THE BIOLOGICAL ASSESSMENT OF CONTAMINATED SEDIMENTS - THE DETROIT RIVER EXAMPLE

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ABSTRACT

Contaminated sediments have been found in almost all water bodies which have at some time received, or are presently receiving, waste inputs from urban and industrial sources.

In the Laurentian Great Lakes, sediments are classified as contaminated from bulk chemical analysis. The chemical criteria used to evaluate these results are somewhat arbitrary and only partially consider biological impacts. The absence of adequate linkage among sediment contamination, bioavailability, effects on organisms, populations, and ultimately ecosystem health, represents a major barrier to the restoration and protection of aquatic ecosystems.

An integrated strategy for the assessment and delineation of contaminated sediments is proposed which provides a comprehensive evaluation of impact, as well as a cost-effective sampling and testing program. The strategy incorporates the triad approach and is to be executed in two stages. Both stages use physical, chemical and biological information; however, the second stage requires more sampling and analyses to specify the severity and extent of the associated problems.

RÉSUMÉ

On a trouvé des sédiments contaminés dans presque toutes les eaux qui ont reçu ou qui reçoivent actuellement des déchets d'origine urbaine ou industrielle.

D'après l'analyse chimique d'échantillons en vrac, les sédiments des Grands Lacs laurentiens sont contaminés. Pour évaluer les résultats de cette analyse, on a retenu des critères d'ordre chimique d'une façon plutôt arbitraire et l'on n'a tenu que partiellement compte des effets biologiques. Comme il n'existe pas de lien adéquat entre la contamination sédimentaire, la biodisponibilité, les effets touchant les organismes, les populations et finalement la santé de l'écosystème, il se pose un grand obstacle à la restauration et à la protection des écosystèmes aquatiques.

On propose une stratégie intégrée d'évaluation et de délimitation de la contamination sédimentaire comportant une évaluation poussée de l'effet produit ainsi qu'un programme

économique d'échantillonnage et d'analyse où l'on met en application une approche en trois parties qui s'exécute en deux étapes. Dans les deux étapes on se sert de données physiques, chimiques et biologiques mais dans la seconde toutefois, il faut un plus grand nombre d'échantillonnages et d'analyses pour déterminer la gravité et l'étendue des problèmes.

MANAGEMENT PERSPECTIVE

Contaminated sediments have been identified in 41 of 42 IJC Areas of Concern. At the present time the significance of levels of contaminants is poorly understood, and there is a serious need for a suitable management strategy for decision making with regard to developing remedial actions for contaminanted sediemnents. This paper, developed while working for the IJC sediemt subcomittee, proposes an assessment strategy for determinng the need for remedial action and furthermore identifies a decision making criteria for judging whether or not remediation has been successful

PERSPECTIVE - GESTION

On a trouvé des sédiments contaminés dans 41 des 42 secteurs de préoccupation de la CMI. Pour l'instant, l'importance de la contamination est mal comprise et il est urgent qu'une stratégie de gestion adéquate vienne sous-tendre les décisions à prendre quant aux mesures correctives. Dans cet article, que l'auteur a préparé alors qu'il travaillait pour le sous-comité des sédiments de la CMI, on propose une stratégie d'évaluation permettant de déterminer s'il y a lieu de prendre des mesures correctives et l'on définit des critères en fonction desquels on puisse juger de l'efficacité des correctifs apportés.

EXECUTIVE SUMMARY

The following paper outlines a strategy for sediment assessment which requires a combination of sediment chemistry and physics together with in situ and laboratory biological assessment to define and bound the extent of sediment contamination. If used, the impact of chemical contamination will be expressed in a biologically meaningful manner and demonstrate linkages between levels of contaminants and community response. Using, as an example, data from the Detroit River for sediment chemistry and benthic invertebrate community structure the power of this information and analysis is demonstrated. Clear boundaries can be placed on an impacted area, the biological effects of sediment contamination are demonstrated, six major and five minor variables have clearly been identified as being responsible for the impact in a specific area of the river, and finally objective levels for clean up can be defined. This type of information is essential to provide a clear and understandable framework for the assessment and remediation of polluted areas in the Great Lakes and other freshwater systems.

SOMMAIRE

Dans l'article qui suit, on donne les grandes lignes d'une stratégie d'évaluation des sédiments suivant laquelle on réalise une analyse combinée des aspects chimiques et physiques sur place et en laboratoire pour définir et délimiter la contamination sédimentaire. Si cette stratégie était mise en application, on pourrait définir les conséquences de la contamination chimique d'une façon utile au point de vue biologique et mettre en évidence les liens pouvant exister entre le degré de contamination et la réaction des communautés d'organismes des lieux touchés. En prenant comme exemple des données sur la chimie des sédiments et la structure des communautés d'invertébrés benthiques dans la rivière Détroit, on montre tout ce qu'on peut faire avec ce genre de renseignements et d'analyses. On délimite avec netteté la zone touchée, on met en évidence les effets biologiques de la contamination sédimentaire, on montre clairement comment six grands facteurs et cinq autres de moindre importance sont à l'origine des effets observés dans un secteur particulier de la rivière et finalement, on explique comment on peut définir les objectifs du

nettoyage. Il est essentiel de disposer de ce genre de renseignements pour établir un cadre de travail clair et compréhensible en vue d'évaluer et de corriger la pollution des Grands Lacs et d'autres eaux douces.

