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STATUS REPORT

FRESHWATER SEDIMENT CRITERIA DEVELOPMENT PROJECT

to
Sediment Management Unit
Washington State Department of Ecology

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Environmental Investigations Program

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INTRODUCTION

Sediment Criteria Project

The adverse impacts of contaminated sediments within freshwater systems have recently become issues of environmental concern. These impacts include the toxic effects of contaminants on benthic organisms, contaminant biomagnification and water criteria violations from contaminant resuspension.

The state of Washington adopted the Sediment Management Standards (WAC 173-204) in March 1991. This rule establishes a narrative standard for the sediments of the state and currently contains chemical and biological criteria for 47 contaminants in Puget Sound. The rule also contains a reserved section for the inclusion of freshwater sediment criteria. This report provides a review of the project to develop those criteria.

This paper summarizes the first 20 months of research (March 1990 through October 1991) on freshwater sediment criteria. The Freshwater Sediment Criteria Development Project at the Environmental Investigations and Laboratory Services Program (EILS) was conducted under the direction of the Sediment Management Unit of the Washington State Department of Ecology.

The results of this work are reported as individual elements. Each element covers a separate topic. Table 1 summarizes the elements and includes:

- FSEDCRIT (criteria and guidelines listings)
- FSEDBIB (bibliography of publications related to sediment criteria)
- FSEDLIST (list of contaminant concentrations in sediment samples in Washington State)
- Bioassays
- Benthic community analysis
- Site-specific field study reports
- Contaminants of concern
- Freshwater Screening Levels Development

The goal of this project is to produce criteria or guidelines that will set levels of contaminants expected to have adverse effects on aquatic life. These criteria will be included in the Sediment Management Standards by 1994. Freshwater sediment guidelines have already been recommended for other areas of the U.S. and Canada by the Ontario Ministry of the Environment, Wisconsin Department of Natural Resources, U.S. Environmental Protection Agency (USEPA), and several consultants. These guidelines are reviewed in Summary of Criteria and Guidelines for Contaminated Freshwater Sediments (FSEDCRIT) (Bennett and Cubbage, 1991).

A short-term goal of this project (by summer 1992) is to develop the freshwater screening level (FSL) for several contaminants of concern. This screening level will establish acceptable concentrations of sediment contaminants. Below this level there will be no expectation of

Table 1. Status of study elements in Freshwater Sediment Criteria Project.

Element	Description	Goal	Product/Status
FSEDCRIT	Summary of all criteria and guidelines proposed or used by other agencies.	Comparison of other values for possible use in Washington State.	Element published: Bennett and Cubbage 1991
FSEDBIB	Computerized bibliography of pertinent freshwater sediment literature, guidelines and methods.	Provide foundation for future regulatory decisions. Provide resource for all interested parties.	Ongoing Dbase IV format file with about 200 entries.
FSEDLIST	Database of chemical values of freshwater sediment in Washington State.	Use to determine chemicals of concern for freshwater sediment. Show potential geographic patterns of contamination.	Ongoing file with 700 entries. Integrated with program to map contamination areas.
Bioassay comparison	Compare different bioassay tests on contaminated sediment.	Test ease, sensitivity and reliability of different bioassays.	Element in review by Sediment Management Unit.
Benthic Analysis	Review of methods used to evaluate sediment characteristics on the basis of benthic conditions.	Develop interpretation method for benthic organisms needed to determine possible impacts of contaminants.	Report on methods in final stage (Kathman 1991). Integration of site projects (see below) not done.
Site projects	Projects at several contaminated lake sites in Washington in cooperation with other studies (L.Steilacoom, L.Union, L.Roosevelt, L.Washington).	Evaluate bioassay, benthic analysis methods, and current proposed guidelines and criteria.	Steilacoom: Draft report Lake Union: Draft report Lake Roosevelt: Draft report Lake Washington: In Prep.
Contaminants of Concern	List of potential contaminants of concern based on occurrence and toxicity.	Focus guideline effort.	Pending
Freshwater Screening Levels Development	Creation of chemical screening levels for freshwater.	Initial guideline: Below these concentrations there is assurance of no adverse effects.	Pending

significant harm to biota, but sediment concentrations above the FSL for a given contaminant may cause adverse impact. Those sediments will then be subject to other tests or guidelines to determine their status.

Because guidelines for metals in freshwater sediments reviewed in FSEDCRIT generally vary by no more than an order of magnitude, we expect to derive metals FSLs within the next six months. Because guidelines for organics vary more widely, we expect that development of FSLs for those compounds will take longer.

