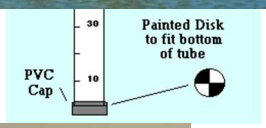
The following guidance document is provided in its original format as approved by the LC/LP governing bodies in 2015 (LC 37/16). The final published guidance is available from the IMO Publications section, in English, French and Spanish as publications reference I542(E/F/S).

Low cost, low technology field monitoring

Assessment of the effects of disposal in marine waters of dredged material or inert, inorganic, geological material



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The use of trade names in this document is not an endorsement. For the most part, a simple internet search on a particular topic found examples of low technology low cost techniques, and those are named strictly as examples.

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Acknowledgements

This document is the culmination of several years of efforts by the Scientific Groups of the London Protocol and London Convention. Co-chaired by Canada (Suzanne Agius) and the United Kingdom (Dr. Andrew Birchenough), members of the working group included Argentina, China, Ireland, Italy, Japan, Nigeria, Republic of Korea, Sierra Leone and the United States.

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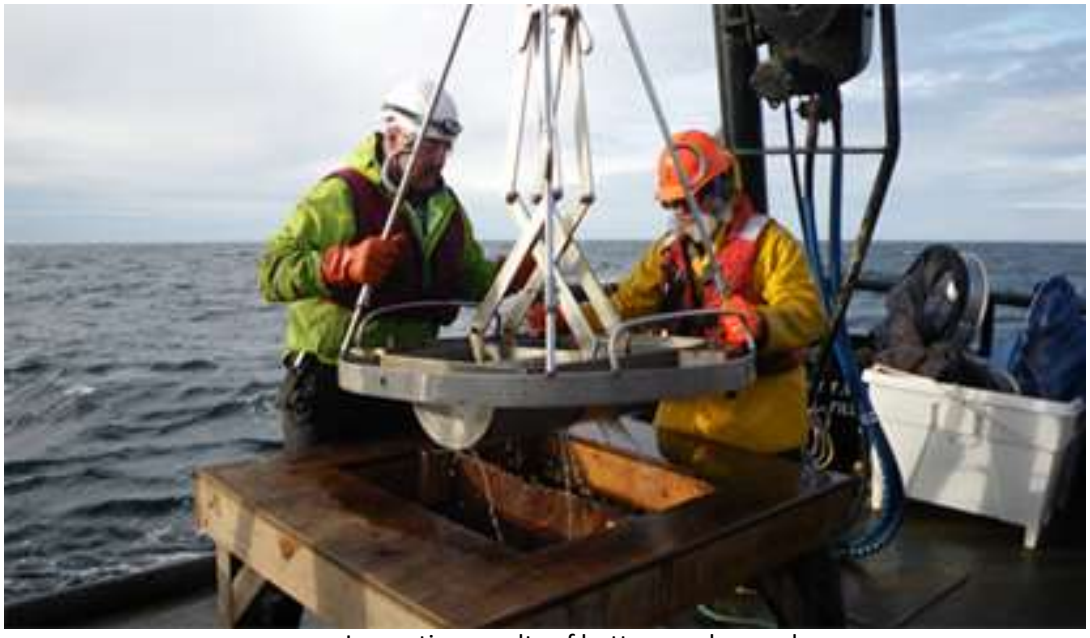
Foreword

The objective of this guidance document is to provide practical information about using low cost and low technology tools that are useful for monitoring of possible environmental impacts associated with disposal at sea of either dredged material or inert, inorganic geological materials. The primary audiences for this guidance are countries that are in the early stages of developing waste assessment and monitoring actions in concert with permit programmes for disposal of wastes and other matter at sea.

Step-by-step waste assessment guidance to determine the acceptability and impacts of wastes and other matter proposed to be disposed in ocean waters is available from the International Maritime Organization's London Protocol and London Convention, the primary international treaties for protection of the world's oceans. While that guidance does address monitoring of potential environmental impacts, it is now recognized that some countries are in the beginning of building environmental management programs, and have limited scientific, technical, and economic capabilities.

This low cost, low technology field monitoring guidance is intended to complement the existing London Protocol and Convention Waste Assessment Guidelines (for the Dredged Material Assessment Guidelines and the Inert, Inorganic Geological Materials Assessment Guidelines, see http://www.imo.org/OurWork/Environment/LCLP/ Publications/wag/Pages/default.aspx).

The London Protocol and Convention website is at: http://www.imo.org/OurWork/Environment/ LCLP/Pages/default.aspx.



Inspecting results of bottom grab sample.
Source: http://ccma.nos.noaa.gov/about/coast/nsandt/musselwatch.aspx.

Abbreviations and glossary

CCME	Canadian Council of Ministers of the Environment
CEDA	Central Dredging Association
Cefas	Centre for Environment, Fisheries, and Aquaculture (United Kingdom)
Chain-of-custody	The documentation that establishes the control of a sample between the time it is collected and the time it is analysed to demonstrate that no tampering or contamination of the sample occurred during that time.
Composite sample	A sample that is formed by combining material from more than one sample or subsample.
Contaminant	Any undesirable agent, substance, or material that is present in sediments, water, or tissue.
Core sample	A column of sediment which, when analysed, represents the vertical distribution of the physical, chemical, and/or biological characteristics of the sediment.
Dispersion	The action or process of distributing sediments over a wide area. The word "dispersion" implicates both transportation of mass by flow such as tidal current and spreading of mass caused by non-uniformity of the velocity field, and does not include molecular diffusion and turbulence diffusion.
Dispersive sites	Material may either be dispersed during deposition or eroded from the bottom over time and transported away from the site by currents and/or wave action.
DQO	Data Quality Objective
EC	Environment Canada
Hypothesis	In science, a hypothesis is an idea or explanation that you then test through study and experimentation. Outside science, a theory or guess can also be called a *hypothesis*. A *hypothesis* is something more than a wild guess but less than a well-established theory. In science, a hypothesis needs to go through a lot of testing before it can be labelled a theory. *Null hypothesis*: The null hypothesis is a hypothesis which the researcher tries to disprove, reject or nullify. The "null" often refers to the common view of something, or in the case of monitoring is the view that is desirable. *Alternative hypothesis:* The alternative hypothesis is the hypothesis used in hypothesis testing that is contrary to the null hypothesis. It is usually taken to be that the observations are the result of a real effect (with some amount of chance variation superposed). *Hypothesis test:* Hypothesis testing refers to the formal procedures used by statisticians to accept or reject statistical hypotheses.

IADC	International Association of Dredging Companies
ISO	International Organization for Standardization
JTU	Jackson Turbidity Units
LC	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (the London Convention)
LP	1996 Protocol to the London Convention (the London Protocol)
Non-dispersive sites	Most of the material remains on the seabed following deposition in a defined area of the disposal site.
NTU	Nephelometric Turbidity Units
Quality assurance (QA)	Standardized processes or qualitative measures designed to ensure consistent and reliable output from laboratory or field test systems. QA is also a program within a laboratory, intended to provide precise and accurate results in scientific and technical work. It includes selection of proper procedures, sample collection, selection of limits, evaluation of data, quality control (QC) and qualifications and training of personnel.
Quality control (QC)	Standardized specifications or quantitative measures (e.g. control limits, tolerances) designed to interface with QA processes to ensure conformance with stated output objectives. (QC) is usually specific actions within the programme of quality assurance. It includes standardization, calibration, replication, control samples, and statistical estimates of limits for the data. (Environment Canada 1999, "Guidance Document on Application and Interpretation of Single-species Tests in Environmental Toxicology "*Environmental Protection Series EPS* 1/RM/34, Ottawa).
QA/QC	Quality Assurance, Quality Control
Reference sediment	*Option A:* Sediment collected near the site of concern that may be used as an indicator of localized sediment conditions exclusive of the specific pollutant of concern. (ISO) *Option B:* Reference sediment may be used as an indicator of localized sediment conditions. Reference sediment is sediment that is as similar as practicable to the grain size of the dredged material and the sediment at the disposal site. Reference sediment is collected near the site of concern and reflects the conditions that would exist in the vicinity of the disposal site had no dredged material disposal ever taken place, but had all other influences on sediment condition taken place. (USEPA). *Option C:* Reference sediment is a field-collected sediment thought to be relatively free of contaminants ("clean sediments"). It is often collected from a site within the general vicinity of a test sediment (i.e. the same body of water), and is frequently selected for biological testing because of its geochemical similarity (e.g. particle size, total organic content) to the test sediments. A reference sediment may be used as an experimental control in addition to a control sediment in a sediment toxicity test (EC 1994).

Replicate samples (field)	A series of samples, collected at the same sampling station, using the same methods, but independent of one another (not composited but stored in separate jars). Used to estimate the sampling error or to improve the precision of estimation. Replicate samples can also be used to help gauge the heterogeneity of the sediment.
Replicate samples (laboratory)	A series of samples or subsamples coming from a sampling station, which are analysed or tested (as in a toxicity test) separately as discrete samples. They are used to measure the variation in the analytical processes or the test population.
Sampling station	The physical location where samples are collected. The stations are usually best defined by coordinates.
Sediment	Particulate material such as sand, silt, or clay suspended in or settled on the bottom of a water body.
Split sample	Sample that has been partitioned into two equal, or unequal, parts with or without prior homogenization of the sample, with the intention of producing representative subsamples.
Storage container	Container used to store field-collected samples. It may or may not be the sample container.
Subsample	A representative part of a sample that is studied in order to gain information about the characteristics and infer properties of the sample.
Testable hypothesis	A working explanation of a phenomenon. It is a statement of an expected result that can be tested to nullify the hypothesis (show explanation is incorrect), suggest other testable hypotheses (other explanations), or lead to provisional acceptance.
TOC	Total Organic Carbon
Toxicity test	An experiment designed to determine the effect of a material or substance on a population of a given species under defined conditions.
Travel blank	A randomly selected sample container that has been treated and handled identically to those containers used for samples collected for analysis. The empty container is filled with clean water (or sediment) and submitted with the field-collected samples for which it serves as a travel blank for either the chemical or toxicological analyses. The purpose of a travel blank is to assess any variation (or effects) that may be attributed to the actual transportation of the samples to the laboratory.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WAG	Waste Assessment Guidance
WDE	Washington Department of Ecology

Part 1

Introduction

Part 1 Introduction

The objective of this document is to provide guidance on monitoring techniques for countries that are developing capabilities to assess environmental impacts of the disposal of wastes or other matter into marine waters, but at this point in time are limited in their scientific, technical, and economic abilities to carry out comprehensive and state-of-the-practice monitoring programmes.

Guidance is provided for use of low cost and low technology sampling and analysis monitoring techniques for two categories of wastes and other matter, dredged materials and inert, inorganic geological materials.

THE WORKING DEFINITION OF LOW COST, LOW TECHNOLOGY MONITORING FOR THIS DOCUMENT:
Monitoring using simplified methods that enable the collection of the minimum information needed to begin validating permit assumptions. The "low-technology" basket includes techniques that are: – low cost in development and implementation; – easy to develop and deploy; – simple to use automated devices; and – practical, and equipment readily available (through purchase or borrowing).

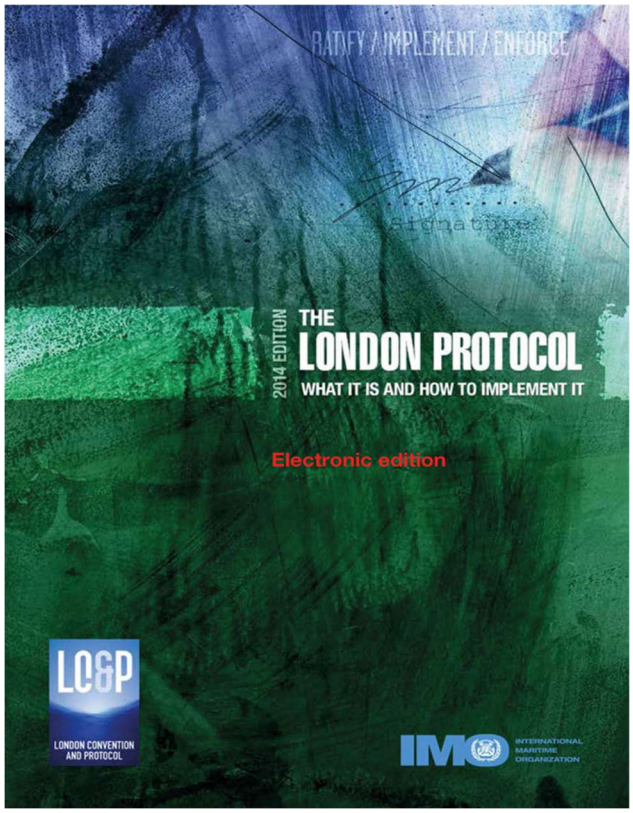
This guidance is based on Annex 2 to the London Protocol and has been developed by parties to the London Protocol and the London Convention, the two primary international treaties protecting the world's ocean from pollution. These treaties are managed under the International Maritime Organization, a specialized agency of the United Nations. Waste Assessment Guidelines (WAGs) are available from the London Protocol and London Convention that provide robust procedures for assessment of wastes proposed to be dumped in the ocean; the WAGs include a section on monitoring of the environmental impacts at the disposal site and in the surrounding areas.

The key elements of the Waste Assessment Guidelines include (see annex 1):

- General – is there a way that the necessity for ocean dumping can be reduced?
- Waste prevention audit – what could be done to reduce or prevent generation of the waste?
- Consideration of waste management options – what are the alternatives to dumping at sea?
- Chemical, physical and biological properties – what are the characteristics of the waste?
- Action List – will the waste cause unacceptable adverse impacts at the dump site?
- Dump Site Selection– where is an acceptable dump site in marine waters?
- Assessment of potential impacts (impact hypotheses) – what are the potential impacts at the dump site? Are management measures needed to alleviate the adverse impacts at the dump site?
- Permits and permit conditions – what special conditions should be included in the permit?
- Monitoring – what compliance monitoring and field monitoring activities are needed?

This guidance document is intended to address the last bullet, specifically, field monitoring, which is the monitoring of environmental conditions at the dump-site and in the surrounding areas to assess whether the predicted effects were on target. Compliance monitoring is checking to ensure that permit conditions are being met (e.g. to ensure that wastes are disposed of at the dump-site coordinates).

Specific WAGs have been developed for the eight categories of waste or other matter that are allowed to be dumped into marine waters under the London Protocol, provided they meet the conditions specified in the guidelines (e.g. not causing unacceptable adverse impacts).



The WAGs are to be used by national authorities responsible for regulating the dumping of wastes or other matter in the ocean. They are intended to assist individuals or bodies who may be regulators, port authorities, or other interested entities to provide the tools from a simple starting point to incrementally building an assessment, management, and permitting system for waste materials or other matter to be considered for dumping at sea. The guidelines contain procedures to guide these authorities in evaluating applications for dumping of wastes or other matter. However, it is recognized that some of the approaches detailed in the Waste Assessment Guidelines require technical equipment and knowledge that may not be available or affordable by those countries in the early stages of issuing permits for waste management and dumping at sea.

This document provides a full discussion of low technology and low cost field monitoring procedures, with **Part 2** of the document providing guidance on development of a monitoring plan, followed by a discussion of possible management actions when the monitoring results are evaluated. The monitoring plan is based upon development of impact hypotheses, which are a guide to specific sampling and testing procedures. **Part 3** of the document describes those sampling and testing procedures with a focus upon measurement of physical impact.

For those waste materials or other matter for which chemical contamination is suspected, low technology low cost procedures are provided that are an indicator of chemical contamination. If, within a country's capabilities, testing for chemical contamination is desirable; procedures for sampling, storage, and transport to a qualified laboratory for chemical analysis are provided.

A simple approach to evaluation of biological effects is provided. In addition, conduct of bioassays to assess toxicity due to chemical contamination can provide excellent information on the overall toxicity of the sediment at the site. The bioassay integrates the possible effects of any chemicals contained in the waste that has been deposited at the dump-site. While some bioassays require meticulous, extensive, and costly laboratory procedures, this document suggests two possible low cost low technology bioassays that can provide an indicator of toxicity.

A discussion of data management, data documentation, and analysis is also included.

The annexes include "do it yourself" procedures for making certain types of field monitoring equipment.

The reader is referred to the London Convention and Protocol website for additional information on the provisions of the treaties and the available guidance materials: http://www.londonprotocol.imo.org.

Part 2

Monitoring Plans and Management Actions

Part 2 Monitoring plans and management actions

2.1 Development of monitoring plans

Field monitoring* is designed to see if predictions of potential environmental impacts made during the assessment of the proposed project are correct. There can be very complex and scientifically vigorous approaches to monitoring. This document is focused upon providing relatively simple and low technology low cost approaches to assess whether unacceptable adverse impacts are occurring to the environment or human health at or near the disposal site, and meeting the environmental quality conditions specified in the permit. For example, figure 1 shows a turbidity plume from disposal at sea of dredged material, and figure 2 demonstrates a simple visual method for assessing potential impacts of disposal.

Monitoring should be designed and conducted with a clear purpose such that the information can be used to assess and modify management actions (e.g. future project evaluations, on-going project operations, or site management actions) and future permitting decisions. Design of the monitoring programme to ensure that collected information can be applied to specific management actions is essential.

2.1.1 Who undertakes the monitoring?

Field monitoring can be done by the permitting authority, or by a body appointed on behalf of the permitting authority. The permitting authority may also direct the permittee, the entity who is doing the project, to do specific monitoring activities; these conditions would be included in the permit.

2.1.2 What is a monitoring plan?

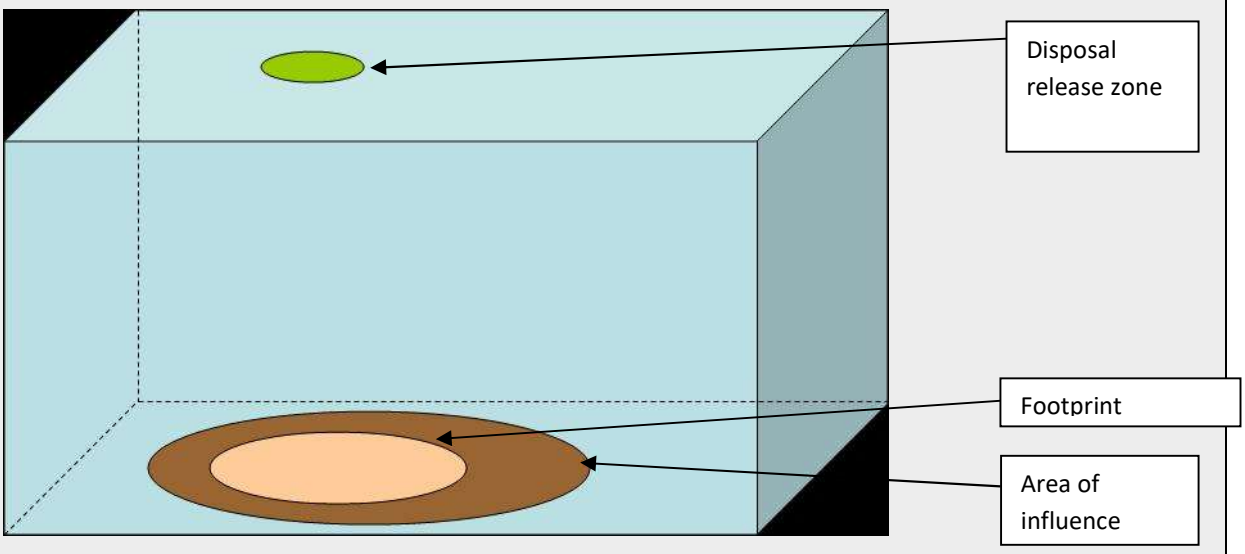
A monitoring plan is a document that is written to help those who need to sample and those who need to make decisions based on the results, to think through, discuss, and agree on how sampling should be done, the objective being that the resulting data from the sampling are of a quality and quantity sufficient to allow sound decision-making and project planning. To achieve this goal, a set of testable hypotheses should be agreed to and form the basis of the plan.

There are several components necessary to develop a successful monitoring plan. The planning process is illustrated in figure 3. In summary, the plan should contain the goals and objectives, description of the study area and available data, maps showing the sampling design, number and type of samples, sampling and physical characteristics testing procedures, quality control and assurance steps, personnel and equipment, transport and storage, and reporting plans. The final box in figure 3, “Evaluation and Management Actions,” could also be entitled “Site Management Plan”, and is discussed in Part 3.2 of this document.

* The other type of monitoring is compliance monitoring which is used to verify that permit conditions are met. Compliance monitoring involves providing assurances that (1) the material dumped is the same as the material authorized under the permit; (2) the material is loaded, handled, and transported in accordance with the permit; (3) the volume is consistent with the permit; and (4) the dumping location and method are the same as specified by the permit. See separate LP/LC Compliance Monitoring Guidance.

DEFINITIONS

In the context of monitoring, *Disposal sites* are defined and described using the following terminology:



Dump-site: Combination of the Disposal Release Zone and the Footprint.

Disposal release zone: Surface coordinates from which disposals may originate.

Footprint: Area physically impacted by the disposed material (as modelled or mapped via bathymetry or other methods).

Area of influence: Zone in which disposed materials have effects (e.g., on benthic community) or undetectable physical presence (e.g. dispersion of very fine material).

Figure 1 –*Turbidity plume from dredged material disposal*
Source: http://boobook48.blogspot.com/2008_05_01_archive.html.

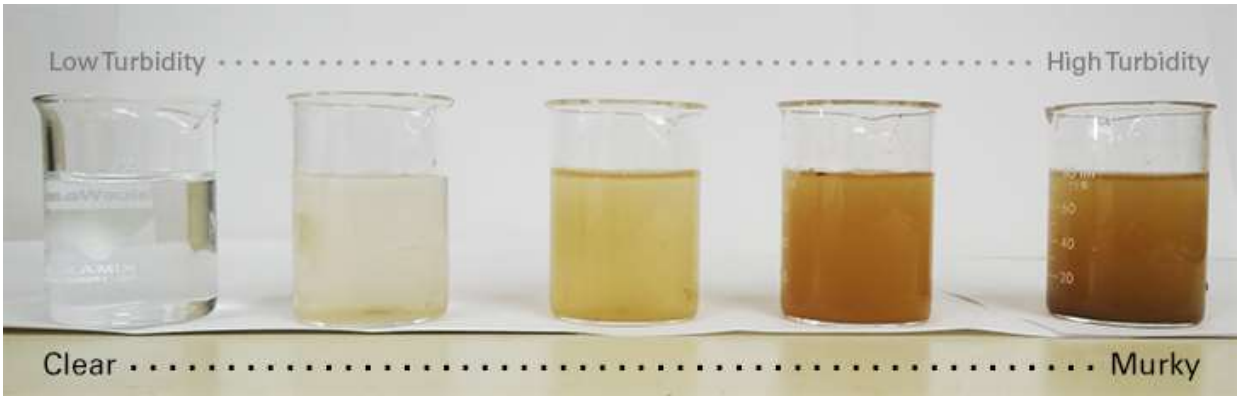


Figure 2 – *Range of turbidity*
Source: http://oos.soest.hawaii.edu/pacioos/focus/modeling/roms_turb.php.

2.1.3 What is tiered monitoring?

Field monitoring involves collection of samples at or near dump-sites and measurements of certain physical, chemical, and biological characteristics at those locations. What is monitored will depend directly on a series of questions or impact hypotheses that are developed to assess whether the waste will cause unacceptable adverse impacts to the ecological resources in the marine waters, to human health, or to other users of the sea.

Monitoring programmes should be multi-tiered with several different levels of intensity incorporated into the monitoring programme. Each level should be designed based upon null hypotheses. Results of monitoring that indicate the acceptance of the null hypothesis at any tier would prevent further, often more costly, monitoring at the next, more complex, level. Results that indicate rejection of the null hypothesis will trigger monitoring in higher tiers and provide an early indication to managers that a predetermined adverse effect may occur (Fredette, 1986), so in this way, the tiers make up a hierarchical progression from simple to more complex monitoring techniques.

In general, a tiered monitoring programme will proceed through the development of a series of predictions regarding the transport, fate, and impact of disposed materials. Each tier should have defined unacceptable thresholds, null hypotheses, and sampling/data collection plans, plus predetermined management actions, if the threshold is exceeded. Evaluation at successive tiers is based on more extensive and specific information that may be more time-consuming and expensive to generate, but that allows more and more comprehensive evaluations of the potential for environmental effects (Zeller, 1986).

The intent of the tiered approach is to use resources efficiently by testing only as intensely as is necessary to provide sufficient information for making decisions.

2.1.4 What goes into the design of the tiered monitoring programme?

The tiered monitoring program should be based on an overall assessment of what is known about the site environs, the past use of the site, and amenities at or near the site that need to be protected (USEPA and USACE, 1996).

The development of the monitoring programme should include an assessment of:

- Baseline or environmental information collected at or near the site describing its condition in the past and/or present;

- Characteristics of materials already dumped at the site and characteristics of materials that may potentially be dumped at the site in the future; and
- Special management conditions used at the site that could affect the environmental effects or fate of dumped material.

Management plans should use this type of information to develop realistic questions (null hypotheses) regarding potential impacts that need to be answered to protect the environment of the site. These questions should address all realistic environmental concerns and should be specific. They should cover such issues as long and short-term fate and effects of the dumped material.

The null hypotheses that serve as a foundation for tiered monitoring programmes help focus the field monitoring programme on critical issues for making management decisions. This eliminates the tendency for a "shotgun" approach to monitoring. Each sample and piece of data generated is required to answer a question, and each answer to a question ultimately leads to a management decision.

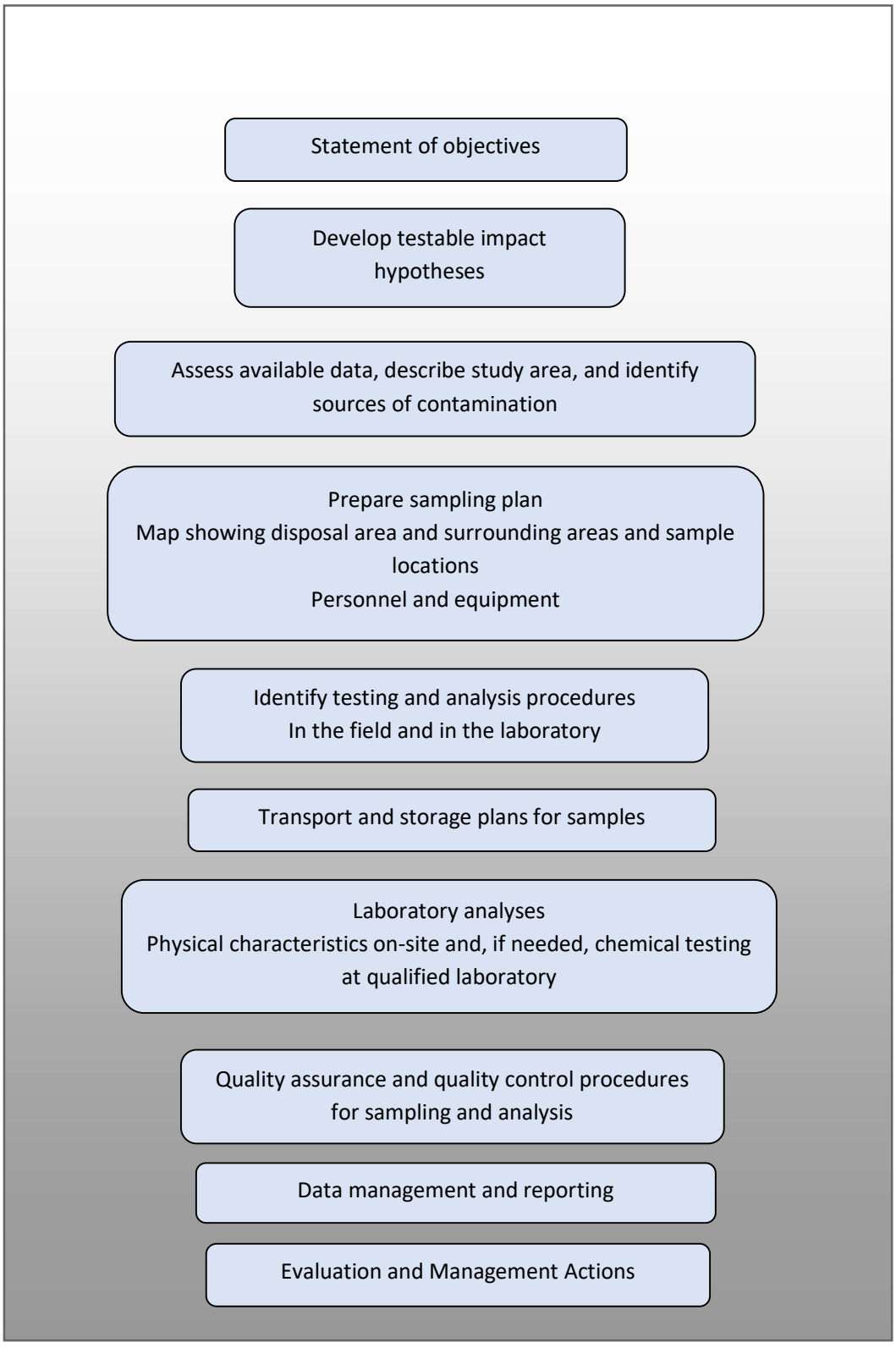


Figure 3 – *Elements of a monitoring plan*

2.2 Key elements of monitoring: impact hypotheses and sampling design

This section describes the factors that should be considered when preparing impact hypotheses, including conceptual models of exposure, key impact hypotheses and a relatively large number of examples of impact hypotheses in table format, the key elements in sampling plans to test the hypotheses, information needs prior to sampling, and the design of the sampling programme.

2.2.1 What goes into preparing impact hypotheses?

Impact assessment proceeds by establishing a hypothesis, or prediction, about the potential impact, and then testing it scientifically. In the present context, an impact hypothesis is a prediction of the likely environmental impact of a disposal event at a given disposal site. The purpose of an impact hypothesis is to provide the basis for field monitoring before and/or after the disposal activity. The measurement programme should be designed to ascertain that changes in the receiving environment are within those predicted. Developing impact hypotheses involves:

- Identifying potential impacts/effects of specific disposal actions;
- Defining predictions of what effects may occur, or not occur;
- Deciding what types and levels of impacts are unacceptable; and
- Determining sampling methods for testing the hypotheses.

WHAT IS THE DIFFERENCE BETWEEN IMPACT HYPOTHESES, NULL HYPOTHESES, AND TESTABLE HYPOTHESES?

For the purposes of field monitoring under the London Convention and Protocol, these are different words for essentially the same concept. The hypotheses address the questions that need to be answered in order to determine whether a particular impact (such as sedimentation outside the designated disposal site) is not happening. Once hypotheses have been established, measurements during monitoring can be developed to assess whether the hypotheses are met.

Measurements should be designed to determine whether the zone of impact and the extent of change outside the zone of impact differ from those predicted. These measurements should be based on a null hypothesis, that no significant change can be detected. Basing monitoring programmes on null hypotheses clearly defines before sampling begins what environmental resources are at risk, the magnitude and extent of that risk from disposal of materials at the site, and what are acceptable and unacceptable adverse impacts. The thresholds at which impacts will be considered to be unacceptably adverse should be clearly defined prior to monitoring (Fredette, 1990).

A NOTE ABOUT PRACTICAL IN-THE-FIELD MEASUREMENTS

Direct observation by a knowledgeable person can provide considerable useful information on whether the assumptions made during the assessment of the proposed project are correct. It is important to do measurements that can be understood, for example, taking multiple water samples does not necessarily help to understand where a plume from a disposal site is going, especially if direct observation is possible to

ensure that the measurements make sense. Documentation by photographs or video may be more useful than water sampling in some situations.

2.2.2 How does using conceptual models of exposure assist in design of the monitoring programme?

Understanding the potential pathways of exposure and potential effects is a basis for determining impact hypotheses. As shown in the simple conceptual model in figure 4, the potential pathways for open-water disposal are water column and benthic. Water column contaminant impacts should consider water quality (physical and chemical) and toxicity (biological). Assessment of benthic impacts should consider physical impacts, and where appropriate and feasible, the toxicity and bioaccumulation of chemical contaminants. Two more detailed conceptual models are included in annex 2. The text box details the differences that should be addressed in development of impact hypotheses between dredged material and inert, inorganic geological material of geological origin.

Use of a conceptual model as a first step in preparing the impact hypotheses will assist in visualizing the range of potential effects at the dump-site. How much of each contaminant is in the waste that was dumped at the disposal site? How would these substances disperse in the marine environment? How would the concentrations change as they disperse and settle? What marine organisms are present (or likely to be present, based on past monitoring or life history information) in the zone of exposure? What are the pathways of exposure? If toxicity is suspected, what would be the consequences to the populations of organisms exposed? These questions can be re-phrased as hypotheses that can be tested statistically with empirical data, during and after the disposal of dredged material at the dump-site.

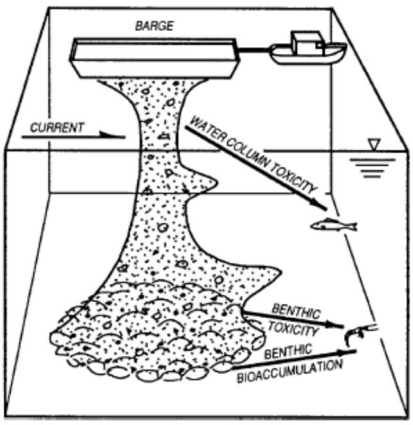


Figure 4 – *Simple display of pathways of exposure to contaminants in dredged material. Source: USACE*

WHAT'S THE DIFFERENCE? DREDGED MATERIAL VERSUS INERT, INORGANIC GEOLOGICAL MATERIAL. PREPARATION OF IMPACT HYPOTHESES

In addition to physical impacts, dredged material may also cause biological impacts to ecological resources and pose risks to humans due to chemical contamination in the dredged materials. However, not all dredged material is chemically contaminated. It depends on the grain size of the dredged materials and whether the sediments in the harbours and channels needing to be dredged have received chemical contaminants from municipal/industrial discharges and storm water runoff.

