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Standard Guide for
Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and for Selection of Samplers Used to Collect Benthic Invertebrates[1]

This standard is issued under the fixed designation E1391; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide covers procedures for obtaining, storing, characterizing, and manipulating marine, estuarine, and freshwater sediments, for use in laboratory sediment toxicity evaluations and describes samplers that can be used to collect sediment and benthic invertebrates (Annex A1). This standard is not meant to provide detailed guidance for all aspects of sediment assessments, such as chemical analyses or monitoring, geophysical characterization, or extractable phase and fractionation analyses. However, some of this information might have applications for some of these activities. A variety of methods are reviewed in this guide. A statement on the consensus approach then follows this review of the methods. This consensus approach has been included in order to foster consistency among studies. It is anticipated that recommended methods and this guide will be updated routinely to reflect progress in our understanding of sediments and how to best study them. This version of the standard is based primarily on a document developed by USEPA (2001 (**1**))[2] and by Environment Canada (1994 (**2**)) as well as an earlier version of this standard.

1.2 Protecting sediment quality is an important part of restoring and maintaining the biological integrity of our natural resources as well as protecting aquatic life, wildlife, and human health. Sediment is an integral component of aquatic ecosystems, providing habitat, feeding, spawning, and rearing areas for many aquatic organisms (MacDonald and Ingersoll 2002 a, b (**3**)(**4**)). Sediment also serves as a reservoir for contaminants in sediment and therefore a potential source of contaminants to the water column, organisms, and ultimately human consumers of those organisms. These contaminants can arise from a number of sources, including municipal and industrial discharges, urban and agricultural runoff, atmospheric deposition, and port operations.

1.3 Contaminated sediment can cause lethal and sublethal effects in benthic (sediment-dwelling) and other sediment-associated organisms. In addition, natural and human disturbances can release contaminants to the overlying water, where pelagic (water column) organisms can be exposed. Sediment-associated contaminants can reduce or eliminate species of recreational, commercial, or ecological importance, either through direct effects or by affecting the food supply that sustainable populations require. Furthermore, some contaminants in sediment can bioaccumulate through the food chain and pose health risks to wildlife and human consumers even when sediment-dwelling organisms are not themselves impacted (Test Method E1706).

1.4 There are several regulatory guidance documents concerned with sediment collection and characterization procedures that might be important for individuals performing federal or state agency-related work. Discussion of some of the principles and current thoughts on these approaches can be found in Dickson, et al. Ingersoll et al. (1997 (**5**)), and Wenning and Ingersoll (2002 (**6**)).

1.5 This guide is arranged as follows:

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[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.47 on Biological Effects and Environmental Fate.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

***A Summary of Changes section appears at the end of this standard**

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1.6 Field-collected sediments might contain potentially toxic materials and should thus be treated with caution to minimize occupational exposure to workers. Worker safety must also be considered when working with spiked sediments containing various organic, inorganic, or radiolabeled contaminants, or some combination thereof. Careful consideration should be given to those chemicals that might biodegrade, volatilize, oxidize, or photolyze during the exposure.

1.7 The values stated in either SI or inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.* Specific hazards statements are given in Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1067 Test Methods for Acidity or Alkalinity of Water
D1126 Test Method for Hardness in Water
D1129 Terminology Relating to Water
D1426 Test Methods for Ammonia Nitrogen In Water
D3976 Practice for Preparation of Sediment Samples for Chemical Analysis
D4387 Guide for Selecting Grab Sampling Devices for Collecting Benthic Macroinvertebrates (Withdrawn 2003)[4]
D4822 Guide for Selection of Methods of Particle Size Analysis of Fluvial Sediments (Manual Methods)
D4823 Guide for Core Sampling Submerged, Unconsolidated Sediments
E729 Guide for Conducting Acute Toxicity Tests on Test Materials with Fishes, Macroinvertebrates, and Amphibians
E943 Terminology Relating to Biological Effects and Environmental Fate
E1241 Guide for Conducting Early Life-Stage Toxicity Tests with Fishes
E1367 Test Method for Measuring the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Invertebrates
E1525 Guide for Designing Biological Tests with Sediments
E1611 Guide for Conducting Sediment Toxicity Tests with Polychaetous Annelids
E1688 Guide for Determination of the Bioaccumulation of Sediment-Associated Contaminants by Benthic Invertebrates
E1706 Test Method for Measuring the Toxicity of Sediment-Associated Contaminants with Freshwater Invertebrates
IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. Terminology

3.1 *Definitions:*

3.1.1 The words "must," "should," "may," " can," and "might" have very specific meanings in this guide. "Must" is used to express an absolute requirement, that is, to state that the test ought to be designed to satisfy the specified condition, unless the purpose of the test requires a different design. "Must" is used only in connection with the factors that relate directly to the acceptability of the test. "Should" is used to state that the specified condition is recommended and ought to be met in most tests. Although the violation of one "should" is rarely a serious matter, the violation of several will often render the results questionable. Terms such as "is desirable," " is often desirable," and" might be desirable" are used in connection with less important factors. "May" is used to mean "is (are) allowed to," "can" is used to mean" is (are) able to," and "might" is used to mean "could possibly." Thus, the classic distinction between "may" and" can" is preserved, and "might" is never used as a synonym for either "may" or "can."

3.1.2 For definitions of terms used in this guide, refer to Guide E729 and Test Method E1706, Terminologies D1129 and E943, and Classification D4387; for an explanation of units and symbols, refer to IEEE/ASTM SI 10.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *site, n*—a study area comprised of multiple sampling station.

3.2.2 *station, n*—a location within a site where physical, chemical, or biological sampling or testing is performed.

4. Summary of Guide

4.1 This guide provides a review of widely used methods for collecting, storing, characterizing, and manipulating sediments for toxicity or bioaccumulation testing and also describes samplers that can be used to collect benthic invertebrates. Where the science permits, recommendations are provided on which procedures are appropriate, while identifying their limitations. This guide addresses the following general topics: (*1*) Sediment monitoring and assessment plans (including developing a study plan and a sampling plan), (*2*) Collection of whole sediment samples (including a description of various sampling equipment), (*3*) Processing, transport and storage of sediments, (*4*) Sample manipulations (including sieving, formulated sediments, spiking, sediment dilutions, and preparation of elutriate samples), (*5*) Collection of interstitial water (including sampling sediments in situ and ex situ), (*6*) Physico-chemical characterizations of sediment samples, (*7*) Quality assurance, and (*8*) Samplers that can be used to collect sediment or benthic invertebrates.

5. Significance and Use

5.1 Sediment toxicity evaluations are a critical component of environmental quality and ecosystem impact assessments, and are used to meet a variety of research and regulatory

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[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

objectives. The manner in which the sediments are collected, stored, characterized, and manipulated can influence the results of any sediment quality or process evaluation greatly. Addressing these variables in a systematic and uniform manner will aid the interpretations of sediment toxicity or bioaccumulation results and may allow comparisons between studies.

5.2 Sediment quality assessment is an important component of water quality protection. Sediment assessments commonly include physicochemical characterization, toxicity tests or bioaccumulation tests, as well as benthic community analyses. The use of consistent sediment collection, manipulation, and storage methods will help provide high quality samples with which accurate data can be obtained for the national inventory and for other programs to prevent, remediate, and manage contaminated sediment.

5.3 It is now widely known that the methods used in sample collection, transport, handling, storage, and manipulation of sediments and interstitial waters can influence the physicochemical properties and the results of chemical, toxicity, and bioaccumulation analyses. Addressing these variables in an appropriate and systematic manner will provide more accurate sediment quality data and facilitate comparisons among sediment studies.

5.4 This standard provides current information and recommendations for collecting and handling sediments for physicochemical characterization and biological testing, using procedures that are most likely to maintain in situ conditions, most accurately represent the sediment in question, or satisfy particular needs, to help generate consistent, high quality data collection.

5.5 This standard is intended to provide technical support to those who design or perform sediment quality studies under a variety of regulatory and non-regulatory programs. Information is provided concerning general sampling design considerations, field and laboratory facilities needed, safety, sampling equipment, sample storage and transport procedures, and sample manipulation issues common to chemical or toxicological analyses. Information contained in this standard reflects the knowledge and experience of several internationally-known sources including the Puget Sound Estuary Program (PSEP), Washington State Department of Ecology (WDE), United States Environmental Protection Agency (USEPA), US Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and Environment Canada. This standard attempts to present a coherent set of recommendations on field sampling techniques and sediment or interstitial water sample processing based on the above sources, as well as extensive information in the peer-reviewed literature.

