables* (MEF 1985).
- *Guide standard de caractérisation de terrains contaminés* (MENVIQ 1998b).
- Liste des méthodes d'analyse relatives à l'application des règlements découlant de la *Loi sur la qualité de l'environnement* (L.R.Q., c. Q.-2) - *Règlement sur les matières dangereuses* (MEF and Centre d'expertise en analyse environnementale du Québec 1997).
- *Lieux d'enfouissement sécuritaire: guide d'implantation et de gestion de lieux d'enfouissement de sols contaminés* (MEF 1995).
- *Lignes directrices pour le traitement des sols par biodégradation, bioventilation ou volatilisation* (MEF 1996).
- *Site Remediation Technologies: A Reference Manual* (Contaminated Sites Management Working Group 1997).
- *National Guidelines for the Landfilling of Hazardous Waste* (CCME 1991b).

D.4 Publications on Good Environmental Practices

All types of dredging and dredged material disposal projects

- *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky 1998).
- *Handling and Treatment of Contaminated Dredged Material From Ports and Inland Waterways* (International Navigation Association [PIANC] 1997).
- *Guide to Selecting and Operating Dredging Equipment and Related Practices* (SLC 1992c).

- *Code de conformité environnementale - obligations réglementaires et d'éthique* (DFO 1997).
- *Evaluating Environmental Effects of Dredged Material Management Alternatives: A Technical Framework* (USEPA/USACE 1992).
- *Beneficial Uses of Dredged Material. Engineer Manual EM 1110-2-5026* (USACE 1987a).
- *Confined Disposal of Dredged Material. Engineer Manual EM 1110-2-5027* (USACE 1987b).
- *Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions* (Cullinane et al. 1986).
- *Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls* (Francingues et al. 1985).
- *Dredging and Dredged Material Disposal. Engineer Manual EM 1110-2-5025* (USACE 1983).

Contaminated sediment remediation and/or treatment projects

- *ARCS Remediation Guidance Document* (USEPA 1994b).
- *Guide to Assessing and Selecting Treatment Technologies for Contaminated Sediment* (SLC 1993c).
- *Site Remediation Technologies: A Reference Manual* (Contaminated Sites Management Working Group 1997).
- *Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett et al. 1990).
- *Sediment Remediation: An International Review* (Averett et al. 1994).
- *Selecting Remediation Techniques for Contaminated Sediment* (USEPA 1993b).
- *Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions* (Cullinane et al. 1986).
- *Options for the Remediation of Contaminated Sediments in the Great Lakes* (International Joint Commission [IJC] 1988).
- *New Bedford Harbor Superfund Project – Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives* (Averett and Otis 1988).
- *New Bedford Harbor Superfund Project – Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives* (Francingues and Averett 1988).

- *New Bedford Harbor Superfund Project – Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives, Report 10, Evaluation of Dredging Control Technology* (Palermo and Pakow 1988).
- *Guide for the Management of Hazardous Materials and Waste and Environmental Emergencies at Federal Facilities in Quebec* (Environment Canada, 1998b).

Aquatic containment projects

- *Site Selection for Capping* (Palermo 1991b).
- *Design Requirements for Capping* (Palermo 1991a).
- *Engineering Considerations for Subaqueous Dredged Material Capping: Background and Preliminary Planning* (Truitt 1987a).
- *Engineering Considerations for Capping Subaqueous Dredged Material Deposits: Design Concepts and Placement Techniques* (Truitt 1987b).
- *Equipment and Placement Techniques for Capping* (Palermo 1991c).
- *Placement Techniques for Capping Contaminated Sediments* (Palermo 1994).
- *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (Palermo et al. 1998).
- *Standards for Confined Disposal of Contaminated Sediments: Development Documentation* (Parametrix 1990).
- *The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring* (Truitt 1986).
- *Dioxin Capping Management and Monitoring Program: Design and Implementation* (May et al. 1994).

Upland containment projects

- *Lieux d'enfouissement sécuritaire: guide d'implantation et de gestion de lieux d'enfouissement de sols contaminés* (MEF 1995).
- *National Guidelines for the Landfilling of Hazardous Waste* (CCME 1991b).
- *Standards for Confined Disposal of Contaminated Sediments: Development Documentation* (Parametrix 1990).

Appendix E Statistical Formulae for Calculating Number of Samples

The formulae presented in this appendix apply to four different situations:

1. Estimation of a mean (Kratochvil and Taylor 1981; Håkanson 1984; Milton et al. 1986).
2. Comparison of a mean with a standard (Aldredge (a) 1987).
3. Comparison of two means (Aldredge (b) 1987; Green (a) 1989).
4. Interaction between area and time effects (Green (b) 1989).

Estimation of a mean. The formula of Milton et al. (1986) is frequently used. Unfortunately, it is known that it seriously underestimates the necessary number of samples. The extent of this underestimation is discussed by Kupper and Hafner (1989), who provide a means of correcting for this underestimation. The formulae of Håkanson (1984) and Kratochvil and Taylor (1981) are variations of the same basic estimation and are subject to the same underestimation of the number of samples. Because they use Student's t-distribution, however, the underestimation problem may not be as great but they require an iterative solution. In the formula of Håkanson, the quantity "y" must be expressed as a proportion (or the right-hand-side multiplied by 100), and the use of $n - 1$ in the formula leads to a slightly larger estimate than that of Kratochvil-Taylor (1981).

Comparison of a mean with a standard. One of the most common comparisons is that of a mean value with a standard value, which essentially tests the hypothesis $H_0: \mu_0 = \mu_A$

against the alternative $H_A: \mu_0 < \mu_A$. The significance level is generally α . The detectable difference that is desirable is generally defined as Δ , with a probability β such that the P (reject H_0 when $\mu_A - \mu_0 > \Delta$) $\geq 1 - \beta$ ($1 - \beta$ represents the power of the test.) The estimate of the sample size, n , required to satisfy these conditions is:

$$n = \frac{Z_\alpha + Z_\beta}{\Delta^2} + 2$$

(with n rounded up to the nearest integer).

