DEVELOPING SEDIMENT QUALITY STANDARDS: COMPREHENSIVE SEDIMENT MANAGEMENT IN PUGET SOUND

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ABSTRACT

High concentrations of potentially harmful toxic chemicals have been identified in the sediments of a number of urban-industrial bays in Puget Sound. In these areas, field studies have documented an increased frequency of fish disease, sediment toxicity, altered benthic communities, and significant bioaccumulation of harmful chemicals in the edible tissue of fish and shellfish. In response to this information, and a growing public concern about the health of the estuary, the Washington state Department of Ecology has established a comprehensive strategy for sediment management in Puget Sound. As a component of this strategy, the agency is now in the process of developing a suite of sediment management standards for use in a variety of regulatory programs. General sediment quality standards are now available in draft form. Once finalized and officially adopted, the standards will be used to identify and designate sediments that have adverse effects on biological resources or pose a health risk to humans. It is anticipated that the general sediment quality standards will also be used as a basis for limiting industrial and municipal discharges, thereby preventing future sediment contamination. Separate, but related, sediment management standards are also being developed for use in establishing cleanup goals for sediment remediation and in making environmentally safe decisions concerning the disposal of contaminated dredged material. The Department of Ecology will be using the apparent effects threshold approach, supplemented by the equilibrium partitioning approach, as the technical basis for the derivation of the sediment standards. Field validation studies indicate that these methods can be used to generate chemical specific standards which are reliable predictors of adverse environmental impacts associated with sediment contamination in Puget Sound. These methods represent tools with potential widespread application.

INTRODUCTION

On December 29, 1987, the Washington state legislature adopted the Puget Sound Water Quality Management Plan (PSWQA plan). The PSWQA plan, prepared by the Washington state Puget Sound Water Quality Authority (PSWQA), in cooperation with the United States Environmental Protection Agency (U.S. EPA), identified existing and emerging environmental problems in Puget Sound, established environmental goals for the restoration and protection of the estuary, and detailed specific actions to be taken by federal, state and local governments towards achieving those goals. The PSWQA plan addressed a variety of environmental issues, including point and nonpoint source pollution, wetlands protection, environmental monitoring, and contaminated sediments. This paper summarizes the PSWQA plan's recommendations concerning sediment contamination, and describes the comprehensive regulatory framework and technical approach currently being developed in Washington state to identity and manage contaminated sediments in Puget Sound.

A COMPREHENSIVE STRATEGY FOR SEDIMENT MANAGEMENT

The PSWQA plan established a long-term management goal for sediment quality in Puget Sound. The goal, "to reduce and ultimately eliminate adverse effects on biological resources and humans from sediment contamination throughout the Sound by reducing or eliminating discharges of toxic contaminants and by capping, treating or removing contaminated sediments.", will not easily be achieved. Sediments in many parts of Puget Sound, particularly the nearshore, urban and industrial areas, are currently contaminated with high levels of potentially toxic substances, including heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, and other organic chemicals. The past and present sources of these contaminants are diverse, including urban runoff and a variety of industrial and municipal discharges. Field studies conducted in Puget Sound in the early and mid-1980s documented increased prevalence of sediment toxicity, altered bottom dwelling communities, and histopathological disease in fish and shellfish living in association with contaminated sediments. Recent evidence of significant bioaccumulation of cancer-causing chemicals in fish tissue has prompted several health departments in the Puget Sound region to advise residents to limit their consumption of locally harvested seafoods.

Past efforts to prevent sediment contamination and to identify, manage and cleanup contaminated sediments in Puget Sound were hampered by the absence of adopted state or federal sediment quality standards or criteria. Recognizing this void, the PSWQA plan identified an overall strategy for sediment management (PSWQA 1987). The strategy consists of four key elements:

(1) classification of sediments in the Sound that cause adverse biological effects,

(2) implementation of Soundwide source control to prevent future sediment contamination,

(3) provision of rules and sites for the disposal of contaminated and uncontaminated dredged material, and,

(4) the development of guidelines for use in sediment cleanup actions at heavily contaminated sites.