5.6 As the scope of this standard is broad, it is impossible to adequately present detailed information on every aspect of sediment sampling and processing for all situations. Nor is such detailed guidance warranted because much of this information (for example, how to operate a particular sampling device or how to use a Geographical Positioning System (GPS) device) already exists in other published materials referenced in this standard.

5.7 Given the above constraints, this standard: (*1*) presents a discussion of activities involved in sediment sampling and sample processing; (*2*) alerts the user to important issues that should be considered within each activity; and (*3*) gives recommendations on how to best address the issues raised such that appropriate samples are collected and analyzed. An attempt is made to alert the user to different considerations pertaining to sampling and sample processing depending on the objectives of the study (for example, remediation, dredged material evaluations or status and trends monitoring).

5.8 The organization of this standard reflects the desire to give field personnel and managers a useful tool for choosing appropriate sampling locations, characterize those locations, collect and store samples, and manipulate those samples for analyses. Each section of this standard is written so that the reader can obtain information on only one activity or set of activities (for example, subsampling or sample processing), if desired, without necessarily reading the entire standard. Many sections are cross-referenced so that the reader is alerted to relevant issues that might be covered elsewhere in the standard. This is particularly important for certain chemical or toxicological applications in which appropriate sample processing or laboratory procedures are associated with specific field sampling procedures.

5.9 The methods contained in this standard are widely applicable to any entity wishing to collect consistent, high quality sediment data. This standard does not provide guidance on how to implement any specific regulatory requirement, or design a particular sediment quality assessment, but rather it is a compilation of technical methods on how to best collect environmental samples that most appropriately address common sampling objectives.

5.10 The information presented in this standard should not be viewed as the final statement on all the recommended procedures. Many of the topics addressed in this standard (for example, sediment holding time, formulated sediment composition, interstitial water collection and processing) are the subject of ongoing research. As data from sediment monitoring and research becomes available in the future, this standard will be updated as necessary.

6. Interferences

6.1 Maintaining the integrity of a sediment sample relative to ambient environmental conditions during its removal, transport, and testing in the laboratory is extremely difficult. The sediment environment is composed of a myriad of microenvironments, redox gradients, and other interacting physicochemical and biological processes. Many of these characteristics influence sediment toxicity and bioavailability to benthic and planktonic organisms, microbial degradation, and chemical sorption. Any disruption of this environment

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complicates interpretations of treatment effects, causative factors, and in situ comparisons. Individual sections address specific interferences.

7. Apparatus

7.1 A variety of sampling, characterization, and manipulation methods exist using different equipment. These are reviewed in Sections 10-14.

7.2 *Cleaning*—Equipment used to collect and store sediment samples, equipment used to collect benthic invertebrate samples, equipment used to prepare and store water and stock solutions, and equipment used to expose test organisms should be cleaned before use. All non-disposable sample containers, test chambers, and other equipment that have come in contact with sediment should be washed after use in the manner described as follows to remove surface contaminants (Test Method E1706). See 10.4 for additional detail.

8. Safety Hazards

8.1 *General Precautions:*

8.1.1 Development and maintenance of an effective health and safety program in the laboratory requires an ongoing commitment by laboratory management and includes: (*1*) the appointment of a laboratory health and safety officer with the responsibility and authority to develop and maintain a safety program, (*2*) the preparation of a formal, written health and safety plan, which is provided to each laboratory staff member, (*3*) an ongoing training program on laboratory safety, and (*4*) regular safety inspections.

8.1.2 Collection and use of sediments may involve substantial risks to personal safety and health. Chemicals in field-collected sediment may include carcinogens, mutagens, and other potentially toxic compounds. Inasmuch as sediment testing is often started before chemical analyses can be completed, worker contact with sediment needs to be minimized by: (*1*) using gloves, laboratory coats, safety glasses, face shields, and respirators as appropriate, (*2*) manipulating sediments under a ventilated hood or in an enclosed glove box, and (*3*) enclosing and ventilating the exposure system. Personnel collecting sediment samples and conducting tests should take all safety precautions necessary for the prevention of bodily injury and illness that might result from ingestion or invasion of infectious agents, inhalation or absorption of corrosive or toxic substances through skin contact, and asphyxiation because of lack of oxygen or presence of noxious gases.

8.1.3 Before beginning sample collection and laboratory work, personnel should determine that all required safety equipment and materials have been obtained and are in good condition.

8.2 *Safety Equipment:*

8.2.1 *Personal Safety Gear*—Personnel should use safety equipment, such as rubber aprons, laboratory coats, respirators, gloves, safety glasses, face shields, hard hats, safety shoes, water-proof clothing, personal floatation devices, and safety harnesses.

8.2.2 *Laboratory Safety Equipment*—Each laboratory should be provided with safety equipment such as first-aid kits, fire extinguishers, fire blankets, emergency showers, and eye wash stations. Mobile laboratories should be equipped with a telephone to enable personnel to summon help in case of emergency.

8.3 *General Laboratory and Field Operations:*

8.3.1 Special handling and precautionary guidance in Material Safety Data Sheets (MSDS) should be followed for reagents and other chemicals purchased from supply houses.

8.3.2 Work with some sediments may require compliance with rules pertaining to the handling of hazardous materials. Personnel collecting samples and performing tests should not work alone.

8.3.3 It is advisable to wash exposed parts of the body with bactericidal soap and water immediately after collecting or manipulating sediment samples.

8.3.4 Strong acids and volatile organic solvents should be used in a fume hood or under an exhaust canopy over the work area.

8.3.5 An acidic solution should not be mixed with a hypochlorite solution because hazardous fumes might be produced.

8.3.6 To prepare dilute acid solutions, concentrated acid should be added to water, not vice versa. Opening a bottle of concentrated acid and adding concentrated acid to water should be performed only under a fume hood.

8.3.7 Use of ground-fault systems and leak detectors is strongly recommended to help prevent electrical shocks. Electrical equipment or extension cords not bearing the approval of Underwriter Laboratories should not be used. Ground-fault interrupters should be installed in all "wet" laboratories where electrical equipment is used.

8.3.8 All containers should be adequately labeled to indicate their contents.

8.3.9 A clean and well-organized work place contributes to safety and reliable results.

8.4 *Disease Prevention*—Personnel handling samples which are known or suspected to contain human wastes should be immunized against hepatitis B, tetanus, typhoid fever, and polio. Thorough washing of exposed skin with bacterial soap should follow handling of samples collected from the field.

8.5 *Safety Manuals*—For further guidance on safe practices when handling sediment samples and conducting toxicity tests, check with the permittee and consult general industrial safety manuals including(**7**),(**8**).

8.6 *Pollution Prevention, Waste Management, and Sample Disposal*—Guidelines for the handling and disposal of hazardous materials should be strictly followed (Guide D4447). The Federal Government has published regulations for the management of hazardous waste and has given the States the option of either adopting those regulations or developing their own. If States develop their own regulations, they are required to be at least as stringent as the Federal regulations. As a handler of hazardous materials, it is your responsibility to know and comply with the pertinent regulations applicable in the State in which you are operating. Refer to the Bureau of National Affairs Inc. (**9**) for the citations of the Federal requirements.

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9. Sediment Monitoring and Assessment Study Plans

9.1 Every study site (for example, a study area comprised of multiple sampling stations) location and project is unique; therefore, sediment monitoring and assessment study plans should be carefully prepared to best meet the project objectives (MacDonald et al. 1991(**10**); Fig. 1).

