Sediment Quality Guideline Options for the State of Alaska

Prepared for the
Alaska Department of Environmental Conservation
Division of Spill Prevention and Response
Contaminated Sites Remediation Program

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Executive Summary

Alaska statute and regulations provide a clear expectation that parties responsible for contaminated sites must include consideration of contaminated sediment in the assessment and cleanup process. At present there is no state guidance that would provide a responsible party with direction in how to comply. This document provides background information on contaminated sediment and presents representative methods of sediment assessment for consideration as possible models for Alaska. DEC managers responsible for deciding how Alaska will proceed with sediment program development are the intended audience. In recognition that not all potential readers have dealt with contaminated sediment, this paper is geared toward those managers with limited knowledge of the issue as well as those with more experience.

This document begins with a brief description of the basic chemical, physical and biological concepts related to contaminated sediment in order to provide a building block toward better understanding of the science involved with deriving sediment criteria. Tools for evaluating sediment are discussed and the various recognized methods of developing sediment quality guidelines are then profiled, including theoretical and empirical methods. Although these two categories of methods take very different approaches, they share the common intent of deriving numerical standards protective of the benthic environment. The theoretical methods consist primarily of equilibrium partitioning (EqP) and acid volatile sulfide (AVS) methods, while the empirical methods are dominated by weight-of-evidence approaches that include criteria of similar narrative intent, but which are derived using different statistical approaches and/or data sets. The empirical approaches typically have lower level criteria, below which toxicity to benthic organisms is not expected to occur, and upper level criteria, above which toxicity is frequently expected to occur.

Seven representative states and two Canadian provinces are offered as examples of jurisdictions that have developed sediment quality guidelines for sediments based on one or more of the profiled methods. U.S. and Canadian federal government-derived criteria are also included, as well as the preferred methods of the international Organization of Economic Cooperation.

Finally, a comparison of approaches is offered along with a discussion regarding the sediment quality assessment methods and their practicality for use in Alaska. In essence, Alaska's choice of how to proceed with program development related to contaminated sediment must balance broad and varying geographic regions, limited existing regional data, and limited staff and fiscal resources.

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1.0 INTRODUCTION

It became apparent during the research phase of this paper that the states with interest in contaminated sediment issues sufficient to warrant program development for this media were exclusively on the eastern or western seaboards, or dealing with contaminated sediment issues on the Great Lakes. Therefore, the short list of states appropriately includes Washington, California, Minnesota, Wisconsin, New York, New Jersey, and Florida. Similarly, the Canadian provinces of Ontario and British Columbia have been chosen as representative. All of these states and provinces have developed guidance related to sediments, either statewide or on a regional basis. Only one state, Washington, has actually promulgated regulations for cleanup of sediments where their numerical criteria are also to be used as cleanup standards.

The most often used general term for the sediment assessment methods that result in numeric guidance is Sediment Quality Guidance, or SQG. The spectrum of sophistication of the SQGs developed by the states, provinces, and federal agencies that are discussed in this paper provides a good array of options for Alaska to consider. There was some initial concern that there may be state or other programs out there that were unresponsive to the initial solicitation for information. Virtually all states were contacted but only about half responded. Although there may in fact be programs that remain undiscovered, as the research for this paper progressed, the comfort level grew that there were no major SQG derivation methods that are not addressed. Therefore, the jurisdictions offered are considered to indeed be representative.

Cleanup of contaminated sediment tends to be expensive and more challenging to address than other media. Zaragoza (1998) noted that sediments drove the cleanup at 14 of 200 Superfund sites that were evaluated in a GAO report a few years ago. Not only were these sites more challenging from a risk assessment perspective, but they were much more problematic as to what to do with the material once it was determined that it was a problem. Even with Alaska’s relatively limited experience with contaminated sediments, this reality is borne out.

This paper focuses primarily on the options available for assessing whether sediment is considered contaminated or not. The methods available for this purpose are almost exclusively driven by protection of the benthic environment and evaluation of the threat to upper trophic level organisms or human health is usually not a consideration. This is felt to be an appropriate first step; however, it should be realized that there are a number of other considerations that would play into a developed sediment program. There are several good examples of tiered or weight-of-evidence frameworks for dealing with sediment once initial screening indicates a problem. These will be mentioned only briefly.

Procedures for the actual gathering and interpretation of chemical and biological data are well established. The American Society of Testing and Materials (ASTM 2001) standards for laboratory analysis, the EPA Puget Sound Protocols (PSEP 1991), and the EPA ARCs Program Assessment Guidance Document (EPA 1994) are examples of excellent standard procedures available for collection and analysis of sediment data. If Alaska chooses to go forward with sediment assessment guidance, it will not have to look far for references to cite relating to the nuts and bolts of data collection and analysis. In fact, the ability to put these references in a convenient location for use by an interested responsible party is one compelling reason to at least develop public information materials regarding contaminated sediment.

The scope of this document is limited to a survey of existing information. It is not the intent of this paper to provide detailed technical information on any one topic. Even the numeric criteria lists associated with the various sediment quality guideline methods have not been included in this paper. This information is, however, readily available in the accompanying references. The summary of methods in Table 1 includes a reference citation where any associated list of numeric criteria can be found. For this, and any other technical questions, the reader is encouraged to refer to the referenced documents, all of which have been provided in their entirety as part of the package. There is no way that a survey paper such as this can do justice to the various contaminated sediment topics the way the authors of the orginal papers can.

Symbols have been added to each citation in the list of references in Appendix C to indicate whether the accompanying full document is a hard copy (denoted by 🗎), electronic version on the accompanying CD-ROM (denoted by ○), or an underlined URL address in the case of cited web pages. Electronic files include Microsoft Word and Acrobat PDF and PL files. The PDF files are text-searchable in Acrobat. The PL files are graphic copies of journal articles obtained through the University of Alaska and, although they are readable in Acrobat, they are not text-searchable.

2.0 THE ALASKA SITUATION

A responsible party for a site in Alaska where contaminated sediment is a potential issue faces a dilemma. Based on existing statute, and language in both the Alaska Water Quality regulations and the Oil and Other Hazardous Substances Pollution Control regulations, the party would be able to conclude that it is necessary to assess contaminated sediments and treat them appropriate to their potential for harm to the environment. Unfortunately, the State of Alaska does not currently have accompanying guidance that would help this person go forward to fulfill the expectation.

2.1 Statutory and Regulatory framework

The Alaska statutory and regulatory language relative to contaminated sediment is summarized as follows:

Alaska Statute, (46.09.900), defines hazardous substance to include:

> "an element or compound that, when it enters into or on the surface or subsurface land or water of the state, presents an imminent and substantial danger to the public health or welfare, or to fish, animals, vegetation, or any part of the natural habitat in which fish, animals, or wildlife may be found; "

It is clear by this definition of a hazardous substance that it is intended to cover impact to the ecological niche provided by bottom sediments, which not only provide an environment for benthic organisms, but which can also, through the food web, be a source of contamination to wildlife or humans. Since Alaska Statute also requires cleaning up hazardous substances that pose a threat to the environment, it can be inferred that cleanup of sediments that pose a threat is required.

Alaska Water Quality regulations, specifically include sediments in the applicability section (18AAC 70.005). Sediment is defined to mean "solid material of organic or mineral origin that is transported by, suspended in, or deposited from water; 'sediment' includes chemical and biochemical precipitates and organic material, such as humus;"

These same regulations (18AAC 70.020) also disallow "concentrations of toxic substances in water or in shoreline or bottom sediments, that singly or in combination, cause or reasonably can be expected to cause, toxic effects on aquatic life, except as authorized by this chapter." This is repeated in both the fresh and marine water tables. Also in the Water Quality regulations, 18AAC 70.250 and 18AAC 70.255 stipulate that the potential for impact on sediments must be considered in establishing mixing zones.

Alaska Oil and Other Hazardous Substances Pollution Control regulations present the following specific requirements with respect to sediments:

- A site characterization workplan must take into account any existing contaminated sediment, or any potential for contaminating sediment due to offsite migration (18AAC 75.335).

- A responsible person is required to propose cleanup levels for approval for contaminated sites, including contaminated sediments (18 AAC 75. 340).

- A responsible party is required to modify a cleanup level, or perform a site-specific analysis of additional site risks if it is found that if contaminated sediment is considered to be a factor (18 AAC 75.345)

- Toxic substances in sediments may not cause, or be reasonably expected to cause, a toxic or other deleterious effect on aquatic life (18 AAC 75.345)

- The department will take the presence of contaminated sediment into account as a measure of whether contaminated groundwater is connected hydrologically to surface water. Exceedence of water quality standards in surface water is prohibited (18 AAC 75.345)

- The department will require long-term monitoring if it is determined environmental media, including sediment, contains residual concentrations of a hazardous substance that exceed the applicable cleanup levels (18 AAC 75.345).

- The department will require groundwater, surface water, soil, or sediment monitoring to estimate contaminant flux rates and to address potential bioaccumulation of each hazardous substance at a site, if it is determined that monitoring is necessary to ensure protection of human health, safety, or welfare, or of the environment (18 AAC 75.345).

- As part of a contaminated site workplan, a responsible person is required to include a hydrogeologic description of the site, including sediments present (18 AAC 75.360).

2.2 Alaska Experience with Contaminated Sediment

Although there have been notable exceptions, for the most part Alaska has not found contaminated sediment to be as pressing an issue as it has been for the several Lower 48 states and Canadian provinces that have been faced with extensive industrial pollution adjacent to water bodies. The National Atmospheric and Oceanic Administration (NOAA) notes that the potential for environmental change due to anthropogenic causes is significant in the Arctic and subarctic regions for the very reason that these areas are among the most pristine (NOAA, 1995). NOAA maintains eleven long-term benthic monitoring stations in Alaska as part of their National Status and Trends (NS&T) program. NOAA (1999c) has reported that the results of the mussel tissue samples taken in Alaska as part of the NS&T program indicate no obvious trends in contaminant concentrations during the course of the monitoring effort. NOAA has also offered that any elevated levels of major and trace elements in sediment appear to reflect local mineralogy and not anthropogenic impacts.

NOAA's data is good news, however it needs to be tempered with the fact that the NS&T sample stations were deliberately chosen to be located away from likely pollution sources in order to ensure that region wide trends could be measured. There are indeed sites in Alaska where contaminated sediment has been an issue. NOAA (1999) has noted that there are a large number of Department of Defense sites in Alaska that were sometimes hastily constructed during World War II, and have since been found to have significant cleanup issues. Many of these sites are located along the coast or rivers. NOAA has also voiced a special concern related to Cook Inlet, where intense military and metal salvage activities around Anchorage have forced local government to recommend against the eating of fish taken from Ship Creek. Two additional, non-military, examples of significant sediment contamination have been Southeast pulp mill cleanup efforts in Ketchikan and Sitka. Both entailed assessment of contaminated sediments and both were considered to be of Superfund caliber. However, only one of these, the Alaska Pulp Corporation (APC) pulp mill cleanup in Sitka, was handled with the State of Alaska as the lead agency, and can therefore add some insight into how a complex contaminated sediment problem has been handled.

The APC cleanup was important for Alaska because it offered a unique opportunity to benefit from the expertise of federal, state, and local agencies that were able to come to a consensus on how to best characterize and address a very complex contaminated sediment issue. In lieu of Alaska sediment standards, the Washington State Sediment Management Standards (SMSs), Florida Department of Environmental Protection (FDEP) Sediment Quality Guidelines, and the NOAA screening guidelines were used to screen and evaluate the APC sediment data (FWEC, 1998). The Florida Threshold Effect Levels (TELs) were used as the initial screening levels, with the other methods coming into play to help in evaluation when these values were exceeded. The TEL values have been found to be at the conservative end of the scale when compared to other available criteria. The other methods helped to further define and confirm areas where contamination was an issue and higher tiers of evaluation could be employed. These methods will be summarized in chapter 5.0. Interestingly, the use of more than one method for considering the significance of sediment chemistry has been highly supported in the literature. In this respect the APC approach appears to have been forward thinking, although there is some question as to the appropriateness of using the Washington SMS values that were developed in Puget Sound. In general, however, it is difficult to criticize particular criteria when they are used as part of a suite of approaches and the bias is toward the conservative.

Although the various sediment quality guidelines were useful to the APC assessment, they were not relevant for several of the contaminants that were targeted as known problems in pulp mill effluent. Compounds of concern included metals, PAHs, resin and fatty acids, extractable organic halogens, phenolic compounds, and dioxins and furans. Where numeric guidelines were not available, the contaminants could not be ruled out by screening. Further testing included three different types of toxicity tests (two acute and one chronic); benthic community analysis; and bioaccumulation evaluations using local algae, mussels, crabs, flatfish and rockfish. Results of the bioaccumulation tests were weighed against literature values for tissue residue and endpoint effects and ultimately were included in the site ecological and human health risk assessments.

There have been several other marine and freshwater sediment contamination issues in Alaska. A review of the Alaska Contaminated Sites Database shows that contaminated sediment issues have generally not been associated with small, “mom and pop,” type operations. Most are related to past military activities and to a lesser extent private industry. Contamination in freshwater sediment in Garrison Slough on Eielson Air Force Base near Fairbanks is one notable case. Contaminated sediments associated with the U.S. Coast Guard base on Kodiak and the Navy station at Adak are two more important examples. While the state has contributed an advisory role for these efforts, it has not had specific standards or guidance with respect to sediments that would otherwise steer the federal agency.

PCBs are one of the more common contaminants found at old military and other sites. Most of the sediment quality guidelines profiled in this document list values for this contaminant. Another common contaminant found on the database, Total Petroleum Hydrocarbons (TPH) arising from petroleum spills, would probably not be addressed with any of the available criteria. There are currently no sediment screening criteria values for TPH. Even without numeric criteria, it is easy to imagine that a general guidance for investigating contaminated sediment sites would benefit the investigation of these types of sites.

3.0 FUNDAMENTALS OF CONTAMINATED SEDIMENTS

Sediments provide essential and productive habitats for communities of sediment-dwelling organisms, including epibenthic (living on top of the sediment) and infaunal (living in the sediment) species. It is well established that the benthic environment provides a critical role in marine, estuarine, and freshwater ecology. The benthos has value in it's own right and also provides a link in the food web to support higher trophic level organisms. Unfortunately, sediments also often represent the ultimate fate for many contaminants, especially those that are insoluble and tend to be associated with particles. For this reason, sediments can frequently constitute a second contaminant source long after the original source is controlled (Maughan 1993). Sediments can also provide a sink for contaminants that reduce their bioavailability, but this may also guarantee their availability for future potential exposure (Chapman and Wang 1999). An example of the latter might be the ingestion of contaminants adhering to particles re-suspended by wave action that may have otherwise reached chemical equilibrium with the porewater.

Benthic species that are not able to tolerate the toxic contaminants that are found in some sediment simply die, reducing the variety of organisms in the affected environment. Animals that survive exposure to contaminated sediments may develop serious health problems, including obvious physical effects and not-so-obvious reproductive effects. Impacts may be present even though the overlying water meets state or EPA water quality criteria (EPA 1992b).

Prior to discussing the various methods for evaluating whether contaminated sediment poses a risk, it is worthwhile to first discuss the following elements of contaminated sediment science and imagine questions that might arise from someone new to the field.

3.1 Physical and chemical attributes of sediment

What is sediment?

The Alaska Water Quality Regulations (18AAC 70) define sediment as, "solid material of organic or mineral origin that is transported by, suspended in, or deposited from water; including chemical and biochemical precipitates and organic material, such as humus." More simply, sediments are loose particles of sand, clay, silt, and other substances that settle at the bottom of a freshwater, estuarine, or marine water body. Sediments can come from eroding soil or from decomposing plants and animals. Some of the particles are brought into a system by streams and currents and others may have been brought in from distances by wind, water, and ice. In Alaska, glaciers have often been an important contributor to sediment deposits.

Contaminated sediments include the particles noted above, plus toxic or hazardous materials that may adversely affect human health or the environment. EPA defines contaminated sediments as aquatic sediments that contain chemical substances in excess of appropriate geochemical, toxicological, or sediment quality criteria or measures, or are otherwise considered to pose a threat to human health or the environment (EPA 1998).

It is important to note that sediment in the context of this paper does not include sediment that may gather in such places as sumps for fuel storage facilities, or catchment basins for storm water runoff. This distinction is important because sediment is commonly used as a descriptor in this context in the problem statement field of the Alaska Contaminated Sites Database, and has been especially prone for use in describing potential problems at defunct military facilities. This type of sediment is not relevant to the present discussion because benthic habitat is not an issue.

Why is sediment chemistry alone insufficient to evaluate the potential risk to the environment?

This may be a misleading notion in the case of the theoretical assessment methods. For example, in the equilibrium partitioning (EqP) method, contaminant chemistry in the sediment is directly related via calculation to an expected porewater concentration of the contaminant after partitioning equilibrium is reached. For this and other theoretical methods, sediment chemistry is in fact a primary consideration.

However, for the empirical methods, sediment chemistry alone can not provide a basis for assessing the potential effects of contaminated sediments because there are a number of environmental variables that affect the bioavailability of toxic chemicals to the biota. Such variables may include sediment grain size distribution, organic content of the sediment, and the availability of chemicals that might moderate the toxic effects of contaminants. In order to develop sediment quality guidelines, it is necessary to match chemistry with toxicity to benthic organisms (Crane *et al*. 2000).

What sediment characteristics besides chemistry are important to measure?

Physical characteristics can have a major impact on the mobility and bioavailability of contaminants and their ability to degrade, transform and affect microorganisms, plants and animals. Key physical characteristics include: 1) texture, as determined by the distribution of sand, silt, and clay particles in the sediment; 2) organic matter content, important because of the affinity of metals and nonpolar contaminants for sediments with high organic material content; and 3) water content. It is also important to note that the vertical and horizontal distribution of contaminants is important, and may be affected by the above physical characteristics (Lamberson *et al*. 1992).

Is knowing contaminated sediment distribution in two dimensions sufficient?

Much of the reported information about contaminated sediments, which is based on grab samples of surficial sediments, gives the impression that it is largely a two-dimensional problem. Coring studies done by EPA's ARCS Program and other coring studies have shown that sometimes the most highly contaminated sediments may be located well below the sediment surface, in the older sediments. For this reason, EPA (1994) has noted that it is essential to have some means of representing contaminant distributions in three dimensions.

EPA (1994) has also noted that, in general, sediment quality data are more easily interpreted when presented in map form, since the goal is to understand how sediment contaminants and toxicity are distributed within a particular area of concern. Quantitative mapping provides valuable insights on the extent and variability of contaminant zones.

Is there an important distinction between freshwater, estuarine, and marine sediments?

The most obvious distinction is the relative salinity level that defines each type of waterbody. The State of Washington defines freshwater sediments as those in which the sediment pore water contains less than or equal to 0.5 parts per thousand salinity. Low salinity sediments, which would include estuarine sediments, are defined as those sediments in which the pore water contains greater than 0.5 parts per thousand salinity and less than 25 parts per thousand salinity. Sediments in waters that exceed 25 parts per thousand salinity in the pore water are considered to be marine sediments (WSDEC 1995). This definition is consistent with that offered by most jurisdictions.