Inert, inorganic geological material is geological material, which, in its unaltered state, is presumed to be free of bioavailable contaminants. Any physical or chemical processing of inert, inorganic geological matter must not have changed the bioavailability of its constituents, and therefore, this type of waste is presumed to have only physical effects.

Conceptual models can be used to identify potential impacts relevant to the disposal activity. From a low technology perspective, not all of the impacts will be easily assessed (e.g. changes in the chemical environment) and not all will be relevant in all cases. However, it should be within the capability of all proponents to make an assessment starting with the physical effects and, as capability increases, a more comprehensive assessment can be pursued. All dredged materials have a significant physical impact at the point of disposal. This impact includes covering of the seabed and short-term local increases in suspended solids levels. Physical impacts in nearby areas may also result from the subsequent transport of the finer fractions by wave and tidal action and current movements. The potential for offsite physical impacts should be identified during the site selection process.

The most important impacts in the conceptual model are usually risks posed to humans and selected flora and fauna (ecological receptors of concern); the extent of the risks and the value of these will influence whether effects are determined to be acceptable or unacceptable. Ecological receptors can be ecosystems, habitats, communities, populations, and individual organisms.

Ecological receptor categories include:

- *Commercially important*: wildlife, fish, and shellfish populations that constitute economically important resource stock or tourist attractions such as coral reefs;
- *Recreationally important*: wildlife, fish, and shellfish populations that are sought for recreational purposes;
- *Ecologically important*: flora and fauna populations whose abundance and/or biomass are important to habitat structure, energy flow, nutrient cycling, marine life (such as sea grass beds, kelp forests, and coral reefs); and
- *Special status*: individual species whose survival is threatened or endangered.

Once the potential adverse effects have been identified and described and the most important and probable effects determined, they can be used to formulate testable hypotheses about possible environmental effects and form the basis of post-disposal monitoring.

Regardless of the scientific, technical, or economic capabilities of a country, a good place to start in assessment of the potential chemical and toxicological impacts of dumped materials at the dump-site is to first review what is known about the historic and current upstream discharges of industrial and municipal wastewaters. Given that toxic chemicals do not adhere to large particles (i.e. greater than 63 μm in size), such as sand, it is important to consider that:

.1 If upstream discharges are known to contain toxic chemicals, dredged materials disposed at the site are probably not of toxicological concern if they contain at least 80% large particles, and conversely,

.2 If upstream discharges are known to contain toxic chemicals and the materials contain more than 20% silts or clay (grain size less than 63 μm), then there is concern for potential toxicity at the site and in surrounding areas (if currents transport material away from the disposal site).

2.2.3 What are key impact hypotheses?

If there are several potentially unacceptable impacts, then more than one testable hypothesis may be required. It is important in a low technology low cost setting to ensure that the hypotheses that are derived are realistic in terms of: (1) the availability of resources to test them and (2) their cost-effectiveness, relative to the proposed disposal activity.

To assist in preparing impact hypotheses, the basic questions regarding the physical aspects of disposal of material at designated disposal sites include (Fredette, 1990):

.1 What are the physical characteristics of the material (i.e. grain size)?

.2 Where are the disposed materials located, and what is the extent of the deposit?

.3 Did the disposed materials deposit at the intended disposal site or did they influence areas outside the disposal site? To what extent?

.4 Is the disposed material stable or mobile?

.5 If the disposed materials are moving, in what directions and in what quantities? Is the material moving outside the disposal site boundaries?

.6 If the disposed materials are stable, how long can the site be used? Is a mound of material being formed that may create a hazard to navigation?

Impact hypotheses should also address the fate and biological effects of the materials that have been deposited at the site. Examples of impact hypotheses[*]:

- Any changes to the physical habitat will be confined to within and the near vicinity of the disposal site, principally along the direction of tidal flow.

[*] Defining clear hypotheses can be simple, if you take the standard scientific approach of testing a null-hypothesis. In brief, the null-hypothesis is that 'there is no difference between x and y'. You then measure various parameters of x and y and use statistics to see if there is a significant difference between x and y. If there is no statistically significant difference, you accept the null-hypothesis and can say 'there really is no difference between x and y; our statistics say so'.

- The dispersal of fine particulates beyond the dump-site boundaries arising from sediment disposal, including any bedload transport, will have no unacceptable adverse consequences for the marine biota or for recreational/amenity interests.

- During past disposal actions or during future disposal, no dredged material in amounts that would have harmful effects on biota have been or will be carried in suspension in the water column to any sensitive area.

HYPOTHESIS TESTING: A SIMPLE EXAMPLE

You may want to know whether the concentration of chemical X at a disposal site is the same or lower than that of the dredged material being disposed of at the site. You construct the null hypothesis that *"There is either no different or less concentration of chemical X at the disposal site compared to the dredged material"*. You then measure the concentration of chemical X in a number of samples from the disposal site, and find the mean and standard deviation.

Compare the data from the disposal site and the dredged material and see if there is a statistically significant difference. If there is not, then you accept the null hypothesis. If there is, there appears to be an inconsistency in results of the earlier dredged material tests and what is being disposed of at the site. Management actions would be to reassess the potential impacts of higher levels of chemical X at the disposal site. Since the dredging has been completed, retesting the dredged material is generally not an option, except in rare cases where similar materials are still in the harbour.

In practice there are usually a number of hypotheses to test. Often they are tiered, for example:

- Will biota be affected by the physical action of sediment in the plume?

- Does the effluent plume contain potentially toxic concentrations of contaminants to biota?

- If present, will the biota be affected by contaminants in the plume?

These hypotheses are stated as questions, but for the actual testing, they will be re-stated as null hypotheses; for example, "Biota will not be affected".

A hypothesis should be tested against pre-agreed thresholds, which should be quantitative, where possible. These can be based on knowledge of baseline conditions, which can be derived from pre-disposal monitoring, information from the disposal site characterization, local knowledge of the area, or any applicable national or local environmental standards. The hypotheses should also be suitable to guide monitoring. Examples in relation to dumping at sea are provided in Table 1.

Table 1 –*Examples of a null hypothesis, criteria for rejection, and associated monitoring*

Hypothesis	Hypothesis is rejected if:	Associated monitoring
Turbidity levels at the dump-site will dissipate rapidly	Four hours after disposal has been completed, NTU will not be more than 100 NTU over	Conduct turbidity measurements in the water column at the edge of the disposal site, four hours after the disposal action.

Hypothesis	Hypothesis is rejected if:	Associated monitoring
	background at the edge of the disposal site.	
Deposited dredged materials in the dump-site are predominantly sand	Grain size analysis shows that deposited materials are greater than 20 % fine grained materials.	Grab samples from deposited material at the site and analysis of grain size distribution.
Any changes to the physical habitat will be confined to within and in the near vicinity of the disposal site, principally along the tidal axis	At sample stations >1km from the disposal site, along the tidal axis, the amount of fine sediment is 20% greater than compared to the pre-disposal baseline and reference sites	Sediment samples taken at relevant stations pre- and post-disposal activity and analysed to determine physical characteristics (depth of new sediments as indicated by grain-size distribution).
During initial deposition, the materials will not be carried through the water column to any sensitive areas in amounts that would be harmful to the value or amenity of such areas.	The turbidity plume reaches sensitive areas consistently (e.g. more than 50% of the time) during disposal activities	Map the initial area of deposition by visual observations of the plume, and determine if a sensitive area was reached outside the dump-site. If so, determine whether or not the scale of deposition is of concern in relation to physical impacts on valued components of the impacted area
The deposited dredged material will not subsequently reach any sensitive areas (through re-suspension and bedload sediment transport) in an amount that would be harmful to the value or amenity of such areas.	Sensitive areas are impacted from re-suspended dredged material after disposal activities have ceased.	Take sediment samples in the target areas of concern timed subsequent to disposal If so, determine whether or not the scale of transport is of concern in relation to physical impacts on valued components of the impacted area.
Sensitive area A outside the dump-site is not at risk.	The abundance in area A of a representative organism is less than 80% compared to baseline pre-dumping monitoring or at the reference site	Collect samples of those organisms from area A.
Disposal of material at the site will not cause a mound interfering with navigation	Depth over the disposal site exceeds 3m during or after disposal operations.	Take depth measurements in the disposal site.

Hypothesis	Hypothesis is rejected if:	Associated monitoring
Water quality standards will be met.	Water quality standard for cadmium is exceeded at the dump-site after allowance for initial mixing.	Collect water column samples and send to qualified laboratory for analysis
The mean density of surf clams at various locations are unchanged subsequent to disposal.	Below a threshold of one surf clam per square metre within the designated region.	Conduct an annual fall sampling at 25 stations and compare to baseline values developed prior to dumping activity
The acreage of shellfish habitat will not change over time	A reduction of 10% of shellfish habitat due to effects from disposal of materials at the site	Conduct an assessment of shellfish habitat before and after dumping
Dissolved oxygen levels will not be impacted by disposal operations	Lowering of mean dissolved oxygen levels by 1 mg/L.	Conduct on-site surveys of dissolved oxygen in the water column over the dump-site and in surrounding waters, taking sufficient samples to statistically represent natural and disposal site variations
Suspended solids levels in the water column will not exceed levels for fish that cause unacceptable adverse impacts	Turbidity levels in the plume dissipate rapidly not exceeding permit thresholds	Take samples in the plume for turbidity
Sediment contaminant levels outside of the dump-site will not change significantly over time.	For example, increases of 20% or more in heavy metals.	Obtain samples from areas outside the site where sedimentation has been found. Analyse for heavy metals.
The sediments at the dump-site will not be harmful to marine organisms.	One or more bioassays conducted on dump-site sediments “fails”.	Obtain samples from within the dump-site footprint and test them using one or more bioassays.
The benthic community outside the dump-site will not be significantly altered.	A reduction of 10% in a representative benthic organism.	Measurement of the abundance of benthic organism(s) before and after dumping in areas possibly influenced by the dumping, as shown by turbidity plumes.

2.2.4 What are the key elements in the sampling plan to test the hypotheses?

Design of the monitoring programme to address the testable hypotheses ideally should involve sampling before, during, and after material is dumped at the site and at an appropriate reference site. Establishing good baseline data prior to disposal actions is helpful in assessing potential impacts at the dump-site and in surrounding areas. Also, observation of the sediment plume during disposal, and possibly taking turbidity measurements will be helpful in assessing whether materials were dispersed away from the dump-site. Key elements include:

.1 The sampling design needs to consider the number of samples necessary to statistically test the hypotheses. The amount and type of testing necessary will vary from project to project. It is important that the scale of the monitoring relates to the extent of the perceived problem and that the physical, chemical, or biological components of the monitoring programme relate to the cause of interest or concern.

.2 The design of the monitoring programme should include identification of the physical fate of the dumped materials as the first step. Is the material within or outside of the dump-site? This information then leads to sampling to address the null hypotheses that assesses physical and, if needed, chemical and biological effects of the dumped materials.

.3 The monitoring programme should be designed to help ensure an appropriate balance between the data collection and analysis effort, and the confidence needed to make judgments on whether permit conditions are being met, if the testable hypotheses are met and if management actions are needed. The programme should be tiered in that sampling results can be used to adapt and modify the monitoring program, or modify the impact questions being addressed by the null hypotheses.

Different levels of intensity (i.e. tiers) should be designed into the monitoring programme, as needed. Each level incorporates its own testable null hypothesis, unacceptable environmental threshold, sampling design, and management options should the environmental threshold be exceeded. Each level should be designed such that there would be no need to implement the next more intensive level unless the threshold is being exceeded.

A NOTE ABOUT ADVERSE EFFECTS VERSUS UNACCEPTABLE ADVERSE EFFECTS

Once the environmental effects have been determined, the investigator needs to compare them with thresholds established in order to provide information on which effects are acceptable and which are unacceptable. It is better to think of environmental effects in terms of acceptable or unacceptable (rather than good or bad). An important point to consider is that most projects will make changes to the environment and that some of the changes may well be adverse, but these adverse changes per se do not necessarily constitute an unacceptable impact (CEDA and IADC, 2008). Certain adverse effects may be acceptable in view of the accrued societal benefits.

2.2.5 What Information is needed before sampling begins?

Information may already be available on bottom topography (including seabed depth) through charts and maps. If information is not available and there is no or limited access to electronic echo sounders, then a simple sounding/lead line could be used to determine the depth of water. All depth measurements were once taken this way and it involves using a line (e.g. piano wire/rope) marked at intervals and weighted at one end which is then lowered to the bottom. At shallower depths divers could be used to gauge the depth.

DISPERSIVE AND NON-DISPERSIVE DISPOSAL SITES

Dispersive sites: Material may either be dispersed during deposition or eroded from the bottom over time and transported away from the site by currents and/or wave action.

Non-dispersive sites: Most of the material remains on the seabed following deposition in a defined area of the disposal site.

Generally, for disposal sites in shallower waters, the more influence waves and currents have which can greatly influence how sediment behaves when it is disposed. For example, the likelihood of erosion of deposited sediment on the seabed increases with decreasing depth.

Examining the sediment at a proposed dump-site may give an indication of whether it is a dispersive or non-dispersive site. A site at which fine grain materials are present would indicate that it is non-dispersive. For materials that are suspected of chemical contamination and pose low risks of toxicity, it is best to use a non-dispersive site. Materials that pose unacceptable levels of toxicity should not be disposed in ocean waters without management techniques.

A PRACTICAL EXAMPLE OF THE NEED FOR CONSIDERATION OF DISPERSIVE VERSES NON-DISPERSIVE SITES:

The disposal site is located in 10 m of water, close to the mouth of an estuary, and is subject to strong tidal currents.

The material being disposed of at the site is fine grained material (with low levels of contamination).

A large proportion of the deposited material is unlikely to stay within the designated disposal site, and will be transported away from the site in suspension immediately after the disposal activity.

The issue to be considered in development of impact hypotheses is whether the material disperses to sensitive habitats such as shellfish beds or coral reefs.

2.2.6 Design of the sampling plan

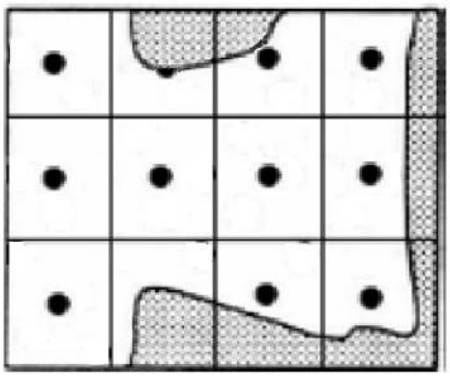
The collection of representative samples is the critical consideration in sampling design. Design of a sampling plan includes determining the number and location of samples to be collected, as well as any subdivision of the collected samples. Sampling designs can be used to avoid sampling bias and allow for statistical analysis of the results. Commonly employed sampling designs are described below, which are usually targeted or random sampling or combinations of the two. The design should allow flexibility to address realities in the field, such as restricted site access, hard bottom, and bad weather. In general, systematic sampling makes the most sense to ensure spatial coverage. Stratified spatial sampling also maximizes the spatial coverage within the area of interest. In general, start at a simple level, and progress to more complicated designs, if needed to meet the goals.

Targeted sampling

Targeted sampling design utilizes judgment based upon knowledge of the site and previous data and information to determine the sample sites. For example, if a disposal site is relatively large and disposal of materials has only occurred in the northwest quadrant of the site, or if a mound of materials has formed within the site, sampling locations would target those areas. If the plume created by disposal shows that materials are likely to be deposited outside the site, those areas should be targeted as well.

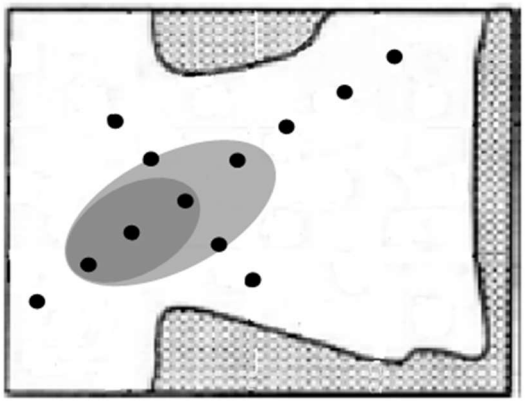
Systematic sampling grid

Systematic sampling designs are typically used to identify the location of contaminated sediments on a quantitative spatial and/or temporal basis (USEPA, 2001). The first sampling location is randomly selected and all other sample sites are determined based on a regular interval. The overall number of samples collected is dependent on the density of cells used for the grid and the area of the project. This approach is thorough (no bias) but can be expensive depending on the size of the boxes in the grid.

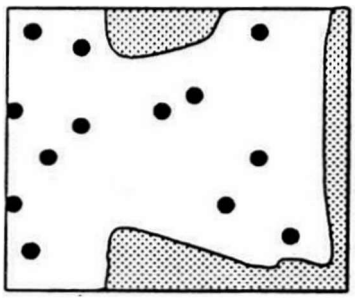


Transect sampling

This figure shows two intersecting transects over an expected dump-site. This sampling design might be useful to determine the size of the disposal site footprint using grain size measurements, or the extent of the spread of contaminants outside the expected dump-site. It may also be used with benthic sampling to determine whether the biological community "on" and "off" the dump-site is appreciably different.

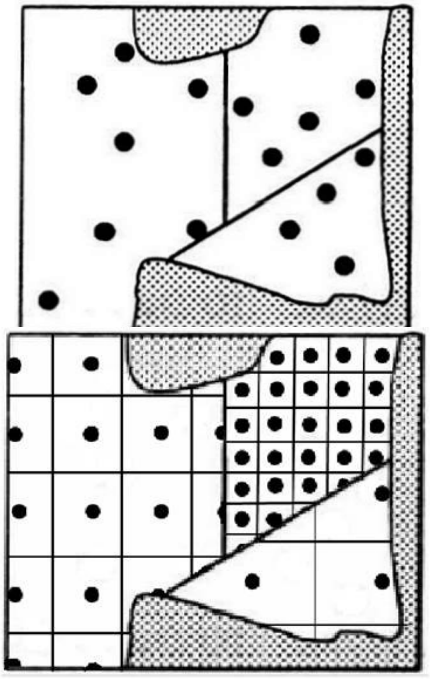


Random sampling



Random sampling implements an approach where a grid pattern of equal-sized cells is placed over a map of the study site to be sampled. A number is assigned to each grid cell. The number of samples for the project area is determined and cell numbers are randomly selected. Samples are collected from within each of the selected cells. This approach limits the possibility of omitting regions of the study site as well as avoiding sampling bias. However, random sampling may not be practical where the study site is not a continuous area.

Stratified: combination of targeted and random sampling



Targeted and random sampling is similar to random sampling but targets areas within the disposal site based upon historical data that indicate concentrated or heterogeneous areas of contamination that require more intense sampling to assess potential impacts. Within targeted areas, sampling sites are selected at random.

Stratified systematic sampling

This sampling approach is based upon taking samples in a systematic manner, but increasing or decreasing the numbers of samples in a given area, based upon knowledge of the dump-site in those areas and the types of tests to be conducted.

EXAMPLE: SELECTION OF SAMPLING LOCATIONS (AUSTRALIA 2009)

First, lay a square grid over a map of the disposal site, sized such that there are at least five times as many grid squares as the required number of samples. If six samples are needed, then lay out the grid such that there are 30 grid squares. The grid squares should be numbered and then random numbers are used to select the six grids where samples should be taken. Random numbers can be simply done by drawing numbers out of a hat or the internet has many useful random number generator sites. For an example of generating random numbers, see http://www.random.org/integers.

How many sample locations should be selected?

This is the age-old question in monitoring programs. The number of samples collected directly affects the representativeness and completeness of generating data to meet the objectives of the monitoring programme. In general, more samples will result in more confidence in the results of analysis. However more samples generally means more analysis, and costs go up. Thus, it is a bit of a balancing act between the ideal and the practical.

In general, the number of sample locations is determined by:

- The size of the disposal area, and the potentially impacted areas nearby;
- The objectives of the sampling program, e.g. physical impacts only verses sampling to assess chemical contamination;
- Characteristics and homogeneity of the disposal site sediments; and
- The desired level of statistical confidence. A general "rule of thumb" is that at least three samples are needed for statistical analysis.

Replicate, composite, and extra samples

The best approach would be to take extra samples at each of the sample locations, and save for later analysis if the composite sample average results show a potential issue. This saves having to resample. Returning for additional samples is much more costly than taking more than enough while you are on-site. Some programmes recommend three samples at each sample location, some composited and some placed into storage.

Because of the need for practicality in determining the number of sample locations and the number of samples, many programmes suggest collecting replicate (i.e. duplicate) samples and compositing samples. For most programmes, replicate samples for analysis on 10% of samples collected are considered adequate. A difference between replicate sample analytical results of less than 20 to 30% is considered normal.

Compositing (also referred to as bulking) several samples into one provides several advantages, including saving on analytical costs; a number of programs find it useful to composite 3-5 samples, resulting in fewer analyses required (USEPA, 2001). The analytical result represents an average condition for all of the sample locations. If, for example, the results show elevated levels of PAHs (polycyclic aromatic hydrocarbons), the next step could be to conduct more focused sampling to attempt to isolate which sample location may have the highest levels. Pinpointing the location of high contaminant levels can lead to management actions such as capping that area that has unacceptably high contaminant levels with clean materials. The information can also be used if there is to be another cycle of dumping to more clearly focus characterization efforts.

A PRACTICAL APPROACH
For PAHs and other volatile contaminants, a very practical approach is to smell the samples as they are brought on board. All this information should be recorded as field notes. Tracking the smell of samples can help to isolate hotspots where sampling should be focused.

This technique should only be employed when sediments are physically similar; that is, similar in texture and located in similar hydrodynamic locations, where there are past data to show the similarity across the area. Routine assessment of a navigational channel that gets regular maintenance dredging might be a good use of this technique.

However, compositing can result in a significant loss of information regarding the variability and distribution of the quantitative characteristics of the study site (figure 5). Compositing should not be used to dilute samples of a suspected heavily contaminated localised area within the project. For example, it would not be appropriate to composite dissimilar samples from around the docks of an oil-loading terminal (potentially contaminated) with those out in the middle of the harbour (lower risk of contamination) unless past data suggested similar contaminant levels. See annex 3 for advice on taking subsamples and creating composite samples.

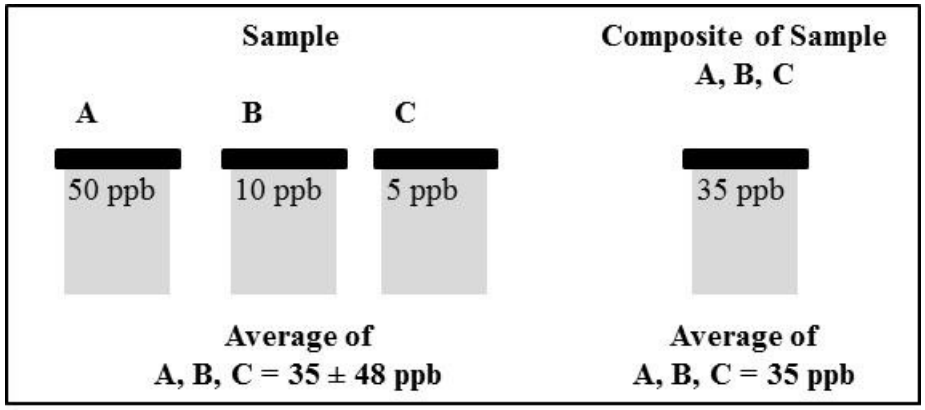


Figure 5 – *Effects of compositing samples* Source: London Convention/London Protocol 2006.

Locating sampling stations

The precise location of each sampling station is important and should be tracked by latitude and longitude. The sampler should be able to return to the sampling location at a later date if it is determined that additional samples and analysis are needed. There are a variety of navigation and position location techniques available, including line-of-site techniques, electronic positioning systems and satellite positioning systems. Global Positioning Systems (GPS) are now considered the most cost-effective choice; GPS is capable of accuracies of 1 to 10 metres. For an overview of hand-held GPS units, see http://gif.berkeley.edu/documents/Handheld_GPS_Buyers_Guide.pdf. The USEPA Manual (2001) recommends using two techniques to ensure calibration and accuracy for return to the sample location. One possible approach is to use the GPS technique and check the depth at the sample station, which can help if the depth of the disposal site is not uniform.

Reference areas

Reference areas should be selected that are of the same general characteristics as the disposal site, but removed from any sources of contamination. Reference areas are needed for comparison and to assess whether observed changes in the disposal site are due to disposal or some other phenomena. Reference site sampling also helps compensate for the lack of pre-disposal sampling at the disposal site.

Monitoring frequency

The first post-disposal monitoring should occur as soon as possible after disposal has been completed (Fredette, 1990). Following the initial monitoring, follow-up monitoring should be conducted several years later. If there are concerns about potential impacts as determined from the initial survey, then more frequent monitoring is suggested.

2.3 Evaluation, interpretation, and management actions

Once field sampling has been completed, evaluation and interpretation of the results is the next step. Information gained from field monitoring should be used to evaluate whether the disposal actions are causing unacceptable adverse impacts, whether follow-up monitoring is needed, whether management actions can minimize those impacts, and whether permit conditions should be modified.

This section addresses evaluation, interpretation, and possible management actions.

2.3.1 Apply the monitoring results to management actions

Depending upon the results and information generated from the assessment and monitoring actions, follow-up actions may be needed. For example, decisions may include the need to conduct additional confirmatory monitoring, or initiate more intense monitoring at the next level. Another possibility, if significant loss of material at the disposal site is found, is that the boundaries of the survey may need to be expanded. In addition, if the results show that the environmental effects are unacceptable, management alternatives may be considered to address the identified unacceptable conditions. Modification of disposal operations can be an effective control for both sediment and water column impacts.

EFFECTS VERSUS ADVERSE EFFECTS VERSUS UNACCEPTABLE ADVERSE EFFECTS

The disposal of materials into ocean waters at designated disposal sites will have effects. Whether these effects are adverse and whether these effects are considered to be unacceptable adverse effects is sometimes difficult to determine, given limitations in scientific, technical, and economic capabilities. The assessment of unacceptability should integrate information on the characteristics of the materials disposed at the dump-site, the characteristics of the disposal site and surrounding areas, the potential effects on human health and living resources, amenities, and other uses of the sea, and the alternatives to disposal in ocean waters.

2.3.2 Evaluation and interpretation

For ocean disposal of *inert, inorganic geological materials*, the effects on the marine environment should only be physical effects (i.e. given the definition of this category of waste), such as smothering the benthic organisms in the disposal site, and also outside the site if the material spreads beyond the site boundaries in sufficient quantities to cause harm. In general, the physical effects of smothering the disposal site are considered to be acceptable adverse impacts, but outside the dump-site, the effects might not be acceptable. The overall intention is that when disposal is completed, benthic organisms will recolonize the dump-site.

For ocean disposal of *dredged materials,* the effects may be similar to disposal of inert, inorganic geological materials in terms of physical effects. However, dredged materials potentially contain chemical contaminants that may pose a risk to ecological resources and human health. If dredged material is primarily sand, or if there is no historical or current upstream source of chemical contaminants, then the effects of disposal at the disposal site are likely just to be physical effects. If the dredged materials contains more than 20% fine-grained materials and there are sources of chemical contaminants in the watershed, then there could be a risk of toxicity to living organisms in the sediments at the site and in the water column. Figure 6 shows sampling of sediments from a hand operated winch on board a small boat.

Figure 6 – *Grab sampling sediments to assess extent of dispersion of sediments from the dump-site*
Source: http://infolink.cr.usgs.gov/Science/EMAP/index.htm.

If monitoring finds material outside the dump-site (e.g. through turbidity measurements showing the direction of the plume or grab samples of sea bottom materials), that could trigger a series of monitoring investigations, depending upon the available scientific, technical, and economic capabilities. The extent of investigations would also be based upon whether chemical contamination was suspected in the dredged material disposed of at the site. These should have been addressed in the development of the impact hypotheses, setting forth a monitoring program that becomes more complex as more information is needed to assess the potential impact of the dumping of material at the site. For example, the increasing levels of monitoring could include:

- Sampling should be conducted to assess the extent and magnitude of the material outside the dump-site and whether sensitive marine areas were possibly being impacted (e.g. shellfish beds).
- Depending on the results, this could then trigger the need for an assessment of whether there are unsafe levels of contaminants in the sediment. The first step would be to conduct a visual examination of the numbers and abundance of organisms in the sediment at the dump-site and in the areas outside the dump-site where sediments have settled out from the disposal actions. These results are compared to a reference site far removed from sources of contamination but with a similar grain size distribution.
    - For those samples from the disposal site which show a healthy abundance of organisms, that is an indication that chemical contamination is not acutely toxic, but there still exists the possibility of longer-term effects, such as bioaccumulation by those organisms.
    - For those samples that exhibit low numbers, if any, or perhaps low diversity, of organisms in the disposal site compared to the reference site, those materials should be considered to be contaminated by chemicals.
- That could then trigger an intensive assessment of the extent and magnitude of the contamination.

- The visual examination of the deposited dredged materials, including smelling the samples, may give an indication whether there are chemical contaminants in the dredged material.
- The experience of a number of countries is that fine-grained materials with chemical contamination have sometimes been described as looking like “black mayonnaise”.
- To be confident of this result, those countries that have sufficient scientific, technical, and economic capabilities should send samples to the laboratory for chemical analysis.

- As noted in Part 2.2 and discussed in Part 3.2, an alternative to chemical testing is to conduct simple bioassays to assess potential toxicities of the material in the dump-site or in the surrounding areas, if the materials have been found to be dispersed beyond the dump-site.

If chemical contamination and unacceptable adverse impacts are suspected but monitoring efforts are limited such that chemical or bioassay testing is beyond the country’s scientific, technical, or economic capabilities, then management actions should be initiated to minimize impacts.

2.3.3 Possible management actions

In the example above, the first management actions to consider would be to change future or continuing disposal operations to reduce water column dispersion and/or spread of material on the bottom. For dredged material disposal, the most obvious control measure for open-water disposal is a modification in the technique or equipment used for dredging and dumping. Suggested approaches include:

- If turbidity or grab samples are showing that materials are being deposited outside the site (or if water column concentrations of contaminants exceed water-quality criteria) when using a hopper dredge to dispose of the materials, changing to mechanical (e.g. bucket) dredging with mechanical dumping at the dump-site would reduce the release of dumped dredged materials into the water column. Dumping of mechanically dredged material from barges would then result in less spread of material as compared with discharges from hopper dredges (mechanically dredged material is usually like a hunk of material whereas hopper dredged material is more like a slurry) (figure 7).
- Other disposal operational modifications include such actions as constraints on rates of disposal from barges, changing the track lines when disposing at the site, and timing the disposal to occur during slack tides.

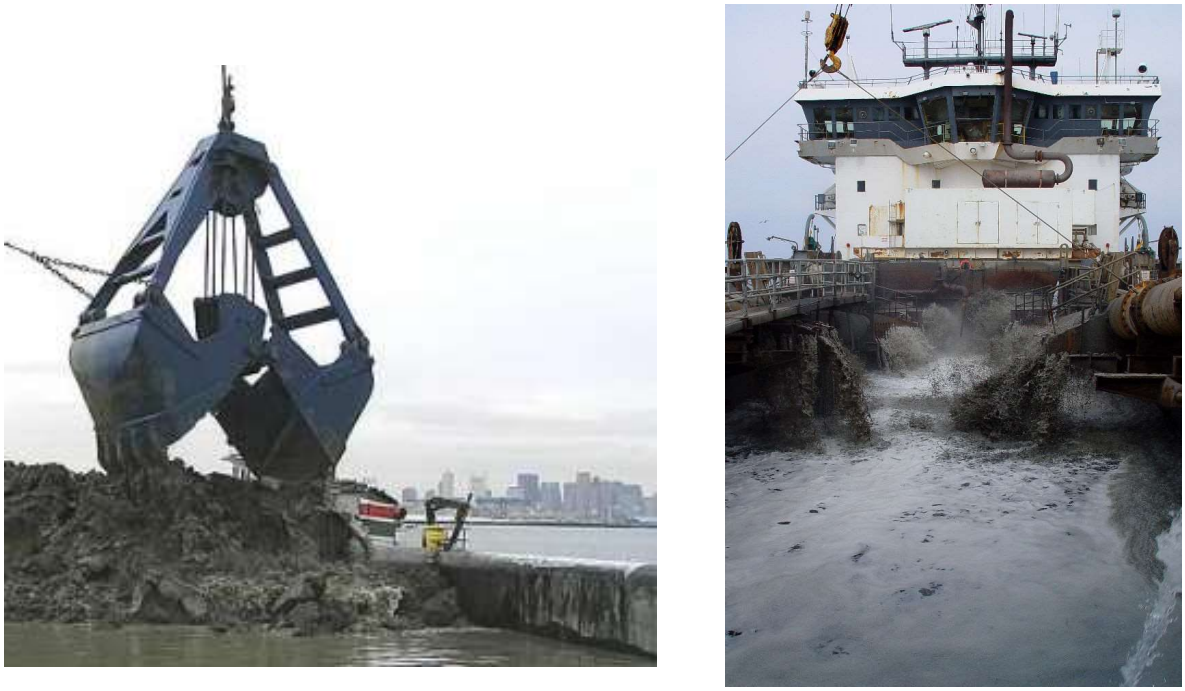


Figure 7 – *On the left, a mechanical bucket dredging showing consolidated material, and on the right, the hopper of a dredge showing a slurry of dredged material*
Sources: Norfolk Dredging Inc. and Seaturtle.org.