9.2 Before collecting any environmental data, it is important to determine the type, quantity, and quality of data needed to

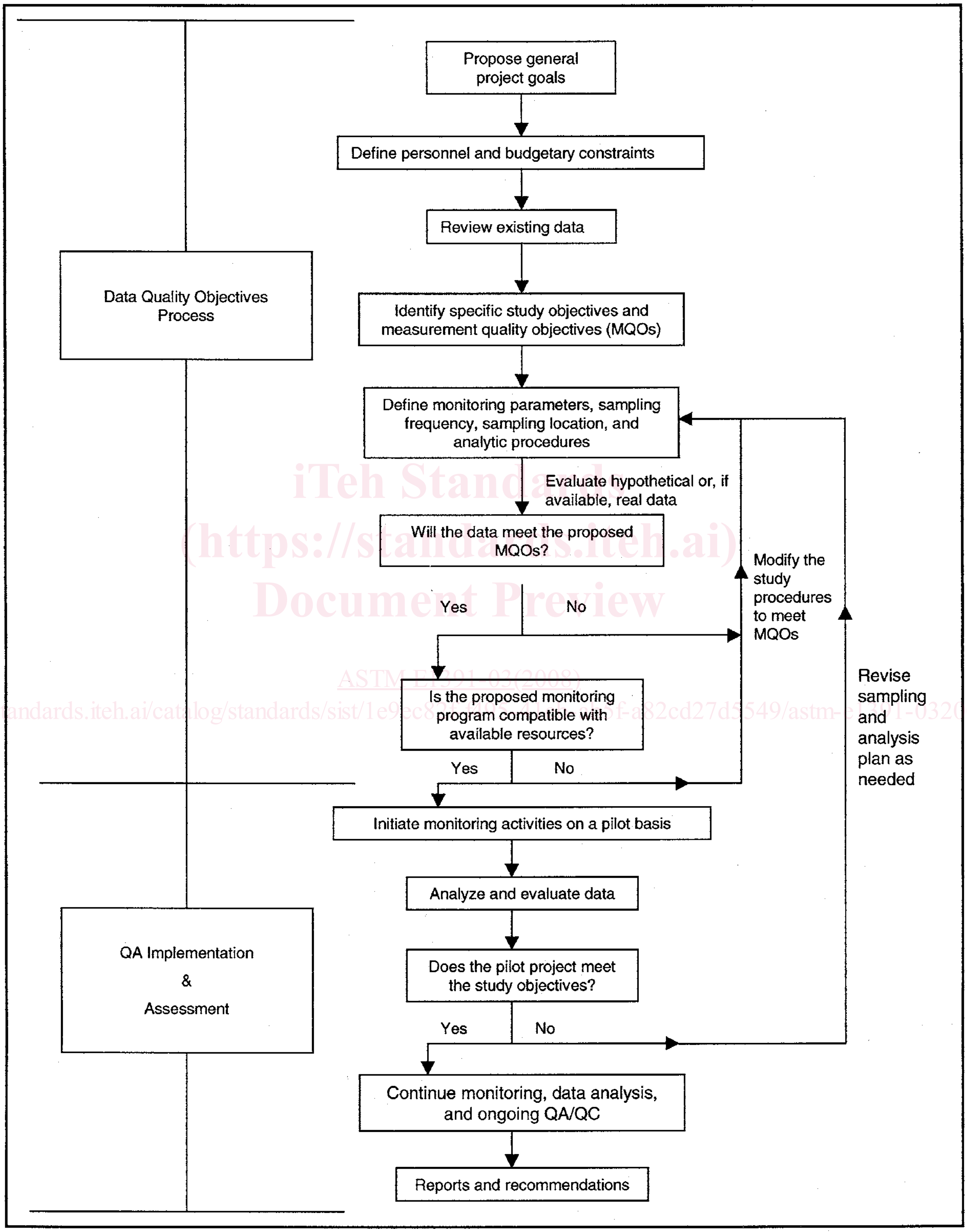

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FIG. 1 Flow Chart Summarizing the Process that Should Be Implemented in Designing and Performing a Monitoring Study (modified from MacDonald et al. (1991 (10)); USEPA 2001 (1))

meet the project objectives (for example, specific parameters to be measured) and support a decision based on the results of data collection and observation. Not doing so creates the risk of expending too much effort on data collection (that is, more data are collected than necessary), not expending enough effort on data collection (that is, more data are necessary than were collected), or expending the wrong effort (that is, the wrong data are collected).

9.3 *Data Quality Objectives Process:*

9.3.1 The Data Quality Objectives (DQO) Process developed by USEPA (GLNPO, 1994 (11); USEPA, 2000a(12)) is a flexible planning tool that systematically addresses the above issues in a coherent manner. The purpose of this process is to improve the effectiveness, efficiency, and defensibility of decisions made based on the data collected, and to do so in an effective manner (USEPA, 2000a(12)). The information compiled in the DQO process is used to develop a project-specific Quality Assurance Project Plan (QAPP; Section 10, USEPA 2000a (12)) that should be used to plan the majority of sediment quality monitoring or assessment studies. In some instances, a QAPP may be prepared, as necessary, on a project-by-project basis.

9.3.2 The DQO process addresses the uses of the data (most importantly, the decision(s) to be made) and other factors that will influence the type and amount of data to be collected (for example, the problem being addressed, existing information, information needed before a decision can be made, and available resources). From these factors the qualitative and

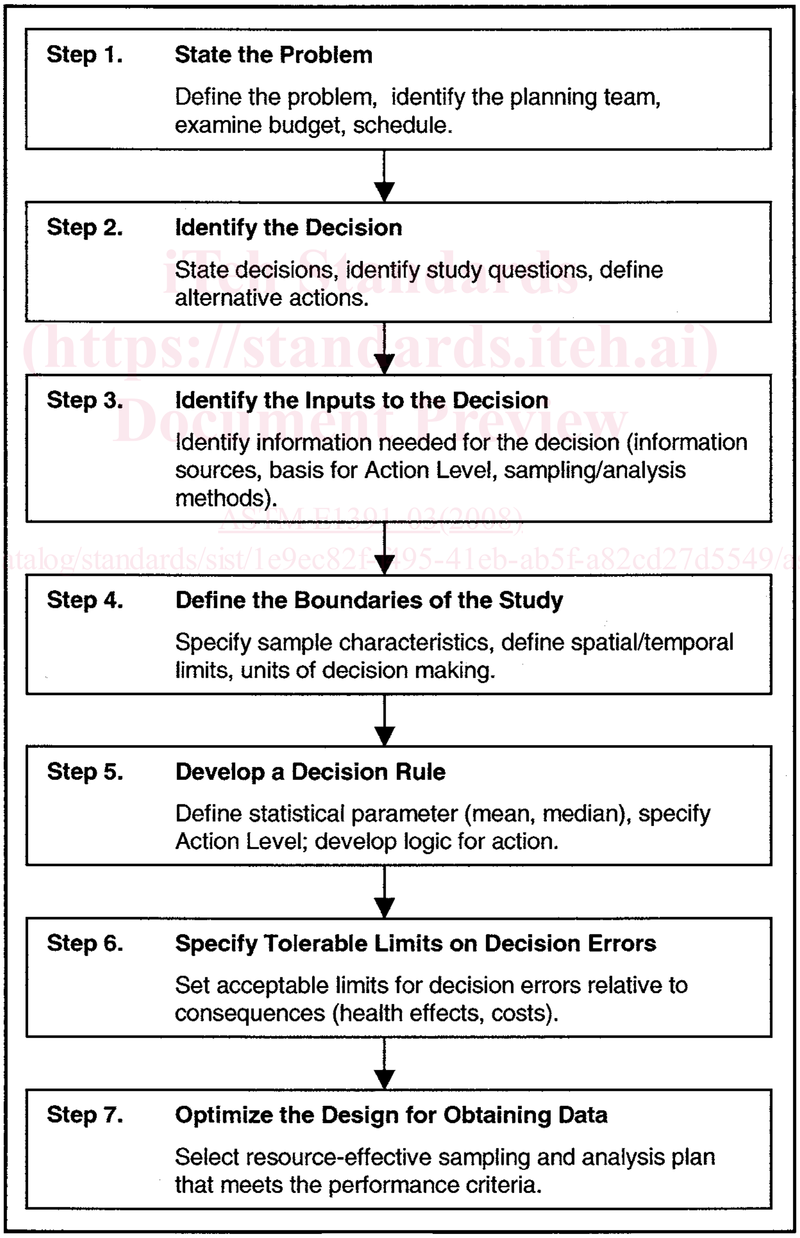

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FIG. 2 Flow Chart Summarizing the Data Quality Objectives Process (after USEPA 2000a (12); 2001 (1))

quantitative data needs are determined Fig. 2. DQOs are qualitative and quantitative statements that clarify the purpose of the monitoring study, define the most appropriate type of data to collect, and determine the most appropriate methods and conditions under which to collect them. The products of the DQO process are criteria for data quality, and a data collection design to ensure that data will meet the criteria.

9.3.3 For most instances, a Sampling and Analysis Plan (SAP) is developed before sampling that describes the study objectives, sampling design and procedures, and other aspects of the DQO process outlined above (USEPA 2001(**1**)). The following sections provide guidance on many of the primary issues that should be addressed in a study plan.