INTRODUCTION

Sediments contaminated with nutrients, metals, organics and oxygen demanding substances can be found in freshwater and marine systems throughout the world. While some of these contaminants are present in elevated concentrations as a result of natural processes, most are due to anthropogenic activities. In addition many of these compounds do not occur naturally. Sediments with elevated levels of contaminants have been identified in many of the nearshore, embayment, and tributary mouth areas in the Laurentian Great Lakes. These sediments have been designated as contaminated almost exclusively on the basis of bulk chemical analyses. In several cases, despite this designation, contaminants are present at levels lower than historic background concentrations found in sediment cores taken from the nearby, open lake depositional basins (Reynoldson et al, 1988). In addition, measuring the concentrations of various chemicals present in the sediments does not address the ultimate concern; namely, whether the contaminants present are exerting biological stress or are being bioaccumulated. A series of bioassessment techniques, along with appropriate criteria, are necessary to identify the type of stress being exerted, as well as its severity, and the bioavailability of the contaminants present.

BIOASSESSMENT APPROACHES

Chapman and Long (1983) suggested that adequate assessments of sediment quality should involve three components; concentrations of toxic chemicals (bulk chemistry); measures of the toxicity of environmental samples (functional bioassessment); and measurements of the species composition and densities of the resident biota (structural bioassessment). Together, these three categories of measurement have been termed the sediment quality triad (Chapman & Long, 1983). The authors tested this approach in Puget Sound, Washington and found good general correspondence between the three measures of sediment quality; however, chemical data alone were not always reliable indicators of biological effects (Long & Chapman, 1985).

There are many bioassessment techniques available, although not all have been used extensively in freshwater. However, a fundamental distinction can be made between structural and functional approaches to bioassessment. Much of the earliest work was of the structural or taxonomic variety, where changes in community structure and indicator species were related to anthropogenic and naturally induced stresses. Community structure information, which provides evidence of impact at one or more trophic levels within the ecosystem, can be easily and rather inexpensively obtained. Sediment related biological stress can best be demonstrated by examining the macrozoobenthic community (IJC, 1987). While structural information is necessary, desirable and readily attained, its specificity is often insufficient to influence a remedial action or effect a regulatory change, since cause and effect cannot be easily inferred from structural data alone. Functional tests or bioassays can provide this necessary information, since they are specific, and are usually capable of discriminating the root cause of structural changes as well as quantifying dose-response relationships.

Functional biological monitoring can be broadly defined as the measurement of any rate process or response of the ecosystem, and can utilize both taxonomic and non-taxonomic parameters (Mathews et al., 1982). Such taxonomic tests include measures of species colonization or emigration rates and the rate of re-establishment of equilibrium densities following perturbation (Cairns et al., 1979). The more frequently used non-taxonomic tests include acute (short-term) and chronic (longer term) measures of behavior, biochemical - physiological changes, bioaccumulation, genotoxicity (mutagenesis, carcinogenesis, teratogenesis), reproductive failure and death. While many of these tests can be conducted in situ, the need for strict control over exposure conditions means that most bioassays are conducted in the laboratory. In addition, most of these tests are performed using single species which may not be indigenous to the area under investigation. Therefore, although functional tests can provide quantifiable relationships between contaminants and organisms and isolate sediment as a contributing factor, their lack of environmental realism and failure to incorporate ecosystem complexity limits their investigative utility and possibly their ability to establish actual impairment (Monk, 1983). The obvious solution to this dilemma is to use both structural and functional methods to examine stress.

STRATEGY

Since a number of functional bioassays as well as data handling techniques are available, a strategy which describes the information requirements, the overall approach, the preferred techniques and the data handling procedures to be followed, is necessary. An ideal strategy should: (1) integrate physical data along with chemical and biological data, to provide an accurate assessment of the specific problems; (2) utilize the results from each technique to reduce subsequent sampling requirements and, therefore costs; (3) provide adequate proof of the linkage between the contaminated sediments and the problem (i.e. cause-effect relationship); (4) quantify problem severity, thereby enabling inter-comparisons between and within areas of investigation; (5) consider the impacts or effects on different species and different trophic levels - since biological impairment may occur in both the water column (if resuspension occurs) and the sediments, and since there is no such thing as the universal, most sensitive species (Cairns, 1986). The proposed strategy (Figure 1) consists of an initial assessment (Stage I), for areas with limited, antiquated, or no prior information, followed by a detailed investigation (Stage II).

Stage I: Initial Assessment

This presents an opportunity to screen for a potential sediment problem or to confirm the persistence of problem conditions where older or limited data are already available. The information collected, in this stage, represents the minimum necessary to assess potential sediment problems and all of the tests should be done. Should further, more detailed sampling be required, these data will further assist the investigator with sampling design.

Sediment sampling sites should be selected based on previous sample collections, bathymetric information and/or known or suspected discharge locations. Samples must also be taken from depositional areas. Since physical, chemical and bioassessment measures are to be made on the same samples, a single field excursion should suffice.

Grain size, water content, redox potential (Eh) and pH should be measured since these factors affect contaminant concentrations and benthic community structure. In addition, surficial sediments should be analyzed for nutrients, metals, total organic carbon, persistent organics, and oxygen consuming contaminants (IJC, 1987 1988).

Many hazardous contaminants are capable of being transferred from the sediments to the biota and accumulating at higher concentrations in subsequent trophic levels. Therefore, body burdens of hazardous contaminants should be examined in both indigenous macrozoobenthic invertebrates and adult demersal fish. The benthos, being more sedentary, provide a more direct measure of the specific relationship between localized sediment contaminant concentration and bioavailability. The fish provide a larger spatial and temporal integration of contaminants (IJC, 1987 1988).

All of the fish collected for body burden analysis, should be examined for external abnormalities. In addition, a subsample of any fish with external deformities should be retained to allow complete histopathological analysis if a detailed assessment is necessary. The subsample should represent a cross-section of external deformity types, so that potential correlations between external abnormalities and histopathologic results can be examined in different fish species. These correlations may allow the expensive and time consuming histopathologic examination to be circumvented in future assessments.