In response to this overall strategy, and the goals set forth in the PSWQA plan, the Washington state Department of Ecology (WDOE) initiated the development of a comprehensive sediment management program for Puget Sound in 1987. Integral to this program are the development of five categories of sediment management standards: (1) general sediment quality standards, (2) effluent particulate discharge limits, (3) disposal standards for unconfined dredged material, (4) disposal standards for confined dredged material, and (5) cleanup guidelines for sediment remedial action at highly contaminated sites. The different standards are currently in varying stages of development.

General Sediment Quality Standards

In December 1989, WDOE issued the general sediment quality standards in draft form. The draft standards are now undergoing public review and comment. WDOE anticipates formal adoption of the general standards, by regulation, in June 1990. Once adopted, the general sediment quality standards will serve the dual purpose of: (1) reaffirming the water quality goals (i.e., maintenance and protection of human health and biological resources) already established for Puget Sound in Washington state's water quality standards, and (2) identifying specific chemical and biological criteria (i.e., acceptable levels of chemicals in sediments, bioassay toxicity limits) which must be met to ensure protection of the beneficial uses of the estuary. As required in the PSWQA plan, the general sediment quality standards will enable identification and designation of sediments that have acute or chronic adverse effects on biological resources or pose a significant health risk to humans. It is currently anticipated that the standards will include chemical, physical and biological tests and clearly defined pass/fail guidelines for the tests. In addition, the sediment quality standards will describe the intended use of the chemical and biological criteria and describe variance procedures for a variety of regulatory programs. The methods that will likely be used to identify chemical concentration limits for the general sediment quality standards are discussed in a later section of this paper.

Effluent Particulate Discharge Limits

WDOE is also required by the PSWQA plan to develop procedures for limiting discharges of pollutants to Puget Sound. The purpose of these procudures will be to ensure that future effluent discharges do not result in violation of the general sediment quality standards, and that the potential for future sediment contamination is minimized. It is currently anticipated that final rules addressing effluent control limits and the relationship between effluent control and the general sediment standards will be issued by WDOE in June 1990. WDOE is currently considering a variety of approaches for enhanced control of pollutant discharges, including, but not limited to, reliance on best available technology, numerical limits on the toxicity of the particulate fraction of the effluent, and numeric limits on the mass or concentration of chemicals discharged. As part of their discharge management strategy, WDOE is contemplating the establishment of sediment impact zones in wastewater discharge permits. Conceptually, sediment impact zones would be similar to dilution or mixing zones in the water column, and would be represented by a limited area near a discharge point in which limited exceedance of sediment quality criteria would be permissible.

Dredged Material Disposal Standards

The rules governing the management of dredged material in Puget Sound are currently in various stages of development. Procedures and guidelines for identifying disposal sites, and for evaluating relatively uncontaminated sediment and disposing of the material at unconfined, open-water sites, were established in 1988 as part of PSDDA, the Puget Sound Dredged Disposal Analysis. PSDDA is a cooperative program sponsored jointly by the U.S. Army Corps of Engineers, the U.S. EPA, WDOE, and the Washington state Department of Natural Resources. The PSDDA sediment evaluation procedures, which combine chemical evaluation of sediment and biological toxicity testing (PSDDA 1988), are now being implemented in Puget Sound by federal and state agencies. WDOE will formally endorse the PSDDA standards for unconfined dredged material disposal as part of the state sediment management strategy in July 1990.

Procedures for evaluating moderately to heavily contaminated dredged material, and guidelines for safe disposal of this material in confined upland or nearshore containment areas, are currently being developed. As called for in the PSWQA plan, the "confined disposal standards" are to be used by WDOE and local governments in the dredged material permit process, and shall address treatment and disposal options for contaminated dredged material both in water and on land. WDOE anticipates the adoption of the final confined disposal standards in July 1990.

