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AN SAB REPORT: REVIEW OF SEDIMENT CRITERIA DEVELOPMENT METHODOLOGY FOR NON-IONIC ORGANIC CONTAMINANTS

PREPARED BY THE SEDIMENT QUALITY SUBCOMMITTEE OF THE ECOLOGICAL PROCESSES AND EFFECTS COMMITTEE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

EPA-SAB-EPEC-93-002
November 5, 1992

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

RE: SAB Review of Sediment Criteria Development Methodology for Non-ionic Organic Contaminants

Dear Mr. Reilly,

The Sediment Quality Subcommittee of the Ecological Processes and Effects Committee of the Science Advisory Board (SAB) has completed its review of sediment criteria. The review was conducted on June 10-11, 1992. As you are aware, the SAB has conducted previous reviews of various approaches for developing sediment quality values. The current methodology is based on the Equilibrium Partitioning Approach (EqP). In our previous review, the SAB found that the scientific basis for the concept was valid but recommended that Agency conduct additional research and testing to evaluate the uncertainties associated with the EqP-based predictions of field effects.

In May, 1992, the SAB was asked by the Office of Water to evaluate the Agency's progress in reducing the uncertainties associated with the EqP approach in light of how the Agency intends to use sediment quality criteria. The review was conducted on June 10-11, 1992 and was attended by scientists from academia, industry, public interest groups, and other government agencies. The Subcommittee reviewed five draft criteria documents, scientific publications, and received presentations from the Agency on possible uses of the sediment criteria. They also received public comments, including a detailed presentation by the US Army Corps of Engineers.

The Subcommittee commends EPA for its progress in addressing many the recommendations from the previous SAB reviews. The Subcommittee believes that EPA has significantly reduced the uncertainty associated with prediction of sediment toxicity generated by the EqP methodology, but there are still questions regarding the application of these estimates to the natural environment. The Subcommittee concludes that the EPA should proceed according to the following sequence of events: 1) establish criteria on the basis of present knowledge within

the bounds of uncertainty discussed in this report; 2) improve the present knowledge so as to improve the procedures for establishing criteria; and 3) periodically revisit the criteria to make them more consistent with conditions in the natural environment.

The Agency should consider how these criteria will be applied in various program offices. At this time, the Subcommittee believes that the criteria can be used to identify three ranges of sediment contamination: 1) concentrations well below the criterion which are unlikely to have adverse effects, 2) a range well above the criterion where adverse effects are likely and management is needed, and 3) a range in between, above and below the criterion, where more information is needed before a management decision can be made. The dividing lines between these ranges are vague and the precise location could vary depending on the intended use among programs. The Subcommittee recommends that these criteria not be used as a stand-alone, pass-fail value for all applications. The Subcommittee also recommends that EPA develop minimum data base requirements for the sediment criteria and prepare a users manual for the derivation and application of sediment quality criteria.

The Science Advisory Board appreciates the opportunity to review this important aspect of EPA's environmental quality criteria program and we look forward to reviewing the Agency's approach to establishing sediment quality criteria for metals in the future.

Sincerely yours,

Raymond C. Loehr

Raymond Loehr, Chair
Executive Committee
Science Advisory Board

Kenneth L. Dickson

Kenneth L. Dickson, Chair
Ecological Processes and
Effects Committee

Robert H. Huggett

Robert Huggett, Chair
Sediment Quality Subcommittee

U.S. ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

The report represents the conclusions and recommendations of the U.S. Environmental Protection Agency's Science Advisory Board regarding EPA's Sediment Criteria Development Methodology. The Review was held June 10-11, 1992 in Arlington, VA by the Sediment Quality Subcommittee of the Ecological Processes and Effects Committee. The report commends EPA for its progress toward reducing the uncertainties associated with estimates of safe levels of non-ionic organic contaminants in sediments using the Equilibrium Partitioning (EqP) approach. The report supports the EqP concept to develop sediment criteria where the conditions of equilibrium among the various phases of sediments are likely. The Agency is cautioned that there are still uncertainties associated with application of the criteria due to limited field validation data currently available. It is recommended that EPA use defined ranges of sediment contaminant concentrations based on the EqP approach that indicate whether or not sediments are acceptable, unacceptable, or require further evaluation. The Subcommittee also recommends further testing to improve the method and reduce uncertainty. It is also recommended that the criteria boundaries be revised periodically to reflect recent knowledge and experience, and that a document be developed to explain the derivation, application, and monitoring procedures for the Sediment Quality Criteria.