If the hypothesis is two-tailed (i.e., $H_A: \mu_0 \neq \mu_A$), Z_α is replaced by $Z_{\alpha/2}$ in the preceding formula. The formula presented by Aldredge (1987) has the term $0.5 Z\alpha^2$, which provides an adjustment for the uncertainty in the estimate of the variance. This addition is probably a good estimator, perhaps a little liberal.

Comparison of two means. The formulae (b) and (a) provided, respectively, by both Aldredge (1987) and Green (1989) agree closely; however, because iteration is required by the latter, the formula by Aldredge may be slightly more desirable.

Interaction between area and time effects. This formula should be used when the objective of the project is to examine differences in contaminant levels at a site relative to a control site over time. The method requires iteration.

Source: Environment Canada (1994b). *Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing*. Report EPS 1/RM/29.

Statistical Formulae for Calculating Number of Samples

Objective	Formula	Reference
To calculate the sample size required to detect an effect in an impacted area versus a control area over time:		
a) resampling same sites before and after impact and testing if the mean change in the control area is the same as that in the impacted area	$n = 2(t_{\alpha} + t_{\beta})^2 (S/\Delta)^2$	Green 1989
b) sampling different sites before and after impact and testing if there is no interaction between area effect and time effect	$n = 4(t_{\alpha} + t_{\beta})^2 (S/\Delta)^2$ where: n = number of samples for each of the control and impact areas S = standard deviation D = magnitude of change required to be a real effect with specified power $(1 - \beta)$ t_{α} = t statistic given a Type I ¹ error probability t_{β} = t statistic given a Type II ² error probability	Green 1989
To determine if the mean value for an impacted area:		
a) differs significantly from a standard value (e.g., sediment quality criterion)	$n = 4(t_{\alpha} + t_{\beta})^2 (S/\Delta)^2$ where: n = sample size Z_{α} = Z statistic for Type I error probability (e.g., $\alpha = 0.05$) Z_{β} = Z statistic for Type II error probability (e.g., $\beta = 0.90$) d = magnitude of the difference to be detected	Aldredge 1987
b) differs significantly from the mean of a control site	$n \geq \frac{(Z_{\alpha} + Z_{\beta})^2}{d^2} + 0,5Z_{\alpha}^2$ where: n = sample size Z_{α} = Z statistic for Type I error probability (e.g., $\alpha = 0.05$) Z_{β} = Z statistic for Type II error probability (E.G., $\beta = 0.90$) d = magnitude of the difference to be detected (i.e., effect level)	Aldredge 1987

Objective	Formula	Reference
To calculate the number of samples required to estimate a mean value (representative of the area) with a given statistical certainty	$y\bar{x} = t_c \frac{S_x}{(n-1)^{1/2}}$ <p>where:</p> <p>y = accepted error in the percent of the mean value (e.g., $y = 10\%$)</p> <p>\bar{x} = mean value of x_i ($i = 1..n$)</p> <p>S_x = standard deviation</p> <p>t_c = confidence coefficient (e.g., 90% or $t_{0.95}$)</p> <p>n = number of samples</p>	Håkanson 1984
To calculate the number of samples required to estimate a mean	$n = \frac{(Z_{\alpha/2})^2 \sigma^2}{d^2}$ <p>where:</p> <p>n = number of samples</p> <p>Z_{α} = Z statistic (standard normal curve)</p> <p>σ^2 = variance</p> <p>$\alpha/2$ = probability of a 95% confidence level</p> <p>d = distance between the centre of the lower confidence and the upper confidence bound</p>	Milton et al. 1986
To calculate the number of samples required for a particular power for: a normal distribution (e.g., $x > S^2$)	$n = \frac{10^4 (t_2 S^2)}{(R^2 \bar{x}^2)}$ <p>where:</p> <p>n = number of samples</p> <p>t = t statistic for a given confidence level</p> <p>\bar{x} = mean value from preliminary sampling or historical data</p> <p>S = standard deviation</p> <p>R^2 = percentage coefficient of variation</p> <p>K = index of clumping</p>	Kratochvil and Taylor 1981
<p>1. Type I (α) error is the probability of rejecting the hypothesis being tested when it is true.</p> <p>2. Type II (β) error is the probability of failing to reject the hypothesis being tested when it is false.</p>		

Source: Environment Canada (1994b). *Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing*. Report EPS 1/RM/29.

Appendix F Mitigation Measures for Remediation Projects

One of the objectives of environmental surveillance and monitoring programs (ESMPs) is to ensure the implementation and effectiveness of the mitigation measures selected during project design and elaborated in the environmental assessment reports to minimize the projects' environmental impacts. Examples of mitigation measures and good environmental practices applicable to dredging and dredged material management projects (aquatic or upland disposal) to be considered in designing an action plan for an ESMP are given in Chapter 3.

As a complement to these measures, this appendix lists the mitigation measures applicable to sediment remediation projects.

F.1 Contaminated Sediment Remediation Scenarios

Table F1 presents contaminated sediment remediation scenarios grouped in four major categories: remediation methods involving *in situ* or offsite containment, or remediation methods involving *in situ* or offsite sediment treatment. The principal technical, economic and environmental advantages and disadvantages of each of the remediation scenarios presented, together with descriptions of contaminated sediment treatment technologies that have been tested virtually around the world, are presented in an Environment Canada document entitled *Guide to Assessing and Selecting Treatment Technologies for Contaminated Sediment* (SLC, 1993c).

While all scenarios involving the treatment of contaminated sediments should *a priori* be considered desirable, they do nonetheless involve significant risks that the contaminants will find their way back into various media (water, air, soil) in the course of the remediation activities. In fact, as indicated in the tables included in this appendix, offsite contaminated sediment remediation or management projects involve a number of steps (excavation, transport, pre-treatment, storage, treatment and disposal) that may result in contaminant migration.

