EPA U.S. Environmental Protection Agency Washington, DC EPA-SAB-EPEC-90-018

Report of The Sediment Criteria Subcommittee of The Ecological Processes and Effects Committee

Evaluation of The Sediment Classification Methods Compendium

A SCIENCE ADVISORY BOARD REPORT July, 1990

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR

July 11, 1990

EPA-SAB-EPEC-90-018

The Honorable William Reilly
Administrator
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, D.C. 20460

Dear Mr. Reilly:

The Sediment Criteria Subcommittee of the Science Advisory Board (SAB) has completed its review of the Sediment Methods Classification Compendium that was developed by the Office of Water Regulations and Standards in the Office of Water and EPA's Sediment Oversight Technical Committee. This guidance describes the strengths, limitations, and applications of ten methods that can be used to evaluate sediment quality. The guidance is intended for use by managers and decision makers and it does not make specific recommendations for applying these approaches for particular sites or types of problems.

This review is the third to be completed in a series of SAB reviews of sediment quality methodology. Previously the Sediment Criteria Subcommittee presented recommendations and conclusions to EPA concerned with the Apparent Effects Threshold and Equilibrium Partitioning approaches. These approaches are also included in the compendium.

The Subcommittee met once, on December 11-12, 1989, to review and evaluate the compendium. The Subcommittee was asked to address the following charge:

1) Identify any serious flaws in the methodologies, expand the list of advantages and limitations, and evaluate whether each methodology is portrayed appropriately as narrow or broad use.

2) Recommend alternative sediment classification methods. and research areas.

3) Assess the robustness of each approach.

The Subcommittee believes that all of the methods in the Compendium and the advice for their application have scientific merit except as noted below. The Subcommittee did not identify any additional methods for inclusion in the Compendium, however, it recommends that whenever possible, a suite of methods should be recommends that whenever possible, a suite of methods should be used to develop sediment quality values.

Overall, the Subcommittee believes that the Compendium will be most useful if it is periodically updated and if the Agency conducts research to address the limitations associated with particular approaches. In addition, the introduction should include a summary of references and advice to managers for sample collection and handling, quality assurance/quality control, tiered approaches for mixtures of chemicals, and data analysis. The Subcommittee suggests that EPA add a table to the Compendium that summarizes information on the status and relative costs of each method.

The Subcommittee recommends that EPA conduct further research to address the limitations of the methods. EPA should develop sediment toxicity test methods for more freshwater and marine species; develop protocols for handling and collecting samples, for sample storage, and basic quality assurance procedures; evaluate applicability of the wastewater procedures for Toxicity Identification Evaluation to sediments; and investigate the mechanism and the role of kinetics in the partitioning of substances on sediments. Additional methods are also needed to assess chronic and sublethal endpoints. The Subcommittee also recommends that the EPA consider further development of the Tissue Residue approach which has the potential to be used as a major tool in assessing sediment quality. The method could have even wider applicability if research could define the mechanisms of partitioning in the "real world" and the relationship between tissue residues and toxicity.

The Subcommittee appreciates the opportunity to conduct this scientific review. We look forward to receiving the Agency response to the scientific advice transmitted in the attached report.

Sincerely,

Dr. Raymond Loehr, Chairman
Executive Committee
Science Advisory Board

Dr. Kenneth Dickson, Chairman
Ecological Processes and
Effect Committee

Dr. Robert Huggett, Chairman
Sediment Criteria Subcommittee

U.S. ENVIRONMENTAL PROTECTION AGENCY

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1.0 EXECUTIVE SUMMARY

The Sediment Methods Classification Compendium was developed by the Office of Water Regulations and Standards to serve as a reference for methods that can be used to assess the quality of chemically contaminated sediments. The compendium describes each method, associated strengths and limitations and existing applications. The guidance is intended for general use by managers and decision makers and it is does not make specific recommendations for particular sites or problems.

Overall, the Subcommittee believes that the Compendium will be useful if it is periodically updated and if the Agency conducts research to address some of the limitations associated with particular approaches. In addition, the introduction should be expanded to include a discussion of references and advice for sample collection and handling, quality assurance/quality control, tiered approaches for mixtures of chemicals, and data analysis.

The Subcommittee recommends that EPA conduct research to expand the battery of freshwater and marine species that can be tested in the Bulk Sediment Toxicity Test Approach. For all approaches, protocols should be developed for handling and collecting samples, for sample storage, and basic quality assurance procedures. This should be added as introductory material to the compendium. Additional methods are needed to assess other endpoints, such as chronic toxicity and teratogenicity.

The Subcommittee recommends that EPA investigate the effects of "aging" of spiked sediments and examine the extent to which the Spiked Sediment Toxicity Approach can be used to estimate the effects from mixtures.

The Subcommittee recommends that EPA expand the discussion of the Interstitial Water Toxicity Approach to emphasize its strengths for identifying sediment toxicity. Additional research should be performed to evaluate the applicability of the TIE procedures to sediments.

The Subcommittee reiterates its recommendations from an earlier review of the Equilibrium Partitioning approach (EPA-SAB-EPEC-90-006, February, 1990). The compendium should caution users of this method to express the uncertainties in the assumptions and to avoid cumulative errors in the calculation of the partition values. The availability of compounds associated with sediment may be controlled by kinetics rather than by partitioning. The possible influence of kinetics should be considered when the equilibrium partitioning approach is used to establish sediment quality values.

The Subcommittee recommends that the EPA consider further development of the Tissue Residue approach which has the potential to be used as a major tool in assessing sediment quality. The method could have even wider applicability if research could define the mechanisms of partitioning in the "real world" and the relationship between tissue residues and toxicity.