Sediment Remedial Action Guidelines

Finally, the PSWQA plan directs WDOE to develop standards for deciding when heavily contaminated sediments should be capped, excavated, or otherwise treated. The sediment cleanup remedial action guidelines which will serve this purpose are currently being developed. When finalized, the guidelines will specify chemical concentration trigger levels for use in identifying sites for expedited remedial action. In establishing these guidelines, WDOE is including consideration of the roles of source control and pollution prevention, natural recovery, and maintenance dredging in sediment cleanup. It is not anticipated that all sediments which exceed the general sediment quality standards will be subject to cleanup per the state remedial action guidelines. Rather, the PSWQA plan allows that a distinction be made between low to moderate exceedance of sediment quality goals and extreme circumstances (i.e., exceedance of sediment remediation trigger levels) that warrant direct intervention. It is anticipated that only the most heavily contaminated, and thus the highest priority, sediments in Puget Sound will exceed the remedial action trigger levels and be subject to expedited cleanup. It is anticipated that WDOE will adopt final remedial action guidelines in June 1990.

EVALUATION OF METHODS FOR DEVELOPING SEDIMENT QUALITY STANDARDS

When the PSWQA plan first directed WDOE to develop a comprehensive program for sediment management, it was understood that innovation would be required due to the absence of formally adopted federal sediment standards or criteria. It was also understood that the sediment assessment methods used in standards development and source control in Washington state would likely represent application of new and controversial techniques.

Over the past decade, a variety of techniques have been developed by federal, regional, and state agencies in the United States for evaluating the significance of chemical contamination in sediments. Many of the early efforts involved simple comparisons of chemical concentrations at contaminated sites to concentrations in sediments from relatively unpolluted reference areas. Later, more sophisticated methods were developed which incorporated not only consideration of sediment chemistry, but also attempted to establish relationships between specific concentrations of individual chemicals in sediment and associated adverse biological and human health effects. As a first step in developing sediment standards for Puget Sound, WDOE and U.S. EPA evaluated a variety of field-based and laboratory-based approaches to establishing numerical sediment criteria. The specific methods which were considered by WDOE and U.S. EPA are listed below.

Field Based Approaches

- Reference Area Comparison - sediment quality values derived based on comparison of chemical concentrations at a site with concentrations at an acceptable reference area (i.e., a relatively unpolluted site with otherwise similar sediment characteristics).

- Field-Collected Sediment Bioassays - sediment management decisions made by exposing test organisms in the lab to field collected sediment. Comparisons are then made between the mortality or sublethal effects observed in field sediments and effects observed in experiments using sediment from a relatively unpolluted reference area.

- Screening Level Concentration - sediment quality values determined using field samples to identify the sediment concentration above which 95% of the enumerated benthic infauna species are present.

- Sediment Quality Triad - sediment quality values qualitatively derived by analyzing relationships among contaminant concentrations in sediment, the results of sediment toxicity bioassays, and the characteristics of in situ benthic communities.

- Apparent Effects Threshold - sediment quality values quantitatively derived by using synoptically collected sediment chemistry, benthic infauna effects, and sediment bioassay data to determine the chemical concentration in sediment above which statistically significant biological effects are always observed.

Laboratory/Theoretically-Based Approaches

- Water Quality Criteria/Interstitial Water - concentrations of chemicals in sediment interstitial water are measured and compared directly to the U.S. EPA chronic water quality criteria.

- Sediment-Water Equilibrium Partitioning - sediment quality values derived by using a theoretical model to predict the partitioning of contaminants between sedimentary organic carbon and interstitial water. Predicted interstitial water concentrations are then compared directly to the U.S. EPA chronic water quality criteria.

- Sediment-Biota Equilibrium Partitioning - sediment quality values determined by using a model to estimate the sediment concentration of a contaminant that would be expected to result in a body burden of the contaminant in benthic organisms exceeding a regulatory limit (e.g., the U.S. Food and Drug Administration limits for chemicals in fish and shellfish).

- Spiked Sediment Bioassays - test organisms are exposed to sediments that have been inoculated with known amounts of chemicals. Dose/response relationships are then used to identify chemical concentrations which do not result in adverse biological impacts.