Table F1
Contaminated sediment remediation scenarios

Remediation methods	<i>In situ</i> management	Off-site management
Containment	Capping with clean sediments or materials	<ul style="list-style-type: none"> - Aquatic containment - Reclamation of excavated contaminated sediments: <ul style="list-style-type: none"> - use as landfill - use for daily sanitary landfill (SLF) or technical landfill (TLF) cover - use for final SLF or TLF cover, with a 15cm cap of clean soil/sediment - Disposal in a licensed secure landfill
Treatment	<ul style="list-style-type: none"> - Biotreatment - Chemical treatment - Immobilization 	<ul style="list-style-type: none"> - Chemical - Biological - Extraction - Immobilization - Physical separation - Thermal

F.2 Contaminant Migration Mechanisms in Sediment Remediation Projects

The contaminant migration mechanisms associated with the various phases and methods of contaminated sediment remediation are discussed and illustrated in Appendix C, which presents conceptual impact models for use in the environmental assessment of these projects and in the preparation of ESMPs, for all the phases of a remediation project identified in Figure C7.

F.3 Mitigation Measures to Minimize Contaminant Migration in Sediment Remediation Projects

Tables F2 to F10 list examples of mitigation measures to reduce the risks of contaminant migration associated with each potential mechanism or pathway of contaminant

migration or dispersion associated with the implementation of the contaminated sediment remediation scenarios.

Table F2 gives examples of mitigation measures for each of the *in situ* remediation or management technologies (capping, containment and treatment), while Tables F3 to F10 present examples of mitigation measures to reduce contaminant migration or dispersion for each phase or activity of an offsite remediation project illustrated in Figure C7, i.e.:

Table	Phase of offsite contaminated sediment remediation
F-3	Excavation
F-4	Transport
F-5	Pre-treatment
F-6	Treatment
F-7	Treatment of water, solid or gaseous residues
F-8	Disposal of pretreatment or treatment residues
F-9	Operation of a permanent treatment centre
F-10	Site closure and post-closure maintenance, surveillance and monitoring

The majority of the mitigation measures listed in this appendix for contaminated sediment remediation projects, some of which are also applicable to dredging and contaminated dredged material management projects, are presented in the document entitled *Assessment and Remediation of Contaminated Sediments (ARCS) Program: Remediation Guidance Document* (USEPA 1994b), which deals with the cleanup of contaminated sediments in the Great Lakes. The good environmental practices are drawn from documents published by Environment Canada: *Guide to Selecting and Operating Dredging Equipment and Related Practices* (SLC 1992) and *Guide to Assessing and Selecting Treatment Technologies for Contaminated Sediment* (SLC 1993c, revised 1994).

Table F2

**Examples of mitigation measures for reducing contaminant migration associated with
in situ remediation of contaminated sediments**

Technology	Migration mechanism	Mitigation measures
<i>In situ</i> capping	- Resuspension/advection during placement of cap	- Use specialized equipment for cap placement (submerged diffusers, tremie tubes, etc.)
	- Long-term diffusion/advection	- Ensure adequate cap design (material and thickness, use of geotextiles, synthetic liners, etc.)
	- Long-term bioturbation	- Establish a long-term environmental surveillance and monitoring program
	- Long-term erosion	- Ensure precise placement of cap materials - Select appropriate equipment for cap placement - Ensure precise control of cap position and thickness - Same measures as for dispersion - Stabilize the cap layer by the addition of a layer of cobbles, gravel or other materials
<i>In situ</i>	- Resuspension during operations	- Isolate the area of operations: cofferdams (sheet piling, dikes or caissons)
	- Losses (seepage during placement and dewatering)	- Install slurry walls
	- Long-term percolation/leaching	- Install drawdown wells around the perimeter of the containment area, use impermeable materials for cell isolation and final capping - Install slurry walls - Establish a long-term environmental surveillance and monitoring program
<i>In situ</i> treatment (chemical, biological, solidification/stabilization)	- Resuspension during treatment	- Use special equipment to isolate the sediments to be treated from the water column (sheet piling, booms, etc.)
	- Long-term dispersion	- Use specialized equipment to inject and mix reagents with the contaminated sediments - Establish a long-term environmental surveillance and monitoring program
	- Long-term bioturbation	
	- Long-term erosion	

Source: Compiled from USEPA (1994b).

Table F3**Examples of mitigation measures for reducing contaminant migration associated with the excavation of contaminated sediments**

Technology	Migration mechanism	Mitigation measures
Mechanical dredges	- Resuspension and advection	- Reduce production rate - Control vertical speed of grab sampler - Install silt screens or silt curtains at the dredging site and near sensitive areas, including: booms, cofferdams (sheet piling, dikes or caissons), combination of permeable/impermeable liners or other innovative technologies (e.g., bubble curtains)
	- Volatilization	- Provide workers with respirators
	- Direct contact with sediments	- Provide workers with personal protective equipment (e.g., gloves, protective clothing, etc.) - Occupational health and safety program
	- Accidental spillage and leakage from grab sampler	- Improve impermeability of grab samplers - Use new impermeable grab samplers (e.g., Cable Arm).
	- All mechanisms	- Adopt good environmental practices*
Hydraulic dredges	- Resuspension and advection	- Reduce all the following parameters: depth of cut, rotation speed of cutterhead and dredging pipeline, depth of dredgehead - Increase capacity of suction pump - Install an impermeable cover near the suction intake or cutterhead - Install pressure gauges and densitometers - Remove the cutterhead in soft, fine sediments - Optimize the water-sediment mixture - Adopt good environmental practices*
Specialized dredges	- Resuspension and advection	- Adopt good environmental practices*

Sources: Compiled from USEPA (1994b); SLC (1992c) for good environmental practices.