According to Klapow and Lewis (1979), the California State Water Resources Control Board concluded on the basis of their analysis of water data that in all cases but cadmium, marine and freshwater acute toxicity data was indistinguishable. Klapow and Lewis also noted that the hardness effect that was expected to distinguish marine waters was overshadowed by more important factors such as species and life stage sensitivities. As a result, California used freshwater, marine, and estuarine acute toxicity data in the development process for marine water quality standards. Only for cadmium were marine and estuarine data used exclusively. It is important to note that these conclusions were reached based on analysis of toxicity associated with water and not sediment. Neff *et al*. (1986) noted a marked difference in similar toxicity tests in freshwater sediments versus marine water sediments. However, he also suggested that the water hardness effect of marine waters played a minor role in the differences between species response in marine and freshwater sediment in comparison with the much more significant differences due to total organic carbons (TOCs), and to a lesser degree, species sensitivity.

Data initially included in NOAA's National Status and Trends (NS&T) database, which was the information basis for Long and Morgan's ERL/ERM method discussed in chapter 5.0, represent marine, estuarine, and freshwater environments (Long and Morgan 1990). A few jurisdictions have adopted the Long and Morgan approach based on their 1990 work on behalf of NOAA. However, in 1995 the database was updated to focus on marine organisms. The data compiled by MacDonald *et al*. (1994) for Florida are also from marine and estuarine locations only. It will be shown that it is not uncommon now to have jurisdictions cite SQGs based on one method for marine sediment versus another for freshwater sediment, because of the nature of the databases that formed the basis for the methods. Smith *et al.* (1996), suggested that SQGs used by Environment Canada (TEL/PEL) for marine water sediment could appropriately be used in the interim for freshwater sediment where the database for the latter is insufficient to allow derivation of freshwater SQGs. This conclusion was reached based on an analysis of the comparability of the two data sets.

There are many similarities in the approach taken to assess sediments, regardless of whether they lay at the bottom of fresh, estuarine, or marine water bodies. Environment Canada has used the same method to develop SQGs for both marine and freshwater sediment. The only distinction between the two is that different databases are used to develop distributions that factor into the numeric values (CCME 1995). In another example, MacDonald et al. (2000b) developed consensus-based sediment effect concentrations (SECs) for PCBs separately for freshwater sediments and for marine and estuarine sediments. Because it was found that the respective SECs were statistically similar, the underlying SQGs were subsequently merged and used to formulate more generally applicable SECs (MacDonald *et al.* 2000b). Still, there are important differences between freshwater and marine/estuarine sediments that need to be noted, as follows.

- Choice of target organisms for toxicity testing is often different, although procedures for freshwater sediment are sometimes used in estuarine water. EPA (2000) reports that estuarine sediments (up to 15‰ salinity) can also be tested in 10-d freshwater sediment toxicity tests with *Hyalella azteca.*

- Freshwater sediments tend to be much higher in total organic carbon (TOC) (EPA, 1992). Neff *et al*. (1986) attributed differences between marine sediment and freshwater sediment predominantly to effects caused by this TOC difference.

- Many marine test species are field collected rather than cultured. Adult organisms are used for tests rather than the young cultured organisms used in freshwater testing. This difference affects feeding regime as well as the necessity for performing routine reference toxicant testing (EPA 1992).

- Jones (1997) cites an analysis of the feeding habits of freshwater benthic species that concluded that these species were not sediment ingesters, except for the oligochaetes (aquatic earthworms) and some chironomids that are both filter feeders and occasional sediment ingesters. In contrast to this, he noted that marine burrowing species frequently ingest sediment.

3.2 The benthic environment

The benthos, or benthic environment, consists of organisms such as worms, crustaceans, and insect larvae that inhabit the sediments at the bottom of a water body. Since some contaminants can kill or stress benthic organisms, and reduce food available to larger animals, the health of the benthic environment is often seen as an important indicator of the presence of contaminants. Most approaches for deriving sediment quality guidelines are based exclusively on protection of the benthic environment.

What is toxicity?

Determination of toxicity of contaminated sediments to benthic organisms depends on any of a number of tests that provide a direct measure of the effect of the sediment on living organisms. The effects noted to biological organisms are commonly referred to as measurement endpoints. The results of toxicity tests depend on which species is tested, which response is measured and the method of exposure. The many combinations among these choices make determinations of toxicity subjective. However, O'Connor and Paul (2000) have noted that measuring survival of amphipods exposed to whole sediment for ten days has become a *de facto* standard. The amphipod test was added to the protocols for testing dredged material in 1991. Before that, sediment toxicity tests were conducted using organisms that were not as sensitive to toxic chemicals. As the result of introducing the amphipod test, dredged sediment near New York City increased from 1% to greater than 30% toxic.

Typically, sediment is considered toxic if there is less than 80% survival of amphipods during 10-day exposures to whole sediment. NOAA used the whole-sediment 10-day amphipod survival test along with other tests in the Bioeffect Survey that resulted in their NS&T (Long and Morgan 1990). The amphipod test was introduced initially because surveys from a variety of locations showed that amphipod species decreased in abundance near sources of contamination (O'Connor and Paul 2000).

It is commonly accepted that a measure of chronic toxicity is necessary in addition to acute toxicity, to ensure the long-term well being of the benthic environment. There have been a number of proposals for measurement of chronic toxicity. One of the issues is where to draw the line. O'Connor and Paul (2000) have argued that letting any available toxicity test be used can put almost all sediments into the toxic category and nullify any effort to find a chemical or physical characteristic that predicts toxicity. However, they also note that relying on the toxicity tests that predate the amphipod test would find toxicity too infrequently to make the search for predictive characteristics relevant.

A more thorough treatment of toxicity tests is beyond the scope of this document. EPA (1994, 2000, 2000b) and ASTM (2001) provide comprehensive lists of available toxicity tests, both acute and chronic.

What is Bioavailability?

If bulk sediment chemistry shows that toxic chemicals and metals are present in sediments, this does not necessarily mean that the presence of these contaminants is harmful, if they are not bioavailable. Bioavailability is the ability of a substance to affect living organisms. Bulk sediment chemistry does not equate to availability of contaminants to these organisms. The premise underlying the equilibrium partitioning (EqP) method described in chapter 5.0 provides a good example of the concept of bioavailability. The EqP method is premised on the fact that TOC content of the sediment preferentially attracts non-ionic organic chemicals, resulting in bioavailable concentrations of these contaminants in the sediment porewater that are far less than the total concentrations. Only the porewater concentrations are defined as being bioavailable. In addition to the amount of organic carbon in the sediment, the size of the sediment grains, the acidity/alkalinity of the water and other characteristics determine the bioavailability of contaminants.

What are Bioaccumulation and biomagnification?

Some contaminants in the sediment are taken up by benthic organisms in a process called bioaccumulation. When animals higher in the food chain feed on contaminated organisms, the toxins are taken into their bodies, moving up the food chain in increasing concentrations in a process known as biomagnification. Fish and shellfish, waterfowl, and freshwater and marine mammals, as well as benthic organisms, are affected by contaminated sediments. Bioaccumulation is not intrinsically an adverse effect endpoint (McCarty 1998). Bioaccumulation is usually not factored into the sediment quality guideline derivation methods discussed in chapter 5.0. The guidelines are geared toward protection of benthic organisms. These considerations do factor into higher tiers of evaluation, including ecological and human health risk assessment.

What is uncertainty?

Uncertainty is a concept that crops up frequently in discussion of the various methods for developing sediment quality guidelines. Uncertainty can be explained simplistically by taking the example of the probability of getting heads versus tails when flipping a coin. One might conclude from the data resulting from four flips of the coin that there is only a 25% probability of getting heads, or even zero probability. However, if the number of coin tosses were increased to one hundred, the probability of getting heads in the coin toss would more accurately converge on a probability of 50%. The comfort level with the weight-of-evidence methods of deriving sediment quality guidelines (SQGs) is premised on the idea that the more data used, the more the likely the statistics based on this data will reflect the real situation.

Invariably, the more applicable data there is available for decision-making, the less uncertainty there will be. The NOAA and Florida SQG values were developed from data from many investigations throughout the United States and these studies used different approaches to evaluate sediment quality (e.g., toxicity tests, EqP, AET). As an added benefit, Jones *et al.* (1997) note that the use of numerous data and the calculation of percentiles help eliminate the influence of a single (possibly outlier) data point, thereby making the sediment quality values more credible.

The regulatory answer to uncertainty is often to make conservative assumptions to create a comfortable safety margin. Klapow (1979) has reminded us that the need for a safety margin, while real, is in essence an admission of ignorance. Maughan (1993) has argued that conservative assumptions made to compensate for the uncertainties often results in unnecessarily stringent and expensive control of sediment quality and requirements for remediation.

Ingersoll *et al.* (1996) provide an example of how uncertainty associated with a particular sediment quality guideline might be managed by reducing the number of exceedences needed to cause sediment to fail a preliminary screening. A low number of exceedences will minimize the potential for false negatives (Type II error), but the tradeoff is the risk of accepting higher false positives (Type I error), with commensurate financial consequences.

As another example of trading one uncertainty for another, there may be an uncertainty associated with using an effects-based sediment quality guideline that is based on a large data set, but which is geared toward a more temperate climate than the subject area. The uncertainty in that instance relates to the transferability of the data set to another area. An alternative approach would be to use a local, likely much smaller data set. The question of whether the uncertainty associated with a relatively small data set is preferable to the former type of uncertainty can be important, and may be very difficult to answer. This question will be very important for Alaska. The indications are that the larger data set covering broader geographic areas may be preferable, especially if the alternative of collecting additional regional data is not feasible because of limited resources.

4.0 SEDIMENT MEASUREMENT TOOLS

The sediment assessment methods covered in chapter 5.0 rely on information gathered using one or more of the following tools for gathering and evaluating data related to contaminated sediments.

4.1 Chemistry and physical characteristics of sediments

Sediment chemistry is determined by extracting and measuring contaminants from the sediment matrix through various analytical techniques. In general, the target analytes to be measured are determined based on land and water use information. Existing sediment chemistry data and fish advisory information is also important in developing a target analyte list. Typical chemistry analyzed in sediments collected near urban or industrialized areas include trace metals, PAHs, PCBs, organochlorine pesticides, and several other organic substances (e.g. TCDDs/TCDFs; chlorophenols, phthalates, etc.). Chemical concentrations are generally reported on a dry weight basis from extracted sediment samples. However concentrations of contaminants in porewater and elutriate samples may also be measured to provide information on the bioavailable fraction of contaminants (Crane *et al.* 2000).

Several conventional variables, such as sediment particle size, total organic carbon (TOC), acid volatile sulfides (AVS), aluminum, lithium, sulfides, and ammonia, are also usually measured to provide information to help interpret information on contaminant concentrations. These conventional variables often provide a measure of binding capacity to prevent bioavailability of a contaminant. Lee and Jones-Lee (1993) have noted that a low concentration of a contaminant in a sediment with low binding capacity for the contaminant can be much more toxic than a high concentration of the same contaminant in a different sediment.

Total ammonia nitrogen can be a confounding factor in sediment toxicity tests, but measures can be taken to manage it during laboratory testing (Ferretti 2000). Chemical data can be normalized to account for AVS, which tend to reduce the effects of metals, and TOC, which tends to reduce the effects of non-polar compounds. Normalizing can reduce the variance in the data or better define the bioavailability of sediment-bound contaminants. Sediments may also be normalized to sediment particle size (Crane *et al*. 2000). Lapota *et al.* (2001) give a good treatment of how to normalize the conventional variables, including a recommended framework for factoring out interference from these variables to ensure that toxicity testing results are a clear measure of a contaminant’s effects.

Not all authors agreed that TOC normalization provides the best results. Cubbage et al. (1997) found better statistical results when using Washington’s freshwater data when it was not normalized for TOC. Ingersoll *et al*. (1997) and MacDonald *et al.* (2000b) concluded that normalizing for TOC gave no net benefit when considering SQG approaches for use in the Consensus method.

As a general rule, chemical pollutants associated with sediments are much less bioavailable and toxic to aquatic organisms than the same pollutants in solution in the water (Neff et al. 1986).

Advantages:

- Sediment chemistry measurements can be both accurate and precise.
- Chemistry measurements can provide a reliable basis for defining the margin between contaminated and uncontaminated sites.
- Sampling and analysis procedures associated with chemistry measurements are well established.
- Chemistry measurements conducted on porewater extracted from contaminated sediment can be related directly to water quality standards.

Limitations:

- Sediment chemistry alone can not provide a basis for assessing the potential effects of contaminated sediments because there are a number of environmental variables that affect the bioavailability of toxic chemicals to the biota.
- When considering the need for cleanup, the combined impact of a mixture of chemicals is the critical question, whereas remediation criteria must generally be established on a chemical-by-chemical basis, because the range of possible mixtures can be close to infinite (Maughan 1993).

4.2 Sediment toxicity

Laboratory sediment toxicity tests assess lethal and sublethal endpoints in surrogate organisms exposed to sediments under controlled conditions. These tests include short-term (10 days) and long-term (>10 days) exposure periods that are used to evaluate the biological significance of sediment contamination. These tests may be as simple as short-term tests on a single contaminant using a single species, or as complex as studies on the long-term effects of mixtures of contaminants on ecosystem dynamics. Tests may be designed to assess the toxicity of whole sediments, suspended sediments, elutriates sediment extracts, or porewater. The organisms that are routinely tested include microorganisms, algae, invertebrates, and fish. MacDonald *et al*. (1996) have recommended that a comprehensive sediment quality assessment should employ a battery of biological tests, including at least one sensitive enough to detect chronic effects.

Whole sediment toxicity tests are the most relevant for assessing the effects of contaminants that are associated with bottom sediments. Standard methods have been established for assessing the acute and/or short-term chronic toxicity of sediment-associated contaminants on the amphipod, *Hyalella azteca*, the midges, *Chironomus* *tentans* and *Chironomus riparius*, the mayfly, *Hexagenia limbata*, and several other species (USEPA 2000b, ASTM 2001). These procedures may be modified to assess toxicity to other benthic invertebrate species. Similar guidance has also been developed under the U.S. EPA's Assessment and Remediation of Contaminated Sediments (ARCS) program (USEPA 1994). Ten-day freshwater acute toxicity tests using *H. azteca* and *C. tentans* have been selected by the U.S. EPA's Sediment Tiered Testing Committee for Agency-wide use (USEPA 1998).

Suspended phase sediment toxicity tests are also used, when the actual environmental conditions at a site may include having bottom sediments stirred up by wave action or other causes. Various procedures are available for assessing the potential for adverse effects on aquatic organisms due to the resuspension of sediments or partitioning of contaminants into the aqueous phase. One of the most sensitive and frequently used of these are the bacterial luminescence tests, also referred to as the Microtox® tests. Tests using algae, invertebrates, and fish also have been used to assess the toxicity of the suspended and/or aqueous phases, including porewater (Crane *et al.* 2000). Mayfield (2001) presents several other potential microbiological toxicity testing procedures, none of which seem to work as satisfactorily as the Microtox® method.

The American Society of Testing and Materials (ASTM) is continually updating and attempting to standardize sediment bioassay methods, and should be consulted in the design of any sediment bioassay program (Maughan 1993). ASTM (2001) provides a table of bioassay methods for both freshwater sediment and marine water sediment. Good summary information is available for each method via hot-keys in the table in this web-based ASTM reference.

Advantages:

- Toxicity tests provide quantitative information on sediment toxicity that allows for discrimination between impacted and unimpacted sites. Standard methods have been established to support the generation of reliable and comparable data, as well as to minimize the effects of the physical characteristics of the sediments (EPA 2000b, ASTM 2001).

- The results of toxicity tests are ecologically relevant because resident species are usually used and the tests provide a way to compare the sensitivities of different organisms (EPA 1992).

- Studies conducted throughout North America have demonstrated that aquatic organisms in standard sediment toxicity tests respond primarily to the contaminants in the sediments and porewater as opposed to physical factors or other variables. These characteristics make them relevant for evaluating contaminant-related impacts in freshwater systems (EPA 1992).

- Techniques for identifying the chemicals that are causing toxicity, such as the toxicity identification evaluation (TIE) procedures, further support the identification of contaminants of concern.

Limitations:

- Field-collected sediments are manipulated prior to testing, which may affect their integrity and toxicity (Crane *et al*. 2000).

- Some test organisms may be more sensitive to certain classes of contaminants than others and a suite of tests may be necessary to cover the range of sensitivities in exhibited by sediment-dwelling species in the field. With limited resource, a balance is often necessary between number of samples and the number of species and endpoints (Crane *et al*. 2000).

- While the endpoints are expedient and extremely useful to evaluate relative toxicity, they are measurement endpoints and do not always automatically directly relate to ecological assessment endpoints of concern (Maughan 1993).

4.3 Benthic invertebrate community structure

Note: This discussion is limited to benthic invertebrate community structure, which has a special role in the assessment methods to follow. Biological assessment in general is a much broader and richer topic, particularly in the upper tiers of sediment assessment that are beyond the scope of this paper. For example, such tiers may include bioaccumulation studies when upper trophic level impacts or human health risks are the endpoints. The interested reader is directed to EPA (2000) and EPA (2000b), which are two excellent references dealing with biological aspects of freshwater sediments and estuarine/marine water sediments respectively.

According to Maughan (1993), the analysis of benthic community structure is the biological equivalent of the bulk chemical testing of sediment. The approach measures the in situ biological character of the sediment and uses the information to evaluate sediment quality.

Benthic macroinvertebrates are relatively sedentary organisms that inhabit or depend on the sedimentary environment for their various life functions. Because of this, they may be sensitive to both long-term and short-term changes in habitat, sediment, and water quality (EPA 1992). Benthic macroinvertebrate communities are routinely used to assess potential impacts caused by many different chemicals or classes of chemicals (EPA 2000b). They cannot be used alone to generate Sediment Quality Guidelines, but they may be an important part of an integrated sediment assessment (EPA 1994). The use of macroinvertebrates to assess sediment contamination is most successful when combined with sediment chemistry and toxicity results, as in the integrated Sediment Quality Triad approach discussed in this chapter.

Assessments of the structure of benthic macroinvertebrate communities provide direct evidence of the effects of sediment contaminants on naturally occurring communities, which is something laboratory tests can not do. Differences from expected community characteristics as demonstrated by comparing with reference conditions might be attributable to chemical contaminants. However, causes for differences due to other factors also need to be considered. These factors may include the sediment grain size and the organic content of the sediments. Because of this it is considered important to make comparisons with the benthic macroinvertebrate communities in reference areas with similar sediment characteristics (EPA 1994).

Benthic macroinvertebrates can be used to screen for potential sediment contamination and source identification by displaying spatial gradients in community structure. Typically, the data are quantified by the surface area of the sampler or sediment being collected. For a system reconnaissance or screening survey, it is generally not necessary to go beyond the family level. Species-level identifications for all organisms are not necessary for a successful program, and they commonly depend on the availability of local keys. General keys available for genus-level identifications are available (EPA 1992).

Assessing biological condition requires reference conditions for comparison and for development of models and indexes to help establish biocriteria and detect impairment. EPA (2000b) is an excellent reference for the various considerations in establishing reference conditions.

Advantages:

- Because benthic infauna have long been used for water quality assessments, a larger body of data has been accumulated for use in comparison and analysis (EPA 2000b).

- Benthic macroinvertebrate community assessment usually provides a conservative measurement. It is more common to observe an impacted community when there is no sediment impact because of the influence of factors other than sediment and water quality (EPA 1992).

- Benthic macroinvertebrate community assessment provides an economical and accurate indication of the health of the benthic ecosystem under study and it is based on direct observation rather than theoretically derived data (EPA 2000b).

- The cost of benthic macroinvertebrate assessments is economical compared to that for chemistry or toxicological evaluations (EPA 1992).

Limitations:

- Relatively few state and federal programs have the necessary in-house taxonomic expertise to support extensive monitoring activities (EPA 2000b).