Generally, the field-based approaches evaluated by WDOE and U.S. EPA relied on empirical observations of biological and/or chemical measurements to establish sediment quality values. Approaches such as the Triad and AET methods identified relationships between specific concentrations of chemicals in field collected sediments and adverse biological responses to exposed organisms. The laboratory/theoretically-based approaches evaluated by WDOE and U.S. EPA generally relied on extrapolation of federal water quality criteria to sediments, models of environmental interactions, or extrapolation of laboratory studies to develop sediment quality values. A more detailed description of each of the methods listed above can be found in Barrick et al. 1989 and U.S. EPA 1989B.

Comparison of Approaches

In evaluating the various methods for use in sediment standards development, WDOE identified eleven criteria that enabled objective assessment of the approaches with respect to three important attributes:

- applicability of the approach to existing and planned sediment management programs in Puget Sound, including those identified in the PSWQA plan,
- ability of the approach to generate criteria that are reliable predictors of adverse environmental effects, and,
- feasibility of implementation of the approach in the near term (i.e., by 1990).

Specifically, each approach was evaluated based on the following eleven criteria:

- data requirements and cost of sediment quality standards development,
- cost of routine application as a regulatory tool,
- ability to develop chemical-specific sediment quality standards,
- ability to develop sediment quality values for a wide range of chemicals,
- current availability of values for a wide range of chemicals of concern in Puget Sound,
- ability to incorporate the influence of chemical mixtures in sediments,
- ability to consider adverse effects on a range of biological indicator organisms,
- extent to which the approach incorporates direct measurement of sediment-associated biological effects,
- compatibility of approach to use of historical sediment chemistry data,
- ease and extent of field verification in Puget Sound, and,
- extent to which the approach provides proof of a cause/effect relationship between concentrations of specific chemicals in sediment and adverse biological effects.

Table 1 summarizes the results of WDOE's comparative analysis. The table highlights the relative advantages and limitations of each of the methods as gauged against the eleven evaluation criteria. For simplicity of presentation, each approach was assigned a subjective scoring of "-", "0", or "+" to enable a relative comparison based on each criterion. A "-" has been assigned in cases in which an approach does not meet the conditions of the criterion (e.g., relative to a cost criterion, a method is expensive to develop), a "0" was assigned in cases in which an approach somewhat meets the conditions of a criterion (e.g., an approach may be moderately expensive to develop), and a "=" is assigned in cases in which an approach substantially or fully meets the conditions of a criterion (e.g., an approach is not expensive to develop). N/A is assigned in cases in which a criterion is not applicable to an approach. A more complete analysis of the advantages and limitations of each method and the scoring rationale for each criterion can be found in Barrick et al. 1989.

Of the nine methods reviewed, two were considered by WDOE to be the most promising for developing potential sediment quality standards for Puget Sound: the apparent effects threshold approach (AET) and the sediment-water equilibrium partitioning approach (EP). Descriptions of the AET and EP approaches, and a brief discussion of the technique used to field validate sediment quality values derived from these methods are presented below.

The Apparent Effects Threshold Approach

The AET approach estimates concentrations of a given sedimentary contaminant above which statistically significant (P 0.05) adverse biological effects are always expected (U.S. EPA 1989). The AET values for individual chemicals or groups of chemicals are derived from actual sampling data, and are based on the statistical relationship between the contaminant level measured in field collected sediments and the results of biological tests conducted on the same sediments. The approach is appropriate for use with any organic or inorganic contaminant, and does not require a priori assumptions concerning the specific mechanism for interactions between contaminants and organisms (Beller et al. 1986). AET-based sediment quality values can be developed for any biological effects indicator that can be statistically evaluated relative to reference conditions. Two kinds of biological effects indicators have been used in developing Puget Sound AET: sediment toxicity bioassays and benthic community evaluations.

The laboratory bioassays that have been used to date in Washington state to develop AETs are the amphipod mortality bioassay (using Rhepoxynius abronius), the oyster larvae abnormality bioassay (using Crassostera gigas), and the Microtox bacterial bioluminescense bioassay (using Photobacterium phosphoreum) (Barrick et al. 1988). Generally, these bioassays involve the controlled laboratory exposure of test organisms to field collected sediment for a fixed period of time, and an assessment of acute or sublethal effects resulting from the exposure. Development of AET based on indigenous biota has been achieved by classifying and counting organisms found in sediment collected from contaminated areas, and by then comparing the abundance of these organisms to conditions in appropriate reference areas.