If monitoring results show that unacceptable adverse impacts have occurred at the dump-site, and possibly in the surroundings areas, possible management actions for continuing or future disposal activities include:

.1 Operational changes to dumping practices as noted above;

.2 Placing future waste materials into a confined disposal facility on-shore; or

.3 Placing the waste into a confined aquatic disposal cell and capping it. Suspected or confirmed contaminated dredged material can be placed in the sea bottom in cases where the material will be isolated from the marine environment by capping. This option would only be appropriate in low energy environments where currents or wave action would not erode the cap. Most experience with placing contaminated dredged material in confined aquatic disposal facilities has been in estuarine harbours, not open ocean waters. These are highly engineered facilities.

If monitoring results show that unacceptable adverse impacts have occurred at the dump-site, and possibly in the surroundings areas, a management action that should be considered is to cap the dump-site with clean materials, or parts of the dump-site that exhibit unacceptable adverse impacts. The intention is to isolate the materials from the surrounding environment, lessening the potential pathways to aquatic life and humans.

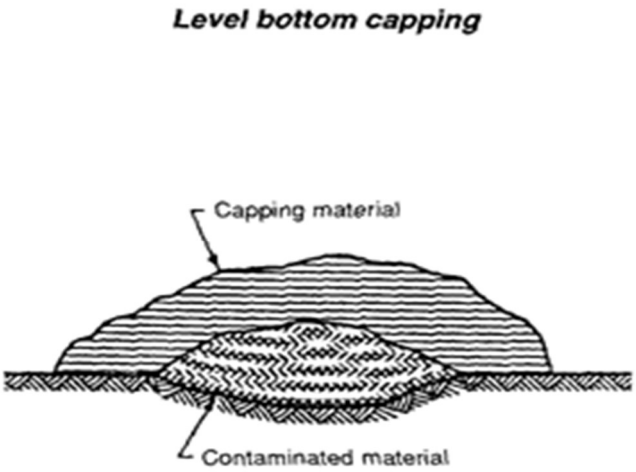


Figure 8 – *Capping of contaminated dump-site with clean dredged material*
Source: Palermo, 1991. (See also annex 8 for information on level bottom capping.)

2.3.4 Bottom line

The results of monitoring should be reviewed at regular intervals in relation to the objectives and can provide a basis to:

.1 Modify or terminate the field-monitoring programme;

.2 Modify the permit to change disposal operations;

.3 Redefine or close the dump-site; and

.4 Modify the basis on which applications to dump wastes are assessed.

Concise reports of monitoring activities and results should be prepared. Reports should detail the measurements made, results obtained, and how these data relate to the monitoring objectives, specifically, the impact hypotheses included in the monitoring plan. The frequency of reporting will depend upon the scale of disposal activity and the intensity of monitoring.

2.4 Case studies of sampling design using null hypotheses with management actions

2.4.1 Case study no. 1 – Monitoring video survey

Background

In 2010, Environment Canada monitored the GI-2 dredged material disposal site in the Magdalen Islands, which has been used for annual disposal since 1994. The total volume of sediment discharged at the site to 2009 was 44,190 m^3 (scow measurement), with an average annual disposal volume of 1,768 m^3 (scow measurement).

A previous study at the disposal site showed that up to 97% of the material deposited there had been transported beyond the site boundaries to neighbouring areas possibly containing sensitive fish habitat. As a result, there was a need to confirm that disposal at the site did not have an effect on the benthic community at the disposal site and beyond the site boundaries.

Impact hypotheses

HYPOTHESIS	HYPOTHESIS IS REJECTED IF:	ASSOCIATED MONITORING
.1 Habitat richness at the disposal site will not be significantly different than at unaffected reference locations.	The seafloor substrate at the disposal and reference are qualitatively different in terms of both substrate type (e.g. sand, gravel) and density of organisms.	Conduct video surveys at the disposal site and reference sites to enable qualitative comparisons of habitat richness.
.2 The diversity of macro-benthic fauna at the disposal site will not be significantly different than at unaffected reference locations.	The number of species observed at the disposal site is significantly different than that observed at the reference locations.	Conduct video surveys at the disposal site and reference sites to enable quantitative comparisons of the number of species.

Sampling plan – description of video survey

To determine whether the disposal of dredged material at disposal sites GI-2 had a significant impact on habitat richness or macro-benthic populations, an underwater video survey was conducted on 3 and 4 November 2010.

Six 50 m transects were recorded, including three at the disposal site and three in reference areas unaffected by the deposition of disposal site material (figure 9). In the field, the geographical coordinates of the transect-ends were measured at the surface with a geographic positioning system (GPS). A total of six transects were filmed. A biologist then viewed each video sequence to assess the morphology of the seabed and the nature of the substrate, identify and count the organisms observed while analysing and comparing them with the diver's recorded comments.

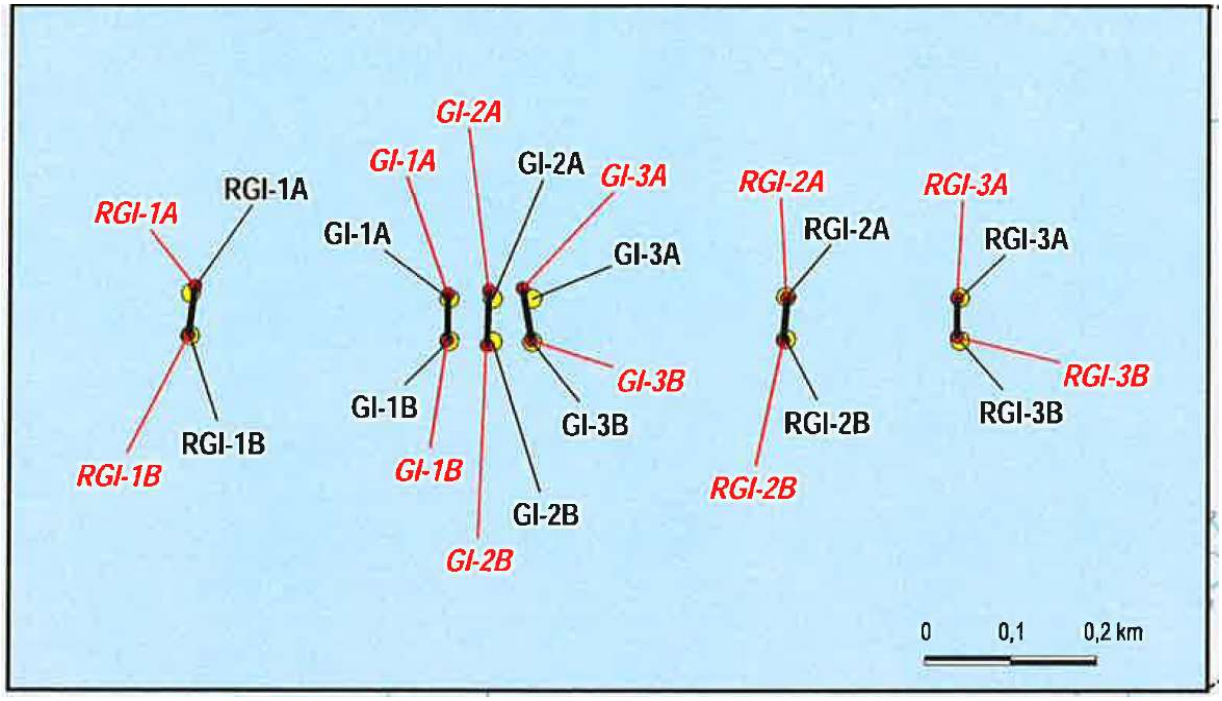


Figure 9 – *Transects filmed at disposal sites GI-2 (2a);*
transects in the reference areas are preceded by the letter R

Results – Richness and Diversity of Benthic fauna at site GI-2

The habitat was very uniform at both the disposal site and the reference sites. There was a pale beige sand seabed, except in reference transect GI-1 (RGI-1) where traces of black sand were very visible. With the exception of a few shells and bits of drifting algae, very little organic debris was observed.

At the disposal site, the epibenthic fauna was dominated by gastropods (snails), with few observations of other types of wildlife along the transects. At the three reference locations, the diver observed extremely large numbers of large bivalves buried in the sand along transects. He dug some out and found that they were clams.

In short, the disposal site GI-2 area was uniform and had a relatively low density of epibenthic organisms. Few differences were noted between the reference transects and transects at the disposal site, as shown in table 2. However, qualitative observations described above suggest that there was greater density at the reference sites than the disposal site.

Table 2 – *Comparison of the total number of species at disposal site GI-2, the neighbouring reference areas and the entire disposal area*

	Disposal Site	Reference Sites	Disposal Area
Total number of species across transects	4	6	6
Average of transects	2	4.5	3
Standard deviation	1	0	1.265

The first impact hypothesis was that *habitat richness at the disposal site will not be significantly different than at reference locations*. The 2010 video monitoring survey showed a uniform seabed habitat with relatively few epibenthic organisms at the disposal site. The reference areas near site GI-2 seemed to have a similar substrate, but a slightly higher density of organisms.

The second impact hypothesis was that diversity of *macro-benthic fauna at the disposal site will not be significantly different than at nearby reference locations*. Based on the video monitoring conducted at disposal site GI-2 and its reference areas, the disposal of dredged material at the site seemed to have little effect on diversity of macro fauna as indicated by the number of species observed.

Management actions

Based on the results, the site can continue to receive dredged material with no changes to current mitigation measures. However, to determine whether qualitative differences observed between the density of fauna at the disposal and reference sites, a more accurate benthic sampling method could be used at site GI-2 in future (e.g. a benthic survey involving the quantification of organisms in grab samples that are sieved).

2.4.2 Case study no. 2 – Monitoring sediment grain size

Background

Environment Canada monitored a dredged material dump-site in a large bay off the eastern North Atlantic Ocean. The site had been used once for the disposal of 70,000 m^3 of dredged material. Monitoring was needed to confirm that the material had been deposited at the correct location, and to determine the measureable zone of influence outside the dump-site footprint.

Impact hypotheses

HYPOTHESIS	HYPOTHESIS IS REJECTED IF:	ASSOCIATED MONITORING
The material suspended during disposal operations will not be measureable beyond mid-field sample locations (located within 500 m of the dump-site centre).	Sediment texture differences are observed in far-field sampling stations.	Collect sediment grab samples for grain size analysis.

Sampling plan

Three replicate baseline samples were collected within 100 m of the dump-site centre before disposal operations started (these are coloured green in figure 5b, and are labelled BL for "baseline" in figure 5c).

After disposal, to determine the location of the dredged material mound, stations were positioned in a gradient transect running through the dump-site, along the direction of major tidal flow. Ten grab samples were taken within the dump-site footprint (coloured black in figure 5b, and labelled DS in figure 5c). Sampling stations were also established at near-field, mid-field, far-field, and reference locations on both sides of the disposal site as follows (shown in figure 5c):

- near-field samples (collected within 250 m of dump-site centre);
- mid-field samples (collected within 500 m of dump-site centre);
- far-field samples (collected within 1000 m of dump-site centre); and
- reference samples (collected within 2000 m of dump-site centre – a distance estimated to be unaffected by disposal activities).

Five replicate grab samples were collected at each of these station locations (n=40, labelled black in figure 10 and labelled by distance from the centre in figure 11).

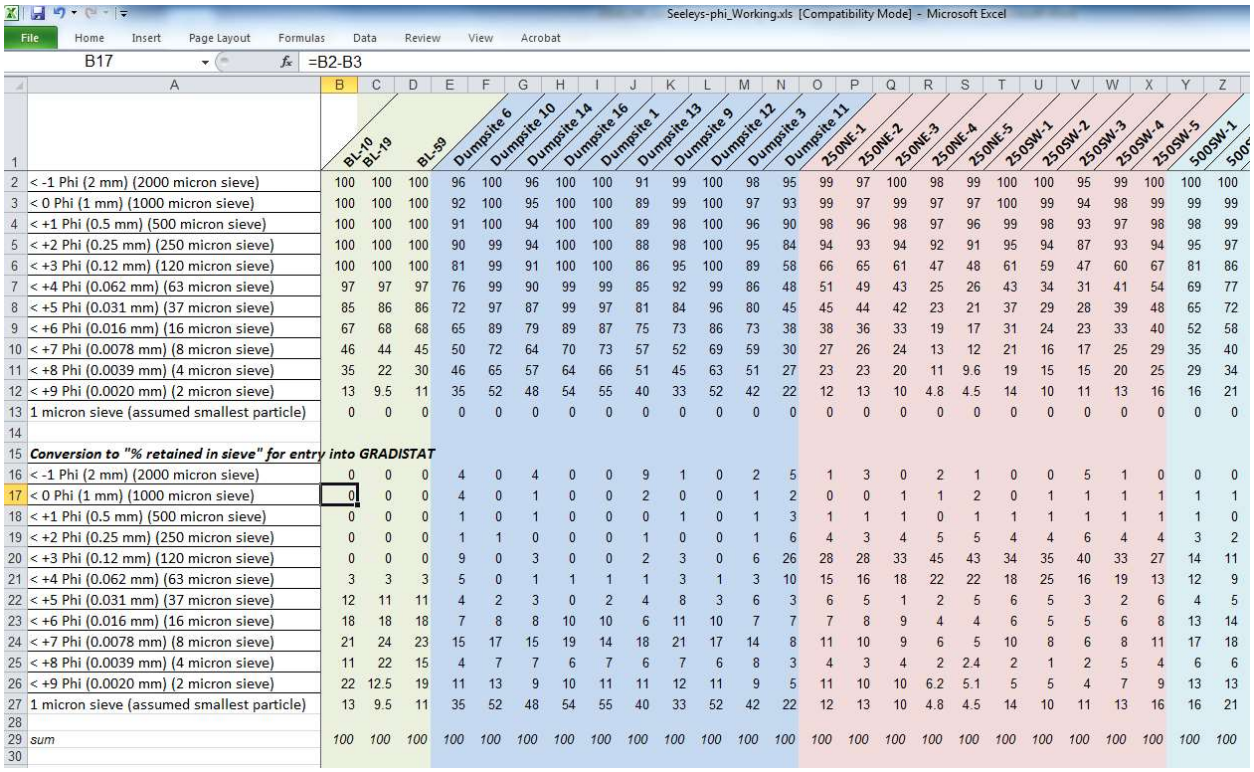
Figure 10 – *Map of dump-site showing dump-site boundaries (innermost oval – expected disposal site footprint) and locations of dump-site, near, mid, and far-field samples (black). Reference (yellow) and pre-disposal (green) sampling locations are also shown. The larger oval marked with a dotted line represents the predicted size of the zone of influence*

Data collection

Each sample was analysed for grain size (using wet-sieve method), and phi values were recorded*.

Data analysis

To determine whether grain size differences could be observed within and outside the disposal site footprint, the grain size analysis results were plotted using GRADISTAT†. Phi values percentages were converted to the percent retained in each sieve (Figure 11). To facilitate the distinction of sample types (e.g. baseline, dump-site, and near-field), samples were plotted group by group (e.g. first the baseline samples, then the dump-site samples, then the near-field samples and so on). The resulting plots transcribed by hand onto a single, colour coded plot using Microsoft Paint™.



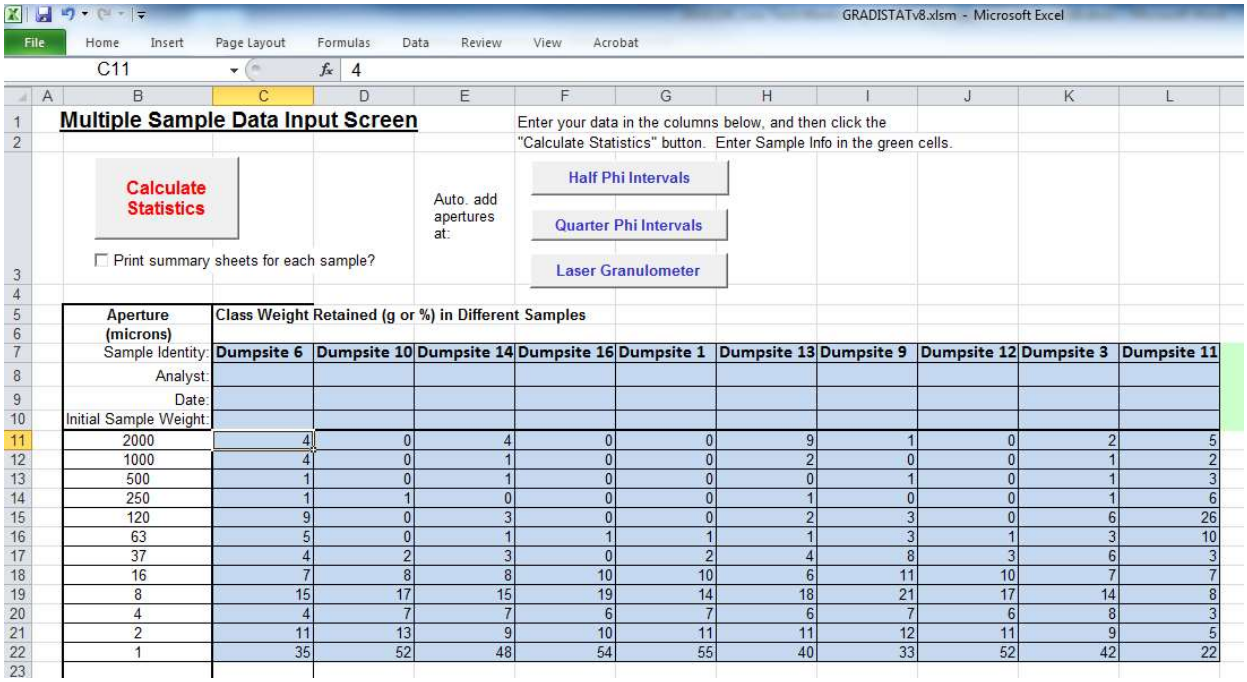
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1		BL-10 BL-19		BL-59	Dumpsite 6		Dumpsite 10		Dumpsite 14		Dumpsite 16		Dumpsite 1		Dumpsite 13		Dumpsite 9		Dumpsite 12		Dumpsite 3		Dumpsite 11		250NE-1		250NE-2	
2	< -1 Phi (2 mm) (2000 micron sieve)	100	100	100	96	100	96	100	100	91	99	100	98	95	99	97	100	98	99	100	100	95	99	100	100	100
3	< 0 Phi (1 mm) (1000 micron sieve)	100	100	100	92	100	95	100	100	89	99	100	97	93	99	97	99	97	97	100	99	94	98	99	99	99
4	< +1 Phi (0.5 mm) (500 micron sieve)	100	100	100	91	100	94	100	100	89	98	100	96	90	98	96	98	97	96	99	98	93	97	98	98	99
5	< +2 Phi (0.25 mm) (250 micron sieve)	100	100	100	90	99	94	100	100	88	98	100	95	84	94	93	94	92	91	95	94	87	93	94	95	97
6	< +3 Phi (0.12 mm) (120 micron sieve)	100	100	100	81	99	91	100	100	86	95	100	89	58	66	65	61	47	48	61	59	47	60	67	81	86
7	< +4 Phi (0.062 mm) (63 micron sieve)	97	97	97	76	99	90	99	99	85	92	99	86	48	51	49	43	25	26	43	34	31	41	54	69	77
8	< +5 Phi (0.031 mm) (37 micron sieve)	85	86	86	72	97	87	99	97	81	84	96	80	45	45	44	42	23	21	37	29	28	39	48	65	72
9	< +6 Phi (0.016 mm) (16 micron sieve)	67	68	68	65	89	79	89	87	75	73	86	73	38	38	36	33	19	17	31	24	23	33	40	52	58
10	< +7 Phi (0.0078 mm) (8 micron sieve)	46	44	45	50	72	64	70	73	57	52	69	59	30	27	26	24	13	12	21	16	17	25	29	35	40
11	< +8 Phi (0.0039 mm) (4 micron sieve)	35	22	30	46	65	57	64	66	51	45	63	51	27	23	23	20	11	9.6	19	15	15	20	25	29	34
12	< +9 Phi (0.0020 mm) (2 micron sieve)	13	9.5	11	35	52	48	54	55	40	33	52	42	22	12	13	10	4.8	4.5	14	10	11	13	16	16	21
13	1 micron sieve (assumed smallest particle)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14																										
15	***Conversion to "% retained in sieve" for entry into GRADISTAT***																									
16	< -1 Phi (2 mm) (2000 micron sieve)	0	0	0	4	0	4	0	0	9	1	0	2	5	1	3	0	2	1	0	0	5	1	0	0	0
17	< 0 Phi (1 mm) (1000 micron sieve)	0	0	0	4	0	1	0	0	2	0	0	1	2	0	0	1	1	2	0	1	1	1	1	1	1
18	< +1 Phi (0.5 mm) (500 micron sieve)	0	0	0	1	0	1	0	0	0	1	0	1	3	1	1	1	0	1	1	1	1	1	1	1	0
19	< +2 Phi (0.25 mm) (250 micron sieve)	0	0	0	1	1	0	0	0	1	0	0	1	6	4	3	4	5	5	4	4	6	4	4	3	2
20	< +3 Phi (0.12 mm) (120 micron sieve)	0	0	0	9	0	3	0	0	2	3	0	6	26	28	28	33	45	43	34	35	40	33	27	14	11
21	< +4 Phi (0.062 mm) (63 micron sieve)	3	3	3	5	0	1	1	1	1	3	1	3	10	15	16	18	22	22	18	25	16	19	13	12	9
22	< +5 Phi (0.031 mm) (37 micron sieve)	12	11	11	4	2	3	0	2	4	8	3	6	3	6	5	1	2	5	6	5	3	2	6	4	5
23	< +6 Phi (0.016 mm) (16 micron sieve)	18	18	18	7	8	8	10	10	6	11	10	7	7	7	8	9	4	4	6	5	5	6	8	13	14
24	< +7 Phi (0.0078 mm) (8 micron sieve)	21	24	23	15	17	15	19	14	18	21	17	14	8	11	10	9	6	5	10	8	6	8	11	17	18
25	< +8 Phi (0.0039 mm) (4 micron sieve)	11	22	15	4	7	7	6	7	6	7	6	8	3	4	3	4	2	2.4	2	1	2	5	4	6	6
26	< +9 Phi (0.0020 mm) (2 micron sieve)	22	12.5	19	11	13	9	10	11	11	12	11	9	5	11	10	10	6.2	5.1	5	5	4	7	9	13	13
27	1 micron sieve (assumed smallest particle)	13	9.5	11	35	52	48	54	55	40	33	52	42	22	12	13	10	4.8	4.5	14	10	11	13	16	16	21
28																										
29	*sum*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*
30																										

Figure 11 – *Partial screen-shot showing data in Excel, with formula for conversion to "percent retained". A Wentworth grain size chart is useful when preparing data to be entered into GRADISTAT or other software*

See figure 12.

* Phi values are used to indicate grain size, and correspond to the diameter of sediment particles. See http://pubs.usgs.gov/of/2000/of00-358/graphics/chapter1/c1f9chrt.gif for further details.

† GRADISTAT was developed by S. Blott and K. Pye in 2001. It is particle size analysis software that runs in Microsoft Excel, and is available free on line from several sources (e.g. http://www.kpal.co.uk/gradistat.html). Many similar tools are also available at no cost and have been compiled by the US Geological Survey (http://woodshole.er.usgs.gov/software/sediment-software.html).



Aperture (microns)	Class Weight Retained (g or %) in Different Samples									
Sample Identity:	Dumpsite 6	Dumpsite 10	Dumpsite 14	Dumpsite 16	Dumpsite 1	Dumpsite 13	Dumpsite 9	Dumpsite 12	Dumpsite 3	Dumpsite 11
Analyst:										
Date:										
Initial Sample Weight:										
2000	4	0	4	0	0	9	1	0	2	5
1000	4	0	1	0	0	2	0	0	1	2
500	1	0	1	0	0	0	1	0	1	3
250	1	1	0	0	0	1	0	0	1	6
120	9	0	3	0	0	2	3	0	6	26
63	5	0	1	1	1	1	3	1	3	10
37	4	2	3	0	2	4	8	3	6	3
16	7	8	8	10	10	6	11	10	7	7
8	15	17	15	19	14	18	21	17	14	8
4	4	7	7	6	7	6	7	6	8	3
2	11	13	9	10	11	11	12	11	9	5
1	35	52	48	54	55	40	33	52	42	22

Figure 12 – *Partial screen-shot showing an example of data (in this case, the dump-site samples) being entered into GRADISTAT. A Wentworth grain size chart is useful when preparing data to be entered into GRADISTAT or other software*

Results

The samples collected all plot on the right hand side of the Sand-Silt-Clay plot (figure 13), where there are notable differences that can be observed. The post-disposal dump-site samples (shown in blue) are the only ones classified as muddy-sand, mud or sandy-mud in the centre and bottom of the plot. The near-field samples are distinct from the dump-site samples, and the sandiest of all the samples; seven are classified as silty sand, while three overlap slightly with the mid-field samples. The mid-field samples are classified as sandy silt. The pre-disposal, far-field and reference samples overlap with each other to a large degree, and are classified as silt in the bottom right corner of the plot. These results suggest that the sediment within the dump-site boundaries is distinct from sediments in the surrounding environment, and that the sediments outside the disposal site have not been influenced to distances beyond what was anticipated.

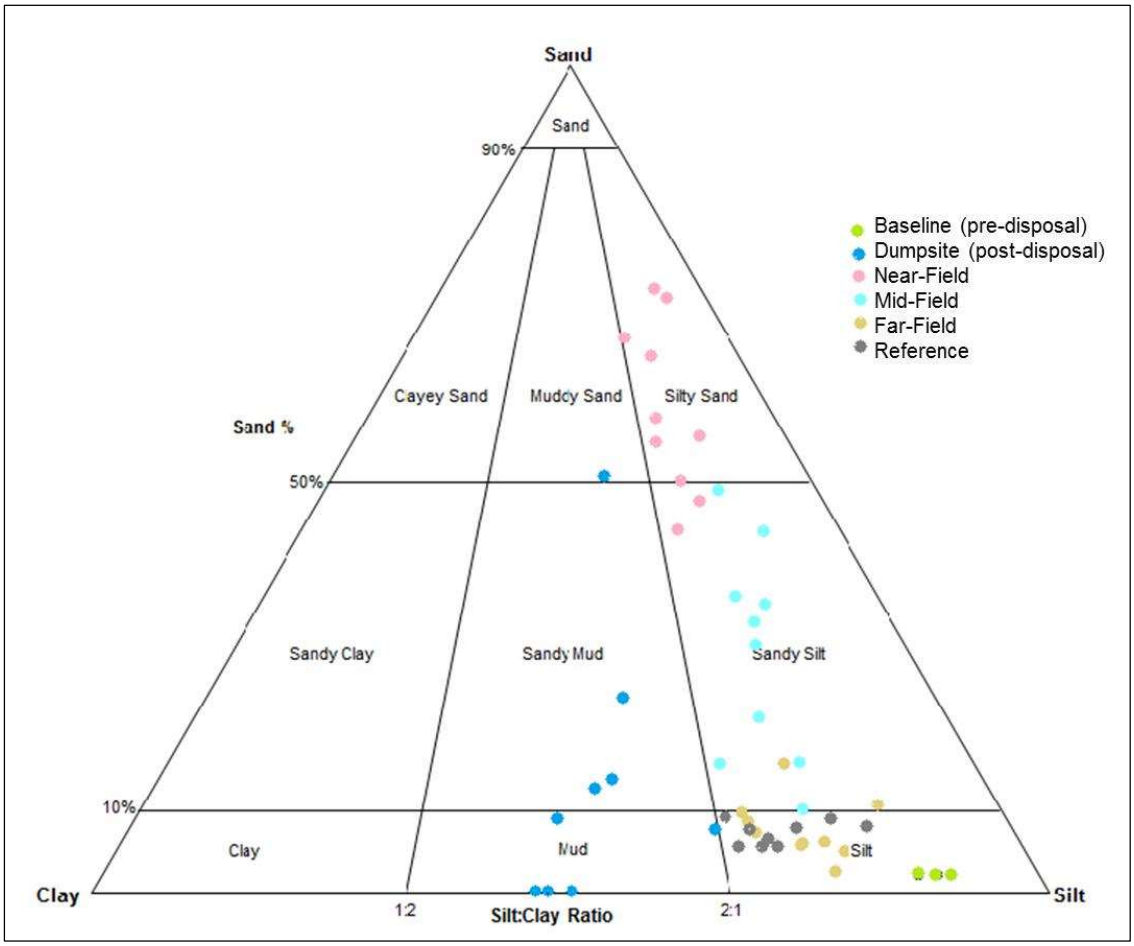


Figure 13 – *Sand-Silt-Clay plot of grain size data from an Atlantic Ocean disposal site*

The impact hypothesis was that *the material suspended during disposal operations will not be measureable beyond mid-field sample locations.* The results show that the dredged material disposed of at the dump-site settled within the expected footprint and did not extend beyond 500 m of the dump-site centre, where mid-field samples were collected. Also, given that the dredged material could be physically distinguished from the surrounding environment, and remained within the expected zone of influence, the results also suggest that the site was stable over the period between disposal and monitoring.

Management actions

The dredged material disposed of at this dump-site was deposited at the correct location on the bottom, and has remained within the expected zone of influence. No management action is required as a consequence of these results, but a repeat of this study may be considered to confirm the stability of the site over time and to determine the biological changes within and outside the disposal site.

Part 3

Field sampling and evaluation techniques

Part 3 Field sampling and evaluation techniques

3.1 Field sampling for physical characteristics

This section provides guidance on low technology and low cost techniques for assessment of physical effects of material deposited at a disposal site.

3.1.1 Physical effects

When material is deposited upon the seabed, it can smother benthic organisms at the disposal site and potentially the surrounding area. This can change community structure and disrupt ecological processes. The deposition of fine grained sediment on coarser grained natural sediment can also change benthic communities and may lead to reduced biodiversity.

Turbidity and suspended solids can cause deterioration in water quality. Waters with high sediment loads are very obvious because of their "muddy" appearance. An increase in turbidity results in a decrease in the depth that light is able to penetrate the water column. This can result in a reduction in plant photosynthesis which reduces biological productivity (which may impair the food availability in higher trophic levels). Visual predators such as fish and fish-eating birds may be hindered as it is more difficult to locate prey. Spawning of marine animals may also be hindered in turbid waters.

Certain biological resources such as coral reefs, shellfish beds, sea grasses, and spawning areas are vulnerable to increased levels of suspended solids. For example, filter-feeding organisms, such as shellfish, can have their feeding and respiration organs damaged. Corals are especially vulnerable to increased sediment levels because they are only able to survive if the rate of settling of suspended particles is relatively low.

Turbidity and suspended sediments in the water column can also interfere with recreational activities, e.g. diving and snorkelling. It can have an aesthetic impact (i.e. look bad) which may affect tourism and recreational activities.

TURBIDITY AND SUSPENDED SOLIDS (SUSPENDED SEDIMENTS)

These two water quality parameters are related but are not the same.

Turbidity is a description of how clear the water is, or in other words, the degree to which the water contains particles that cause cloudiness or backscattering and the extinction of light.

Suspended solids (suspended sediments) comprise fine particles of inorganic solids (e.g. clay, silt, sand) and organic solids (e.g. algae, detritus). Suspended solids (sediments) can affect turbidity.

(CEDA and IADC, 2008)

It is important to note that turbidity occurs naturally and therefore the effects of turbidity from disposal begin to occur when it is increased above background levels. Effects can be more pronounced in waters not used to periodically receiving higher levels of turbidity and large quantities of suspended solids (or suspended sediments).

3.1.2 Physical monitoring techniques

A number of techniques are available for assessing the physical characteristics and potential impacts of dumping of dredged material or inert, inorganic geological material at a disposal site. Meeting the working definition of low technology low cost for this document, brief summaries of the following techniques are provided in this subsection.

- Navigation and positioning equipment provide key data on where the sample station is, and how to get back to that station is the key to maintaining confidence in monitoring survey results.

- Simple equipment is available that measures the depth of the water at sampling stations. Measuring the basic bathymetry can be accomplished with some effort with a “lead line” or using relatively inexpensive hand held or boat-installed depth finders. Measuring the bottom configuration and sub bottom profiles is a bit more difficult; side scan sonar and sub bottom profilers are expensive and not simple to use.

- Collection of sediment samples from the disposal site and surrounding areas can be accomplished using grab samplers or core samplers.

- Relatively inexpensive and simple to use techniques are available for measurement of sediment and water column characteristics, such as grain size distribution or turbidity.

- To know the location where disposed materials may settle to the bottom requires knowledge of the currents in the area. Simple techniques are available, as well as very sophisticated current meters transmitting to satellite based receivers.

Low technology and low cost monitoring methods for assessment of physical impacts that could easily be employed in a monitoring programme are outlined below.

3.1.3 Simple observations

To assess the impacts of disposal upon water quality and on the benthic environment, simple observations can be made from the shore or from vessels to monitor the disposal activity. These observations can ensure that disposal is taking place in the right location and at the appropriate time, if stipulated. Observations can be documented by taking photographs or videos of the operation. These observations provide basic knowledge about the disposal operations such that upcoming sampling programmes are conducted where the material has been disposed. This information can also provide information for determining compliance with the permit.