KEY WORDS: Equilibrium Partitioning, Sediment Quality Criteria, Uncertainty.

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MRS. MARCIA K. JOLLY (MARCY), Secretary to the Designated Federal Official

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1. EXECUTIVE SUMMARY

The Sediment Quality Subcommittee of the Ecological Processes and Effects Committee of the Science Advisory Board (SAB) met June 10-11, 1992 to review EPA's Sediment Criteria Development Methodology and evaluate its progress in addressing the uncertainties associated with the Equilibrium Partitioning (EqP) approach. In an earlier review (EPA-SAB-EPEC-90-006), the SAB recommended that the Agency conduct additional research and testing to evaluate more thoroughly field and laboratory effects and the effect of various chemical properties on bioavailability.

In this review, the Subcommittee reaffirmed that the EqP approach is scientifically sound. The Subcommittee considered broad sources of uncertainty including laboratory measurements to determine the precision or reproducibility of the EqP and field verification of the values predicted in the laboratory. The Subcommittee found that EPA had substantially reduced the uncertainty associated with laboratory measurements. The Subcommittee recommended that EPA set criteria with ranges of sediment contamination denoting where adverse biological effects are likely to occur, unlikely to occur, or unknown and further evaluation is required. This approach recognizes uncertainty that is associated with the theory and the site specific application, in contrast to pass-fail, single-value criteria. They also encouraged the Agency to give high priority to developing a chronic sediment toxicity test and additional field verification of the laboratory predictions. The Subcommittee recommended further research on bioavailability, sediment chemistry, and bioaccumulation. It was recommended that EPA provide guidance on the derivation of sediment criteria and effects of the assumptions, application of the criteria by various programs, and monitoring for site assessments, trends, or compliance. The Subcommittee encouraged the Agency to revisit its criteria and revise the sediment contaminant ranges based on its research and monitoring data. The Subcommittee also encourages the Office of Water to consider using similar weight-of-evidence approaches that reflect uncertainties for other environmental criteria.

2. INTRODUCTION

The Office of Water has served as a technical manager and focal point for EPA's development of the Sediment Quality Criteria (SQC). The Agency has evaluated several approaches to determining these values. It has supported extramural and EPA laboratory research to develop methods for measuring the effects of contaminated sediments on aquatic organisms and to validate the assumptions underlying the equilibrium partitioning (EqP) approach. The Office of Water is also developing a contaminated sediments management strategy to coordinate the use of SQC values and biological assays among different regulatory programs within EPA. The various programs within EPA must deal with contaminated sediment problems within the bounds of their regulatory statutes, their policies, and the options that are available for management of those sediments. The scientific foundation of the EqP and the Apparent Effects Threshold approaches to developing sediment quality values have been reviewed in the past by the Science Advisory Board (EPA-SAB-EPEC-90-006 and EPA-SAB-EEFTC-89-027 respectively). In addition, the SAB has reviewed an Agency summary of other approaches (EPA-SAB-EPEC-90-018).

At the time of the SAB review, the potential uses of SQC by EPA programs were not well defined. In general, the SQC would be the threshold for identifying the sediment as contaminated. Management alternatives would be program specific. For example, in monitoring programs, SQC could be used to identify where sediments are contaminated and pose a threat to benthic organisms, or in the Dredged Material Management program, SQC could be used as part of the disposal management decision process.

2.1 Statement of the Charge

The Subcommittee accepted the following charge to guide them in their review:

> Evaluate the Agency's progress in addressing the uncertainties associated with the Equilibrium Partitioning (EqP) approach, as pointed out in the SAB review and evaluate how the Agency intends to use the Sediment Quality Criteria in light of the uncertainties.

2.2 Subcommittee Review Procedures

The Sediment Quality Subcommittee is a standing Subcommittee of the Ecological Processes and Effects Committee of the SAB. For this review, expert scientists were added as liaisons from three federal agencies. The Subcommittee was provided with the charge, five draft SQC documents (phenanthrene, endrin, acenaphthene, dieldrin, and flouranthene), technical articles (Bruijn et al (1989) and Di Toro et al (1991)), and public comments prior to the meeting.