The Subcommittee believes that the Freshwater and Marine Benthic Macroinvertebrate Community approaches are useful for screening sediments for potential contamination and for source identification. Discussion should be added to the compendium to help users identify reference sites for both approaches.

The Subcommittee recommends that the Sediment Triad and the Apparent Effects Threshold (AET) approaches be cross- referenced. The AET approach should provide a full and balanced discussion of its strengths and weaknesses. Additional comments were provided on the AET approach in a separate report (EPA-SAB-EEFTC-89-027, August, 1989).

The Subcommittee recommends that EPA highlight the International Joint Commission Sediment Strategy for its conceptual strength in addressing the potential effects of contaminants in sediment.

The Subcommittee did not identify any additional sediment classification methods for inclusion in the compendium.

2.0 INTRODUCTION

The Compendium is essentially a synopsis of methods that can be used to assess chemically contaminated sediments. It contains a brief description of each method, associated advantages and limitations, and existing applications. It is intended to serve as a common frame of reference to assist users in assessing contaminated sediments and determining whether sediment contamination exists to a degree that warrants an evaluation of needs for further action. It should be noted that these methods are not at an equal stage of development, and certain ones (or combinations) are more appropriate for specific management actions than are others. The Compendium is not meant to provide guidance on which method(s) to apply for specific situations, nor how they can be used together as part of a decision-making framework.

2.1 Request for Science Advisory Board Review

At the request of the Office of Water, the Science Advisory Board (SAB) agreed to conduct a scientific review of the Sediment Classification Methods Compendium. With the approval of the Board's Executive Committee, the SAB's Ecological Processes and Effects Committee authorized the formation of a Subcommittee to perform a series of tasks related to the technical aspects of sediment quality assessment and criteria development.

2.1.1 Charge to the Subcommittee

This review is the third to be completed in a series of SAB reviews related to sediment quality values. The first and second reports of the Subcommittee presented recommendations and conclusions concerned with the Apparent Effects Threshold (AET) Approach and the Equilibrium Partitioning (EqP) Approach respectively.

The Office of Water Regulations and Standards and the Office of Marine and Estuarine Programs requested that the Subcommittee review the Compendium as an encyclopedia of sediment classification methods, rather than a "how to" manual on implementing the methods or as a technical defense of each method. Specifically, the charge accepted by the Subcommittee was to:

1) Identify any serious flaws in the methodologies, expand the list of advantages and limitations, and evaluate whether each methodology is portrayed appropriately as narrow or broad use.

2) Recommend alternative sediment classification methods.

and research areas.

3) Assess the robustness of each approach.

2.2 Subcommittee Review Procedures

The Sediment Criteria Subcommittee met on December 11 and 12, 1989, in Washington, DC, to begin its review of the Sediment Classification Methods Compendium. Following the meeting, members of the Subcommittee submitted evaluations of individual chapters of the compendium. Each evaluation included an assessment of the charge. This report contains the advantages and limitations that the Subcommittee believes were most important for each method, including some of those listed in the Compendium. The Subcommittee did not identify any alternative sediment classification methods for inclusion in the compendium at this time.

2.3 Expected Future Activities

Other sediment quality assessment methods, including methods for assessing metal availability, are expected to be developed and refined by EPA/OW's Contaminated Sediment Technical Committee. Periodically, revised and new methods will be submitted to the Sediment Criteria Subcommittee for review, prior to the final draft of the guidance.

During the course of these critical evaluation processes, it is likely that areas for additional or future research will be targeted. To facilitate the incorporation of these recommendations into EPA research planning, the Subcommittee may conduct a review of the Office of Research and Development's proposed Sediment Initiative. The time sequence of these proposed events is contingent on the completion by Agency staff.

3.0 BULK SEDIMENT TOXICITY TEST APPROACH

3.1 General description of the approach

The Bulk Sediment Toxicity Test Approach consists of exposing test organism(s) to sediments. At the end of a specified exposure period, the response(s) of the test organisms is examined using several biological endpoints. Endpoints commonly used include mortality, growth, reproduction, cytotoxicity, alterations in development, and behavior. Results are compared to control and reference sediments to estimate sediment toxicity. Test organisms routinely used in the Bulk Sediment Toxicity Testing include amphipods, midges, polychaetes, and oligochaetes.

3.2 Advantages of the approach

The major strength of the Bulk Sediment Toxicity Test Approach is that it provides a direct measure of toxicity of the sediment assayed. It measures the combined toxicities of all chemical contaminants that are available. By utilizing test organisms that are in intimate contact with the sediments, the test simulates exposure regimes experienced by sediment dwelling-organisms. There exists a long history of using the method for assessing the spatial distribution of sediment contaminants and in conducting trends analyses.

The available bulk sediment toxicity methods are relatively simple to perform and do not require expensive equipment nor highly trained personnel. They are, however, relatively expensive, because they are labor intensive.

3.3 Limitations of the approach

The Bulk Sediment Toxicity Test Approach cannot be used by itself to generate sediment quality values since the approach may not always provide information on the causative toxic agent(s). However, the method has been integrated into the Sediment Triad and the Apparent Effects Threshold (AET) approaches which have been used to develop numeric estimates of sediment quality.

While not a conceptual weakness, the Bulk Sediment Toxicity Test Approach is limited by the relatively few species which are available for testing. Control or reference sediments are clearly critically important to the quality of the toxicity evaluation, but little information is available on how to choose them and on what characteristics are important. In addition, the collection, preparation, and storage of the sediments may influence the outcome of the test by causing the active chemicals to be more or less biologically available.

3.4 Robustness of the approach

The Bulk Sediment Toxicity Test Approach is extremely robust because sediment toxicity tests for certain species have been widely used, methods are being standardized, and the data interpretation of the results is understood.