Legend for Table F3:

* Adoption of good environmental practices includes:

- 1) Selecting equipment compatible with site conditions, the nature and scope of the operations and the constraints and characteristics of the other components of the remediation project (transport, pretreatment, treatment, etc.).
- 2) Using reliable, innovative equipment.
- 3) Implementing ESMPs for all dredging and mitigation effectiveness monitoring activities.
- 4) Performing frequent monitoring of dredged sediment volume (area and depth).
- 5) Using qualified operators.
- 6) Decontaminating dredging equipment before leaving the work site.
- 7) Collecting, treating or disposing of cleaning water in a licensed site.
- 8) Isolating the dredging site by means of enclosed basins (piling) or protective screens or curtains.
- 9) Equipping dredges with position control systems for grab samplers or cutterheads.
- 10) Equipping dredges with instruments to control extraction (underwater positioning equipment), sediment surface visualization systems and control panels for monitoring operations.
- 11) Using stepped cutting planes rather than vertical cuts.
- 12) Overlapping cutting planes to minimize the creation of residue fields.
- 13) Limiting operations to appropriate points in the tidal/hydrological cycle.
- 14) Dredging at a rate compatible with the capacity of the disposal and/or treatment sites.

Table F4**Examples of mitigation measures for reducing contaminant migration associated with the transport of contaminated sediments**

Technology	Migration mechanism	Mitigation measures
Waterborne transport	- All mechanisms	- Routing - Implement good environmental practices*
- Pipelines	- Leakage - Accidental spillage	- Install gaskets between sections
- Hopper dredges	- Volatilization - Leakage from hull or valves	- Cover hoppers with tarpaulins - Inspect hull regularly - Improve watertightness of hull and valves - Add polymers to promote particle sedimentation
- Barges, scows	- Volatilization - Leakage from hull or valves - Resuspension of sediments as a result of propeller movement and hull drag	- Same measures as for hopper dredges - Use watertight grab samplers to contain contaminated sediments during transport - Ensure towboat drafts are consistent with transport route water depth - Reduce speed during acceleration and deceleration
Overland transport	- All mechanisms	- Routing - Implement good environmental practices*
- Pipelines	- Leakage	- Install gaskets between sections
- Railcar transport	- Accidental spillage	- Use tank cars to transport water-sediment mixtures - Load cars uniformly - Use tank railcars or covered hopper railcars

Table F4 (Continued)

Technology	Migration mechanism	Mitigation measures
Overland transport (Continued)		
- Road transport	- Leakage - Accidental spillage	- Use tank trailers or watertight dump trailers
	- Volatilization	- Use tank trailers or dump trailers equipped with trailer covers
- Conveyor transport	- Leakage - Accidental spillage	- Use closed conveyors
	- Volatilization	- Ensure that transfer points are watertight
Loading/unloading	- All mechanisms	- Routing - Implement good environmental practices*
	- Overflows	- Prevent or prohibit overflows
	- Spillage	- Discharge bucket over the barge whenever possible and avoid sediment freefall - Load barges uniformly to avoid excessive tilting or overturning - Equip all loading/unloading equipment with drip pans or aprons - Equip handling areas with a solid- or liquid-spill collection system
	- Volatilization	- Provide workers with personal protective equipment (e.g., gloves, respirators, protective clothing, etc.) - Occupational health and safety program

Sources: Compiled from USEPA (1994b); SLC (1992c) for good environmental practices.

Legend for Table F4:

* Adoption of good environmental practices includes:

- 1) Selecting equipment compatible with site conditions, the nature and scope of the operations and the constraints and characteristics of the other components of the remediation project (transport, pre-treatment, treatment, etc.).
- 2) Using reliable, innovative equipment.
- 3) Implementing ESMPs for all dredging and mitigation effectiveness monitoring activities.
- 4) Performing frequent monitoring of dredged sediment volume (area and depth).
- 5) Using qualified operators.
- 6) Decontaminating dredging equipment before leaving the work site.
- 7) Collecting, treating or disposing of cleaning water in a licensed site.
- 8) Ensuring that transport equipment is watertight and properly maintained.
- 9) Installing submerged diffusers at the end of the pipeline or conduit.
- 10) Transporting sediments at densities as close as possible to their *in situ* densities.
- 11) Ensuring that barges/trucks are not filled to their maximum capacity.
- 12) Suspending transport during unfavourable weather conditions.
- 13) Ensuring that waterborne and overland transport are performed in a manner consistent with existing legislation and regulations.
- 14) Other good environmental practices listed in Table 23, Chapter 3.

Table F5**Examples of mitigation measures for reducing contaminant migration associated with the pretreatment of contaminated sediments**

Technology	Migration mechanism	Mitigation measure
Dewatering technologies	- All mechanisms	-Adopt good environmental practices*
- Passive dewatering (upland contained disposal facilities, temporary holding/rehandling facilities, lagoons)	- Effluent	- Treatment - Other
	- Runoff	- Maintain holding facility conditions - Treatment - Other
	- Volatilization	- Cover surface - Place in storage tank
	- Leachate	- Cover surface - Provide watertight covering - Collection and treatment - Other
	- Seepage	- Cover surface - Provide watertight covering - Other
	- Uptake by animals	- Cover surface - Other
	- Uptake by plants	- Cover surface - Control vegetation type
- Mechanical dewatering technologies (belt filter press, recessed plate filter, diaphragm plate filter, vacuum filter, centrifuge, gravity thickening)	- Volatilization	- Equip systems with mechanisms to capture and treat volatile and semi-volatile contaminant losses
	- Leakage and accidental spillage of solids and water	- Equip systems with mechanisms to capture and treat all losses
- Active evaporative technologies (flash dryers, rotary dryers, multiple hearth furnaces, heated auger dryers)	- Volatilization	- Equip systems with mechanisms to capture and treat volatile and semi-volatile contaminant losses
	- Leakage and accidental solid and liquid spillage	- Equip systems with mechanisms to capture and treat all losses

Table F5 (Continued)

Technology	Migration mechanism	Mitigation measures
Physical separation technologies	- All mechanisms	-Adopt good environmental practices*
Debris removal	- Sediment drippage	- Use appropriate containers to store debris - Install drip aprons or construct a low-permeability, drained rehandling area
	- Cleaning water	- Collect and store spillage and cleaning water for subsequent treatment
	- Volatilization	- Cover equipment to capture volatile contaminants
Screens and classifiers	- Volatilization	- Cover equipment to capture volatile contaminants
	- Splashing - Spillage	- Install drip pans, aprons or construct a low-permeability, drained rehandling area
Hydrocyclones	- Volatilization	- Use equipment with devices to capture gases
Gravity separation	- Volatilization	- Enclose the equipment or house in a building with air capture and treatment capability
Froth flotation	- Volatilization	- Fit flotation cells with ventilation hoods to capture volatile emissions
Magnetic separation	- Volatilization	- Use equipment with devices to capture all leaks for treatment

Source: Compiled from USEPA (1994b).