Figure 1 illustrates the derivation of a toxicity AET for lead. Each square on the figure represents a sediment sample that was analyzed for lead (and many other chemicals), and a hypothetical measure of adverse biological response (e.g., amphipod mortality). All available sediment samples were classified into two groups: (1) samples that did induce statistically significant adverse biological response (top bar), and (2) samples that did not induce statistically significant adverse biological response (bottom bar). Lead concentrations of samples within each group were then rank ordered by increasing concentration. The AET was established by the station in Group 2 with the highest concentration that did not exhibit statistically significant biological effects (660 mg/kg lead in this example). Above the AET, non-contridictory evidence exists that only significant biological effects were observed in this data set. If the lead AET derived from this dataset were applied to an independent dataset, it is expected that a high percentage of samples with lead concentrations above 660 mg/kg would be associated with toxicity to this test organism, or organisms of similar sensitivity.

The AET approach focuses on the fact that sediments can have concentrations of a given chemical as high as that chemicals AET and still have no observed biological effects. Thus, it is assumed in the AET approach that effects observed at concentrations below the AET for one chemical could have resulted from unmeasured, covarying chemicals, interactive effects of multiple chemicals, or other chemicals present at concentrations above their respective AET values. The occurrence of biologically impacted stations at concentrations below the AET of a single chemical does not imply that AET in general are not protective against biological effects. Rather, the implication is that single chemicals may not account for all stations with biological effects. Field validation studies indicate that a high percentage of all stations with biological effects can be accounted for by developing AET for multiple chemicals.

Sediment-Water Equilibrium Partitioning Approach

The EP approach is based on a simple model that describes the equilibrium partitioning of a contaminant between sedimentary organic carbon and interstitial water, with little dependence on other physical or chemical factors. A sediment quality value based on the EP approach is the sediment contaminant concentration (organic carbon normalized) that would be expected to result in an uncomplexed interstitial water concentration equivalent to the corresponding U.S. EPA chronic water quality criterion for that chemical (U.S. EPA 1989B). If the predicted interstitial concentration for a given contaminant exceeds its respective chronic water quality criterion, then the sediment would be expected to cause adverse biological effects. The approach is assumed applicable to a variety of environmental settings, including sediments with very low total organic carbon content (U.S. EPA 1988).

The primary advantage of the EP approach is that it uses the existing EPA water quality criteria toxicological database as a means of estimating the potential for contaminated sediment to cause adverse biological effects. Thus, use of this method does not require incurring the expense of collecting new, site-specific biological data. For nonpolar organic compounds, the EP model has a firm theoretical and empirical basis (U.S. EPA 1988), and field verification studies indicate that EP-based sediment criteria are reasonably predictive (Read et al. 1989). For ionic, polar organic contaminants and metals, the mechanisms controlling the partitioning of contaminants between sediment and interstitial water are not fully understood. Therefore, the ability of interested agencies to develop sediment quality standards for metals and polar organic contaminants using the EP approach is currently limited. U.S. EPA has initiated an extensive research effort to refine partitioning models and to expand the utility of the EP approach to these groups of compounds.

Overview of Approach to Field Validation of Sediment Quality Values

Because none of the available approaches to developing sediment quality standards are fully capable of addressing all concerns over interactive effects among chemicals and the effects of multiple chemicals on organisms, WDOE and U.S. EPA determined that field verification using diverse environmental samples was important to the evaluation of sediment criteria derived using the AET and EP methods.