3.5 Research recommendations

Research to expand the battery of both freshwater and marine test species that can be used in the Bulk Sediment Toxicity Test Approach is needed. At present, there are only a limited number of species available. This is particularly true for marine and estuarine organisms. Methods are needed which better assess chronic toxicity and other effects endpoints such as reproduction, growth, teratogenicity or genotoxicity. Appropriate sampling, handling, and testing methods for sediment to be used in the Bulk Sediment Toxicity Test Approach should be determined. Improper sampling, handling, and storage of sediment samples may complicate the interpretation of contaminant effects.

4.0 SPIKED SEDIMENT TOXICITY TEST APPROACH

4.1 General description of the approach

This approach establishes relationships between sediment contaminants and organisms by spiking sediments in the laboratory with known concentrations of specific chemicals and exposing organisms to those sediments. In that sense it is similar to the conceptual development of water quality data. The approach can be used with many different types of chemicals, potentially any sediment, and a variety of toxicity testing methods. It is assumed with this test that the chemicals and biota behave the same in a laboratory spiked sediment as they would under real world conditions.

4.2 Advantages of the approach

A major advantage of this approach is the potential to use almost any combination of sediment and chemical. Since the toxicity evaluation is conducted in the laboratory, it is possible to add a wide variety of chemicals. Sediments from diverse sources can also be used, including both marine and freshwater. This is one of the few approaches that can potentially address questions of chemical interactions (synergism, antagonism, etc.), although results from mixtures with a large number of chemicals may be difficult to interpret.

Any of a number of toxicological methods can be used to assess the biological impact of the added materials. These can include acute or chronic tests with a variety of endpoints (mortality, growth, reproduction, cytotoxicity, respiration, and/or alteration in development). Due to the controlled laboratory environment, it may be possible to derive cause-and-effect relationships from the data generated.

4.3 Limitations of the spiked sediment approach

Many of the advantages of this approach are due to the control that the use of laboratory spiked sediments gives over the parameters to be tested. This factor is also the major problem with the approach. The basic assumption of the method is that "laboratory results for a given sediment and overlying water represent biological effects of similar sediments in the field, and that the behavior of chemicals in spiked sediments is similar to that in natural *in situ* sediments." This major assumption has not been justified. Real sediments contain mixtures of materials that will be difficult to simulate in the laboratory even if one knew the exact composition.

Major differences in sorption properties of sediment-bound chemicals have been reported depending on whether the chemical was artificially spiked into sediment or occurred naturally [Karickhoff and Morris (1985) and DiToro and Horzempa (1982)]. Slower desorption from "aged" spiked sediments may reduce bioavailability of contaminants, and, hence, the toxicity of the sediments. If the chemicals desorb more rapidly in spiked-sediments tests, there may be an overestimate of the toxicity. There are insufficient data to evaluate the magnitude of this problem and whether it applies to all classes of chemicals and all types of sediments.

There are a number of ways to incorporate or spike chemicals into sediments. Toxicity results will likely vary depending on whether the chemical is added to intact sediments or a slurry approach is used. Procedures for "aging" spiked sediments should also be addressed. The document gives little guidance as to the nature of the various choices to be made and their significance.

4.4 Robustness of the approach

The approach appears to be in an early developmental stage. Assuming that the proper spiking and aging scenarios are followed, the method would require effort that is equivalent to the Bulk Sediment Toxicity Approach.

4.5 Recommendations

The spiked-sediment method is conceptually attractive because controlled conditions can be used, specific chemicals and mixtures assessed, and cause-effect relationships explored. However, more data are needed on the influences of sediment aging on sorption of spiked contaminants. Most of the testing has involved acute toxicity tests; comparison using chronic and life cycle tests need to be conducted. The extent to which the approach can estimate effects from mixtures needs to be examined.

5.0 TOXICITY IDENTIFICATION EVALUATIONS: INTERSTITIAL WATER TOXICITY APPROACH

5.1 General description of the approach

This approach for assessing the toxicity of chemicals sorbed to sediments is based on the idea that once a sediment is determined to be toxic to aquatic organisms the toxicity can be linked to one or more chemicals. The chemical or chemicals responsible for the toxicity are then identified by taking bulk sediments and carrying them through various extraction or fractionation schemes which allow for separation of the chemicals into chemical classes, such as organics versus inorganics and polar organics versus non-polar organics. This is accompanied at each step of the fractionation procedure with an aquatic bioassay to determine the toxicity of the separated class of chemical. Subsequently, the specific chemicals within the class are identified using specific analytical techniques for identification of various chemicals (e.g., HPLC, GC/MS).

5.2 Advantages of the approach

The advantages of this approach are that this is the only method to date other than sediment spiking approaches which describes a procedure for identifying classes of chemical agents which may be responsible for the toxicity associated with a particular bulk sediment. Identification of the causative agent potentially offers the opportunity to apply corrective action to either eliminate the source of the problem or to remediate the sediment. Additionally, this method should be useful for demonstrating that site remediation has been successful in reducing the toxicity of the sediments to aquatic life.

Additional advantages of this method that may be proven with time and usage of the method include: (1) suitability for a broad array of sediment types; (2) suitability for many different classes of chemicals; (3) suitability for predicting effects on several different organisms; and (4) suitability for determining the adequacy of point-source controls.

5.3 Limitations of the approach

The state of development of this toxicity identification evaluation (TIE) approach for sediments is in its infancy. There are no peer-reviewed published papers at this time. Therefore, the extent to which this method will become useful is yet to be determined.

At the present time one would have to list "ease of use" as a limitation for TIE procedures, both for sediment and waste water. Only a few laboratories can successfully perform TIE studies. One of the main reasons is that the method requires a high degree of skill, a multi-disciplined team, as well as state-of-the-art analytical capabilities for identification of specific chemicals.