- It can be difficult to discriminate between slightly or moderately impaired areas, particularly in estuaries due to their natural spatial and temporal variability (EPA 2000b).

- It is difficult to relate the findings to the presence of individual chemicals and specific concentrations of those chemicals for numeric in-place pollutant management. That is why the method should be integrated with chemistry and toxicity information (EPA 1992).

4.4 Sediment Quality Triad

The Sediment Quality Triad (Triad) was developed as a tool to support site-specific assessments of sediment quality. MacDonald (1994) has also cited the Triad method as having been used to develop SQGs. The method has been included in the Tools chapter preferentially over the Methods chapter because it appears to be primarily a method for evaluating sediment on a sample specific and site specific basis.

The Triad is based on correspondences between the three preceding tools for measuring sediment quality conditions: sediment chemistry; sediment toxicity tests; and, benthic invertebrate community structure. Data on sediment chemistry and other physical characteristics are collected to assess the level of contamination at a particular site and to document other factors that could influence the distribution and abundance of benthic species. The results of toxicity tests provide information that may be used to evaluate the effects of sediment-associated contaminants on resident or indicator species. Measures of in situ biological effects, such as benthic infaunal community structure or histopathological abnormalities in benthic fish species, provide information on alterations of resident communities that may be related to sediment chemistry. Integration of these three components provides comprehensive information which may be used to evaluate and rank the relative priority of the areas that have been surveyed (EPA 1992).

Since each of the three measures used with the Triad involves different types and units of measurement, they can not be directly combined. However, the data can be normalized to the reference site or to values for the reference sediment by developing a ratio-to-reference value. The value is expressed as a percent of the comparable reference measurement (i.e., sediment of concern/reference value) such that 1.0 indicates an identical quality to the reference (Maughan 1993).

Although there are numerous approaches to the analysis and interpretation of multivariate data sets produced by the Triad approach, data are often summarized as indexes plotted on three axes of a Triad plot. One axis represents sediment chemistry; a second axis represents sediment toxicity; and a third axis represents in situ biological effects. The indexes plotted on the Triad axes are ratio-to-reference (RTR) values. Measurements from the site being assessed are divided by the values of the same parameters measured at a reference site that is not contaminated. Plotted in this way, the relative degree of anthropogenic “impact” along each axis can be presented visually (Alden 1992).

According to Canfield *et al*. (1992), the Triad has been used to: identify and differentiate pollution-degraded areas in marine, estuarine, and freshwater sediments; determine concentrations of contaminants associated with effects; predict where degradation may occur based on chemistry and toxicity; and rank areas for possible remediation.

Advantages:

- The Triad method enables differentiation between the natural variability in benthic characteristics from variability due to the toxic effects of environmental contaminants. (Crane *et al.* 2000).

- When Triad is displayed as RTR plots, the information is readily understandable (Alden 1992).

- The Triad may be used for any measured contaminant (Crane *et al.* 2000).

- The Triad analysis may include both acute and chronic effects (Crane *et al*. 2000).

- The Triad does not require information on the specific mechanisms of interaction between organisms and toxic contaminants (Crane *et al*. 2000).

- The integration of the three data types provides a weight-of-evidence regarding contaminant-related impacts on the benthic community (Crane *et al*. 2000).

Limitations:

- The Triad approach can not be used alone to establish cause-and-effect relationships for individual substances (MacDonald 1994).

- The results can be strongly influenced by the presence of unmeasured toxic contaminants that may or may not co-vary with the measured chemicals (EPA 1992).

- RTR plots of Triad information do not lend themselves to ready interpretation of confidence levels associated with the data; i.e., data from one sample location is often displayed in the same manner as data from a long term regional study (Alden 1992).

- Sample collection, analysis, and interpretation is labor-intensive and costly; and, the choice of a reference site is often made without adequate information on how degraded the site may be (EPA 1992).

- The Triad may not explicitly consider the bioavailability of sediment-associated contaminants (EPA 1992).

4.5 Tissue Residue

Tissue residue does not typically play into qualitative analysis of the benthic environment, and is therefore not usually used in deriving the SQGs discussed in chapter 5.0. SQGs based on tissue residue would generally be developed from tissue residue guidelines applicable to the protection of wildlife or human health (MacDonald 1994). The tool is presented here for information purposes regarding its use in upper tier analysis of contaminated sediment.

The tissue residue approach is premised on the fact that sediments represent important sources of bioaccumulative contaminants in aquatic food webs. The approach is also referred to as biota-water-sediment equilibrium partitioning approach. It applies to protection of animals in the upper trophic levels and human health more than protection of the benthic environment. The goal is to assure that the concentrations of sediment-associated contaminants remain below the levels that are associated with the bioaccumulation of contaminants to harmful levels in the food web. Safe sediment concentrations for individual chemicals or classes of chemicals are established by determining the chemical concentrations in sediments that are predicted to result in acceptable tissue residues (Crane *et al.* 2000).

The first step in deriving numerical SQGs using the TR approach is to select contaminants based on their potential to accumulate in the aquatic food web. Numerical tissue residue guidelines (TRGs) are then identified for these contaminants. While most of the available TRGs are intended to provide protection for human health, it is also important to obtain TRGs that are explicitly designed to protect piscivorus wildlife species (fish). Following the selection of TRGs, biota-to-sediment accumulation factors (BSAFs) are determined for each of the substances of concern. Such BSAFs can be determined from the results of bioaccumulation assessments, from matching sediment chemistry and tissue residue data, or from the results of bioaccumulation models. Numerical SQGs are then derived using the equation:

$$SQG = TRG \div BSAF$$

The Tissue Residue approach has been used on several occasions to develop SQGs for the protection of human health (most notably for DDT, Hg, and PCBs) (CCME 1999). In addition, sediment contamination limits for 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) have been established for Lake Ontario on the basis of fish tissue residues (Crane *et al.* 2000). MacDonald (1994) considered the approach to be a logical companion to the effects-based approach to deriving SQGs

Advantages:

- Most existing sediment quality guidelines and interpretive frameworks, such as the sediment quality triad, address only benthic toxicity. The Tissue Residue method allows focus on food web models and bioaccumulation issues necessary for ecological or human health risk assessment (Michelsen 1999).

- SQGs can be derived directly from tissue residue guidelines if bioaccumulation factors are available (MacDonald 1994).

Limitations:

- The method applies to protection of animals in the upper trophic levels and human health more that protection of the benthic environment. Most sediment screening methods are based on evaluation of impact to the benthic environment (Crane *et al.* 2000).

- Species sensitive to the contaminants of concern, which might otherwise be used as endpoint species, may not be present due to the toxicity of the sediments (Maughan 1993).

- Tissue residue guidelines for the protection of wildlife have not been established for most contaminants (MacDonald 1994).

- Tissue analysis only detects the effects of compounds that bioaccumulate, which is usually restricted to metals and persistent organic contaminants (Maughan 1993).

4.6 Toxicity Identification Evaluation

If remediation is warranted because sediment of concern has been shown to be toxic, pore water bioassay techniques can help provide important input to the selection of the appropriate remediation method. The process follows the toxicity identification evaluation (TIE) procedure developed by EPA for the evaluation of municipal and industrial effluents (EPA 1994).

The TIE procedure is a phased approach to characterize, identify, and then confirm the toxic components of a complex aqueous solution. The toxicity of the pore water is first quantified in laboratory toxicity tests, and then TIE procedures are used to identify and quantify the chemical constituents of the interstitial water responsible for the sediment toxicity. The solution is subjected to a series of treatments to remove or render inactive various categories of compounds. If the treatment does not alter the toxicity of the pore water compared to the untreated pore water, then the category of compounds vulnerable to the specific treatment can be eliminated as contaminants of concern. Treatments or inactivating methods might include pH to alter ammonia toxicity and the effects of various metals, aeration to eliminate volatile or oxidizable contaminants, and chelating agents to produce complexes of many metals (Maughan 1993).

Advantages:

- The method can identify the cause-effect relationship for toxicity, something the effects-based SQG methods cannot do.

- The method can assist in determining remedial action targets for individual contaminants.

Limitations:

- EPA (1994) notes that the TIE method is not as readily applied to sediments because of the difficulty in collecting sufficient volumes of interstitial water for toxicity testing

- TIE procedures may be difficult and costly (Maughan 1993).

- No universally accepted method for extracting porewater from sediment exists (Jones *et al*. 1997).

- Porewater is difficult to extract from sediment without potentially altering the toxicity of the pore water (EPA 1994).

- TIE procedures are most effective when a single substance or a limited number of contaminants is responsible for the observed toxicity. Discrimination of the effect of individual substances is difficult when many chemicals are contributing to sediment toxicity (Crane *et al.* 2000).

4.7 Sediment Profile Imaging

Sediment profile imaging, or SPI, involves sending a camera down to the bottom floor of a water body. When the camera hits the bottom, it digs into the sediment layer and takes a picture of the top 10 to 30 centimeters of the sediment column. The resultant images allow assessment of sediment quality and mapping of benthic conditions affected by contamination. Under the right circumstances, the SPI has proven to be a useful benthic reconnaissance tool to help cost-effectively direct chemical and biological sampling (Minnick 1996).

As part of the site investigation at the Alaska Pulp Corporation in Sitka, a SPI camera was utilized as a tool for evaluation of the potential boundaries of depositional materials in Sawmill Cove associated with historical mill operations. The camera was also able to discern infaunal (organisms within the sediment) succession stages, which in effect gave another dimension to evaluation of the benthic community structure. It was not as successful as was initially hoped however, partially because of mechanical failure and partially because of bottom obstructions such as sunken logs (FWEC 1998).

Advantages:

- The method can provide a relatively inexpensive method of bottom reconnaissance, both for physical and biological attributes.

Limitations:

- Any image data gathered can not be used alone. It must be correlated with field data.

- Alaska experience has shown that irregular bottom structure, such as sunken logs, can interfere with the gathering of images.

5.0 THE METHODS OF SEDIMENT QUALITY ASSESSMENT

The general term "Sediment Quality Guidelines" (SQGs) is commonly used to describe the tables of numeric values that are derived using the methods described in this chapter. This acronym is also used as the general term in this paper. The lists of numeric values derived using the various methods have not been reproduced in this paper; however, they are available in the documents that have been cited as the primary reference associated with each method summarized in Table 1 on the following page. These documents are included as part of the package of reference information accompanying this paper. Data from several of the more common methods have also been summarized in the NOAA SQuiRTs tables for sediments (NOAA 1999b).

Chapman and Wang (1999) have advocated use of the term "Sediment Quality Values" (SQVs) to denote the derived tables of numeric values. They argue that words such as "guidelines" or "criteria" have regulatory and legal implications that should not be lightly used. Several of the jurisdictions that have developed SQGs appear to agree with him and have stressed that their numeric tables should not be used alone for the purpose of establishing cleanup goals, but should only be used along with other measurements that give the whole picture. A few, however, have offered their SQG tables as numeric cleanup goals, or as numeric screening levels that can clear a site from further investigation.

The scientific and regulatory communities remain in debate on the best methods to be used to develop sediment quality guidelines. Jones *et al*. (1997) note that this diversity of opinion is demonstrated by the wide variety of methods being studied. One example given is that fact that the state of Washington has implemented sediment quality standards based on the apparent effects threshold (AET) approach, whereas the equilibrium partitioning (EqP) approach is favored by the EPA Office of Water.

The SQG methods described in this chapter have addressed many of the chemicals that have proven to be most problematic in sediment. States and provinces commonly borrow individual chemical values from numeric tables derived by other jurisdictions when their SQG method of choice has gaps. However, there are no state or federal sediment quality standards for conventionals, dioxin/furan isomers, resin acids, or many other potentially toxic chemicals. Derivation of screening or cleanup levels for these chemicals therefore will still need to be considered on a case-by-case basis regardless of the SQG method chosen.

Several methods of categorizing the SQG methods are available. The choice of presentation in this chapter follows the format used by Crane *et al*. (2000), wherein the sediment evaluation methods are broken into two types, theoretical and empirical. Some of the methods, particularly the empirical methods, build on one another. It is therefore advantageous to start with the simplest techniques and work up to the more encompassing methods. Table 1 provides a summary of the SQG derivation methods included in this chapter. A narrative description of each method follows the table.

Table 1. Sediment Assessment Methods

Method/Chapter	SQG Acronym	Description
Sediment Background Approach (5.1.1)	SBA	Sediment chemistry samples are compared to reference background samples. It is assumed that samples that do not exceed background levels significantly are not hazardous (MacDonald 1994).
Equilibrium Partitioning (5.1.2)	EqP	A sediment quality value for a given contaminant is determined by calculating the sediment concentration of the contaminant that would correspond to a porewater concentration equivalent to the EPA or state water quality criteria for the contaminant (Di Toro *et al*. 1992).
Acid Volatile Sulfides (5.1.3)	AVS	Acid volatile sulfides (AVS) and simultaneously extracted metals (SEM) are compared. If the SEM concentration is less than the AVS concentration on a molar basis, the sediment is considered to be non-toxic to benthic organisms (EPA 2000b)
Porewater Effect Concentration (5.1.4)	PEC	Porewater concentrations of contaminants are compared to tables of porewater effect concentrations based on water quality standards (Carr 1997).
Apparent Effects Threshold (5.2.1)	AET	The AET is the sediment concentration of a contaminant above which statistically significant biological effects would always be expected based on paired chemistry and a range of biological effects indicators (EPA 1992)
Screening Level Concentration (SLC) (5.2.2)	LEL/SEL	The SLC is an estimate of the highest concentration of a contaminant that can be tolerated by a specific proportion of a benthic species. Only the presence or absence of a species is evaluated (Persaud 1993)
Spiked Sediment Toxicity Test (5.2.3)	SSTT	Dose-response relationships are established by exposing test organisms to sediments that have been spiked with known amounts of chemicals or mixtures of chemicals (EPA 1992).
NOAA Method (5.2.4) (also referred to as weight-of-evidence method)	ERL/ERM	Values for an effects range low (ERL) and an effects range median (ERM) are derived arithmetically from a database consisting of matched chemical and biological effects data, including field data and laboratory bioassays, and EqP models (Long and Morgan 1990).
Florida Method (5.2.5) (also referred to as the modified weight-of-evidence method)	TEL/PEL	Similar to the NOAA method except for inclusion of the "no effects" data set and use of a geometric mean instead of an arithmetic mean to define the effects levels (MacDonald 1994).
Consensus Method (5.2.6)	TEC/PEC	Available SQGs which meet narrative intent and other criteria are included and averaged via geometric mean, resulting in composite SQGs (MacDonald 2000)
Logistics Regression Method (5.2.7)	LRM	Matched chemical and biological effects data is statistically analyzed, resulting in regression curves that can define the probability of a toxic response from a given sample (Field 1999).

5.1 THEORETICAL METHODS

5.1.1 Sediment Background Approach

Criteria have been established in several jurisdictions based upon an approach involving the use of reference or background values in sediments. The basis for the sediment background approach (SBA) is the assumption that concentrations above these background values have an adverse effect on aquatic organisms. In this approach, the data from a pristine area are used as the standard and concentrations in sediments from target areas that exceed these background values by some specified amount are considered unacceptable. A suitable reference site may be one where sediments are considered to be relatively unaffected by anthropogenic inputs. In some cases the criteria have been set at some value above the background concentration, for example 125 percent of background or two standard deviations above the mean background concentration (Long and Morgan 1990). This approach does not involve any determination or estimation of effects.

The SBA is considered by the government of Ontario as having value where adequate data do not exist for application of any of the other methods or where the methods used are inappropriate for the type of contaminant. In addition, background levels are considered to provide a practical lower limit for management decisions (Persaud 1993).

Comparison of site contaminant levels with background levels is a simple screening method. The assumption is that concentrations that are not higher than background are not hazardous. Appropriate background samples must be obtained. The American Society for Testing and Materials (ASTM) has developed guidelines for selection of sediment and soil background sampling locations (Jones *et al*. 1997)

Advantages:

- Data requirements are minimal in that the method requires only measurement of the chemical concentrations of contaminants in the sediments (MacDonald 1994).

- The method does not require quantitative toxicological data and avoids the need to seek explanations for contaminant behavior or biological effects (MacDonald 1994).

- Background concentrations can be used to screen the other sediment benchmarks so that sediment benchmarks that are within the range of background concentrations are not used to identify chemicals of potential ecological concern (Jones *et al*. 1997).

Limitations:

- The method cannot be used for screening synthetic organic compounds, which should not be present in background sediments.

- The method has no biological basis and assumes that the chemicals are present totally in their biologically available forms, which is not often true.

- Cause-effect relationships between sediment contaminant levels and sediment-dwelling organisms cannot be determined.

- Sediment characteristics (i.e., grain size, organic content, dissolved oxygen levels) have been shown to be major factors affecting benthic community composition and these are not taken into account by this method (Persaud 1993).

- The method background levels tend to be highly site-specific (Persaud 1993).

5.1.2 Equilibrium Partitioning

Equilibrium Partitioning (EqP) is an approach for establishing SQGs for nonpolar (i.e., non-ionic) organic chemicals such as chlorinated hydrocarbon pesticides and polynuclear aromatic hydrocarbons (PAHs). The method is based on estimates of a contaminant's equilibrium partitioning between the solid phase organics and the liquid phase (porewater) of sediment. The total concentration of the contaminant in the sediment and the octanol/water partition coefficient for the chemical taken together are assumed to reliably describe the partitioning of that chemical that will occur between the organic carbon in the sediment and the sediment's porewater (Lee and Jones-Lee 1993).

SQGs based on EqP, such as EPA's recommended criteria for non-ionic compounds, assume that porewater is in equilibrium with sediment and that, to be non-toxic, porewater must meet water quality standards. The equilibrium assumption allows porewater concentrations to be calculated from the more readily measured bulk sediment concentrations of non-ionic compounds and total organic carbon. EPA used the EqP method to derive draft freshwater sediment quality criteria to protect benthic organisms for five nonionic organic contaminants, and it has been used to derive values for a number of contaminants in addition to the five for which EPA proposed draft criteria. (USACE 1998).

EqP is most often used such that, if the estimated interstitial water concentration of the nonpolar organic chemical exceeds the EPA's water quality criterion, or a given state's criterion, then the chemical is judged to be present in the sediment in an excessive amount that can cause toxicity to aquatic life (O'Connor and Paul 2000).

Normalization of nonionic organic compounds is accomplished by calculating chemical concentrations per gram of sediment organic carbon rather than per gram of dry sediment.

This approach allows comparisons of the potential bioavailability of non-ionic organic compounds across different sediment types and can be used to screen for chemicals of concern (EPA 2000b).

Advantages:

- Biological data collection at the time of sediment sampling is not necessary with this method because the EqP approach is based solely on sediment chemistry data.

- The EqP approach relies on an existing toxicological rationale which has been established during the development of the water quality criterion being used (Persaud 1993).

- Because EqP-based SQGs are keyed to water quality criteria, the methods are biologically based and, therefore, provide more defensible guidelines than the Background Approach.

Limitations:

- The partitioning approaches are applicable only to nonpolar organics.

- The published values for partition coefficients obtained by different authors can differ by an order of magnitude (Persaud 1993).

- Uncertainties related to EqP-based sediment criteria include particle size, particle density, organic carbon content, K_{ow}/K_{oc} relationship, route of exposure, impact of dissolved organic carbon, and the uncertainty of extrapolating laboratory data to field conditions (NYSDEC 1998).

- The EqP theory may not adequately represent the feeding habits of sediment-dwelling organisms, which could include food chain effects and ingestion of sediments (NYSDEC 1998). For example, compounds such as 2,4,7,8-tetrachlorodibenzo-p-dioxin are insufficiently soluble to be toxic in the aqueous phase, but once ingested from food or sediment they exert biological changes that can lead to toxic effects (O'Connor and Paul 2000).