Shore-based observations can be used to record the start and finish times of vessels and the direction of travel. If relatively close to shore where the material is to be deposited, vessels can be observed to see how low in the water they are; when carrying their cargo (i.e. dredged material or inert, inorganic geological material), they will have more freeboard than when they are empty following disposal. Equally, observations from other vessels can provide this information and can be used if the disposal site is farther off shore.

Once the materials have been disposed of, then depending on the material and site conditions, there may be a plume. Observations of the plume can confirm predictions made about the direction of the plume, where it is expected to travel, and how long before it dissipates. This may be relevant if there are sensitive areas near the disposal site. For example, the disposal activity may have been restricted to a certain state of the tide to avoid suspended sediments impacting sensitive areas.

Observers could also be put on board the disposal vessel. The permitting authorities may appoint a person to ensure activities are being carried out in accordance with the permit and include that as a condition in the permit.

3.1.4 Vessel considerations for monitoring

The vessel should be large enough to accommodate the necessary types of sampling gear, including lowering and raising the gear and removing samples. Storage space for empty sample containers and preservation of samples in a cool area after collection are necessary. If cores are being collected, the vessel should be held as motionless as possible while the core is lowered and raised (IADC, 1997a). It should be noted that some samples can be collected near shore by hand or by using cranes or derricks. A small boat with a small hand-operated grab or corer may be able to provide satisfactory samples. Appropriate storage and preservation can be achieved either on the boat or on shore nearby.

3.1.5 Measurement of Water Currents

To obtain information on water currents and tides, it is suggested to consult local tide tables and speak to the local fishermen and other marine users. Observations of water currents can be made by simply tossing an object into the water and then timing how long it takes for the object to reach a certain point. The object could be a float or a sealed bottle partially filled with water. Place it into the water at the location of the disposal site and see in which direction it moves and how fast it travels from one known point (A) to another (B) where the distance between them is known or can be measured. Divide the distance by the time to calculate the water current velocity. A simple way of doing this is by attaching a known length of cord to the object and measuring the time from release to when the cord becomes taught. An advantage is that the object can be retrieved. This method would give an indication of flow direction and speed near the surface and the information could then be used to estimate where plumes from the disposal operation would travel.

It is important to note that currents can be localized, varying greatly over short distances through the influence of tides, winds, river inflow, bottom contours, and shoreline configuration. Underwater currents may be different to those on the surface. Water bodies can be stratified due to salinity (halocline) and temperature (thermocline) resulting in density changes (pycnocline) which can alter flows. This will influence where suspended sediment from disposal operations settles out. Therefore, observations should also ideally be carried out in mid-depth and/or at depth.

A relatively simple but effective technique to measure sub-surface currents is to use a sub-surface drogue (figure 14). This method can give more accurate information on currents and tides as the drogue is not influenced by the wind, unlike floats or bottles on the surface. It can also determine if flows differ at varying depths in the water column. As they are easily visible, the drogues can be tracked from land to determine the flow direction and velocities. Figure 14 gives an indication of how to construct a sub-surface drogue. Note that the length between the buoy and the cotton sheet is variable so it can be altered to determine at which depth flows are monitored.

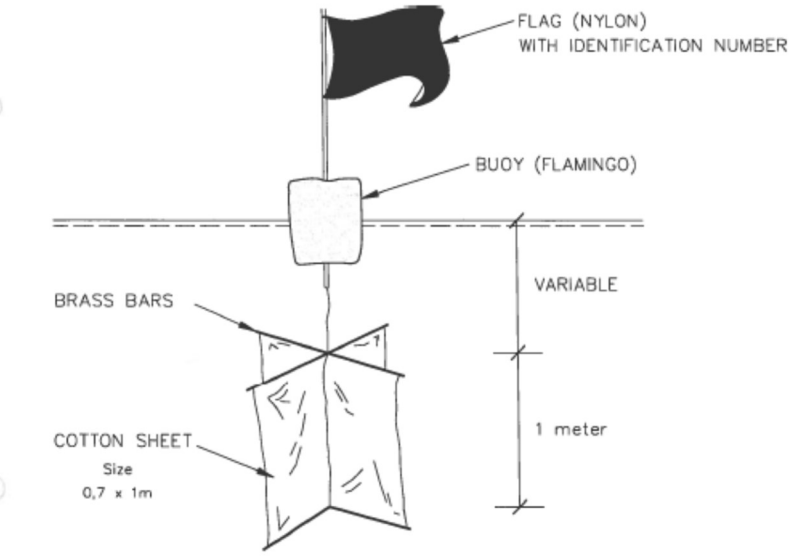


Figure 14 – *Sketch of a sub-surface drogue*

Near bed flow and sediment transport patterns can be investigated by using seabed drifters (figure 15) which are released at the disposal site. Each drifter would have an individual number and a label requesting return information and promising a small reward. They are often recovered by, for example, beachcombers or in fishermen's nets. By plotting tracks of returned seabed drifters, then an indication of near bed flow and residual drift can be gained from which assumptions of the fate of disposed materials can be made. Drifters can also be weighted to determine or monitor the fate of different particle sizes.

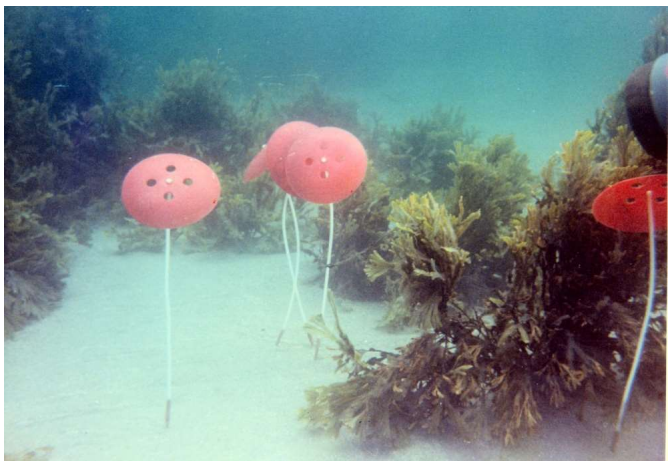


Figure 15 – *Cefas mushroom drifters floating along the seabed*
Source: Cefas: Centre for Environment, Fisheries & Aquaculture Science, United Kingdom.

Wave action is also an important factor when considering currents and the directions of sediment transport and deposition. Disposal sites that are more exposed and subject to strong wave action are more likely to influence the movement of sediments post- disposal through resuspension from the seabed.

For further information on the behaviour of sediments after deposition, see CEDA and IADC (2008).

3.1.6 Depth of the site/bathymetry

Bathymetry is one of the primary tools for determining where the disposed material has been placed and how much of it remains at the site. Figure 16 shows a simple and time-tested method of finding depths to the bottom, and figure 19 shows a newer technique using a depth finder and computer software to map the bathymetry. One alternative to the lead line is to use a hand-held or boat-mounted depth finder and also use a hand-held GPS to manually map the seafloor. One note of caution: it might be assumed that disposal of tens of thousands to millions of cubic metres of material on the sea bottom would leave a measurable mound. However, not finding a mound of material does not mean the material has left the site. Some sites are very large compared to the amount of material deposited and thus may spread out to less than measurable depths. Whether the material is dumped from a moving or stationary vessel can also influence development of a mound at the site.

Figure 16 – *Soundings with a lead line. This works. While somewhat tedious, combined with a hand-held GPS monitor, a representative understanding of the bathymetry can be achieved*
Source: http://cambriahikes.blogspot.co.uk/p/alaska.html.

A wide array of hand-held and boat mounted depth meters are available at reasonable prices. Figure 17 shows a hand-held depth sounder, and figure 18 provides a boat mounted depth sounder.

Figure 17 – *Portable depth sounder. This Hondex Remote Portable Depth Sounder quickly determines water depth for sampling and depth studies. A transducer transmits high frequency pulses that reflect off the bottom and back to the unit where they are processed to determine depth. Depth range of 1.8 feet (0.5 m) to 240 feet (74 m). Cost US$259*

Source: https://www.google.com/#q=depth+sounders&tbm=shop&spd=13241620507779175746.

Figure 18 – *Boat mounted depth sounder. This boat mounted depth meter has a range up to 199 feet (60 m). The cost is US$117*

Source: https://www.google.com/#q=depth+sounders&tbm=shop&tbs=vw:l,price:1,ppr_min:100,ppr_max:150&spd=11364459871750854540.

Figure 19 – *Electronic bathymetric mapping system. While not low technology or low cost, the figure shows an easy-to-use kayak-mounted bathymetric mapping system which creates simple bottom terrain maps, using the Humminbird 788ci HD depth sounder and a 12V power supply. Cost of the depth sounder ranges from US$500 to US$700. The data is imported and processed using CARIS BASE Editor, which is a desktop application for compiling and analysing source bathymetry* Sources: http://www.hydro-international.com/ news/id5963-Taking Bathymetry Using a Kayak.html and http://www.caris.com/ products/bathydatabase/base-editor.

3.1.7 Sediment plume monitoring

Information on the extent and nature of suspended sediment plumes generated by dredging and disposal activities is necessary to understand technical issues, including sediment transport and associated environmental concerns. During dredging projects, permit conditions commonly require that methods are put in place to monitor operations and ensure that the suspended sediment levels do not exceed pre-defined ranges.

Most sediment plume monitoring efforts focus on monitoring total suspended solids and/or turbidity associated with the disposal plume. Total suspended solids or sediments (TSS) is a measure of the total mass of material in a given volume of water and is measured in milligrams/litre (mg/L). Turbidity, a measure of the light-scattering properties of a volume of water, is related to the type and quantity of particles suspended in the water. Turbidity is defined as cloudiness or haziness of a fluid caused by individual particles, or suspended solids. It is relatively difficult and often cost-prohibitive to directly measure total suspended solids; therefore, turbidity measurements are often used for monitoring suspended sediment in the field as a substitute for total suspended solids.

Turbidity measurements are reported in nephelometric turbidity units (NTU) or Jackson turbidity units (JTU). Different units are used depending on which method is chosen to measure turbidity. The two units are roughly equivalent and can be used interchangeably for field purposes.

From a low technology perspective, plume monitoring can be employed to identify when an excessive amount of suspended solids or sediments are released into the water column as a result of disposal activities. With more advanced monitoring techniques, such as water turbidity meters fixed in place or moving with the current in the disposal plume, information can be collected in real time. This real time information can provide direct feedback to the operations managers to slow down or change disposal operations until turbidity reaches acceptable levels. Visual observation of the plume reaching a sensitive shellfish bed should result in a change in timing or location of disposal.

Low technology methods for sediment or turbidity plume monitoring

Low technology methods can be used to derive a relatively inexpensive general picture about turbidity. A number of approaches are available for sampling and analysis of turbidity. Collecting a sample of water to be tested, especially from a particular depth within the plume is important. The following method using a "home-made" sampler is one approach.

The Cola Water Sampler consists of a cola bottle in concrete (figure 20). The concrete increases the weight of the sampler. The stopper is made of cork and fastens to the bottle with rope. The rope is held in the hand, and can be released by the stopper by tugging the rope.

Another similar relatively simple way to take a sample of seawater from within the water column is using a device called a Niskin bottle (also called Nansen bottle) (figure 21). This is basically a plastic cylinder with stoppers at each end, connected by an elastic cord. The bottle that can be opened at both ends, the open bottle is lowered into the water on a wire until it reaches a certain depth and then the bottle is closed by a weighted trigger sent down the cable from the surface. Niskin bottles can be used individually, set up in a series of bottles that trigger each other in turn as they close, or set up in a circular rosette of as many as 24 bottles attached around a CTD (conductivity-temperature-depth) instrument (see below). The USEPA has a Standard Operating Procedure for using a Niskin bottle in the field. This can be found at: http://www.epa.gov/grtlakes/monitoring/sop/chapter_2/LG201.pdf.

While not considered to be low technology or low cost, more sophisticated water samplers are shown in figure 22.

- In figure 22, a cylindrical piece of equipment holds multiple specialized water bottles that can take separate water samples at different depths every time it goes in the water. Scientists can use electronic equipment to remotely control the water bottles to open and close as it moves up and down in the water column. Water sampling is often done at specific depths so scientists can learn the physical properties of the water column at that particular place and time.

- Figure 22 also shows a CTD and Rosette water sampler and a package of instruments that can take in-water measurements of a number of parameters. Although CTD stands for conductivity-temperature-depth, the modern version of this instrument includes probes that measure pH, oxygen, chlorophyll, turbidity, and other parameters. The CTD is attached to a cable and is lowered to the bottom generating real-time and archived depth profiles of physical, chemical, and biological conditions. Mounted above the CTD is a circle of water bottles called the Rosette sampler. The bottles are set to trip at specified depths, collecting water for later analysis. If something interesting shows up on the CTD, the operator can trip a bottle to collect an extra sample.

Figure 20 – *Cola water sample in the locked position and once released* Source: DHI, Denmark.

Figure 21 – *Nisken bottle sampler Source NOAA National Marine Sanctuaries* Source: http://flowergarden.noaa.gov/ image_library/ nabsyes2013images.html, and http://www.kc-denmark.dk.

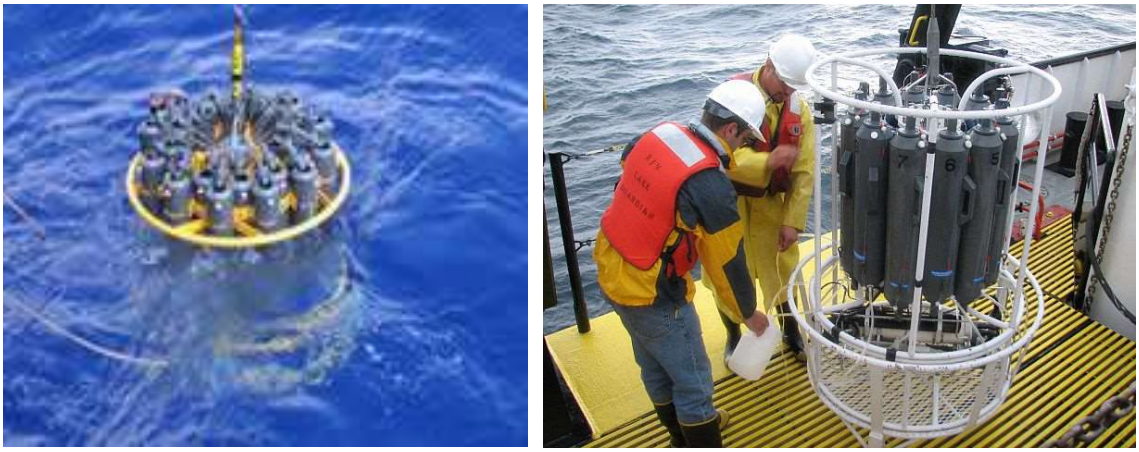


Figure 22 – *Rosette water sampler and CTD and Rosette samplers*
SourceS: USEPA, http://www.epa.gov/boldkids/scienceonboard.html and
http://www.cee.mtu.edu/great_lakes/images2/ spotlight_rosette_CDT.html.

Table 3 below provides a number of low technology methods than can be used for measurement of turbidity detailing their strengths and weaknesses (adapted from Myre and Shaw, 2006).

Table 3 – *Summary of low technology turbidity and suspended solids (siltation) methods*

Method	**Advantages**	**Disadvantages**
Naked eye - Water poured in tube	Fast Cheap	Inaccurate, rather indicative Steps 20NTU/200NTU/2000NTU
Jackson candle turbidimeter - Water poured into tube. - Reading taken when candle burning under tube can no longer be seen	Historical method	No longer a standard method. Cannot measure < 25 JTU (25 NTU).
Turbidity tube (transparency tube) - Combination of Jackson candle and Secchi disk methods	Low cost Portable No consumables Easy to learn Suitable for all water sources	Less accurate. Cannot measure < 5 NTU. See figure 9.

Naked eye

With the naked eye, an average person can begin to see turbidity levels starting at around 5 NTU and greater. If water appears muddy, its turbidity has reached at least 100 NTU. At 2,000 NTU, water is completely opaque (Joyce, 1996). The type of particles present in water can often be estimated by inspection. Organic particles such as algae give a greenish-brown colour to water. Colloidal particles look like a very fine suspension. Two examples are shown in figures 23 and 24.

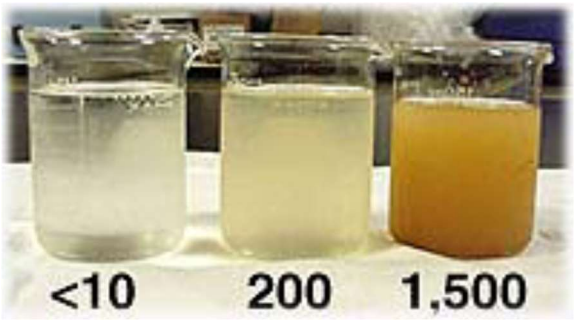


Figure 23 – *Turbidity of <10 NTU, 200 NTU and 1,500 NTU*

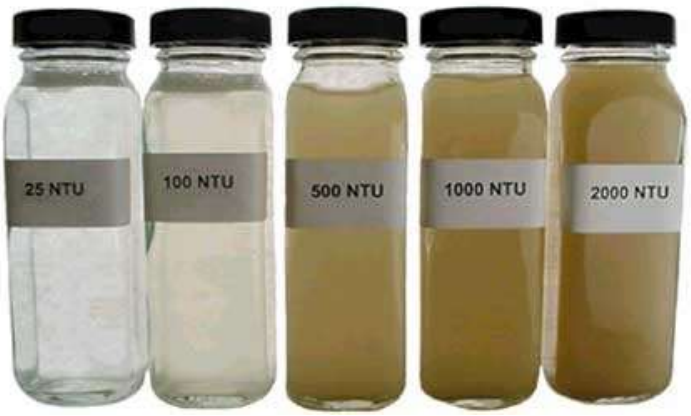


Figure 24 – Turbidity from 25 to 2000 NTU
Source: Agrichemical and Environmental News, September 2002, Issue No. 197 http://www.aenews.wsu.edu/Sept02AENews/Sept02AENews.htm.

Jackson candle turbidimeter

This consists of a flat-bottomed glass tube that sits over a candle. A water sample is poured into the tube until the visual image of the candle flame diffuses into a uniform glow. The depth of the sample corresponds to a certain number of Jackson turbidity units, or JTUs (figure 25).

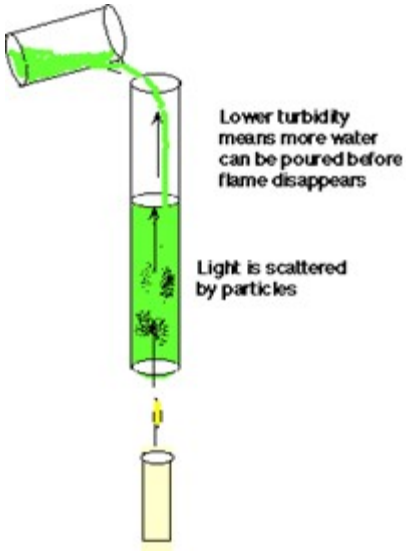


Figure 25 – *A Jackson candle turbidimeter*

The Jackson turbidimeter does have some practical limitations because it cannot measure turbidity lower than about 25 JTU and depends on human interpretation. In addition, the candle flame is in the yellow-red part of the spectrum which is not scattered effectively by small particles.

Secchi disk

A Secchi disk (figure 26) is a device typically used to measure the turbidity of larger bodies of water. It is a simple weighted disk used to measure the water depth at which the disk just disappears from view as it is lowered into the water—the Secchi depth. It has an advantage over the above methods as it can be used to determine an estimate of turbidity in the field before or while disposal is taking place. This uses the same principle as a turbidity tube, but instead of pouring the water over the disk like in a turbidity tube and measuring the height of non-visibility, the Secchi disk is lowered below the surface to the depth of non-visibility.

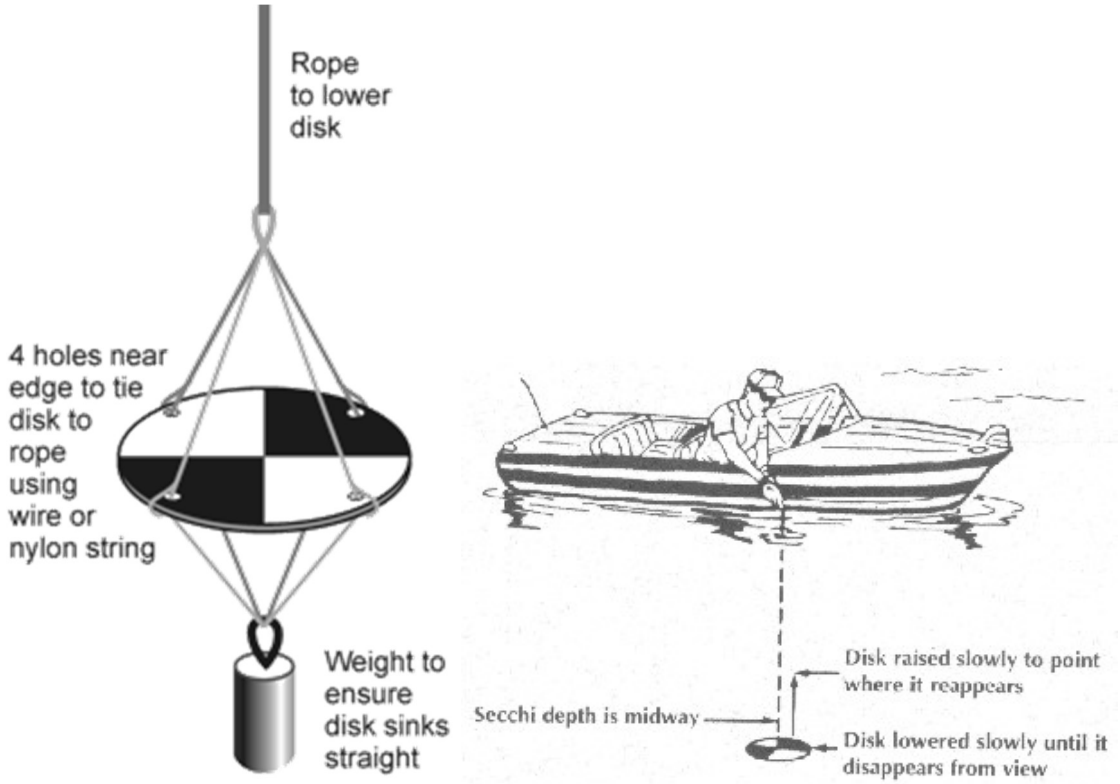


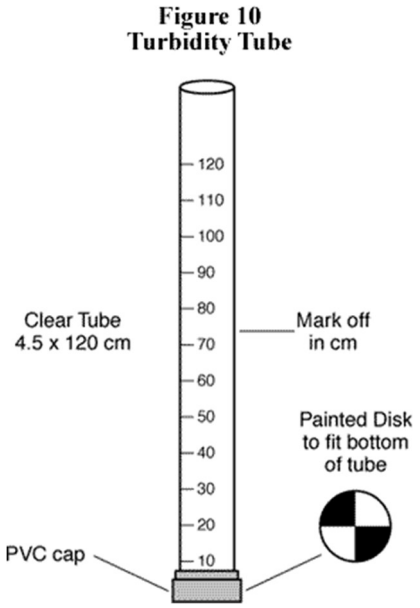
Figure 26 – *A Secchi disk and the disk being deployed from a small boat*

The clearer the water, the greater the distance before the disk is no longer visible. Clear, clean water may have Secchi depths of more than 30 to 40 m, while in some turbid waters (plumes) the depth may be 1 m or less. A Secchi disk is a simple piece of equipment and is relatively easy to make. They are extensively used in volunteer monitoring programs, such as the U.S. Environmental Protection Agency Volunteer Estuaries Monitoring Programme (http://water.epa.gov/type/watersheds/monitoring/vol.cfm) and the Global Secchi Disk Project (https://www1.plymouth.ac.uk/marine/secchidisk/Pages/default. aspx), a unique study in which seafarers equipped with a Secchi disk measure phytoplankton in the world's oceans.

Further information on how to construct and use Secchi disks and also turbidity tubes can be found in annex 4 and in Ohrel and Register (2006) and on the USEPA website: http://water.epa.gov/type/oceb/nep/ monitor_index.cfm.

Turbidity tube

The turbidity tube (sometimes called a "transparency tube") is a clear, narrow plastic tube marked in units (usually centimetres) with a light and dark pattern painted on the bottom (figure 27). Water is poured from a bucket into the turbidity tube until the image at the bottom of the tube is no longer visible when looking directly through the water column. The observer rotates the turbidity tube while looking down at the image to see if the black and white areas of the decal are distinguishable. This depth of water is recorded to the nearest centimetre. Data is entered for each observer, not the average of the different observations. If the image on the bottom of the tube can been seen even after filling it, the depth is recorded as greater than (>) the depth of the tube. Source: Grand Valley State University http://www.gvsu.edu/wri/education/instructor-s-manual-turbidity-10.htm. Annex 4 provides details on how to construct and use a turbidity tube.



Centimetres	NTU
6.7	240
7.3	200
8.9	150
11.5	100
17.9	50
20.4	40
25.5	30
33.1	21
35.6	19
38.2	17
40.7	15
43.3	14
45.8	13
48.3	12
50.9	11
53.4	10
85.4	5

Figure 27 – *Turbidity tube and universally applicable conversion chart to NTU*
Source:http://www.gvsu.edu/wri/education/instructor-s-manual-turbidity-10.htm.

Electric turbidity meters

A variety of excellent electric turbidity meters are available, either hand-held for direct measurements in the field or for use in the office or laboratory using samples from the field. Costs range from US$ 750 to US$ 1,500 and up. See figures 28 and 29 for two examples. These examples are not endorsements, just samples from an internet search for turbidity meters.

Figure 28 – *Hand-held turbidity meter using water samples. 0.01 to 1000 NTU, 2 to 3% accuracy* Source: http://www.camlab.co.uk/palintest-micro-950-turbidity-meter-p26036.aspx.

Figure 29 – *Hand-held turbidity meter for in-water measurement. Range: 0.50 NTU to 1000 NTU Accuracy: + 5%* Source: ENVCO website: http://www.envcoglobal.com/catalog/product/other-handhelds/wq770-handheld-turbidity-meter.html.

3.1.8 Sedimentation monitoring

The amount of fines in suspension and where they settle out of the plume is a concern related to knowing whether the disposed material stays within the bounds of the designated disposal site. A simple way to monitor sedimentation is to use divers to survey relevant areas before and after disposal operations to observe if there has been any increase in sediment on the seafloor and in particular compare the disposal site with areas outside the site.

One technique that can help to estimate where they settle on the seafloor is the siltation test shown in figure 30. The test determines the rate of settling for silt present in a sample based on measurement of the settled silt after 6 hours, 12 hours, 24 hours and 48 hours in a clear tube or bottle with fixed length indications. Silt percentage equals the height of the silt in the tube, at a specific time, divided by the total length of the tube, multiplied by 100. Although this method is rather inaccurate, it will give a good first indication of the amount of fines in a solution and the time it takes to settle under perfect laboratory conditions. Using this information with knowledge of the depth of the disposal site and an idea of the currents provides an indication of whether the suspended sediments will settle in the disposal site or extend beyond the site.

Figure 30 – *A simple way of measuring percentage of fines*

Another common method for assessing sedimentation is to use sediment traps. A simple sediment trap is shown in figure 31. Figure 32 shows several different types of sediment traps. For further information on sediments traps see Grasshoff *et al*. (1999).

Figure 31 – *Simple anchored sediment trap* Source: www.blogbus.com.

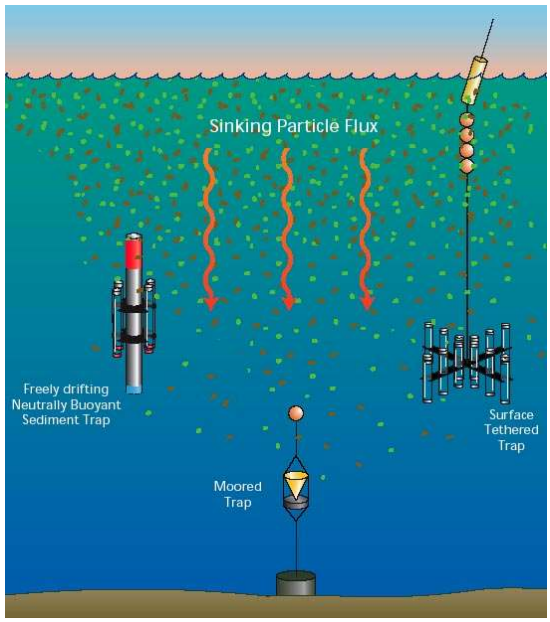


Figure 32 – *Three types of sediment traps. The funnel design uses a large collection area to sample sediments. Neutrally buoyant, drifting sediment traps catch falling material instead of letting it sweep past in the current. Drawings are not to scale* Source: www.whoi.edu.

Sediment traps are instruments used to measure the quantity of sinking particulate matter in the aquatic environment. Sediment traps normally consist of an upward-facing funnel that directs sinking marine suspended solids towards a mechanism for collection and preservation. Typically, traps operate over an extended period of time (weeks to months) and record the magnitude and changes in sinking flux with time. Traps are often moored at a specific depth in the water column in a particular location, but some are so-called Lagrangian traps that drift with the surrounding ocean currents (though they may remain at a fixed depth).

The basic sediment trap consists of a broad funnel with a collecting jar at the bottom. The funnel opening covers a standard area (such as 0.25 m^2) and has baffles at the top to keep out very large objects that might clog the funnel. The trap clamps at a specific depth to a fixed cable attached to an anchor or buoy. Traps are often placed very deep, where they can catch sediment near the ocean bottom.

In deeper waters and for more sophisticated survey work, when a vessel returns to retrieve the trap, the crew activates a remote-controlled device called an acoustic release. The release severs the line between the trap and its anchor, and the trap floats to the surface with its samples. (WHOI website https://www.whoi.edu/instruments/viewInstrument.do?id=10286).

3.1.9 Sediment monitoring

Sediment at the disposal site and in nearby areas can be sampled and evaluated with relatively simple procedures to establish whether the zone of impact and the extent of change outside the zone of impact

differ from those predicted. There are two main types of sediment sampling devices used for disposal site monitoring: grab samplers and core samplers*.

- Grab samplers are typically used to collect surficial sediments for the assessment of the horizontal distribution of sediment characteristics (figure 33).

- Core samplers are typically used to sample thick sediment deposits, or to collect sediment profiles for the determination of the vertical distribution of sediment characteristics or to characterize the entire sediment column. In most cases, in sampling to assess impacts at ocean disposal sites, grab samplers will be the choice. Core samplers are very useful for assessing sediments that are proposed to be dredged (figure 34). These could be cores taken from a boat or from diver-operated corers.

Sediment can be obtained and analysed from grab samplers from a boat, and they can also be taken relatively easily using small hand-held grabs (depending upon the depth of water) which can be deployed from a small boat or even over the side of a quay or jetty.

For monitoring and assessment studies where historical contamination is not the focus, the upper 10 to 15 cm is typically the horizon of interest. Generally, the most recently deposited sediments and most epifaunal and infaunal organisms are found in this horizon. To ensure minimum disturbance of the upper layer during sampling, a minimum penetration depth of 6 to 8 cm is recommended, with a penetration depth of 10 to 15 cm being preferred.

It is often the case that a specific vessel, having a fixed lifting capacity based on the configuration of its winch, crane, boom, A-frame, or other support equipment, is the only one available for use. This will affect the type of sampling equipment that can be safely operated from that vessel.

Figure 33 – *Seabed clamshell sampler*

Deployed by hand or crane on a single line, the unit is deployed in the "open" position and, when the weight comes off the launch line, the latch releases leaving the bucket grab to "scoop" samples as it is recovered. Simple, and very effective. Source: ROV Downunder http://www.rovdownunder.com/products-overview.html.

* Much of the discussion on grab and core samplers was extracted directly from the EPA Sample Collection Manual, i.e. USEPA; *Methods for Collection, Storage and Manipulation of Sediments for Chemical and toxicological analyses: Technical Manual*, EPA-823-B-01-002, October 2001. http://water.epa.gov/polwaste/sediments/cs/upload/collectionmanual.pdf.

Figure 34 – *Hand coring devices are generally suitable for collecting sediment samples in marshes, streams, shallow rivers, in some cases in shallow coastal waters, or at some depth by divers. Depending upon the sediment composition, the samples typically are less than 1 m in depth. Samplers need to be equipped with a top valve that allows water to pass through when set in the sediment and closes during withdrawal to prevent washout*.
Source USEPA website: https://clu-in.org/programs/21m2/sediment/#water.

Grab samplers

Grab samplers consist either of a set of jaws, a clamshell, that shuts when lowered into the surface of the bottom sediment or a bucket that rotates into the sediment when it reaches the bottom (figure 35). Grab samplers have the advantages of being relatively easy to handle and operate, readily available, moderately priced, and versatile in terms of the range of substrate types they can effectively sample. Graphic displays of several grab samplers are shown in figure 36.

