90-e04

Environmental Investigations
Toxics Investigations/Groundwater Monitoring Section

TECHNICAL MEMORANDUM

First Progress Report
Freshwater Sediment Criteria Project

September 1990

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Report Produced for the Sediment Management Unit

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ACKNOWLEDGEMENTS

We would like to thank the following persons for their support with this project and for their help in supplying us with the information needed to write this report:

Keith Phillips, for his support and ideas

Tom Luster, for his support and review

Brett Betts, also for his support and review

Bill Yake, for his overall supervision of the Toxics group and his in-depth review of this report

John Tooley, for his help with the data processing

Art Johnson, for his knowledge of benthic studies

The many contacts, especially those listed in Table 3, who have provided us with valuable information.

Sonya Kirkendall and Kelly Carruth, for their expertise in word processing and for "putting it all together".

SUMMARY

This is the first progress report on the Washington State Freshwater Sediment Criteria Project. The overall objectives of this project are to: 1) identify and evaluate efforts to develop freshwater sediment criteria outside of Washington State, 2) gather and evaluate data and procedures relating to bioassays, benthic infaunal surveys, and freshwater sediment contaminant levels, 3) conduct chemical and toxicological studies on Washington State freshwater sediments and 4) develop biological and/or numerical criteria to be applied to Washington freshwater sediments. This progress report covers the extent of these efforts through July 1990.

INTRODUCTION - THE NEED FOR CRITERIA

Problems associated with contaminated sediments have become a serious concern. While it has long been recognized that criteria are needed for water quality, concerns regarding the possible hazards to aquatic life and human health from contaminated sediments have only recently been addressed.

This concern is based on several factors: 1) contaminant levels are often higher in sediments than in the water column, 2) contaminants can both be stored in the sediments and transferred to the water column, 3) sediment contaminant concentrations vary less through time than those in the water column, 4) sediments are a vital part of the aquatic habitat, 5) sediment-bound contaminants can adversely affect benthic and related organisms, and 6) contaminants in the sediments can be bioaccumulated in the food web and can lead to unacceptable human health risks.

Criteria based on concentrations of contaminants are needed for management decisions on sediment quality, source control, remediation, dredging and dredged material disposal, wasteload allocations, toxics studies, and monitoring programs. Various agencies over the last ten years have worked to develop freshwater sediment criteria. This report summarizes some of those efforts and describes the recent work within the EILS program designed to provide the necessary background information to produce freshwater criteria for Washington State.

METHODS FOR CRITERIA RESEARCH

The following sections report the methods we used to research criteria, gather sediment data from Washington State, and evaluate bioassays and chemical criteria approaches.

DEFINITION OF FRESHWATER

For this report, interstitial fresh water is considered to be of a salinity that can normally be found in the pores of sediments underlying Washington State rivers, lakes, streams, ponds, etc. We use a working definition which places the dividing line between fresh and brackish water at a salinity of one part per thousand. This definition is derived from the Water Quality Standards for Waters of the State of Washington, WAC 173-201-035 (2), General Considerations. At 10°C, the specific conductance of water containing one part per thousand salinity is approximately 1,000 millimhos/centimeter.

This definition is adequate for the present purposes because 1) none of the literature reviewed up to now has addressed the problem of saline, non-marine waters, including those reports which establish criteria and 2) as currently planned, the problem of estuarine and other saline waters may be addressed in later aspects of this work.

OTHER CRITERIA

Literature Search

To date, 98 reports have been read, abstracted, and indexed into a data base. All of the entries so far have dealt predominantly or solely with freshwater sediments with minimal estuarine or marine influence. Articles which deal exclusively with marine or estuarine environments are not included in the current bibliographic file. All citations within our database are listed at the end of this report in the bibliography.

The articles selected for the bibliography cover a broad range of sediment-related subjects. These include chemical criteria, evaluations of chemical criteria development methods, toxicity, bioassay and benthic infaunal studies, testing methods reviews and applications, analytical methods, and policy. New articles are being obtained weekly and added to the list as soon as they are reviewed. At present, the backlog is over 100 articles.

Articles of considerable significance, however, are closely scrutinized. These reports may receive extensive abstracting with emphasis on the more relevant points. Because of the extent of the subject covered and the difficulty of condensing such material in some reports, abstracts highlighting these issues are written and the reports designated for later, more in-depth review as needed.

The bibliographic database was designed to provide easy access to significant and relevant information contained in the reports. Part of this goal is achieved through the use of data codes to represent sediment characteristics, compounds, locations, contaminant sources, conventional analyses, etc. Table 1 lists the database structure showing the fields. Table 2 shows the codes for the fields, and lists the abbreviations for the sediment criteria bibliography. The abstract field summarizes the report, describes important findings and discusses possible applications to the sediment criteria project.

Other Researchers

A list of 29 persons involved in sediment criteria or related work who have been contacted for this study is shown in Table 3. Several major sediment programs currently in progress have also been identified and many of the primary contributors are included in this list. So far, everyone contacted has been helpful and willing to provide assistance and to maintain contact as our respective programs develop.

Although the Washington State project is still new, we are pleased to have been instrumental in providing useful information and direction to several other groups. It also appears that our bibliographic database is unique in its extent and accessibility. We may find it desirable to eventually distribute this system to other interested parties.

FRESHWATER DATA IN WASHINGTON

To compare potential criteria concentrations against current freshwater sediment quality in Washington, sources of freshwater sediment data were searched. Included in the search were Washington Dept of Ecology, USEPA, USGS, and US Army Corps of Engineers. The most data came from the database STORET (STOrage/RETrival) maintained by the USEPA. Sediment data on contaminants (metals, pesticides) in sediments from STORET categories ("stream or lake or canal or reserve or wetland"), were retrieved. With a custom program, STORET reports were reduced to a form that can be read by Lotus 123 in which each line is a site and columns are contaminant values. Other data were hand-entered into a worksheet with a similar format. Current plans call for keeping the Washington State data in a Lotus worksheet file with all pertinent data in separate fields (including location in latitude/longitude). Data with both biological parameters and chemical contaminants will be formatted in Puget Sound Ambient Monitoring Database that will allow transfer to other programs including SEDQUAL. An example of the data structure is shown in Table 4.

EVALUATION OF BIOLOGICAL MEASURES

Most sediment criteria efforts require measures of the biological effects of contaminants on biota. These effects are usually assessed through the use of laboratory bioassays, benthic analyses, and histopathological examinations.

No single test is universally applicable under all conditions, nor will any one test effectively, reliably and consistently give all the information desired. Instead, the use of a battery of tests is usually recommended by researchers working with contaminated sediments. Essentially, it involves the use of multiple tests such as microbial enzymes, benthic invertebrates, aquatic invertebrates, etc. Each test in the battery is scored based on its response to the sediment, toxicant or other factor. The overall sum of results indicates the level of toxicity of the test material. The battery has become a popular approach to toxicity testing. An important requirement for its use is a thorough knowledge of the range of responses of each test in the battery.

We have identified eight measures which we consider important in evaluating the utility of biological measures in sediment studies. These measures are: applicability, ecological significance, organism response, endpoint reliability, cost to use, standardization of protocols, ease of use, and organism availability. Each measure is discussed in detail below. We may also develop a weighting method to prioritize the value of each measure.

In the final report, we will evaluate each of these measures and display the results in matrix form. One axis of the matrix will show the various biological tests we consider important. The most likely candidates are those listed in the section entitled: Biological Tests for Use in Criteria Development. The other axis will show the eight evaluating measures.

Applicability

The applicability of a test organism to the development of criteria values depends on how well the results can be used to answer the specific questions at hand. For instance, a laboratory test organism should have similar requirements (food, temperature, grain size, etc.) as the organisms in the environment to which the criteria will be applied. Ideally, the test organisms should be the same as those actually found in the regions of interest. However, this is not always possible, since a considerable amount of testing is required to document an organism for toxicological studies and only a limited selection of organisms are used for bioassays.

The result is that some of the organisms considered for testing may not be ideally suited to the particular ecoregion or contaminants under study. Therefore, a concerted effort must be made to choose those available test organisms which most closely match, or are applicable to, the environment of interest. Since it would be unusual for one single variety of organism to be applicable to all environments in a region, or be sensitive to all likely contaminants, several kinds of test organisms must normally be chosen. Obviously, other evaluation factors, such as ecological significance and sensitivity, are closely related and contribute to the level of applicability.

Ecological Significance

It is a frequent goal of researchers that lab tests be designed so that they closely resemble conditions in the field. In addition, the test results should meaningfully reflect perturbations in the field. For example, the phosphorescent bacterium used in the Microtox test responds to some pollutants with decreased luminosity. The ecological significance of this decrease is not well understood. More problematic is the interpretation of increased luminosity.

Such complications apply to essentially all efforts which try to relate a specific biological response as an indication of the relative health of a whole ecosystem. For instance, numerous microbial enzyme assay procedures can show a response to specific toxicants. This response may indicate the presence of a contaminated sediment. However, the connection between the response and the actual health of the environment (however one wishes to define it) so far has frequently remained elusive. Such revelations will probably depend on the accumulation of large amounts of data. The battery of tests approach, discussed later in this report, was designed to assimilate several tests and funnel the results into a common conclusion.

Organism Response

The response of a test organism (what contaminants it responds to and at what levels) help determine its usefulness to any particular testing program. Such data are obtained largely through the tabulation and analysis of the results from numerous research projects and studies.

A test organism should respond to the contaminants of concern at an acceptable sensitivity and with a high level of efficiency. It should also be able to survive the known range of water and sediment characteristics it may encounter and still remain responsive to the tests. For instance, an organism which only shows a response under highly toxic conditions would have limited value under more moderate conditions. However, an organism which exhibits increasing mortality or behavioral responses under worsening conditions would likely be useable throughout a broad environmental range.

Endpoint Reliability

The degree to which the endpoint is unequivocal affects the overall reliability of the test. For example, mortality is an unequivocal endpoint. However, many tests have a less definitive endpoint such as one determined by a characteristic response to a specified stimulus, the response presumably being related to the toxicant in question. How definitive this endpoint is and how reliably it can be determined are both important factors.