Cost is also a limitation for this methodology. Since expenses could exceed $100,000 for samples which are highly contaminated. In some cases cost could be much less, but it is clearly not a routine procedure. However, in some cases the cost of this analysis could be justified due to better data and hence better remediation efforts.

The level of acceptance of this method for sediments may be a limiting factor. There are a number of scientists who believe that the interstitial water approach for measuring sediment toxicity underestimates the potential toxicity of chemicals sorbed to sediments. This is because the availability of contaminants sorbed on particles is not taken into account. For some species ingestion may be the primary route of chemical uptake.

The method is somewhat limited by the fact that the sediment interstitial water samples must come from the site of concern and that a sufficiently large amount of sediment and water must be collected and stored for extended periods of time. To insure the integrity of the interstitial water, the sediment samples often are processed on site. This increases the level of complexity required for obtaining samples.

There is no universally accepted method for collecting sediment interstitial water from sediment nor is there any consensus that the chemical properties of interstitial water collected from laboratory or field sediments are the same as that which exists in situ. Several of the steps in the TIE evaluation can introduce chemical artifacts or contaminants which necessitate the use of both positive and negative controls.

The approach is theoretically suitable for application to a wide variety of organisms, but to date it has only been validated using freshwater sediments and Pimephales promelas, Ceriodaphnia sp. and Daphnia magna. Although other organisms can be used, a significant amount of baseline data is needed for these other species (e.g., how much methanol, EDTA, or thiosulfate can be tolerated?, what is the background control mortality?).

5.4 Robustness of the approach

The information presented is basically sound. However the method is in an early state of development. Most of what the authors have presented is speculation about how the method should perform and how it could be used for various sediment assessment purposes. The comments, to a large extent, are based on data developed for wastewater TIEs and there are only a few laboratories that have successfully performed these tests. The application of these same wastewater procedures to sediment interstitial water has been performed at only one laboratory to date. Therefore, it is premature to draw conclusions as to their ease of use or direct application for sediment interstitial water samples. This is because humic and fulvic acids, as well as other substances that could bind materials in sediments, present special problems that will have to be overcome.

It appears to offer a useful tool for evaluating sediment toxicity. This method should not be presented as one which is ready for use, but rather as one that is being considered for future development because it appears to be very promising. Sections 2.2,2.3 and 3.1 should be rewritten to reflect this viewpoint.

It is stated on page 4-4 "the major assumption of the method is that chemicals that cause toxicity in pore water are the same as those chemicals that cause toxicity in the sediment". In addition to this assumption, it should be mentioned that the current procedure measures acute toxicity to a surrogate sediment organism (Ceriodaphnia sp.) and it is assumed that this organism is as sensitive or more sensitive than representative sediment-dwelling organisms. This method also implies that the chemicals causing acute toxicity will cause chronic toxicity. This probably is not the case.

In applying this method for in-place pollutant control (section 3.1.4) the authors have crossed the line between using interstitial water for identifying the toxic component and using interstitial water toxicity tests as a way of controlling and monitoring pollution. The thrust of the present paper is not aimed at demonstrating that an interstitial water toxicity test is the best approach for monitoring sediment toxicity, but only that it appears to be the best for toxicant identification.

This approach is described as being suitable for source control. This may or may not prove to be true depending on cost, ease of use, reliability, etc., all of which have yet to be determined. It appears to be useful to identify toxic components in sediments. Other more simple toxicity procedures may be more suitable for routine source control monitoring.

5.5 Recommendations

The title of this method could be changed to be more descriptive of the procedure described. The existing title (Interstitial Water Toxicity Approach) would lead one to believe that this is a sediment classification method based on an approach similar to the Equilibrium Partitioning Approach. What is really described is a sediment toxicity identification method. The title could be modified to read: Sediment Toxicity Identification Evaluation: Interstitial Water Approach.

It is recommended that additional research be done to evaluate the applicability of TIE procedures to sediments. Initial research efforts need to concentrate on: developing the necessary separation steps for sediments, developing several sediment interstitial bioassays, and publishing data sets for several different sediments and different chemicals.

It is difficult to assess synergistic and antagonistic interactions in TIE procedures. A large amount of data now indicate that synergism rarely occurs in acute toxicity test with aquatic organisms. Statements relating to antagonisms and synergism are pure speculation and should be dropped.

The authors should acknowledge that other TIE schemes exist (e.g., Doi and Grothe, 1988) and that a successful TIE sometimes requires the use of more that one method.

6.0 EQUILIBRIUM PARTITIONING APPROACH

6.1 General description of the approach

Equilibrium Partitioning (EqP) is a method which predicts concentrations of chemicals in pore water from the concentrations sorbed to sediments. It is assumed that hydrophobic chemicals partition to the organic carbon portion of the sediment and that the ratio of chemicals between organic carbon and pore water is approximated by the n-octanol-water partitioning coefficient. Therefore, if one knows the fraction of organic carbon in the sediments, the n-octanol-water partitioning coefficient, and the "safe" level for a chemical in water, one can calculate the acceptable concentration of the material in sediment.

6.2 Advantages of the approach

The method relies on a fundamental chemical parameter, fugacity. The n-octanol-water partitioning coefficient (K_{ow}) is rather easily measured, and therefore, these data are often available for given chemicals. When a concentration of a chemical is known in one medium, such as sediment, the concentration can be predicted in water, within certain confidence limits and subject to some restrictions. The method reduces the amount of analytical work necessary and thus provides a quick and relatively easy method to make preliminary estimates of concentrations in interstitial water. This, when compared to water quality criteria concentration, forms a basis for estimating whether the surrounding sediment concentrations are of suitable quality.