- Chemicals may not be in equilibrium in porewater. O'Connor and Paul (2000) argue that PAHs found in soot are definitely not in equilibrium in porewater.

- Uncertainty exists with respect to the K associated with the specific octanol/water coefficient for a chemical because it is an experimentally determined quantity (Jones *et al*. 1997).

- O'Connor *et al.* (1998) studied the success of EPA's EqP-derived criteria as a predictor of toxicity using the combined NOAA NS&T and EPA EMAP-E databases for comparison. It was concluded that the EPA criteria were exceeded in so few samples that they might be of limited value.

- Various types of organic matter present in sediments can have significantly different binding capacities for organic contaminants. The affinity depends in large part on the source and nature of the carbon. For example, organics associated with sediments contaminated with petroleum hydrocarbons would tend to be much less toxic than those associated with sediments whose organic carbon is natural organic carbon (Jones *et al*. 1997).

- The EqP approach is known to not work for all nonpolar organics. It is well known that many pesticides that are sorbed onto soils and sediments are in the form of "bound" pesticide residues that do not participate in equilibrium reactions with water (Jones *et al*. 1997).

5.1.3 Acid Volatile Sulfides

While the Acid Volatile Sulfide (AVS) method is based on equilibrium partitioning theory, it differs from EqP described above in that AVS addresses partitioning of ionic metals between sulfides and water, rather than partitioning of nonionic organics between organic carbon and water.

The AVS normalization approach assumes that select trace metals bind to sediment sulfide, specifically the sulfide fraction soluble in cold acid, known as acid volatile sulfide. In the laboratory procedure the metals are extracted at the same time as the sulfide and are referred to as the simultaneously extracted metals (SEM). The overall method is commonly abbreviated as SEM/AVS. The proportion of metal ions not bound to sulfide will determine the bioavailability of trace metals capable of forming insoluble metal sulfides. On a molar basis, if the concentration of SEM is less than the molar concentration of AVS, all of the metals should precipitate as metal sulfides and not be bioavailable. On the other hand, if SEM exceeds AVS then free metal ions may exist in the porewater. This approach appears to work best in situations when the ratio of SEM to AVS is less than 1.0 or the difference between SEM and AVS concentrations is less than 0.0 (Di Toro *et al*. 1992). The SEM/AVS tool is primarily intended for use as a no-effects tool and caution is advised in using it as a predictor of toxicity or other effects (EPA 2000b).

O'Connor *et al*. (1998) studied the success of AVS-derived criteria as a predictor of toxicity using the combined NOAA NS&T and EPA EMAP-E databases for comparison. It was noted that toxicity was present in many cases when the AVS concentrations exceeded the sum of the concentrations of sulfide-insoluble metals. However, Long *et al.* (1998b) reported that the SEM/AVS tool and SQGs based upon bulk sediment chemistry for trace metals performed equally well in correctly predicting samples as either toxic or non-toxic.

Laboratory toxicity tests using amphipods, oligochaetes, and snails with spiked freshwater and marine sediments and with contaminated sediments collected from an EPA Superfund site demonstrate that no significant mortality occurs relative to controls if the molar concentration of AVS in the sediment is greater than the molar concentration of simultaneously extracted cadmium and/or nickel (Di Toro *et al*. 1992).

Advantages:

- As with the EqP method, SQGs can be derived from chemistry data alone.

- The method works comparatively as well as other methods based on bulk sediment chemistry for correctly predicting trace metal contaminated sediment as toxic or nontoxic (Long *et al*. 1998b).

Limitations:

- Porewater is the primary route of exposure to many contaminants for benthic organisms; however, ingestion is also an important route for some organisms.

- The method is primarily intended as a no-effects tool and caution is advised in using it as a predictor of toxicity (EPA 2000b).

5.1.4 Porewater Effect Concentration

Carr (1997) worked with USGS colleagues to compile a list of independent SQGs referred to as porewater effect concentrations (PECs). Carr found that there was remarkably close correspondence between the PECs based on the porewater data and the SQGs developed by Long *et al.* (1995), and MacDonald *et al*. (1996). Winger and Lasier (1997) reported that USGS is compiling a large database consisting of sediment chemistry and toxicities from solid-phase and porewater exposures from the same sediment that will allow the exploration of relationships between the toxicities of these two matrices. Preliminary evaluations suggest that inclusion of both measurements of toxicity increases the ability to identify contaminated sediments.

In most sediment, 20%-50% of the volume consists of porewater. Porewater testing might be necessary as a screening technique, if there are no ecological benchmarks for bulk sediment but accepted porewater toxicity data existed for the contaminants of concern (Maughan 1993).

It has been shown that the porewater toxicity test method is amenable for use with a wide variety of test species including embryo/larval stages of molluscs, polychaetes, crustaceans, echinoderms, and fish. These studies have also provided a direct comparison between porewater tests and the more commonly employed whole-sediment toxicity test methods. The porewater toxicity tests with gametes and embryos of sea urchins are approximately an order-of-magnitude more sensitive than the standard 10-day solid-phase test with amphipods. Excellent correspondence between bulk sediment contaminant concentrations and porewater toxicity has been observed. A high degree of concordance has been observed between porewater toxicity and the toxicity predicted on the basis of SQGs (Carr 1997).

Advantages:

- Toxicity is generally more pronounced in porewater exposures than in solid-phase sediment exposures (Winger and Lasier 1997).

- Porewater tests provide a direct measure of EqP (Carr 1997).

- Porewater tests provide the ability to conduct tests with very sensitive life stages of sensitive species, which is not possible with solid-phase tests.

- Porewater testing can be used as a screening technique when there are no ecological benchmarks for bulk sediment but accepted water toxicity data exists for the contaminant of concern (Maughan 1993).

Limitations:

- Porewater is difficult to extract from sediment without potentially altering the toxicity of the porewater (Jones *et al*. 1997).

- A very large amount of sediment must be obtained to get the minimum 1.5 liters of porewater needed. An order of magnitude more is needed if the porewater is to be subjected to TIE procedures (Maughan 1993).

- Porewater testing is generally not appropriate if a simple yes/no determination of toxicity is the issue (Maughan 1993).

- Porewater testing ignores dermal contact and ingestion as pathways (Maughan 1993).

5.2 EMPIRICAL METHODS

The empirical methods are used to calculate SQG values based on contaminant presence in sediment and a biological response. They are fundamentally statistical methods that provide no basis for assuming any cause-and-effect relationship between a contaminant of concern and a biological response (USACE 1998).

5.2.1 Apparent Effects Threshold Approach

SQG: *Apparent Effect Threshold (AET)*

The AET method is a statistically based approach that attempts to establish quantitative relationships between individual sediment contaminants and observed biological effects. The biological effects can be both field-measured effects such as changes in benthic community structure and laboratory measured effects obtained through the use of sediment bioassays. The basis of this technique is to find the sediment concentration of a contaminant above which significant biological effects are always observed. These effects can be any or all of a number of different types, such as chronic or acute toxicity, changes in community composition and bioaccumulation. The effects are considered in conjunction with the measured sediment contaminant levels. The AET is the sediment contaminant concentration above which the biological response of concern occurred in all samples in the data set used to derive the values. Inherent in the approach is the assumption that observed effects above this level of contamination are specifically related to the contaminant of interest, while below this level any effects observed could be due to other contaminants (Persaud 1993; USACE 1998).

The Apparent Effects Threshold (AET) method was developed and has been mostly used in Puget Sound. The AET values reported were based upon the evaluation of data from many surveys of various portions of that region (Long and Morgan, 1990). The state of Washington has used the various AET values to establish sediment quality standards and minimum clean-up levels for contaminants of concern in the state (Crane *et al*. 2000). At other locations, the AET approach is reportedly best suited for discriminating between contaminated and uncontaminated areas within a site, since the data used tend to be highly site-specific. As a result, any guidelines derived will be site specific. There is also a lack of chronic effects data suitable for AET applications that would allow consistency in the level of protection (Crane *et al*. 2000). EPA's Science Advisory Board allowed that the AET approach is appropriate for deriving site-specific SQGs, such as Puget Sound AETs, but they also recommended against the AET approach being used to develop general, nationally applicable SQGs (MacDonald 1994).

Ingersoll *et al.* (1996) utilized a similar approach to the AET method to develop freshwater no effect concentration (NEC) values using data from various freshwater locations. Cubbage *et al.* (1997) refined the AET approach to support the development of probable AETs (PAETs) using matching sediment chemistry and toxicity data for freshwater sediments from the state of Washington. The PAET method uses a percentile instead of the highest data point, and thereby ensures against the effects of random error.

Advantages:

- The AET method is effects-based and therefore more defensible that the partitioning approaches in relation to the protection of benthic organisms.

- AET requires no assumptions regarding contaminant bioavailability.

- The effects on biota can be due to contaminants available through both adsorption from sediments and interstitial water and through the adsorption form ingested matter.

- The method is considered sensitive and efficient, although the number of stations has a marked effect on AET uncertainty (EPA 1992).

Limitations:

- The method is unable to separate the biological effects that may be due to a combination of contaminants.

- While assuming a cause-effect relationship, the method cannot clearly demonstrate a cause-effect relationship for any single contaminant.

- If the data used consist of mixed species and endpoints, the least sensitive of these will always predominate and the guidelines derived may not protect other more sensitive species.

- The method is primarily field-validated for Puget Sound. Further testing would be required before application to other geographic regions. For this reason, the EPA Science Advisory Board has cautioned against using AETs outside the areas for which they were developed (FDEP 1994).

5.2.2 Screening Level Concentrations

SQGs: *Lowest effect level (LEL)*
Severe effect level (SEL)

The Screening Level Concentration (SLC) approach, like the AET, is an effects-based approach applicable mainly to benthic organisms. The SLC approach uses field data on the co-occurrence in sediments of benthic infaunal species and different concentrations of contaminants. Similar to the AET approach, it is assumed that the chemicals causing observed effects occur in mixtures (Long and Morgan 1990). The SLC is an estimate of the highest concentration of a contaminant that can be tolerated by a specific proportion of benthic species. In its original derivation and application, the 95th percentile was used (Persaud 1993).

The SLC is determined through the use of a database that contains information on the concentrations of specific contaminants in sediments and on the co-occurrence of benthic organisms with varying contaminant levels. For each benthic organism for which adequate data are available, a species screening level concentration (SSLC) is calculated. The SSLC is determined by plotting the frequency distribution of the contaminant concentrations over all of the sites at which the species occurs. Information from at least ten sites is required to calculate a SSLC. The 90th percentile of this distribution is taken as the SSLC for the species being investigated. The SSLCs for all of the species for which adequate data are available are then compiled as a frequency distribution to determine the concentration that can be tolerated by a specific proportion of the species. This concentration is termed the SLC of the contaminant (Crane *et al*. 2000).

The precision of the SLC is directly related to the size of the database and the range of variability of the various factors within the database. Therefore great care must be taken to include data taken over the full range of conditions since a database skewed to either lightly or heavily contaminated areas will yield guidelines that are either too conservative or do not provide adequate protection for aquatic life (Persaud 1993).

A number of jurisdictions have used the SLC approach to derive numerical SQGs. In the St. Lawrence River, Environment Canada developed two types of SQGs for five groups of PCBs using the SLC approach, including a minimal effect threshold (MET) and a toxic effect threshold (TET). The MET was calculated as the 15th percentile of the SSLCs, while the TET was calculated as the 90th percentile of the SSLC distribution for each substance. Therefore, the MET and TET are considered to provide protection for 85% and 10% of the species represented in the database, respectively (Crane 2000). The Ontario Ministry of the Environment and Energy (OMEE) set out to define three levels of ecotoxic effects based on the chronic, long-term effects of contaminants on benthic organisms (Persaud 1993). These levels are:

- A no effects level at which no toxic effects have been observed on aquatic organisms. This is the level at which no biomagnification through the food chain is expected. Other water quality and use guidelines will also be met at this level.

- A Lowest Effect Level (LEL) indicating a level of sediment contamination that can be tolerated by the majority of benthic organisms.

- A Severe Effect Level (SEL) indicating the level at which pronounced disturbance of the sediment-dwelling community can be expected. This is the sediment concentration of a compound that would be detrimental to the majority of benthic species.

Advantages:

- The use of a percentile to define the SLC helps limit the effect of outlying data (Crane *et al*. 2000).

- The SLC-derived values are based on biological effects and are suitable for all classes of chemicals and of types of sediment (MacDonald 1994).

Limitations:

- The SLC approach can not take into account multiple contaminant interactions in sediments. As a result, the SLC value for a particular contaminant will tend to be conservative (MacDonald).

- Great care must be taken to ensure that the database used is not skewed (Persaud 1993).

- The method is not quite as defensible as the weight-of-evidence methods since it does not include toxicity measurement other that the presence or absence of a species (Neff *et al*. 1986).

- Basing SLC values on species absence is considered to be insensitive in relation to other methods (MacDonald 1994).

- A qualitative comparison of the SLC values to the NOAA ERL and Florida TEL values suggests that the LEL values may be moderately underprotective for most organics (Jones *et al*. 1997).

- Unless the sediment factor that normalizes for bioavailability is known, this procedure must be applied for every sediment; i.e. a value derived for one sediment may not be applied with predictable results to another sediment with different properties (EPA 1992).

5.2.3 Spiked Sediment Toxicity Test

SQG: Spiked sediment toxicity test (SSTT)

In the Spiked Sediment Toxicity Test (SSTT) approach, dose-response relationships are determined by exposing test organisms, under controlled laboratory conditions, to sediments that have been spiked with known amounts of contaminants. Sediment quality guidelines can then be determined using the sediment bioassay data in a manner similar to that in which aqueous bioassays are used to establish water quality criteria. Where chronic toxicity data are not available, an approximation can be obtained by using acute toxicity endpoints that have been adjusted downwards by a factor of ten to obtain a chronic protection level and then applying a suitable safety factor (Persaud 1993). At the end of a specified time period, the response of the test organism is examined in relation to the biological endpoint. Results are then statistically compared with results from control reference sediments to identify toxic concentrations of the test chemical (EPA 1992).

An important use of the SSTT approach has been as one element included with databases used to derive some of the effects-based sediment assessment methods. These methods also typically combine this data with field data and laboratory toxicity tests on field-collected sediments. The method is not cost-effective to use alone to develop SQGs (EPA 1992).

Advantages:

- The major advantage is that a direct cause-effect relationship can be determined.
- A high degree of accuracy is possible (EPA 1992).

Limitations:

- The biggest limitation is that the laboratory cannot address all the variables that occur in a natural setting.
- A relatively large level of effort is needed to generate a large database (EPA 1992).

5.2.4 NOAA Approach

SQGs: Effects range low (ERL)/Effects range median (ERM)

MacDonald *et al*. (1996) refers to the Effects Range Low/Effects Range Median (ERL/ERM) method as the weight-of-evidence approach. It has also been referred to as the as the NOAA approach, and as the Long and Morgan approach (Long and Morgan 1990).

NOAA originated the ERL/ERM method for correlating sediment chemical concentrations with biological responses as part of the National Status and Trends (NS&T) program. The SQGs were initially intended for use by NOAA scientists in ranking areas that warranted further detailed study on the actual occurrence of adverse effects such as toxicity. SQGs were derived using a database compiled from studies performed in both saltwater and freshwater and published in NOAA Technical Memorandum NOS OMA 52 (Long and Morgan 1990). A large data set was assembled from studies throughout North America where chemical measurement and co-occurring biological effects data were available. For each chemical, data were arranged in order of increasing concentration. In addition to field-collected effects-based data, data from samples using the EqP model and SSTT method were also included. All of the information in the database was weighted equally, regardless of the method that was used to develop it (MacDonald 1994). Concentrations not associated with an effect were excluded. The ERL was calculated as the lower 10th percentile of the "effects" concentrations and the ERM as the 50th percentile of the "effects" concentrations. It was reasoned that the use of percentiles of aquatic toxicity data effectively minimized the influence of single (potentially outlier) data points on the resultant assessment values (MacDonald *et al*. 1996).

Long *et al*. (1995) refined the ERL/ERM method in 1995, but did not change the basic conceptual approach. Data from freshwater studies and/or of marginal quality used in 1990 were removed from the database, and a considerable amount of higher quality data related to estuarine and saltwater sediment was added to the database, including data from Canada. The NOAA database is now referred to as the biological effects database for sediments (BEDS). Sufficient information now exists on marine and estuarine sediments to calculate assessment values for 34 substances and chemical classes (Smith *et al*. 1996). As with the original method, data from each study were arranged in order of ascending concentrations. Study endpoints in which adverse effects were reported were identified. From the ascending data tables, the 10^{th} percentile values were named the ERL values, indicative of concentrations below which adverse effects rarely occur. The 50^{th} percentiles were named the ERM values, representative of concentrations above which effects frequently occur (NOAA 1999).

Unlike many other approaches to the development of SQGs, the ERL/ERM approach does not attempt to establish absolute sediment quality assessment values. Instead the approach delineate ranges of contaminant concentrations that are probably, possibly, and not likely to be associated with adverse biological effects. The approach recognizes the uncertainty associated with the prediction of biological effects under a variety of field conditions and relies upon the evidence assembled from numerous independent studies (NOAA 1999).

According to NOAA (1999), the ERL/ERM SQGs are best applied when accompanied by measures of effects such as laboratory toxicity tests and/or benthic community analyses and/or bioaccumulation tests, which lead to the preparation of a weight of evidence. NOAA also noted that the SQGs are best applied in a comprehensive assessment framework involving the establishment of clear study objectives, *a priori* methods for data analyses, and well-understood decision points regarding the uses of the data. By considering matching sediment chemistry and biological effects data from studies conducted in the field, the influence of mixtures of chemicals in sediments is incorporated in the resultant SQGs. The feature increases the degree of environmental realism and, thus, the applicability of the guidelines.

Mean ERM quotients:

Long *et al*. (1998) also introduced ERM quotients, a calculation that emphasizes sediments that have many ERM exceedences or a few extreme exceedences. The idea is to divide the bulk concentrations of each chemical by its ERM, add up all the ratios, and divide by the number of ratios. If the resulting ERM Quotient for a sediment sample is greater than one, the sediment is considered to have a greater chance of being toxic than if there were simply just an ERM exceedence (O’Connor and Paul 2000).

To provide a tool useful in assessing the potential toxicological significance of the presence of mixtures, mean ERM quotients were calculated for all 1068 samples used in a field validation study (Long *et al.* 1998). These indices were derived as the average of 25 quotients obtained by dividing the individual chemical concentrations by their respective ERM values. The percentages of samples that were not toxic, marginally toxic, and highly toxic were determined within ranges in the quotients. The data suggested a relatively consistent dose-response relationship. As the mean ERM quotients increased, the incidence of highly toxic responses increased (Long *et al*. 1998). NOAA considered the method to be useful in assessing the potential significance of chemical mixtures in sediment samples (NOAA 1999).

Long *et al.* (1998) found that the ERLs and mean ERM quotients for saltwater were more effective at correctly predicting non-toxicity (100% and 93%, respectively) than SEM/AVS ratios (80% correct) based on analyses of data compiled to field-validate the SEM/AVS criteria. Also, the ERMs and ERM quotients were slightly more predictive of toxic conditions (33% and 42% correct, respectively) than the SEM/AVS ratios (26% correct). These data suggest that the predictive abilities of SQGs based on bulk trace metals data are not improved with SEM-to-AVS normalizations (Long *et al*. 1998).