Cost to Use

There are a growing number of bioassays, benthic study methods, and related practices which are specifically designed for or are being adapted to sediment toxicity evaluations. Each of these has various cost factors which are inherent to the procedure. For example, bioassays can be an expensive part of a study since a single analysis can cost several hundred dollars for organisms, lab help, supplies, reference standards, overhead, and data processing. When one considers the broad range of contaminants and sediment types which may have to be tested, each possibly using several different organisms, the potential costs of a project become obvious.

In trying to predict costs, it should be realized that biological measures are generally applied in two different ways. One application is the filling of data gaps, usually those resulting from the transfer of data from one project to another. The other application is the testing and use of criteria in the actual sediment testing. Both of these applications have associated costs which are a part of almost any development project.

Standardization of Protocols

Protocols for biological measures used for sediment criteria must be standardized in order for the results to be consistent, comparable and usable. This requirement is based on the fact that the numerous groups involved in criteria development, especially those doing bioassays and benthic studies, need to produce data of a comparable nature. With reduced standardization, cross-reference of test results will become more difficult. Tests should be standardized where possible.

Ease of Use

The ease with which a test can be done reflects the time needed to perform the test, the equipment used, the extent to which personnel need to be trained, and the ultimate cost. Ease also determines how many samples can be run within a specified period and helps determine the ultimate size of the resultant dataset.

Organism Availability

The availability of the test organisms is important since a readily accessible supply of adequate numbers of animals in good health prevents delays. Some test animals are generally available only at certain times of the year, which limits their usefulness. Additionally, some organisms are neither maintained nor raised by most labs and must be gathered from the wild for each test.

EVALUATION FACTORS FOR CRITERIA DEVELOPMENT METHODS

Several organizations are developing freshwater sediment criteria. It is likely that the Washington State project will rely on one or more of these efforts. We will use the factors described below to evaluate the results of each of these projects to determine if they can be applied to Washington. Similar to the procedure for the evaluation of biological measures described earlier, we plan to use a matrix and possibly a weighting factor system. The five factors we propose applying to the evaluation of the development methods are: applicability, defensibility, cost of development and use, size of data set, and ease of development and use.

Applicability

It is important to determine whether results from the various criteria development projects will be directly transferable to Washington sediments. Some values may have to be specifically adapted before they can be applied to the Washington environment. Application of any particular method or set of results will be based on parameters such as the chemicals of concern and their concentrations, sediment types, indigenous fauna, organic content, salinity, climate, history, extent of protection needed, etc.

Defensibility

The defensibility of a set of criteria is the result of how clearly it can be shown that the criteria reliably establish a chemical or biological point or points that satisfactorily protect the environment. Defensibility requires a high level of reliability in predicting biological harm. Reliability and defensibility of criteria should be validated under a range of field conditions. Since we may adopt criteria that derive from several sources and methods, the levels of defensibility could vary from one set of values to another.

Cost of Development and Use

The dollar cost of programs used to develop and use criteria can be sizeable. Starting from the beginning can be an expensive and complex task. By adopting previously developed methods and criteria values we can substantially reduce expenses. As with the biological measures, there are two main sources of expense which must be considered.

The first is the cost of filling data gaps such as extra field work, bioassays, investigation of new test organisms, finding additional sources of information and transferring them for in-house use, data analysis, validation, etc. The second cost is that of actually using the criteria. These expenses derive from the testing of sediments to determine if they fall within the accepted criteria ranges. Factors in this category include how many tests are required, which organisms to use for bioassays, chemical and data analyses, etc.

Size of Data Set

The size and type of data set used in setting criteria essentially determines the method which can be used, as well as the completeness of the results. Methods which require intensive evaluation of benthic epifauna and infauna, such as the AET, require significant field efforts to produce the necessary data. As an example, the EqP approach is more theoretically based and does not require such extensive use of field derived information. It does use, however, an extensive toxicological data set, data on equilibrium partitioning coefficients (usually empirically derived) and, in some cases, interactive effects data.

Additionally, data obtained for the derivation of criteria using one method can sometimes be used to augment and verify criteria from alternate methods. For instance, the EPA is considering using the screening level concentration (SLC) approach, which is field based, as a check on EqP results (63)*.

Ease of Development and Use

Certain methods of criteria development are easier to apply and use than others. For our purposes, we may use a method which has been previously established and criteria derived, such as AET (Apparent Effects Threshold), EqP (Equilibrium Partitioning) or SLC (Screening Level Criteria). The decision to use one or more criteria-setting methods will depend on the theoretical basis of the method itself, the extent of the available data, computation complexity, quality control, transferability of results, chemicals of concern and concentration levels, types of bioassay tests used, sediment diversity, etc.

* Refer to the Bibliography for all numbers in parentheses.

FRESHWATER SEDIMENT CRITERIA STATUS

The following is a summary of some of the other projects we have found where freshwater sediment criteria development or related work are being pursued. Even though interim criteria values have actually been established from some of these projects, none of the values are absolute and efforts at refinement and revision seem to be ongoing. Other projects are still in the development stage and have not yet released their results.

CANADA

In February 1990, the Water Resources Branch of the Ontario Ministry of the Environment published the "Provincial Sediment Quality Guidelines" (30). These guidelines include values for 10 metals, 3 nutrients, 22 chlorinated hydrocarbons (pesticides and PCBs), and Total PAH. Values are given for three levels; the No-Effect Level, the Lowest Effect Level, and the Limit of Tolerance. The values derived are largely based on the screening level concentration approach, or SLC. However, to determine the No-Effect Levels the equilibrium partitioning method was used for the non-polar organics and the background approach was used for metals and polar organics. Our initial copy was obtained from Dr. Ian Orchard of Environment Canada.

Dr. Alena Mudroch of the Canada Centre for Inland Waters (personal communication) disagrees with the notion of a single value for criteria. This argument seems to be based largely on the variable geology of the Great Lakes. Her group is helping develop the Canadian sediment guidelines. It will be at least 1993 before the project is completed.

The guidelines developed through these efforts have already been useful to the Washington sediment criteria project. We have made frequent reference to them as being one of the few reasonably complete lists currently available.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

A publication dated November, 1985, titled "Report of the Technical Subcommittee on Determination of Dredge Material Suitability for In-Water Disposal", (35) was issued by the Wisconsin Department of Natural Resources. It gives interim criteria and guidance criteria for in-water disposal using a background approach, the mechanics of which are explained later.

Although problems inherent to this method were acknowledged, it was used with the recommendation that the criteria remain flexible. It provides values for PCB's, 10 metals, 8 pesticides, and oil and grease.

This is the only project located to date based on the background approach. The work was done prior to the development of more advanced methods and the values were intended for interim purposes only. The Department recently indicated it was using the EqP method and Wisconsin water quality values to update the criteria. Information has been requested from our contact, Linda Talbot.

GREAT LAKES

A massive effort is currently underway in the Great Lakes region to develop freshwater sediment guidelines, largely for fisheries protection, through the Assessment and Remediation of Contaminated Sediments program, or ARCS. This undertaking involves researchers from universities and agencies in the region. Although we haven't received much information because the work is not yet finished, we do have several draft proposals which give the basic goals of the effort (71)(72)(73).

This project involves an ambitious sampling program complete with chemical analyses, as well as benthic and bioassay studies. Sampling sites will be designated as either Reconnaissance, Primary Master, Priority Master, or Extended Priority Master Stations, with the complexity of the investigations increasing respectively. Different methods will be used to establish guidelines including AET, EqP, and possibly others. The results will then be compared. A final report is expected in November, 1990.

We have requested an update on the project from one of the chief investigators, Dr. Chris Ingersoll. Dr. G. Allen Burton, located at Wright State University, is another active participant in this project with whom we are maintaining contact. Because of its size, it is likely that data from this project will have considerable transfer value to the Washington effort.

ENVIRONMENTAL PROTECTION AGENCY - REGION V

A recent newsletter from EPA/ORD (90) discusses a study on the Lower Fox River and Green Bay, Wisconsin being conducted through the Duluth, Minnesota Environmental Research Lab. Our contact there is Gary Ankley. This is another ambitious project with multiple objectives including analysis of benthic community structure, toxicity of bulk and resuspended sediments, chemical analyses, carcinogenic and mutagenic effects on fish, avian toxicity, and model development. The toxic effects of ammonia are a primary emphasis. The data will be used to evaluate and develop methods for setting sediment criteria. We will maintain contact on this project through Dr. Ankley. As results become available, we will review them for transferability to the Washington project.

TRINITY RIVER PROJECT

This work is being conducted through the University of North Texas under the direction of Dr. Ken Dickson. The study area is the Trinity River near Dallas. It is described as having natural sediments with industrial input. The project includes studies of benthos, fish, macrobenthos, lab bioassays, spiked bioassays, and analyses of chemical and physical parameters. It appears to be a highly detailed and well planned operation which should produce a significant volume of data. At present, there are no plans to produce criteria. Data and reports should be forthcoming. We will review the results, with emphasis on the bioassay and benthic data, to determine how much can be transferred to the Washington project.

EUROPE

Our one contact in Europe is Dr. Tiedo Vellinga in Rotterdam, Holland. His work focuses largely on setting of criteria for the disposal of dredged material. Since contaminant loads seem to be higher in that region of Europe than in Washington State, he claims that the criteria will probably be higher also. He did not go into detail regarding specific reasons for this statement. We are awaiting reports and additional references.

OREGON

Gene Foster at the Oregon Department of Environmental Quality stated that they have set criteria using equilibrium partitioning since there were not enough site specific data for the AET method. This is apparently a tiered approach similar to that used by the Army Corps of Engineers (see below). The Oregon State criteria have been issued for public comment and a copy should be arriving soon.

U.S. ARMY CORPS OF ENGINEERS - WES

Dr. Tom Wright, of the Waterways Experimental Station in Vicksburg, Mississippi, has supplied us with documentation on the approach the Corps uses to determine the suitability of dredged material for disposal.