9.4 *Study Plan Considerations:*

9.4.1 *Definition of the Study Area and Study Site:*

9.4.1.1 Monitoring and assessment studies are performed for a variety of reasons (ITFM, 1995 (**13**)) and sediment assessment studies can serve many different purposes. Developing an appropriate sampling plan is one of the most important steps in monitoring and assessment studies. The sampling plan, including definition of the site (a study area that can be comprised of multiple sampling stations) and sampling design, will be a product of the general study objectives Fig. 1. Station location, selection, and sampling methods will necessarily follow from the study design. Ultimately, the study plan should control extraneous sources of variability or error to the extent possible so that data are appropriately representative of the sediment quality, and fulfill the study objectives.

9.4.1.2 The study area refers to the body of water that contains the study sampling stations(s) to be monitored or assessed, as well as adjacent areas (land or water) that might affect or influence the conditions of the study site. The study site refers to the body of water and associated sediments to be monitored or assessed.

9.4.1.3 The size of the study area will influence the type of sampling design (see 9.5) and site positioning methods that are appropriate (see 9.8). The boundaries of the study area need to be clearly defined at the outset and should be outlined on a hydrographic chart or topographic map.

9.4.2 *Controlling Sources of Variability:*

9.4.2.1 A key factor in effectively designing a sediment quality study is controlling those sources of variability in which one is not interested (USEPA 2000a,b (**12**),(**14**)). There are two major sources of variability that, with proper planning, can be minimized, or at least accounted for, in the design process. In statistical terms, the two sources of variability are sampling error and measurement error (USEPA 2000b(**14**); Solomon et al. 1997 (**15**)).

9.4.2.2 Sampling error is the error attributable to selecting a certain sampling station that might not be representative of the site or population of sample units. Sampling error is controlled by either: (*1*) using unbiased methods to select stations if one is performing general monitoring of a given site (USEPA, 2000b (**14**)) or (*2*) selecting several stations along a spatial gradient if a specific location is being targeted (see 9.5).

9.4.2.3 Measurement error is the degree to which the investigator accurately characterizes the sampling unit or station. Thus, measurement error includes components of natural spatial and temporal variability within the sample unit as well as actual errors of omission or commission by the investigator. Measurement error is controlled by using consistent and comparable methods. To help minimize measurement error, each station should be sampled in the same way within a site, using a consistent set of procedures and in the same time frame to minimize confounding sources of variability (see 9.4.3). In analytical laboratory or toxicity procedures, measurement error is estimated by duplicate determinations on some subset of samples (but not necessarily all). Similarly, in field investigations, some subset of sample units (for example, 10 % of the stations) should be measured more than once to estimate measurement error (see Replicate and Composite Samples, 9.6.7). Measurement error can be reduced by analyzing multiple observations at each station (for example, multiple grab samples at each sampling station, multiple observations during a season), or by collecting depth-integrated, or spatially integrated (composite) samples (see 9.6.7).

9.4.2.4 Optimizing the sampling design requires consideration of tradeoffs among the procedures used to analyze data. These include, the effect that is considered meaningful, desired power, desired confidence, and resources available for the sampling program (Test Method E1706). Most studies do not estimate power of their sampling design because this generally requires prior information such as pilot sampling, which entails further resources. One study (Gilfillan et al. 1995 (**16**)) reported power estimates for a shoreline monitoring program following the Valdez oil spill in Prince William Sound, Alaska. However, these estimates were computed after the sampling took place. It is desirable to estimate power before sampling is performed to evaluate the credibility of non-significant results (see for example, Appendix C in USEPA 2001(**1**)).

9.4.2.5 Measures of bioaccumulation from sediments depend on the exposure of the organism to the sample selected to represent the sediment concentration of interest. It is important to match as close as possible the sample selected for measuring the sediment chemistry to the biology of the organism (Lee 1991(**17**), Test Method E1706). For instance, if the organism is a surface deposit feeder, the sediment sample should to the extent possible represent the surficial feeding zone of the organism. Likewise if the organism feeds at depth, the sediment sample should represent that feeding zone.

9.4.3 *Sampling Using an Index Period:*

9.4.3.1 Most monitoring projects do not have the resources to characterize variability or to assess sediment quality for all seasons. Sampling can be restricted to an index period when biological or toxicological measures are expected to show the greatest response to contamination stress and within-season variability is small (Holland, 1985 (**18**); Barbour et al. 1999 (**19**)). This type of sampling might be especially advantageous for characterizing sediment toxicity, sediment chemistry, and benthic macroinvertebrate and other biological assemblages (USEPA, 2000c (**20**)). In addition, this approach is useful if sediment contamination is related to, or being separated from, high flow events or if influenced by tidal cycles. By sampling overlying waters during both low and high flow conditions or tidal cycles, the relative contribution of each to contaminant

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can be better assessed, thereby better directing remedial activities, or other watershed improvements.

9.4.3.2 Projects that sample the same station over multiple years are interested in obtaining comparable data with which they can assess changes over time, or following remediation (GLNPO, 1994 (**11**)). In these cases, index period sampling is especially useful because hydrological regime (and therefore biological processes) is likely to be more similar between similar seasons than among different seasons.

9.5 *Sampling Designs:*

9.5.1 As mentioned in earlier sections, the type of sampling design used is a function of the study DQOs and more specifically, the types of questions to be answered by the study. A summary of various sampling designs is presented in Fig. 3. Generally, sampling designs fall into two major categories: random (or probabilistic) and targeted (USEPA, 2000b (**14**)). USEPA (2000b,c (**14**),(**20**)) Gilbert (1987 (**21**)), and Wolfe et al. (1993 (**22**)) present discussions of sampling design issues and information on different sampling designs. Appendix A in USEPA (2001, (**1**)) presents hypothetical examples of sediment quality monitoring designs given different objectives or regulatory applications.

9.5.2 *Probabilistic and Random Sampling:*

9.5.2.1 Probability-based or random sampling designs avoid bias in the sample results by randomly assigning and selecting sampling locations. A probability design requires that all sampling units have a known probability of being selected. Both the USPEA Environmental Monitoring Assessment Program and the NOAA National Status and Trends Program use a probabilistic sampling design to infer regional and national patterns with respect to contamination or biological effects.

9.5.2.2 Stations can be selected on the basis of a truly random scheme or in a systematic way (for example, sample every 10 m along a randomly chosen transect). In simple random sampling, all sampling units have an equal probability of selection. This design is appropriate for estimating means and totals of environmental variables if the population is homogeneous. To apply simple random sampling, it is necessary to identify all potential sampling times or locations, then randomly select individual times or locations for sampling.

9.5.2.3 In grid or systematic sampling, the first sampling location is chosen randomly and all subsequent stations are placed at regular intervals (for example, 50 m apart) throughout the study area. Clearly, the number of sampling locations could be large if the study area is large and one desires "fine-grained" contaminant or toxicological information. Thus, depending on the types of analyses desired, such sampling might become expensive unless the study area is relatively small, or the density of stations (that is, how closely spaced are the stations) is relatively low. Grid sampling might be effective for detecting previously unknown "hot spots" in a limited study area.