6.3 Limitations of the approach

There is great lack of understanding of the uncertainties associated with the basic assumptions used in this approach. For instance, does all sediment organic carbon sorb/desorb hydrophobic chemicals equally? How well does the octanol-water partitioning coefficient approximate the sediment partitioning coefficient normalized to organic carbon? Is the only biologically available fraction of a hazardous chemical that which is dissolved? There are only a limited number of water quality criteria available for contaminants associated with sediments. Sediments in the field may not be in equilibrium.

The availability of compounds associated with sediment may be controlled by kinetics rather than partitioning. These and other limitations have been presented in a previous Science Advisory Board evaluation of this method (EPA-SAB-90-006, 1990). Without a better understanding of these uncertainties, the accuracy and precision of the method will remain in doubt.

6.4 Robustness of the Approach

The usefulness of the approach will be limited by three factors. The first, as mentioned above, relates to the uncertainties inherent in the assumptions. The second is that the method, as presently proposed, should relate to water quality criteria or other well-documented protective dissolved levels of chemicals. There are very few of these for chemicals associated with sediment. The third limitation is that the method, as constructed, is not intended to evaluate effects from complex mixtures of contaminants sorbed to sediments.

6.5 Recommendations

The uncertainties in all of the assumptions used in determining the EqP should be determined along with the probability of cumulative errors in each step of the calculations. Validation experiments should be conducted using natural or spiked sediment to determine the influence of aging on the biological availability of chemical(s) in question. These and other recommendations concerning needed research and validation exercises are given in the previously mentioned Science Advisory Board review (EPA-SAB-EPEC-90-006).

7.0 TISSUE RESIDUE APPROACH

7.1 General description of the approach

The Tissue Residue Approach involves determining concentrations of contaminants sorbed to sediments above which the associated biota will contain unacceptable tissue residues. Key to success of the method is the determination of acceptable tissue concentrations. Two basic approaches can be used to determine these levels. One is to establish Maximum Permissible Tissue Concentrations (MPTC) for an organism at the chronic water quality criterion concentration. An assumption that is made in this approach is that body burden of a contaminant is correlated to a toxic effect. Once this number is known, calculations to determine acceptable water concentrations resulting from sediment levels (e.g., the Equilibrium Partitioning approach) can be made. Field observations which compare tissue residues to associated sediment contaminant concentrations can also be used to derive sediment quality values.

Another approach to determining an acceptable tissue concentration is to use a human health Action Level or Tolerance

Level for a contaminant in freshwater fish or in seafood and back-calculate the level in sediment that would result in these concentrations.

The linkage between tissue residues and associated sediment concentrations can be approximated through either site-specific observations, equilibrium partitioning modeling, or pharmacokinetics-bioenergetics modeling.

7.2 Advantages of the approach

There are a number of advantages to this approach if properly executed and validated. One is that, in many cases, direct field observations can be made to relate sediment and tissue concentrations. For example, kepone concentrations were found in the James River sediments and correlated to concentrations in fish and shellfish inhabiting the river. In such a case, the methodology does not require a knowledge of bioavailability relationships, because the organisms have already integrated all the variables. Care must be taken, however, to properly interpret the tissue residue data relative to spawning cycle, time of year and migratory patterns. For instance, should tissue residues be measured immediately after spawning, total body burdens of lipophilic chemicals which had concentrated in the eggs, would be less than before spawning. "Acceptable sediment levels" based on these post-spawning measurements may not be appropriate for pre-spawning conditions.

There is greater uncertainty generated when pharmacokinetics-bioenergetics modeling is used. This is because of uncertainties associated with the assumptions used in the models. For the same reasons, there are uncertainties inherent with the use of equilibrium partitioning models to back-calculate acceptable sediment levels.

7.3 Limitations of this Approach

The approach works best for aquatic ecosystems that are close to steady state. The fact that some chemicals are metabolized to substances of higher toxicity, and that such transformations must be recognized for the approach to be valid, is acknowledged in the Compendium. One limitation that needs to be documented is the fact that our data base and understanding of the relationship between body burden and toxicity is virtually non-existent. While this may be less of a problem if one uses species for which tissue residues have been measured at the chronic water quality concentration, extrapolation to other species is extremely risky.

The document does not adequately address which tissues are most appropriately used. This aspect needs further expansion. The ability of the method to assess effects of complex mixtures in sediments should also be better explained.

There are real-world examples which support the utility of this approach. There is also research which shows that laboratory derived bioconcentration factors and depuration rates are not always the same as those observed in the "real-world." Therefore, extreme caution must be used when applying this method without field validation. This is an area deserving of more research effort.

7.4 Robustness of the Approach

The method has been used in the field and had been shown to be effective. A major advantage is realized when correlations between sediment contamination levels and tissue concentrations can be made in the environment. Such relationships derived in the laboratory have greater uncertainties which carry over to sediment quality values thus derived.

7.5 Recommendation

It is recommended that this method be considered by the Agency for further development as a major tool in assessing sediment quality. Research should be supported to better define the relationships between tissue resides and toxicities. Should a mechanistic understanding be obtained, the method will have a much broader applicability.

8.0 FRESHWATER BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE AND FUNCTION APPROACH

8.1 General description of approach

This is an integrated approach which utilizes sediment chemistry, sediment toxicity, and benthic macroinvertebrate community structure and function to evaluate sediment quality, in a manner similar to the approaches now used to evaluate surface water quality. The community structure and function of benthic macroinvertebrates are used extensively to evaluate water quality and characterize impacts in lotic and lentic freshwater ecosystems. Benthic macroinvertebrates inhabit or depend upon the sedimentary environment for their various life functions, therefore, they are sensitive to both long-term and short-term changes in sediment and water quality.