The Corps has a tiered testing program based on 1) reason to believe there is contamination based on existing information, 2A) bulk sediment inventory - reason to believe that elevated levels of contamination may exist, 2B) elutriate analysis (chemistry), 3A) acute bioassay tests and 3B) bioaccumulation tests (27).

In a tiered approach, only tests which are shown to be required are performed. The Corps favors this approach rather than the use of a single numerical value for criteria so they can remain flexible. Dr. Wright feels this concept encompasses the best of the AET approach because it makes use of an amphipod bioassay, which he claims is the most sensitive test of the AET series.

Regarding Washington freshwater sediment criteria, there has been discussion that, as a preliminary move, biological testing similar to that used by the Corps may be implemented before the issuance of more definitive numerical criteria. Whether numerical values would then entirely replace the biological testing requirements would be determined later.

TRANSFERABILITY OF DATA

Numerous ongoing efforts to produce freshwater sediment criteria imply the future availability of several sets of results for us to adapt to our use. Our main concern is the extent to which these data will be transferable to outside the area of origin, if at all.

Many variables must be considered before criteria are transferred from one project or location to another, especially when using a method which relies heavily on field data such as the AET. Such variables are essentially those mentioned earlier under "Applicability" as a measure of criteria evaluation. The problems of transferability of criteria are well recognized. Most likely, the best solution is a careful comparison of ecosystems and other available data to determine if the results of a particular project are applicable elsewhere.

BIOLOGICAL TESTING

A number of biological tests are available for use in freshwater sediment toxicity testing. Many of the commonly used tests are listed in the top portion of Table 5, adapted from the Great Lakes ARCS Program (73). Others, mainly those based on microbiological characteristics, are then listed as "additional tests". It is not anticipated that all the tests available for the ARCS Program will produce usable data, and a revised list (shorter, presumably) has been requested from Dr. Ingersoll. It is a good example, however, of the various parameters and methods which can be used.

Discussions with various researchers as well as published reports regarding appropriate tests of sediment quality have invariably emphasized two points. The first is that it is best to use the standardized, well documented, "non-trendy" tests which will produce results comparable to those of other groups. Such tests may also be accepted in regulatory context because they may be more technically defensible than those which are less well- known.

The second concept is that it is essential to use a battery of tests, described earlier. This conclusion is based on the fact that no single method seems to satisfactorily elucidate the biological effect of a contaminant in freshwater sediment, especially when multiple contaminants are present. Differing sensitivities to different contaminants among test organisms appear to be responsible for this effect. Therefore, knowledge of the standard responses of the various organisms used will help bracket the most likely range of contamination present.

Several reports have been reviewed and added to the bibliography which document the use of the battery of tests. They are usually based on a variety of microbiological responses in addition to chemical analyses, invertebrate bioassays and benthic enumerations. Some tests, especially those based on microbiology, do not rely on lethality as an endpoint indicator. Instead, they use an analog response, such as light evolution or color development, to permit sediment categorization through the establishment of response levels characteristic of successive levels of contaminant concentration.

Organisms which live predominantly in the water column may be useful as indicators of sediment quality. Such tests are applicable if the sediment contaminants are naturally transferable to the water column. Transfer is generally dependent on factors such as contaminant solubility and sediment agitation either by physical forces or the local infauna.

A report by Gary Ankley on the Lower Fox River and Green Bay, Wisconsin (89) mentions the centrifugation of bulk sediment samples to obtain pore water for toxicity tests on fathead minnows. One value of using an organism such as Pimephales promelas is that it provides a good reference for other tests which may not be well documented. Equally important, the method exposes sensitive water column organisms to pore water contaminant levels which may be higher than those found in the water column itself. The same organism can act as an indicator and as a reference for both the aqueous and the sedimentary environments.

Species particularly suitable for sediment toxicity tests are the standard, well-documented test organisms for which results are defensible and can be compared between similar efforts. This approach mediates against the use of the more experimental techniques often discussed in battery of test reports. For this reason we recommend focusing on well-established tests and using developmental methods only in situations where they appear to be the best or only way to resolve issues critical to the development of criteria.

Based on information gathered from both written reports and discussions with researchers in the field, the biological tests listed below should be considered for use in setting Washington State freshwater sediment criteria. Whether they are actually recruited for application specific studies depends on the type of study, the conditions of the study, contaminants present and their concentrations.

BIOLOGICAL TESTS FOR USE IN CRITERIA DEVELOPMENT

Daphnia magna, a cladoceran or water flea, is an organism representative of the planktonic fauna used in survival tests to establish toxicity (7). It is considered to be more sensitive than many of the other organisms used in contaminant tests (31) (64).

Ceriodaphnia dubia, another planktonic cladoceran but smaller and with a shorter generation time than D. magna, can be cultured using similar techniques. It is now widely used in aquatic toxicity testing and as a sensitive indicator in sediment assessments (15). There are usually two endpoints considered in toxicity testing. The endpoint for acute tests is lethality; for the chronic tests it is both lethality and neonate production in surviving females (62). Burton et. al. consider it to be a more sensitive indicator species than Hyalella azteca (58).

Pimephales promelas, the fathead minnow, is commonly used in fish bioassay tests and to test the survival and reproductive effects of contaminants in the embryo-larval and juvenile stages (17)(19).

Hyalella azteca This crustacean (amphipod) and epibenthic detritivore, has a short generation time, is easily cultured or collected, and toxicity tests provide data on survival, growth and reproduction. It is frequently used as an indicator of sediment contaminants. Interactions with benthic material are shown by the fact that it consumes bacteria and algae from ingested sediment particles (22). Nebeker has demonstrated its survivability and usefulness in both freshwater and estuarine environments (8).

Chironomus riparius (Diptera: Chironomidae), a midge, is fairly large, has a short generation time, and the larvae are sediment burrowers. It is considered to be sensitive to many sediment contaminants (22). The test is not generally available from labs in this area.

Chironomus tentans (Diptera: Chironomidae), a midge, is fairly large, has a short generation time, is easily cultured, and the larvae are sediment burrowers. It is used in both the larval and adult stages to test for survival (7) and is considered to be sensitive to many sediment contaminants (22). The test is not generally available from labs in this area.

Hexagenia limbata, a burrowing mayfly nymph, is a representative organism of the sub-surface fauna. Mortality studies of this organism are used to help determine sediment toxicity (17). The test is not generally available from labs in this area.

Selenastrum capricornutum, a freshwater algae, is used as food substrate for daphnids and related organisms (7). It can be valuable in the study of contaminant bioaccumulation in the food chain. It is also used in growth inhibition tests which show the deleterious effects of toxicants through a decrease in biomass production.

Photobacterium phosphoreum, a bacterium used in the frequently-cited Microtox bioassay procedure. Atkinson (57) suggests an examination of the variations in responses of this organism in oxic versus anoxic environments, a situation highly relevant to the sediment criteria project.

Future literature research will tend to focus on finding tests using infaunal benthic organisms such as the oligochaete, *Lumbriculus variegatus*, (mentioned by Ankley in a recent draft report) which live in sediments and are therefore exposed more directly to contaminants associated with both sediments and pore water than epifaunal or water column organisms. Although infaunal organisms are an important part of many aquatic studies, they do not seem to have been as well examined for their use in sediment bioassays as other organisms.

We also suggest the use of microbiological tests in addition to Microtox. Several experiments using multiple microbiological tests have shown sensitivities and response patterns different from those given by Microtox. As mentioned earlier, these various response patterns are useful in delineating the extent of sediment contamination. Microbiological tests have also been shown to have a greater range of responses than those using macrofaunal organisms. This permits greater discrimination among sites (58). Listed below are some of the microbiological tests which appear to be most promising.

A) b-galactosidase because its response to contaminants was highly correlated to biological, chemical and physical stream parameters (21)(46).

B) b-glucosidase and electron transport system assays because they were also correlated to biological, chemical and physical stream parameters, although to a lesser extent (21).

C) ATP-TOX because it is at least as sensitive as Microtox and adds life cycle tests to the evaluation (44)(59)(75).

D) Modified Ames Salmonella assay with the addition of the S-9 microsomal fraction because of its ability to detect mutagenic contaminants (79)(80).

One of the immediate goals of the project is to accumulate more information on the use of these tests and their respective response patterns to various types and concentrations of contaminants.

BENTHIC INFAUNAL MEASUREMENTS

Several different measures are designed to determine effects of contaminants on endemic macroinvertebrates. The most direct measurement is the reduction of endemic populations. Other measures include indices which attempt to represent the diversity of the benthic community. Effects on the community are then compared based on the principle that stressed communities often exhibit decreased abundance and/or diversity. The following is a short list of potential measures of indigenous community diversity and abundance.

Abundance of Major Taxa

The Puget Sound marine AET approach relies on counts of animals in three major taxa (Polychaeta, Mollusca, and Crustacea), and the total individuals of all benthic macroinvertebrates (98). These measures are then compared to control and/or reference areas.

The main advantage of this method is low relative cost to identify animals to class or phylum. Another advantage is error in identification at the high taxonomic level is unlikely. In a limited test in Puget Sound, PTI (98) examined taxa at the genus or species level and compared resulting AET's (Apparent Effects Threshold; see criteria models section following) to higher taxa AET's and found they were similar in magnitude.

Abundance of Separate Species

The enumeration of individual species is the cornerstone of the Screening Level Concentration method (see later section). Presence and number of all species are identified. This method is comparably expensive and reflects the time and expertise needed for individual identification. Other disadvantages include increased error rates in identification. One major advantage is that less community structure information is lost, thereby preserving data from one of the most sensitive measures.