The Sediment Quality Subcommittee met in Washington, D.C. on June 10-11, 1992. At that time it received briefings on the Agency's response to earlier SAB recommendations for EqP, the development of SQC, and the intended uses by the Agency. At the meeting, the Subcommittee received comments from the public and the U. S. Army Corps of Engineers. Following the meeting, a draft report was provided to EPA and the public for information.

3. EVALUATION OF THE EqP APPROACH AND INTENDED USE

The Sediment Quality Subcommittee of the Environmental Processes and Effects Committee reviewed the Equilibrium Partitioning (EqP) approach to developing sediment quality criteria (SQC) in 1989. The resulting report (EPA-SAB-EPEC-90-006 Evaluation of the Equilibrium Partitioning Approach for Assessing Sediment Quality) raised a number of questions related to the scientific basis of the technique and suggested that more information was needed before it could be reasonably used for generation of SQC. The Subcommittee commends EPA for addressing those questions and suggestions in the subsequent three years. The results of these efforts have reduced the uncertainties related to utilizing the EqP approach to establish SQC. There are, however, a number of issues remaining. This document presents the consensus of the Subcommittee on those issues.

3.1 Sources of Uncertainty

Toxicity data from laboratory experiments generally fall within a factor of 5 of the toxicity predicted by the EqP. Often the levels differ only by a factor of 2 to 4 and appear to be unbiased. However, limited field data are available to assess the uncertainty associated with extrapolating values derived by the method to the natural environment. Thus, the accuracy and reliability of the method has not been fully characterized.

Nonconformity with theoretical assumptions inherent in the EqP methodology may affect the accuracy of the derived criteria when they are applied to the natural environment. The following are examples of how this may occur: 1) the extent to which factors other than organic carbon which may influence bioavailability for non-ionic organic chemicals may vary in the environment, (2) sensitivity to chemicals may be different between water column and benthic organisms in ways which are not affected by the tests used to establish water quality criteria, (3) not all sediments are in equilibrium with the pore water, (4) occasionally Kow may not be a good predictor of Koc, (5) partitioning of contaminants to and from sediments may be kinetic-limited, and (6) short-term bioassays may underestimate effects observed in long-term or full life cycle exposures to contaminants. The above points do not negate the EqP method, but they may limit the reliability and applicability of the approach.

The EqP methodology assumes that sediment contaminant activities, predicted by organic carbon normalization, correlate with contaminant bioavailability. Consideration of bioavailability is an important step in the development of contaminant criteria. The concept seems reasonably well supported for the five chemicals evaluated to date (acenaphthene, dieldrin, endrin, flouranthene, and phenanthrene). The supporting experiments, however, are limited to short term (days) bioassays with a few species (mostly arthropods). Most experiments have been conducted with spiked and/or manipulated sediments although some recent supportive data also exist from experiments with field-collected sediments. It is of some concern that, in general, only one experimental paradigm has been employed to test the concept. As a result, the predictive capability of EqP-derived criteria has not been demonstrated across a range of circumstances and field environments. For example, there are few examples of its applicability in nature to resident species. The Subcommittee recognizes the challenges inherent in testing the bioavailability hypothesis of EqP in nature with resident species, but feels efforts to verify this concept in the field should continue, even as the initial five SQC's are implemented. Field testing need not be limited to toxicity tests. It could (and probably should) take the form of appropriate field bioaccumulation studies, biomarker studies, or studies at population or community levels of organization.

EPA should be aware of the growing number of studies that point toward the importance of uptake from food by benthic species for some organic contaminants (Louma et. al., 1992 and Boese et. al., 1990). Pore water concentrations, indeed, might allow prediction of bioavailability, in nature, when all routes of uptake are in equilibrium. The question of whether sediment associated organic contaminants are at equilibrium in nature is central to this point. The theoretical explanations that suggest that near-equilibrium is common in sediments are reasonable, although largely untested. Even so, it is possible, and demonstrated in the case of at least one trace element, (Luoma, et. al., 1992) that water only toxicity tests in the laboratory will underestimate the exposures occurring in nature, which may involve several additive routes of exposure. The above discussion does not dispute that the bioavailability concept is a valuable first order principle. Rather it emphasizes the need to understand under what conditions sediment associated organic contaminants are or are not at equilibrium with respect to the sediment particles, organic carbon, and interstitial water.