It is recommended that a preliminary estimate of community structure impairment be made at the same sampling sites. Since this is an initial assessment only, it is not recommended that a quantitative study be undertaken; instead, qualitative estimates should suffice to identify the existence of a stressed community. Sample replication should be minimal, and taxonomic detailing to the family level at this stage will be sufficient to identify severe impact.

Criteria for Initial Assessment

The concentrations of metals in sediments should not exceed the background levels found, in the nearest open lake depositional basin. In the Great Lakes, the background concentrations have conventionally been taken as those occurring below the ragweed pollen layer, which is associated with deforestation. Other regions may have other such convenient markers. Sediment concentrations of hazardous persistent organics should be less than detection levels using the best scientific methodology available. In the absence of existing objectives, the concentrations of hazardous persistent organics in fish or benthos should also be non-detectable using the best scientific methodology. Concentrations of metals should be assessed on a case-by-case basis recognizing the physiological requirements for certain metals by each species.

The absence of a healthy benthic community represents an additional assessment criterion. This condition is defined by the absence of clean water organisms such as amphipods or mayflies, or a community dominated by oligochaetes, or the complete absence of invertebrates. These conclusions should be supported by evidence that the conditions are not due to a major perturbation such as dredging and/or substrate modification.

The presence of one or more external abnormalities on fish are often indicative of anthropogenically induced stress or damage. In the Great Lakes, external abnormalities such as stubbed barbels, skin discolouration (melanoma) and skin tumors are found to be highly correlated with liver cancer in brown bullheads (*Ictalurus nebulosus*; Smith et al., 1988). Therefore, external abnormalities with a strongly suspected contaminant etiology should be absent (IJC, 1987 1988).

If any of these criteria are violated, then a more detailed investigation of the sediments is required.

Stage II: Detailed Assessment

The objectives of the detailed assessment are to determine the nature and severity of the sediment problem(s), and to determine the spatial and temporal extent of the contamination. The procedures are phased, but ALL ARE REQUIRED, and emphasis is placed on the use of physical information to assist the investigator in reducing sampling and testing requirements in subsequent phases. These phases do not represent rigid bounds, but rather logical groupings of work with the final design being the responsibility of the investigator. For example, in geographically small areas which require few sampling stations, Phases 2 and 3 could be combined. This modification would eliminate the need for further field collections to be made.

Phase 1

The first step is the development of a three dimensional map of the physical composition of the sediments throughout the study area. The depositional areas should be precisely determined since more effort will be focused in these areas. Methods for obtaining this information are outlined in IJC (1987, 1988). Sampling results should be examined using cluster analysis (or a similar technique) which is simple to perform with available computer packages and provides good synthesis of complex data matrices. The resultant maps will define homogeneous areas for further examination in subsequent phases.

Phase 2

A second field collection will analyze benthic community structure and coincident surficial chemistry (total organic carbon, redox potential, pH, metals and persistent organics). Based on the previous mapping of homogeneous zones of sediment type, a stratified random sampling technique should be employed with more effort expended in the depositional areas and those areas with fine grained sediments.

Since the main objective of community structure assessment is to examine subtle distinctions in stress response, more detailed taxonomic data are required. In many nearshore areas, the community may be dominated by oligochaetes or chironomids, or both. While this may be indicative of impairment, there are considerable variations in environmental tolerance between species in these groups to adverse conditions. Species level identification can provide invaluable information for distinguishing and mapping zones of sediment impact.

In addition to examining the results for indications of adverse environmental conditions (or impacts), chemical, physical and community structure data should be combined to test for further homogeneity using multivariate analyses.

Phase 3

For this phase, an additional field excursion is required for the collection of surficial sediments, sediment cores and indigenous fish. Information collected previously on impact and areas of homogeneity should allow sediment sampling sites to be reduced to an absolute minimum.

While effects on communities and ecosystems can best be studied by directly looking at changes in these systems, such methods can only be used after impacts have manifested themselves. Therefore, bioassays form an important part of a comprehensive approach to contaminant hazard assessment. Where possible, bioassays should be performed with sensitive, indigenous species so that results can be directly related to the infauna. Also, tests which examine the same effect in two or three species are better since this ensures a comprehensive data set, especially for areas with moderate contamination that may be at or near the toxicity threshold for some species. Sublethal effects should provide the major testing focus, and in particular, emphasis should be given to reproductive impairment.

Sediment bioassays which examine biochemical and physiological effects, bioaccumulation, genotoxicity, reproductive alteration and lethality (both acute and chronic) were reviewed. Tests which evaluate these effects, had standardized protocols, extensive use, comparative data and were relatively simple to perform, were selected (IJC, 1988). The following bioassays also examine the effects on multiple trophic levels (bacteria, phytoplankton, zooplankton, benthic invertebrates and fish), and their exposure to dissolved as well as bound contaminants are recommended.

1. Microtox (Bulich & Isenberg, 1980; Bulich, 1984).

2. Algal Photosynthesis Bioassay (Ross et al., 1987; Munawar et al., 1983).

3. Fish and Benthic Invertebrate Bioaccumulation (Mac et al., 1984).

4. Ames Test (Ames et al., 1975).

5. Zooplankton Life Cycle Test (Nebeker et al., 1984).

6. Benthic Invertebrate Bioassay using the mayfly *Hexagenia limbata* or the midge larva *Chironomus tentans* (Mosher et al., 1982; Malueg et al., 1983; Nebeker et al., 1984).