9.5.2.4 In stratified designs, the selection probabilities might differ among strata. Stratified random sampling consists of dividing the target population into non-overlapping parts or subregions (for example, ecoregions, watersheds, or specific

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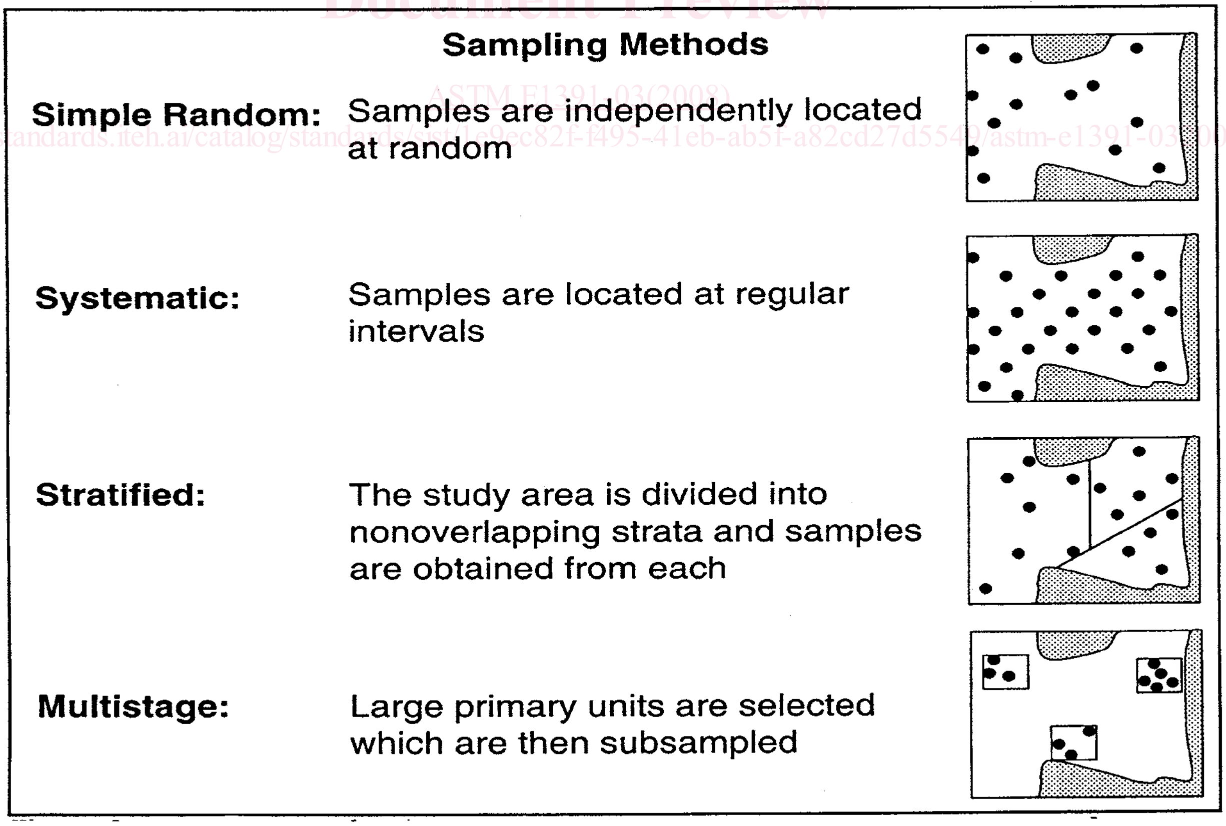

Sampling Methods

Simple Random: Samples are independently located at random

Systematic: Samples are located at regular intervals

Stratified: The study area is divided into nonoverlapping strata and samples are obtained from each

Multistage: Large primary units are selected which are then subsampled

FIG. 3 Description of Various Sampling Methods (adapted from USEPA 2000c (20); 2001(1))

dredging or remediation sites) termed strata to obtain a better estimate of the mean or total for the entire population. The information required to delineate the strata and to estimate sampling frequency should either be known before sampling using historic data variability, available information and knowledge of ecological function, or obtained in a pilot study. Sampling locations are randomly selected from within each of the strata. Stratified random sampling is often used in sediment quality monitoring because certain environmental variables can vary by time of day, season, hydrodynamics, or other factors. One disadvantage of using random designs is the possibility of encountering unsampleable stations that were randomly selected by the computer. Such problems result in the need to reposition the vessel to an alternate location (Heimbuch et al. 1995 (**23**), Strobel et al. 1995 (**24**)) Furthermore, if one is sampling to determine the percent spatial extent of degradation, it might be important to sample beyond the boundaries of the study area to better evaluate the limits of the impacted area.

9.5.2.5 A related design is multistage sampling in which large subareas within the study area are first selected (usually on the basis of professional knowledge or previously collected information). Stations are then randomly located within each subarea to yield average or pooled estimates of the variables of interest (for example, concentration of a particular contaminant or acute toxicity to the amphipod Hyalella azteca) for each subarea. This type of sampling is especially useful for statistically comparing variables among specific parts of a study area.

9.5.2.6 Use of random sampling designs might also miss relationships among variables, especially if there is a relationship between an explanatory and a response variable. As an example, estimation of benthic response or contaminant concentration, in relation to a discharge or landfill leachate stream, requires sampling targeted locations or stations around the potential contaminant source, including stations presumably unaffected by the source (for example, Warwick and Clarke, 1991(**25**)). A simple random selection of stations is not likely to capture the entire range needed because most stations would likely be relatively removed from the location of interest.

9.5.3 *Targeted Sampling Designs:*

9.5.3.1 In targeted (also referred to as judgmental, or model-based) designs, stations are selected based on prior knowledge of other factors, such as salinity, substrate type, and construction or engineering considerations (for example, dredging). The sediment studies conducted in the Clark Fork River (Pascoe and DalSoglio, 1994 (**26**); Brumbaugh et al. 1994 (**27**)), in which contaminated areas were a focus, used a targeted sampling design.

9.5.3.2 Targeted designs are useful if the objective of the investigation is to screen an area(s) for the presence or absence of contamination at levels of concern, such as risk-based screening levels, or to compare specific sediment quality against reference conditions or biological guidelines. In general, targeted sampling is appropriate for situations in which any of the following apply (USEPA, 2000b (**14**)):

(1) The site boundaries are well defined or the site physically distinct (for example, USEPA Superfund or CERCLA site, proposed dredging unit).

(2) Small numbers of samples will be selected for analysis or characterization.

(3) Information is desired for a particular condition (for example, “worst case”) or location.

(4) There is reliable historical and physical knowledge about the feature or condition under investigation.

(5) The objective of the investigation is to screen an area(s) for the presence or absence of contamination at levels of concern, such as risk-based screening levels. If such contamination is found, follow-up sampling is likely to involve one or more statistical designs to compare specific sediment quality against reference conditions.

(6) Schedule or budget limitations preclude the possibility of implementing a statistical design.

(7) Experimental testing of a known contaminant gradient to develop or verify testing methods or models (that is, as in evaluations of toxicity tests, Long et al. 1990 (**28**)).

9.5.3.3 Because targeted sampling designs often can be quickly implemented at a relatively low cost, this type of sampling can often meet schedule and budgetary constraints that cannot be met by implementing a statistical design. In many situations, targeted sampling offers an additional important benefit of providing an appropriate level-of-effort for meeting investigation objectives without excessive use of project resources.

9.5.3.4 Targeted sampling, however, limits the inferences made to the stations actually sampled and analyzed. Extrapolation from those stations to the overall population from which the stations were sampled is subject to unknown selection bias. This bias might be unimportant for programs in which information is needed for a particular condition or location).

9.6 *Measurement Quality Objectives:*

9.6.1 As noted in 9.3, a key aspect of the DQO process is specifying measurement quality objectives (MQOs): statements that describe the amount, type, and quality of data needed to address the overall project objectives Table 1.

9.6.2 A key factor determining the types of MQOs needed in a given project or study is the types of analyses required because these will determine the amount of sample required (see 9.6.5) and how samples are processed (see Section11). Metals, organic chemicals (including pesticides, PAHs, and PCBs), whole sediment toxicity, and organism bioaccumulation of specific target chemicals, are frequently analyzed in many sediment monitoring programs.

9.6.3 A number of other, more “conventional” parameters, are also often analyzed as well to help interpret chemical, biological, and toxicological data collected in a project (see Section 14). Table 2 summarizes many of the commonly measured conventional parameters and their uses in sediment quality studies (WDE, 1995 (**29**)). It is important that conventional parameters receive as much careful attention, in terms of sampling and sample processing procedures, as do the contaminants or parameters of direct interest. The guidance presented in Sections 10 and 11 provides information on proper

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TABLE 1 Checklist for the DQO Process (USEPA 2001(1))

Clearly state the problem: purpose and objectives, available resources, members of the project team: For example, the purpose might be to evaluate current sediment quality conditions, historical conditions, evaluate remediation effects, or validate a sediment model. It is important to review and evaluate available historical data relevant to the study at this point in the process.

Identify the decision; the questions(s) the study attempts to address: For example, is site A more toxic than site B?; Are sediments in Lake Y less toxic now than they used to be?; Does the sediment at site D need to be remediated? What point or nonpoint sources are contributing to sediment contamination?

Identify inputs to the decision: information and measurements that need to be obtained: For example, analyses of specific contaminants, toxicity test results, biological assessments, bioaccumulation data, habitat assessments, hydrology, and water quality characterization.