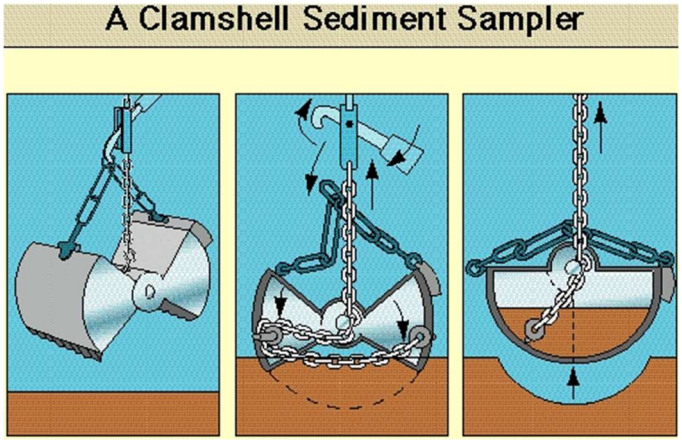


Figure 35 – *Grab sampler*
Source: http://geoclasses.tamu.edu/ocean/wormuthwork/marinesediments/schematicbottomgrab.gif.

Of the grab samplers, the *Van Veen, Ponar***,** and *Petersen* are the most commonly used. These samplers are effective in most types of surface sediments and in estuaries and marine waters. The *Van Veen* sampler, or the modified *Van Veen (Ted Young),* is used because it can sample most types of sediment, is less subject to blockage and loss of sample than the *Peterson* or *Ponar* samplers, is less susceptible to forming a bow wave during descent, and provides generally high sample integrity. The *Van-Veen* sampler is relatively heavy and requires a power winch to operate safely.

Grab samplers penetrate to different depths depending on their size, weight, and the bottom substrate. Heavy, large volume samplers such as the *Smith-McIntyre*, large *Birge-Ekman, Van Veen,* and *Petersen* devices can effectively sample to a depth of 30 cm. These samplers might actually sample sediments that are too deep for certain study objectives (i.e. not reflective of recently deposited sediments). Smaller samplers such as the small *Birge-Ekman*, standard and petite *Ponar*, and standard *Shipek* devices can effectively collect sediments to a maximum depth of 10 cm. The mini-*Shipek* can sample to a depth of 3 cm.

Careful use of grab samplers is required to avoid problems such as loss of fine-grained surface sediments from the bow wave during descent, mixing of sediment layers upon impact, lack of sediment penetration, and loss of sediment from tilting or washout upon ascent.

When deploying a grab sampler, the speed of descent should be controlled, with no “free fall” allowed. In deep waters, use of a winching system is recommended to control both the rate of descent and ascent. A

ball- bearing swivel should be used to attach the grab sampler to the cable to minimize twisting during descent. After the sample is collected, the sampling device should be lifted slowly off the bottom, and then steadily raised to the surface at a speed of about 30 cm/second.

Core samplers

Core samplers (corers) are used: (1) to obtain sediment samples for geological characterizations and dating, (2) to investigate the historical input of contaminants to aquatic systems and, (3) to characterize the depth of contamination at a site. Graphic displays of several core samplers are shown in figure 37.

One limitation of core samplers is that the volume of any given depth horizon within the profile sample is relatively small. Thus, depending on the number and type of analyses needed, repetitive sampling at a site might be required to obtain the desired quantity of material from a given depth.

With the obvious exception of hand corers, there are only a few corers that can be operated without a mechanical winch. The more common of these include the standard *Kajak-Brinkhurst corer*, suitable for sampling soft, fine-grained sediments, and the *Phleger corer*, suitable for a wider variety of sediment types ranging from soft to sandy, semi-compacted material.

Gravity corers are appropriate for recovering up to 3 m long cores from soft, fine-grained sediments. *Vibracorers* are perhaps the most commonly used coring device in sampling programmes, because they collect deep cores in most types of sediments, yielding excellent sample integrity. *Vibracorers* are one of the only sampling devices that can reliably collect thick sediment samples (up to 10 m or more). *Vibracorers* have an electric-powered, mechanical vibrator located at the head end of the corer which applies thousands of vertical vibrations per minute to help penetrate the sediment.

When deployed properly, box corers can obtain a relatively large amount of undisturbed sediment samples of excellent quality. The basic box corer consists of a stainless steel box equipped with a frame to add stability and facilitate vertical penetration on low slopes. Box corers are recommended particularly for studies of the sediment-water interface or when there is a need to collect larger volumes of sediment from the depth profile up to about 30 cm below the sediment water interface. Because of the heavy weight and large size of almost all box corers, they can be operated only from a vessel with a large lifting capacity and sufficient deck space.

Figures 38 to 40 show samplers being used in the field.

Acceptability of samples

Acceptability of grabs can be ascertained by noting that the samplers were closed when retrieved, are relatively full of sediment (but not over-filled), and do not appear to have lost surficial fines. Core samples are acceptable if the core was inserted vertically in the sediment and an adequate depth was sampled.

For most sampling applications, site water rinse of equipment in between stations is normally sufficient. However, if one is sampling many stations, including some that could be heavily contaminated, a site water rinse might not be sufficient to minimize cross-contamination of samples among stations. In these cases, it might be necessary to decontaminate all sampling materials in between stations. See the discussion in annex 6 and the USEPA Manual (2001).

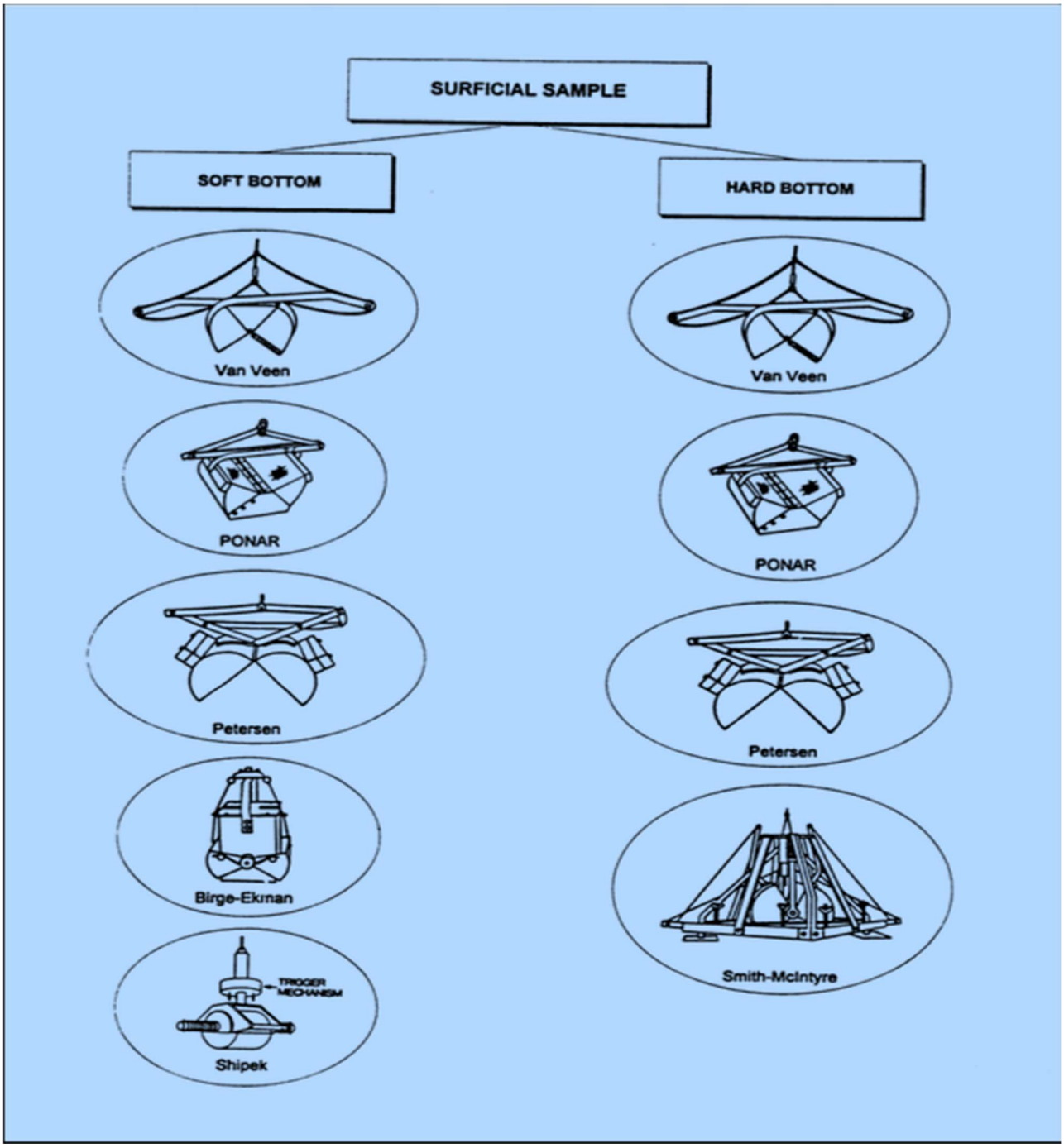


Figure 36 – *Grab samplers — some recommended devices for collecting surficial sediments (drawings from Murdoch and Azcue 1995 and Fredette et al., 1990)* Source: USEPA Manual, 2001.

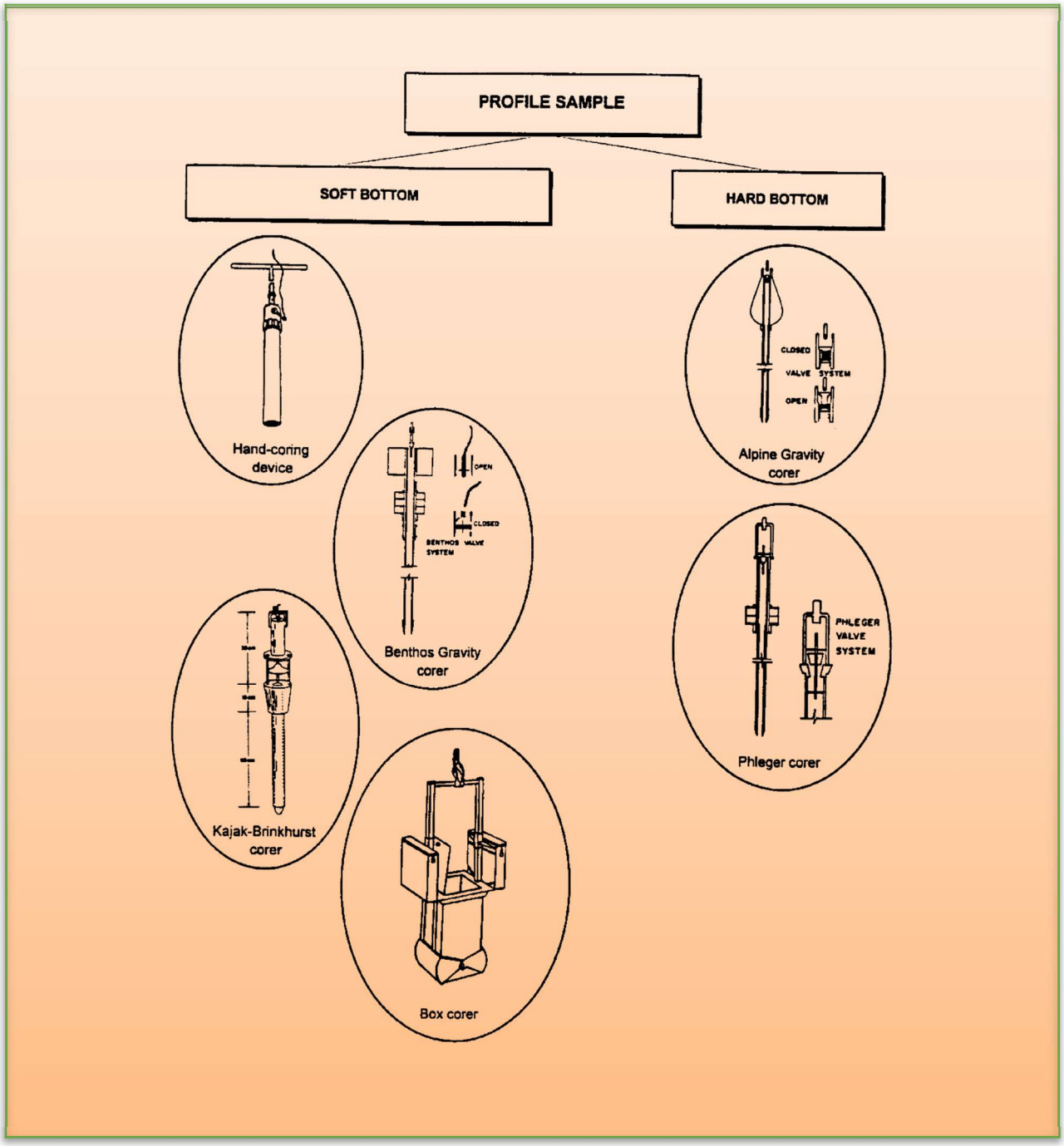


Figure 37 – *Core samplers — some recommended devices for obtaining sediment profiles (drawings from Murdoch and Azcue 1995 and Fredette et al. 1990)* Source USEPA Manual 2001.

Figure 38 – *Sampling using a* Ted Young *modified* Van Veen sampler. *Large grab samplers such as these require winches and sufficient boat size for efficient operation*

Figure 39 – *Ponar* grab sampler

Figure 40 – *Taking subsamples from a* Ted Young *modified* Van Veen *sampler*

Figures 38 to 40 – *Grab samplers in the field* Source USEPA Manual, 2001.

3.1.10 Sediment monitoring: physical testing techniques of grab or core samples

After collecting the sediment samples, the sediment can then be evaluated for its physical characterization, and chemical composition as needed. The methods outlined below are simple ways of achieving physical characterization of sediment. These include:

- Visual and textural description;
- Smell;
- Rapid mud assessment; and
- Wet sieving a sample to produce a summary particle size distribution.

Visual description

Visual descriptions of sediment samples are completed as soon as the sample is brought aboard and are used to supplement particle size distribution data. They aid determination of the mineral content, presence of shell material and organic material visible in the wet sample before analysis has commenced. Such visual assessment can help to build a set of assumptions regarding the likelihood and distribution of any contamination of the sediments in question (i.e. appearance of oil, paint flakes, or debris, or smell of hydrocarbons or anaerobic conditions—smell of rotten eggs). The sediment odour evaluation is potentially dangerous to human health depending on the chemicals present in the sediment and should therefore be carried out cautiously (e.g. starting from a distance, and wafting a hand over top of them). These observations are subjective. The description should contain the following points:

- Colour;
- Homogeneity (presence or absence of stratification);
- The presence or absence of animals (as an indication of bioturbation);
- Smell;
- Visual contamination (e.g. oil sheen, paint flakes); and
- Textural description (is the material gritty or smooth).

Textural description and particle size distribution

A description of the texture of the material provides information regarding its potential to include contaminants that are attached to the fine particles, and gives an indication whether the material will cause turbidity and increased suspended solids in the water column when deposited in marine waters (figure 41). To determine the textural description:

.1 First remove a representative subsample of sediment into a sample container, for example, a foil tray. The description of the sample needs to include details of larger or single particles present such as large shell or gravel pieces.

.2 Add some water to the sample container, stir around, and begin observations of the sediment.

.3 Make an evaluation of the amount of mud material present stirring and tipping off water/mud i.e. if there is not very much material left after tipping off mud (fine material), then this sample would be identified as mud/very muddy depending on what has been left in the sample container.

.4 Roll a small piece of suspected clay between the fingers while wearing protective gloves. If the piece easily rolls into a ribbon, it is clay; if it breaks apart, it is silt.

.5 Try to characterize the sediment in the following terms: presence of gravel (coarse, cobble), sand (coarse, medium, fine, very fine) or mud, presence of clay lumps, colour of sediment, visible shell fragments with description or identification of shell if possible, plant matter, and coal particles. The use of a sediment-sizing wheel is invaluable in assisting in this process. Figure 30 is a photograph of a sediment sizing wheel, which is also a good representation of the size and appearance of sediments.

.6 Include as much detail about the sediment as possible. Include any indication of influence of humans, such as paint fragments, broken glass, cigarette butts, clinker (mining waste), smell, and pieces of cloth within the description.

Figure 41 – *Sediment sizing wheel and physical appearance of sediments*

Rapid mud assessment

Rapid mud assessment is a quick method that can be used to indicate relative mud (i.e. fine particles) content. It gives a rough estimate but it should be understood that aggregated particles will be included within the sand, and therefore this method may give higher estimates of sand than using traditional particle separation methods.

Place a defined quantity of sediment in a tube. Add water (preferably from the source the sample was collected). Shake the sample until it is fully mobile and then allow the sediment to settle out in layers. Make sure the sample is fully disaggregated. The top layer is representative of the mud content, and the depth of this relative to the depth of the rest of the sample will give a broad measurement of mud content.

Particle size distribution by wet sieving

Wet sieving provides a good summary of particle size distribution using minimal equipment (2 sieves) providing quantitative results. The procedure:

.1 Place a 2 mm sieve over a bucket. Add the sample to the sieve and wash sediment <2 mm through the sieve into the bucket. Remove the >2 mm material and allow to dry. Record the weight of the sediment >2 mm.

.2 Place a 63 µm sieve over a bucket. Tip the water and sediment <2 mm into the 63 µm sieve and gently drain this sediment through the sieve. Wash through with more water until the water running through this sieve is clear and no more mud (sediment <63 µm) is present in the 63 µm sieve. Some manipulation of the sediment to disaggregate the sediment may be required. Remove the >63 µm sediment from the 63 µm sieve and allow to dry (air dry). Record the weight of the sediment <2 mm, >63 µm.

.3 Allow sediment <63 µm to settle out from the water in the remaining bucket. Drain off the water. Remove the <63 µm sediment from the bucket allow the material to dry and record the weight of the sediment <63 µm.

.4 Convert the individual weights into percentage gravel, sand, and mud (fines which include silt and clay).

DESIGN OF THE SAMPLING PROGRAM: PRE-DISPOSAL SAMPLES OF THE DISPOSAL SITE
– Grain size analysis is very important in determining where materials have been placed. – Samples can be compared to the grain size distribution of the placed material, grab samples from the disposal site, and from reference areas. – It is desirable to have a pre-disposal grab sample at the precise location of the post disposal sample.

3.2 Field sampling and analysis for chemical contamination and/or toxicity

In determining whether to sample and test the sediments at the dump-site (and possibly in the areas that may be impacted near the dump-site) for chemical contaminants and possible sediment toxicity, there are a number of steps which can be taken to minimize the amount of analysis needed.

3.2.1 Is monitoring for chemical contaminants and/or toxicity needed?

The first step is to review whether the dredged material that has been dumped was suspected of contamination (based on the dump-site history and current uses), and what testing has been conducted to confirm this. Inert, inorganic geological materials that had been dumped at the disposal site would not be normally be tested for chemicals, except to confirm that the waste had been appropriately categorized.

Most natural and anthropogenic contaminants (metals and organics) tend to be associated with the finer particles in sediments, mainly silts and clays that are less than <63 μm in diameter. Therefore, knowledge of whether the dredged material contains silt or clay is very helpful. Dredged materials composed predominantly (i.e. 80% or more) of coarse-grained materials, e.g. rock, gravel and sand, have a low potential to carry significant amounts of chemical contaminants. For example sediments, which are predominantly sand, containing little or no silt or clay, will usually be relatively free from contamination/toxicity. In addition, analysis may not be necessary if the dredged materials that have been deposited are glacial in origin, are composed of undisturbed geological material, or if they came from areas of an approach channel where contamination was highly unlikely.

Based on this knowledge, a simple visual and textural assessment can therefore be used as a low technology screening approach to determine the likelihood of contamination. In addition, the relative homogeneity of the material can be used to determine the likelihood of sediments containing contaminants by examining: (1) whether sediments are recent or historic deposits when cross-referenced with knowledge of human activities, and (2) whether any known surface deposits of contaminants might be mixed into underlying sediment layers.

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CHEMICAL CONTAMINATION RELATED EFFECTS

If the dredged material contains elevated levels of contaminants, such as heavy metals, PCBs, PAHs, organic matter or nutrients, then contaminant-related effects may occur.

- Heavy metals and organic pollutants can cause toxic effects on organisms that are exposed to higher than normal levels of these contaminants. Exposure effects can be acute (occur right away, or over a very short time period) or chronic (occur over a longer time period). Benthic organisms are most susceptible as they live and feed on deposited sediments at a disposal site and its surrounds.

- In addition to causing harmful effects, over time, toxic substances can accumulate in marine organisms (i.e. bioaccumulation), which can cause negative effects in the marine organisms but also pose a risk to human health through consumption of fish and shellfish.

- Dredged sediment with high organic matter content can affect dissolved oxygen levels in relatively enclosed bodies of water, such as estuaries and coastal embayments. Decomposition of organic matter can deplete dissolved oxygen, and, if the water column becomes hypoxic or anoxic, the result can be mortalities of marine animals.

Excess amounts of nutrients can cause an increase in algal growth (eutrophication) which can affect water quality and increase the organic matter when the algae die off.

Some preliminary analysis can also help to determine whether chemical testing is needed, and which chemicals to test for. For example, if the area that was dredged is known to be contaminated through previous pollution incidents or on-going inputs, then this information can influence what to consider measuring at the dump-site.

Ideally, material deposited at the dump-site will have been characterized before disposal. Monitoring for chemical contamination or toxic effects (using bioassays) is advisable when there are concerns about potential dump-site contamination based on the physical properties of the deposited material and/or the contamination sources near the load site.

WHAT ARE SOURCES OF CONTAMINATION?

Contamination of estuarine and coastal marine sediments, both as a consequence of historical and present day inputs, presents a continuing problem for the management of dredged material. Contamination can enter marine sediments from point or non-point (diffuse) sources. Point sources enter at a specific site, such as a discharge pipe or through an accidental spill, and are therefore more readily identified. Contaminants from land use activities, such as urban development, mining, or agriculture, enter the marine environment through rainfall run-off or groundwater seepage, i.e. non-point sources. Sources of contamination in marine sediments include:

- Agricultural practices, which can provide inputs such as pesticides and nutrients from upstream catchment areas.

- Industrial practices, such as discharges (e.g. from factories, power plants, industrial sites, or mines) mainly resulting in heavy metals, PCBs, and oil-based contaminants (e.g. PAHs).

- Vessel bottom paints, resulting in such chemical contaminants as organotin compounds or copper.

- Urban discharges, including road run off, can contain heavy metal, oil, and PAHs.
- Accidental spillages, which can be direct into the marine environment or reach it through drains, can also include leakage from engines or storage tanks.
- Erosion or disturbance of river and/or estuary banks and beds, where in situ sediments contaminated through historic activities (such as those described above) are remobilized, creating a current source of contamination. Erosion could occur through natural events such as storms or flooding, or sediments can become mobilized as a result of construction or dredging operations.

In summary, as a first tier, based upon the assessment of the physical characteristics of the dredged material that has been disposed of, and the sources of contamination near the dredging site, the need for chemical testing or bioassays can be eliminated or confirmed. If chemical contamination is indicated and if chemical testing or bioassays are beyond a country's scientific, technical, and economic capabilities, it is suggested that the dump-site be considered contaminated and managed appropriately, isolating the deposited material from the surrounding marine environment either by capping in place with clean material (see annex 8), or placing future materials to be disposed of in confined disposal facilities.

3.2.2 What chemical contaminants should be tested?

If chemical contamination appears to present concerns, contaminants monitored at dredged material disposal sites are typically substances of either an organic, organometallic, or inorganic nature. Organic contaminants include polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, polybrominated diphenyl ethers, and organometallics including organotins, such as tributyltin (TBT). Inorganic compounds consist of metals such as mercury, cadmium, chromium, and copper.

Rudimentary tests involving smell, colour, and a visual inspection can be used, particularly to ascertain if high levels of PAHs are present. For example, samples that are highly contaminated with hydrocarbons tend to have a petrogenic smell (smells like oil or gas) and may be black in colour, although it is important to note anoxic material is also often black in colour (in which case the smell could be like rotten eggs, i.e. hydrogen sulphide), as is often the case with organic-rich material. PAH-contaminated sediments would also give off an oily sheen when mixed with water and shaken.

3.2.3 Is monitoring for chemical contaminants needed when inert, inorganic geological materials have been disposed of at dump-sites?

In short, no.

To be categorized and considered to be inert, inorganic geological materials, the materials should only have the potential to result in physical effects upon the marine environment at the disposal site and surrounding areas. Depending upon the source and type of materials, testing to confirm their "inertness" may have been conducted in assessing the material being proposed to be deposited at the disposal site. Further confirmatory testing of chemical constituents is optional for disposal site sampling and analysis.

3.2.4 When dump-site chemical contamination is a concern, how can toxicity be tested?

Low cost, low technology toxicity tests (bioassays) can be considered to confirm whether dredged material deposited at a dump-site may be causing toxic effects on marine organisms. These effects may be caused by chemical contamination present at the dump-site, and so, bioassays can be used to:

- Indicate the presence of potential contamination; or
- Confirm whether contamination at the dump-site is available to marine organisms.

WHAT IS TOXICITY?

For the purposes of this guide, toxicity is defined as a negative effect on an organism (or organisms) following exposure to dredged material. The cause of toxic effects will often be chemical (i.e. due to the presence of chemical contamination in the dredged material at a level (dose) sufficient to cause a harmful effect). There are many possible types of toxic effects, such as effects on survival, reproduction, or growth.

Although bioassays can be complex to conduct and interpret, there are some tests that can be conducted at low cost and interpreted easily. Even when standard procedures are not available, toxicity tests can provide useful insights into the possible toxicity of the sediment at the dump-site, if they are conducted the same way on all sediment and control sediments used in a monitoring study.

WHAT IS A TOXICITY TEST (BIOASSAY)?

A toxicity test or bioassay involves exposing an organism to a potential toxicant (e.g. dredged material), and collecting information about the effects (toxic end points) resulting from this exposure (e.g. death, reduced rates of reproduction, changes in behaviour).

One example of a low cost, low technology bioassay is a marine rotifer lethality test, using a species such as *Brachionus plicatilis*. Figures 42 and 43. Rotifer tests can be completed in one to two days, require small sample volumes (e.g. 250 ml) and minimal equipment to perform, and are available as kits (e.g. http://BioToxicity.com) that have a long (several month) shelf life. There is no need to culture and maintain organisms for use in testing. Rotifer tests cannot be used to test whole sediment, but can be performed on elutriates made from test sediments and that are free from small particles (i.e. that have been centrifuged, or filtered when a centrifuge is not available). In general, conducting a rotifer test involves:

- Hatching juveniles from cysts under a continuous light source before the start of the test;
- Preparing a dilution series from the elutriate(s) to be tested;
- Filling test chambers with elutriate(s);
- Adding rotifers to test chambers (a dissecting microscope is needed for this);
- Incubating the test chambers in darkness for a set period of time;
- Counting the number of dead (immobile) rotifers; and
- Calculating the percent mortality.

Figure 42 – *Salt water rotifer,* Brachionus plicatilis Source: Yale University. http://www.yale.edu/caccone/ecosave/past_phylo.html

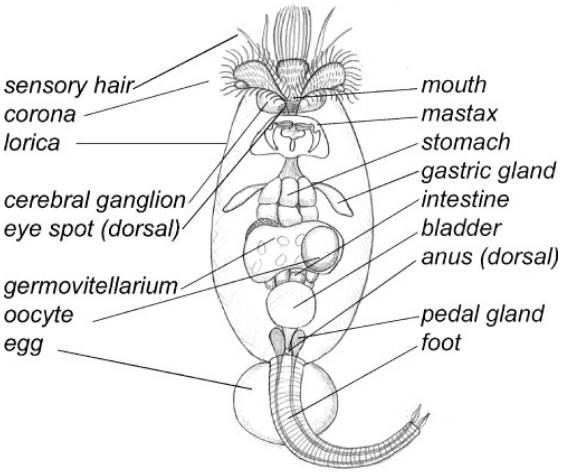

Figure 43 – *Schematic of* Brachionus plicatilis*. Shown is an adult female in a ventral view carrying one shed egg* Source: Science Open. https://www.scienceopen.com/document/vid/c31b556e-7174-4173-abd7-f172afe3739c;jsessionid=0NfuxoMsQJlcLex5vhft+MvN.slave:so-app2-prd?0.

Another low technology low cost bioassay is a marine diatom (algae) growth test, using a species such as *Phaeodactylum tricornutum*. Marine diatom tests take two to three days to complete, and share many of the same properties as rotifer tests; they are available as kits with long shelf lives, are easy to interpret, and require minimal sample volumes and specialized equipment (a spectrophotometer is required to collect test results). Marine diatom tests measure toxic effects on growth (e.g. they assess whether an elutriate inhibits the growth of organisms). They cannot be used on whole sediments, but can be performed on elutriates made from test sediments and that are free from small particles (i.e. that have been centrifuged, or filtered when a centrifuge is not available). In general, the test protocol for a marine diatom test involves:

- Pre-culturing the diatoms under a continuous light source before the start of the test;
- Preparing a concentrated diatom suspension and determining its concentration;
- Preparing a dilution series from the elutriate(s) to be tested;
- Inoculating elutriate dilutions with diatoms from the concentrated suspension;
- Transferring diatom-elutriate solutions to test chambers;
- Incubating algae for three days under a continuous light source;

- Recording optical densities of solutions each day; and
- Calculating daily mean daily optical density values for replicates of each sample.

Results from bioassays can be used to accept or reject null hypotheses about the presence of contaminants at the dump-site, or the toxicity of dump-site sediments. Having pass/fail criteria for bioassays will help with this; for example, a lethality test "fails" if the difference between percent mortality observed in a sample differs by more than 25% from mortality observed in a seawater control; or, a growth inhibition test "fails" if the difference in mean daily optical density at the end of the test is more than 35% different from that observed in reference or control samples.

There are several other salt-water sediment toxicity tests that may be adaptable for low cost, low technology situations (Shuba et al., 1981; USEPA, 1991; USEPA, 1998). As capacity increases, tests involving organisms that are present in the sediments in or near the dump-site can be considered for their increased ecological relevance. Figure 44 shows a number of common species used for more advanced bioassays than are suggested in this guidance.

Type	Test	Country
Screening	Microtox (STP)	The Netherlands Canada Australia Spain
Solid phase	Amphipods	The Netherlands Canada USA UK Australia Spain
	Benthic algae viability	Australia
Liquid phase	Sea urchin embryo development	Canada Spain USA
	Sea urchin fertilization and larval development	Australia USA
	Bivalve larval development	Australia
	Tiger prawn survival (post-larvae)	Australia
	Algal growth inhibition test	Australia
Bioaccumulation	Bivalves	Canada USA
	Polichaetae	USA

Figure 44 – *Examples of advanced sediment bioassays used by various countries* Source: DelValls et al. 2004.

When interpreting bioassay results, it is important to note that no organism is universally sensitive to contamination. This means that when a sample "passes" a bioassay using a particular organism, one cannot rule out the presence of contamination that may be toxic to another organism. For this reason, using more than one bioassay, and including different organisms and toxic end points, can increase confidence that dump-site sediments are or are not toxic, or that dump-site sediments probably do or do not contain chemical contamination. It is also worth noting that bioassay results and chemistry results may not align with each other, because observed toxicity may be caused by a contaminant that was not analysed, or a test organism may not be sensitive to a contaminant that was detected. When chemical results and bioassays both suggest reasons to be concerned about effects at the dump-site, a progression to more advanced biological effect monitoring techniques or management of contaminant sources at the site being dredged should be considered.

3.2.5 Sampling and laboratory testing for chemical contaminants or toxicity

Sampling of water quality at the dump-site or of sediments for chemical or biological testing can be conducted using procedures described in this guidance.

The analytical methods for potentially relevant parameters range from simple, straightforward and reasonably available throughout much of the world, to complicated, difficult, and not practically available in many countries.

It would be counterproductive to request analyses that cannot reliably and reasonably be performed in association with the project being evaluated. For example, if a given chemical analysis or bioassay could only be done after several days of transport to get the samples from the dredging and disposal project to the laboratory at tropical temperatures, and in addition, the performance of that analysis was new to the laboratory (or they were untrained or unequipped to reach the required detection levels), the results may be of little value.

No matter how desirable sophisticated analyses may be, it is usually best to request analyses that are logistically practical and within the demonstrated capabilities of the available laboratories. However, it may be appropriate to encourage the available laboratories to progressively expand their capabilities.

3.2.6 Sediment elutriate bioassay tests

The elutriate test should be conducted by mixing a sample of sediment from the dump-site with water collected just above the dump-site and mixing vigorously. After allowing time for larger particles to settle, the water (i.e. the elutriate) can be poured off and used in the rotifer or diatom toxicity test. The standard elutriate test involves the mixing of one part bottom material from a dump site with four parts native water (volume per volume) from a disposal site for 30 minutes, followed by centrifugation (or filtration through a 0.45 µm filter if a centrifuge is not available).

Specific procedures are provided below:

Prior to use, all lab ware should be thoroughly cleaned. At a minimum, the lab ware should be washed with detergent, rinsed five times with tap water, placed in a clean 10% hydrogen chloride acid bath for a minimum of 4 hours, rinsed five times with tap water, and then thoroughly flushed with either distilled or deionized water.

The elutriate should be prepared by using water from the dump-site. The elutriate is prepared by subsampling approximately 1 litre of the sediment from a well-mixed original sample. The sediment and unfiltered water are then combined in a sediment-to-water ratio of 1:4 on a volume basis at room temperature (20 to 24 degrees Celsius). This is best accomplished by volumetric displacement. After the correct ratio is achieved, the mixture is stirred vigorously for 30 min with a magnetic stirrer. At 10-min intervals, the mixture is also stirred manually to ensure complete mixing. After the 30-min mixing period, the mixture is allowed to settle for 1 hour. The supernatant is then siphoned off and centrifuged or filtered through a 0.45 µm mesh filter to remove particulates prior to chemical analysis, without disturbing the settled material, and immediately used for chemical or bioassay testing (USEPA, 1991). Note that centrifugation is preferred, as filtration can affect bioassay test results. Control tests should always be conducted to allow proper interpretation of the results.