The continuum of effects, or differences in organism response is documented in all of these bioassays, rather than the pass/fail results of a single endpoint. For example, the percent reduction in egg production and hatching of *Daphnia magna* for each sample (compared to a control) is measured. In this way, the relative toxicity of each sample can be examined test by test, as well as the combined test results for a geographic area. Controls should be established from samples taken well outside each area of study. Particular attention should be paid to obtaining sediments which are physically similar so that effects due to substrate differences are minimized or eliminated.

The data generated should be used in two ways: statistically significant departure of test results from control for any of the tests implies that some form of corrective action will likely be necessary; and plots of individual results should be overlapped to produce a "toxicity map" which will rank, by severity, each area tested.

Since the ultimate goal of this assessment is to provide sufficient information to affect some remediation of the contaminated sediments. Furthermore decisions on remediation will require information on historic trends to allow appropriate decisions to be made. Therefore sediment cores must be collected to ascertain the vertical extent and temporal trend of contamination. Chemical analyses of the dated core sections should be conducted, based on the surficial chemical results, to identify the volume or total mass of contaminated sediments. These chemical measurements should be further supported with a few bioassays which should also be chosen on the basis of the surficial test results.

Histopathologic examinations should be conducted on indigenous, demersal adult fish since many of the observed abnormalities, particularly liver tumors, have an etiology linked with contaminants (Couch & Harshbarger, 1985; Smith et al.,1988).

Criteria

Existing data are insufficient to develop precise criteria which dictate the action threshold for the remediation of contaminated sediments. Therefore, it is recommended that data necessary to establish action threshold criteria for community health, bioaccumulation, and chronic toxicity be collected.

In the absence of bioassay specific criteria, it is recommended that any effect which is significantly different from a control, at the 95% probability level,should be sufficient to establish test failure. A sediment of similar particle size and organic content, collected from a nearby area should be used as a control. Mortality, or other relevant changes in the control should not exceed 10% to validate the test. The incidence of liver tumors should not exceed 2% in brown bullheads. It is suggested that statistically significant departures from a normal or expected community (as described in Phase 2) be considered unacceptable.

THE DETROIT RIVER

To illustrate the anticipated results from the proposed sediment assessment protocol, existing data sets in the Great Lakes basin were sought which had a combination of sediment chemistry, physics, benthic invertebrate community structure and sediment bioassays, for a retrospective analysis. The most comprehensive data were those from the Detroit River (Fig. 2). This river connects Lake St. Clair to

Lake Erie, and is one of the most industrialized regions in the Great Lakes. Results were provided by the Ontario Ministry of the Environment from 1980 sampling of surficial sediments and benthic invertebrates from the same stations. Sediment bioassays were not conducted at that time, and although Giesy et al. (1988) performed assays in this region, differences in site location made them incompatible for this analysis.

Phase 1

The first step in the proposed strategy requires a detailed physical mapping of the sediments to define areas of homogeneity. Samples were taken from 59 stations (Fig. 2) and Wentworth particle size determined. Data from eight sediment size fractions (Table 1) were used in a divisive clustering algorithim (k means) to determine site similarity.

TABLE 1.

PHYSICAL AND CHEMICAL SEDIMENT CHARACTERISTICS AND BIOLOGICAL VARIABLES ANALYZED IN THE DETROIT RIVER 1980, AND USED IN CLUSTER ANALYSIS

PHYSICAL	CHEMICAL	BIOLOGICAL
Gravel	Mercury	Tubificidae
Sand 18	Cadmium	Naididae
Sand 35	Zinc	Lumbriculidae
Sand 60	Chromium	Enchytraeidae
Sand 120	Lead	Hirudinoidea
Silt	Nickel	Nematoda
Clay (2 hr)	Iron	Coelenterata
Clay (3.2 hr)	LOI	Turbellaria
	Total Phophorus	Sphaeriidae
	Total Nitrogen	Gastropoda
	DDT & metabolites	Unionidae
	Lindane	Amphipoda
	PCB	Isopoda
	HCB	Decapoda
	Dieldrin	Hydracarina
	Endrin	Chironomidae
	Thiodene	Coleoptera
	Chlordane	Odonata
		Trichoptera
		Ephemeroptera

The results have been plotted on a representative map of the river and interpolated by hand. The sediment distribution is extremely complex and heterogeneous, as one would anticipate in a large river. Particle size distribution would tend to be less variable in an embayment or harbour and therefore such a survey and analysis would provide more assistance in reducing subsequent sampling requirements. In this system, the fine sediments (Gps. 1 and 2), which are usually associated with higher levels of contaminants, are found downstream of Zug Island and the Rouge River on the U.S. bank of the Trenton Channel, downstream of Grosse Isle and Fighting Island and at the mouth of the Detroit River.

Phase 2

The second phase of the assessment strategy consists of more extensive sampling and analysis of surficial sediment chemistry and the resident benthic invertebrate community. Once these data are obtained, a clustering technique can again be used to determine areas of similarity and perturbation. Eighteen chemical variables and the benthic invertebrate species enumeration data were analyzed using the same clustering technique.

The chemical data show the majority of the sites to comprise one group (Gp. 5), having comparatively low levels of metals and organic contaminants (Fig. 4). Sediments with higher contaminant levels comprise the four Groups on the U.S. side of the river and values for those contaminants contributing most to group formation are presented in Fig. 4. The chemistry of the sediments is being impacted by major point source discharges from the various steel and chemical industries in the vicinity of the Rouge River and Zug Island area.