Define the study boundaries (spatial and temporal): Identify potential sources of contamination; determine the location of sediment deposition zones; determine the frequency of sampling and need for a seasonal sampling and/or sampling during a specific index period; consider areas of previous dredged or fill material discharges/disposal. Consideration of hydraulic patterns, flow event frequency, and/or sedimentation rates could be critical for determining sampling frequency and locations.

Develop a decision rule: define parameters of interest and determine the value of a parameter that would cause follow-up action of some kind: For example., exceedance of Sediment Quality Guidelines (Wenning and Ingersoll 2002 (**6**)) or toxicity effect results in some action. For example, in the Great Lakes Assessment and Remediation of Contaminated Sediments (ARCS) Program, one decision rule was: if total PCB concentration exceeds a particular action level, then the sediments will be classified as toxic and considered for remediation (GLNPO, 1994 (**11**)).

Specify limits on decision errors: Establish the measurement quality objectives (MQOs) which include determining the level of confidence required from the data; precision, bids, representativeness, and completeness of data; the sample size (weight or volume) required to satisfy the analytical methods and QA/QC program for all analytical tests; the number of samples required, to be within limits on decision errors, and compositing needed, if any.

Optimize the design: Choose appropriate sampling and processing methods; select appropriate method for determining the location of sampling stations; select an appropriate positioning method for the site and study. Consult historical data and a statistician before the study begins regarding the sampling design (i.e., the frequency, number, and location of field-collected samples) that will best satisfy study objectives.

TABLE 2 Conventional Sediment Variables and Their Use in Sediment Investigations (adapted from WDE, 1995(29) and USEPA 2001(1))

Conventional Sediment Variable	Use
Total organic carbon (TOC)	Normalization of the concentrations of nonionizable organic compounds Identification of appropriate reference sediments for biological tests
Acid Volatile Sulfide (AVS)	Normalization of the concentrations of divalent metals in anoxic sediments
Sediment grain size	Identification of appropriate reference sediments for biological tests Interpretation of sediment toxicity test data and benthic macroinvertebrate abundance data Evaluation of sediment transport and deposition Evaluation of remedial alternatives
Total solids	Expression of chemical concentrations on a dry-weight basis
Ammonia	Interpretation of sediment toxicity test data
Total sulfides	Interpretation of sediment toxicity test data

TABLE 3 Typical Sediment Volume Requirements for Various Analyses per Sample (USEPA 2001(1))

Sediment Analysis	Minimum Sample Volume
Inorganic chemicals	90 mL
Non-petroleum organic chemicals	230 mL
Other chemical parameters (for example, total organic carbon, moisture content)	300 mL
Particle size	230 mL
Petroleum hydrocarbons^{A}	250 to 1000 mL
Acute and chronic whole sediment toxicity tests^{B}	1 to 2 L
Bioaccumulation tests^{C}	15 L
Benthic macroinvertebrate assessments	8 to 16 L
Pore water extraction	2 L
Elutriate preparation	1 L

[A] The maximum volume (1000 mL) is required only for oil and grease analysis; otherwise, 250 mL is sufficient.

[B] Amount needed per whole sediment test (that is, one species) assuming 8 replicates per sample and test volumes specified in USEPA, 2000d(**35**).

[C] Based on an average of 3 L of sediment per test chamber and 5 replicates (USEPA, 2000d(**35**)).

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sampling and sample processing procedures to establish that one has appropriate samples for these analyses.

9.6.4 The following sections concentrate on three aspects of MQO development that are generally applicable to all sediment quality studies, regardless of the particular objectives: sample volume, number of samples, and replication versus composite sampling.

9.6.5 *Sample Volume:*

9.6.5.1 Before commencing a sampling program, the type and number of analyses and tests should be determined, and the required volume of sediment per sample calculated. Each physicochemical and biological test requires a specific amount of sediment which, for chemical analyses, depends on the detection limits attainable and extraction efficiency by the analytical procedure and, for biological testing, depends on the test organisms and method. Typical sediment volume requirements for each end use are summarized in Table 3. Recommendations for determining the number of samples and sample volume are presented in Table 4.

9.6.5.2 When determining the required sample volume, it is important to know all of the required sample analyses (considering adequate replication), and it is also useful to know the general characteristics of the sediments being sampled. For example, if interstitial water analyses or elutriate tests are to be conducted, the percent water (or percent dry weight) of the sediment will greatly affect the amount of water extracted. Many non-compacted, depositional sediments have interstitial water contents often ranging from 30 to 70 %. However, there is a low volume of water in these types of sediments.

9.6.5.3 For benthic macroinvertebrate bioassessment analyses, sampling a prescribed area of benthic substrate is at least as important as sampling a given volume of sediment (Annex A1). Macroinvertebrates are often sampled using

TABLE 4 Recommendations on Determining How Many Samples and How Much Sample Volume Should Be Collected (USEPA 2001(1))

The testing laboratory should be consulted to confirm the amount of sediment required for all desired analyses.
The amount of sediment needed from a given site will depend on the number and types of analyses to be performed. If biological, toxicological, and chemical analyses are required (sediment triad approach), then at least 10 L of sediment might be required from each station.
Since sampling events might be expensive and/or difficult to replicate, it is useful to collect extra samples if possible, in the event of problems encountered by the analytical laboratories, failure of performance criteria in assays, or need to verify/validate results.
Consider compositing samples from a given station or across similar station types to reduce the number of samples needed.

multiple grab samples within a given station location, typically to a consistent sediment depth (for example, per 10 to 20 cm of sediment; Klemm et al. 1990 (**30**); GLNPO, 1994 (**11**); Long et al. 1996 (**31**); USEPA 2000c (**20**)). More than 6 liters of sediment from each station might be necessary in order to have adequate numbers of organisms for analyses, especially in many lakes, estuaries, and large rivers (Barbour et al. 1999 (**19**)). However, this is very site specific, and should be determined by the field sampling crew. This only applies to whole sediment sampling methods and not to surficial stream methods using methods such as kick-nets and Surber samplers. If the sediment quality triad approach is used (that is, biological, toxicological, and physicochemical analyses performed on samples from the same stations), more than 10 liters of sediment from each station might be required depending on the specific analyses conducted. NOAA routinely collects 7 to 8 liters of sediment at each station for multiple toxicity tests and chemical analyses (Long et al. 1996 (**31**)).

9.6.6 *Number of Samples:*

9.6.6.1 The number of samples collected directly affects the representativeness and completeness of the data for purposes of addressing project goals Table 4. As a general rule, a greater number of samples will yield better definition of the areal extent of contamination or toxicity.

9.6.6.2 Accordingly, sample requirements should be determined on a case-by-case basis. The number of samples to be collected will ultimately be an outcome of the questions asked. For example, if one is interested in characterizing effects of a point source or a gradient (for example, effects of certain tributaries or land uses on a lake or estuary), then many samples in a relatively small area might need to be collected and analyzed. If, however, one is interested in screening "hot spots" or locations of high contamination within a watershed or water body, relatively few samples at regularly-spaced locations might be appropriate. In most monitoring and assessment studies, the number of samples to be collected usually results from a compromise between the ideal and the practical. The major practical constraints are the costs of analyses and logistics of sample collection.

9.6.6.3 The major costs associated with the collection of sediment samples are those for travel to the site and for sample analysis. The costs of actual on-site sampling are minimal by comparison. Consequently, it is good practice to collect an excess number of samples, and then a subset equal to the minimum number required is selected for analysis. The archived replicate samples can be used to replace lost samples, for data verification, to rerun analyses yielding questionable results, or for the independent testing of a posteriori hypotheses that might arise from screening the initial data. However, storage of sediments might result in changes in bioavailability of chemical contaminants (see 11.6) or in exceeding analytical holding times. Therefore, follow-up testing of archived samples should be done cautiously.

9.6.7 *Replicate and Composite Samples:*

9.6.7.1 *Replicate samples*: As mentioned in the previous section, the number of samples collected and analyzed will always be a compromise between the desire of obtaining high quality data that fully addresses the overall project objectives (MQOs), and the constraints imposed by analytical costs, sampling effort, and study logistics. Therefore, each study needs to find a balance between obtaining information to satisfy the stated DQOs or study goals in a cost-effective manner, and yet have enough confidence in the data to make appropriate decisions (for example, remediation, dredging; Step 3 in the DQO process, Fig. 2). Two different concepts are used to satisfy this challenge: replication and sample compositing.