Additional work to be conducted in the next six to 12 months includes a concordance analysis that will compare different criteria methods. More data on the toxicity of several freshwater sediment contaminants are expected from the Great Lakes Assessment and Remediation of Contaminated Sediments Program (ARCS) and the USEPA 404 Gold Book. These data will be incorporated into our analyses and recommendations as they become available.

DATA SETS

Review of Sediment Criteria - FSEDCRIT

FSEDCRIT, an acronym for Freshwater Sediment Criteria, is a Lotus® data table containing a comprehensive list of U.S. and Canadian freshwater sediment criteria and guidelines for metals, pesticides and other chlorinated organics, polycyclic aromatic hydrocarbons (PAHs), conventionals, etc. The data table has been published with derivation methods, data sources, current status, and references. (Bennett and Cubbage, 1991). For consistency, data are normalized to mg/kg dry weight for metals and mg/kg organic carbon for organics. FSEDCRIT will be updated as new data become available.

The following are the current FSEDCRIT data sources:

A) Provincial Sediment Quality Guidelines Proposed by the Ontario Ministry of the Environment.
B) Wisconsin Department of Natural Resources Sediment Quality Criteria.
C) Sediment Quality Guidelines Proposed by Beak Consultants, Ltd.
D) USEPA Region V Guidelines for the Pollutional Classification of Great Lakes Harbor Sediments.
E) Screening Level Concentrations for Freshwater Sediments (Battelle).
F) USEPA Interim Sediment Criteria for Nonpolar Hydrophobic Organic Contaminants.
G) Dredged Material Disposal Classification Criteria Used by the Ontario Ministry of the Environment.

The several sets of FSEDCRIT data for metals generally agree with each other within an order of magnitude. For example, the Provincial Sediment Quality Guidelines severe effect level for copper is 110 mg/kg dry weight. Similarly, the USEPA Region V Guidelines for Harbor Sediments classifies a sediment as heavily polluted if it has a copper concentration greater than 50 mg/kg dry weight. This close agreement is probably because: 1) many of the metals guidelines were determined by similar derivation procedures; and 2) some data sets share common origins and have evolved very little since being developed. Additionally, data are often divided into effects levels such as the Provincial Sediment Quality Guidelines (Persaud, 1991, In Draft), or classifications such as the USEPA Region V Guidelines for the Pollutional Classification of Great Lakes Harbor Sediments (U.S. Environmental Protection Agency, 1977), thereby producing similarly valued data groups.

There is less agreement among criteria for organic compounds than for metals criteria. This lack of agreement may be due to differences in procedures that produce various criteria. These methods are often complex. Additionally, they often rely on limited data. As a result, organics criteria derivations often diverge. There are also fewer data available for organics than for metals.

Bibliography - FSEDBIB

The Freshwater Sediment Bibliography (FSEDBIB) contains abstracted information from the research literature and government reports on criteria, bioassays, sediment chemistry, toxicity tests, benthic community studies, and related subjects. This bibliographic information is stored on a disk in dBase IV format. An accompanying document explains the nomenclature, numerical references, and data codes. Data from the articles are coded and entered into several data fields. All pertinent citations may be found through a keyword or code search. The first version will be available for public release in spring 1992. FSEDBIB currently contains nearly 200 entries. Finalized reports, data, and associated information will be available through the Sediment Management Unit.

Literature sources include published and government research papers, newsletters, journal articles, memos, personal communications, etc. Relevant articles are filed and abstracts entered into a computerized bibliography. Reference lists are used to locate additional information.

FSEDLIST

The Freshwater Sediment List (FSEDLIST) is a compilation of sediment data from several sources. The primary source is USEPA Storage and Retrieval (STORET), a nationally supported database of environmental measurements including pollutant concentrations. Major contributors to this database are USEPA, its subcontractors, and the U.S. Geological Survey. Though data sources and some data quality qualifiers are recorded the overall quality of data in STORET cannot always be verified. FSEDLIST also contains data collected through the Department of Ecology's sampling inspections at National Pollutant Discharge and Elimination System (NPDES) permitted discharges, comprehensive environmental studies, and a statewide lakes monitoring program. Data quality from these sources has been verified.

FSEDLIST contains data from about 700 samples, many of them taken periodically at one location over a number of years. For example, Figure 1 shows the locations of DDT, copper and mercury samples from information in the database. An important limitation is that most sampling was not random, but occurred in suspected problem areas. Therefore, average contaminant concentrations may be biased high.