Analysis of the benthic invertebrate data shows a larger area of impact (Fig. 5). The main factor determining group formation is the number of tubificid oligochaetes. These small aquatic worms are known to occur in large numbers in areas of extreme environmental degradation (Milbrink, 1980 1983), and can tolerate high levels of nutrient enrichment as well as metals and organic contaminants (Wentsel et al, 1977; Chapman et al., 1980). Numbers of more than 1 million per square metre are extraordinary however and have seldom been recorded in the literature (Caspers, 1980). The impact on the benthic community is seen in the elimination of sensitive groups, such as the Ephemeroptera (mayflies) and amphipods at various sites (Grps. 1 and 2), a reduction in numbers at Group 3 sites (Fig. 5), and the large increases in the tubificid populations throughout.

Data Interpretation

Beyond the simple documentation of impact in terms of chemical concentration levels, the geographical extent of contaminants, and biological impacts, these data can also be used to examine the relationships between the community structure and sediment characteristics. They can be used to determine linkages among sediment physics, chemistry and biota, and provide information on both the geographical extent of required remediation and the level to which contaminants need to be reduced to maintain a healthy and viable community.

The five site groups, identified from the benthic community data (Fig. 5), were correlated individually against each of the physiochemical variables from Table 1. Because the tubificids so dominated the benthic site groups, a second clustering was done without them, and the site groups thus formed also tested against the same variables (Table 2).

TABLE 2.

RANKING OF UNIVARIATE CORRELATIONS BETWEEN ENVIRONMENTAL VARIABLES AND BENTHIC INVERTEBRATE SITE GROUPS FORMED FROM CLUSTER ANALYSIS

Groups formed with Tubificidae			Groups formed without Tubificidae		
Variable	P	F ratio	Variable	P	F ratio
HCB	**0.000**	**273.632**			
TP	**0.000**	**78.346**			
Hg	**0.000**	**15.842**			
Cr	**0.000**	**14.134**			
Zn	**0.000**	**12.195**			
Ni	**0.000**	**10.269**			
LBHC	*0.001*	*13.466*	*Sand 60*	*0.019*	*3.224*
Pb	*0.002*	*4.990*	*Sand 18*	*0.027*	*2.967*
Cd	*0.002*	*4.839*	*Sand 35*	*0.047*	*2.579*
Cu	*0.003*	*4.664*			
LOI	*0.039*	*2.710*			
Silt	0.139	1.815	LOI	0.081	2.202
Sand 120	0.309	1.231	Silt	0.112	1.970
LCHLOR	0.384	1.193	Gravel	0.149	1.768
Sand 18	0.468	0.904	Clay	0.265	1.346
PCB	0.521	0.871	TP	0.386	1.058
Gravel	0.643	0.630	Sand 120	0.432	0.969
Sand 35	0.706	0.542	Zn	0.520	0.817
Sand 60	0.743	0.490	Ni	0.573	0.734
Clay	0.756	0.472	Cr	0.610	0.679
TN	0.904	0.257	Pb	0.655	0.613
			Cu	0.691	0.562
			Cd	0.733	0.503
			TN	0.871	0.308
			Hg	0.974	0.121

The distribution of six variables, four metals Hg, Cr, Zn and Ni, hexachlorobenzene (HCB) and phosphorus, was highly correlated (P<0.001) with the site groups formed when the tubificids were included. Five other variables were also significant (P<0.050) in affecting the benthic community, as expressed by their correlation with the five benthic groups. These included three other metals, Pb, Cd, and Cu. Analysis showed that particle size only correlates for the coarse to fine sands in the sites grouped without the tubificids (Table 2).

To determine the ability of the physiochemical variables to predict benthic invertebrate community structure multiple discriminant analysis (MDA) was used, first for the six highly significant variables (P<0.001), and second for all eleven significant variables (P<0.050) identified in Table 2. The use of more variables resulted in sites being correctly assigned to groups for all stations, for which complete data was available. When only the six variables were used, site membership in the most impacted groups was accurately predicted but not so for less impacted sites (Table 3).

TABLE 3.

THE PREDICTION OF STATIONS TO CORRECT GROUPS USING MDA WITH ENVIRONMENTAL VARIABLES

Six Variables (P<0.001)				Eleven Variables (P<0.050)			
GP	OBS	PRED	CORRECT %	GP	OBS	PRED	CORRECT %
1	2	2	100	1	2	2	100
2	2	2	100	2	1	1	100
3	3	2	67	3	2	2	100
4	5	2	40	4	3	3	100
5	23	16	70	5	12	12	100

Finally, this type of information can be used to determine acceptable levels to which remediation should be undertaken. The mean values of the eleven variables shown to have impacted the benthic community have been determined for the five site groups defined by that community. Clearly, levels of contaminants in the Group 1 and 2 sites are unacceptable as demonstrated through their biological impact. Similarly levels at Group 5 sites are presumed acceptable based on these data. It is suggested, therefore, that an interim goal for sediment remediation in the Detroit River should be the concentrations observed in Group 5 sites (Table 4).

TABLE 4.

MEAN VALUES FOR ENVIRONMENTAL VARIABLES AT SITE GROUPS
FORMED FROM BENTHIC INVERTEBRATE DATA

GROUP	1	2	3	4	5
n	2	2	7	5	43
VARIABLE					
HCB(ng.g)	5.500	196.00	5.670[2]	15.800	6.609[4]
TP(mg.g)	3.25	3.00	0.65	0.87	0.45
Hg(μg.g)	0.32	4.50	0.32	0.27	0.25
Cr(μg.g)	225.00	192.00	41.14	39.56	29.60
Zn(μg.g)	1465.00	975.00	199.86	165.40	150.21
Ni(μg.g)	118.50	73.50	24.14	30.00	22.30
LBHC(ng.g)	5.50	35.00[1]	18.00[3]	11.67	3.10[5]
Pb(μg.g)	300.00	404.50	70.66	43.606	68.73
Cd(μg.g)	7.00	9.85	2.73	1.50	1.18
Cu(μg.g)	239.50	171.00	49.04	32.40	39.87
LOI(%)	5.30	4.00	3.01	3.90	2.36