Legend for Table F5:

* Adoption of good environmental practices includes:

- 1) Selecting equipment compatible with site conditions, the nature and scope of the operations and the constraints and characteristics of the other components of the remediation project (transport, pretreatment, treatment, etc.).
- 2) Using reliable, innovative equipment.
- 3) Implementing ESMPs for all pretreatment and mitigation-effectiveness monitoring activities.
- 4) Using qualified operators.
- 5) Decontaminating dredging equipment before leaving the work site.
- 6) Collecting, treating or disposing of cleaning water in a licensed site.
- 7) Performing treatability studies of contaminated sediments.
- 8) Removing debris by means of specially developed techniques.

Table F6**Examples of mitigation measures and good environmental practices (1) for reducing contaminant migration associated with the treatment of contaminated sediments**

Technology	Migration mechanism	Mitigation measures
Bioremediation	<ul style="list-style-type: none"> - Solid residues - Wastewater - Atmospheric emissions 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Treatment of atmospheric emissions
Chemical	<ul style="list-style-type: none"> - Solid residues - Wastewater - Atmospheric emissions (2) 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Treatment of atmospheric emissions
Extraction	<ul style="list-style-type: none"> - Solid residues (3) - Wastewater - Oil/organic compounds - Absorbent media 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Safe disposal of organic residues - In-process recycling
Thermal desorption	<ul style="list-style-type: none"> - Solid residues - Wastewater - Atmospheric emissions - Oil/organic compounds - Absorbent media - Dusts (scrubbers) 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Safe disposal of organic residues - Continuous process control - Safe disposal of absorbent media - Safe disposal of dusts
Thermal destruction	<ul style="list-style-type: none"> - Solid residues - Atmospheric emissions - Scrubber water - Dusts (scrubbers) 	<ul style="list-style-type: none"> - Safe disposal of residues - Continuous process control - Safe disposal of scrubber water - Safe disposal of dusts
Immobilization	<ul style="list-style-type: none"> - Solid residues - Leachates (4) - Atmospheric emissions (5) 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Safe disposal or further treatment of organic residues - Process control - Treatment of atmospheric emissions
Particle separation	<ul style="list-style-type: none"> - Solid wastes - Wastewater - Atmospheric emissions (6) - Oil/organic compounds 	<ul style="list-style-type: none"> - Safe disposal of residues - Treatment of wastewater - Safe disposal or further treatment of organic wastes - Treatment of atmospheric emissions

Sources: Compiled from USEPA (1994b); SLC (1993, revised 1994).

Legend for Table F6:

- (1) Adoption of good environmental practices includes:
 - Selecting treatment equipment compatible with site conditions, the nature and scope of the operations and the constraints and characteristics of the other components of the remediation project (transport, pretreatment, treatment, etc.).
 - Using reliable, innovative equipment.
 - Implementing ESMPs for all treatment and mitigation effectiveness monitoring activities (Tables F7 to F9).
 - Using qualified operators.
 - Decontaminating dredging equipment before leaving the work site.
 - Collecting, treating or disposing of cleaning water and other residues in a licensed site.
 - Performing treatability studies of contaminated sediments.
 - Removing debris by means of specially developed techniques.
- (2) Processes requiring gas-phase reactions that result in atmospheric emissions.
- (3) Processes for extracting organic substances do not treat metals, which are therefore found in the solid residues. Heavy metals may be removed by a treatment system using acids or chelating agents as solvents.
- (4) Long-term contaminant losses can be estimated by means of leaching tests and contaminant transport models similar to those used for upland containment of contaminated sediments. The leaching associated with solid residues may be equally extensive in the case of residues from other treatment processes.
- (5) Atmospheric emissions may be produced when contaminated sediments are mixed with reagents or cements, particularly in the case of exothermic processes.
- (6) Atmospheric emissions may be produced as a result of the agitation associated with most treatment technologies.

Table F7**Examples of mitigation measures for reducing contaminant migration from the aqueous, solid and gaseous residues generated by most sediment treatment technologies**

Type of wastes	Migration mechanism	Mitigation measures
Water residues (wastewater)	<ul style="list-style-type: none"> - Discharges from an upland contained disposal facility - Surface runoff from an upland contained disposal facility - Sidestreams from a dewatering process - Wastewater or condensate from a pretreatment or treatment process - Leachate from an upland contained disposal facility or landfill - Accidental leakage due to failure of treatment systems 	<ul style="list-style-type: none"> - Suspended solids removal technologies (e.g., sedimentation, filtration) - Metals removal technologies (e.g., ion exchange, precipitation, flocculation/coagulation) - Organic contaminant removal technologies (e.g., carbon adsorption, oil separation, oxidation, biofiltration) - Permanent leachate collection and treatment system - Continuous process control
Solid residues	<ul style="list-style-type: none"> - Debris and oversized materials separated during dredging and pretreatment - Sludge from wastewater treatment systems - Spent media from granular filters - Spent media from carbon adsorption systems - Particulates collected from air pollution control systems - Treated sediments 	<ul style="list-style-type: none"> - Use excess process water or wastewater to wet fine sediments - Mix solid wastes with uncontaminated wet sediments - Solidify wastes by adding cement or other agents and water - Adequate handling and storage methods and disposal in a licensed site - Other approved disposal methods
Oil/organic residues	<ul style="list-style-type: none"> - Concentrated organic liquids and oil produced by certain desorption and solvent extraction technologies 	<ul style="list-style-type: none"> - Thermal destruction technologies - Chemical treatment technologies - Bioremediation technologies - Commercial oil residue treatment facility - Containment on site - Disposal in a licensed secure landfill