Indices

Diversity indices are designed to reflect community structure. Biotic indices are based on indicator organisms that respond predictably to contaminants in an ecosystem. Washington (96) examined 42 macro-invertebrate diversity, biotic and similarity indices for their theoretical and practical ecological application in aquatic ecosystems. From a review of 18 diversity indicies (including Shannon-Weaver, Brillouin's, and evenness), he concluded that the most common indices that are based on information theory (H and H') lack biological relevance. The only diversity indices he considered appropriate were Simpsons D, Hurlberts PIE and indices based on the theory of Runs (SCI and TU). The nineteen biotic indices are highly specialized to reflect one type of water pollution, usually organic pollution. Chutter's and Chandler's biotic index were favored. Of the five similarity indices examined the percentage similarity index (PSC) and Pinkham and Pearson's index (B) appear most favored for aquatic systems.

CRITERIA MODELS - ADVANTAGES AND DISADVANTAGES

Various methods for establishing sediment criteria have been devised. Some of these, like the equilibrium partitioning method (EqP) are theoretically based. Others, like the apparent effects threshold method (AET) are empirically based. AETs have been applied extensively to Puget Sound. The AET approach is the keystone of the Interim Sediment Quality Chemical Criteria issued by the Washington State Department of Ecology in 1989. There are also several ongoing projects evaluating freshwater sediments using the AET. The EqP method has had limited application to date. It may be more frequently used in the future because of a high level of support from the EPA. Others, like the screening level concentration (SLC) and the background approaches have valid points but are less popular.

Chapman (88) believes that the AET and EqP methods seem to be the more appropriate approaches to use at present. However, groups using these methods often have access to very large databases, a situation not necessarily true for the Washington project and which may influence our future decisions.

Brief descriptions and the advantages and disadvantages of the more frequently cited methods for establishing criteria are given below (27)(35).

BACKGROUND

The background approach compares sediments from what are considered to be background sites to those from the supposed or expected contaminated sites. It is sometimes referred to as the antidegradation approach since it requires sediment components to be restored to their natural levels. The method is inherently simple in that concentrations of contaminants in sediments which are above the background level, or some function thereof, could be considered to be unacceptable.

Advantages:

It may be the only means of setting criteria in areas where there is a lack of adequate data relating chemical concentrations to sediment toxicity.

In many areas, the data needed for setting criteria based on this approach are already available.

It avoids the need for toxicity testing and providing mechanistic chemical explanations.

It could be used to provide a base level for cleanup requirements for metals and some naturally occurring organics.

Disadvantages:

Many of the criteria established this way would be site specific and probably difficult to transfer.

There would probably be problems associated with technical defensibility because of a lack of cause and effect relationships as required for water quality criteria.

Actual biological toxicity questions are not addressed in the method so there is no real maximum, safe level established.

It does not distinguish bioavailable chemicals from those which are not.

Synthetic chemicals are inherently not present in the background data because sediment deposition predated the manufacture of the compound of interest. Although it is not inherently a disadvantage to set criteria at the analytical detection limit by default as with synthetics, the values could be unnecessarily low as a result.

SCREENING LEVEL CONCENTRATION (SLC)

The SLC approach is field-based and uses the survivability of benthic infauna and epifauna to determine the highest concentration of a particular contaminant which can be tolerated by 95% of the species expected to be present.

The first step in determining SLC criteria is to find a value known as the SSLC, or species screening level concentration. This goal is accomplished by finding the level of contaminant where 90% of the sites contain the particular individual indicator species. Such a value is set for each selected species and for each contaminant. The SLC itself is then determined by comparing SSLCs with contaminant concentrations to find the concentration value above which 95% of the SSLCs occur. Minimum requirements for this method have been estimated at 20 stations for each SSLC, 20 taxa for each SLC, a contamination gradient and similar taxonomy at each station (60).

The method relies on three basic assumptions. These are: A) factors other than contamination can be disregarded if the database is large enough, B) there is no biological effect from contamination if a species is present, and C) no assumptions are made concerning mechanisms of interaction.

Chris Zarba (EPA), who administered the development of the SLC by Battelle, is concerned about use of the method because it was designed only for rapid screening purposes and as a quick check on criteria, not for setting them.

Advantages:

It conforms to EPA water quality criteria goals.

It is usable with any chemical contaminant.

It can make use of existing databases and methodologies.

No assumptions regarding mechanisms are required.

Disadvantages:

A large database is required including taxonomy to the species level.

SLC values are affected by the range of concentrations of contaminants and numbers of organisms used.

No species selection criteria have been established, giving a variable list of representative species.

It does not separate out single contaminants from contaminant combinations.

Unmeasured toxic compounds could strongly influence the results.

Procedure may incur high costs because of taxonomy requirements.

SEDIMENT QUALITY TRIAD

The triad approach uses three interrelated components to derive criteria. These are A) sediment chemical concentration analyses, B) sediment toxicity bioassays, and C) benthic community assessment. It independently measures sediment contamination, sediment toxicity, and biological alteration to assess sediment quality. Chemical concentrations used to derive criteria are determined to be at levels either below which biological effects would be minimal or above which biological effects would be severe. An assumption required for this method is that a large database smooths out chemical and sediment variables and unknowns.

Advantages:

Natural variability and laboratory influences are differentiated with regards to toxic effects on each of the three separate measures.

No mechanistic assumptions are considered or required regarding toxic effects on organisms.

Both acute and chronic effects are included in the criteria which can be developed for any measured contaminant.

Disadvantages:

No standardized statistical criteria for the triad approach has yet been set, although a number of possible approaches do exist.

A large database is required.

Unmeasured toxics could have a strong influence on the results.

Changes in sediment characteristics can simulate the toxic effects of chemical contaminants (87).

APPARENT EFFECTS THRESHOLD (AET)

The AET approach, with similarities to the triad, uses sediment chemistry concentrations and at least one bioeffects indicator to determine the lowest contaminant concentration level above which statistically significant biological effects are always recorded. The primary use of the method is that it identifies contaminant levels which are related to adverse biological effects. It uses site-specific indicators such as bioassays and benthic infaunal enumerations as the data base. The method also assumes that a large database will smooth out irregularities from sediment mixture interactions, synergism, additivity, etc. and that appropriate indicators can be determined from field and lab data.

Advantages:

There are no mechanistic requirements relating to the toxic effects of contaminants on organisms.

Criteria can be developed for any measured contaminant using any bioindicator where statistically significant effects are shown.

The results are based on noncontradictory evidence because adverse effects are always found above the sediment quality values.

Addresses synergistic and antagonistic interactions.

Disadvantages:

A large database is required.

Results can be influenced by unmeasured toxicants.

Biota may not be properly protected from chronic effects if bioindicators are solely measures of acute toxicity.

The system generally cannot separate the individual versus combined effects of contaminants.

Changes in sediment characteristics can simulate the toxic effects of chemical contaminants (87).

EQUILIBRIUM PARTITIONING (EqP)

The EqP approach is based on using contaminant concentrations in the sediment to estimate concentrations in the interstitial water. Results are compared to water quality criteria to determine sediment toxicity. The method is currently applicable only to nonpolar, nonionic organics. The resulting values describe the equilibrium partitioning between the sediment organic matter and aqueous interface based on organic-carbon-normalized partition coefficients. The behavior of polar organic compounds and metals are not as yet well described by this method. However, a recent EPA publication (63) and an article on metals normalization using acid volatile sulfides (43) show promise in these areas. Use of the term EqP generally refers to sediment-water equilibrium partitioning, although a related method known as sediment-biota equilibrium partitioning (35) has also been derived. Current EPA plans are to use the SLC as a field check for EqP derived criteria.

The equilibrium partitioning approach is complex and highly theoretical. It is only briefly described here. We will present a more in-depth explanation of the methodology, as well as an update on recent advances, in the second quarterly report.

Advantages:

Toxicological data already exist in the EPA (or other) water quality criteria, although they are of varying age and quality.

Definition of the theoretical basis is improving, and conclusions are amenable to field and lab verification and refinement.

Disadvantages:

Water quality criteria must exist for a compound before the method can be applied.

It relies only on contaminant de-sorption, not ingestion or contact.

Equilibrium may not exist between solid and aqueous phases in the environment.

EqP is not currently structured to address interactive effects of multiple chemicals.

BIOASSAY

The bioassay approach normally uses a laboratory setting to attempt to simulate field conditions, although there are occasional reports of bioassays being done in-situ in streams, lakes, etc. The sediments are usually analyzed to determine what potentially toxic chemicals are present and in what concentrations.

In the bioassay method, benthic and/or water-column organisms are exposed to contaminants either by direct exposure to the sediment or through transfer to the water by solubilization or related processes. The influence the contaminants have on the organisms is determined through the observation of effects such as death, failure to reproduce, deformity, response, growth, etc. *Daphnia* and *Ceriodaphnia* are the common water column test organisms, while *Chironomus* (which inhabits near surface sediments) and *Hyalella* (a burrower) are often used in direct contact sediment tests. Also used are fathead minnows, green algae and duckweed.

Several different methods exist for many of these organisms depending on the concentrations of contaminants in the sediments, thus determining whether one tests for acute or chronic values. When results from the contaminated sediments are compared to reference sediments, the biological effects of the sum total of the sediment contaminants can be ascertained (88).

Advantages:

Methods are similar to those used to develop water quality criteria thereby facilitating technical acceptance.

Problem sediments can be identified.

Toxicological data for chemical mixtures in sediments can be empirically derived.

All contaminant exposure routes are accounted for.

Disadvantages

May not be able to provide chemical specific data and can be influenced by unmeasured and covarying contaminants.

SPIKED-SEDIMENT BIOASSAY

The spiked-sediment bioassay approach makes use of sediments which have been artificially contaminated with the compound of interest. As with the bioassay approach, test organisms are then exposed to the sediment and/or overlying water and examined for toxic effects. The method assumes that laboratory derived contaminated sediments will behave in a manner similar to those occurring naturally and will give similar bioassay results. It is the only method capable of producing dose-response relationships and, at least in theory, should provide a simplified means of deriving criteria. We have reviewed several excellent papers which reported spiked-sediment bioassays that determined acute and chronic toxicity levels of metals (11)(29)(31).

Although the spiked-sediment bioassay has been considered for use in establishing criteria, it is labor intensive and costly. This situation is unfortunate since the method provides the only currently available means of empirically determining the extent of synergistic and antagonistic contaminant interactions. We may use the procedure to check against field data and to develop criteria for contaminants or organisms which are otherwise unavailable.