Advantages:

- The method can be applied using existing data.

- Sediment chemistry can be directly related to biological effect.

- The influence of chemical mixtures is incorporated directly into the resultant SQGs.

- The approach does not rely on individual data points, so outliers do not excessively influence the result (MacDonald *et al*. 1996).

- The large size of the database used helps reduce uncertainty (Long and Morgan 1990).

Limitations:

- Cause and effect cannot be quantitatively determined.

- The abilities of the SQGs to correctly predict toxicity of co-varying substances for which there are no SQGs are unknown (NOAA 1999).

- The SQGs were derived in units of dry weight sediments; therefore, they do not account for the potential effects of geochemical factors in sediments that may influence contaminant availability (NOAA 1999).

- The SQGs do not lend themselves to predicting effects in wildlife or humans through bioaccumulation pathways (NOAA 1999).

- The SQGs were neither calculated nor intended as toxicological thresholds; therefore, there is no certainty that they will always correctly predict either non-toxicity or toxicity (NOAA 1999).

5.2.5 Florida Method

SQGs: Threshold Effects Level (TEL)/Probable Effects Level (PEL)

The Threshold Effects Level/Probable Effects Level (TEL/PEL) method for correlating sediment chemical concentrations with biological responses was developed by the Florida Department of Environmental Protection (FDEP 1994) with assistance from Donald D. MacDonald. MacDonald has referred to this method as the “modified weight-of-evidence” method (MacDonald *et al*. 1996). It has also been referred to as the Florida method, and the “effects level” approach (Crane *et al*. 2000). The method is similar to the method for deriving ERL/ERM values, but both "effect" and "no effect" data are used in calculating TEL and PEL values.

The orginal ERL/ERM procedure that the TEL/PEL method builds upon did not utilize the information in the “no effects” data set. MacDonald *et al.* (1996) felt that data on the concentrations of contaminants that are not associated with adverse effects may provide additional information for defining the relationship between contaminant exposure and biological effects and it was therefore used in their investigation. Essentially, the TEL corresponds to the ERL and the PEL to the ERM, with the TEL and the PEL values adjusted upward or downward depending on the overlap of the distributions of the "effects" and "no effects" data for each contaminant (USACE 1998). In contrast to the AET approach, the ERL/ERM and TEL/PEL approaches do not rely heavily on individual data points. Therefore outliers do not excessively influence values in the overall guidelines derivation process (MacDonald *et al.* 1996).

Florida also felt the need to compensate for what they considered to be a bias in the NOAA database for northeastern and west coast data. As a result, the database was augmented with additional data, with an emphasis on existing data from southeastern sites. However, data was also added from other regions all over North America, including Canada (MacDonald 1994).

For each analyte, a TEL was derived by calculating the geometric mean of the 15^{th} percentile of the effects data set and the 50^{th} percentile of the no effects data set. Similarly, a PEL was developed for each chemical by determining the geometric mean of the 50^{th} percentile of the effects data set and the 85^{th} percentile of the no effects data set. The TEL was intended to estimate the concentration of a chemical below which adverse effects only rarely occurred (minimum effect range). Similarly, the PEL was intended to provide an estimate of the concentration above which adverse effects frequently occurred (probable effects range). The TEL and PEL were intended to define three concentration ranges for a chemical, including those that were rarely, occasionally, and frequently associated with adverse effects (MacDonald *et al*. 1996).

The arithmetic methods used in the TEL/PEL derivation (geometric means instead of arithmetic means) are important to distinguish. A geometric mean is used because of the uncertainty regarding the distributions of the data sets. In other words, it was expected that the data would not be normally distributed.

The Florida method is being used as a basis for developing national sediment quality guidelines for freshwater systems in Canada and sediment effect concentrations as part of the ARCS Program in the Great Lakes (Smith *et al*. 1996).

MacDonald *et al*. (1996) compared values derived for TELs with those derived for the lower range levels for other methods including ERL, Puget Sound screening levels, and EPA chronic sediment quality criteria. The comparison showed that TELs were usually lower than values developed using other guidelines, indicating that the TELs could be more protective.

Advantages:

- The advantages for the ERL/ERM method also apply to the TEL/PEL SQGs.

- The “no-effects” data has been included to ensure representative statistics.

- The geometric mean is used rather than the arithmetic mean that was used with the ERL/ERM method, in recognition that the data are not normally distributed (MacDonald 1994).

- The large size of the database, assembled from extensive information from numerous estuarine and marine sites across North America, helps reduce uncertainty associated with the derived SQGs (MacDonald 1994).

- High internal reliability of the TELs for the majority of the chemicals indicated these values are good estimates of sediment-associated chemical concentrations below which adverse biological effects are not expected to occur (Smith *et al*. 1996).

Limitations:

- The limitations for this method also apply to the ERL/ERM method (MacDonald *et al*. 1996):

- The relatively low internal reliability of PELs indicate that they may not adequately identify sediment-associated chemical concentrations above which biological effects are expected to occur frequently, and they therefore may be too conservative (Smith *et al*. 1996).

- Information from spiked-sediment toxicity tests and equilibrium partitioning models is included in the BEDS; however, the weight-of-evidence approach is still largely based on associations between contaminant concentrations and biological responses.

- Various factors other than concentrations of the contaminants under consideration could have influenced the actual response observed in any given investigation, including the additive and synergistic effects of co-occurring contaminants.

- The guidelines do not address either the potential for bioaccumulation or the associated adverse effects of bioaccumulation on higher trophic levels.

5.2.6 Consensus Method

SQGs: Threshold Effect Concentration (TEC)/Probable Effect Concentration (PEC)

The Consensus Method is being used as a basis for developing national sediment quality guidelines for freshwater systems in Canada and sediment effect concentrations as part of the Assessment and Remediation of Contaminated Sediments (ARCS) program in the Great Lakes. The State of Minnesota has also recently used this method to establish a framework for evaluating freshwater sediments in the St. Louis River Basin (Crane *et al*. 2000).

For each contaminant of concern, two SQGs were developed from the existing published SQGs, including a threshold effect concentration (TEC) and a probable effect concentration (PEC). The resultant SQGs for each chemical were evaluated for reliability using matching sediment chemistry and toxicity data from field studies conducted throughout the United States.

Published SQGs for 28 chemical substances were assembled and classified into two categories in accordance with their original narrative intent. These published SQGs were then used to develop two consensus-based SQGs for each contaminant, including a TEC; below which adverse effects are not expected to occur and a PEC; above which adverse effects are expected to occur more often than not.

A stepwise approach was used to develop the consensus-based SQGs for common contaminants of concern in freshwater sediments (MacDonald *et al*. 2000).

- In the first step, published SQGs that have been derived by various investigators for assessing the quality of freshwater sediments were collated.

- In the second step SQGs obtained from all sources were evaluated to determine their applicability to the study. SQGs were further considered for use in the study if: (1) the methods that were used to derive the SQG were readily apparent; (2) the SQGs were based on empirical data that related contaminant concentrations to harmful effects on benthic organisms or were intended to be predictive of effects on benthic organisms; and (3) the SQGs were not simply adopted from another jurisdiction or source. It was not the intent to collate bioaccumulation-based SQGs.

The TECs were intended to identify contaminant concentrations below which harmful effects on sediment-dwelling organisms were not expected. TECs included the following SQGs of similar narrative intent:

- Threshold Effect Levels (TELs)
- Effect Range Low values (ERL)
- Lowest Effect Levels (LELs)
- Minimal Effect Thresholds (METs)
- Sediment Quality Advisory Levels (SQAL)

The PECs were intended to identify contaminant concentrations above which harmful effects on sediment-dwelling organisms were expected to occur frequently. PECs included the following SQGs of similar narrative intent:

- Probable Effect Levels (PELs)
- Effect Range Median Values (ERMs)
- Severe Effect Levels (SELs)
- Toxic Effect Thresholds (TETs)

The consensus-based TECs or PECs were determined by calculating the geometric mean of the published SQGs in the TEC and PEC categories and rounding to three significant digits. The geometric mean, rather than the arithmetic mean or median, was calculated because it was felt to provide an estimate of central tendency that is not unduly affected by extreme values and because the distributions of the SQGs were not known. Consensus-based TECs or PECs were calculated only if three or more published SQGs were available for a chemical substance or group of substances (MacDonald *et al*. 2000).

ERLs that were developed by the EPA were not utilized because they were developed from the same data that were used to derive the TELs (i.e., from several areas of concern in the Great Lakes). Also simultaneously extracted metals-acid volatile sulfide (SEM/AVS) based SQGs were not used because they could not be applied without simultaneous measurements of SEM and AVS concentrations, and none of the SQGs that were derived using the sediment background approach were used because they were not effects-based. Finally, no bioaccumulation-based SQGs were used to calculate the consensus-based TECs or PECs (MacDonald *et al*. 2000).

The results of this evaluation indicated that the consensus-based SQGs, when used, together provide an accurate basis for predicting the absence of sediment toxicity. The consensus-based SQGs also provided an accurate basis for predicting sediment toxicity in sediments that contained mixtures of contaminants. Ingersoll *et al.* (2000) found that the consensus-based PECs could be used to reliably predict toxicity of sediments on both a regional and national basis. He also found that PECs developed using a database from across North America can be used to reliably predict toxicity of sediments on a regional basis.

The consensus-based PECs were also compared to equilibrium partitioning values. The EqP approach provides a theoretical basis for deriving sediment quality guidelines for the protection of freshwater organisms. It was found that the PECs were comparable to the EqP-based SQGs (Ingersoll et al. 2000).

PEC Quotients:

To address the issue of mixtures of contaminants, MacDonald *et al*. (2000) also used the PEC data to develop PEC quotients. Long *et al*. (1998) had first developed the concept of ERM quotients for evaluating the biological significance of contaminant mixtures. To develop the PEC quotients a similar three-step process is used:

1. The concentration of each of each substance in each sediment sample is divided by its respective consensus-based PEC.

2. The sum of the PEC quotients is calculated for each sediment sample by adding the PEC quotients that were determined for each substance; however, only the PECs that are demonstrated to be reliable are used in the calculation.

3. The summed PEC quotients are then normalized to the number of PEC quotients that are calculated for each sediment sample. The normalization step is conducted to provide comparable indices of contamination among samples for which different numbers of chemical substances were analyzed.

MacDonald *et al*. (1996) reported that, overall, the results of the various evaluations demonstrated that the consensus-based SQGs provide a unifying synthesis of the existing SQGs, reflect causal rather than correlative effects, and account for the effects of contaminant mixtures. MacDonald proposed that the SQGs can therefore be used to identify hot spots with respect to sediment contamination, determine the potential for and spatial extent of injury to sediment-dwelling organisms, evaluate the need for sediment remediation, and support the development of monitoring programs to further assess the extent of contamination and the effects of contaminated sediments on sediment-dwelling organisms.

In their review of MacDonald's work on Consensus-based standards, Ingersoll *et al.* (2000) noted that the results of their analysis indicate that the PECs developed using a database from across North America can be used to reliably predict toxicity of sediments on a regional basis.

Advantages:

- Since the Consensus Method incorporates numeric criteria developed via the EqP, weight-of-evidence, and SLC methods, each of the advantages and limitations with those methods are inherent.

- The consensus-based SQGs provide a unifying synthesis of the existing SQGs (MacDonald *et al*. 2000).

- The consensus-based SQGs reflect causal rather than correlative effects (MacDonald *et al*. 2000).

- PEC quotients can be used to assess sediment that contains complex mixtures of contaminants (MacDonald et al. 2000).

Limitations:

- Consensus-based SQGs do not consider bioaccumulation.

- Any weakness of the constituent SQGs apply.

- Amalgamation of data from multiple sources could result in unknown biases in the database.

5.2.7 Logistic Regression Modeling Approach

SQG: Logistic Regression Model (LRM)

In the logistic regression modeling (LRM) approach, numerical SQGs are derived from the results of field studies of sediment quality conditions. The first step in this process involves the collection, evaluation, and compilation of matching sediment chemistry and toxicity data from a wide variety of sites in North America. Next, the information that is compiled in the database is retrieved on a substance-by-substance basis, with the data from individual sediment samples sorted in order of ascending concentration. For each sediment sample, the ascending data table provides information on the concentration of the contaminant under consideration (on either a dry weight- or organic carbon-normalized basis) and the toxicity test results (i.e., toxic or not toxic) for each toxicity test endpoint (e.g., 10-day survival of amphipods) (Crane *et al*. 2000).

In the next step of the process, the data contained in the ascending data tables are screened to minimize the inclusion of samples in which the selected contaminant did not contribute substantially to the observed toxicity. The chemical concentration in each toxic sample is compared to the mean concentration in the non-toxic samples from the same study and geographic area. The toxic samples with concentrations of the selected contaminant that were less than or equal to the average concentration of that chemical in the non-toxic samples were not used in further analyses of the data.

In the final step of the analysis, the screened data are used to develop logistic regression models, which express the relationship between the concentration of the selected contaminant and the probability of observing toxicity.

Using a preliminary database consisting of the results of 10-day marine amphipod toxicity tests, Field *et al*. (1999) derived logistic regression models for seven chemical substances to illustrate the methodology. SQGs were derived to represent the chemical concentrations that correspond to a 10%, 50%, and 90% probability of observing sediment toxicity for four metals, two PAHs, and total PCBs. The method can also be used to determine the concentration of a contaminant that corresponds to any probability of observing toxicity. A sediment manager can identify an acceptable probability of observing sediment toxicity at a site (e.g., 25%) and determine the corresponding chemical concentrations. The calculated value can then be used as the SQG for the site. The LRM approach is data intensive and has primarily been applied to marine data sets. Limited freshwater data make this approach difficult to develop at this time for freshwater sediments (Field *et al*. 1999).

Field *et al*. (1999) offered that the LRM method may be a good way to compare otherwise incomparable SQGs. For example, the AET and ERL/ERM methods, which have different narrative objectives.

Advantages:

- The probability of a given sediment sample being toxic can be taken directly from the logistics regression curve (Field *et al*.1999).

- The LRM approach provides a way to put the individual SQG values into perspective with a large amount of field-collected data and a measure of goodness of fit (Field *et al*. 1999).

Limitations:

- The LRM method is data intensive. Crane *et al*. (2000) attempted to use the method for derivation of Minnesota criteria but found that the freshwater database was insufficient to support it.

- Field *et al.* (1999) reported that, in order to refine the method, additional data from both marine and freshwater sediments with high concentrations of contaminants is needed.

5.2.8 Comparative studies

Several studies have summarized and compared the various SQGs. Only a few of the more important comparative studies are mentioned here.

EPA's 1992 Compendium of Sediment Classification Methods (EPA 1992) is likely the most thorough analysis of available methods. However, since it was written there have been several advancements, particularly with the weight-of-evidence methods. For example, neither Florida's modified weight-of-evidence method or the Consensus method had been developed at the time of EPA's analysis. Still, the 1992 EPA document is valuable for providing a general sense of the capabilities and relative costs of the most common methods.

MacDonald (1994) and MacDonald *et al*. (1996) provide excellent background information on the methods considered for use at the time Florida settled on its preferred modified weight-of-evidence SQG method for coastal sediments. Cubbage *et al.* (1997) ranked SQG methods by sensitivity and efficiency as part of their analysis while developing proposed freshwater sediment criteria for Washington. Jones (1997) and USACE (1998) provide two more summaries and comparisons of SQGs. Most recently, the authors of the State of Minnesota's framework for developing SQGs for the Saint Louis River Basis reviewed SQG methods available for freshwater sediment prior to settling on the Consensus method as the preferred approach (Crane *et al*. 2000). Interestingly, the same MacDonald that was key to development of the Florida SQGs was also one of the primary authors of the Minnesota framework.

6.0 STATE APPROACHES

6.1 Washington

Preferred assessment method: AET

The Washington State Sediment Management Standards (SMS) are found in Chapter 173-204 of the Washington Administrative Code. Unlike most other sediment quality criteria currently used in state and provincial programs, these criteria are not just used as screening levels, but as actual cleanup standards (Michelsen 1999). The standards are for the protection of benthic organisms and apply to Puget Sound marine sediment only. These sediment quality standards correspond to a sediment quality that will result in no adverse effects, including no acute or chronic adverse effects on biological resources. The criteria are used to initially designate a sample as passing or failing the sediment quality standards (WSDEC 1995).

Washington has a three-tier method for assessing contaminated sediments. AETs are used as chemical criteria under Tier 1. At least 4 AETs are calculated for each chemical, each of which represents a different species or biological test. AETs currently promulgated include the amphipod *Rhepoxynius abronius* acute bioassay, oyster larva survival and abnormal development test, Microtox ®, and benthic effects. AETs have also been recently calculated for the echinoderm *Dendraster excenticus* larval bioassay, and the *Neanthes arenaceodentata* growth test. The lowest of the AETs is used as the long-term goal for sediment quality in the State, and the second-lowest AET is used as an upper limit for cleanup. A site-specific cleanup level is selected as close as possible to the long-term goal, but no higher than the second-lowest AET. This gives site managers some flexibility to address site-specific conditions of cost, feasibility, and net environmental benefit (Michelsen 1999).

Once the numeric criteria are calculated, they can be used as a “short-cut” at smaller or less controversial sites, to save money, time, and resources. For this approach to work well, the chemical criteria must be relatively accurate in predicting biological effects, rather than weighted toward the conservative side. One reason that AETs appear less conservative when compared to approaches such as TELs/PELs is because they are designed to be used as actual cleanup standards, not as screening levels (Michelsen 1999).

Washington’s Tier 2 assessment allows that field measurements of biological effects can be taken by the state or the responsible party in lieu of using chemical criteria. These results always override the chemical criteria, because they are considered more direct measurements of adverse effects. This is true regardless of whether the chemical criteria were passed or failed (Michelsen, 1999).

Tier 3 essentially entails a site-specific risk assessment. If there are no effects-based criteria yet developed that are representative of the types of pathways or effects seen at the site, then the narrative standards are used to guide a site-specific ecological or human health risk assessment that addresses that specific pathway of concern (Michelsen 1999). With the exception of choice of SQGs in Tier 1, Washington's tiered approach is very similar to that used by British Columbia (BCE 1999).

Tiers 1 and 2 are available for benthic effects in marine sediment. Both numeric chemical and biological standards exist. Tier 3, site-specific risk assessment, is seldom or never used for benthic effects because adverse effects can be directly measured and compared against numeric criteria. Washington therefore considers there to be no need for modeling or probabilistic approaches related to benthic effects (Michelsen 1999).

In December 1998 and again in June of 1999, Washington issued draft, interim revisions to the SMS Rule, which included the addition of a new bioassay endpoint to the suite of confirmatory biological effects tests: a 20-day growth test using the juvenile polychaete Neanthes arenaceodentata. This endpoint lowered the lowest AET, the value reported on the NOAA SquiRTs (NOAA 1999b), for many contaminants. Washington is still resolving some statistical issues of data analysis and classification of bioassay results. Since AET values are essentially determined by a single result (i.e., the highest non-toxic sample) as opposed to the entire distribution of results (e.g., as with a TEL or PEL), the final AET values used by the state may vary substantially depending on the outcome of their analyses (NOAA 1999b).