9.6.7.2 Replication is used to assess precision of a particular measure and can take many forms depending on the type of precision desired. For most studies, analytical replicates are the most frequently used form of replication because most MQOs are concerned with analytical data quality (USEPA 2001(**1**)). The extent of analytical replication (duplicates) varies with the study DQOs. Performing duplicate analyses on at least 10 % of the samples collected is considered satisfactory for most studies (GLNPO, 1994 (**11**); USEPA/USACE, 1991(**32**); PSEP, 1997a (**33**); USEPA/USACE, 1998 (**34**)). An MQO of less than 20 to 30 % relative percent difference (RPD) is commonly used for analytical replicates depending on the analyte.

9.6.7.3 Field replicates can provide useful information on the spatial distribution of contaminants at a station and the heterogeneity of sediment quality within a site. Furthermore, field replicates provide true replication at a station (analytical replicates and split samples at a station provide a measure of precision for a given sample, not the station) and therefore can be used to statistically compare analyses (for example, toxicity, tissue concentration, whole sediment concentration) across stations.

9.6.7.4 Results of field replicate analysis yield the overall variability or precision of both the field and laboratory operations (as well as the variability between the replicate samples themselves, apart from any procedural error). Because field replicate analyses integrate a number of different sources of variability, they might be difficult to interpret. As a result, failure to meet a precision MQO for field replicates might or might not be a cause of concern in terms of the overall study objectives, but would suggest some uncertainty in the data. Many monitoring programs perform field replicates at 10 % of the stations sampled in the study as a quality control procedure. An MQO of less than 30 to 50 % relative percent difference

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(RPD) is typically used for field replicates depending on the analyte (USEPA 2001(**1**)). Many regulatory programs (for example, Dredged Disposal Management within the Puget Sound Estuary Program) routinely use 3 to 5 field replicates per station. Appendix C of USEPA (2001 (**1**)) summarizes statistical considerations in determining the appropriate number of replicate samples given different sampling objectives.

9.6.7.5 Split sample replication is less commonly performed in the field because many investigators find it more useful to quantify data precision through the use of analytical and field replicates described above. However, split sample replication is frequently used in the laboratory in toxicity and bioaccumulation analyses (USEPA, 2000d (**35**)) and to verify homogeneity of test material in spiked sediment tests (see 12.4). In the field, samples are commonly split for different types of analyses (for example, toxicity, chemistry, benthos) or for inter-laboratory comparisons rather than to replicate a given sample. This type of sample splitting or subsampling is further discussed in 11.3.

9.6.7.6 *Composite Samples*—A composite sample is one that is formed by combining material from more than one sample or subsample. Because a composite sample is a combination of individual aliquots, it represents an "average" of the characteristics making up the sample. Compositing, therefore, results in a less detailed description of the variability within the site as compared to taking field replicates at each station. However, for characterizing a single station, compositing is generally considered a good way to provide quality data with relatively low uncertainty. Furthermore, many investigators find it useful to average the naturally heterogeneous physicochemical conditions that often exist within a station (or dredging unit, for example), even within a relatively small area (GLNPO, 1994 (**11**); PSEP, 1997a(**33**)). Some investigations have composited 3 to 5 samples from a given location or depth strata (GLNPO, 1994 (**11**)).

9.6.7.7 Compositing is also a practical way to control analytical costs while providing information from a large number of stations. For example, with relatively little more sampling effort, five analyses can be performed to characterize a project segment or site by collecting 15 samples and combining sets of three into five composite samples. The increased coverage afforded by taking composite samples might justify the increased time and cost of collecting the extra 10 samples in this case (USEPA/USACE, 1998 (**34**)). Compositing is also an important way to provide the large sample volumes required for some biological tests and for multiple types of analyses (for example, physical, chemical, toxicity, and benthos). However, compositing is not recommended where combining samples could serve to "dilute" a highly toxic but localized sediment "hot spot" (WDE, 1995 (**29**); USEPA/USACE, 1998 (**34**)). Also, samples from stations with very different grain size characteristics or different stratigraphic layers of core samples should not be composited (see 11.4).

9.7 *Site-Specific Considerations for Selecting Sediment Sampling Stations:*

9.7.1 Several site-specific factors might ultimately influence the appropriate location of sampling stations, both for large-scale monitoring studies, in which general sediment quality status is desired, and for smaller, targeted studies. If a targeted or stratified random sampling design is chosen, it might be important to locate sediment depositional and erosional areas to properly identify contaminant distributions. Tables 5 and 6 presents a summary of site-specific factors that should be considered when developing a sampling plan. A more detailed review of such considerations is provided by Mudroch and MacKnight (1994 (**36**)).

9.7.2 *Review Available Data*—Review of available historical and physical data is important in the sample selection process and subsequent data interpretation. Local experts should be consulted to obtain information on site conditions and the origin, nature, and degree of contamination. Other potential sources of information include government agency records, municipal archives, harbor commission records, past geochemical analyses, hydrographic surveys, bathymetric maps, and dredging or disposal history. Potential sources of contamination should be identified and their locations noted on

TABLE 5 Practical Considerations for Selection of Sampling Stations in Developing a Sampling Plan (USEPA 2001(1))

Activity	Consideration
Determination of areas where sediment contamination might occur	Hydrologic information: quality and quantity of runoff potential depositional inputs of total suspended solids up-wellings seepage patterns
Determination of depositional and erosional areas	Bathymetric maps and hydrographic charts: water depth zones of erosion, transport, and deposition bathymetry distribution, thickness, and type of sediment velocity and direction of currents sedimentation rates Climatic conditions: prevailing winds seasonal changes in temperature, precipitation, solar radiation, etc. tides, seiches seasonal changes in anthropogenic and natural loadings
Determination of potential sources of contamination	Anthropogenic considerations: location of urban lefts historical changes in land use types, densities, and size of industries location of waste disposal sites location of sewage treatment facilities location of stormwater outfalls and combined sewer overflows location, quantity, and quality of effluents previous monitoring and assessment or geochemical surveys location of dredging and open-water dredged material disposal sites location of historical waste spills
Factors affecting contaminant bioavailability	Geochemical considerations: type of bedrock and soil/sediment chemistry physical and chemical properties of overlying water
Determination of representativeness of samples	area to be characterized volume to be characterized depth to be characterized possible stratification of the deposit to be characterized

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TABLE 6 Recommendations for Positioning of Sampling Stations (USEPA 2001 (1))

Depending on level of accuracy needed, regular calibration of the positioning system by at least two methods might be required to ensure accuracy.
For monitoring and assessment studies of large areas (for example, large lakes or offshore marine environments), where an accuracy of ± 100 m typically is sufficient, either the Long Range Navigation (LORAN) or Global Positioning System (GPS) system is recommended.
For near-shore areas, or areas where the sampling stations are numerous or located relatively close together, GPS or a microwave system should be used if the required position accuracy is less than 10 m. Where visible or suitable and permanent targets are available, RADAR can be used if the required position accuracy is between 10 and 100 m.
For small water bodies and urban waterfronts, GPS is often capable of giving precise location information. Alternatively, visual angular measurements (for example, sextant) by an experienced operator, a distance line, or taut wire could also provide accurate and precise positioning data.

a map or chart of the proposed study area. It is important that recent hydrographic or bathymetric data be used in identifying representative sampling locations, especially for dredging or other sediment removal projects. The map or chart should also note adjacent land and water uses (for example, fuel docks, storm drains). The quality and age of the available data should be considered, as well as the variability of the data.

9.7.3 *Site Inspection:*

9.7.3.1 A physical inspection of the site should be performed when developing a study plan in order to assess the completeness and validity of the collected historical data, and to identify any significant changes that might have occurred at the site or study area (Mudroch and MacKnight, 1994 (**36**)). A site inspection of the immediate drainage area and upstream watershed might also identify potential stressors (such as erosion), and help determine appropriate sampling gear (such as corer vs. grab samplers and boat type), and sampling logistics.

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9.7.3.2 If resources allow, it is useful to perform some screening or pilot sampling and analyses at this stage to further refine the actual sampling design needed. Pilot sampling is particularly helpful in defining appropriate station locations for targeted sampling, or to identify appropriate strata or subareas in stratified or multistage sampling.