Advantages:

Interpretation of results is straightforward.

Addresses synergistic and antagonistic interactions.

All contaminant exposure routes are accounted for.

Does not assume specific mechanism of interaction.

Disadvantages:

Spiking/dosing techniques are not well established.

A complete study of all possible contaminants, sediment types and chemical interactions would be very large and expensive.

Chronic effects may not be apparent depending on the type of bioassay used.

Numerous organisms and sediment types must be tested.

Results could be erroneous because of the presence of unknown contaminants in field-collected sediments.

Artificially-spiked sediments may not behave in a manner identical to those occurring naturally.

CONCLUSIONS ON APPROACHES

The work summarized above indicate that several approaches are being used to establish freshwater sediment criteria. The major effort being pursued by EPA on the EqP method and the acceptance given the AET method by groups such as ARCS indicate the favored status of these two approaches.

However, the SLC approach is also a good candidate because it is relatively easy to use, especially for the production of interim values as was done by the Ontario Ministry of the Environment. Since it is an effects based approach, it does not require a complex theoretical justification like the EqP. This fact alone simplifies its use and makes it highly amenable to the Washington project where it can be used to fill data gaps in "imported" criteria. Finally, even the background method has merit, especially for metals, and is actually used in parts of the Canadian guidelines.

We believe it is too early to decide on a definite "best" method at this time. It is quite likely that, as seems to be done with other efforts, the Washington criteria will be based on the results of several methods rather than just one. The continued accumulation of sediment data and criteria values from other projects, once evaluated using the procedures described earlier, will help determine which method, or methods, will produce the most satisfactory results.

WASHINGTON FRESHWATER SEDIMENT DATA

By comparing current freshwater sediment quality in Washington with data and criteria from other areas, the extent of sediment contamination can be estimated.

SOURCES OF DATA

Data on contaminants in freshwater sediment exist in many different forms in many locations. Following is a short review of the sources and condition of the data. With the exception of Department of Ecology data, none of the sources have bioassay data associated with contaminated sediments data.

STORET

Storet provided the most data with over 336 records of freshwater sediment sites that were analyzed for some chlorinated pesticide (primarily congeners of DDT). Metals were reported from 130 sites in Washington. No PAH were reported in freshwater sediment. Nationally, only 18 sites reported one or more PAH. STORET reports were useful once translated to a common format. Unfortunately, the quality control information is rudimentary and limited to qualifiers that signify limits of detection. The advantages of using STORET for this work is that the data is easily gathered. Among the disadvantages are the lack of quality control information and the biased nature of the sampling scheme; that is, STORET data are often from areas that are contaminated or are suspect of having a problem.

Dept of Ecology

Washington Department of Ecology has conducted several studies of freshwater sediment. These studies are not centrally listed and the data not yet centrally archived. As these studies are found, they are noted for entry into the record of freshwater sediment studies. Approximately 10 studies have been entered or will be entered into a worksheet. If biological data are available along with chemistry data, they will be entered into Puget Sound Ambient Monitoring Program (PSAMP) format.

USEPA

Because STORET is their creation, EPA supports it avidly and enters much of its and others data into it. For this reason, we have not yet sought data directly from EPA.

USGS

USGS has data, not yet entered into STORET, from the Yakima River Basin. These data (approximately 25 sites) will be incorporated into analyses but will not be published separately until USGS publishes them in a data report. Other USGS data are still being sought.

US Army Corps of Engineers

USACE has some freshwater sediment data from work in Lake Union. Data and reports from additional locations are being pursued.

STORET from Idaho and Oregon

Freshwater sediment data from Idaho and Oregon have been gleaned for comparison to criteria and to Washington concentrations. The number of records were comparable to those found for Washington with the exception of Idaho metals where over 2250 records were collected, most of them from the middle 1970's.

Analysis

In the next phase of this work the freshwater sediment data from Washington will be analyzed to determine problem areas and problem chemicals. One analysis will plot the cumulative frequency distribution for each chemical to illustrate the median and the 95 percentile concentrations for that chemical. Several potential criteria will be plotted against these distributions. Figure 1 shows the cumulative percent of total DDT in freshwater sediments in Washington State along with the Canadian Limit of Tolerance (LOT)(30), one potential criteria. Note that all samples fall below the LOT. These distributions can be compared to regional and national data.

Problem areas can be discerned based on historical analyses. Locations of copper sampling sites are shown in Figure 2. The sites that exceed the Canadian LOT for copper are highlighted. Certain obvious problem areas appear for copper. These types of analysis and summaries will extend through most organic and inorganic chemicals found in Washington freshwater sediments.

These analyses of median and 95% concentrations in the state and locations of high concentrations, coupled with several potential criteria, will help highlight pollutants of concern in freshwater sediments.

RECOMMENDATIONS

This progress report describes initial efforts aimed at developing criteria for freshwater sediments in Washington State. Based on the material discussed in this report, a plan for the ongoing development of criteria has been drafted. This workplan identifies the overall objectives for this effort as well as specific interim products and outputs which will be generated during the process of meeting the objectives. The following workplan outlines the second phase of the Washington State Freshwater Sediment Criteria Project.

FRESHWATER SEDIMENT GUIDELINES DEVELOPMENT WORKPLAN, STEP 2

INTRODUCTION: The primary goal of the freshwater sediment guidelines development project during step 2 of the Workplan is to produce an initial concordance combining information from bioassays, benthic studies, imported criteria, Washington State freshwater screening levels, and Washington State chemicals of concern. After appropriate peer review, the results of the concordance analysis will be applied to the development of the Workplan, Step 3. The timetable for the completion of the Workplan, Step 2 and the issuance of a final report is March 1991.

PROCEDURE: Reference to Diagram 1 shows the assignment of Task numbers to individual goals or sets of goals for Step 2 of the Workplan. Individual tasks are defined and their approximate due dates given.

Task Number 1

Obtain criteria and sediment guidelines for freshwater sediments from sources such as Environment Canada, Great Lakes Harbors, Great Lakes Areas of Concern, EPA, Chicago Guidelines, Trinity River project (Texas), etc. Maintain contact with sources of information such as Drs. Ankley, Burton, Dickson, Ingersoll. Periodically review articles and publications which might lead to sources of sediment values. Due date: September 1990.

Task Number 2

Obtain data on chemicals of concern emphasizing those found in Washington State freshwater sediments. The list of chemicals includes priority pollutant metals, organics (especially wood preservatives), chlorinated pesticides and related compounds. Requires review of all available sources of information on contaminated Washington State sediments. Due date: March 1991.

Task Number 3

Obtain data on benthic and bioassay studies from Washington State projects such as Quendal-Baxter, Lake Union, etc. as well as out-of-state sources (see list for Task 1). Finalize the applicability and interpretability of the data with a brainstorming session composed of representatives from SMU and EILS. Due date: September 1990.

Task Number 4

Obtain bioassay data from both Washington State and other sources (see Task 1) with emphasis on information relating specifically to chemicals of concern and test organisms indigenous to regional sediments. Due date: September 1990.

Task Number 5

Select appropriate organism or organisms, including test endpoints, for in-house or contracted bioassays using specific chemicals of concern. Use contaminated sediments from local sources, or prepare spiked sediments as needed. Organisms should be representative of, or be actual residents of, regional freshwater systems. Due date: November 1990.

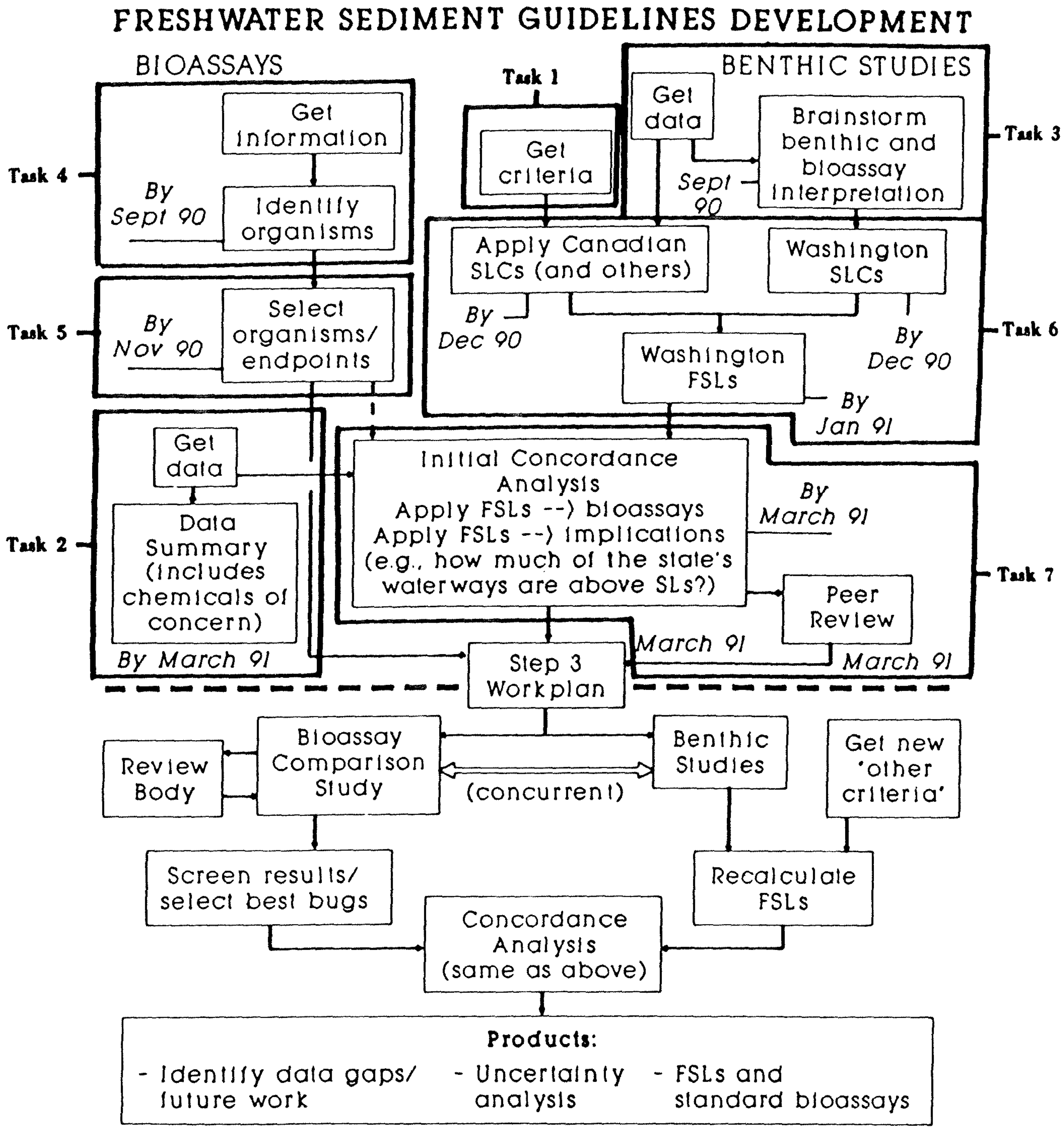
Task Number 6

As a result of brainstorming session in Step 3, produce Washington State screening level concentrations. Apply these SLCs, Canadian and other SLC values, as well as other types of criteria or guidelines, to produce Washington State freshwater screening levels. Due date: January 1991.