Figure 1. DDT, copper and mercury sample sites in freshwater sediments.

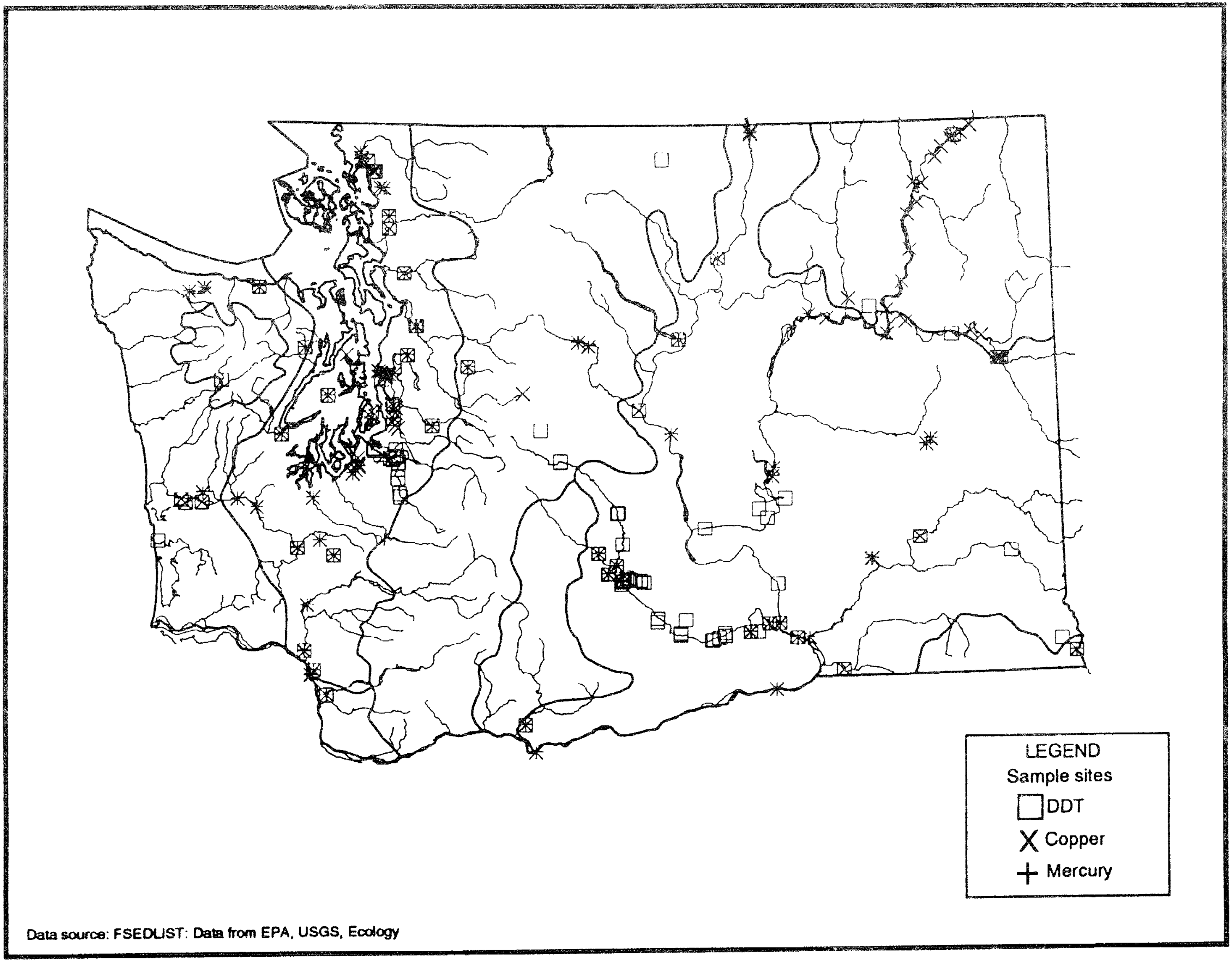

Table 2 gives the FSEDLIST pesticide data summary. Table 3 gives the metals data summary with potentially contaminated lakes separated from the reference lakes. Median values for cadmium, arsenic, lead and zinc are lower than the reference lakes median values. However, the values at the 90th percentile of the non-reference lakes are high and exceed some criteria contained in FSEDCRIT. PAHs were not found in searches of USEPA freshwater sediment data, so no data are given. PAH data are available for Lake Union and parts of Lake Washington from individual project reports.