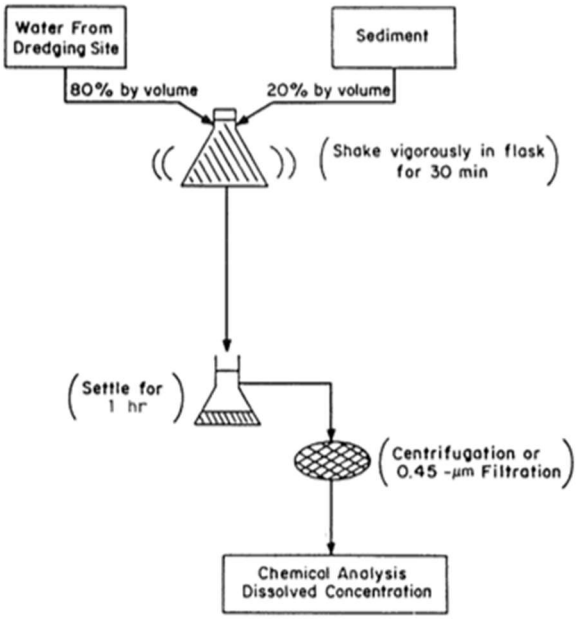

Figure 45 – *Standard Elutriate Test for Chemical Analysis or Bioassays* Source: Ludwig et al., 1988.

3.2.7 Sending samples to out-of-the-country laboratories

If analyses of possible chemical contamination are needed and there is no/limited access to qualified laboratory facilities within a country, then an option is to have the samples tested in laboratories in other countries. There are many reputable laboratories in various countries that can test the samples for a suite of chemicals. Laboratories generally provide instructions of how to take, store, and send samples. Many countries that are already Contracting Parties to the London Convention/Protocol should be able to provide advice on selection criteria for such laboratories. Sending samples abroad for toxicity testing may also be possible, although long storage and transport times in controlled conditions may compromise the quality of the sediment samples and the test results.

3.2.8 Sampling, storage, handling, and analysis considerations for chemical contaminants/bioassays

Annex 6 provides background information on sampling, handling, storage, and analysis for chemical contaminants and bioassays.

3.3 Field sampling and evaluation techniques for biological health of sediments at the dump-site

This section provides guidance on a visual approach to a biological evaluation of the health of sediments, which can provide useful information on the potential impacts of chemical contamination in the sediments at the dump-site.

3.3.1 Sampling and evaluation of the biological health of sediments

To achieve a qualitative assessment of the effects of the material deposited at the disposal site, an assessment and comparison of marine life at the disposal site, outside the disposal site, and in the material to be dredged

provides useful information. Traditional sampling tools (e.g. grabs) can be used to obtain samples from which sediments and their associated benthic organisms can be evaluated (i.e. macrofauna) (e.g. Boyd, 2002; Eleftheriou and McIntyre, 2005). Samples of fish and shellfish at the site can also provide valuable information.

3.3.2 What marine life is in the proposed material to be disposed of?

An assessment of the potential impacts upon the biological community at the disposal site should be undertaken by obtaining a sample of the sediment to be dredged (or a sample similar to the material already dredged and disposed of at the site) and examining the marine life it supports. If there is an abundance of marine life present, then this would suggest that the sediment will not have a significant negative impact on the biota at the disposal site due to chemical contamination. If the material being placed at the disposal site is devoid of biota, or if it contained high numbers of only a few species, then this can indicate the opposite. A sample of the sediment from the proposed dredging area can also be compared to a sediment sample of similar composition from a nearby area where sources of contamination are unlikely. See figure 46.

Figure 46 – *Sorting through sediment sample for macroinvertebrates (generally, sieving is considered as the preferred in the first step* Source: http://www.sciencelearn.org.nz/Contexts/Life-in-the-Sea/Sci-Media/Images/Sorting-sediment-samples.

3.3.3 Practical assessment of the habitat and species at the site before disposal

Before disposal occurs, surveys by divers of the disposal site and surrounding areas, or simple boat-based surveys obtaining bottom sediment samples, will give an indication of the species and habitats present within the potential dumpsite and will help provide information about the potential impacts associated with dumping of dredged material at the site. Monitoring of marine organisms can be undertaken by divers in areas where monitoring sites are shallow enough for divers to be able to reach the seabed for suitable lengths of time. Some habitats such as sub-tidal rocky areas and ecologically sensitive areas (such as coral reefs or seagrass beds), which may be near the disposal site, do not lend themselves to being monitored using grab samples as described above. Often, these types of environments are more sensitive than soft sediments to potential impacts (e.g. siltation). Therefore, to obtain data, divers can be used to survey these areas and undertake visual observations of the sediment type and species that they encounter.

3.3.4 Simple evaluation of the benthic community

Several years after disposal of sediment at the site, evaluation of the status of the organisms living directly on the seabed is another useful procedure. Physical smothering and adverse effects upon benthic communities is expected, but depending upon the amount of material being placed at the site and the size of the site, analysis of the recolonization of benthic organisms can provide useful information. Benthic communities are especially suited for comparative investigations since many of the constituent species have low mobility, are relatively

long lived, and integrate effects of environmental change over time (e.g. from dredged material disposal). Several simple approaches can be used for a basic evaluation of the benthic community, such as total number of species, total abundance, and the presence of key indicator species, providing useful information on the sediment condition. Comparison to a reference site is helpful. Also, if information is available on the benthic community at the disposal site prior to dumping, this information can provide a good comparison to assess the health of the benthic community at a point in time after disposal when recolonization should have occurred.

Pohle and Thomas (undated) provide recommendations and guidelines for sampling, sample processing and data analysis of marine benthos. See the text box.

SEDIMENT SAMPLING FOR BENTHIC COMMUNITY EVALUATION (POHLE & THOMAS, UNDATED)

Sampling

Grab samplers need to be deployed from vessels and lowered vertically to the seafloor. On reaching the seabed, the jaws of the grab "bite" out a volume of sediment.

Initial handling

Before unloading of the grab, the condition of the sample needs to be ascertained and recorded before emptying the contents into a container. Samples can be emptied into appropriately marked or labelled buckets until further processing is possible.

Sieving of the samples

Benthic samples need to be sieved to separate the animals from the sediment. The sieves/screens used are made from stainless steel, bronze or brass gauze attached to the bottom of a sturdy frame 15-25 cm high. The size of the holes in the sieve will greatly affect the numbers and types of animals retained. Using a 5 mm mesh sieve will retain larger individual animals, 1 mm mesh can also be used but this would retain more animals and take longer to process. Organisms are removed and transferred to plastic bottles or buckets (depending on the size of the sample).

Processing

Samples can be processed immediately, however, usually they are fixed with a preservative so they can be sorted later. Samples can be fixed with a formaldehyde preservative solution, sometimes with Rose Bengal stain added to enable easy identification of organisms (it makes the organisms colour pink which aids the sorting from the remaining sediment and detritus in a sample). Samples should be appropriately labelled with relevant information to identify when and where they were taken.

Sorting

The sorting is generally carried out using a microscope together with fine stainless steel forceps. A small amount of the sample to be sorted is processed initially for ease of identification of the organisms. This process is repeated until the entire sample has been completely sorted. The data are recorded. The identification of the organisms would require a suitably experienced/qualified person.

Analysis

The data should be analysed statistically to determine if there are any significant changes in the benthic communities at the monitoring sites (both potentially impacted and reference stations) before and after the disposal operations.

3.3.5 Sampling for fish — the otter trawl

The otter trawl is a specialized net for catching fish on the bottom of the ocean in sandy or silty sea beds. In trying to determine the health of the ocean bottom environment, it is sometimes helpful to collect real fish for the study. If the ocean bottom is too muddy, or has too many rocks or boulders, the otter trawl does not work very well. It is slowly dragged along the bottom, (at about 2 knots, or 3 km per hour). Comparison between the fish and shellfish caught in the otter trawl the disposal site and at a reference site can be very helpful in determining whether unacceptable adverse impacts are occurring as a result of the disposal actions (figure 47).

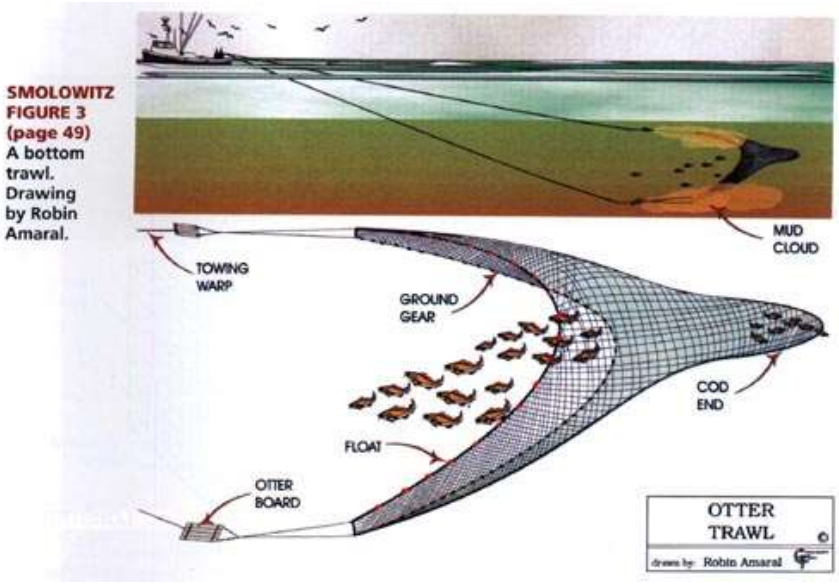

Figure 47 – *Otter trawl. Deployment of an otter trawl to sample hard-bottom associated fish and invertebrates is another assessment technique for biological evaluation of the site*
Source: http://www.fishingnj.org/diaotter.htm.

3.3.6 Characterize the sediment habitat through image profiling*

Another useful technique is the use of a sediment profiling camera, although not thought of as low technology, it can be a cost-effective monitoring tool. The equipment is placed into the sediment up to 18 cm deep and a camera takes a photograph of a profile of the sediment-water interface (figures 48 and 49). The sediment profiling camera can provide qualitative information on physical and biological characteristics of the bottom sediment. Camera surveys enable delineation of bottom habitats into "strata" based on similarities in physical and biological parameters. Use of sediment profilers to qualitatively characterize the disposal site can help to reduce the number of sampling stations in efforts to more fully understand the physical and biological characteristics. The primary advantages of sediment profiling cameras are cost-effectiveness and rapidly obtaining qualitative data about the site. Use of the camera system is not recommended as the sole source of biological data for the site (Fredette, 1990). In addition, most sediment profilers include an underwater camera that takes a photograph of the bottom just before the profiler is deployed into the sediment. This provides additional information that can be used to evaluate the site.

* Sediment profiling is not really considered as low technology and the profiler in figure 32 is unlikely to be considered low cost. However, if there is access to a profiler, the costs are likely to be less than a full benthic survey.

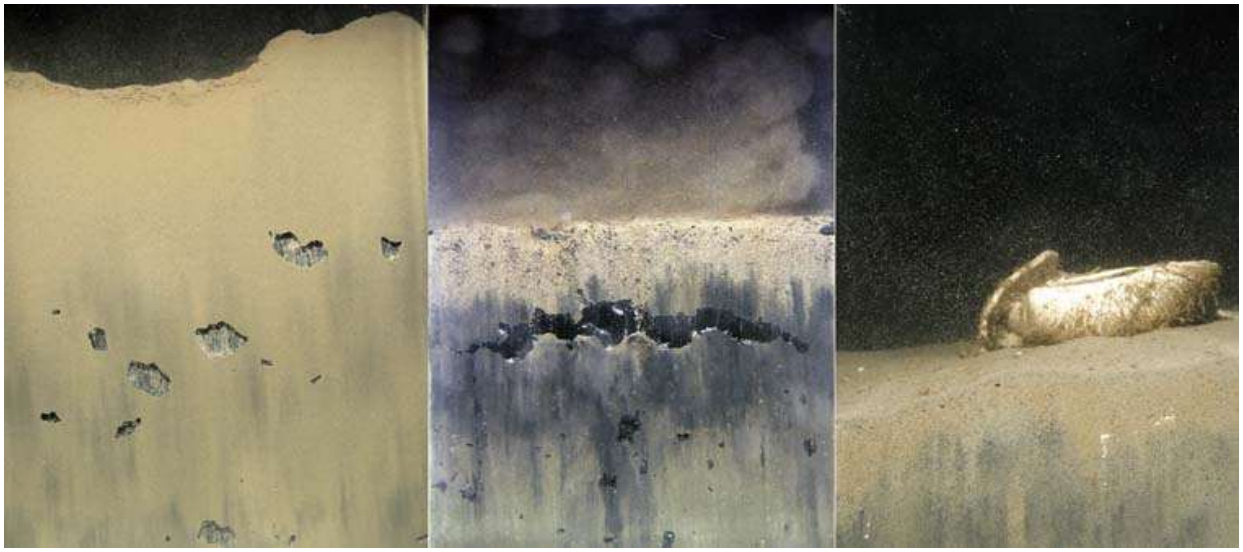

Figure 48 – *Sediment profile camera images* Source: Joe Germano, copyright. http://www.remots.com.

SEDIMENT PROFILE CAMERA Source: http://www.coml.org/investigating/observing/spi

The sediment profile camera can provide the following information to characterize a benthic habitat: grain size sediment surface relief, epifauna present in the image area, organism tube density and types, and infauna present in the image area. From this information, the benthic faunal assemblage can be predicted, infer the relative abundance of the fauna, examine the animal-sediment relationships, and identify the relative importance of bioturbation and biogenic sedimentation (Roads and Germano, 1982).

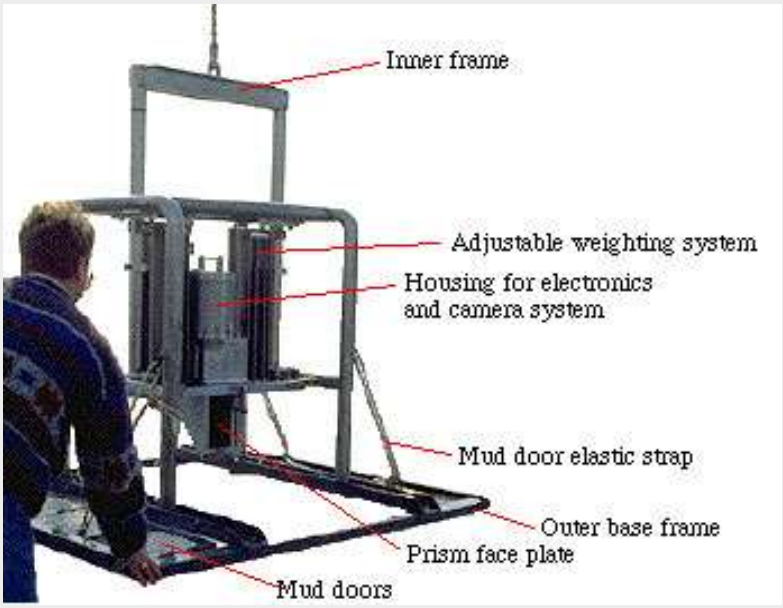

Figure 49 – *A sediment profile imager, highlighting the key components*
Source: John Costello, Aqua-Fact International Services Ltd.

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Annexes

Page

Annex 1

London Protocol and London Convention Waste Assessment Guidelines
Where does field monitoring fit into the assessment process? (see bold type)

London Protocol and London Convention Dredged Material Waste Assessment Guidelines:

1. Evaluation of the need for dredging and disposal
    a. Is dredging necessary?
    b. Can the dredged material be used in a beneficial manner?
2. What are the characteristics of the dredged material?
    a. Is sufficient information available regarding the physical, chemical, and biological characteristics to determine whether the material will likely cause unacceptable adverse impacts?
    b. Develop a conceptual model of pathways and receptors
    c. What are the physical characteristics of the dredged material?
    d. Is the dredged material exempt from further testing based upon the exemption criteria?
    e. Identify contaminants of concern. What historic upstream sources of contamination or current sources exist or what types of chemical constituents may be in the proposed dredged material?
    f. What existing information and data are available?
    g. If needed, conduct chemical testing, and assess bioavailability of contaminants
    h. If needed, conduct bioassay testing
3. Waste prevention audit
    a. Are there practical opportunities to reduce the volume of dredged material to be disposed of?
    b. Are there practical opportunities to control the sources of contaminants in the dredged material?
4. Is the dredged material acceptable for ocean disposal?
    a. Prepare the action list
        i. Identify the physical, chemical, and biological characteristics relative to causing potential impacts to the marine environment
        ii. Identify the associated effect levels (i.e. benchmarks) for each characteristic
        iii. Specify an upper level and a lower level
    b. Prepare action levels—integrate characteristics and benchmarks to set decision rules; consider:
        i. Simple pass/fail approach
        ii. Combining multiple lines of evidence in a weight of evidence approach
5. Evaluation of disposal options
    a. Is the dredged material acceptable for disposal in marine waters?
    b. Can the dredged material be used beneficially?
    c. Can management options be used to control impacts to acceptable levels?
6. Dump-site selection considerations
    a. Physical, chemical, and biological characteristics of the water column and seabed
    b. Location of amenities, biological features, and other uses of the sea
    c. Size and capacity of the dump-site
    d. Potential impacts
    e. Economic and technical feasibility

7. Assessment of potential effects
    - **a. Prepare impact hypotheses**
        - **i. Use conceptual model**
        - **ii. Identify potential impacts and describe in null hypotheses**
    - b. **Design the field monitoring programme based on the impact hypotheses**
8. Issue permit
    - a. Specify conditions
        - i. Types, amounts, sources of materials
        - ii. Location of the dump-site
        - iii. Method of dumping
        - iv. Monitoring and reporting requirements
    - b. Review results of monitoring to determine if revisions to permit needed
9. **Conduct monitoring**
    - a. Compliance monitoring
    - **b. Field monitoring**

Annex 2

Conceptual models of pathways of exposure

A simple example of a graphical conceptual model for use in a sediment assessment, where contaminants associated with the sediment represent the focus of concern, is shown below (PIANC, 2006b; Bridges et al., 2005). In this case, receptors in the environment are expected to come in contact with contaminants in the sediment through one of three primary pathways: (1) through contact with bedded sediment particles, (2) through contact with water that is contaminated via the sediment, and (3) through contact with contaminants that bioaccumulate within the food chain.

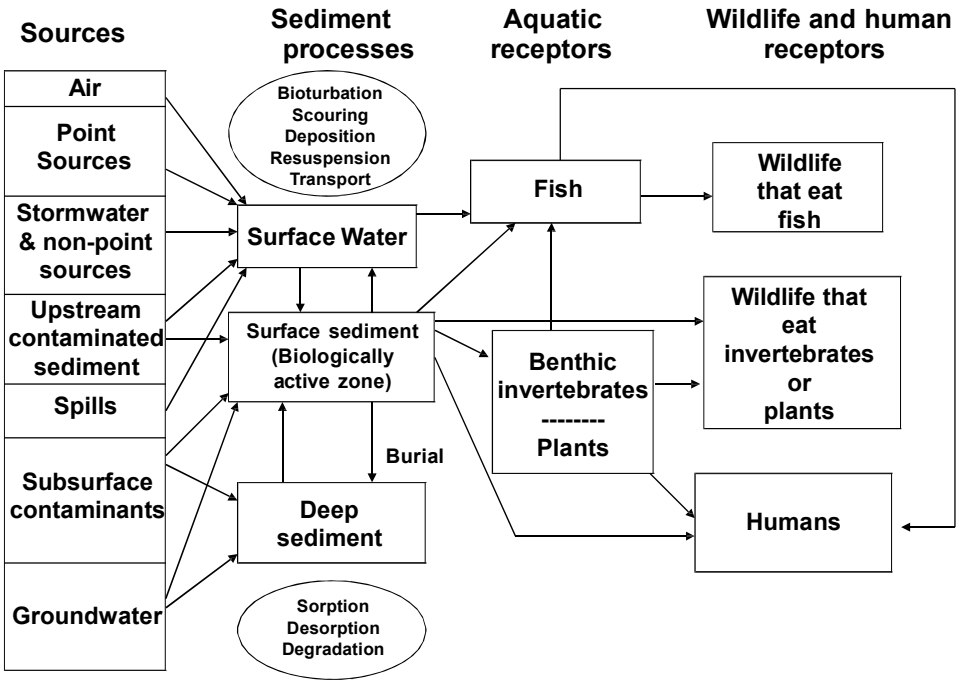


Figure A2-1 – *Graphical conceptual model for use in a sediment assessment*

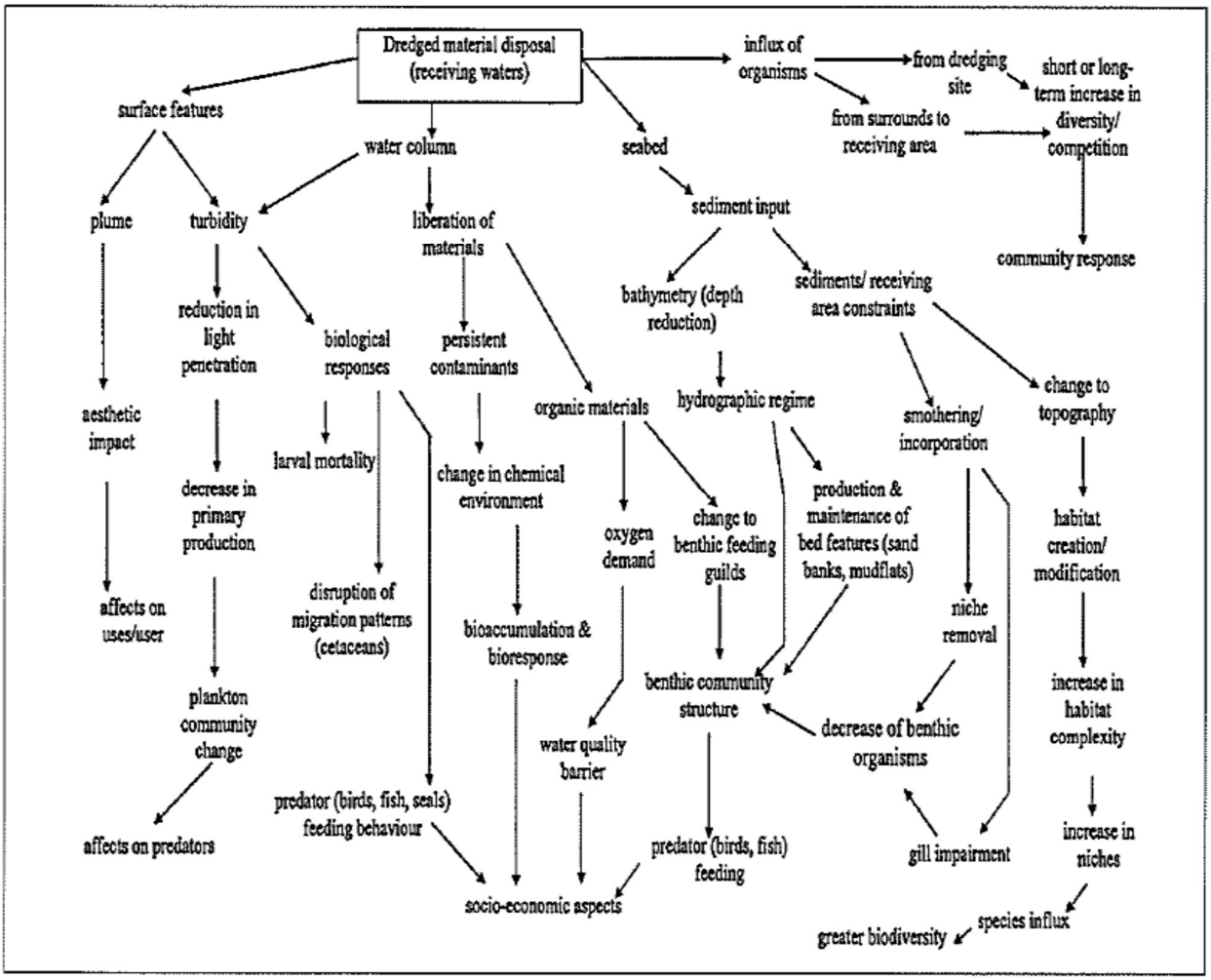


Figure A2-2 – *Overall risk assessment framework*

Extracted directly from the PIANC Guidelines on Risk Assessment (PIANC, 2006), this conceptual model provides the overall risk assessment framework for addressing a proposed dredged material disposal project. The reader is directed to the document for more information.

Annex 3

Compositing of samples*

Subsampling and compositing samples

The decision to subsample and/or composite sediment samples within or among stations depends on the purpose and objectives of the study, the nature and heterogeneity of the sediments, the volume of sediment required for analytical and/or toxicity assessment, and the degree of statistical resolution that is acceptable. Subsampling and compositing might be accomplished in the field if facilities, space, and equipment are available, or alternatively, in a laboratory setting following sample transport.

HOW SHOULD SEDIMENT SAMPLES BE SUBSAMPLED AND COMPOSITED?

- Overlying water should be siphoned off, not decanted, from grab samplers prior to subsampling.
- All utensils that are used to process samples should be made of inert materials such as Teflon® or quality stainless steel.
- Subsamples should be collected away from the sides of the sampler to avoid potential contamination.
- Sediment samples should be processed prior to long-term storage, within 72 hours (and preferably within 24 hours) of collection.
- Sufficient sample homogenization, prior to placing in containers, is critical for accurate measurements and correct sediment quality determinations.
- If rigorous evaluation of metal contamination is a focus of the study, or if anaerobic conditions need to be maintained for other reasons, it might be necessary to homogenize, subsample, and composite samples in an oxygen-free glovebox or other suitable apparatus.
- Similar depth horizons or geologic strata should be subsampled when compositing core samples.

General Procedures

Subsampling is useful for collecting sediment from a specific depth of a core sample, for splitting samples among multiple laboratories, for obtaining replicates within a sample, or for forming a composite sample.

Compositing refers to combining aliquots from two or more samples and analysing the resulting pooled sample (Keith, 1993). Compositing is often necessary when a relatively large amount of sediment must be obtained at each sampling site (for instance, to conduct several different physical, chemical or biological analyses). Compositing might be a practical, cost-effective way to obtain average sediment characteristics for a particular site (see Table 2-2), but not to dilute a polluted sample. Also, if an objective of the study is to define or model physicochemical characteristics of the sediment, it might be important not to composite samples because of model input requirements (EPRI, 1999).

All utensils (e.g. spoons, scoops, spatulas) which come in direct contact with sediment samples during handling and processing should be made of non-contaminating materials (e.g. glass, high-quality stainless steel and/or Teflon®).

* Reproduced from USEPA, Office of Water. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual,* EPA-823-B-01-002. October 2001.

ALL HANDLING PROCEDURES CARRY THE RISK OF SAMPLE CONTAMINATION. THEREFORE, SEDIMENT SAMPLE HANDLING SHOULD BE KEPT TO A MINIMUM

Potential sample contamination can be caused by the following common situations:

- Making field measurements of sediments using contaminated probes, utensils, or other instruments.
- Contaminated and uncontaminated stations are sampled without appropriate decontamination of equipment between stations.
- The parameter of interest is volatile (e.g. ammonia, acid volatile sulphides, or volatile organics) and samples are exposed to air.
- Samples are exposed to vessel exhaust fumes, lubricants, or rust.

Grab Samples

If a sediment grab sample is to be subsampled in the laboratory, the sample should be released carefully and directly into a labelled container that is the same shape as the sampler and made of a chemically-inert material (see [annex 6?] for recommendations on containers). The container must be large enough to accommodate the sediment sample and should be tightly sealed with the air excluded.

If the grab sample is to be subsampled in the field, it is desirable to subsample from the sampler directly to minimize sediment handling and associated artefacts. Therefore, the sampler should allow access to the surface of the sample without loss of water or fine-grained sediment. This typically dictates the use of a grab sampler with bucket covers that are either removable or hinged to allow access to the surface of the sediment sample (e.g. Ponar, Van Veen).

Prior to subsampling from the grab sampler, the overlying water should be removed by slow siphoning using a clean tube near one side of the sampler (WDE, 1995; PSEP, 1997a). If the overlying water in a sediment sampler is turbid, it should be allowed to settle if possible.

WHEN WORKING WITH GRAB SAMPLES

- Decanting the water, or opening the jaws lightly to let the water run out is not recommended as these methods might result in unacceptable disturbance or loss of fine-grained sediment and organic matter.
- If metal contamination or sediment oxygen demand are of concern, oxidation of sediments could significantly alter their characteristics. Process the sample in a glovebox or similar apparatus under an oxygen-free environment.
- For samples that are suspected of heavily elevated polynuclear aromatic hydrocarbons (PAHs), process immediately under low light upon retrieval to minimize ultraviolet light- activated toxicity of PAHs (Ankley et al., 1994).

The general subsampling and compositing process for grab samples is illustrated in figure 4-2. Subsampling can be performed using a spoon or scoop made of inert, non-contaminating material. *Sediment which is in direct contact with the sides of the grab sampler should be excluded* as a general precaution against potential contamination from the device. Subsamples may be combined or placed into separate clean, pre-labelled

containers. If the sample is to be frozen, it is advisable to leave approximately 10% head space in the container to accommodate expansion and avoid breakage.

There are two alternatives for compositing sediment samples from grab samplers (see figure 1): (1) compositing and homogenizing (mixing) in the field, and (2) compositing in the field and homogenizing in the laboratory.

In some studies (e.g. where metals are the pollutants of concern), it might be necessary to subsample a grab sample under oxygen-free conditions to minimize oxidative changes. In these cases, it is recommended that a hand-coring device be used for subsampling. The core should be inserted immediately upon retrieval of the sampler, then removed and placed into a glove box or bag which is flushed with a constant, controlled volume of inert gas. The sediment within the core can then be extruded under oxygen-free conditions into deaerated containers. The presence of oxygen during handling and storage might be relatively unimportant (Brumbaugh et al., 1994) or very important (Besser et al., 1995), depending on the sediment characteristics, the contaminants of concern, and the study objectives.

COMPOSITING SAMPLES INVOLVES:

In the field

- Placing equal volumes of subsamples from individual grab samples in a clean container to form a composite sample.
- Transporting the composite to a laboratory.
- Homogenizing the sample at the laboratory to prepare it for testing (See Section 4.3 for further details).

In the lab

- Placing subsamples from multiple grabs in a clean container.
- Mixing the subsamples to form a homogeneous composite sample.
- Placing the composite sample in one or more containers, depending on the number of analyses to be performed.
- Transporting the composite sample to a laboratory (or laboratories) for testing.

Core Samples

Subsampling sediment core samples is usually done to focus the assessment on a particular sediment horizon or horizons and/or to evaluate historical changes or vertical extent in contamination or sedimentation rates. For example, core sampling may be important to assess the integrity of the cap at a disposal site that has been capped with clean material. Whenever subsampling of retrieved sediment cores is required, particularly for analysis of contaminants, the sediment should be extruded from the core liners and subsampled as soon as possible after collection. This can be accomplished in the field if appropriate facilities and equipment are available, or in the laboratory after transport.

Systematic subsampling (see figure 2) involves removing the sediment from the core in sections of uniform thickness. Each incremental core section corresponds to a particular sediment depth interval. In remedial dredging and geological applications, longer sections (e.g. 25-50 cm) are typically used to characterize a site.