The numeric standards in the Washington SMS apply to benthic toxicity to marine sediment only. The Department of Ecology is also developing human health criteria and freshwater sediment criteria. Although freshwater sediment numeric criteria have not yet been finalized, the decision framework is the same as for marine sediment, and is equally applicable to all environments. According to Betts (2001), The Washington Department of Ecology will be developing an updated report on freshwater criteria by the end of 2001. In the meantime, Ecology recommends putting all the numbers from Cubbage *et al*. (1997) and Ingersoll *et al*. (2000) for any one chemical together in a distribution to try to establish an expected response range, and then using that accordingly for the necessary sediment management decision. Cubbage *et al*. (1997) establish freshwater sediment quality values (FSQVs) consisting of the AET-derived marine criteria found in the Washington SMS, and a newly developed freshwater Probable Apparent Effect Threshold (PEAT). The PAET is similar to the AET with the exception that it is derived using the 95th percentile of the no effect data, instead of the highest no effect data point. The Ingersoll *et al*. (2000) numeric tables are based on PECs derived through the consensus-based approach.

The State of Washington maintains a Puget Sound sediment database (SEDQUAL) that has been used along with the EPA EMAP-E and NOAA NS&T databases to perform regional analyses (Field 1999). A freshwater version of the database (FSEDQUAL) has also been developed and used as a basis for developing freshwater sediment criteria. The database includes sites in both Oregon and Washington (Cubbage *et al*. 1997).

6.2 California

Preferred sediment assessment methods: ERL/ERM, TEL/PEL

The information reported here pertains to two major regions of California and does not necessarily reflect statewide approaches. Water quality issues in California have historically been handled through strong regional authorities.

The California Regional Water Quality Control Board in San Francisco published interim sediment screening criteria in December 1993. The criteria apply to marine and estuarine conditions only and are not applicable for assessment of potential freshwater impacts from sediment reuse or disposal. The screening criteria are not applied without consideration of site-specific factors. The document is intended to facilitate creation, enhancement, and restoration of wetlands. The sediment screening values were developed using ERL and ERM values from Long and Morgan (1990) and dredged material values typically found in the Bay Area. SQGs are offered for 10 metals, DDT, total PCBs and total PAHs (CDWR 1995).

Using a weight-of-evidence approach based on the Sediment Quality Triad, measures of chemical contamination, toxicity, and benthic community structure were completed at 43 stations to determine the relative degradation in selected Southern California bays, estuaries, and lagoons. The degree of chemical contamination was assessed using two sets of sediment quality guidelines: the ERL/ERM guidelines developed by NOAA, and the TEL/PEL guidelines developed for the State of Florida (CSWRCB 1997).

6.3 Minnesota

Preferred sediment assessment method: Consensus approach, TEL/PEL

While the State of Minnesota does not have statewide guidance per se, the state has recently developed a framework for developing SQG that has been recommended for use throughout the state. Minnesota's SQGs are derived preferentially using the consensus-based approach (MacDonald *et al.* 2000, Ingersoll *et al.* 2000). Sediment quality targets from other jurisdictions (Environment Canada and the State of New York) are used when insufficient site-specific data are available to support the consensus-based approach. The Consensus SQGs were evaluated and found to provide a reliable basis for classifying sediments as toxic and non-toxic in the St. Louis River Area of Concern (AOC). SQGs for the protection of wildlife and human health were adopted from the state of New York (Crane *et al*. 2000).

A total of seven distinct approaches were evaluated to support the selection of procedures for deriving numerical SQGs for the St. Louis River AOC. Initially, it was thought that the LRM approach (Field *et al.* 1999), applied to the matching sediment chemistry and toxicity data from the St. Louis River AOC, would provide the most effective means of establishing SQGs. However, the results of preliminary analyses conducted using the entire North American freshwater sediment database revealed that insufficient data were available to generate reliable logistic regression models for any of the toxicity test endpoints that were represented in the database (e.g, *Hyalella azteca* growth or survival in 10-14 day tests). It became apparent that it would not be possible to develop logistic regression models using a portion of the database only (Crane *et al*. 2000).

In recognition of the potential limitations of the LRM approach for deriving SQGs for the St. Louis River AOC, a number of alternative approaches were considered to support the establishment of numerical SQGs. The following strategy was used to recommend numerical SQGs for the protection of benthic organisms:

- adopt the consensus-based SQGs that were derived by MacDonald *et al.* (2000); and,

- adopt the most reliable of the other effects-based freshwater SQGs that have been published in the scientific literature for those chemicals for which consensus-based SQGs are not available (Crane *et al*. 2000).

As a result of the analysis of available methods, The TELs and PELs were selectively identified as candidate SQTs for chemicals lacking consensus-based SQG values (Crane *et al*. 2000).

6.4 Wisconsin

Preferred sediment assessment methods: ERL/ERM, LEL/SEL, EqP

While other agencies have taken a more prescriptive approach and developed specific guideline concentrations and criteria to serve as SQGs and/or clean-up levels, the Wisconsin Department of Natural Resources (WDNR) has focused its attention on site-specific approaches for determining SQGs. WDNR’s focus on site-specific approaches is based on the following principles:

- flexibility in approach is preferred to consistency in values because it better addresses the inherent complexity and uniqueness of sediment contamination sites; and

- site-specific evaluations of effects should be encouraged because they minimize uncertainties about the bioavailability and potency of sediment contaminants.

WDNR recommends comparison to currently available guidelines from the following sources:

- Guidelines for the protection and management of aquatic sediment quality in Ontario, (Persaud 1993). These are the LELs and SELs based on the Florida method, but with emphasis on Great Lakes data.

- NOAA Sediment Quality Guidelines (Long and Morgan 1990). These are the ERLs and ERMs.

- EPA draft EqP-based sediment quality criteria for five organic chemicals

Wisconsin recommends that concentrations at and above the LEL trigger site-specific investigation of benthic community effects and, if deemed appropriate, concentrations above the SEL trigger active remediation to protect the benthic community.

WDNR recommends that the NOAA guideline ERL and ERM values can also be used in the same manner recommended above for OMEE's LEL and SELs. Specifically, the ERLs (like the LELs) are recommended as triggers for site-specific analyses and the ERMs (like the SELs) are recommended as triggers, as appropriate, for active remediation (WDNR 1995). However, in cases where both the OMEE and NOAA guidelines are available, WDNR recommends that OMEE's guidelines be given slightly more weight than the NOAA guidelines (especially for metals). WDNR makes this recommendation because the data behind OMEE's guidelines were derived from Ontario's waters, which are through to be more representative of Wisconsin's waters than the data from marine, estuarine, and freshwater systems used to develop NOAA's guidelines.

Because these guidelines were not developed specifically for use in Wisconsin, WDNR recommends that they be used as preliminary indicators of the potential for adverse effects from sediment contamination. Where uncertainty exists about the potential for bioavailability of toxicity of contaminants (i.e., in most cases), WDNR recommends that site-specific approaches of identifying sediment quality concentrations protective of benthic invertebrates should be used. If it has been determined that the greatest risk from site contaminants is to benthic organisms, and if site concentrations are clearly above or below the established guideline values, Wisconsin allows that it may be appropriate depending on the risk and costs of such decisions, to make site management decisions based solely on these existing guidelines (WDNR 1995).

WDNR takes note of EPA's work on establishing criteria based on SEM/AVS, but also notes that EPA is not yet using this method, while at the same time they recommend the method be considered in the future as needed and supported by scientific consensus (WDNR 1995).

Wisconsin without a doubt offers the most succinct guidance for contaminated sediment cleanup. Brevity is in fact the most inspiring aspect of this guidance. In a relatively few pages, they are able to cover program policy that sets a preference for site specific information, discuss risk management, and offer preferred SQG methods for consideration. The information is very general and yet informative.

6.5 New York

Preferred sediment assessment methods: ERL/ERM, LEL/SEL/, EqP

New York's non-polar organic contaminant criteria are derived using the EqP approach. EqP-based sediment criteria are tied to state water quality standards, guidance values, or EPA criteria where New York State standards are not available (NYSDEC 1998).

New York's metals criteria are derived from the Ministry of Ontario guidelines (Persaud 1993) and NOAA data (Long and Morgan 1990). Toxicity mitigating conditions such as acid volatile sulfides are not considered because with these methods the metal concentrations present are correlated directly to a measurable ecological impact (NYSDEP 1998).

Both the Ontario and NOAA SQGs are based on observed effects from field studies, although Persaud is restricted to Great Lakes data while Long and Morgan (1990) used both fresh and marine sediment data. For six metals (arsenic, cadmium, chromium, copper, lead, and nickel), the lowest effects levels described by Persaud are lower than the ERL from Long and Morgan. It is speculated that this could be because in the relatively pure waters of Lake Ontario, fewer ligands were available to complex metal ions, so biological effects were noted at lower metals concentrations. The Long and Morgan study included more eutrophic waters, wherein, metals could be complexed to a greater extent into biologically unavailable forms. Exposed organisms were able to tolerate higher total metals concentrations because the greater fraction of metal present was biologically unavailable (NYSDEC 1998).

The ERL and ERM from NOAA were compared with the Ontario LEL and SEL. The lowest concentration in each of the two effect levels was selected as the New York sediment screening criteria. If the total metals concentration in a sediment sample is less than the listed LEL, the effects of the metal in the sediment are considered to be acceptable. If the concentration is greater than the lowest effect level but less than the severe effect level concentration, the sediment is considered to be contaminated, with moderate impact to benthic life. If the concentration is greater than the SEL, the sediment is contaminated and significant harm to benthic aquatic life is anticipated (NYSDEC 1998).

New York guidance (NYSDEC 1998) lists sediment criteria for 52 non-polar organic compounds or classes of compounds and 12 metals. New York's EqP-based SQGs for non-polar organics distinguish between freshwater sediment and marine sediment by virtue of the respective water quality standard that are the basis of calculations. New York does not draw a distinction between SQGs for freshwater sediment and marine sediment for metals. A potential difference is acknowledged but not felt to be important. For polar organics, New York recommends direct comparison of porewater to surface water quality criteria.

In terms of a model for Alaska, the strength of the New York's guidance (NYSDEC 1998) lies in its good coverage of the basic science involved from a layman's point-of-view.

6.6 New Jersey

Preferred sediment assessment methods: LEL/PEL (freshwater sediment), ERL/ERM (marine/estuarine water sediment)

Freshwater sediment screening values used for New Jersey's Baseline Ecological Evaluation (BEE) are the Ontario Lowest Effects Levels (LEL). Marine/estuarine sediment screening values used are the Effects Range-Low (ERL) values derived by Long and Morgan (1995) (NJDEP 1998). Although the orginal Long and Morgan data set included freshwater sediment as well as marine and estuarine sediment (Long and Morgan, 1990), the 1995 database was restricted to marine sediment. New Jersey focuses primarily on the lower level values for the two methods (ERL and LEL), and considers exceedences of these values as a signal of a potential risk, and cause for further investigation.

New Jersey also provides SQGs for volatile organic sediment screening that are to be applied to both freshwater and marine sediments. This appears to be relatively unique among the various state or provincial approaches (NJDEP 1998).

New Jersey's guidance is particularly good with its discussion of the specifics of sampling for sediment in various circumstances, including streams as well as tidally influenced areas.

6.7 Florida

Preferred sediment assessment methods: TEL/PEL, metal/aluminum ratios

Florida's effects-based SQGs were derived using a modified version of the NOAA National Status and Trends (NS&T) Program Approach. The SQGs apply to marine and estuarine conditions only, although it is allowed that they can be applied to freshwater settings with caution. Florida notes that the guidelines compare favorably with similar guidelines derived from freshwater studies. It is also noted that Florida coastal sediments have similar geochemical compositions as freshwater sediments, so this isn't necessarily a universal ability (MacDonald 1994).

As with the original NOAA method, Florida's numerical SQGs define three ranges of concentrations for the contaminants: a no effects range, a possible effects range, and a probable effects range. Two values are used to define these ranges: a threshold effects level (TEL) and a probable effects level (PEL). TEL defines the upper limit of the no effects range and the lower limit of the possible effects range. PEL defines the upper limit of the possible effects range and the lower limit of the probably effects range (MacDonald 1994).

Florida chose to develop what became referred to as the Florida Method, or modified weight-of-evidence method, after concern was raised that the NOAA NS&T database originally used by Long and Morgan (1990) might not be representative of Florida or southeastern United States coastal sediments. The original The Florida method that was eventually published (MacDonald 1994) made several adjustments to the NOAA method. Adjustments included: adding screening criteria to ensure only the highest quality data were considered; adding further data from North America studies, with an emphasis on southeastern sites, utilizing the no effects portion of the database which had been discounted by NOAA, and using a geometric mean instead of an arithmetic mean to better reflect the data distributions. The resultant expanded database, referred to as the Biological Effects Database for Sediments, or BEDS, was used as the sole source of information about the potential effects of sediment-associated contaminants.

NOAA's original derivation procedures were modified to develop a TEL and a PEL for each analyte. Originally, the 10th (ERL) and 50th (ERM) percentile values in the effects data were used to establish sediment quality guidelines (Long and Morgan 1990). It was reasoned that the use of percentiles of aquatic toxicity data effectively minimized the influence of single (potentially outlier) data points on the resultant assessment values.

The NOAA procedure did not use the information in the no effects data set. It was felt that data on the concentrations of contaminants that are not associated with adverse effects may provide additional information for defining the relationship between contaminant exposure and biological effects and was therefore used in this investigation. For each analyte, a TEL was derived by calculating the geometric mean of the 15th percentile of the effects data set and the 50th percentile of the no effects data set. A PEL was developed for each chemical by determining the geometric mean of the 50th percentile of the effects data set and the 85th percentile of the no effects data set (MacDonald 1994).

The TEL was intended to estimate the concentration of a chemical below which adverse effects only rarely occurred (minimum effect range). Similarly the PEL was intended to provide an estimate of the concentration above which adverse effects frequently occurred (probable effects range). Therefore, the TEL and PEL were intended to define three concentration ranges for a chemical, including those that were rarely, occasionally, and frequently associated with adverse effects.

A geometric mean instead of an arithmetic mean was used because of the uncertainty regarding the distributions of the data sets. In other words, the data were not expected to be normally distributed. MacDonald et al. (1996) noted that these procedures were recently adopted for deriving national SQGs in Canada.

The TELs and PELs were compared with four sets of similar guidelines each. For example, TELs were compared with the NOAA ERLs and other SQGs derived with a similar narrative intent, and the PELs were similarly compared with the NOAA ERMs and other similar SQGs that defined a level above which toxicity to the benthos was likely to occur. The results were comparable, with the greatest agreement with metals and the poorest agreement with high molecular weight PAHs. Significantly, the TELs were usually lower than values developed using the other SQGs, indicating that the TELs could be more protective (MacDonald 1994). Cubbage et al. (1997) also found the TELs to be the most sensitive SQGs of those compared while deriving draft Washington State freshwater sediment criteria.

Florida also still relies on a 1988 guidance for evaluating metals in estuarine sediments (Schropp 1988). This unique method is based on the coexistence of aluminum with metals and is highly specific to the Florida environment. A series of regression curves for various metals and aluminum were derived for the purpose of determining when the presence of metals was natural or man-caused. The Florida Department of Environmental Protection Sediment Program website (FDEP 2000) offers that the method is still valid today. Florida has found that the metals relationship with aluminum is also a cost effective means of raising concern that other contaminants may be present, if the presence of metals is found to be man-caused.

Table 2 on the following page summarizes the preferred SQGs for all of the state, provincial, and federal jurisdictions covered in chapters 6.0 through 8.0.

Table 2. SQGs by Jurisdiction

Jurisdiction/Agency	Freshwater SQGs	Marine/estuary SQGs
Washington	AET, PEC, PAET (Cubbage 1997)	AET (WSDEC 1995)
California	ERL/ERM (CDWR 1995)	TEL/PEL (CDWR 1995)
Minnesota	Consensus (Crane *et al.* 2000)	_
Wisconsin	ERL/ERM, LEL/SEL (WDNR 1995)	_
New York	ERL/ERM, LEL/SEL (NYSDEC 1998)	ERL/ERM, LEL/SEL (NYSDEC 1998)
New Jersey	LEL (NJDEP 1998)	ERL (NJDEP 1998)
Florida	TEL/PEL (MacDonald 1994)	TEL/PEL (MacDonald 1994)
EPA	EqP, AVS (EPA 1998)	EqP, AVS (EPA 1998)
NOAA	ERL/ERM (Long and Morgan 1990)	ERL/ERM (Long and Morgan 1990)
DOE	ERL/ERM (Jones 1997)	TEL/PEL (Jones 1997)
Environment Canada	TEL/PEL, SSTT (CCME 1995)	TEL/PEL, SSTT (CCME 1995)
British Columbia	TEL/PEL (BCE 1999)	TEL/PEL (BCE 1999)
Ontario	Background, EqP, LEL/SEL (Persaud 1993)	_
Organization of Economic Cooperation	EqP, Porewater, SSTT (Jones 1997)	EqP, Porewater, SSTT (Jones 1997)

7.0 THE FEDERAL AGENCY ROLE

Primary regulatory responsibility for managing contaminated sediments falls to three federal agencies: the Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers (USACE), and the National Oceanic and Atmospheric Administration (NOAA). Federal jurisdiction is covered by at least six federal statutes: CERCLA; RCRA; CWA; Rivers and Harbors Act of 1899; Marine Protection, Research and Sanctuaries Act; and the Coastal Zone Management Act (McDowell 1999). These statutes are implemented to ensure environmental cleanup (EPA), natural resource protection (NOAA), and maintenance of navigation (USACE).

Other federal resource agencies, including the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey (USGS), provide a strong scientific support role in relation to contaminated sediments. Agencies such as the U.S. Department of Defense (DOD) and the U.S. Department of Energy (DOE) have also contributed toward advancement of sediment science because of their roles as responsible parties for contaminated sites.

7.1 EPA

Preferred sediment assessment methods: EqP, AVS

EPA's 1998 Sediment Management Strategy document (EPA 1998) proposed the EqP method as the technical basis for developing a national sediment quality criteria. It was intended that the criteria would be applicable to any sediment, anywhere in the country, for determining whether unacceptable contamination was present. According to Singarella (1999), recent developments suggest that EPA may have given up on the goal of developing single-value national standards. EPA has acknowledged that current scientific understanding does not support the setting of enforceable numerical standards for sediment cleanups. Instead, the agency has expressed a preference for publishing EqP based Sediment Quality Criteria (SQCs), which specify levels under which ecological or human health would not be harmed, as guidance or recommendations (Renner 1998). SQC are intended to apply to sediments permanently inundated with water, intertidal sediments, and sediments inundated periodically for durations sufficient to permit development of benthic communities (CDWR 1995).

EPA's EqP approach assumes that the bulk sediment concentrations of chemicals, organic carbon, and the interstitial water trapped in the sediment are in equilibrium. On the basis of assumptions about each chemical's affinity for water, the SQC are calculated so that the interstitial water meets water quality criteria established in Clean Water Act regulations. Initially SQC were proposed for five non-ionic contaminants for freshwater sediment. EPA has now developed, but not proposed, some 30 SQCs for organic compounds and expects to have criteria for metals ready soon (Renner 1998).

EPA is also developing sediment quality criteria that include the simultaneously extracted metals/acid volatile sulfide (SEM/AVS) method. It has been proposed that a SEM/AVS ratio serve as an indicator of metal toxicity in sediments. If a sediment has a higher SEM than AVS, then a sediment is considered toxic (HSRC 1999).

EPA has also acknowledged that quantifying contaminant concentrations alone cannot always provide enough information to adequately evaluate potential adverse effects that arise from interactions among chemicals, or that result from time-dependent availability of sediment-associated contaminants to aquatic organisms. Because relationships between bioavailability and concentrations of chemicals in sediment are not fully understood, determination of contaminated sediment effects on aquatic organisms may require the use of controlled toxicity and bioaccumulation tests (EPA 2000).