Contaminants of Concern

The contaminants of concern are those substances for which Ecology first plans to develop standards. Currently metals, PAHs, pesticides, and polychlorinated biphenyls (PCBs) have priority consideration. Specific contaminants may be selected based on the following factors:

1) contaminants prevalent in freshwater sediment in Washington State for which there is some evidence of biological harm at the reported or expected concentrations.
2) contaminants listed in freshwater sediment criteria or standards from other states, provinces or countries,
3) contaminants currently listed in the marine sediment standards for Washington State,

Contaminants will be evaluated for their prevalence (factor 1) based on data from FSEDLIST. Concentration of candidate sites in Washington will be rank ordered. The median, 90th and 95th percentile will be compared to criteria values as well as reference areas. The exact criterion that will be designated for a chemical of concern with this method (e.g., median exceeds criteria or median exceeds five times the reference concentration) has not yet been decided. Criteria from other sources (factors 2 and 3 above) will also be considered for inclusion in the rule.

Additional Sources of Data

The ARCS Program, sponsored by the U.S. EPA Great Lakes National Program Office, is assessing the nature and extent of contaminated sediments in the Great Lakes areas of concern. The goal is to identify threshold levels of contamination for metals, organics, PAHs, PCBs, chlorinated pesticides, and to identify appropriate bioassays and endpoints for sediment toxicity testing. The results are expected during the first quarter of 1992. A related effort by the Ecosystem Objectives Work Group is studying benthic interpretation and analysis tools.

Table 2. Summary of statewide pesticides concentrations (ug/kg dry weight)

	SUMDDT	PCB	Aldrin	Lindane	Chlord.	Dield.	Endrin	Hepta.	H Epox	Mirex	HCB
Sites Examined	324	58	271	6	144	281	272	273	134	23	79
Detects	123	15	6	0	11	55	7	2	8	0	2
Avg of detects	29	2.6	182	.	8.5	4.2	5.6	8.0	4.1	.	1800
Min of detects	0.01	0.10	0.40	.	1.00	0.17	0.10	3.00	0.10	.	1800
Max	234	23	1065	0	19	30	37	13	18	0	1800
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
90%	34.8	0.7	ND	ND	ND	1.8	ND	ND	ND	ND	ND
95%	71	1.2	ND	ND	10	3.5	ND	ND	0.1	ND	ND

ND=None detected

Source: FSEDLIST: Inventory of sediments reported by USGS, USEPA, and Ecology.

Table 3. Comparison of statewide metals concentrations with reference sites. (ug/g dry weight)

	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
All sites after 1975									
Total N	176	46	136	183	126	113	162	42	57
Detect	167	37	136	183	126	113	162	39	57
Min	0.8	0.12	0.6	1.3	0.005	5.8	0.7	0.02	39.8
Max	1150	2.6	740	4870	0.75	154	900	4.3	904
Avg	22.4	1.0	44.2	247.0	0.1	38.2	123.0	0.6	247.1
Median	10.2	0.75	26	41	0.05	27	25	0.48	134
90th	28	1.8	79	600	0.37	73	425	0.8	630
95th	52.1	2.3	100	1010	0.50	79	598	1.3	689
Reference (Lake Crescent and Lake Wenatchee, 1988)									
Total N	4	4	4	4	4	4	4	4	4
Detect	4	4	4	4	4	4	4	4	4
Min	4.8	0.2	74.8	42.0	0.1	41.0	6.7	0.5	64.1
Max	7.1	0.5	215.0	78.4	0.2	154.0	13.8	0.5	172.0
Avg	6	0.32	149	62	0.12	91	11	0.48	108
Median	6.1	0.31	154	62.5	0.15	85	12.7	0.48	98

Source: FSEDLIST: Inventory of sediments reported by USGS, USEPA, and Ecology.

SITE PROJECT STATUS

To evaluate different methods needed to develop criteria, four separate field projects were conducted:

Site:	Purpose:	Status:
Steilacoom Lake	Determine the effects of high levels of copper contamination	Report due February 92
Quendall-Baxter	Determine the effects of high PAH concentrations	Report due March 92
Lake Union	Determine the effects of a combination of metals and PAHs	Report due February 92
Lake Roosevelt	Determine the effects of a suite of metals	Completed

Some of these projects were conducted for other goals besides determination of freshwater sediment criteria. All four projects are reported in separate documents in various stages of completion. Summaries of the projects are listed below:

Steilacoom Lake

Steilacoom Lake, in Pierce County, was selected as a study site to determine if adverse biological effects could be traced to copper. Steilacoom Lake has a history of treatment with copper sulfate to control algae. Some of the copper has precipitated into the sediment and has become the predominant identified toxicant in the lake sediment. Sediment copper levels range from about 200 mg/kg dry weight to about 1100 mg/kg dry weight, which exceeds the 110 mg/kg dry weight severe-effect level of the Provincial Sediment Quality Guidelines established by the Ontario Ministry of the Environment (Persaud *et al.*, 1991). Copper levels in Steilacoom also exceed levels identified by the U.S. Army Corps of Engineers that resulted in adverse effects to the amphipod *Pontoporeia affinis* in Lake Superior. *P. affinis* was found in lower densities in areas where sediment contained over 100 mg/kg sediment copper, and was completely absent above 800 mg/kg copper (Wright *et al.*, 1977).

Steilacoom Lake sediments were evaluated using 11 different types of chronic and acute bioassays. Where possible, bioassay results were correlated with sediment and pore water copper concentrations. Both *Hyalella azteca* (an amphipod) and *Hexagenia limbata* (a burrowing mayfly) showed significant mortality at the site with the highest copper concentrations as measured in sediment and pore water. Microbial enzyme analyses correlated well with sediment and pore water concentrations at all three Steilacoom Lake sites examined. No other bioassay results corresponded to copper concentrations. Black Lake, in Thurston County, was the source of reference sediment for the Steilacoom Lake study. Unidentified toxic components in Black Lake reference sediment produced mortality in several bioassay organisms (Burton, 1991a).

Analyses of benthic infaunal invertebrates were also done on Steilacoom Lake sediments. Following organism identification and enumeration, results were analyzed using several statistical approaches. Excessive variation between sites, as well as among replicate samples at each site, precluded conclusions. Further information can be found in reports by Brinkhurst (1991) and Wisseman (1991a).

Copper criteria cannot be established from these Steilacoom Lake results. However, based on other work, the high level of copper in Steilacoom Lake sediments may have already resulted in adverse biological impacts.

Acid Volatile Sulfide Theory: Steilacoom Lake sediments were also used to test the acid volatile sulfide theory which states that copper and certain other metals will be bound, and thus be biologically unavailable, by sulfides present in the sediment. Only when the molar ratio of copper to acid volatile sulfides exceeds one (Cu/AVS > 1), will the free form of the metal (Cu^{2+}), considered the primary toxic species, become biologically available. The greater the ratio, the more toxic the sediment (Ditoro *et. al.*, 1990). Steilacoom Lake sediments had ratios ranging from approximately 0.6 to 60.

However, even Steilacoom Lake sediments with high Cu/AVS ratios caused no significant mortality to *Hyalella azteca* or any other bioassay organism. These sites also had low concentrations of aqueous free copper. It appears that copper can be bound in several forms other than as a sulfide so that AVS is not the sole controller of copper toxicity.

The draft Steilacoom Lake project report will be completed by January 1992.

Quendall/Baxter (Lake Washington)

Creosote contaminated sediments were collected from Lake Washington for chemical analyses, bioassays, and benthic infaunal invertebrate analyses to determine the effects of high PAH concentrations. Sampling was done at Quendall/Baxter terminals near Renton, the site of several creosote spills in the late 1930's to early 1940's.

PAH concentrations ranged from negligible to over 300,000 mg PAH/kg TOC. *Hyalella azteca* showed significant toxicity at the most contaminated sites. *Chironomus tentans* (a midge larvae) showed significant chronic toxicity (50% weight loss) at one of the less contaminated sites. *Hexagenia limbata* showed no toxicity at any site. Two of the Microtox® bioassay series showed increasing toxicity with increasing PAH.

Benthic infaunal analysis shows change in benthic structure, including a reduction in species diversity with increasing levels of contamination. Identification and enumeration of the benthic infauna from one sampling effort have not yet been completed. However, initial findings indicate the results may not agree with earlier samples.

Results of the first of three sampling efforts have been reported (Norton, 1991). Draft reports for the second and third Quendall/Baxter sampling efforts will be completed in February 1992. Completed reports will be available through the Sediment Management Unit.