Table F7 (Continued)

Type of wastes	Migration mechanism	Mitigation measures
Gaseous residues	- Point vapour sources	<ul style="list-style-type: none"> - Adsorption (activated carbon or other media) - Condensation - Spray towers - Scrubbers - Packed columns - Thermal oxidation systems - Catalytic oxidation systems - Bacterial beds - Similar systems
	- Point particle sources (dusts)	<ul style="list-style-type: none"> - Cyclones - Scrubbers - Bag filters - Similar systems
	- Fugitive emission sources	<ul style="list-style-type: none"> - Enclose the entire process in a building or other structure - Pump gases vented from these systems through a treatment unit (e.g., activated carbon)
	- Volatile emissions	<ul style="list-style-type: none"> - Cover the contained disposal facilities or storage tanks (e.g., buildings, bubbles, floating covers, foams and sorbent materials) - Submerge the discharge below the surface - Construct fences around the perimeter of the facility - Adopt good environmental practices*

Source: Compiled from USEPA (1994b).

* Good environmental practices: see Table F8 and Table 23 in Chapter 3.

Table F8

Examples of mitigation measures for reducing contaminant migration associated with the disposal of pretreatment and treatment residues

Type of disposal	Migration mechanism	Mitigation measures
Shoreline disposal	Effluent	- Collection and treatment
	Volatilization or gaseous emissions	- Cap materials - Provide workers with personal protective equipment (e.g., respirators, etc.) - Occupational health and safety program
	Direct contact with sediments	- Provide workers with personal protective equipment (e.g., gloves, protective clothing, etc.) - Occupational health and safety program - Cap with clean materials - Watertight partitions - Watertight barriers
	Groundwater seepage through dikes	- Keep contaminated sediments within the saturated zone - Install physical barriers in dikes
	Convection/diffusion	- Inspection and maintenance program - Long-term environmental surveillance and monitoring program
Confined disposal (upland)	Effluents	- Collection and treatment - Add physical barriers or flocculants to improve sedimentation
- Confined disposal facilities (CDFs) - Municipal or commercial landfills - Secure landfills	Volatilization or gaseous emissions	- Cap materials - Vertical barriers or vegetation screens to control wind erosion - Collection and treatment of gases - Maintain water cover over sediments - Provide workers with personal protective equipment (e.g., respirators) - Occupational health and safety program - Cap and covering materials

Table F8 (Continued 1)

Type of disposal	Migration mechanism	Mitigation measures
Confined disposal (upland) <i>(Continued)</i>	Runoff	<ul style="list-style-type: none"> - Promote sediment dewatering - Plant vegetation - Collection and treatment of groundwater - Long-term environmental surveillance and monitoring program for groundwater - Collection and treatment - Watertight liners - Seal dikes using clay or bentonite - Regular dike inspection and maintenance programs
	Leaching	<ul style="list-style-type: none"> - Cap and covering materials - Promote sediment dewatering - Plant vegetation - Collection and treatment of groundwater - Long-term environmental surveillance and monitoring program for groundwater - Collection and treatment
	Percolation through dikes	<ul style="list-style-type: none"> - Vegetation control - Selection of plant species - Cover vegetation with clean sediments - Treat with lime or herbicides - Capping
	Uptake by plants	<ul style="list-style-type: none"> - Vegetation control
	Uptake by animals	<ul style="list-style-type: none"> - Animal control
	Direct contact with sediments	<ul style="list-style-type: none"> - Provide workers with personal protective equipment (e.g., gloves, protective clothing) - Occupational health and safety program - Capping with clean sediments or excavated materials

Table F8 (Continued 2)

Type of disposal	Migration mechanism	Mitigation measures
Open-water disposal - Unrestricted disposal	Resuspension and advection in the water column	- Limited to treated sediments - Use submerged diffusers - Deposit in thin layers - Operational modifications: good environmental practices*
- Capping and contained disposal	All mechanisms	- Limited to previously treated or treated sediments with low to moderate contamination
	Dispersion/advection/erosion/bioturbation	- Lateral containment of contaminated sediments - Capping with clean sediments - Use equipment that ensures precise positioning of materials - Long-term environmental surveillance and monitoring program - Good environmental practices*
Beneficial uses	All mechanisms	- Limited to treated sediments
- Beach nourishment, land application, landscaping, general construction fill, gravel production, etc.	Same mechanisms as for upland contained disposal facilities	- Same mitigation measures as for upland contained disposal facilities

Sources: Compiled from USEPA (1994b); Francingues et al. (1985); Cullinane et al. (1985); SLC (1992c) for good environmental practices.

Legend for Table F8:

* Adoption of good environmental practices includes:

- 1) Selecting developments compatible with site conditions, the nature and scope of the operations and the constraints and characteristics of the other components of the remediation project (dredging, transport, treatment, etc.).
- 2) Using reliable, innovative equipment.
- 3) Implementing ESMPs for all disposal and mitigation effectiveness monitoring activities.
- 4) Using qualified operators.
- 5) Decontaminating cleaning water equipment in a licensed site.

Table F9**Mitigation measures for other environmental problems associated with the operation of a permanent contaminated-sediment treatment centre***

Management practice	Objectives	Mitigation measures
Materials handling (e.g., contaminated sediments and residues)	Ensure immediate secure storage of all contaminated sediments and residues generated at all stages of the treatment system, before post-treatment or disposal	- Detailed planning of logistics for handling contaminated sediments and residues (discharge, transport, storage and loading)
Storage of chemicals, reagents and treatment residues	Ensure secure storage of all hazardous materials used in the treatment process and residues of treatment technologies	- Install appropriate storage containers (number, size, location, type) for temporary storage of hazardous materials and residues
Dust management	Control airborne contaminants that may present a risk to the health and safety of workers	<ul style="list-style-type: none"> - Install an air-monitoring system to determine if airborne contaminants are present and assist in the selection of respiratory-protection equipment - Ensure constant control of the production of particulates, aerosols or gaseous by-products from all activities in the treatment system (excavation, handling, transport, treatment and disposal) - Include provisions in the contract to ensure that the treatment facilities are operated in compliance with the legislation and regulations on environmental protection and occupational health and safety - Install sprinkling systems or other equipment to control particulates
Energy/power generation and distribution	Ensure that the energy requirements of all equipment used in the treatment system are met at all times	<ul style="list-style-type: none"> - Provide adequate outlets and electrical connections for all high energy-consuming equipment - Provide back-up or replacement generators for use in the event of power failures - Adequate design of fuel transport and storage systems