As previously mentioned, the Subcommittee recognizes that the EPA has made progress in quantifying and minimizing the uncertainties associated with

SQC's derived from the EqP. The uncertainties have diminished largely as a result of more accurate determinations of the Kow's. The Subcommittee recommends that the EPA continue their efforts to identify and quantify the sources of uncertainties in EqP derived sediment criteria.

3.2 Appropriate Uses and Limitations

Within the framework of the known uncertainty, it appears that the EqP method provides a useful sediment assessment tool. The SAB concludes that the method is sufficiently valid to be used in the regulatory process if the uncertainty associated with the method is considered, described, and incorporated. For sediments with contaminant levels outside the boundaries of uncertainty, the EqP-derived criteria may generally be used to support regulatory decisions; and for levels within the bounds of uncertainty, confirmatory tests are required. The SAB concludes that the EqP-derived criteria, if applied properly, are ready for publication and use.

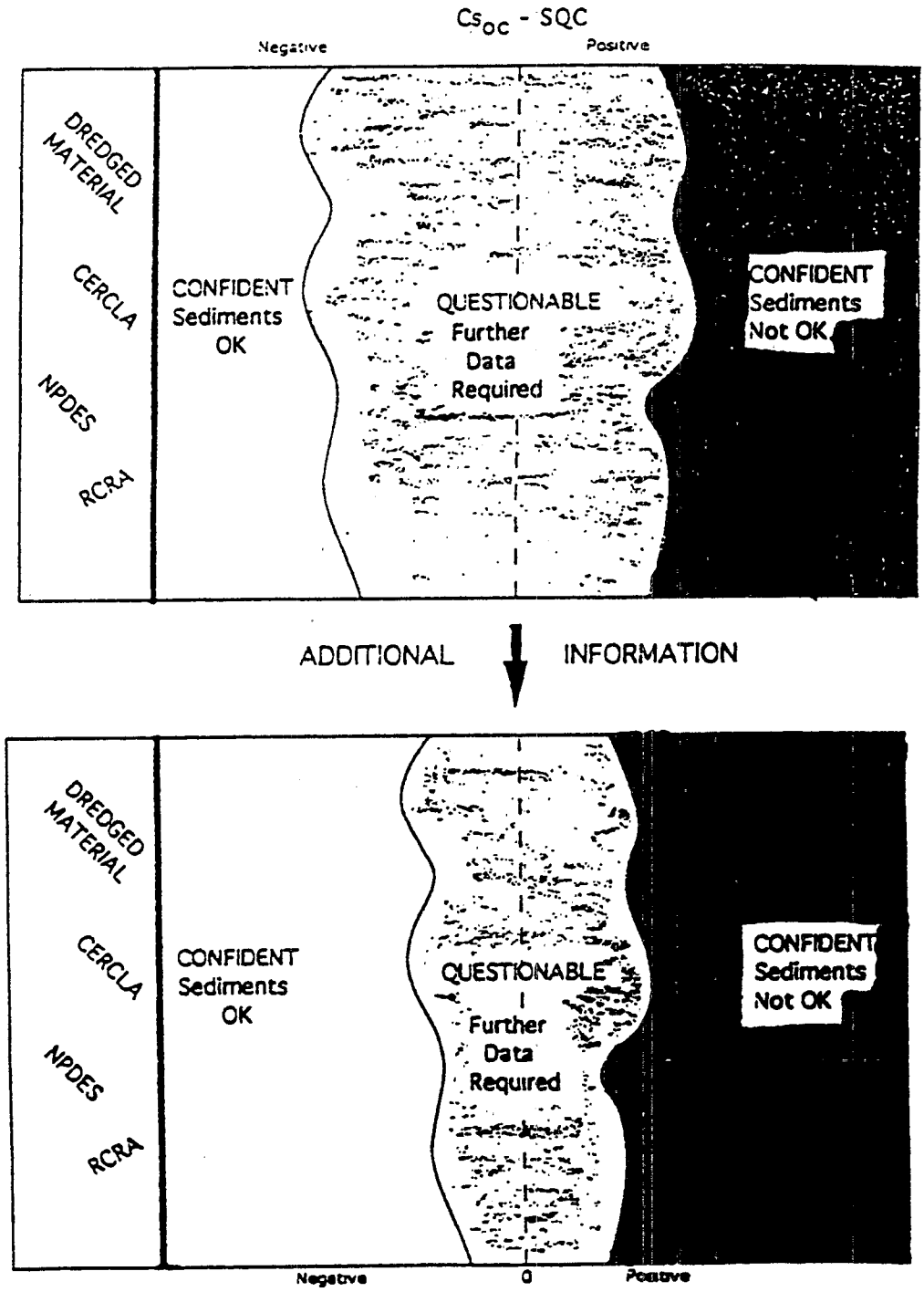
The Subcommittee recommends that EPA prepare a SQC users manual for internal and external programmatic uses before the SQC are implemented. The users manual should identify legislated programs (CERCLA, CWA, MPRSA, RCRA, 301h, NPDES, etc.) to which the SQC's would apply and how they would apply. Confusion and controversies regarding the proposed uses of the SQC's are apparent and should be resolved. The users manual should be program-specific and represent the consensus policy of the Agency. The manual should identify the significance of exceedances and non-exceedances of the lower and upper confidence intervals of the SQC concentrations and the anticipated actions (and nonactions) triggered by those non-exceedances and exceedances. The document should clearly state the inappropriate uses of the SQC's, such as mandatory target clean-up standards, unless additional site specific studies are completed. The Subcommittee recommends that EPA set a range of values above and below the SQC for which particular decisions will be made. The manual should also include requirements for sampling strategies that address the issues of on-site spatial and temporal variability.