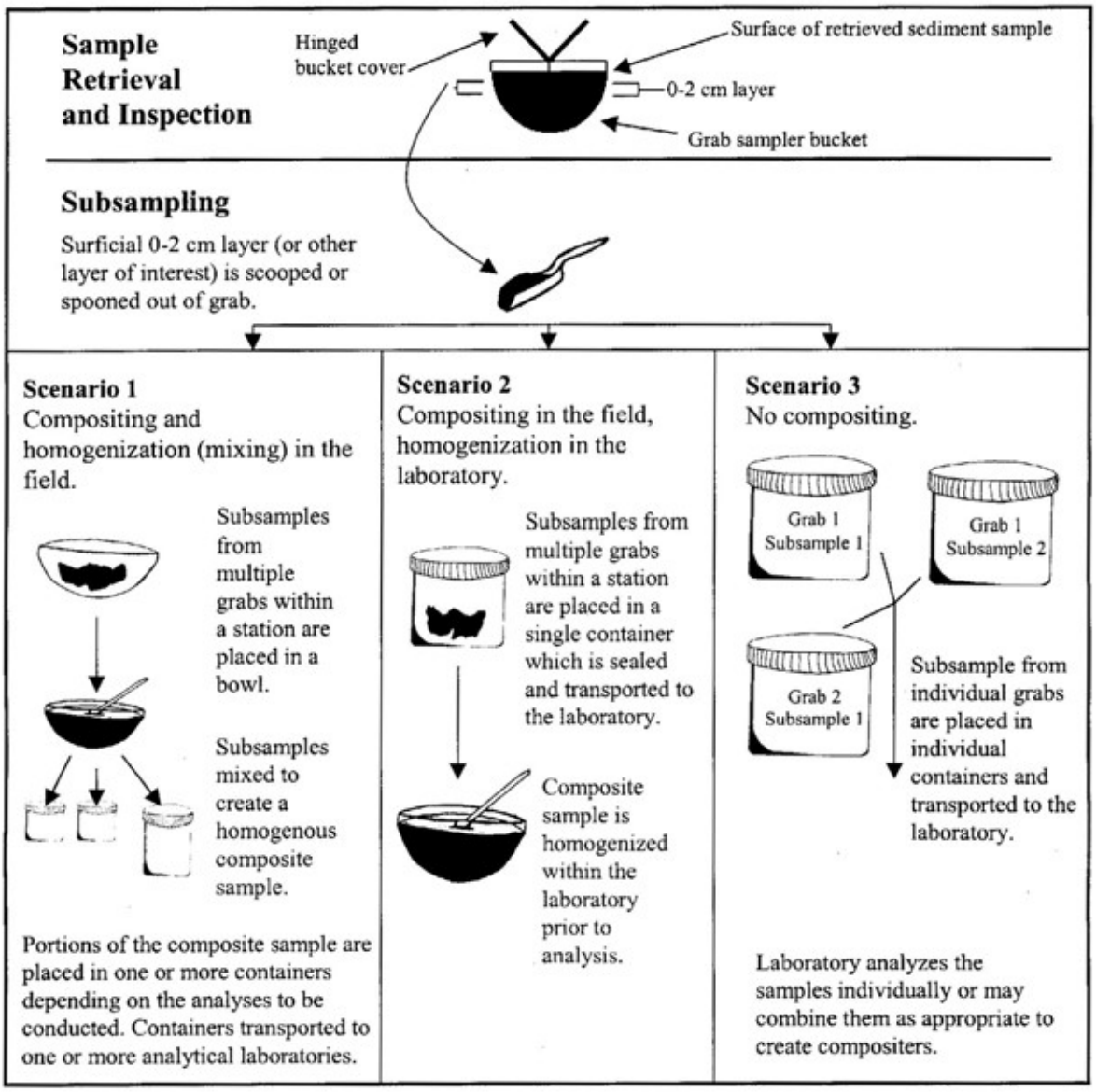


Figure A3-1 – *Alternatives for subsampling and compositing sediment grab samples*

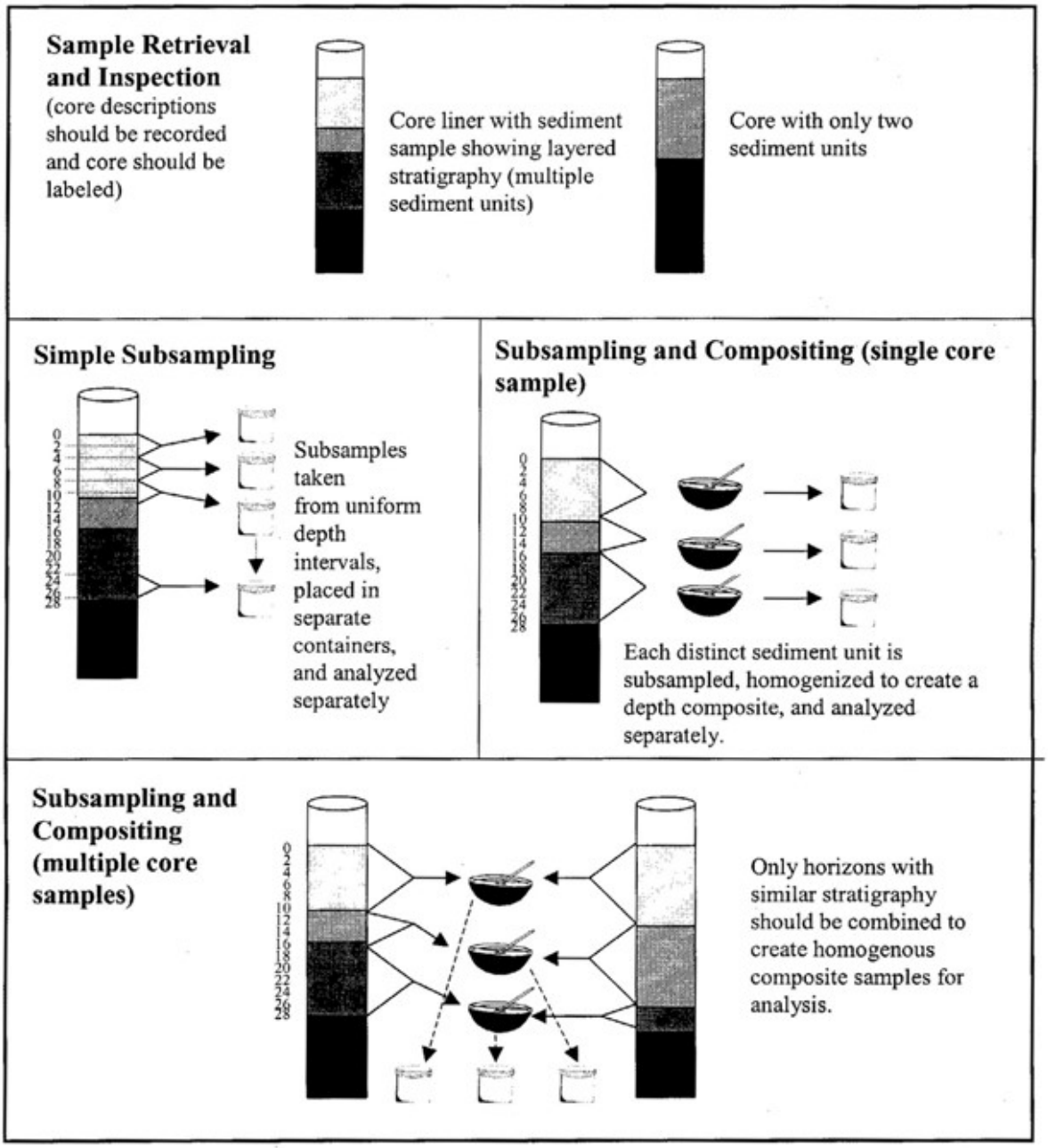


Figure A3-2 – *Alternatives for subsampling and compositing sediment core samples*

The depth horizon(s) sampled will depend on the study objectives as well as the nature of the substrate. Many programs have project-specific depths corresponding to study requirements, such as dredging depths for navigation or remediation dredging. In many regional or national environmental monitoring programs (e.g. EMAP), the uppermost surficial layer is sampled because information on the horizontal distribution of sediment contaminants is desired (USEPA, 2000d).

There are various methods for subsampling sediment cores including gradual extrusion, dissection of a core using a jig saw, reciprocating saws, use of a segmented gravity corer, a hand corer, or scoops and spoons. Cutting devices range from stainless steel knives to Teflon® or nylon string.

A piston-type extruder that applies upward pressure on the sediment is an instrument commonly used to gradually expose a core for sectioning in some monitoring programs where specific sediment depths have been defined a priori (Kemp et al., 1971). Note: For dredged material studies and other types of remediation projects, where pre-determined depth strata are not necessarily defined, it is usually important to view the entire core prior to sectioning or compositing. The capped core liner containing the sediment and overlying

water is uncapped at the lower end and placed vertically on top of the piston. The top cap is removed and the water is siphoned off to avoid disturbance of the sediment-water interface. The core liner is then pushed slowly down until the surface of the sediment is at the upper end of the liner. Sediment sections are collected by pushing the liner down and cutting the exposed sediment into sections of the desired thickness using a stainless steel or Teflon® cutter (Environment Canada, 1994; Mudroch and Azcue, 1995). A 1 to 2 mm outer layer of sediment that has been in contact with the plastic or metal liner should be removed and discarded, if possible, to avoid contamination. Each sediment subsample should be placed into a labelled, clean and chemically-inert container, or, if subsamples are being composited, into an appropriately sized mixing bowl. The size of the container should be as close to the volume of the sediment as possible to minimize the head space in the container. If it is desirable to maintain an oxygen-free environment during subsampling, then all handling or manipulations should take place in a glove box or bag filled with an inert gas and modified to accommodate the core liner through an opening (Environment Canada, 1994; Mudroch and MacKnight, 1994).

Cores of more consolidated material can be mounted onto a horizontal U-shaped rail and the liner cut using a saw mounted on a depth-controlling jig. The final cut can then be made with a sharp knife to avoid contamination of the sediment by liner material, and the core itself can be sliced with Teflon® or nylon string. The core then becomes two D-shaped halves that can be easily inspected and subsampled (Mudroch and Azcue, 1995). Sediment in contact with the saw blade should not be used for toxicity tests or metals analyses due to potential contamination from the saw blade. Another alternative for sectioning and subsampling is a segmented gravity corer described by Aanderaa Instruments of Victoria, BC, Canada. The core tube of the sampler consists of a series of rings placed on top of one another. Subsampling is carried out by rotating the rings around its other axis so that it cuts sediment layers of similar thickness. This segmented core tube is suitable for sampling fine-grained sediments and allows one person in the field to subsample the core into 1-cm sections (Mudroch and Azcue, 1995).

Sediment from box-core samples can be effectively subsampled with a small hand corer after the overlying water has been carefully siphoned off and discarded. Hand corers with small inner diameters less than 3 cm tend to compact sediments, so they must be used with care. Spoons or scoops have also been used to subsample surface sediments from a box corer (Environment Canada, 1994).

Like grab samples, core samples may be composited or subsampled in the field or laboratory after evaluating them for acceptability. Although there might be occasions when it is desirable to composite incremental core depths, it is recommended that only horizons of similar stratigraphy be composited. Depending on the study objectives and desired sampling resolution, individual horizons within a single core can be homogenized to create one or more “depth composites” for that core, or corresponding horizons from two or more cores might be composited (figure A4-2). Composite samples must be homogenized prior to analysis or testing.

Homogenization

Homogenization refers to the complete mixing of sediment to obtain consistency of physicochemical properties throughout the sample prior to using in analyses. Homogenization is typically performed on individual samples, as well as on composited samples and can be done either in the field or the laboratory.

General Procedures

Prior to homogenization, unrepresentative materials (e.g. twigs, shells, leaves, stones, wood chips and seagrass) are often removed and documented in an appropriate field log (see Section 5.2 for techniques to remove unrepresentative material). The need for removal of larger matter depends on the analyses to be conducted.

Mixing should be performed as quickly and efficiently as possible, because prolonged mixing can alter the particle-size distribution in a sample and cause oxidation of the sediments (Ditsworth et al., 1990; Stemmer et al., 1990a; b). If metal contaminants or volatile chemicals are a concern, samples should be mixed in a glovebox under an inert atmosphere and quickly partitioned into sample containers for analysis. See figure 3.

Figure A3-3 – *Homogenizing a composited sediment sample using a mechanical mixer* Photo by Chris Ingersol.

Mixing should be performed in a large, pre-cleaned glass or stainless steel bowl. The sediment should be thoroughly stirred with a clean glass, high density polyethylene, or stainless steel spoon until textural, colour, and moisture homogeneity are achieved (Environment Canada, 1994; PSEP, 1995). Hand mixing has also been performed by rolling the sediment out flat on a sheet of plastic or pre-combusted foil and tumbling the sediment by alternately raising each corner of the sheet (Mudroch and Macknight, 1994). This procedure, however, is not recommended where the anaerobic integrity of the sediment must be maintained.

HOW SHOULD SAMPLES BE HOMOGENIZED?

- Use a sufficiently large, pre-cleaned glass or stainless steel mixing bowl to homogenize the sample.
- Use clean glass polyethylene, or stainless steel implements (e.g. spoon) to mix sediment.
- Mixing should be performed as quickly and efficiently as possible while attempting to reduce oxidation of the sample.
- Intensive manual mixing of wet sediment, in a suitably large container, is usually sufficient to homogenize the sample (Burton et al., 1989; Ingersoll and Nelson, 1990; Johns et al., 1991a; Carr and Chapman, 1992).
- Regardless of the mixing method selected, the effectiveness of the method should be demonstrated using a homogenate replicate.

Mechanical mixers have also been used to homogenize samples (Ditsworth et al., 1990; Stemmer et al., 1990b; Kemble et al., 1993), including portable cement mixers (bare metal and Teflon®-lined) and portable drills fitted with a variety of stainless steel paddles (Kemble et al., 1994b).

Homogenate replicates consist of two or more subsamples, taken from different locations within a mixed sample, and then comparing analytical results of the replicate samples. After the sediment has been homogenized, it is generally partitioned among sample containers. Partitioning sediments for chemical or toxicity analyses may be accomplished using various methods. In one method, a number of small portions are removed from random locations in the mixing container and distributed randomly in all sample jars until the appropriate volume of sediment is contained in each sample jar for each analysis. During distribution, the

sediment is periodically mixed using a glass rod or porcelain spatula to minimize stratification effects due to differential settling, especially if the sediment is prone to rapid settling (ASTM, 2000a). An alternative is to use a splitter box designed to contain and then divide the homogenized sediment.

HOMOGENIZATION OF ANAEROBIC SEDIMENTS
Beware of over-mixing and/or introducing air to the sample. Such mixing is likely to change the chemical characteristics of the sample and yield unrepresentative results. This is especially important if samples are initially anaerobic or if volatile or labile chemicals are of interest (e.g. e.g. acid volatile sulfide (AVS)).

Annex 4

Do-it-yourself: construct your own monitoring tools*

Turbidity tube: how to construct and use a turbidity tube (Adapted from Myer and Shaw, 2006) for more detailed step by step instructions†).

A turbidity tube can be purchased commercially, or can be constructed at a nominal cost using a wide range of locally available materials. It is particularly well-suited to situations when decisions can be made based on approximate turbidity (rounded to the nearest 5 NTU).

The turbidity tube uses the correlation between visibility and turbidity to approximate a turbidity level. A marker is placed at the bottom of the turbidity tube until it can no longer be seen from above due to the "cloudiness" of the water. This height from which the marker can no longer be seen correlates to a known turbidity value. Although this correlation is less accurate than what would be obtained from other methods, it is almost certainly accurate enough in a low technology environment. Generally, the cost savings of using a turbidity tube outweigh this loss of accuracy.

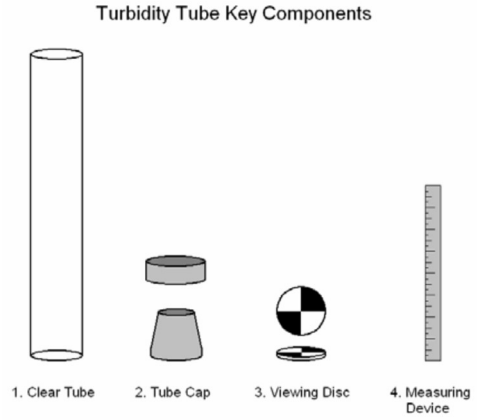


Figure A4-1 – *Turbidity tube key components*

Key components

A turbidity tube is made up of four key components:

.1 A clear tube

.2 A tube cap

.3 A viewing disk

.4 A measuring device

* Extracted from London Convention/London Protocol; *Waste Assessment Guidelines training set extension for application of low-technology techniques for assessing dredged material*; http://www.imo.org/OurWork/Environment/LCLP/Publications/wag/Pages/default.aspx.

† Myre, Elizabeth, Shaw, Ryan; *Simple and Accurate Measurement of Turbidity in the Field,* April 2006. http://www.cas.umn.edu/assets/pdf/Turbidity%20Tube.pdf.

.1 **Clear tube**: The clear tube will hold the water sample being tested. The tube must be clear to allow for maximum light reflectance off of the marker being viewed. Even a light coloured or white plastic tube will not let in enough light for the tube to work properly. A clear plastic tube will provide the most durability and reduce the chances of damage during transport, but a glass tube can be used if handled with caution. Possible clear tube materials: fluorescent light sleeve, graduated cylinder, etc.

.2 **Tube cap**: The tube cap prevents the water sample from leaving the clear tube. A seal to the end of the tube can be used, but a removable tube cap is preferred for cleaning of the tube and view disk. Make sure that whatever cap is used prevents leakage (a good seal is more important than removability). The size of your cap will depend on the size of your tube. Possible tube caps: rubber stopper, PVC pipe cap, Gatorade lid with rubber washer, chair leg end cap, etc.

.3 **Viewing disk**: The viewing disk will be submerged in the water sample. A clear pattern must be visible on the disk as well. Generally, it is best to use a white background that is coloured with a black checker pattern (this is the pattern typically found on a Secchi disk as well). The contrast makes the viewing disk very clear, which improves the accuracy of the reading. A white plastic disk patterned with black permanent marker works extremely well. The disk should be sized to fit inside the plastic tube. If necessary, the disk can be made of a porous material such as wood or cardboard, but it must be sealed by lamination or with varnish. Possible viewing disks: yogurt container lid cut into a circle, white poker chip, etc. Possible marking device: black permanent marker, black paint, etc.

.4 **Measuring device**: The level of the water at the point of non-visibility needs to be measured. This can be done in two ways. The water level can be directly measured from the viewing disk to the top of the water, and a chart can be used to find the turbidity level that corresponds to the measurement. A better way is to mark the turbidity tube with the corresponding turbidity levels before testing begins so that no conversion is necessary. Your choice will depend on the availability of materials and the construction of your tube (for example, if the removal and reinsertion of your tube cap changes the height of your viewing disk, the marking will no longer be correct.) Possible measuring device: ruler, tape measure, etc.

General construction

As stated earlier, these instructions are very broad to encourage adaptations in the design. After obtaining the materials discussed above, do the following:

Step 1: Plan the placement of viewing disk

You will need to be able to see the viewing disk from the top of your clear tube. The placement of the disk will depend on your tube cap. The disk can be dropped to the bottom of your tube if it is not made of a floating material. A dropped disk will need to be marked on both sides. You can also attach the disk to your tube cap with adhesive so that it will be visible when the cap is inserted. Another possibility is to mark the tube cap with a chequered pattern so that it can be treated as a viewing disk.

Figure A4-2 – *Step 1: Viewing disk placement*

Step 2: Combine tube cap and viewing disk

Here, you can use adhesive or sealant to bind the viewing disk to the tube cap. Make sure the disk will fit properly when the tube cap is inserted into the tube (i.e. try it before you glue it). Again, you can also mark the chequered pattern directly on your tube cap, or a non-floating disk can be dropped from above (just make sure it is small enough so as not to get stuck in the tube or the bottom).

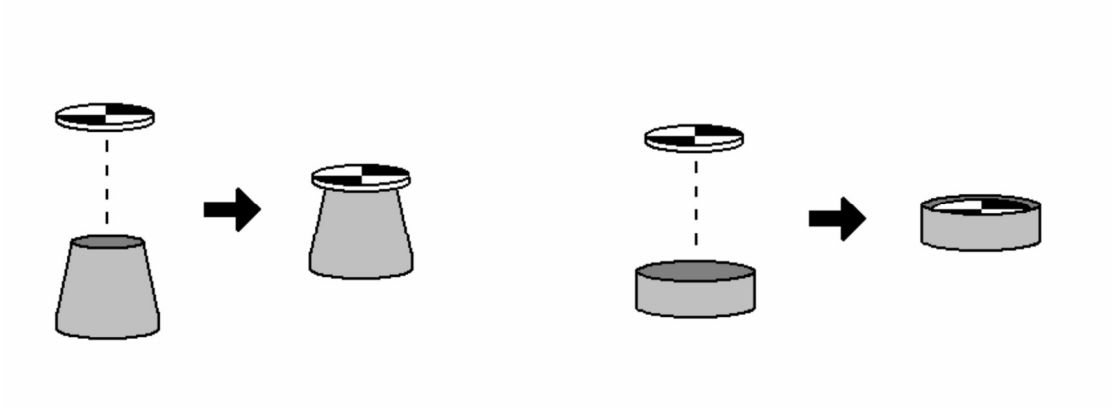


Figure A4-3 – *Step 2: Combining the tube cap and viewing disk*

Step 3: Affix tube cap to bottom of tube

Ideally, the tube cap will be removable for cleaning, but the primary concern is that water does not escape the tube during testing. Some sort of sealant or putty can be used to seal the cap well. Make sure the disk is still clearly visible from the top of the tube.

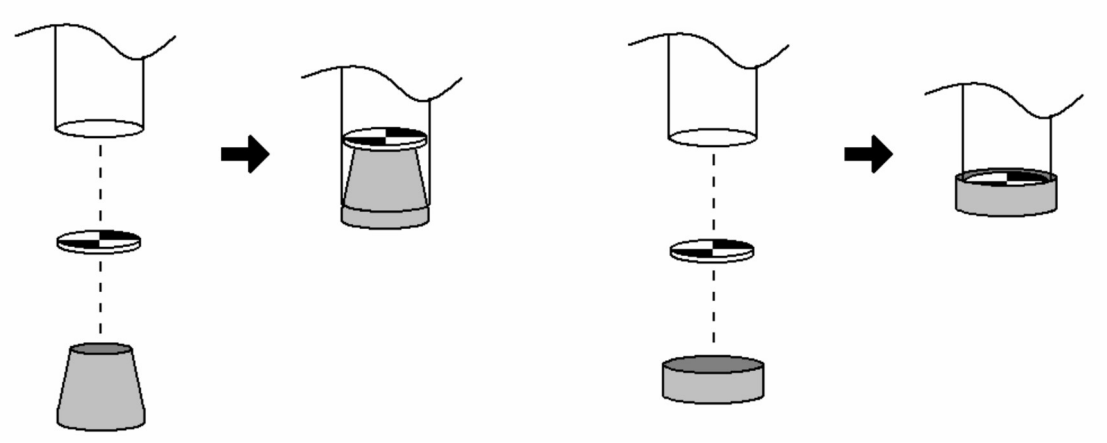


Figure A4-4 – *Step 3: Affixing the tube cap to the tube base*

Step 4: Mark tube with measurement increments

Ideally, the turbidity level will be marked directly onto the tube. Place the zero mark of a measuring tape or ruler *even with the viewing disk* and measure up the tube, marking the proper intervals found in the table below. Two rubber bands on each end of the tape will hold it in place well while you mark levels with a marker. If the tube is not easily marked, measurements in centimetres can also be taken and then used to find the corresponding turbidity in the table below.

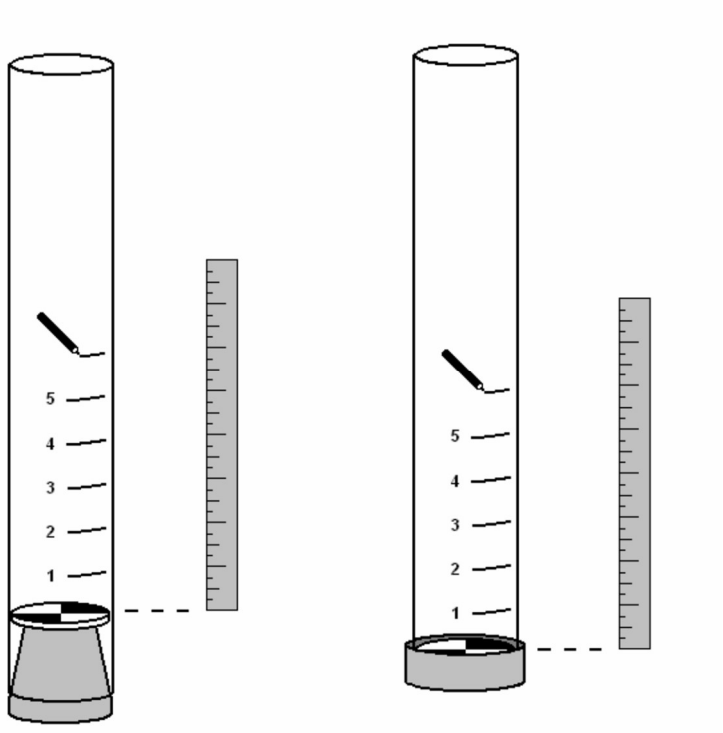


Figure A4-5 – *Step 4: Marking measurements on the tube*

The tube should now be complete. After all components have dried, test the tube for leakage and make adjustments accordingly. If you are not able to mark the tube directly and will be measuring the depth of the disk below the surface for each reading, try to attach the measuring device to the side of the tube (again, rubber bands work well).

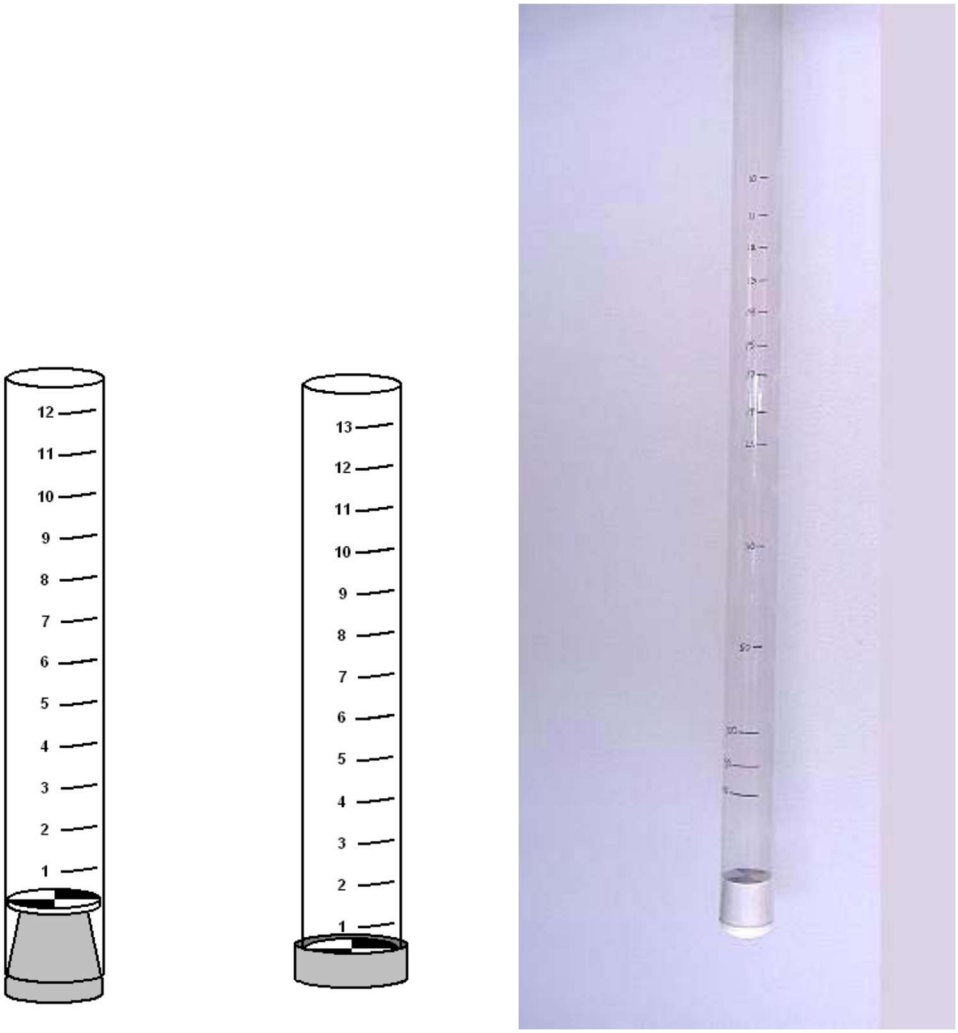
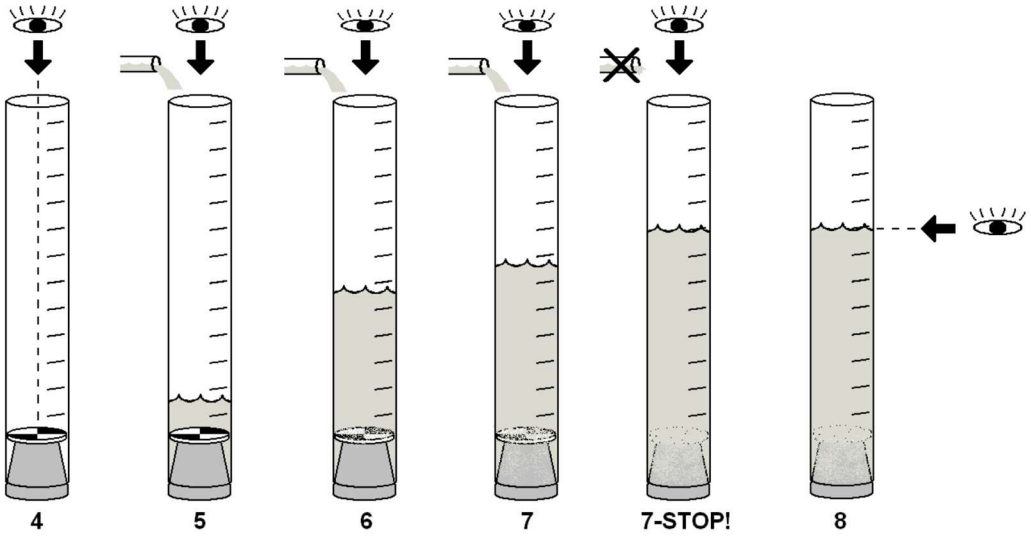


Figure A4-6 – *Completed turbidity tubes*

Of the available approaches to turbidity testing, a turbidity tube is the most appropriate method to test water when funds are limited. The turbidity tube is inexpensive, easy to use, and does not need to be restocked with batteries or testing supplies. A turbidity tube can be understood intuitively, even by non-engineers. Moreover, the use of a turbidity tube conveys more information about what is being measured than does looking at a read-out on a digital screen. This provides an opportunity to educate community members about many water quality issues, including source protection and treatment options. Turbidity tubes are also very portable and are designed for use in the field. This is an added benefit; turbidity is more accurately measured on-site as it can change rapidly during transport or storage (WHO, 2004).



Centimetres	NTU
6.7	240
7.3	200
8.9	150
11.5	100
17.9	50
20.4	40
25.5	30
33.1	21
35.6	19
38.2	17
40.7	15
43.3	14
45.8	13
48.3	12
50.9	11
53.4	10
85.4	5

Figure A4-7 – *Depth in centimetres = 244.13 *(turbidity in NTU)-0.662*

How to make a Secchi disk to measure turbidity

Purpose: To determine water transparency (turbidity), using a Secchi disk.

Overview: The Secchi disk is a widely used measure of the transparency of water to light. The Secchi disk transparency depends on the amounts of suspended and coloured material in the water, material that comes from either sediment washed into a water body or primary productivity in the water body.

Materials and tools to make a Secchi disk:

.1 5 m length of rope (or longer or shorter, depending on depth of body of water at site)

.2 latex enamel spray paint: black and white

.3 heavy steel pipe

.4 drill

.5 circular piece of wood 2.5 cm (1 in) thick and 20 cm (8 in) in diameter

.6 2 hook screws

.7 15 cm (6 in) length of string

.8 small bottle of wood glue or super glue

.9 waterproof markers (red, blue, and black)

.10 metre stick

.11 data sheets

To make a Secchi disk:

.1 Divide top of wooden disk into four quadrants drawing lightly in pencil (draw 2 lines crossing at a 90 degree angle).

.2 Paint two opposite quadrants in black and the other two in white.

.3 Screw a hook screw into the top centre and bottom centre of the disk. Then tie the 5 m (or longer) rope through the hook screw in the top of the disk.

.4 Tie a short piece of rope through the hook screw on the bottom of the disk and string it though the pipe. Tie a large knot at the bottom of the pipe so that it is does not fall off when hanging vertically underneath the disk.

.5 Hold the rope attached to the top of the disk and use the metre stick and measure distance from the disk. Mark rope with a black waterproof marker every 10 cm. Mark every 50 cm up from the disk with a blue marker and every metre with a red marker. Now you are ready to take a measurement.

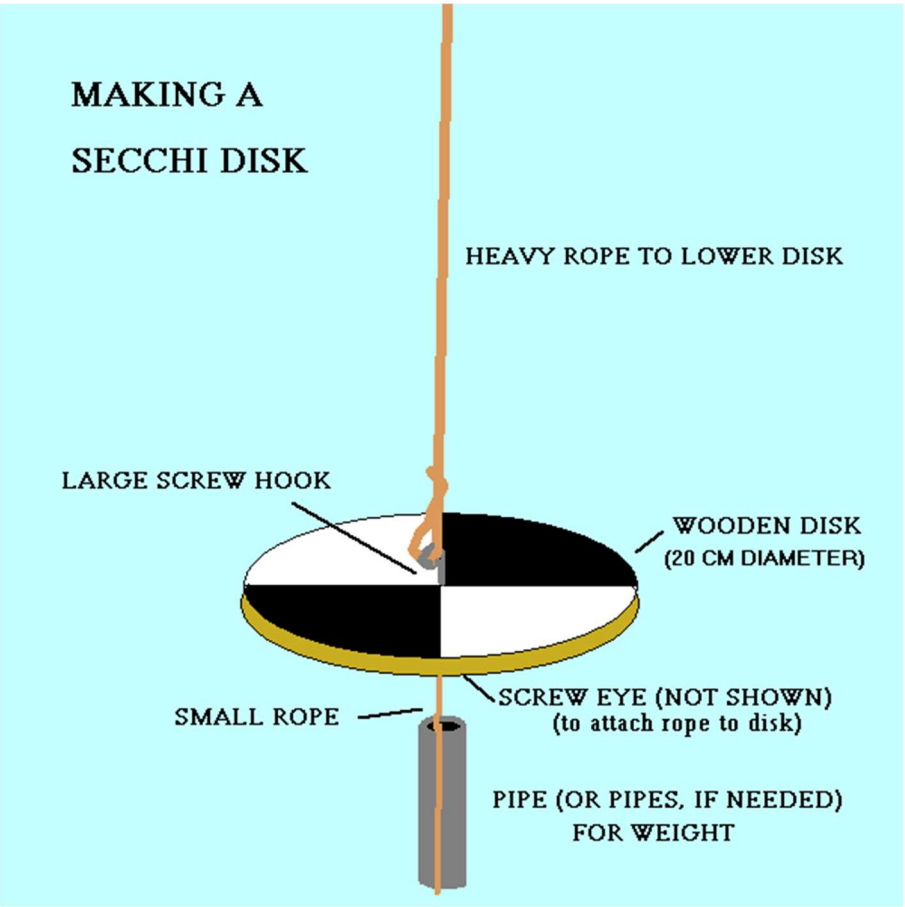


Figure A4-8 – *Making a Secchi disk*

Protocol

Note: Make sure that measurements are made in the shade with the sun to your back to make an accurate reading. If there is no shade available, use an umbrella or a large piece of cardboard to shade the particular area where the measurement is being made.