Table F9 (Continued 1)

Management practice	Objectives	Mitigation measures
Water management	<p>Maximize the efficiency of the containment area for various types of wastewater (runoff, leachate, process water from pretreatment and treatment technologies)</p> <p>Maximize the retention efficiency of the containment area</p>	<ul style="list-style-type: none"> - Collect wastewater effluents and route to the treatment system - Depending on their quality and flow rate, some wastewater streams may be routed together and mixed before treatment - Operate the dredge intermittently - Install more extensive treatment systems for effluent from the disposal site - Slow the rate of drawdown in the settling basins - Route rainfall to one or more collection point(s) - Add other methods (e.g., trenching, underground irrigation) to promote drainage and desiccation
Management of plants	<p>Help to dewater dredged material, control dust, reduce volatilization losses and improve effluent quality by filtering</p> <p>Optimize the storage capacity of the containment area</p> <p>Minimize uptake and environmental recycling of sediment contaminants</p>	<ul style="list-style-type: none"> - Management of plants; periodic cutting or burning, pruning, herbicides, planting acceptable species or placing new sediments on top of existing vegetation - Disposal of contaminated vegetation in licensed sites
Management of animals	<p>Minimize uptake and environmental recycling of sediment contaminants</p> <p>Minimize conflicts with animal species (e.g., waterfowl) on the site by changing the scheduling of operations</p>	<ul style="list-style-type: none"> - Use of noisemakers - Use of predator images - Vegetation management - Use of repellents or shocking to repel fish - Vegetation management and trapping to control populations of small mammals

Table F9 (Continued 2)

Management practice	Objectives	Mitigation measures
Occupational health and safety program	Protect workers and the public when the treatment system requires high temperatures, pressure, or hazardous, reactive or combustible reagents or products	<ul style="list-style-type: none"> - Occupational health and safety program - Provide workers with adequate personal protective equipment (e.g., gloves, respirators) - Prepare an emergency plan - Personnel awareness and training program
Site security and maintenance	Prevent contamination of workers, protect public health, prevent vandalism and theft	<ul style="list-style-type: none"> - Develop a site control plan, including a site map, signage of work zones, site security and safe work practices - Install a fence around the site, post signs and limit access points - Implement procedures for safe transport, handling and storage of hazardous materials and wastes - Keep records (manifests) of all materials entering, stored on and leaving the site - Implement a routine maintenance system including periodic inspections of dikes, fence enclosures, storage areas and other site features presenting potential problems for the environment and the protection of public health - Develop an equipment and vehicle decontamination plan
Site environmental surveillance and monitoring program	<p>Ensure that the contaminated sediment remediation project meets the objectives of technological and environmental effectiveness</p> <p>Ensure compliance with the exposure levels defined in the occupational health and safety program</p>	<p>Components to be monitored:</p> <ul style="list-style-type: none"> - Pond water levels - Sediment delivery/flow rates - Physical/chemical characteristics of sediment inflow and outflow - Quality and quantity of pretreatment and treatment inputs, intermediate effluents and outputs - Treated effluent/leachate quality - Ambient air and groundwater quality

Source: Compiled from USEPA (1994b).

* In a large contaminated sediment-treatment facility, facilities similar to those required for upland containment of dredged material may be required for temporary pretreatment storage of the contaminated sediments, which will require the same mitigation measures as those identified in this table.

Table F10**Mitigation measures for closure and post-closure maintenance, environmental surveillance and monitoring of a contaminated-sediment treatment site**

Management practice	Objectives	Mitigation measures
Site closure, post-closure maintenance, closure surveillance and monitoring	Ensure long-term protection of the site environment	<ul style="list-style-type: none"> - Decontamination of equipment used on site - Collection, treatment or safe disposal of cleaning water - Disposal in a licensed landfill of all soils and other materials that may have been contaminated by contact with contaminated sediments - Capping an upland contained disposal facility, ensuring that the site is graded for positive drainage and compacted - Periodic inspections and repairs of dikes and cap/cover, if required - Functional leachate collection and treatment system - Ensure site security for areas where permanent leachate collection/treatment systems will operate following site closure - Management of plants and animals - Periodic groundwater monitoring - Develop the contained disposal facility for productive purposes (industrial park, park and recreational areas, wildlife habitat, etc.)

Source: Compiled from USEPA (1994b).

Index

Action plan

Design	73, 74
Definition	73, 125
Example for aquatic or open-water disposal	81
Example for a dredging project	78
Example for aquatic or open-water disposal projects	80
Example for aquatic capping projects	81
Example of a decision tree	78
Implementation	87

Action thresholds

Definition	34
Examples for dredging projects	36
Examples for aquatic capping projects	81
Examples for open-water/aquatic disposal projects	39, 80-81
List of applicable statutes, regulations and guidelines	36

Bioassay(s)

Definition	113
------------------	-----

Canadian Environmental Assessment Act (CEAA)

13, 21, 132

Canadian Environmental Protection Act (CEPA)

131

Compensation measures

Definition	114
Definition (according to EQA)	4

Comprehensive study

14

Conceptual impact models

Definition	33
Development	158
General	33, 144, 158
Cumulative impacts	165
Mathematical models	159-164
Laboratory tests	159-160

Containment of contaminated sediments

Aquatic, shoreline or upland	155
------------------------------------	-----

Contaminant migration pathways

See Contaminant transport mechanisms

Contaminant transport mechanisms

Open-water containment	155
Shoreline containment	155
Upland containment	154-155
Disposal in a waterway with lateral containment	153
Aquatic confined disposal	152
Confined disposal in shallow water	150
Confined disposal in deep water	151
Upland confined disposal	154
Open-water disposal	149
Shoreline disposal	149
Hydraulic dredging	148