Photo-enhanced Toxicity: The toxicity of certain PAHs can be significantly increased after uptake by aquatic organisms through ingestion, adsorption, or other means, and exposure to ultraviolet (UV) wavelengths (Burton, 1991b). Spacie (1991) has demonstrated significant increases in toxicity to *Ceriodaphnia* after exposure to UV wavelengths with contaminated sediments from the Grand Calumet River. Some of the known photo-enhanced toxic compounds include anthracene and benzo(a)pyrene. Experiments using toxicity identification evaluation (TIE) established that the components are water soluble. Dr. Spacie speculates the cause may be a highly reactive oxygen radical. Under natural conditions such as with shallow, PAH contaminated sediments exposed to direct sunlight, the actual toxicity may greatly exceed that seen in the laboratory under artificial light. The use of special lamps or natural sunlight when doing bioassays may help duplicate the *in situ* environment.

Lake Union

Sediment samples from Lake Union were used to help determine the combined effects of metals and PAH contamination. Samples were taken from 22 sites throughout the Lake to examine background contaminant concentrations. Of those sites unaffected by saltwater intrusion, sediment from nine of them were tested for *Hyalella, Daphnia,* and Microtox® bioassays. Four replicate sediment samples from each bioassay site were also analyzed for benthic infaunal densities. While the primary purpose of this study was to guide clean-up alternatives for Lake Union, the sediment criteria project has also benefitted.

Sediments were analyzed for metals, PCBs, PAHs, and volatile organic compounds. Metals concentrations in Lake Union sediments were high when compared to concentrations found throughout the state. Medium levels of PCBs were also found. PAHs were found in high concentrations near Gasworks Park on the north shore, the past site of a coal gas plant. Microtox® showed effects when exposed to samples from throughout the lake. *Hyalella* and *Daphnia* showed significant mortality from exposure to samples from the Gasworks Park site (see Bioassay Report: Bennett and Cubbage, In Draft). Benthic community changes were equivocal. Results from this study are in draft form and will be final by mid-February 1992. In earlier work at this site, Yake *et al.* (1986) found increased toxicity at Gasworks Park when compared with one up-drainage control site. This study site (Lake Union) has provided good supporting data for PAH toxicity and considerable information on metals.

Lake Roosevelt

The Lake Roosevelt work focused on the potential biological implications of metals contamination in sediments. The source of these metals is a copper and zinc smelter that discharges slag and wastewater into the Columbia River upstream of Lake Roosevelt. Although metals concentrations were elevated at some sites, bioassay results and benthic studies were both inconclusive (Johnson, 1991).

BIOASSAYS

Laboratory bioassays are used in the sediment criteria development project to help determine the contaminant levels that produce no acute or chronic adverse effects on biological resources, as required under the Sediment Management Standards.

Bioassays have been used to test aquatic organisms against copper contamination of Steilacoom Lake sediments, PAHs in Lake Washington, metals and PAHs in Lake Union, and metals in Lake Roosevelt. A primary goal was to determine which organisms would show a measurable and consistent response to the various contaminants. Details will be included in the individual project reports. Bioassay results are discussed in greater detail in Bennett and Cubbage (In Draft). The following section provides a summary of the results.

Bioassay Organisms

Daphnia magna, a "water flea", is predominantly a water column organism. It showed significant mortality, as well as chronic toxicity indicated by a reduction in the number of young produced, with Black Lake reference sediment (the reference area for the Steilacoom report). *D. magna* also showed significant mortality at two sites at Lake Roosevelt and one site at Lake Union. The latter was the only result which could be correlated to known contaminants (PAHs).

Ceriodaphnia dubia, a closely related species, showed toxicity similar to that seen with *Daphnia magna* with Black Lake reference sediment. It also showed significant mortality with one PAH contaminated sample from a Quendall/Baxter site.

Hyalella azteca, an amphipod, is an epibenthic detritivore and will burrow in the sediment surface (Nelson *et al.*, 1990). *H. azteca* has shown the toxic effects of the most contaminated of sediments from the Steilacoom Lake, Quendall/Baxter, and Lake Union sites. Our results show this bioassay organism has a consistent response to PAH contaminated sediments. In these tests, a sharp decrease in survival is associated with sediment concentrations above approximately 4,000 mg PAH/kg organic carbon (Bennett and Cubbage, In Draft).

Chironomus tentans, which may become resistant to metal contaminants (Wentsel *et al.*, 1978), showed neither significant mortality nor significant weight reduction when exposed to Steilacoom Lake sediments. Results were more definite with Quendall/Baxter (PAH contaminated) sediments collected by Bennett. One of three contaminated sites caused significant chronic toxicity (50% weight loss) in the *C. tentans* bioassay.