As a means of testing the predictive reliability of the AET and EP approaches when applied to field situations, WDOE and U.S. EPA conducted a series of field validation studies (Beller et al. 1986, Barrick et al. 1988, Read et al. 1989). In designing these studies, WDOE and U.S. EPA acknowledged that definitive confirmation of chemical-specific predictions would require additional controlled laboratory spiking studies. However, the costs associated with a large-scale laboratory program addressing many chemicals was prohibitive. Furthermore, a feasible approach was not available for confirming that the results of single chemical laboratory studies could be extrapolated, in a meaningful way, to environmental samples which contained complex mixtures of chemicals and represented a wide range of sediment conditions. As an alternative, the agencies selected an approach to field validation which relied on the use of AET and EP values to predict biological impacts associated with contaminated sediments collected from the field. Data from approximately 330 stations, representing 13 embayments in Puget Sound, were compiled into a single database. Each station included in the database had been subjected to extensive chemical analyses of the sediment, and evaluated for sediment associated bioassay toxicity and/or effects to indigenous benthic organisms collected form the field.

As the basis for the AET and EP evaluation, sediment chemistry results for each station were compared to two different sets of AET and EP values for a range of contaminants of concern. In the first evaluation, a comparison was made for all chemicals detected in the Puget Sound database and available for either of the approaches (i.e., 12 chemicals for the EP approach and 60 chemicals for the AET approach). A second comparison was then made only for two chemicals, total PCBs and phenanthrene, that were widely detected in Puget Sound and common to both approaches. In both the complete and partial comparisons, exceedance of a chemical specific AET or EP value for any one chemical at a station resulted in a prediction that the results of the biological assessment at that station would indicate adverse biological effects.

During the comparative analyses, the AET and EP predictions were evaluated according to three measures of reliability: sensitivity, efficiency, and overall reliability. Sensitivity was defined as the proportion of all stations exhibiting adverse biological effects that were correctly predicted as impacted (i.e., all biologically impacted stations were identified as such by the AET or EP predictions). Efficiency was defined as the proportion of all stations predicted to have adverse biological effects that actually were impacted (i.e., only biologically impacted stations were identified as such by

AET or EP predictions). Overall reliability was defined as the proportion of all stations for which correct predictions were made for either the presence or absence of adverse biological effects. High overall reliability results from correct predictions of a large percentage of the impacted stations (i.e., high sensitivity, few false negatives) and correct predictions of a large percentage of the nonimpacted stations (high efficiency, few false positives) (Read et al. 1989). The concepts of sensitivity, efficiency and overall reliability are illustrated in Figure 2.

As independent measures of reliability, sensitivity and efficiency are important concepts to consider in selecting an approach to sediment management. A sediment standards approach that sets criteria for a wide range of chemicals near their analytical detection limits will probably be sensitive but inefficient. That is, it will predict a large percentage of sediments with biological effects but will also predict, as impacted, many biologically nonimpacted sediments with only slightly elevated chemical concentrations. Such an approach may be environmentally protective but also may result in overregulation that would not be cost effective. Conversely, a sediment standards approach that sets criteria values at the upper end of the range of environmental concentrations may be efficient but insensitive. That is, a high percentage of the stations with predicted impacts may indeed be biologically impacted, but the approach may fail to predict other biologically impacted stations with moderate to high chemical concentrations. Such an approach would be cost-effective and defensible in pursuing high priority remedial actions (i.e., would not result in overregulation) but would not be environmentally protective. The overall reliability of any method for establishing sediment criteria addresses both sensitivity and efficiency, and provides perspective relative to the ability of potential sediment quality criteria to balance the need for environmental protection and cost effective environmental regulation.

Results of Field Validation of Sediment Quality Values

The results of the field validation comparison using all available sediment quality values indicated that the Puget Sound AET (i.e., mixed organic carbon/dry weight normalized AET for 60 organic contaminants and metals) were generally reliable predictors of adverse biological effects. When evaluated relative to the Puget Sound database, the benthic AET values for the 60 contaminants demonstrated a 77 percent sensitivity, 100 percent efficiency, and an overall reliability of 88 percent in predicting the presence or absence of adverse biological effects in benthic infauna samples collected from 201 stations. Similarly, the sensitivity, efficiency and overall reliability of the amphipod AET values were 55 percent, 100 percent, and 83 percent, respectively, with regard to accurately predicting the presence or absence of amphipod mortality in laboratory bioassays performed on samples from 287 stations (Read et al. 1989).