The sediment assessment approach favored by EPA's 1998 Sediment Management Strategy is not always the approach preferred by EPA regional or special project offices. EPA Region IV has recommended the NOAA ERL and Florida Department of Environmental Protection (FDEP) TEL values as potential lower screening values, and EPA OSWER has recommended the NOAA ERL values as potential ecotoxicological threshold values. (Jones *et al*., 1997). Under the EPA Assessment and Remediation of Contaminated Sediments (ARCS) Program, the integrated sediment assessment approach developed by the Toxicity/Chemistry Work Group included chemical analyses of sediments, whole sediment toxicity testing, and analyses of benthic community structure. The ARCs Program scientists declined to recommend specific methods, but instead advocated use of a variety of existing methods that could be used in a complementary way (EPA 1994).

EPA has intensive involvement with regional inter-agency groups working on sediment issues. Two such notable groups include EPA Region 10's involvement in Puget Sound and EPA Region 5's involvement in Great Lakes Basin sediment issues. EPA has authored and co-authored a number of guidance documents growing out of this involvement. The Puget Sound Protocols provide a wealth of knowledge regarding standard methods for the collection and treatment of sediment-related data in Puget Sound (PSEP 1991). EPA's involvement with the ARCS Program, administered by the EPA Great Lakes Program Office (GLNPO) has also resulted in valuable guidance. One of the major findings and recommendations which came out of the ARCs program was that use of an integrated sediment assessment approach; incorporating chemical analysis, toxicity testing, and benthic community surveys, is essential to define the magnitude and extent of sediment contamination at a site (Fox and Tuchman 1996).

In 1990, EPA initiated their Environmental Monitoring and Assessment Program (EMAP). EMAP is a nationwide research, monitoring, and assessment program to analyze the status and trends of various environmental resources of the United States. Estuaries are one ecological component of EMAP (EMAP-Estuaries) (Bourgeois 1997). The EMAP program uses the NOAA NS&T suite of contaminants as the basis for measurements in homogenized sub-samples of collected sediments (EPA 2000b). See NOAA (2001) for a list of these analytes. EPA (2000b) depicts four EMAP biogeographical provinces for Alaska: Arctic, Bering, Aleutian, and Alaskan.

7.2 NOAA

Preferred sediment assessment method: ERL/ERM

In carrying out its mission, NOAA has a number of management responsibilities that require scientific information concerning sediments (Robertson 1997). These include: coastal zone management, oversight of marine sanctuaries and Reserves, hazardous materials response and assessment, damage assessment and restoration, and living marine resource habitat conservation and restoration.

Through its National Status and Trends (NS&T) Program, NOAA generates considerable amounts of chemical data on sediments. Numerical sediment quality guidelines were developed as informal, interpretive tools for the NS&T Program (NOAA 1999). NOAA (2001) provides an excellent summary of the target analytes for the NS&T program.

The NOAA Sediment Quality Guidelines (SQGs) were initially intended for use by NOAA scientists in ranking areas that warranted further detailed study on the actual occurrence of adverse effects such as toxicity. Without national criteria or other widely applicable numerical tools, NOAA scientists found it difficult to estimate the possible toxicological significance of chemical concentrations in sediments. The SQGs also were intended for use in ranking chemicals that might be of potential concern. In many regional surveys of sediment toxicity performed throughout North America, NOAA has used the guidelines to compare the degree of contamination among sub-regions, and to identify chemicals elevated in concentration above the guidelines that were also associated with measures of adverse effects. The guidelines were not promulgated as regulatory criteria or standards. They were not intended as cleanup or remediation targets, nor as discharge attainment targets. Nor were they intended as pass-fail criteria for dredged material disposal decisions or any other regulatory purpose. Rather, they were intended as informal (non-regulatory) guidelines for use in interpreting chemical data from analyses of sediments (Long and Morgan 1990)

NOAA maintains a set of Screening Quick Reference Tables (SQuiRTs). The SQuiRT "cards" were developed for internal use by the Coastal Protection and Restoration Division of NOAA. The Division identifies potential impacts to coastal resources and habitats likely to be affected by hazardous waste sites. The SQuiRT cards are helpful as tools for evaluating the potential risk from contaminated water, sediment, or soil. Screening values for various media, including sediments, are listed. For sediments, values for ERL/ERM, TEL/PEL, and AETs for both organic and inorganic compounds in water are provided.

The SquiRTs lists have a code denoting what sort of toxicity information was used. Water quality standards tables are also included, which is helpful as sediment screening information since the numeric criteria using the EqP method is based on porewater not exceeding these standards. The SquiRTs also include guidelines for preserving samples and analytical technique options (NOAA 1999b).

7.3 USACE

Preferred sediment assessment method: Tiered testing

When carried out in navigable waters, the excavation, placement, or treatment of sediments requires a USACE permit under Section 10 of the Rivers and Harbors Act. Section 10 is not an environmental provision. Its original purpose was simply to protect the navigable capacity of waterways. However, when an activity for which a permit is required may "significantly affect the quality of the human environment," an Environmental Impact Statement may be required under NEPA, which requires the complete assessment and full disclosure of the environmental impacts of, and alternatives to, proposed major federal actions (Kamlet and Shelley, 1997). The USACE also has authority to regulate the disposal of dredged material in the oceans under the Marine Protection, Research, and Sanctuaries Act (Engler 1999).

Under authority of Section 404 of the Clean Water Act, the EPA develops guidelines in conjunction with the USACE for specification of dredged or fill material disposal sites in waters other than the ocean. The contaminant status of the material is determined using a manual commonly called the "Gold Book." The Gold Book procedures are used to determine whether the sediment is suitable for unrestricted open-water disposal or whether restriction might be required.

In ocean waters, EPA develops guidelines for discharge criteria for dredged material in conjunction with the USACE under the authority of Section 102 of the Ocean Dumping Act. The contaminant status of the material is determined using an ocean dumping manual commonly called the "Green Book."

The USACE uses tiered testing procedures to evaluate the suitability of dredged sediments for open water disposal under both CWA and the Ocean Dumping Act. The suitability of dredged material for open-water disposal is determined by an ecological effects-based approach rather than consideration of the concentrations of chemical contaminants in the sediment. The rationale for this is that dredged material is a complex mixture of many substances whose bioavailability and potential interactions cannot be predicted merely on the basis of the concentrations of the chemicals of concern (Engler 1999).

This effects-based approach uses physical, chemical, and biological assessments, and consists of contaminant mobility/bioavailability modeling; acute toxicity bioassays, which address the benthic and water column environments; and contaminant uptake bioassays, which provide information on the potential for bioaccumulation. Risk assessment procedures are available for the more difficult projects. The procedures followed by the Corps in accordance with EPA regulations have significant potential for the evaluation of sediment in general. However, it must be recognized that the disposal of dredged material is usually an instantaneous event (hopper, dredges, dump scows), or very short-term (hydraulic pipeline). Thus, acute, rather than chronic effects, are of primary concern (Engler 1999).

For 10 years, the USACE has effectively opposed publication of EPA Sediment Quality Criteria (SQC), claiming that the state of the science is insufficient to justify pass-fail standards. The Corps has blocked publication of SQC by predicting that adopting enforceable criteria would slow down dredging and have severe economic consequences on major U.S. ports (Renner 1998). Seemingly in response to EPA's 1998 Sediment Strategy document (EPA 1998), which sets out an intent to promulgate sediment standards, the Corps issued a memorandum in October 1998 that stated: "It is the policy of the Corps that SQGs cannot be used deterministically in dredged material management decision making" (USACE 1998b).

The state of Alaska may become involved with USACE dredging projects in one of two ways: 1). If the project may cause exceedence of state water quality standards when dumping in or near state waters, a water quality certification from the state is required under Section 401 of the Clean Water Act; and 2). A state consistency determination under the Coastal Zone Consistency Act may be required if an activity is conducted in the coastal zone (Kamlet and Shelley 1997).

7.4 USGS

The USGS has long been the lead Department of Interior agency for coordination of water data acquisition. On December 10, 1991, the Office of Management and Budget issued OMB Memorandum M-92-01, which expanded the USGS's role to encompass all water information. This included data critical to water resources with respect to sediment. Memorandum M-92-01 covers primarily freshwater bodies, and includes: "development and distribution of consensus standards, field data collection and laboratory analytical methods, data processing and interpretation, data-base management, quality control and quality assurance, and water-resources appraisals, assessments, and investigations" (Kamlet and Shelley 1997).

USGS is also involved with research on marine waters and maintains the Marine Ecotoxicology Research Station (MERS). An example of the important sediment research being conducted at MERS, Carr (1997) has published the results of a porewater toxicity test approaches for evaluating the quality of marine and estuarine sediments which was conducted at the laboratory.

One of the charges given the USGS in OMB Memorandum M-92-01 was the development of consensus standards for data collection and analysis. The Water Resource Committee of USGS works closely with ASTM working groups on sediment data collection, and has a goal to get as many of its own techniques for collection and analysis of water data, as appropriate and possible, accepted as ASTM standards (Glysson, 1997). USGS (2001) provides a comprehensive bibliography of sediment toxicity testing methods and data interpretation.

Chris Ingersoll with the USGS Columbia Laboratory is working on a sediment assessment framework document that is expected to be available in 2001. This is a

USGS project funded by GLNPO (Crane *et al*. 2001). Mr. Ingersoll's name plays prominently in the contaminated sediment literature and he has co-authored a number of technical papers with other prominent sediment scientists.

7.5 DOE

Preferred assessment method: ERL/ERM, TEL/PEL

The DOE's Oak Ridge National Laboratory (ORNL) is involved in sediment research in support of DOE's role as a responsible party for contaminated sites. The NOAA and Florida values are supported by ORNL as Sediment Quality Benchmarks (SQBs) when bulk sediment chemical concentrations are available (Jones *et al*. 1997).

ORNL has also recommended the use of multiple benchmarks for screening chemicals of concern in sediments. Integrative benchmarks developed for NOAA are included for inorganic and organic chemicals. Equilibrium partitioning benchmarks are included for screening nonionic organic chemicals. Freshwater sediment effect concentrations developed as part of the EPA's ARCs Program are included for inorganic and organic chemicals (EPA 1996). Field survey benchmarks developed for the Ontario Ministry of the Environment are included for inorganic and organic chemicals. In addition, EPA-proposed sediment quality criteria are included along with screening values from EPA Region IV and Ecotox Threshold values from the EPA Office of Solid Waste and Emergency Response. Pore water analysis is recommended for ionic organic compounds. Comparisons are then made against water quality benchmarks (Jones *et al*. 1997).

To make decisions as to whether a chemical or biological measurement of sediment quality indicates impairment, site-specific data may be compared with benchmarks that indicate whether sediment quality is acceptable. Existing criteria and standards are considered a type of benchmark (Jones *et al*. 1997)

8.0 CANADIAN AND INTERNATIONAL JOINT EFFORTS

8.1 Canadian Council of Ministers of the Environment

Preferred sediment assessment methods: TEL/PEL, SSTT

The Canadian Council of Ministers of the Environment (CCME) is a national organization made up of environment ministers from federal, provincial and territorial governments. The SQG protocol developed by CCME relies on both the modified NOAA NS&T approach (TEL/PEL) and the Spiked Sediment Toxicity Test (SSTT) approach. The modified NS&T approach was initially referred to as the Florida approach. Together these two approaches are considered by CCME to provide complementary information to support the development of national SQGs. The protocol is applicable to freshwater and marine (including estuarine) sediment. Separate guidelines are derived for each using separate freshwater sediment and marine sediment databases.

As with the orginal NS&T method, the modified approach relies on field data that demonstrate associations between chemicals and biological effects. The SSTT approach establishes cause-effect relationship. Because SSTT data are currently available for only a few substances, such as cadmium, copper, fluoranthene, and pyrene, the Threshold Effects Levels (TELs) calculated using the modified NS&T approach have been adopted as interim SQGs (ISQGs) (CCME 1998). A Canadian SQG is recommended when the ISQG derived using the modified NS&T program approach is supported by a weight-of-evidence of the available information that links the ISQG to specific sediment types, and/or characteristics of either the sediment or the overlying water column. A Canadian ISQG is recommended when the ISQG derived using the modified NS&T approach is based on the available toxicological information only (CCME 1995). While the TEL is typically recommended as an interim sediment quality guideline, the PEL and the information compiled in the ascending data tables are used as additional tools for assessing sediment quality (Smith *et al*. 1996).

The development of sediment quality guidelines in Canada is dependent on scientific information available in the published literature. Because information on freshwater sediments existed in the orginal NOAA database (Long and Morgan 1990), this information compiled by NOAA was expanded by Environment Canada in 1992 to incorporate additional information available on the toxicity of chemicals in freshwater sediments. Many large data sets, including the screening level concentration data sets generated through the ARCS program (Ingersoll et al. 1996) were integrated into the freshwater BEDS. Other relevant studies available in the published literature were also used. The expanded freshwater database now supports the calculation of numerical sediment quality assessment values for a range of chemical substances (CCME 1998).

The format of the freshwater biological effects database for sediments (BEDS) is identical to the format of the marine BEDS. Each record in the freshwater BEDS includes the citation, the type of test and/or biological response observed or predicted, the approach that was used, the study area, the test duration (if applicable and reported), the species tested or the benthic community characteristics considered, and the chemical concentration (expressed in dry weight). Ancillary information such as total organic carbon (TOC) concentrations, acid-volatile sulfide (AVS) concentrations, and particle size distributions were also summarized (if reported) (CCME 1998).

8.2 Ontario Ministry of the Environment

Preferred sediment assessment methods: Background, EqP, SLC (LEL/SEL)

The Ontario Ministry of the Environment (OMEE) has prepared provincial sediment quality guidelines using the SLC approach. These values are based on Ontario sediments and benthic species from a wide range of geographical areas within the province. The lowest effect level (LEL) is the level at which actual ecotoxic effects become apparent. The severe effect level (SEL) represents contaminant levels that could potentially eliminate most of the benthic organisms (Persaud 1993).

The guidelines specify contaminant concentrations associated with varying levels of adverse biological effect developed by the SLC approach. In applying this approach, OMEE used data from Ontario waters on the co-occurrence in sediments of benthic infaunal species and different concentrations of contaminants. The screening level concentration for each contaminant is an estimate of the highest concentration of that contaminant that can be tolerated by 95 percent of the benthic infaunal species. The OMEE guidelines define three levels of ecotoxic effects (Jaagumagi and Persaud 1999):

- No Effect Level (NEL) is intended as the level at which contaminants in sediment do not present a threat to water quality and uses, benthic biota, wildlife, or human health. The NEL is principally designed to protect against biomagnification through the food chain. EqP approaches are used to set these guidelines in conjunction with Provincial Water Quality Objectives (PWQOs).

- Lowest level (LEL) indicating a level of sediment contamination that can be tolerated by 95 percent of benthic organisms. It is derived using field-based data on the co-occurence of sediment concentrations and benthic species. The procedure is based on the Screening Level Concentration (SLC) method described in Neff *et al.* (1986).

- The Severe Effect Level (SEL). This level represents contaminant concentrations in sediment that could potentially eliminate most of the benthic organisms. The procedure used is identical to the calculation of the LEL except that the 95th percentile of the SLC (the level below which 95% of all SSLCs fall) is calculated in the second step of the SLC calculation, and this level becomes the Severe Effects (SEL) guideline.

OMEE has defined LELs and/or SELs for 10 metals, 21 PCBs and organochlorine pesticides and 12 individual and the sum of all PAHs (WDNR 1995).

Ontario concluded that the SLC approach offered the best means of developing sediment quality guidelines for the protection of the benthic community. This was felt to be especially true since a good database already existed for the Great Lakes Region. Partitioning approaches have been used to develop virtual no-effect levels for the protection of water quality and uses, and health risks associated with humans and wildlife through the consumption of fish. The Background approach is felt to have value where adequate data do not exist for application of any of the other methods or where the methods used are inappropriate for the type of compound. In addition, background levels provide a practical lower limit for management decisions (Persaud 1993).

8.3 British Columbia Environment

Preferred sediment assessment method: TEL/PEL

British Columbia Environment (BCE) has two distinct approaches for managing contaminated sediments, including a numerical concentration-based approach based on CCME protocols and a risk-based approach. These approaches give rise to three types of sediment quality criteria for assessing and remediating sites with contaminated sediments in British Columbia; including generic criteria, site-specific criteria, and risk-based standards (BCE 1999).

In general, a modified weight-of-evidence approach, which makes use of multiple lines of evidence, is recommended to support decision-making activities at the site. While BCD states that no single line of evidence should drive decision making in the weight-of-evidence approach, some lines of evidence may be weighted higher than others, in consideration of the decisions that needs to be made. For example, it may be appropriate to select the criteria-based approach at small sites where the cost of collecting data needed to support human and ecological risk assessments are likely to greatly exceed remediation costs. At larger, more complex sites, however, the costs associated with conducting detailed risk assessments may be warranted to reduce uncertainties and focus limited resources on the remedial actions that provide the greatest benefits (BCE 1999).

As an example, BCE's Level I sediment quality criteria, which are also termed the average effects levels (AELs), were developed by calculating the mean of the CCME (1995) threshold and probable effects levels (TEL and PEL). Other numeric criteria for freshwater sediments and marine sediments were established using comparable guidelines from other sources (e.g. Long and Morgan 1990).

BCE recommends that the generic criteria should be applied at sites with contaminant concentrations above background levels, with typical assemblages of aquatic organisms, and typical levels of organic carbon (i.e., 0.4 to 10.1% for freshwater sediments; 0.1 to 4.7% for marine and estuarine sediments.)

For site-specific sediment quality criteria, the same procedures are used but additional site-specific information is needed to support adjustment of the criteria to account for conditions at the site and/or new relevant studies (BCE 1999).

8.4 Organization of Economic Cooperation

Preferred sediment assessment methods: EqP, Porewater, SSTT

The Organization for Economic Cooperation and Development (OECD) is a cooperative international group composed of 30 countries. The original 20 members of the OECD are located in Europe and North America. Japan, Australia, New Zealand and Finland, Mexico, Mexico, the Czech Republic, Poland, Korea and the Slovak Republic have since joined.

The OECD has recommended three methods for deriving sediment quality objectives (Jones 1997):

- the EqP approach;
- the measurement of interstitial water and comparison to water criteria; and
- spiked sediment toxicity tests.

9.0 SEDIMENT AND RISK ASSESSMENT

The purpose of this chapter is not to go into depth regarding sediment evaluation as part of the risk assessment process, but rather to flag for future reference some of the interesting approaches that became apparent while researching the guidance documents developed by the various jurisdictions.

Although development of Alaska SQGs using the Washington AET-based approach is probably not a viable option for Alaska for the reasons given in the next chapter, Washington does otherwise present an attractive framework because it includes a three-step progression for establishing cleanup goals that is familiar to Alaska. The steps include: a table of numeric standards; the ability to modify these standards based on site specific information; and a full risk assessment. This is essentially the same progression that Alaska has used with its soil cleanup standards. The distinction with Washington's SMS values is that they are based on the AET approach derived expressly for use as cleanup standards. In other jurisdictions SQG methods are considered to be tools for arriving at cleanup goals, along with other site specific information that may include toxicity testing and analysis of benthic communities.

Michelsen (1999) has noted that Washington's Tier 3, site-specific risk assessment, is seldom or never used for benthic effects because adverse effects can be directly measured and compared against numeric criteria. Washington therefore considers there to be no need for modeling or probabilistic approaches. This seems to be a good rule of thumb for distinguishing when risk assessment is necessary. In other words, if the compounds of concern are reliably addressed in sediment SQG values, and sediment chemistry shows that compounds are not otherwise bioaccumulative or toxic in extraordinary ways, then consideration of appropriate cleanup standards based only on protection of the benthic environment may very well be sufficient.