The structural assessment relates to the numeric taxonomic distribution of the community, and the functional assessment involves trophic level and morphological aspects. The proposed methodology addresses the specific benthic community assessment methods that are available, or being developed, to complement the chemical and toxicological portions of this sediment quality assessment.

Freshwater benthic macroinvertebrate communities can be used to assess sediment or water quality in the following ways:

(a) identification of the quality of ambient sites through a knowledge of the pollution tolerances and life history requirements of benthic macroinvertebrates,

(b) comparison of the quality of reference (or least impacted) sites with test (ambient) sites, and

(c) determination of spatial gradients of contamination for point or diffuse source characterization.

8.2 **Advantages of the approach**

Perhaps the main advantage of using a variety of benthic macroinvertebrate measures is that, in many cases, it can provide an economical and useful indication of the comparative health and well-being of the specific aquatic ecosystem under study.

A real advantage is that it provides a direct observation rather than theoretically derived data. A natural real-world mix of benthic macroinvertebrates may be more useful than a standard list of species for a generalized bioassay or other laboratory evaluation. Benthic macroinvertebrates provide substantial information that the chemistry and toxicity data alone cannot provide.

The sampling strategies outlined should detect spatial differences and temporal trends. These will assist in the overall process of detecting, quantifying, and attributing the source or cause of change or, also important, the lack of change.

Rapid assessment techniques can be very useful to guide decisions as to how much detailed biological sampling and analysis is required as well as the level and type of effort needed for other labor-intensive, long-duration, and expensive physical or chemical sampling, analyses, or modeling efforts. Full quantitative sampling is not needed to determine the relative abundance of the various species of benthic macroinvertebrates.

Benthic community assessments can help determine whether sediment quality is impairing the designated uses and biotic integrity.

8.3 Limitations of the approach

Benthic macroinvertebrates will be effective in helping to indicate in-place pollutant control needs through site-specific knowledge of surface water quality, habitat quality, and sediment chemistry and toxicity. Optimal use of benthic macroinvertebrates may be as part of an integrated approach as described. But the benthic macroinvertebrate data may well be, in some instances, more quantitative, more valid, and less suspect than other sediment toxicity or contamination assessment methods included in the compendium.

One limitation is the difficulty in relating the findings to the presence of individual chemicals and specific concentrations of those chemicals for numeric in-place pollutant management. However, this is a problem for many of the methods available to estimate sediment quality.

By itself, this method should not be used to generate chemical-specific values in situations where there are multiple outfalls or a number of pollutants because multiple sources or peculiar depositional or flow patterns may make interpretations difficult. In some less complex situations, it probably could be the basis for remedial actions; but in all cases analysis of benthic macroinvertebrates can be extremely helpful.

It must be realized that low community diversity can be caused by factors other than water quality impacts including seasonal differences, poor habitat which may result from an influx of clean non-toxic inorganic soil, or from some other physical perturbation. Comparisons should be made among benthic communities inhabiting similar substrates since different organisms will inhabit different types of substrate.

8.4 Robustness of the approach

Benthic organisms are holistically integrating all of the environmental perturbations which are occurring. Such integration is ideal for assessing the overall condition of a particular environment and is especially useful in simple circumstances where sources or inputs of contaminants are limited and gradients can be established. In other cases, cause-and-effect relationships may be more difficult to determine. For instance, navigational dredging projects are most commonly found in highly industrialized or urbanized areas which have a wide variety of perturbations, and navigation itself is a form of perturbation. The physical effects of traffic and of repeated dredging in a channel may eliminate or severely reduce the benthic fauna, particularly in navigation channels.

Likewise, water quality contaminant impacts from outfalls, thermal discharges, surface runoff, and a host of other perturbations may completely confound any effects of sediment contaminants. Further, it must be remembered that the method is a "snapshot in time" and the organisms present are representing the events, and particularly the extreme events, which have occurred over some period of time.

The method can yield two results. Either a healthy fauna will be found, in which case no further action is required, or the fauna will not be healthy. In the latter, if the cause is unknown, bioassays may be necessary to separate physical effects, water-column effects, or episodic events. Bioassays might best be used instead of benthic community assessments.

8.5 Recommendations

Benthic macroinvertebrates alone can be used to screen for potential sediment contamination and source identification by displaying spatial gradients in community structure, but they should not normally be used alone to definitively determine sediment quality or develop chemical-specific guidelines.

It is probably true that a benefit of reducing complex benthic community measurements to a single number was that it could be used by non-biologist decision-makers. It is still important for scientists to be very sensitive to the needs of decision-makers and to provide them with appropriate output or results that will be useful in making the sort of decisions facing them. Some discussion should be provided that would help users balance the desirability of providing one or several numbers.

9.0 MARINE BENTHIC COMMUNITY STRUCTURE ASSESSMENT

9.1 General Description of the Approach

The Marine Benthic Community Structure Assessment Approach involves a field survey that includes replicated sampling at stations; sorting and identification of the collected organisms to the lowest possible taxa; and analyses of species richness, number of individuals, diversity, and sometimes biomass. Results of field surveys are interpreted by comparison to reference stations (sites) which are (should be) ecologically similar. Effects of sediment physical/chemical properties are also integrated into data interpretations.

9.2 Advantages of the approach

The Marine Benthic Community Structure Assessment Approach can directly assess sediment quality since it provides an empirical determination of the benthic community present in a sediment sample. When compared to reference (uncontaminated) sites, the effects of sediment contaminants on benthic organisms can be determined. It provides a direct *in situ* assessment.

9.3 Limitations of the approach

The Marine Benthic Community Structure Assessment Approach can not be used by itself to generate numeric sediment quality values. The approach provides no information on the contaminant(s) causing the effects on benthic organisms. However, the method can be integrated into several other approaches (i.e., the Sediment Triad and AET) to develop numeric sediment values. Benthic community structure is impacted by a variety of factors other than the presence of chemical contaminants in sediments. Interpretation of Marine Benthic Community Structure Assessment results must include consideration of the influence of abiotic factors such as substrate type and quality.