9.7.4 *Identify Sediment Deposition and Erosional Zones:*

9.7.4.1 When study DQOs target sampling to the highest contamination levels or specific subareas of a site, it might be important to consider sediment deposition and sediment erosional zones, since grain size and related physicochemical characteristics (including conventional parameters, such as total organic carbon and acid volatile sulfide, as well as other contaminants), are likely to vary between these two types of zones. Depositional zones typically contain fine-grained sediment deposits which are targeted in some sampling programs because fine-grained sediments tend to have higher organic carbon content (and are therefore a more likely repository for contaminants) relative to larger sediment particle size fractions (for example, sand and gravel; Environment Canada 1994(**2**), USEPA 2001(**1**)). However, for some studies such as remediation dredging evaluations or USEPA Superfund sites, eroding sediment beds and non-depositional zones might be of most concern as these could be a major source of contaminants in the water column and in organisms USEPA/USACE,(1991 (**32**)).

9.7.4.2 Various non-disruptive technologies are available to assist in the location of fine-grained sediments ranging from simplistic to more advanced. For example, use of a steel rod or PVC pipe can be used in many shallow areas to quickly and easily probe the sediment surface to find coarse (sand, gravel) vs. fine sediments (silt, clay). This technique can not, however, determine sediment grain size at depth. Other more advance methods, including acoustic survey techniques (for example, low frequency echo sounding, seismic reflections) and side-scan sonar used with a sub-bottom profiler (Wright et al. 1987 (**37**)), can provide useful information on surficial as well as deeper sediment profiles. However, these techniques are often limited in their accuracy and have high equipment costs (Guignè et al. 1991 (**38**)). Sediment Profile Imaging (SPI) or REMOTS can also assist in the identification of grain size and substrate type in advance of field-sampling activities (Germano 1989 (**39**); Rhoads and Germano 1982 (**40**), 1986 (**41**)).

9.7.4.3 Aerial reconnaissance, with or without satellite imagery, might assist in visually identifying depositional zones where clear water conditions exist. However, these methods are not reliable if the water is turbid. Other methods that can be used to locate sediment deposition zones include grab sampling, inspection by divers, or photography using an underwater television camera or remotely operated vehicle (Burton, 1992 (**42**)).

9.8 *Positioning Methods for Locating Sampling Stations:*

9.8.1 The most important function of positioning technology is to determine the location of the sampling station (for example, latitude and longitude), so that the user can later re-sample to the same position (USEPA, 1987 (**43**)). Knowing the precise location of sampling stations is also important to determine if the area(s) of interest have been sampled. There are a variety of navigation or position-fixing systems available, including optical or line-of-site techniques, electronic positioning systems, and satellite positioning systems. Global Positioning System (GPS) is generally regarded as the positioning technique of choice as it is accurate, readily available, and often less expensive than many other comparably sophisticated systems. Given the removal of selective availability of satellite data by the U.S. military, GPS is now capable of high accuracy positioning (1 to 10 m).

9.8.2 Regardless of the type of system selected, calibration of the system should be done using at least two of these methods to determine accuracy, particularly for stations that may be resampled. At each sampling station, a fathometer or meter wheel can be used to determine the sampling depth. This will help to establish that the water is the desired depth and the bottom is sufficiently horizontal for proper operation of sampling equipment. Ideally, it is best to print out a copy of the ship's location from the GPS monitor navigation chart, as well as the latitude and longitude, so the sampling station can be placed in a spatial context. Tidal or subsurface currents may push either the vessel or its suspended sampler away from the intended location which can lead to inaccurate sampling location.

9.9 *Preparations for Field Sampling:*

9.9.1 Proper preparation for any field sampling study is an essential part of Quality Assurance is important to the successful project outcome and adherence to the objectives specified in the QAPP. Section 15 further discusses related Quality Assurance/Quality Control procedures that should be used in sediment quality studies.

9.9.2 Before performing field work, characteristics of the site and accessibility of the individual sampling stations should be determined. Pictures of sampling stations both before as well as during sampling are often useful to document that the correct stations were sampled, and to document weather and water conditions during sampling. Adequate reconnaissance of stations before sampling is also valuable for preparing against potential sampling hazards or unforeseen difficulties. Such a reconnaissance can also help determine the necessary time needed to perform the desired sampling (that is, time to get from one station to the next).

9.9.3 The appropriate vessel or sampling platform is one of the most important considerations in preparing for field sampling. The vessel should be appropriate for the water body type, and should provide sufficient space and facilities to allow collection, any on-board manipulation, and storage of samples. Ice chests or refrigeration might be required for sample storage, depending on the time course of the operation. The vessel should provide space for storage of decontamination materials, as well as clean sampling gear and containers to minimize contamination associated with normal vessel operations. Space for personal safety equipment is also required.

9.9.4 Additionally, the vessel should be equipped with sufficient winch power and cable strength to handle the weight of the sampling equipment, taking into account the additional suction pressure associated with extraction of the sediments. Large sampling devices typically weigh between 50 and 400 kg empty, and when filled with wet sediment might weigh from 125 to over 500 kg.

9.9.5 Care should be taken in operating the vessel to minimize disturbances of the sediment to be sampled as well as sampling equipment. This would include physical disturbance through propeller action and chemical contamination from engines or stack emissions. For example, Page et al. (1995 a,b (**44**),(**45**)) reported that they positioned the ships' stern into the wind to prevent stack gases from blowing onto sampling equipment during deployment, recovery, and subsampling of sediments in Prince William Sound, Alaska.

9.9.6 The sampling plan and projected time schedule should be posted for view by all personnel. The names, addresses, and telephone numbers of all participants involved with the preparation and execution of the sampling program should be available to all participants, and the duties and responsibilities of each participant clearly documented. The study supervisor should determine that the appropriate personnel clearly understand their role and are capable of carrying out their assigned responsibilities and duties. Contingency planning should address the need for backup personnel in the event of accident or illness.

9.9.7 A variety of sampling and sample handling equipment and supplies are often needed in sediment monitoring studies. Besides the actual samplers themselves (for example, grab or core device to be used), equipment is needed to remove and process the samples such as spatulas, scoops, pans or buckets, and gloves. If it is important to maintain anoxic conditions of the sample, a glove box and inert gas source (for example, nitrogen) is needed. Sample storage and transport equipment and supplies need to be available as well. These include refrigeration, ice chests, dry ice or ice, insulation material to stabilize samples in transport, custody seals, and shipping air bills.

9.9.8 The reagents for cleaning, operating, or calibrating equipment, or for collecting, preserving or processing samples should be handled by appropriately qualified personnel and the appropriate data for health and safety (for example, Material Safety Data Sheets) should be available. Standard operating procedures (including QA/QC requirements) should be readily accessible at all times, to facilitate the proper and safe operation of equipment. Data forms and log books should be prepared in advance so that field notes and data can be quickly and efficiently recorded. Extra forms should be available in the event of a mishap or loss. These forms and books should be waterproof and tear resistant. Under certain circumstances, audio or audio/video recordings might prove valuable.

9.9.9 All equipment used to collect and handle samples should be cleaned and all parts examined to facilitate proper functioning before going into the field. A repair kit should accompany each major piece of equipment in case of equipment failure or loss of removable parts. Backup equipment and sampling gear should be available.

9.9.10 Storage, transport, and sample containers, including extra containers, should be available in the event of loss or breakage (see 11.2 for more information on appropriate containers). These containers should be pre-cleaned and labeled appropriately (that is, with a waterproof adhesive label to which the appropriate data can be added, using an indelible ink pen capable of writing on wet surfaces). The containers should have lids that are fastened securely, and if the samples are collected for legal purposes, they should be transported to and from the field in a locked container with custody seals secured on the lids. Samples to be frozen before analyses should not be filled to the very top of the container. Leave at least 10 % headspace to accommodate expansion during freezing (laying glass jars on their side during freezing may help to reduce the chance of the container breaking during freezing). Whether for legal purposes or not, all samples should be accompanied by a chain-of-custody form that documents field samples to be submitted for analyses (see Section 15). Transport supplies also include shipping air bills and addresses. Whole-sediment sediment samples should never be frozen for toxicity or bioaccumulation testing (Test Method E1706 and Guide E1688).

9.9.11 A sample-inventory log and a sample-tracking log should be prepared in advance of sampling. A single person should be responsible for these logs who will track the samples from the time they are collected until they are analyzed and disposed of or archived.

10. Collection of Whole Sediment Samples

10.1 *General Procedures:*

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ASTM E1391-03(2008)
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f495-41eb-ab5f-a82cd27d5549/astm-e1391-032008