Hexagenia limbata showed significant mortality (50%) at the Steilacoom Lake site with the highest concentration of both sediment and pore water copper, but not at any other site. It did not show chronic toxicity, as measured by significant weight loss, at any Steilacoom site. This bioassay did not give significant results with Quendall/Baxter sediments. *H. limbata* can only be partially cultured in the lab (eggs and young are collected from the wild) and sensitivity varies with age.

Ostracod tests were invalid due to high control mortality (Quendall/Baxter) or increased mortality with decreased sediment contaminant concentrations (Steilacoom and Black Lakes). A change in experimental procedure might solve this problem.

Microtox® is a popular bioassay based on light production by the marine bacterium *Photobacterium phosphoreum*. Microtox® data are generally reported as an EC_{50}, or the proportion of sample extract required to reduce the light output by 50%. Values less than 100% indicate toxicity and statistical analyses may be applied to the data to determine significance. An alternate procedure, specified by both the Sediment Management Standards and PSDDA (Puget Sound Dredged Disposal Analysis), uses a significant 20% light reduction compared to control to indicate toxicity.

Two different analytical procedures were used for these tests. One of them was a modification of the procedure used by the Puget Sound Estuary Program (1987), while the other was the 100% Assay Procedure (Microbics, Inc., 1989) which used higher extraction dilutions. The two methods gave contradictory results with Quendall/Baxter sediments. Additional procedures, such as the solid phase test, should be evaluated to determine the best method to use for sediment toxicity testing.

Steilacoom Lake sediments were not toxic to Microtox®. Reference sediments at Black Lake were toxic. Microtox® results correlated with sediment cadmium levels in Lake Roosevelt. Microtox® toxicity increased directly with increasing PAH concentrations in some Quendall/Baxter sediments, although the results apparently depended on the type of extraction procedure used. Though all eight sample sites in Lake Union were toxic to Microtox®, no clear relationship was found between toxicity and any one contaminant (Cubbage, In Prep.).

Indigenous microbial enzyme activity analyses are promising approaches to sediment toxicity testing. Correlations were found between the reduction in microbial activity and increasing levels of both total sediment copper and total pore water copper. Microbial enzymes seem to indicate chronic effects of contamination before effects are shown by higher organisms, and can therefore act as early warning indicators of potential problems. However, the ecological relevance of the microbial enzyme test needs to be verified. These tests must also be standardized.

Bioassay Recommendations

Based on the bioassay results from the projects described above, we make the following recommendations for further use in support of freshwater sediment criteria:

Daphnia magna showed inconsistent response at all sites and **is not recommended.**

Ceriodaphnia dubia showed inconsistent response at all sites and **is not recommended.**

Hyalella azteca was a good to excellent toxicity indicator at all sites and **is recommended.**

Chironomus tentans, because of its general lack of response to contaminants, **is not recommended.**

Hexagenia limbata results agreed with other bioassays indicating toxicity at Steilacoom. Despite some problems with the procedure, continued use **is recommended**.

Microtox®, despite its apparent lack of response at metals' contaminated sites, **is recommended.**

Microbial enzyme activities correlated well with both sediment and pore water copper concentrations at Steilacoom Lake. However, further research into this method is needed. Until certain questions are resolved which will directly affect the interpretation of these tests, microbial enzymes **are not recommended.**

Summary

The majority of bioassays used to test for toxicity at these sites were based on acute, rather than chronic, endpoints. None of the bioassays with chronic endpoints examined so far have shown consistent results.

Many investigators consider the bioassay organisms *Daphnia magna* and *Ceriodaphnia dubia* to be highly sensitive indicators of sediment toxicity. However, our results were inconsistent with these findings. In our opinion, for water-column organisms to demonstrate sediment toxicity, toxic components from the sediment must first migrate into the aqueous phase. Such migrations apparently did not occur in the majority of our tests, rendering these organisms ineffective as toxicity indicators. Our recommendations are based accordingly.

Additionally, the battery of tests approach is often used in connection with aquatic toxicity studies. This approach incorporates the use of multiple bioassays to determine sediment toxicity. The basis for the battery of tests is that different organisms may show considerable variation in sensitivity to pollutants, so that what is highly toxic to one may be less so to another. Several factors may account for these variations including the level of exposure, mode of exposure, and the test endpoint. Therefore, the bioassays selected for a typical sediment study should include a broad range of test organisms to account for these variations.