In addition, there is some evidence that the NOAA ERL levels, that were based on benthic community studies and do not directly address biomagnification, are generally similar to the values found to be protective of the food chain (NJDEP 1998). Other weight-of-evidence methods would likely be even more so (see NOAA SQuiRTs for sediments [NOAA 1999b]). As a note, although the SQuiRTs tables indicate the TEL value is generally the most conservative for marine sediment, the *H. azteca* TEL is given as the most conservative for the freshwater sediment. This is a value developed by Ingersoll, *et al*. (1996) in an effort to classify the toxicity of Great Lakes sediments. Only specific organisms were used in the study, as opposed to the typically all-encompassing studies in the other weight-of-evidence methods.

New Jersey offers a good example of guidance that addresses when a sediment assessment effort geared toward the benthos should grade into an ecological risk assessment. As part of the Baseline Ecological Evaluation, the site is examined for the co-occurrence of chemicals of potential ecological concern, environmentally sensitive areas, and complete chemical migration pathways, to assess the potential for ecological risk. If this initial evaluation indicates the potential for adverse ecological effects, a subsequent, more rigorous evaluation will be required for the full Ecological Risk Assessment to further characterize risk (NJDEP 1998).

New Jersey's guidance also distinguishes between risk assessment and risk management. As an example, the guidance states that reference contaminant levels comparable to site levels do not indicate absence of site risk, but do indicate that reference area and site risks that are similar. A risk management decision to forego further action is based on no observable additional site-generated risk.

10.0 DISCUSSION

The biggest question facing the State of Alaska is whether expending the resources necessary to develop a framework for dealing with contaminated sediments is warranted by the magnitude of the problem. If it were a matter of starting from scratch and putting together a program that would require extensive new regional data, then it would probably not be considered a cost-effective venture. However, there are several options in between a "no action" alternative and the other, data-intensive, extreme that should be considered before the idea of developing a framework is abandoned.

Given the vast diversity among Alaska's several geographic regions, the relative lack of regional chemistry data and matching biological effects data, and the limited resources that are available to collect additional data, it is easiest to start with SQG approaches that probably won't work in these circumstances; i.e., those methods that are local-data intensive. Methods that have been cited as requiring intensive local data to work include the SSTT, AET, and SLC methods. These same methods have also been rated as being among the most expensive to develop by MacDonald (1994) and EPA (1992), which is of course another count against them from the Alaska perspective. The more recent LRM method can probably also be discounted because of its need for extensive local data. The State of Minnesota and associates considered the method but then abandoned it after concluding that sufficient freshwater sediment data did not exist to make it statistically viable (Crane *et al*. 2000). Certainly Minnesota had more area studies available for data than would be at Alaska's disposal.

Should Alaska consider promulgating cleanup standards based on any of the remaining SQGs? This is another option that can probably be ruled out. Most jurisdictions take great care to specify that their preferred SQGs are meant to screen sediments and work in combination with other site information to aid in cleanup decisions. We also have a mini-straw poll of sediment-minded Alaskans on this topic by virtue their attendance at the 18th Annual Meeting of the Society of Environmental Toxicology and Chemistry (SETAC) (USGS 1997). The three Alaskan SETAC conference attendees (two DEC employees and one consultant) voted with others in expressing their opinion that SQGs are important tools, but should not be considered as cleanup standards by themselves. In general, participants felt SQGs were useful for screening level purposes and that site-specific cleanup objectives and weight-of-evidence approaches were more useful for basing remedial decisions. Cited advantages of SQGs included the ability to focus preliminary screening and site investigation on specific chemicals and areas; the ability to compare other national/regional sites; reducing sampling cost for the manager; and the ability to gain statistical confidence with a large database and peer-review.

On the other end of the scale from ruling methods out, one factor that should be included with any Alaska guidance is consideration of background. The background approach for initial sediment screening should get special consideration for the state when it comes to metals, at least in certain areas of the state. As NOAA has shown in its limited sampling in the state as part of the NS&T Program, metal exceedences of the ERL values were usually associated with natural mineralization. Using anything other than background in mineralized areas would lead to false conclusions and SQG values for metals would likely be too conservative in these instances. If the background concentrations are valid and represent an uncontaminated media, and if the site does not contain forms of the chemicals that are more bioavailable or toxic than the forms at the reference site, then SQGs for metals lower than background concentration should not be used.

One of the concerns raised for using weight-of-evidence SQGs included the potential for geographical differences in bioavailability. Chapman and Wang (1999) also caution against using SQGs based on temperate organisms in more severe climate areas. These observations may have special relevance for Alaska because they have a direct bearing on the scientific defensibility of using weight-of-evidence SQGs based on nationwide databases. To further complicate the issue, Alaska is not a single geographic area unto itself. EPA (2000b) has offered consideration of four different Alaska regions: Arctic, Bering, Aleutian, and Alaskan. The so-called "Alaskan" region is essentially the southeastern part of the state. Decisions made on the appropriateness of using CCME TEL/LEL values in Southeast, for example, would likely need to be separated from any conclusions related to the other regions. In the end, the best management scheme does not always equate to the best science. As MacDonald (1994) has pointed out, no one can afford to develop the ideal SQGs.

If Alaska decides to go forward with adoption of a preferred SQG method for evaluating contaminated sediment, an appropriate place to start is with criteria for weighing the strengths and weaknesses of the various available options based on the state's special circumstances. Fortunately, a good model for this analysis exists with Florida. Florida's primary considerations in the selection of an SQG strategy were related to practicality, cost-effectiveness, scientific defensibility, and broad applicability to the assessment of sediment quality (MacDonald 1994).

Florida's 11,000 miles of coastline make it second only to Alaska in marine sediment habitat and its extensive lake systems and wetlands probably make it not too far behind Alaska for freshwater sediment habitat. Florida found that the extent of area covered coupled with limited agency resources made collection of significant quantity of additional data impractical. Because of this, it was necessary to choose an approach that relied on data that were already available. Gathering additional data was not felt to be an option. This ruled out methods such as the AET approach or the SLC approach, because they are dependent on intensive local data. It also made the modified NOAA approach more attractive, since it was predicated on using the existing NS&T database and other already available studies. Alaska faces a similar issue, undoubtedly with even fewer resources for data collection.

Table 3 on the following page has been borrowed from the analysis MacDonald (1994) used for Florida, with minor changes to reflect the Alaska perspective and to add more recent methods.

Table 3 . Evaluation of approaches for deriving sediment quality assessment guidelines. (Based on a similar table for evaluating approaches for Florida sediment quality assessment guidelines [MacDonald 1994]).

Evaluation Criteria	***SBA*** (5.1.1)	***SSTT*** (5.2.3)	***EqP*** (5.1.2)	***SLC*** (5.2.2)	***AET*** (5.2.1)	***NOAA*** (5.2.4)	***Florida*** (5.2.5)	Consensus (5.2.6)	***LRM*** (5.2.7)
Practicality									
Supports development of numerical SQGs?	Y	Y	Y	Y	Y	Y	Y	Y	Y
Feasible to implement in near term?	Y	N	Y/N	Y/N	N	Y	Y	Y	Y
Cost Effectiveness									
Expensive to implement?	N	Y	N	Y	Y	N	N	N	N
Requires generation of new data?	N	Y	N	Y	Y	N	N	N	N
Scientific Defensibility									
Considers bioavailability?	N	Y	Y	N	Y/N	Y/N	Y/N	Y/N	Y/N
Considers cause and effect relationships?	N	Y	Y	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Based on biological data?	N	Y	Y	Y	Y	Y	Y	Y	Y
Considers data from Alaska?	Y	N	N	N	N	Y/N	Y/N	Y/N	Y/N
Provides weight of evidence?	N	N	N	N	Y	Y	Y	Y	Y
Supports definition of ranges of concentrations rather than absolute assessment values?	N	N	Y/N	N	N	Y	Y	Y	Y
Considers mixtures of contaminants?	N	N	N	Y	Y	Y	Y	Y	Y
Requires field validation?	Y	Y	Y	Y	Y	Y	Y	Y	Y
Considers site-specific conditions?	Y	Y/N	Y/N	N	Y	N	N	N	N
Applicable to all classes of chemicals?	Y	N	Y/N	Y	Y	Y	Y	Y	Y
Applicability									
Supports monitoring programs?	Y/N	Y	Y	Y	Y	Y	Y	Y	Y
Supports problem identification?	Y/N	Y	Y	Y	Y	Y	Y	Y	Y
Supports regulatory programs?	N	Y	Y/N	Y/N	Y	Y/N	Y/N	Y/N	Y/N
Overall Assessment	*	***	***	**	***	****	****	****	****

* = poor; ** = fair; *** = good; **** = excellent

The only changes made to Table 3 from the orginal were to insert consideration of data from Alaska where it had originally read “Florida” and addition of the Consensus and LRM methods to those being considered. Where Florida had a “Y” for the question of whether Florida data were considered in the weight-of-evidence methods, a “Y/N” has been added in Alaska’s case, to reflect a minimal amount of data coming from the NS&T Program. This is a rather subjective response and it is possible that this would be considered an “N” by some, but it would be unlikely to greatly change the rating outcome for the methods. The weight-of-evidence methods clearly have a lot going for them, especially when it comes to mixtures of chemicals.

When Florida opted for a modified NOAA method, it had the advantage of the availability of at least some existing regional data to help refine their database. A number of data sources were added to the final BEDS including studies from all over North America, with a special emphasis on southeastern United States. The table for sediment SQG values available in NOAA’s SQuiRTs (NOAA 1999b) provides a good comparison of ERL/ERM values against TEL/PEL values, to give an indication of how Florida’s approach ended up varying from NOAA’s original approach. Unfortunately, the effect of the geographic distribution of the data is masked by other factors, including the differing statistical approach used by Florida.

Alaska will not have the benefit of extensive regional data to help ensure that any peculiarities of the region will be weighted into a biological effects database. NOAA, for instance, only maintains 11 NST&T sampling sites in the state. That being the case, the most important question for Alaska regarding the choice of a weight-of-evidence method as a favored SQG approach will be whether the uncertainty of using a database biased toward more temperate climates will be acceptable.

It could be argued that using a method based on the NOAA weight-of-evidence method, or modified weight-of-evidence method such as Florida’s, or that compiled by the Canadian Council of Ministers of the Environment (CCME) in developing their own version of the Florida method, is preferable as a matter of practicality to the other existing methods, even with the uncertainty involved. Certainly it would be easy to argue that a CCME method that uses data from a more northerly latitude would be preferable to the same method biased to a more temperate area such as Florida.

Balanced on the other end of the database uncertainty issue is the observation that the lower level value for the Florida method, the TEL, tends to be the most conservative of the SQGs (Cubbage 1997). The regulatory axiom is that uncertainty breeds more conservative standards. One model that may have potential for how to address this uncertainty is provided with the CCME (1995) list of sediment quality values. CCME lists values as interim sediment quality guidelines (ISQGs) that become SQGs only after a relationship has been established showing that the values and inherent assumptions are appropriate based on ground-truthing with site data. This may be an oversimplification of the Canadian approach but it presents an interesting idea nonetheless.

The next step in Alaska’s deliberations for how, or whether, to proceed with sediment program development would logically be to develop a few scenarios and then look more closely at their relative merits. A “no action” scenario would be one, or perhaps a variation on no action that would allow putting basic elements of sediment assessment into a guidance without advocating any particular SQG method. Development of a weight-of-evidence approach using multiple SQGs would be another option at the other extreme from no action. In between would be consideration of the EqP and other theoretical methods, and further evaluation of the option of advocating a single empirical method. Consideration of the comparison factors offered in Table 3 should help guide the choice of final options to consider.

In general, it appears that the most defensible programs are those that allow comparison of SQGs from multiple sources. None of the various methods outline in this paper have been declared indefensible despite the limitations cited. There may be a time and a place for each to show it’s worth. As an example, a site where a single non-polar organic chemical is the known issue might be most efficiently dealt with by employing the EqP method. Similarly, the AVS method might make the most sense with a metal contamination issue. Mixtures of compounds are undoubtedly best characterized by the weight-of-evidence methods. Employing several methods, especially if it is a simple matter of referring to existing tables of values, is a reasonable course of action.

The most recent innovation, the Consensus method, offers an interesting way of accomplishing this and yet arriving at a single numeric value for a contaminant. This is achieved by using a geometric mean to estimate the central tendency of the published SQGs. According to MacDonald *et al.* (2000b), this effectively reconciles guidance values that have been derived using various approaches. At the time of this writing, reports on the Consensus method had been limited to freshwater sediment results. The one exception was consideration of a consensus value for total PCBs (MacDonald *et al*. 2000b). Given the established similarity of approaches for deriving SQGs between freshwater sediment and marine sediment, it is reasonable to expect that marine sediment SQGs based on the Consensus method will be forthcoming.

APPENDIX A

Acronyms

AET	Apparent Effects Threshold (Washington)
AEL	Average Effect Level (British Columbia)
ARCS	Assessment and Remediation of Contaminated Sediments
AOC	Area of Concern
AVS	Acid Volatile Sulfides
ASTM	American Society for Testing and Materials
BEDS	Biological Effects Database for Sediments
BSAF	Biota-sediment accumulation factor
CCME	Canadian Council of Ministers of the Environment
DW	Dry Weight
EqP	Equilibrium Partitioning
EMAP	Environmental Monitoring & Assessment Program
EMAP-E	Environmental Monitoring & Assessment Program - Estuaries
ERL	Effects Range-Low (NOAA)
ERM	Effects Range-Median (NOAA)
FDEP	Florida Department of Environmental Protection
FSQV	Freshwater sediment quality value (Washington)
GLNPO	Great Lakes National Program Office
HA28	28-day *Hyalella azteca* Toxicity Test
IJC	International Joint Commission
ISQG	Interim Sediment Quality Guideline (CCME)
Koc	Organic Carbon Partition Coefficient

Kow	Octanol-Water Partition Coefficient
Kp	Sediment-Water Partition Coefficient
LC50	Median Lethal Concentration
LEL	Lowest Effect Level
MENVIQ	Ministere de l’Envionnement du Quebec
MET	Minimal Effect Threshold
MPCA	Minnesota Pollution Control Agency
NEC	No Effect Concentration
NEL	No Effect Level (Ontario)
NS&T	National Status & Trends
NOAA	National Oceanic and Atmospheric Administration
NOECs	No Effect Concentrations
NOEL	No Observed Effect Level (Florida)
NS&T	NOAA’s National Status and Trends Program
NYSDEC	New York State Department of Environmental Conservation
OC	Organic Carbon
OMEE	Ontario Ministry of the Environment and Energy
PAET	Probable Apparent Effects Threshold
PAH	Polycyclic (or Polynuclear) Aromatic Hydrocarbon
PEC	Probable Effect Concentration (MacDonald, 2000)
PEC	Porewater Effect Concentration (Field, 1999)
PEC-Q	Probable Effect Concentration Quotient
PEL	Probable Effects Level

PEL-28	Probable Effect Level for *Hyalella aztec*a, 28-day Test
PEL-Q	Probable Effect Level Quotient
SBA	Sediment Background Approach
SECs	Sediment Effect Concentrations
SEDTOX	Sediment Toxicity Database
SEL	Severe Effect Level (Florida, CCME)
SEM	Simultaneously Extracted Metals
SETAC	Society of Environmental Toxicology and Chemistry
SLC	Screening Level Concentration (Ontario)
SMS	Sediment Management Standards (Washington)
SQB	Sediment Quality Benchmark (DOE Oak Ridge National Laboratory)
SQC	Sediment Quality Criteria (EPA)
SQG	Sediment Quality Guideline (NOAA et al.)
SQT	Sediment Quality Target (Minnesota)
SQT	Sediment Quality Triad
SSLC	Species Screening Level Concentration (Ontario)
SSTT	Spiked-sediment Toxicity Test
TEC	Threshold Effect Concentration
TEL	Threshold Effects Level (Florida, CCME)
TEL-28	Threshold Effect Level for *Hyalella aztec*a, 28-day Test
TET	Toxic Effect Threshold
TIE	Toxicity Identification Evaluation
TOC	Total Organic Carbon
TR	Tissue Residue

TRG	Tissue Residue Guideline
TU	Toxic Unit
μg	Microgram
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
WEA	Weight-of-Evidence Approach
WSDEC	Washington State Department of Ecology

APPENDIX B

GLOSSARY

Acute toxicity – the immediate or short-term response of an organism to a chemical substance. Lethality is the response that is most commonly measured in acute toxicity.

Bioconcentration - a process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., via gill or epithelial tissue) and elimination.

Benthos - animals without backbones, living in or on the sediments, of a size large enough to be seen by the unaided eye, and which can be retained by a U.S. Standard No. 30 sieve (28 openings/in, 0.595-mm openings). Also referred to as benthic macroinvertebrates, infauna, or macrobenthos.

Bioaccumulation - a process by which chemicals are taken up by aquatic organisms directly from water as well as through exposure via other routes, such as consumption of food and sediment containing the chemicals.

Bioassay – acute and chronic toxicity tests performed to determine the effects of wastewater or chemicals on aquatic plants and animals within the natural environment.

Biomagnification - the result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels in the food chain.

Biota-sediment accumulation factor - the ratio of tissue residue to source concentration (e.g., sediment at steady state normalized to lipid and sediment organic carbon).

Brackish - water with salt content ranging between that of seawater and freshwater; commonly used to refer to oligohaline waters.

Bulk sediment – sediment and associated pore water.

Chronic toxicity – the response of an organism to long-term exposure to a chemical substance. Among others, the responses that are typically measured in chronic toxicity tests include lethality, decreased growth, and impaired reproduction.

Consensus-based PECs – the probable effect concentrations that were developed from published sediment quality guidelines of similar intent.

Consensus-based TECs – the threshold effect concentrations that were developed from published sediment quality guidelines of similar narrative intent.

Contaminated sediment – sediment containing chemical substances at concentrations that pose a known or suspected threat to environmental or human health.

Demersal fish species – fish that are associated with bottom sediments, such as carp or sculpin.

Effects Range-Low - concentration of a chemical in sediment below which toxic effects were rarely observed among sensitive species (10^{th} percentile of all toxic effects).

Effects Range-Median - concentration of a chemical in sediment above which toxic effects are frequently observed among sensitive species (50th percentile of all toxic effects).

Endpoint – the response measured in a toxicity test.

Epibenthos - those animals (usually excluding fishes) living on the top of the sediment surface.

Epifauna - benthic animals living on the sediment or on and among rocks and other structures.

Estuarine waters - semi-enclosed body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage.

Histopathology – the study of tissue change due to disease.

Infaunal organisms - organisms that live in bottom sediments.

Littoral zone - the intertidal zone of the estuarine or seashore; i.e., the shore zone between the highest and lowest tides.

Lotic - biological organisms living in flowing water systems

Lentic - biological organisms living in standing water systems

Microtox ® - A process for evaluating the toxicity of a contaminant by measuring the decrease in respiration and associated luminescence of effected bacteria.

Oligohaline - the estuarine salinity zone with a salinity range of 0.5-5-ppt.

Pelagic - pertaining to open waters or the organisms which inhabit those waters.

Porewater – the water that occupies the spaces between sediment particles.

Sediment – particulate matter that usually lies below water.

Sediment quality guideline – chemical benchmark that is intended to define the concentration of a sediment-associated contaminant that is associated with a high or low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

APPENDIX C

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