Conducting benthic surveys can be expensive and require high levels of taxonomic expertise. Frequently, available resources limit the design of studies and statistical power is low due to insufficient replication.

9.4 Robustness of the approach

The assessment of benthic community structure is a direct measure of the environmental effects of pollutants and is an extremely robust method. In general, the comments in this section apply equally to marine or freshwater benthic community assessments.

9.5 Recommendations

Criteria need to be developed to identify reference sites to be used in the Marine Benthic Community Structure Assessment. Research should be conducted to evaluate the usefulness of identifying marine macroinvertebrates to different taxonomic levels (i.e., Is taxonomic family adequate or is genus always required?).

10.0 SEDIMENT QUALITY TRIAD APPROACH

10.1 General Description

In the Sediment Quality Triad Approach, chemical analyses of sediments, studies of the benthic infaunal communities, and laboratory bioassays of sediments are used to provide a qualitative and numerical description of sediment quality. The major emphasis has been on an integrated qualitative description of sediment quality.

The Sediment Quality Triad Approach has many similarities to the AET Approach, in that both methods use sediment chemistry data, an assessment of benthic infauna, and sediment toxicity studies. The methods used for the analysis of the resulting data and their interpretation in these two methods differ.

The Triad Approach develops "ratios to reference" (RTR) values and combines these in a matrix or in diagrammatic form to illustrate the degree of divergence from the selected reference. The pattern of divergence is used as an aid in the interpretation of the significance of the data.

To date the Triad Approach has been used primarily in setting priorities for addressing sediment contamination.

10.2 Advantages

The major strength of the method is that it can deal with interactions of components in the types of mixtures that are encountered in a specific locality. The method integrates chemical studies, benthic population studies, and laboratory bioassays.

The method offers an integrated approach to prioritizing areas of sedimentary contamination within a single geographic region.

10.3 Limitations

The major weakness of the Triad method is its site-specific nature. In addition, the Triad method does not establish causal relationships between specific contaminant concentrations and observed adverse effects. In its original form the Triad method does not develop numerical sediment quality values. Data generated may be difficult to interpret if normalizing factors for bioavailability are unknown.

10.4 Robustness of the method

Conceptually, within its limitations, the method is robust. The reliability of the individual Triad prioritizations is strongly influenced by the quantity and quality of the data available for integration.

10.5 Recommendations

The section on the Triad Approach is well written. The write-up of the Triad method should make more explicit references to the AET approach, briefly indicating similarities and pertinent differences.

11.0 APPARENT EFFECTS THRESHOLD APPROACH

11.1 General description of the approach

For the Apparent Effects Threshold (AET) approach, biological data (e.g., benthic community structure or laboratory bioassays) and chemical analyses of contaminants in sediments are used to develop sedimentary concentration limits for specific contaminants.

The AET Approach has many similarities to the Sediment Quality Triad Approach, in that both methods use sediment chemistry data, an assessment of benthic infauna, and sediment toxicity studies. The methods used for the analysis of the resulting data and their interpretation in these two methods differ.

The AET method was originally developed to evaluate conditions in Puget Sound on the basis of an extensive data set that was available for that region.

This method received extensive evaluation by EPA's Science Advisory Board (SAB), and the reader is referred to the report of the SAB Subcommittee on Sediment Criteria ("Evaluation of the Apparent Effects threshold Approach for Assessing Sediment Quality" SAB-EETFC-89-027, July, 1989) for their evaluation.

The AET method is based upon an assessment of the concentrations of locally encountered contaminants and identifies those concentrations that are associated at some confidence level with decrements of benthic biota. Field data may be augmented by laboratory toxicity screening tests (e.g., bacterial bioluminescence, amphipod mortality, and developmental abnormalities in oyster larvae). The AET method can establish sedimentary quality values on the basis of benthic infaunal changes, or on the basis of laboratory toxicity data derived from sediment samples, or on some combination of both field and laboratory data.

11.2 Strengths of this Method

The major strength of the method is that it can deal with interactions of components in the types of mixtures that are encountered in a specific locality. Effects measured in the field as well as in the laboratory can be accommodated by the method.

The AET method can be particularly advantageous when many environmental samples are already being collected as part of other program needs.

11.3 Limitations of this Method

The major weakness of the AET method is its site-specific nature. AET values developed for one location cannot be readily exported to other sites without repeating most of the field and laboratory analyses for the new location, so that the interactions of the various chemicals in the new sediments on the biota could be determined. In addition, the AET method does not establish causal relationships between specific contaminant concentrations and observed adverse effects. Non-protective AETs could be generated if biological results were incorrectly classified. By definition an AET can only increase with additional non-impacted (e.g., incorrectly classified) data. It also requires a large data base and is therefore costly.

11.4 Robustness of the method

Conceptually, within its limitations, the method is robust. The reliability of the individual AET values is strongly influenced by the quantity and quality of the data available for their derivation.

11.5 Recommendations

The presentation of the AET method needs to be revised. Most of Chapter 10 deals with the history, derivation, and potential uses of the AET method. The discussions of the AET method should make reference to the Sediment Quality Triad Approach, briefly indicating similarities and pertinent differences. In an earlier evaluation of the AET method, this Subcommittee recommended that EPA use the AET method in combination with other approaches and that the AET approach could be strengthened by using replicate sediment samples, devising criteria for selecting reference sites, including considerations of physical factors, and developing measures of variance.