The uncertainty related to the EqP-derived SQC means that there is a range of sediment chemical contaminant concentration above and below the SQC in which decisions about the effects of the contaminant are too questionable for decision-making on the basis of SQC alone. This concept is illustrated in Figure 1. Since SQC are different for every contaminant, for illustration purposes, the

SQC values have been "normalized" by plotting the difference between the concentration of the chemical in the ambient sediment per unit of organic carbon (Cs_{oc}) and the Sediment Quality Criterion, SQC. If the difference is greatly negative, so that the Cs_{oc} is much smaller than SQC, one can be somewhat certain that there will be no adverse biological effects. However, if site-specific data indicate that such a "clean" sediment may cause adverse effects, the biological information should override the criterion, and EPA should require further evaluation. Likewise, if the difference is greatly positive so that the contaminant concentration is much above the SQC, one can conclude that there will be effects from this contaminant. In either of these cases, the decision may be obvious. For cases in which the Cs_{oc} is in some indefinite range near the SQC, further evaluations are necessary. This would be an indication of the need to proceed to the next testing tier in the case of dredged material disposal, for example. The lack of adverse effects from limited field testing of sediments that exceed an EqP derived criterion should not override the presumption that the sediments contaminants are adversely impacting the environment. However, given that sufficient testing (toxicity, bioaccumulation, and field verification) has been performed the criterion could be overridden or revised.

The vertical locations of the various programs in Figure 1 are jumbled in the left hand column in order to indicate that there is no effort to suggest that any one of them has a wider or more narrow range for the questionable zone than others. It is important that each of these programs have its own lower and upper limits of the questionable zone. The lower part of Figure 1 indicates that, in the course of time, further testing and refinement of the SQC procedures may well result in a general narrowing of the questionable range and possibly a shift in the value of SQC, and hence also change in the value of Cs,oc - SQC. Likewise, if the understanding of the biological effects is advanced, the questionable zone may narrow.

FIGURE 1. Conceptual sediment management scheme for contaminated sediments utilizing the EqP-based Sediment Quality Criteria (SQC). On the horizontal axis, values have been "normalized" by plotting the difference between the concentration of the chemical in the ambient sediment per unit of organic carbon (Cs_{OC}) and the SQC.



In summary, the scientific rationale underlying the EqP-based SQC is sufficiently valid that it can be used in sediment management decisions for the five chemicals presented. The use of the SQC's as stand-alone, pass-fail criteria is not recommended for all applications. Rather, they should be used along with other tools as guidance in management and regulatory decisions. The use of the SQC's should not preclude the use of biological effects testing.