Mechanical dredging.....	148
Post-treatment.....	157
Pretreatment.....	157
Sediment remediation project.....	185-207
Remediation.....	156
Treatment.....	154, 157
Transport.....	157
Cumulative environmental effects	12, 28, 119, 165
Data	
Analysis and interpretation methods.....	68, 183
Dredging and sediment management activities	
Good environmental practices.....	83, 188-191, 193-194, 197-198
Definition (according to EQA).....	4
Reference criteria.....	34
Environmental impact study.....	21
Environmental assessment.....	21
Applicable legislation.....	22, 131-136
Management mechanism(s).....	16, 17
Conceptual impact models.....	141, 158
Mitigation measures.....	73, 75, 185
General and specific objectives.....	21-29
Selection of sampling parameters.....	43, 44
Migration pathways/transport mechanisms.....	157
Emergency measures	
Standard plan.....	76-77
Emergency plan	76-77
Employee awareness and training program	86
Environmental assessment	13
Environmental components	
Requiring surveillance.....	29, 31
Environmental impacts	
Aquatic containment.....	24, 31
Shoreline containment.....	25, 31
Upland containment.....	25, 31
Definition (according to EQA).....	4
Aquatic or open-water disposal.....	24, 26, 31, 144
Dredging.....	24, 31, 144
General.....	144
Impact mechanisms to be considered.....	31, 144
Transport.....	24, 31, 144
Treatment.....	31
Environmental monitoring	
Definition (according to EQA).....	4
Environmental protection measures	<i>See Mitigation measures</i>
Environmental surveillance	
Definition (according to EQA).....	4

Environmental surveillance and monitoring program	
Sequence of activities involved in design and implementation	19
Periodic review	92
Scientific boundaries.....	33
Spatial/temporal boundaries.....	33-34
Implementation	84-85
Objectives	6
Guidelines	7
Preparation of the report and dissemination of the results.....	88-90
Environment Quality Act (EQA)	14, 134
Federal authorities	
Definition (according to CEAA)	
Responsibilities	6, 26, 131
Fisheries Act (FA)	13
Good environmental practices	
Useful reference documents.....	179
General.....	82
Aquatic containment projects.....	83, 203
Upland containment projects	83, 201
Dredging projects.....	83, 191
Pretreatment projects.....	196
Treatment projects.....	83, 198, 200
Transport projects	83, 194
Transport of contaminated sediments	192
Impact hypothesis/es	
Aquatic containment	42
Definition	38
Aquatic or open-water disposal.....	42, 170-171
Ocean disposal	42, 170-171
Aquatic or open-water disposal/containment.....	42, 172
Upland disposal/containment.....	42, 173-174
Shoreline disposal/containment	42
Dredging	42, 168-169
Formulation: examples.....	166
Formulation.....	41
Treatment of contaminated sediments	42, 175
Example	40
Impact matrix	29
Cumulative effects or impacts.....	167
Environmental impacts	146
Impact mechanisms	
Identification of mechanisms to be considered.....	30, 145
Impact mechanisms to be monitored	
Aquatic containment	24, 150-153, 155, 157
Shoreline confined disposal	25, 149, 155, 157
Aquatic or open-water disposal.....	24, 149
Upland disposal/containment.....	25, 154-155

Dredging	24, 157
Hydraulic dredging	146, 148
Mechanical dredging.....	146, 148
General	30
Sediment post-treatment	157
Sediment pretreatment	157
Sediment remediation/treatment	25, 154, 157
<i>In situ</i> treatment	156
Transport.....	24, 157
Impact study	15
Measurement tools	
Selection.....	53
Mitigation measures	
Loading/unloading of contaminated sediments	193
Design	73, 82
<i>In situ</i> containment.....	189
Definition	111, 123
Definition (according to EQA)	4
Aquatic or open-water disposal.....	203
Shoreline disposal	201
Upland disposal/containment.....	75, 201
Disposal/elimination of contaminant pretreatment or treatment residues.....	201
Hydraulic dredging	190
Mechanical dredging.....	190
Specialized dredges.....	190
Site closure and post-closure.....	207
General	185
Implementation	87
Sediment pretreatment	195
<i>In situ</i> remediation of contaminated sediments.....	188
Treatment of contaminated sediments	197
<i>Ex situ</i> treatment.....	204
<i>Ex situ</i> treatment (water, solid, gaseous residues)	199
<i>In situ</i> treatment	189
Transport of contaminated sediments	73, 192
Navigable Waters Protection Act (NWPA)	13, 132
Occupational health and safety program	76, 206
Ocean disposal	
Sample list of parameters.....	46
CEPA permit.....	13
Project proponent(s)	
Responsibilities	15, 17, 22
Quality assurance and quality control (QA/QC) program	
Design	51
Content.....	53
Definition	9, 126
Useful reference documents.....	176

Objectives	9
Data quality objectives	124
Remediation of contaminated sediments	
Migration mechanisms - <i>in situ</i> remediation	156
Mitigation measures	185
Phases	187
Scenarios	186
Sampling plan	
Design	43, 45, 61
Sampling program	
Design	43
Design of the sampling plan	61
Useful reference documents	179
Examples of lists of parameters	
Upland disposal/containment	48-49
Ocean disposal of dredged material	46-47
Dredging projects	43, 64
Contaminated sediment treatment projects	51
Screening	13
Screening tests	58-59
Secure landfills	
Parameters required by MENV	49
Specific components	
Requiring surveillance	82
Technological, environmental and economic issues	22
Aquatic containment	24
Open-water disposal	24
Shoreline or coastal disposal/containment	25
Dredging	24
Sediment remediation	25
Transport	24
Useful reference documents	
Design of a sampling plan	178
General	1
Guides	140-142
Guidelines	36, 138
Guidelines (criteria)	139
Mitigation measures and/or good environmental practices	179
Measurement tools	177
Policies	137
QA/QC program	176