Reference and Control Sediments

In addition to testing sediments from contaminated areas, laboratory bioassays usually include both reference and control sediments. We consider a reference sediment to have similar characteristics as the test sediment, such as grain size, carbon content, benthic life, etc., but with only background or biologically insignificant concentrations of the contaminant of interest. The reference sediment preferably comes from the same lake as the test sediments. In the case of widespread contamination, it may be necessary to sample from a separate lake.

Black Lake reference sediment, used in the Steilacoom Lake project, and some of the Quendall/Baxter reference sediments was unsatisfactory because of unexplained bioassay toxicity and sparse benthic life. We are planning to sample for reference sediments at other lakes which may be more satisfactory.

By our definition, there is no requirement that a bioassay control sediment have physical or chemical characteristics similar to those of either the reference sediment or the test sediment. The main criteria for control sediment is that it be consistent and not impact the health of the test organisms. Control sediment is used with organisms such as *Hyalella, Hexagenia,* and *Chironomus,* which spend all or part of their time in contact with sediment. Manchester Lab uses an upland agricultural soil as its control. This practice is consistent with the ARCS Program (Ingersoll, Personal Communication). The soil used at the Manchester Lab has not yet been analyzed to determine its chemical or physical characteristics.

BENTHIC INFAUNA STUDIES

Benthic infauna studies are also used in the sediment criteria development project to help determine contaminant levels that produce no acute or chronic adverse effects on biological resources, as required under the Sediment Management Standards.

Progress to Date

Benthic invertebrates from each of the four project sites have been identified, counted, and statistical methods applied to evaluate the influence of sediment contaminants on community structure, organism distribution, population density, and diversity. Benthic interpretation has been performed for each site, although the most extensive so far has been with the Steilacoom Lake data.

Dr. Ralph Brinkhurst, of Aquatic Resources Center in Franklin, Tennessee, has applied numerical methods to data from Steilacoom Lake (Brinkhurst, 1991) to determine correlations between benthic infaunal populations and sediment contaminant concentrations. Inconsistencies in the Steilacoom Lake data precluded any conclusions. Analyses of the other sites are not yet complete.

Bob Wisseman of Western Aquatic Institute identified benthic organisms for the Steilacoom Lake project (Wisseman, 1991a) and Quendall/Baxter, (Wisseman, 1991b) although the latter group has only been identified to major taxa. Dr. Deedee Kathman (1991) of Young-Morgan & Associates has written an informative report on different methods of benthic interpretation. Further work remains to interpret the Quendall/Baxter and Lake Union benthic organism data. No significant correlations have yet been found for the Lake Roosevelt benthic data, although further analyses are planned.

A full report on the benthic portion of these four projects is being prepared.

CONCLUSIONS

1) The following bioassays demonstrated acceptable sensitivity and consistent response to sediment contamination: *Hyalella azteca, Hexagenia limbata,* and Microtox®.

2) The following bioassays did not demonstrate acceptable sensitivity or consistent response to sediment contamination: *Daphnia magna, Ceriodaphnia dubia, Chironomus tentans,* and microbial enzymes.

3) Some bioassay reference sediments used so far, especially Black Lake, have been unacceptable because of apparent toxic effects.

4) Benthic infauna data for Steilacoom Lake was inconsistent and unsuitable for purposes of numerical analyses.

5) Analyses of benthic communities may be potential indicators of sediment quality.

6) Additional sediment data, such as from the ARCS Program, will be important additions to FSEDCRIT as well as to the development of FSLs and concordance analyses.

7) Additional bioassays, beyond those used here, are needed to adequately determine criteria for metals contaminated sediments.

8) As indicated by microbial enzyme analyses, pore water metals' concentrations can be important indicators of sediment toxicity.

RECOMMENDATIONS

1) Use the following bioassays to detect freshwater sediment contamination: *Hyalella azteca, Hexagenia limbata,* and Microtox®.

2) Do not use the following bioassays to detect freshwater sediment contamination: *Daphnia magna, Ceriodaphnia dubia, Chironomus tentans,* and microbial enzymes.

3) A search for better (non-toxic) reference sediments for bioassays should be instituted. This sediment should be used in future tests.

4) Implement suggestions provided by Wisseman, Brinkhurst, and others to improve benthic invertebrate sampling procedures and increase data interpretability.

5) Investigate the use of benthic analyses to determine sediment quality.

6) Incorporate data from studies, such as the ARCS Program, into FSEDCRIT when results become available. Add these results to the FSLs and concordance analyses.

7) Continue the literature search for bioassays useful in the analysis of sediments with high metals' contamination.

8) Further examine the relationship of pore water metals' concentrations and their relationship to sediment toxicity and bioassay response.

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