In general, the sediment quality values generated using the EP approach were less reliable than the AET-based values when evaluated relative to the entire Puget Sound database and all available AET. Taken in combination, the EP values (i.e., organic carbon normalized mean EP values for 12 nonpolar organic chemicals) demonstrated a 30 percent sensitivity, 65 percent efficiency and 54 percent overall reliability in predicting adverse impacts to in situ benthos. Similarly, the EP values were 28 percent sensitive, 51 percent efficient, and 63 percent reliable, overall, with respect to predicting amphipod bioassay mortality. The somewhat lower overall reliability of the 12 EP values in comparison with the 60 AET values is likely attributed to the lower number of detected chemicals for which EP values were available relative to AET values. Higher predictive reliability will likely be possible using the EP approach when partitioning coefficients for metals and polar organic contaminants become available for use in generating EP-based sediment quality criteria.

The results of the reliability tests performed using only phenanthrene and total PCB values for the AET and EP approach indicate that the EP-based values are slightly more predictive than the AET values for these two contaminants. The demonstrated sensitivity, efficiency and overall reliability of the EP values in predicting adverse effects to benthos at 190 stations were 29 percent, 65 percent, and 54 percent, respectively, compared to a sensitivity, efficiency, and overall reliability of 14 percent, 100 percent, and 52 percent for the benthic AET values. Similarly, the sensitivity, efficiency and overall reliability of the EP-based values in predicting amphipod mortality in laboratory bioassays were 27 percent, 51 percent and 63 percent, respectively, compared to a sensitivity, efficiency and overall reliability of 3 percent, 100 percent, and 64 percent for amphipod AET. The reduced sensitivity of AET-based sediment quality values for total PCBs and phenanthrene, relative to the sensitivity demonstrated when AET for all available chemicals were used, may reflect the fact that there are a number of areas in Puget Sound for which other nonionic organic contaminants, metals or alkylated phenols are in high concentrations in sediments and likely contributing to site-specific toxicity.

The results of the reliability analysis suggest that elements of both the AET and EP approaches are useful in making environmental decisions. For this reason, WDOE is proposing that the Puget Sound sediment quality standards incorporate the best of both methods (i.e., that the standards for PCBs and phenanthrene be EP-based and the standards for all other contaminants be AET-based). However, the results of the reliability analyses also suggest that available chemical specific sediment criteria alone may serve as incomplete surrogate indicators of biological effects associated with unmeasured chemicals or the interactive effects of multiple chemicals. For this reason, WDOE acknowledges that a combination of biological and chemical testing will be necessary, in the near term, for effective management of contaminated sediments. In addition to EP and AET-based sediment standards, WDOE will be requiring confirmatory, site-specific biological testing as part of the general sediment quality standards for Puget Sound.

CONCLUSIONS

Chemical contamination of marine and estuarine sediments in developed coastal areas is a significant problem not only in Puget Sound but also throughout the United States and internationally. The regulatory framework adopted by EPA, PSWQA and WDOE for sediment standards development and implementation in Puget Sound will likely be the first such comprehensive program in the United States and it may well serve as an appropriate model for sediment management elsewhere. The AET and EP approaches, used as methods for establishing sediment quality standards, also have potential widespread application. The AET and EP-based sediment quality values appear to be reasonably predictive in Puget Sound and can be generated independently for other locations. Supplemented by limited site-specific biological testing, AET and EP-based sediment quality values provide a defensible basis for regulatory decisions concerning the identification, management and cleanup of contaminated sediments.

For additional information on the comprehensive sediment management program being developed by WDOE, please contact Mr. Keith Phillips, Washington Department of Ecology, Sediment Management Unit, PV-11, Olympia, Washington 98504. For additional information on the AET approach, please contact Ms. Catherine Krueger, U.S. Environmental Protection Agency, Hazardous Waste Division, HW-113, 1200 Sixth Avenue, Seattle, Washington 98101. For additional information on the EP method, please contact Mr. Christopher Zarba, Environmental Protection Agency, Office of Water Regulations and Standards, WH-585, 401 M Street S.W., Washington D.C., 20460.

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