3.3 Additional Comments and Recommendations

3.3.1 Limitations for Current Use of the Criteria

a) The EqP method requires equilibrium conditions on the sediments. It should be used only with extreme caution for sediments in zones of rapid deposition or erosion. In these cases the assumption of chemical equilibrium between the sediment and the pore water may not be valid (e.g., areas where more than 10 cm/yr is deposited such as dredge disposal areas, barge and boat impacted areas, and some river channels).

b) The SAB concludes that the EqP method should not be applied to broad classes of compounds or mixtures if one Kow value is used to represent the entire class or the mixture.

3.3.2 Future Research to Improve the Method

a) The Subcommittee recommends that, in support of both the development of SQC's and the overall Sediment Management Strategy, the EPA should develop appropriate chronic (life cycle) sediment toxicity tests to use in the SQC validation process. Since the SQC's are based upon chronic and acute sediment water toxicity tests, the laboratory validation and field verification tests should be conducted with chronic life cycle end-points.

b) Field verification studies are needed to evaluate the accuracy and reliability of the SQC method. These should include both new studies and greater use of existing data from contaminated sites where both contaminant and species presence/absence data are available.

c) Additional measurements of chemical concentrations in interstitial water from natural sediment samples are needed. Those values should be compared to predicted values for the same sediments. The effects of dissolved organic carbon should be evaluated in these studies of the distribution of contaminants between sediments and interstitial water.

d) Additional research is needed to evaluate the relative significance of factors other than organic carbon which may affect bioavailability. The principal work cited by the Agency for the conclusion that carbon dominates the sorption process for various size fractions of sediment does not agree completely with the conclusions of the Prahl study (1982). It is recommended that additional sorption studies be performed to define the boundaries of the utility of organic carbon for normalizing sediment concentrations for non-ionic organic chemicals. Presently it is thought that the lower boundary ranges from 0.2 to 0.5% and the upper boundary is about 10 to 12% organic carbon.

e) Bioaccumulation from food and kinetic limitations on contaminant bioaccumulation need to be further evaluated, and their relevance determined, for both equilibrium and non-equilibrium situations.

f) Additional work by the Agency is required to establish how mixtures of contaminants in sediments should be handled. Most contaminated sites contain a variety of materials that could have a biological impact. Conceptually and practically, how should SQC be determined for such sediments? Work in this area needs to be continued and expanded.

g) The time and space scales over which sediment quality criteria generated by the EqP model are valid should be assessed. These time and space scales are likely to be site specific. For example, oyster reefs influence the rates of sediment deposition and they have very patchy distributions. They also harbor a diverse community of organisms, including species that may be particularly sensitive to contaminants or accumulate them efficiently.

3.3.3 Guidance for using the Criteria

a) The Subcommittee recommends that the EPA prepare a methods manual for the derivation the EqP-based SQC's. This manual should include a description of the: (a) step-wise process for derivation of the criteria; (b) the acceptable uncertainties in the Kow factors; (c) the acceptable analytical error in the chemical analyses performed in support of the Kow coefficient derivations; (d) the minimum acceptable water-toxicity data base necessary for derivation of SQC's; and (e) the minimum acceptable degree of agreement in sensitivities between the benthic animals to which the SQC's would apply and the pelagic/planktonic animals from which they were derived. The manual should include the minimum acceptable level of effort to validate the criteria with laboratory spiked-sediment bioassays and to verify the criteria with field-collected data. It should also describe the assumptions used in the derivation of SQC and their possible effects on the application of SQC and the sources of uncertainty for EqP-derived criteria. Further, the Agency should establish "Minimum data" requirements for determining a SQC when Water Quality Criteria for that substance does not exist. The Subcommittee recommends that the guidelines for deriving numerical national sediment quality criteria should outline the minimum database requirements for toxicity, chemistry, and bioavailability. The minimum data requirement should be specified for the number and type of benthic species used in the derivation of final acute values, final chronic values, and sediment bioavailability.

b) EPA should publish guidelines for sediment monitoring including rules regarding spatial averaging of sample results.

c) There does not appear to be a consensus within EPA on how reference area definition and characterization for dredged material should be approached. The Subcommittee is concerned that the EqP method could be used too conservatively or too liberally, depending on how the reference site is chosen. EPA should consider whether reliance on a reference area site should be maintained given that a single definition seems elusive at this time.

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