1 1 value
2 3 values
3 4 values
4 23 values
5 21 values

SUMMARY

The strategy outlined here for sediment assessment uses a combination of sediment chemistry and physics together with in situ and laboratory biological assessment to define and bound the extent of sediment contamination. Furthermore, it expresses the impact of chemical contamination in a biologically meaningful manner and demonstrates the linkages between levels of contaminants and community response. Even with these data, which were not collected for the prime purpose of sediment assessment, and without supporting bioassays, the power of this information and analysis has been demonstrated. Clear boundaries have been placed on an impacted area, the biological effects of sediment contamination are demonstrated, six major and five minor variables have clearly been identified in a specific area of the river, and finally objective levels for clean up can be defined. This type of information is essential to provide a clear and understandable framework for the assessment and remediation of polluted areas in the Great Lakes and other freshwater systems.

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FIGURE LEGENDS

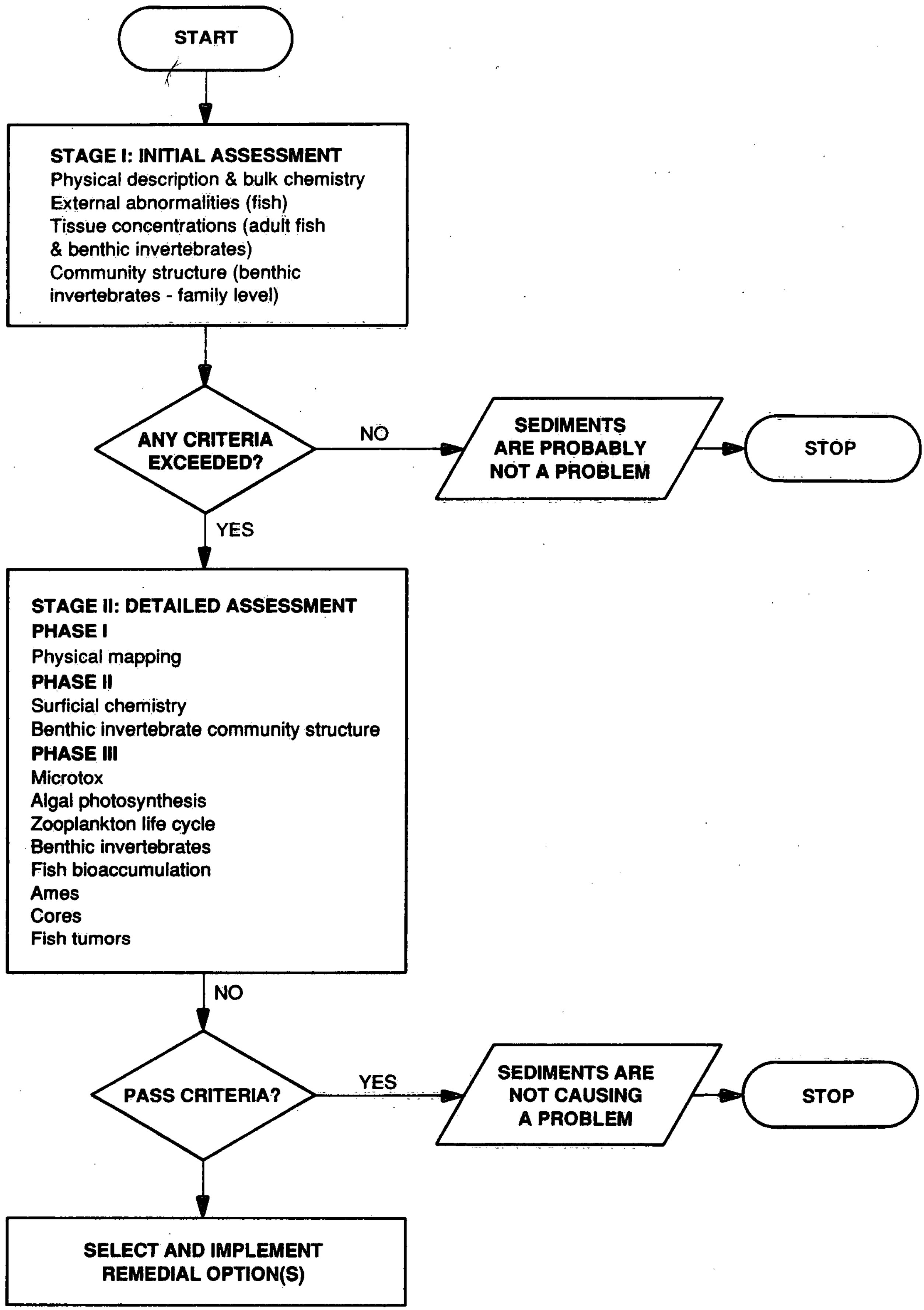
FIGURE 1. SEDIMENT ASSESSMENT FLOWCHART.