Task Number 7

Produce initial concordance analysis based on the application of the derived Washington State freshwater screening levels from Task 6 to the bioassay results from Tasks 4 and 5. Use the resulting implications to determine how much of the State's waterways are above the screening levels. Submit concordance for peer review. Due date: March 1991. Following revisions, proceed to development of the Workplan, Step 3.

Diagram 1


FRESHWATER SEDIMENT GUIDELINES DEVELOPMENT
BIOASSAYS
BENTHIC STUDIES
Task 1
Task 2
Task 3
Task 4
Task 5
Task 6
Task 7
Get information
Identify organisms
By Sept 90
Get criteria
Get data
Brainstorm benthic and bioassay interpretation
Sept 90
Apply Canadian SLCs (and others)
Washington SLCs
By Dec 90
By Dec 90
Washington FSLs
By Jan 91
Select organisms/ endpoints
By Nov 90
Get data
Data Summary (includes chemicals of concern)
By March 91
Initial Concordance Analysis
Apply FSLs --) bioassays
Apply FSLs --) implications
(e.g., how much of the state's waterways are above SLs?)
By March 91
Peer Review
March 91
March 91
Step 3 Workplan
Review Body
Bioassay Comparison Study
(concurrent)
Benthic Studies
Get new 'other criteria'
Screen results/ select best bugs
Recalculate FSLs
Concordance Analysis (same as above)
Products:
- Identify data gaps/ future work
- Uncertainty analysis
- FSLs and standard bioassays

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FIGURES

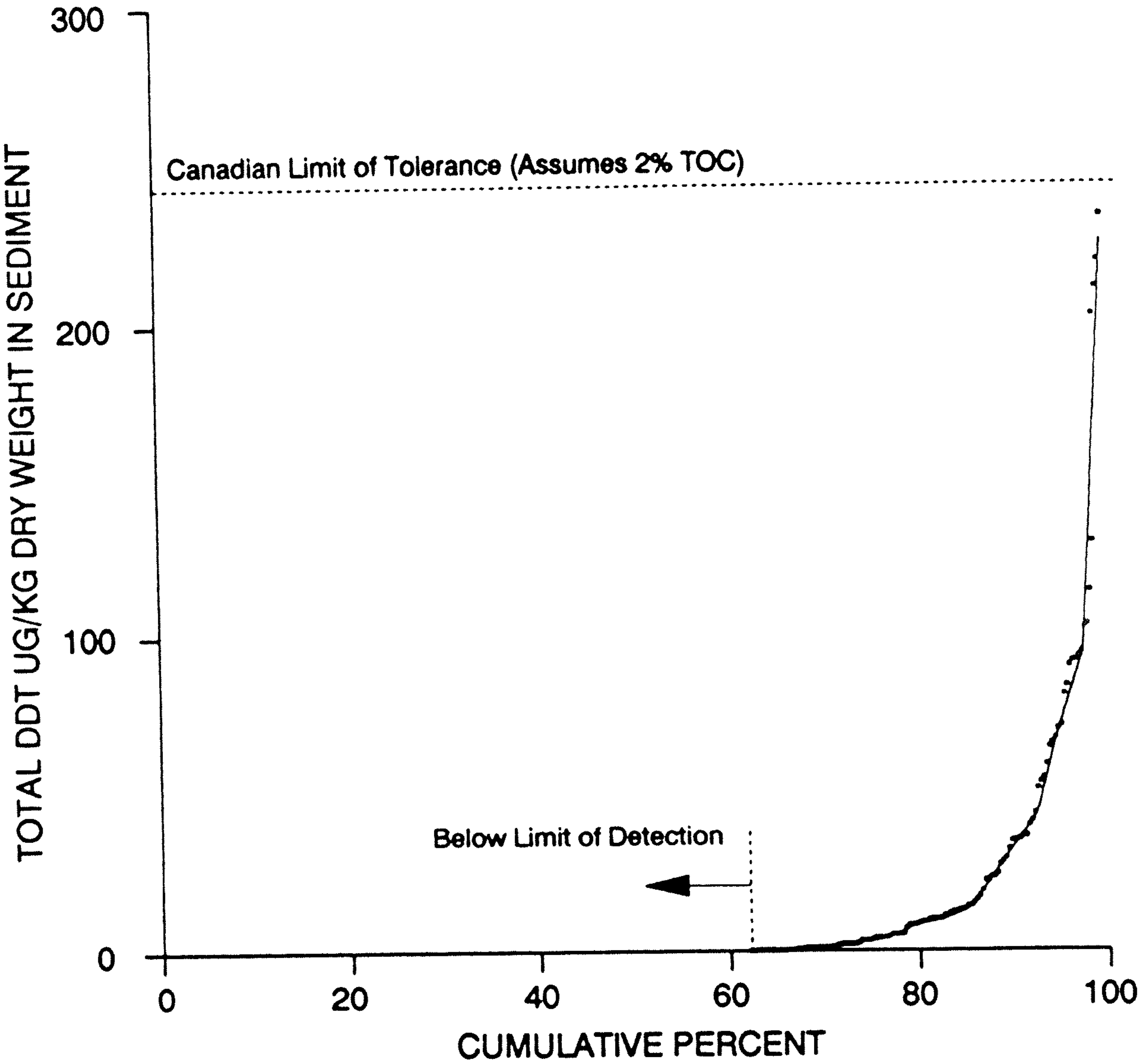

Figure 1 DDT in Washington Freshwater Sediments (n=228 From EPA STORET)

COPPER IN FRESHWATER SEDIMENTS

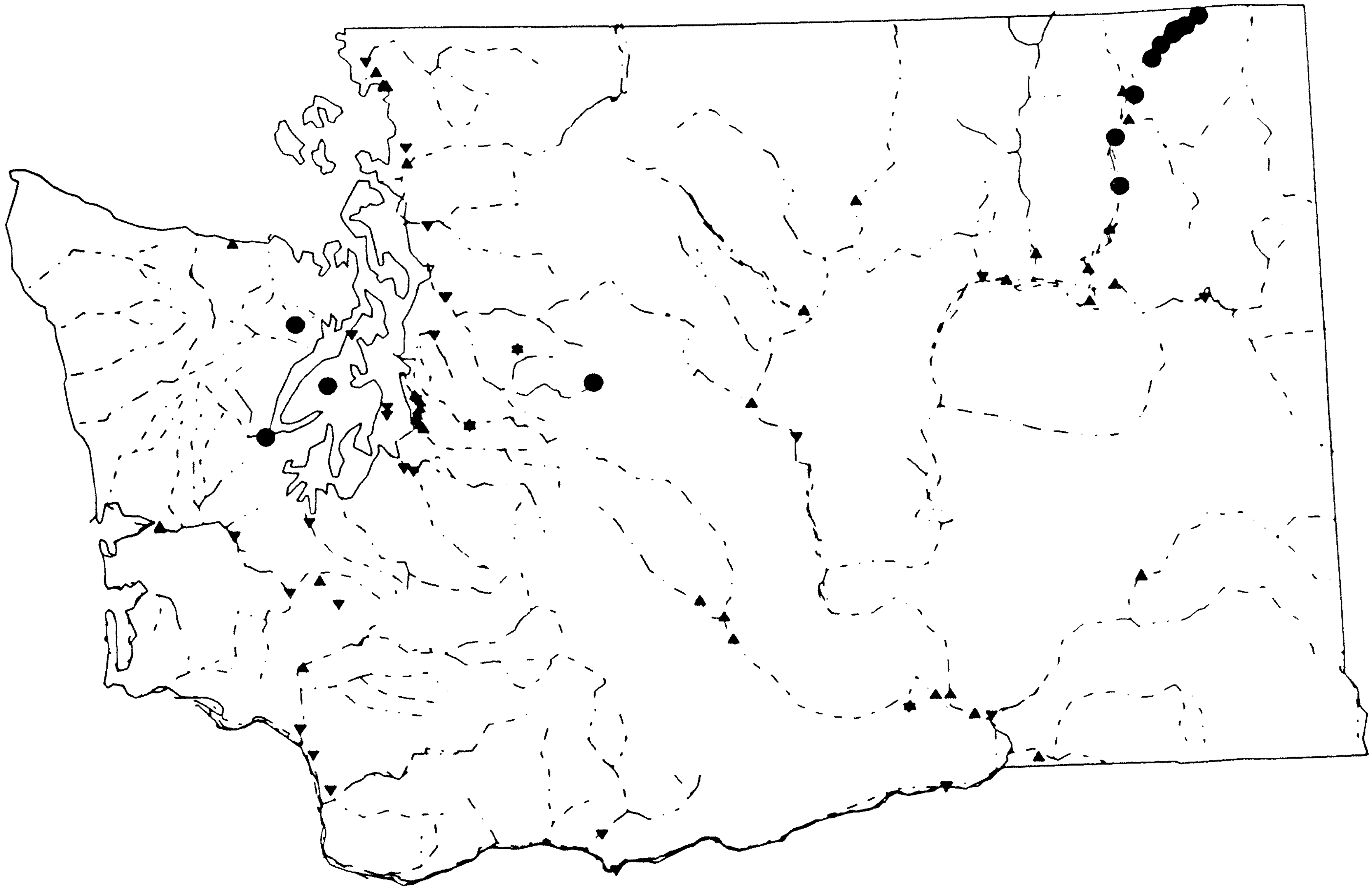

Figure 2 Sites where copper was examined in freshwater sediments. Triangles facing up = sites sampled before 1980. Down triangles = since 1980. Circles = exceed Canadian criteria.