.1 Lower the disk slowly into the water until it just disappears. Grab the rope at the surface of the water and hold it between your fingers, or use a clothes pin to mark that point. Then bring the Secchi disk back up until it just reappears into sight again. There should only be a few centimetres' difference between these two points.

.2 Grab the line at the surface of the water when the Secchi disk reappears. The rope should now be marked at two points.

.3 Record both depths on your field data work sheet to the nearest 1 cm.

.4 Average the two depths to get the Secchi disk transparency.

Annex 5

Sediment sampling and analysis checklist

Sediment sampling and analysis plan outline and checklist **Source:** WDE, 1995

1. **Introduction and background information**
    - Site history
    - Regulatory framework
    - Summary of previous investigations, if any, of the site
    - Location and characteristics of any current and/or historical wastewater or storm water discharge(s) at the site
    - Location and characteristics of any current and/or historical wastewater or storm water discharge(s) in the local area
    - Information on on-site waste disposal practices or chemical spills in the local area, if any
    - Site location map showing the surrounding area
    - Site map showing site features

2. **Objectives and design of the sediment investigation**
    - Objectives of the sediment investigation
    - Overall design of the sediment investigation, including related investigations, if any
    - Chemical analytes (including description of their relevance to the objectives and the regulatory framework)
    - Biological tests (including description of their relevance to the objectives and the regulatory framework)
    - Sampling station locations
        - Rationale for station locations
        - Site map(s) showing sampling stations and other pertinent features (e.g. bathymetry and current regime; outfall(s)/diffuser(s); authorized mixing zone(s), if any; sites of waste disposal, spills, or other activities that may have affected the sediments, such as sandblasting, boat repair, etc.; historical dredging activities)
        - Proposed reference stations
        - Table showing the water depth at each proposed station
        - Proposed depth(s) below the sediment surface where sediments will be collected

Figure A5-1 – *Sediment sampling and analysis plan outline and checklist developed by Washington Department of Ecology* (WDE, 1995).

3. Field sampling methods

- Station positioning methods
- Sampling equipment
- Decontamination procedures
- Sample compositing strategy and methods
- Sample containers and labels
- Field documentation procedures
- Procedures for disposal of contaminated sediments

4. Sample handling procedures

- Sample storage requirements (e.g. conditions, maximum holding times) for each type of sample
- Chain-of-custody procedures
- Delivery of samples to analytical laboratories

5. Laboratory analytical methods

- Chemical analyses and target detection limits
- Biological analyses
- Corrective actions

6. Quality assurance and quality control requirements

- QA/QC for chemical analyses
- QA/QC for biological analysis
- Data quality assurance review procedures

7. Data Analysis, Record Keeping, and Reporting Requirements

- Analysis of sediment chemistry data
- Analysis of biological test data
- Data interpretation
- Record keeping procedures
- Reporting procedures

Figure A5-1 (cont.) – *Sediment sampling and analysis plan outline and checklist developed by Washington Department of Ecology* (WDE, 1995).

8. Health and safety plan (required for cleanup investigations)

- Description of tasks
- Key personnel and responsibilities
- Chemical and physical hazards
- Safety and health risk analysis for each task
- Air monitoring plan
- Personal protective equipment
- Work zones
- Decontamination procedures
- Disposal procedures for contaminated media and equipment
- Safe work procedures
- Standard operating procedures
- Contingency plan
- Personnel training requirements
- Medical surveillance program
- Record keeping procedures

9. Schedule

- Table or figure showing key project milestones

10. Project team and responsibilities

- Description of sediment sampling programme personnel
- Table identifying the project team members and their responsibilities

11. References

- List of references

Figure A5-1 (cont.) – *Sediment sampling and analysis plan outline and checklist developed by Washington Department of Ecology* (WDE, 1995).

Annex 6

Sampling, storage, handling, and analytical considerations for evaluation of chemical contaminants

In certain cases, analysis of chemical constituents in the sediments of the disposal site and surrounding areas is desirable in order to have a fuller understanding of the potential impacts of waste disposal at the site. Provided in this section are details regarding field sampling procedures to collect samples for laboratory analysis of chemical contaminants and quality control and quality assurance considerations.

Building sampling and analytical plans

It is very helpful to set up sampling and analytical plans as part of the overall monitoring plan, focusing particularly on the questions of sampling, sample handling procedures, and selecting and analysing chemical parameters. Most of the considerations that go into the development of an "analytical plan" will also be relevant to the “sampling plan”, as discussed in Part 2.2. Therefore, both sampling and analytical plans should be constructed concurrently, recognizing that the initial assessment may reveal that some disposal sites will not need sampling and testing for chemical contaminants.

Annex 5 provides a checklist for preparation of sampling and analytical plans, developed by the Washington State Department of Ecology in 1995.

A high degree of flexibility is necessary in developing sampling and analytical plans:

- The choice of an analytical method will dictate sample storage conditions, sub-sampling methods, and laboratory equipment.
- The quality assurance programme will influence the level of sampling, reporting, and documentation required.
- Limitations imposed by components of the plan may necessitate a revision to the budget, scope and/or assumptions of the working plan (conversely, changes in budget may necessitate revisions to the plan).
- If a plan cannot be devised within the constraints described above, then the goals may have to be revised.

Provided in this section are brief discussions of the key elements for development of sampling and analytical plans for measurement of chemical contaminants in disposal sites and surrounding areas.

Sample containers

Sample containers must be carefully chosen to reduce the potential of contaminating the sediment sample or altering its physical or chemical characteristics. The same type of container should be used for all samples to be analysed for the same parameter. All packaging should be watertight to prevent evaporation of

labile compounds and leakage of gas or water (ISO, 2000). While general guidance for selecting an appropriate container is listed below, specific testing methodology should be consulted prior to selection (Environment Canada, 1994).

Generally, samples to be analysed for trace metals should not come into contact with metals, and samples to be analysed for organic compounds should not come into contact with plastics.

- Metals and organic carbon: Wide-mouth high-density plastic bags or bottles (polyethylene) are suitable for the storage of whole sediments. Samples to be analysed for metals should not come into contact with PVC, nylon, soda or flint glass, or metallic surfaces, including stainless steel (Environment Canada, 1994). Samples should be collected from the centre of steel samplers.

- Organic chemicals: Amber glass and stainless steel wide-mouth containers with aluminium foil-lined lids are suitable for storage of whole sediments for the subsequent determination of organic analytes. Amber glass is preferable to avoid degradation of aromatic compounds that degrade with exposure to light. Clear glass can be stored in the dark or wrapped with an opaque material to eliminate light and reduce accidental breakage.

Teflon® or Teflon®-lined containers are recommended for storage of whole sediments, regardless of the nature of the contaminants of concern. High density polyethylene (HDPE) or polytetrafluoroethylene (PTFE; i.e. Teflon®) containers are suitable and preferred for most analytical measurements because they are made of relatively inert material and they are generally unbreakable. Samples for which bioassays are to be conducted should be stored in PFTE.

Care should be taken to prepare containers prior to their use (see Loring and Rantala, 1992). Sample containers should be clean. It is suggested that consideration be given to the use of certified, pre-cleaned containers, commercially available from many vendors.

Documentation of field information

Good documentation will improve the confidence that can be placed in the data and may help explain unexpected results. Specific details concerning sample documentation should be included in the study plan. Preferably, a logbook should be dedicated to an individual project. The investigator's name, project name, project number, and book number (if more than one is required) should be entered on the inside of the front cover of the logbook. All entries should be written in indelible ink, and the date and time of entry recorded. Additionally, each page should be initialled and dated by the investigator. At the end of each day's activity, or entry of a particular event if appropriate, the investigator should enter his or her initials. All aspects of sample collection and handling as well as visual observations and field conditions should be documented in the field logbooks at the time of sample collection.

Logbook entries should also include any circumstances that potentially affected sampling procedures and/or any field preparation of samples. Data entries should be thorough enough to allow station relocation and sample tracking. Since field records are the basis for later written reports, language should be objective, factual, and free of personal opinions or other terminology which might appear inappropriate. Data sheets can be prepared before the sampling and will help the data collector record consistent information.

An example of a field documentation form for water and sediment sampling surveys is provided in annex 7

SAMPLING AND PROJECT DOCUMENTATION (LONDON CONVENTION/LONDON PROTOCOL 2006)

Documentation of sampling should include:

- Sample labels should include an identifying sample number and the label or sample data sheet should also include site identification, sampling station location (positioning), sample type, and method of collection, name of the collector, and date and time of collection and depth. Other information should include:
  - An estimate of the quantity of sediment recovered by the grab sampler or length and appearance of recovered cores
  - Description of the sediment including texture and consistency, colour, odour, and presence of biota
  - Presence of oily sheen, changes in sediment characteristics with depth (a change in colour often indicates anoxia)
  - Photographs of the samples are desirable
- For legal samples, chain of custody records to show who has had custody of the sample
- Conditions during the sampling event (weather, waves)
- Records of the sample conditions (temperature, exposure to contaminants, oxygen)
- Personnel involved in the sample collection
- Deviations from the sampling plan or protocols

Project documentation should include:

- Type of vessel used (e.g. size, power, type of engine)
- Notation of the system used to define the position of the sampling site
- Notation of the system used to identify and track samples
- Level of personal protective equipment worn
- Notation of any visitors to the site
- Sketch of sampling area with photographs, if possible
- Ambient weather conditions, including wind speed and direction, wave action, current, tide, vessel traffic, temperature of both the air and water, thickness of ice if present
- Type of sediment collection device and any modifications made during sampling

Sample acceptability

Samples should be collected following the standard operating procedures for the selected sampler and the sampling plan. A sediment sample should be inspected as soon as it is taken. A sample should meet the following criteria of acceptability before it is considered adequate:

- Overlying water is clear or not excessively turbid, compared to the water in the sampling area.
- Sediment-water interface is intact, undisturbed and relatively flat with no sign of channelling, sample washout, or over-penetration.
- The desired depth of penetration has been achieved.
- There is no evidence that the grab sampler is incompletely closed or that the grab or core sampler was inserted at an angle or tilted upon retrieval (thereby risking loss of sediment).
- The core is complete with no air space at the top of the liner before capping, (i.e. there has been no loss of sediment).
- The length or the core is within the range stipulated in the sampling protocol.

Samples not meeting these criteria should be discarded in a manner that will not affect subsequent sampling (Environment Canada, 1994). Consecutive attempts to replace the discarded sample should be taken as close to the original location as possible but, if practical, slightly "upstream" of previous sampling.

Volumes and mass of sediment required for analysis

Sample size should be large enough to attain the appropriate detection limits or bioassay volume, but small enough to be conveniently handled and transported within the requirements for all planned analyses.

Table 1 provides the volumes and weights of samples needed for analysis, but the actual requirements with the chosen laboratory should be checked.

In many cases, 500 grams is sufficient for basic chemical analysis of metals and organic compounds (e.g. PAHs and PCBs) and XXX ml of water or XXX grams of sediment for bioassays.

Table A6-1 – *Commonly required volumes and weights for particle size and chemical tests*

Analysis	**Volume (ml)**	**Weight (g wet weight)**
Particle size	230	
Chemical		
Metals	90	100
Organics	230-2000	250-1100
Others (TOC, Moisture, Particle)	230-300	250-330
Sources: EC, 1994; USEPA, 1998; USEPA, 2001		

Sample handling and storage

All samples should be handled in such a way as to avoid affecting the analytical results, and the QA/QC programme should address these concerns. Changes to the sediment (i.e. physical, chemical, and biological) during sample storage should be minimized to the greatest extent possible. Exceptions are with the preservation of samples where manipulations are specifically identified. Sample holding time, the period for which a sample can be stored, should also be minimized (ISO, 2008). Suggested sample handling and storage methodologies are in the text box and Table 7-2.

SAMPLE HANDLING AND STORAGE (LONDON CONVENTION/LONDON PROTOCOL 2006)

- Proper personal protection equipment should be worn at all times to prevent human exposures or contamination of samples.
    - Sediments may contain a mixture of hazardous substances including bacterial or viral agents; therefore, skin contact should be avoided where possible.
    - Handling of samples should be performed in a well-ventilated area.
- Work surfaces should be clean, easily cleaned, and unlikely to absorb contaminants.
- Handling of samples should be minimized and carried out as soon as possible after the sample is taken to avoid changes in temperature and oxygen conditions that can affect geochemical and biochemical conditions in the sediment samples.
- In general, avoid contact with the sides of the sampler when sub-sampling to minimize cross-contamination from the sampler (this will be important for metals, when a steel or iron sampler is used; also, painted samplers may contaminate the sample with paint chips).
- Protect samples from contamination on deck (vessel exhaust, grease from the winch).
- Samples should go directly into a pre-labelled container with minimum headspace.
- For analysis of volatile compounds, samples should completely fill the storage container, leaving no air space. These samples cannot be frozen or the containers will crack.
- Sediment samples should generally be stored at 4°C. Samples can be temporarily stored in the field using refrigerated units on board vessels, freezers, or refrigerators at a local land facility or in insulated containers (coolers) filled with ice or ice packs. Keep intact cores upright.
- Samples that are to be frozen in containers that cannot accommodate expansion of the sample during freezing should not be filled completely. A headspace of about 2.5 cm should be left to accommodate expansion. It should be noted that there is a body of research demonstrating that freezing alters the chemistry and the toxicity of sediment samples.
- Sediments destined for chemical analysis may be stored with or without preservation reagents as appropriate, and should ideally be analysed within two weeks of collection. Various texts advise that storage should not exceed 6 months.

- Samples having regulatory or legal implications must have a tape seal and appropriate accompanying documentation.
- If sediments adhere to the outside of the sampler, the external surface of the sampler should be carefully hosed with clean water upon retrieval before the sample is transferred to a storage container.
- The sampler and sampling equipment should be rinsed thoroughly with water at the sampling station between within-station samples (i.e., lower sampler overboard and dip to ensure last sample has been rinsed off), and rinsed with water from the next sampling station before collecting a sample. Equipment used in the handling of sediment must also be washed thoroughly between samples.
- Samples for which bioassays are to be conducted should be stored in PTFE containers, sorted in the dark, transported in closed containers at 4°C, and analysed within 48 hours.

GUIDELINES FOR SAMPLING/STORAGE OF SEDIMENTS FOR CHEMICAL ANALYSES/BIOASSAYS

These are general guidelines. Alternative approaches may be used if assessed and validated.

Analysis	Container	Sampling procedure	Container preparation	Transportation	Storage
Organic carbon	➢ Glass ➢ Polyethylene ➢ PTFE ➢ Plastic	➢ Clean plastic/PTFE equipment, or stainless steel grab/corer.	➢ Containers should be clean.	➢ Transport preferably in cool-boxes	➢ Can be refrigerated for short-term ➢ Should be dried or frozen if imminent analysis is not expected within 1 month
Metals	➢ Glass ➢ Plastic ➢ PTFE	➢ Clean plastic/PTFE equipment, or stainless steel grab/corer. ➢ Avoid sample within 1 cm of sampler wall ➢ Sample should be sieved to < 2mm as soon as possible after sampling	➢ Jars should be acid washed.	➢ Transport cool	➢ Samples may be refrigerated for several weeks ➢ Samples may be frozen/ freeze–dried then milled/ homogenized for prolonged storage,
Mercury	➢ Glass ➢ Quartz ***Plastics must not be used***				➢ Samples should be frozen (<-20°C)
Polycyclic aromatic hydrocarbons (PAH)	➢ Glass (Darkened) ➢ PTFE ***Plastics must not be used***	➢ PTFE equipment or stainless steel grab/corer. ➢ Avoid sample within 1 cm of sampler wall ➢ Sample should be sieved to < 2mm as soon as possible after sampling	➢ Jars should be detergent washed and solvent rinsed. ➢ Lids should be lined with solvent washed foil	➢ Transport cool in light protected closed containers	➢ If analysis not carried out within 48hrs, can be refrigerated short-term ➢ Should be frozen if analysis is not expected within 1 month ➢ Must be stored in the dark
Organochlorine contaminants	➢ Glass ➢ PTFE ***Plastics must not be used***		➢ Jars should be solvent rinsed. ➢ Lids should be lined with solvent washed foil.	➢ Transport cool in closed containers	➢ Freeze / Freeze-dry
TBT / DBT / MBT	➢ Glass (Darkened) ➢ Polycarbonate ➢ Aluminium		➢ Jars should be acid washed and solvent rinsed.	➢ Transport cool in light protected closed containers.	➢ If analysis not carried out within 48hrs, can be refrigerated ➢ Can be stored dried or frozen for a year or more. ➢ Must be stored in the dark
Bioassays	➢ Darkened container	➢ PTFE equipment or stainless steel grab/corer.	➢ Containers should be clean.	➢ Transport cool in closed containers	➢ Keep cool ~ 4°C for analysis within 48hrs. Otherwise, should be frozen. ➢ Must be stored in the dark

Table A6-2 – *Guidelines for sampling/storage of sediments for chemical analyses/bioassays* (adapted from OSPAR JAMP guidelines for monitoring contaminants in sediments).

Those doing basic analysis limited to grain-size and bulk metal determinations may need less strict transport protocols but should nonetheless assure that sediments are transported in such a way as to keep them cool and in the dark, using well-sealed, clearly labelled containers (figure 36).

Figure A6-1 – *Storage containers for physical testing of grain size*

Sample transport and custody

Transport of samples should be conducted to maintain the structural, chemical, and biological characteristics of the sediment to the degree appropriate. The duration of storage in the field should be minimal and carefully monitored. The following points are identified as best laboratory practices for transport of samples for later analysis.

- Deviations in temperature should be avoided and reported when they occur.
- All field-collected samples that require further processing before storage should be transported to the laboratory as soon as possible, preferably within 24 hours of collection.
- Chain-of-custody procedures should commence on board the sampling vessel and will track delivery of each of the samples to the analytical laboratory. Specific procedures are as follows:
    - Coolers should be clearly labelled with sufficient information (name of project, time and date container was sealed, person sealing the cooler and the analytical laboratory name and address) to enable positive identification;
    - A sealed envelope containing chain-of-custody forms should be enclosed in a plastic bag and taped to the inside lid of the cooler; and
    - Signed and dated chain-of-custody seals should be placed on all coolers prior to shipping. Upon transfer of sample possession to the laboratory, the persons transferring custody of the coolers should sign the chain-of-custody form. Upon receipt of samples at the laboratory, the shipping container seal should be broken and the receiver should record the condition of the samples.

Quality Assurance and Quality Control programme for sampling plans

Quality assurance and quality control (QA/QC) should be followed throughout the implementation of a sediment sampling plan. QA/QC integrates management and technical practices into a single system to provide environmental data that are sufficient, appropriate, and of known and documented quality. Quality assurance includes outlining specific standard operating procedures and guidelines prior to implementation. Quality control includes documentation that all of the procedures and guidelines outlined in the plan were followed by the reporting laboratory. Good QA/QC will help to reduce sampling error (by using unbiased methods to choose sampling sites) and measurement error (by standardization of methods and procedures) (USEPA, 2001).

There is a need to set reasonable data quality objectives (DQO) for the plan. DQOs are an important aspect of quality assurance and are statements that provide critical definition of the confidence required in drawing conclusions from the entire project data. These objectives will determine the degree of total variability (uncertainty or error) that can be tolerated in the data. DQOs must be balanced against the cost of sampling and analysis, and realistic objectives should be established with concurrence of the data users.

What level of assurance is required?
To determine the level of assurance needed to support a regulatory or other decision, there needs to be a dialogue between the decision makers and the project planners to negotiate the amount of uncertainty that will be tolerated in the expected results (Radian, 1992).

If sampling design and sample collection are undertaken by different groups, what is expected/agreed to with respect to QA/QC should be well communicated prior to sampling. The following specific criteria should be included:

- A complete record of all field procedures, including field preparations, and any deviations from the sampling plan should be maintained.
- A clear record of custody must be ensured for all samples that are collected and/or analysed to satisfy legal requirements. Appropriate data quality objectives (DQOs) and QC sample type and number should be set and integrated into all aspects of the plan.
- All sampling devices and instruments used to collect data in the field should be regularly maintained and calibrated (meters, positioning equipment) as appropriate; these activities should be documented.
- Personnel should be familiar with all aspects of the study plan and sampling plan.
- Properly trained personnel should operate equipment.

Another important consideration in planning for sampling and analysis of dredged material is the type and number of quality control (QC) samples to analyse. These become more important where detailed chemical analyses are to be done, or in any case where precision or bias need to be estimated. It is critical that QC samples be selected to meet DQOs or the time and money spent analysing data will be wasted by obtaining data of unknown quality (Radian, 1992).

A basic QC field programme usually includes replication. Collecting separate samples within a sampling station (replicates) will impart valuable information on the spatial distribution of contaminants and the heterogeneity of the sediments within the site. Furthermore, replication within a project is necessary to make statistical comparisons:

- It is recommended that at least a percentage of the sampling stations be replicated and kept separate for QA/QC purposes (e.g. 10 percent is suggested in Environment Canada, 1994). If replicate samples from each sampling station are required, ISO (2008) recommends at least three.

- The number of replicate samples may be determined from preliminary sample collection and analysis, with higher numbers of replicates taken in areas where sediments have patchy distribution or are near sources of contamination (e.g. harbours, shallow waters).

- Pseudo-replication, the subdivision of a single field sample into multiple laboratory samples, should be avoided, unless they are being collected as split samples (see below).

Other types of QC samples may be more appropriate in certain cases, depending on the type of variability or bias that is of concern.

For example, if chemical values reported are near an action level, then variance becomes particularly important. The consequences of knowing whether a pollutant is above or below that action level may be large. In this case, greater attention may need to be devoted to sample collection and to the use of split samples to assess sampling variability (after Radian, 1992).

- Split samples, created by dividing the sample into two containers, are collected in order to assess the variation associated with sample handling. It should be noted that where sediments are heterogeneous, split samples will be less useful for this purpose as differences in contaminant levels between the split samples may be due to differences in the sediment rather than in the handling.

- Travel blanks may be necessary where samples are being analysed for volatile or semi-volatile organics, to determine if these have escaped and contaminated the rest of the samples during transport and storage. They are probably not necessary for other sediment analyses.

For additional information see: CCME (1993), USEPA (1995), USEPA (1991), and Keith (1990, 1992).

Quality assurance and quality control programme for laboratory analysis of chemicals

Quality assurance and quality control are essential to ensure that analysis and data collected meet the requirements for assessment of dredged material.

QA/QC at the laboratory involves practices undertaken to assure the reliability of the data that result from the analyses. Good laboratory procedures include:

- Written standard operating procedures for all work carried out on the project. A standard operating procedure is a detailed, laboratory-specific description of all actions taken to accomplish chemical analysis
- Documentation that shows that all procedures of sample handling and analyses were followed successfully.
- Routine analytical quality control protocols should be used involving the analysis of blanks and reference materials with each batch of samples.
- The reference materials should include both laboratory reference materials and independently produced certified reference materials. In addition, the basis of certification must match the methods chosen for sample analysis.
- Quality control charts should be constructed allowing day-to-day analytical performance to be monitored. If the results obtained for the reference material in any batch of samples fall outside established acceptance limits then the batch should be rejected and re-analysed.
- Participation in laboratory proficiency schemes is advised and involves the (regular) analysis of samples, in which the analyte concentrations are known but undisclosed.
- Chain of custody documentation should be prepared to ensure analytical data are traced to actual sample and sample location.

As with the QA/QC plan for sampling, an important consideration in planning for analysis of dredged material is the type and number of quality control (QC) samples to analyse. The sampling plan will indicate the number of QC samples and these should be factored into the cost of analysis.

Annex 7

Example: Water and sediment sampling documentation form

Field Monitoring Grab Sample Logsheet

Station sample data

CRUISEID:_____ Survey:_____ Project:_____ Stn No:_____

Station Code:_____ Date:_____ Nav-Log file:_____

Water Depth:_____ m Sampling Gear:_____ Position Ref Point:_____

Notes on Station:

Sample data:

Sample No:_____ GPS Time:_____ Fix No: _____ Pos'n

Sediment Description:_____

Sediment Depth (Day grab):_____*cm* Sediment volume (Hamon grab):_____*litres* Sieve mesh*1 mm*

Samples Collected:___*Macro / Meio / Micro / PSA / Metals / Organics / Photo*_____

Faunal sample

Faunal Fraction	Container Volume (Ltrs)	Faunal Container Ref. No
> 1mm		

Sediment sample

Sample Type	Container Type	Sediment Container Ref. No
PSA		

Notes on Sample: (e.g. Smell, Litter)

Field assessment of Broad-Scale Habitat (BSH)

Folk Class	Folk symbol	EUNIS sublittoral sediment type	Present?	Equivalent BSH
ravel	G	Coarse		Coarse
uddy Gravel	mG	Mixed		Mixed
uddy sandy gravel	msG	Mixed		Mixed
andy Gravel	sG	Coarse		Coarse
ravelly Mud	gM	Mixed		Mixed
ravelly muddy Sand	gmS	Mixed		Mixed
ravelly Sand	gS	Coarse		Coarse
slightly gravelly) Mud	(g)M	Mud and sandy mud		Mud
slightly gravelly) sandy Mud	(g)sM	Mud and sandy mud		Mud
slightly gravelly) muddy Sand/1	(g)mS/1	Mud and sandy mud (sand:mud ratio <4:1)		Mud
slightly gravelly) muddy Sand/2	(g)mS/2	Sand and muddy sand (sand:mud ratio >4:1)		Sand
slightly gravelly) Sandy	(g)S	Sand and muddy sand		Sand
lud	M	Mud and sandy mud		Mud
andy Mud	sM	Mud and sandy mud		Mud
uddy Sand/1	mS/1	Mud and sandy mud (sand:mud ratio <4:1)		Mud
uddy Sand/2	mS/2	Sand and muddy sand (sand:mud ratio >4:1)		Sand
and	S	Sand and muddy sand		Sand

Sample No:_________ GPS Time:___________ Fix No: ____________ Pos'n

Sediment Description:____

Sed. Depth (Day grab):_________ *cm* Sample Vol. (Hamon grab):______________ *litres* Sieve mesh *0.5 / 1 mm*

Samples Collected: *Macro / Meio / Micro / PSA / Metals / Organics / Photo*

Faunal samples

Faunal Fraction	Container (L)	Bar Code

Sediment samples

Sample Type	Container Type	Bar Code

Notes:

Sample No:_________ GPS Time:___________ Fix No: ____________ Pos'n

Sediment Description:____

Sed. Depth (Day grab):_________ *cm* Sample Vol. (Hamon grab):______________ *litres* Sieve mesh *0.5 / 1 mm*

Samples Collected: *Macro / Meio / Micro / PSA / Metals / Organics / Photo*

Faunal samples

Faunal Fraction	Container (L)	Bar Code

Sediment samples

Sample Type	Container Type	Bar Code

Notes:

Sample No:_________ GPS Time:___________ Fix No: ____________ Pos'n

Sediment Description:____

Sed. Depth (Day grab):_________ *cm* Sample Vol. (Hamon grab):______________ *litres* Sieve mesh *0.5 / 1 mm*

Samples Collected: *Macro / Meio / Micro / PSA / Metals / Organics / Photo*

Faunal samples

Faunal Fraction	Container (L)	Bar Code

Sediment samples

Sample Type	Container Type	Bar Code

Notes:

Completed by:…………………………..Checked by:………………………………….Entered by:……………………..

Figure A7-1 – *Field monitoring grab sample log sheet*

Annex 8

Management actions: capping of marine dump-sites to isolate sediments causing unacceptable adverse impacts*

If monitoring finds that materials dumped at a disposal site are likely contaminated and posing unacceptable adverse impacts at the site or in surrounding areas, management techniques can be applied with the intention to reduce risk to acceptable levels. Part 2.3 provided a brief summary of several operational changes, such as changes in the type of dredging equipment and disposal rates that may reduce the risk for future disposal at the dump-site. In addition, Part 2.3 also included level bottom capping as a possible management technique to reduce risks at the dump-site. This annex provides more specifics on level bottom capping.

What techniques are used for isolation of existing dump-sites with contaminated dredged material in estuarine and ocean waters?

If results of the monitoring programme show that sediments in the dump-site are causing unacceptable adverse impacts, level bottom capping can serve to isolate the existing dump-site sediments from potential exposure pathways (figure 1).

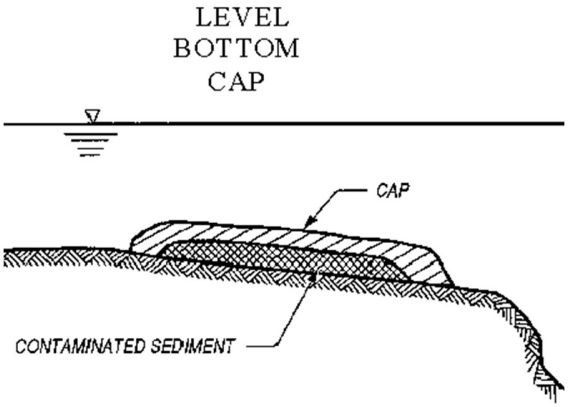


Figure A8-1 – *Level bottom capping of dump-sites for which monitoring has found unacceptable adverse effects in sediments at the dump-site* Source: http://www.epa.gov/greatlakes/sediment/gltem/backg.htm.

What is capping?

Capping is the controlled placement of clean material over the contaminated dredged material to effectively isolate it from the surrounding environment.

* Extracted from *International Review of Practices and Policies for Disposal in Ocean and Coastal/Estuarine Waters of Contaminated Dredged Material*, 30 March 2009. http://www.craigvogt.com.

What is level bottom capping?

If ocean dump-sites have been found to contain materials posing unacceptable adverse effects to ecological resources or to human health, one alternative is to cap the dump-site with clean material to isolate the materials from the marine environment. This option would be best in extremely low energy environments where currents or wave action would not erode the cap.

What are the key parameters of level bottom capping

Note: the material below is extracted directly from Palermo, 2000

Level bottom capping

Capping is a contaminant control measure to isolate the contaminated dredged material to prevent impacts to the marine environment. A capping operation should be treated as an engineered project with carefully considered design, construction, and monitoring to ensure that the design is adequate.

There are several issues which therefore must be carefully considered within the context of a capping project design. These include:

- *Potential water column impacts during disposal.* The assessment should consider evaluation of potential release of contaminants to the water column, evaluation of potential water column toxicity, and evaluation of initial mixing.

- E*fficacy of cap placement.* The assessment should consider available capping materials, methods for dredging and disposal of contaminated material and placement of cap material, and compatibility of site conditions, material physical properties, and dredging and placement techniques.

- *Long-term cap integrity.* The assessment should consider the physical isolation of contaminants, potential bioturbation of the cap by benthic animals, consolidation of the sediments, long-term contaminant losses due to advection/diffusion, and potential for physical disturbance or erosion of the cap by currents, waves, and other forces such as anchors and ship traffic.

Other considerations include:

- Evaluation of the feasibility of capping include site bathymetry, water depth, currents, wave climate, physical characteristics of contaminated and capping sediments, and placement equipment and techniques.

- Because long-term stability of the cap is of concern, capping is generally considered to be more technically feasible in low-energy environments.

- Precise placement of material is necessary for effective capping. Equipment and techniques applicable to disposal of contaminated material to be capped and clean material used for capping include conventional discharge from barges, hopper dredges, and pipelines; diffusers and Tremie approaches (see figure 2) for submerged discharge; and spreading techniques for cap placement.

- The site volumetric capacity, nearby obstructions or structures, haul distances, bottom shear as a result of ship traffic (in addition to natural currents), location of available cap material, and potential use of bottom drag fishing equipment.
- The effects of shipping are especially important, since bottom stresses, because of anchoring, propeller wash, and direct hull contact at shallow sites, are typically of a greater magnitude than the combined effects of waves and other currents.

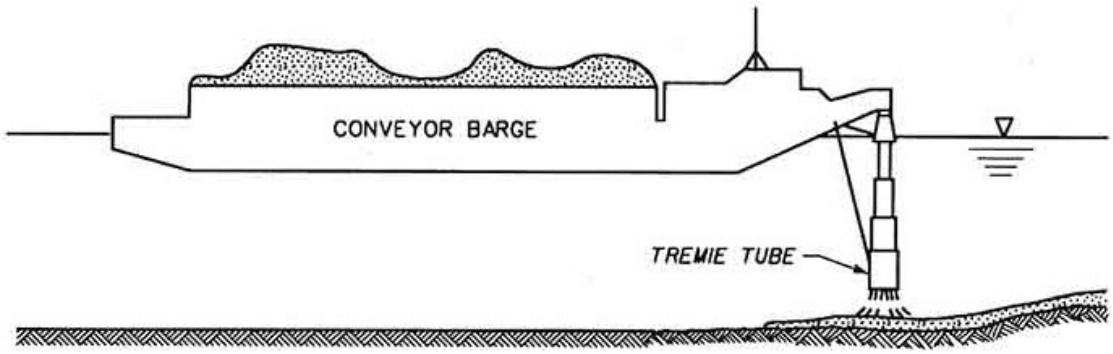


Figure A8-2 – *Capping of dump-sites with clean material using a Tremie tube* Source: USACE.