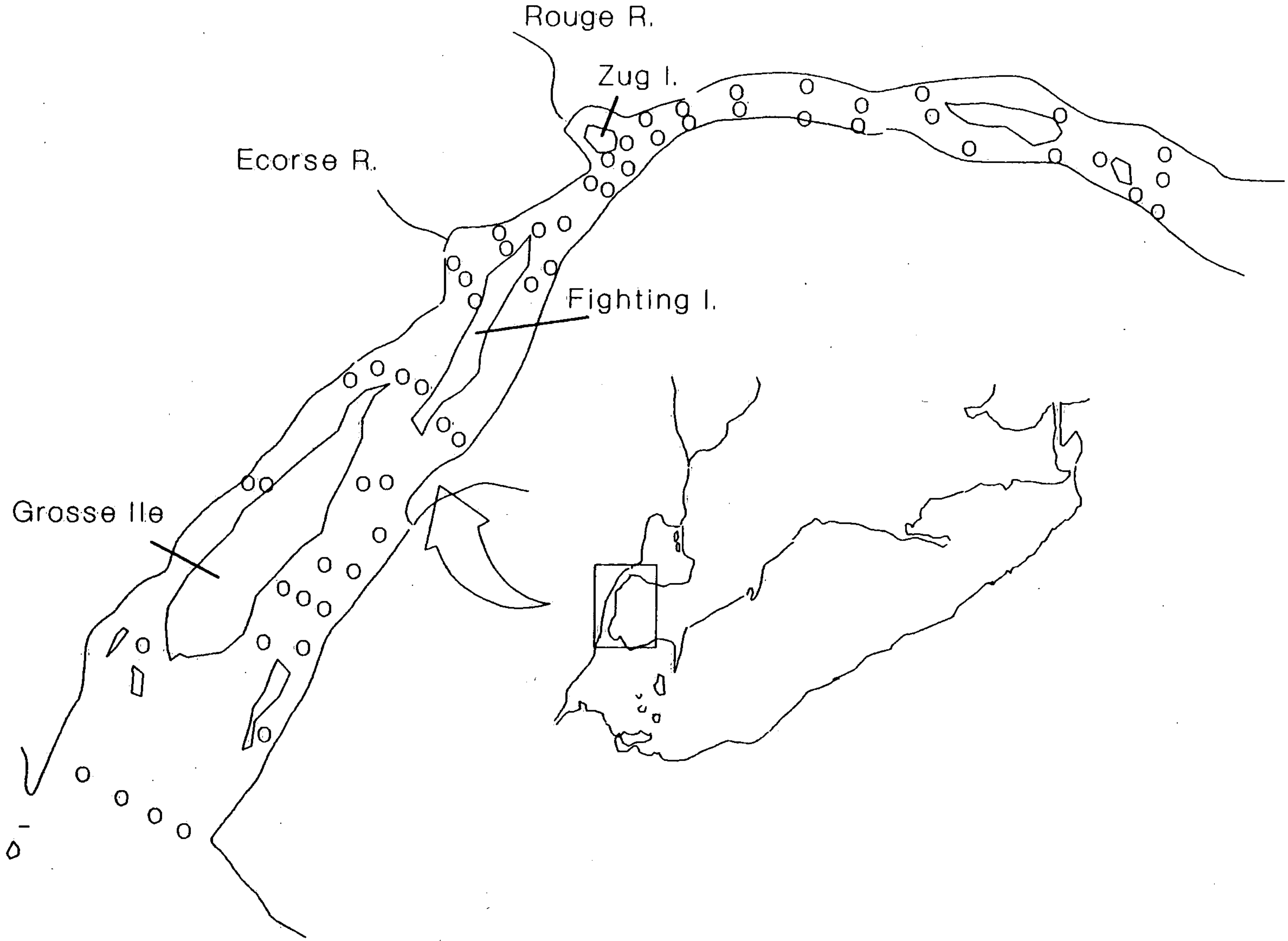
FIGURE 2. THE STUDY AREA AND SAMPLING LOCATIONS.