TABLES

Table 1. Freshwater Sediment Bibliographic Data Base Structure

Name	Description	Data	Length
SERN	Serial Number	Num	4
DATE	Date coded	Date	8
TITL	Title	Char	50
AUTH	Author(s)	Char	50
YEAR	Year	Num	4
CITE	Citation	Char	25
KEYW	Keywords	Char	40
TYS1	Type of study	Num	2
TYS2	Type of study	Num	2
TYS3	Type of study	Num	2
MATR	Matrix	Num	3
CSOU	Contaminant source	Char	2
STAT	State location of study	Char	2
COUN	Country	Char	2
METH	Methods	Num	3
NSED	Number of sediment samples	Num	2
QUAL	Data quality grade	Num	2
CREA	Bioassay creatures	Char	40
METS	Metals tested	Char	40
PEST	Pesticides/PCB's	Char	40
BNAS	BNAs tested	Char	40
VOAS	Volatile organics tested	Char	30
CONV	Conventionals tested	Char	30
GERM	Germane to criteria	Num	1
RECR	Report criteria	Num	1
ABS1	Abstract 1	Char	240
ABS2	Abstract 2	Char	240
ABS3	Abstract 3	Char	240
ABS4	Abstract 4	Char	240
		TOTAL	1385

Table 2. Freshwater Sediment Bibliographic Data Codes

Name	Description	Data Code	Data	Length
DATE	Date coded		Date	8
CITE	Citation		Char	25
	Include journal			
TYST	Type of study		Num	2
	Policy	10		
	Contamination	20		
	Bioassay	30		
	Benthic diversity	40		
	Triad	50		
	Review of above	60		
	Freshwater Criteria	90 (generalized)		
	Evaluate method	91 (compare different method)		
	Review of literatur	92		
	Review:other data	93		
	Natural Sources	70		
MATR	Matrix		Num	3
	Freshwater Sediment	1xx		
	River	110		
	Stream	120		
	Ephemeral	125		
	Lake	130		
	Reservoir	135		
	Pond	140		
	Ditch	150		
	Wetland	160		
	Great Lake	170		
	Assorted	180		
	Artificial	190		
	Saltwater Sediment	2xx		
	Estuary	10		
	Open ocean	20		
CSOU	Contaminant Source		Char	2

CODE	CONTAMINANT SOURCE
AF	animal feedlot
AG	agricultural runoff
CN	construction site
CO	combined sources
CS	combined sewer outfall
DR	dam release
EL	electroplating operation
ER	erosional
GR	grazing
GW	groundwater
IN	industrial
LA	lab (artificial)
LL	landfill leachate
MI	mining
MU	municipal
NA	natural

NC	no contamination	
SE	sewage	
SR	silviculture runoff	
UN	unknown	
UR	urban runoff	

STAT State location of study — Char 2

- WA
- OR (etc)

COUN Country (add as used) — Char 2

- US
- CA
- GB
- GR

METH Methods — Num 3

Established = 1xx (used EPA methods or other methods)
Development = 2xx (developed methods)
Comparison = 3xx (compared methods)
Validation = 4xx (compared models to actual results)
xx =

Field	= 10
Lab	= 20
Both	= 30
Theory	= 40
Model	= 50

QUAL Data quality grade — Num 2

QA data reported	10
QA data absent	20
QA review reported	30
QA acceptable under PSEP	50
QA unacceptable under PSEP	60
QA reported in some cases	70
QA mentioned, but uncodeable	80
All mention of QA absent	90

CREA	Bioassay creatures Name creatures tested	Char	35
METS	Metals tested use periodic table abbreviation (Ag As)	Char	40
PEST	Pesticides/PCB's use letter abbreviations (DDT PCB HCB)	Char	40
BNAS	BNAs tested group (LPAH HPAH Phenol CLPhenol)	Char	40
VOAS	Volatile organics tested group (BTX)	Char	30
CONV	Conventionals tested sulfide, cyanide	Char	30
GERM	Germane to criteria 1 (most germane) to 5 (least germane)	Num	1
RECR	Report criteria 1= yes 0 = no	Num	1
ABST	Condensed abstract	Char	960

Table 2. (Continued)

ABBREVIATIONS FOR SEDIMENT CRITERIA BIBLIOGRAPHY

ABBREVIATION	MEANING
AET	apparent effects threshold
ALK	alkalinity
ATP	adenosine tri-phosphate
AVS	acid volatile sulfide
BII	benthic infaunal invertebrates
BIO	bioassay
BOD	biological oxygen demand
CEC	cation exchange capacity
CL	chloride
CLST	cholesterol
CN	cyanide
CO2	carbon dioxide production
CON	conductivity
CPST	coprostanol
DEN	density
DO	dissolved oxygen
DOC	dissolved organic carbon
DPT	depth
EH	Eh (redox potential)
EQP	equilibrium partitioning
ETS	electron transport system
GSZ	grain size
H	hardness
H2S	hydrogen sulfide
HCO3	bicarbonate
HPE	histopathological examination
IC	inorganic carbon
IS	ionic strength
KP	equilibrium partition coefficient
LGP	octanol/water partition coefficient
MOS	moisture
MPN	most probable number (microbiology)
MUT	mutagenicity
N	nitrogen
NH3	ammonia
NH3-N	ammonia nitrogen
NH4	ammonium ion
NO2	nitrite
NO2-N	nitrite nitrogen
NO3	nitrate
NO3-N	nitrate nitrogen
O&G	oil and grease
O2	oxygen
ORG	organic matter
PAH	polycyclic aromatic hydrocarbon
PB-210	lead-210 (dating)
PCB	polychlorinated biphenyl
PE	log Eh
PH	pH
PO4	phosphate

POR	porosity
RSD	residue
RSP	respiration
S/WR	sediment to water ratio
S2	sulfide
SAL	salinity
SLC	screening level concentration
SLD	solids
SO4	sulfate
SOL	solubility
SS	suspended solids
T	temperature
TC	total carbon
TCLP	toxicity characteristics leaching procedure
TDS	total dissolved solids
THD	theoretical oxygen demand
TM	time
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TP	total phosphorous
TUR	turbidity
XCA	exchangeable calcium
XK	exchangeable potassium
XP	exchangeable phosphorous
XRD	X-ray diffraction
XRF	X-ray fluorescence

Table 3.

LIST OF SEDIMENT CRITERIA CONTACTS

NAME	AFFILIATION
John Lunz	S.A.I.C., Everett, WA
Warren Banks	EPA-DC, Sediment Criteria Project
Chris Ingersoll	U.S. Fish and Wildlife, Columbia, MO
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Ian Orchard	Environ. Canada, Conserv. & Prot., Toronto
Christine Holm	NW Pulp and Paper Assn., Seattle, WA
Sydney Munger	Metro, Seattle, WA
Dave Updegraff	Colo. School of Mines, Chem. Dept.
Del Nimmo	National Parks Service, Water Res. Div., CO
M. Switzenbaum	Univ. of Mass., Env. Eng. Dept.
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Allen Knight	U. of Cal., Davis, Land, Air, Water Res.
Chris Zarba	EPA-DC, Sediment Criteria Project
Rick Schwartz	EPA-Newport, OR
A. Davis	Environment Canada, Ottawa
Elena Mudroch	Canada Centre for Inland Waters, NWRI, Ont.
Tom Wright	Corps of Engineers, WES, Vicksburg, Miss.
Robert Huggett	Va. Inst. of Marine Sci., Gloucester Pt., VA
Don Schultz	EPA-Newport, OR
Stu McKenzie	U.S.G.S., Portland, OR
Tiedo Vellinga	Gemeentewerken, Rotterdam, Holland
Linda Troop	Polybac Corp., Allentown, PA
Gene Foster	Oregon DEQ, Water Quality Div.
Gary Ankley	EPA-Duluth, Env. Research Lab
Linda Talbot	Wisconsin DNR
Ken Dickson	Univ. of North Texas, Denton, TX
Michael Wong	Env. Canada, Water Qual. Branch, Ottawa
Peter Chapman	E.V.S. Consultants, Vancouver, B.C.

Table 4. Example of STORET data summarized for this study.