12.0 INTERNATIONAL JOINT COMMISSION SEDIMENT STRATEGY

12.1 General description of the approach

The approach developed by the International Joint Commission (IJC) for the assessment of contaminated sediments in the Great Lakes differs significantly from the other approaches cited in the "Sediment Classification Methods Compendium." The approach emphasizes strategy rather than methodological details. The IJC method is focused on large-scale problems and considers the cost-effectiveness of the initial studies. The major concerns are the potentials for biological effects and bioconcentration. The strategy employs chemical, physical, and biological approaches to define the qualitative and quantitative severity of an impact. The strategy is comprised of a series of data-gathering activities: physical mapping, including benthic communities; laboratory bioassays; and characterizing sediment dynamics, which may be important in developing remedial options.

12.2 Strengths of this Approach

The major strength of the method is the recognition of the need for a strategy to attack a series of problems that may range from the small to problems of major extent. The IJC approach clearly recognizes the need to reconcile the costs of the investigation of sedimentary quality with the costs of any remedial actions, and provides general guidance for a threshold for investigating sediment associated problems. In addition, the IJC approach recognizes the need for using multiple avenues to demonstrate the extent and depth of the problem.

12.3 Limitations of this Approach

The method has the earmarks of a process developed in a conference room, rather than being developed in accordance with field experience. The magnitude of required data for Stage I is irreconcilable with a strategic approach that would sequence a reconnaissance investigation with a more descriptive investigation, followed by a detailed investigation targeted at remediation, followed by a compliance investigation during and after the remediation process. Furthermore, the strategy for Stage I combines aspects that are extremely specific (e.g., the analysis of phosphorus) with aspects that are poorly specified (e.g., benthic community structure). Ideally, the initial reconnaissance studies should be the least expensive, the most general, the most inclusive, and the least definitive. This is clearly not the case for the IJC method, where stages I and II are the most expensive.

The specifications for additional phases and stages vary considerably in the general guidance and specificity of instructions that are provided.

The discussion of the IJC method in the Methods Compendium needs to be improved with regard to any distinction between stages and phases in the methodology.

12.4 Robustness of the approach

The IJC method is fragile. It has not been proven in the assessment of actual environmental conditions. Nevertheless, certain aspects of this methodology deserve their generalized incorporation into any comprehensive methodology. Thus, this overall strategy for dealing with contaminated sediments is so valuable that it should be incorporated into all methodologies associated with the evaluation of sediments. Although the IJC method was designed specifically for the Great Lakes, its present methodology is so general that it can be applied globally; the only exceptions to this may be the emphasis of the Great Lakes method on bioconcentration and on finding tumors in fish. However, these latter two issues may well be sufficiently important that they should receive priority treatment for the evaluation of sediments in other localities.

Many of the specific methodologies cited as part of the IJC approach have also been cited previously as part of other approaches, especially in the Sediment Triad and the AET methodologies.

12.5 Recommendations

Regardless of the shortcomings of the IJC methodology, the concept of using a strategy to attack this complex problem has a great deal of merit. It is important that the concepts of IJC strategy be incorporated into the resolution of all complex approaches on the potential effects of contaminants in sediments.

13.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

A. The Subcommittee finds that the Compendium is scientifically acceptable for its intended use and encourages EPA to expand the introduction with references and discussion for sample collection and handling, quality assurance/quality control, tiered approaches for mixtures of chemicals, and data analysis. The Subcommittee also suggests that EPA add a table to the Compendium that summarizes information on the status and relative costs of each method. The status information could include relevant and comparative information on: the number and type of species tested, site specificity, field validation, and the availability of an uncertainty analysis for each method.

B. The Subcommittee recommends that EPA conduct research to expand the battery of freshwater and marine species that can be tested in the Bulk Sediment Toxicity Test Approach. For all approaches, protocols should be developed for handling and collecting samples, for sample storage, and basic quality assurance procedures. This could be added as introductory material to the Compendium or published as a separate document. Additional test methods are needed to assess other endpoints, such as chronic toxicity and teratogenicity.

C. The Subcommittee recommends that EPA investigate the effect of the effect of "aging" of spiked sediments and examine the extent to which the Spiked Sediment Toxicity Approach can be used to estimate the effects from mixtures.

D. The Subcommittee recommends that EPA revise the discussion of the Interstitial Water Toxicity Approach to emphasize its strengths for identifying sediment toxicity. Additional research should be performed to evaluate the applicability of the TIE procedures to sediments.

E. The Subcommittee reiterates its recommendations from an earlier review of the Equilibrium Partitioning approach (EPA-SAB-EPEC-90-006, February, 1990). The compendium should caution users of this method to express the uncertainties in the assumptions and to avoid cumulative errors in the calculation of the partition values. The availability of compounds associated with sediment may be controlled by kinetics rather than by partitioning. The possible influence of kinetics should be considered when the equilibrium partitioning approach is used to establish sediment quality values.

F. The Subcommittee recommends that the EPA consider further development of the Tissue Residue approach which has the potential to be used as a major tool in assessing sediment quality. The method could have even wider applicability if research could define the mechanisms of partitioning in the "real world" and the relationship between tissue residues and toxicity.

G. The Subcommittee recommends that the Freshwater and Marine Benthic Macroinvertebrate Community approaches be used to screen for potential sediment contamination and source identification. Discussion should be added to the compendium to help users balance the desirability of providing one or several numbers, and guidance should be added to identify reference sites for the Marine approach.

H. The Subcommittee recommends that the Sediment Triad and the Apparent Effects Threshold (AET) approaches should be cross-referenced. Additional comments were provided on the AET approach in a separate report (EPA-SAB-EEFTC-89-027, August, 1989).

I. The Subcommittee recommends that EPA highlight the International Joint Commission Sediment Strategy for its conceptual strength toward addressing the potential effects of contaminants in sediment.

14.0 REFERENCES CITED

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