FIGURE 3. RESULTS OF CLUSTER FORMATION WITH PHYSICAL VARIABLES

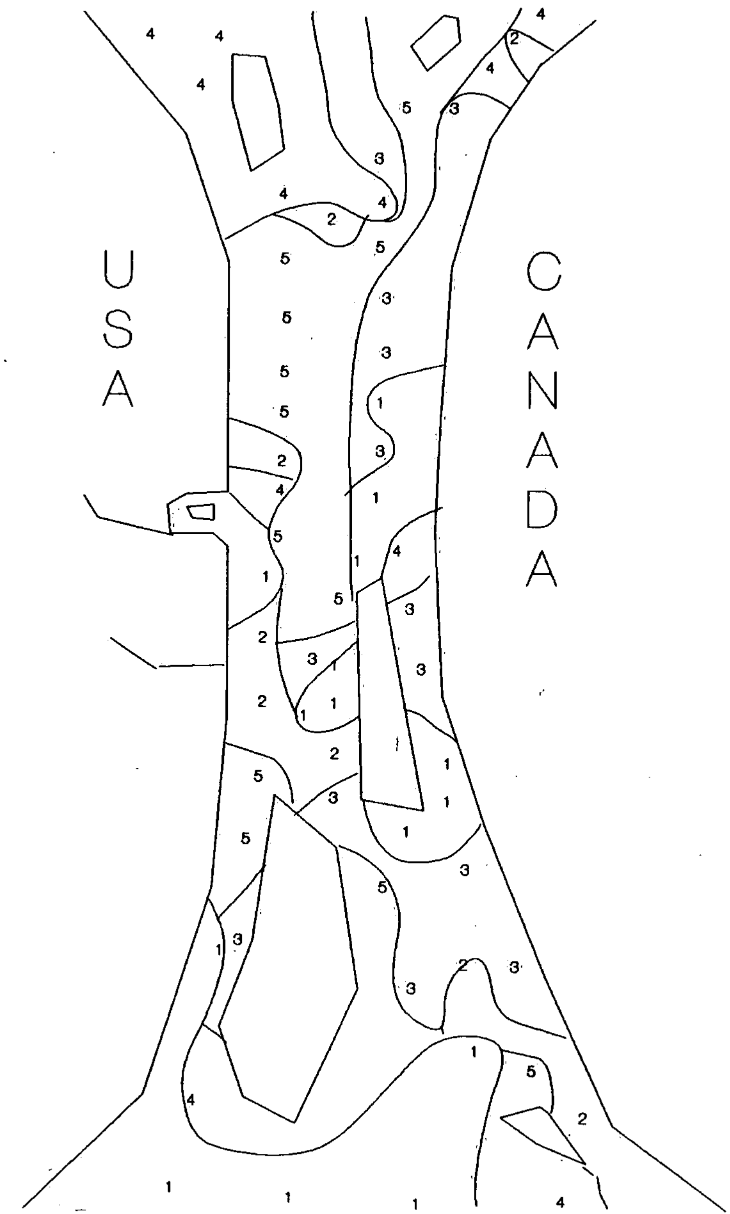
FIGURE 4. RESULTS OF CLUSTER FORMATION FOR CHEMICAL VARIABLES

FIGURE 5. RESULTS OF CLUSTER FORMATION FROM BENTHIC INVERTEBRATE COMMUNITY STRUCTURE

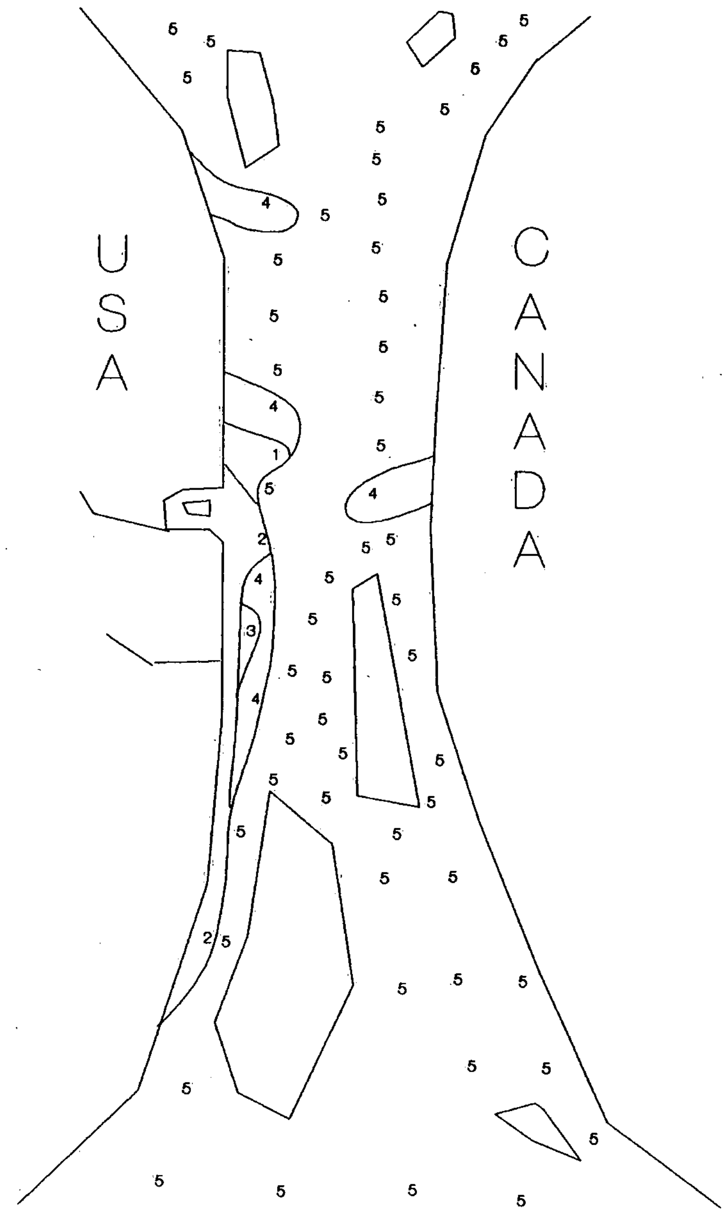

START
STAGE I: INITIAL ASSESSMENT
Physical description & bulk chemistry
External abnormalities (fish)
Tissue concentrations (adult fish & benthic invertebrates)
Community structure (benthic invertebrates - family level)
ANY CRITERIA EXCEEDED?
NO
SEDIMENTS ARE PROBABLY NOT A PROBLEM
STOP
YES
STAGE II: DETAILED ASSESSMENT
PHASE I
Physical mapping
PHASE II
Surficial chemistry
Benthic invertebrate community structure
PHASE III
Microtox
Algal photosynthesis
Zooplankton life cycle
Benthic invertebrates
Fish bioaccumulation
Ames
Cores
Fish tumors
NO
PASS CRITERIA?
YES
SEDIMENTS ARE NOT CAUSING A PROBLEM
STOP
SELECT AND IMPLEMENT REMEDIAL OPTION(S)


Rouge R.
Zug I.
Ecorse R.
Fighting I.
Grosse Ile

GP	Gravel %	Sand %	Silt %
1	5.2	11.7	46.0
2	3.2	24.4	30.1
3	8.7	47.7	13.6
4	13.0	28.5	6.4
5	59.6	17.9	5.8



GP	DDT ng.g	PCB ng.g	ZN ug.g	CU ug.g
1	16016.0	2960.0	760.0	370.0
2	162.5	2210.0	1350.0	192.0
3	40.0	3800.0	2400.0	380.0
4	38.0	539.0	508.0	134.8
5	22.9	120.2	103.3	24.6



GP	TUBIF.	EPHEM. No. m2	AMPH.
1	1691000	4	0
2	59829	4	0
3	5192	130	8
4	2780	241	72
5	323	142	60