Lat	Long	State	Yr	Mo	Da	Hr	p'DDT	DDT	TDDT	DDD	DDF	SUMDDT	PCB	Aldrin	Indane	Chlord	Dield	Endrin	Hepta	Epox	Mirex	HCB	Location	Basin	Agency
47.596	123.623	WA	70	9	2	1105	.	0	.	0	0	0	.	0	.	0	0	0	0	0	.	.	NORTH FORK QUINAULT R NEAR AMAND		112WRD
48.824	120.147	WA	71	12	2	1200	.	0	.	0	0	0	.	0	.	0	0	0	0	0	.	.	ANDREWS CREEK NEAR MAZAMA, WASH.		112WRD
46.254	119.477	WA	72	1	19	1530	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
46.254	119.477	WA	72	6	30	1015	.	2.9	.	0.7	1.2	4.8	0	0	.	0	0	0	0	0	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
46.254	119.477	WA	72	12	18	1520	.	2.8	.	15	17	34.8	0	0	.	0	0	0	0	0	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
46.254	119.477	WA	73	6	1	915	.	2	.	0.3	2.9	5.2	0	0	.	0	0	0	0	0	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
48.824	120.147	WA	73	6	21	1010	.	0	.	0	0	0	0	0	.	0	0	0	0	0	.	.	ANDREWS C NR MAZAMA, WASH.		112WRD
47.596	123.623	WA	73	12	17	1320	.	0	.	0	0	0	0	0	.	0	0	0	0	0	.	.	NORTH FORK QUINAULT R NEAR AMAND		112WRD
46.254	119.477	WA	73	12	27	1215	.	24	.	14	26	64	0	0	.	0	0	0	0	0	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
46.518	119.259	WA	74	1	18	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.888	119.333	WA	74	1	18	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	CRAB CREEK LATERAL WASTEWAY NEAR	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.833	119.824	WA	74	1	18	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	LOWER CRAB CR- ENTERS COLUMBIA R	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.938	119.400	WA	74	1	18	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	FRENCHMAN HILLS WASTEWAY NR POTH	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.992	119.192	WA	74	1	18	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	LIND COULEE WASTEWAY	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.938	119.400	WA	74	2	19	.	0	.	.	.	.	0	.	0	.	.	10	0	0	.	.	.	FRENCHMAN HILLS WASTEWAY NR POTH	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.888	119.333	WA	74	2	19	.	10	.	.	.	.	10	.	0	.	.	13	0	0	.	.	.	CRAB CREEK LATERAL WASTEWAY NEAR	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.833	119.824	WA	74	2	19	.	0	.	.	.	.	0	.	0	.	.	22	0	0	.	.	.	LOWER CRAB CR- ENTERS COLUMBIA R	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.518	119.259	WA	74	2	19	.	0	.	.	.	.	0	.	0	.	.	30	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.992	119.192	WA	74	2	19	.	0	.	.	.	.	0	.	0	.	.	20	0	0	.	.	.	LIND COULEE WASTEWAY	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.254	119.477	WA	74	4	8	1110	.	0.4	.	0.2	0.5	1.1	0	0	.	0	0	0	0	0	.	.	YAKIMA RIVER AT KIONA, WASH.		112WRD
48.000	118.500	WA	74	5	21	1300	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	NINEMILE MAIN BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
46.167	117.083	WA	74	5	23	1800	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	TUCANNON R.BENTHIC SEDIMENT CTR	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	5	24	1645	16	.	28	.	.	28	.	.	.	.	.	.	.	.	.	.	CUMMINGS CR BENTHIC SEDIMENT CTR	LOWER SNAKE	1119MOTH
48.000	118.500	WA	74	5	25	1600	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	NINEMILE SF BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
46.167	117.083	WA	74	5	29	1115	10.06	.	12.76	.	.	12.76	.	.	.	.	.	.	.	.	.	.	IDAHO QUARTER MI BELOW HATCHERY	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	5	29	1400	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	STREAM SED GRANDE RONDE R BOGGAN	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	5	29	1440	4.1	.	8.33	.	.	8.33	.	.	.	.	.	.	.	.	.	.	IDAHO SEDIMENT 200YD S. BRIDGE	LOWER SNAKE	1119MOTH
48.000	118.500	WA	74	6	3	1200	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	OWHI CR BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
46.167	117.083	WA	74	6	18	2145	18	.	36	.	.	36	.	.	.	.	.	.	.	.	.	.	MILL CR.BENTHIC SEDIMENT CONTROL	LOWER SNAKE	1119MOTH
48.824	120.147	WA	74	6	20	1120	.	1.7	.	0	0	1.7	0	0	.	0	0	0	0	0	.	.	ANDREWS CREEK NEAR MAZAMA, WASH.		112WRD
46.167	117.083	WA	74	6	22	1400	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	TOUCHET R BENTHIC SEDIMENT BELOW	LOWER SNAKE	1119MOTH
48.000	118.500	WA	74	6	24	1230	9	.	15	.	.	15	.	.	.	.	.	.	.	.	.	.	NINEMILE S FORK BOTTOM SEDIMENT	UPPER COLUMBIA	1119MOTH
48.000	118.500	WA	74	6	25	1200	1	.	3	.	.	3	.	.	.	.	.	.	.	.	.	.	OWHI CREEK BOTTOM SEDIMENT	UPPER COLUMBIA	1119MOTH
48.000	118.500	WA	74	6	25	1630	12	.	23	.	.	23	.	.	.	.	.	.	.	.	.	.	NINEMILE MAIN BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
46.167	117.083	WA	74	6	29	1830	9	.	29	.	.	29	.	.	.	.	.	.	.	.	.	.	GEORGE CR BENTHIC SEDIMENT BELOW	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	7	2	1200	32	.	103	.	.	103	.	.	.	.	.	.	.	.	.	.	GEORGE CR BENTHIC SEDIMENT IN	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	7	10	1630	2	.	2	.	.	2	.	.	.	.	.	.	.	.	.	.	STREAM SED GRANDE RONDE R BOGGAN	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	9	18	1100	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	STREAM SED GRANDE RONDE R BOGGAN	LOWER SNAKE	1119MOTH
48.000	118.500	WA	74	9	26	1115	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	NINEMILE SF BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
48.000	118.500	WA	74	9	26	1400	0	.	0	.	.	0	.	.	.	.	.	.	.	.	.	.	NINEMILE MAIN BENTHIC SEDIMENTS	UPPER COLUMBIA	1119MOTH
46.167	117.083	WA	74	10	2	930	0.01	.	0.04	.	.	0.04	.	.	.	.	.	.	.	.	.	.	GEORGE CR BENTHIC SEDIMENT BELOW	LOWER SNAKE	1119MOTH
46.167	117.083	WA	74	10	3	1700	0	.	0.01	.	.	0.01	.	.	.	.	.	.	.	.	.	.	CUMMINGS CR BENTHIC SEDIMENT	LOWER SNAKE	1119MOTH
46.888	119.333	WA	74	10	21	.	2	.	.	.	.	2	.	0	.	.	1	0	0	.	.	.	CRAB CREEK LATERAL WASTEWAY NEAR	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.518	119.259	WA	74	10	21	.	0	.	.	.	.	0	.	0	.	.	2	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.938	119.400	WA	74	10	21	.	1	.	.	.	.	1	.	0	.	.	2	0	0	.	.	.	FRENCHMAN HILLS WASTEWAY NR POTH	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.833	119.824	WA	74	10	21	.	1	.	.	.	.	1	.	0	.	.	3	0	0	.	.	.	LOWER CRAB CR- ENTERS COLUMBIA R	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.992	119.192	WA	74	10	21	.	5	.	.	.	.	5	.	0	.	.	2	0	0	.	.	.	LIND COULEE WASTEWAY	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.992	119.192	WA	74	11	29	.	7	.	.	.	.	7	.	0	.	.	4	0	0	.	.	.	LIND COULEE WASTEWAY	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.518	119.259	WA	74	11	29	.	0	.	.	.	.	0	.	0	.	.	1	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.833	119.824	WA	74	11	29	.	0	.	.	.	.	0	.	0	.	.	2	0	0	.	.	.	LOWER CRAB CR- ENTERS COLUMBIA R	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.888	119.333	WA	74	11	29	.	8	.	.	.	.	8	.	0	.	.	0	0	0	.	.	.	CRAB CREEK LATERAL WASTEWAY NEAR	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.518	119.259	WA	74	11	30	.	0	.	.	.	.	0	.	0	.	.	2	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.518	119.259	WA	75	1	1	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	RINGOLD WASTEWAY- ENTERS COLUMBI	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.938	119.400	WA	75	1	1	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	FRENCHMAN HILLS WASTEWAY NR POTH	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.992	119.192	WA	75	1	1	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	LIND COULEE WASTEWAY	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.833	119.824	WA	75	1	1	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	LOWER CRAB CR- ENTERS COLUMBIA R	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR
46.888	119.333	WA	75	1	1	.	0	.	.	.	.	0	.	0	.	.	0	0	0	.	.	.	CRAB CREEK LATERAL WASTEWAY NEAR	COLUMBIA RIVER ABOVE YAKIMA R	1119USBR

Table 5.
Sediment Criteria Project - Possible Bioassay Methods

The following are tests considered
for use by the Great Lakes Arcs Program

METHOD	USE
Ceriodaphnia dubia	3-brood survival and reprod.-solid phase
Ceriodaphnia dubia	3-brood survival and reprod.-elutriate p.
Daphnia magna	3-brood survival and reproduction-solid p.
Daphnia magna	48-hour survival-solid phase
Hyalella azteca	48-hour survival-solid phase
Hyalella azteca	days to 100% mortality-solid phase
Selenastrum capricornutum	48-hr growth-elutriate phase
Selenastrum capricornutum	carbon-14 uptake-elutriate phase
Lemna minor	frond production-solid phase
Pimephales promelas	7-day embryo-larval survival and terata-solid phase
Pimephales promelas	7-day larval growth and survival-solid phase
Photobacterium phosphoreum	luminescence-elutriate phase
Hydrilla sp.	growth and biochemical parameters-solid phase
Diporeia sp.	survival-solid phase
Hexagenia limbata	survival-solid phase
Panagrellus redivivus	mortality and development-elutriate phase
Indigenous microbial enzyme activity	*in situ*
Artificial substrate macrobenthos	*in situ*
Pimephales promelas	10 day fathead minnow bioaccumulation assay, bulk sediment samples and chemical analysis of fish tissue

The following are additional
tests from the literature search

- Alkaline phosphatase
  - Amylase
  - Arylsulfatase
  - Electron transport system activity
  - B-galactosidase
  - B-glucosidase
  - Protease
  - Metal resistance
  - Heterotrophic uptake (C14)
  - Microtox (*P. phosphoreum*)
  - ATP-Tox
  - Thymidine incorporation
  - Resazurin reduction
- Modified plate agar method
- Fecal coliform
- *Clostridium perifrengens*
- Algal-ATP
- *Spirillum volutans*
- SOS Chromotest