A REVIEW OF CRITERIA FOR EVALUATING OCEAN DUMPING PERMIT APPLICATIONS WITH RECOMMENDATIONS FOR FUTURE MONITORING REQUIREMENTS

Prepared For

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Project #6510

December, 1981

E.V.S. consultants ltd.

E.V.S. File: #6510

December 17, 1981

Mr. H. Nelson
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Dear Mr. Nelson

Re: A Review of Criteria for Evaluating Ocean Dumping Permit Applications with Recommendations for Future Monitoring Requirements

We are pleased to present our report on criteria used to evaluate ocean dumping permit applications.

Generally, we found considerable evidence recommending a move towards the adoption of biological tests for evaluating the ecological impacts of dredge spoil disposal in the oceans. Recent legislation in the United States has made similar recommendations based on a number of scientific studies which we have reviewed. Our recommendations have been made in light of our review of data on ocean dumping from the Pacific Region, and include suggestions for modifying the System 2000 Ocean Dumping Data Base.

We have enjoyed working on this project and hope it meets with your satisfaction.

Yours very truly,

E.V.S. CONSULTANTS LTD.

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ERM:dcm

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ACKNOWLEDGEMENTS

The authors would like to extend their appreciation to Hal Nelson and Barbara Smyth of the Environmental Protection Service for their assistance and co-operation in the preparation of this review.

E.V.S. Consultants Ltd. would like to acknowledge the principal investigators, E.R. McGreer and D.E. Konasewich who undertook this study and the following members of E.V.S. Consultants Ltd. staff: G.A. Vigers, N. Treloar, D. MacNicol and L. Borleske.

SUMMARY

McGreer, E.R. and D.E. Konasewich. 1981. A review of criteria for evaluating ocean dumping permit applications with recommendations for future monitoring requirements. Report prepared for the Environmental Protection Service by E.V.S. Consultants Ltd., North Vancouver, B.C. 27 p. + Tables and Figures.

Current legislation on ocean dumping in Canada and the United States was reviewed with emphasis on assessing the parameters used to evaluate ocean dumping permits. Generally, the review showed a trend towards the use of biological testing to assess possible ecological impacts of dredge spoil disposal. Scientific studies which pointed to the need for biological evaluations, and to the inadequacies of relying solely on chemical criteria (e.g. bulk chemical content) to assess dumping impacts were discussed. Parameters incorporated in the Canadian System 2000 Ocean Dumping Data Base were evaluated, and recommendations were made for modifications and additions to those presently listed. Specific recommendations included the need to have more accurate information reported on field sampling methods, and chemical analytical techniques. Monitoring data from selected dredge and dump sites in the Pacific Region were reviewed but trends were not well defined due to the paucity of time series data, and differences in sampling methods and analytical techniques employed. Recommendations for future monitoring included implementation of bioassay testing for evaluating long-term effects of spoil disposal, and standardization of methodologies for physical, chemical and biological sampling and analysis to be used by contractors and government agencies involved in ocean dumping monitoring.

1.0 INTRODUCTION

In Canada, the disposal of dredged spoils and hazardous solid waste materials to the ocean is regulated by the Ocean Dumping Control Act (ODCA) which was promulgated on December 13, 1975 as a result of an international agreement under the 1972 London Convention.

In the Act, a number of potentially hazardous contaminants were identified under Schedule 1 Prohibited Substances, and maximum quantities and concentrations for these substances in ocean dumped materials were established. Schedule 1 substances include organohalogen compounds, mercury and mercury compounds, cadmium and cadmium compounds, persistent plastics and other synthetic materials, a variety of oils, radioactive wastes and substances produced for biological and chemical warfare (Table 1). Additional substances and specific chemical compounds of concern were identified under Schedule II Restricted Substances in the Act (Table 1), but no maximum quantities or concentrations were prescribed. Compounds identified in Schedule II included arsenic and lead. A number of other factors to be taken into account in granting permits were also listed in the Act under Schedule III including the total amount and composition of material to be dumped, and its chemical and biological properties (Table 2).

Data on the common parameters used in evaluating ocean dumping permits in Canada are presently being compiled by computer in the System 2000 Ocean Dumping Data Base by the Environmental Protection Service of Environment Canada. Parameters listed are those which have been used to evaluate ocean dumping permits across Canada. The System 2000 Data Base is designed to store and collate data from ocean dumping permit applications, and from dumpsite monitoring programs.

As the System 2000 Data Base has only recently been implemented, "debugging" of the program is continuing and comments on errors or omissions have been solicited. The primary purpose of the present report was to critically review the parameters listed in the national Data Base, and to assess their relative importance in light of current thinking with respect to ocean dumping in North America. In addition, a representative cross-section of permit applications from the Pacific Region were reviewed, and comments made on the methodology of parameter measurements and apparent trends in the data.

1.1 Objectives

The objectives of the present review were as follows:

1. To review current ocean dumping legislation in Canada and the United States with emphasis on evaluating parameters used to evaluate ocean dumping permits.

2. To compare and assess parameters presently listed in the System 2000 Ocean Dumping Data Base with respect to their relevance/importance in light of current ocean dumping monitoring requirements.

3. To evaluate trends in ocean dumping permit data from the Pacific Region.

4. To make recommendations for modifications or additions to the list of parameters presently included in the national System 2000 Ocean Dumping Data Base.

2.0 REVIEW OF CURRENT OCEAN DUMPING LEGISLATION IN CANADA AND THE UNITED STATES

2.1 Background

In the past, most ocean dumping regulations involved the application of simple chemical criteria based on the bulk analysis of the material to be dumped. The concentration of the contaminant(s) of concern in the spoil were evaluated in light of established guidelines, and a decision made whether or not to dump the material in the sea. However, the use of chemical criteria alone has come under increasing criticism as the inadequacies of this method as a basis to reliably and consistently predict ecological effects have been realized. In part, this criticism has grown with the knowledge of the persistent nature of many contaminants in materials being considered for ocean disposal. Many of these substances have been shown to persist for long periods of time in the environment, and to be biologically available. Recent legislation in the United States based on a number of scientific studies has emphasized the need for alternate forms of testing to accurately evaluate ecological effects of the ocean disposal of such materials. Some of the major, recent advances in this area are reviewed in this report.

2.2 Ocean Dumping Control Act Regulations

In Canada, dumping of contaminated dredge spoils can be rejected if concentrations of contaminants exceed maximum quantities and concentrations prescribed for Schedule I Prohibited substances under paragraph 9 (5) (b) of the Act. Under Schedule II of the ODCA, factors to be taken into account in granting Permits include toxicity; (Subsection 1(4)) persistence: physical, chemical and biological 1 (5); and accumulation and biotransformation in biological materials or sediments 1(6). However, the absence of a place for reporting toxicity or biological testing within the System 2000 Data Base would indicate that these tests have not been an integral part of the permit review process in Canada to date. A number of studies (e.g. Swiss et al., 1980; Great Lakes Research Advisory Board, 1978) have recently criticized the sole use of chemical criteria to evaluate possible impacts of dredge spoil and ecological effects. Swiss et al. (1980) assessed the appropriateness of existing regulatory levels for Schedule I substances in light of existing knowledge on:

a) background concentration, both natural and polluted
b) effects of various concentrations of each contaminant on marine biota
c) availability of each substance for incorporation into tissues of marine biota
d) possible implications of the disposal at sea of each substance to the human food web.

The working group concluded that "hard" number limits were not appropriate because data demonstrating relationships between sediment contamination and the biosphere were lacking for each substance. It was felt that changes to existing regulations could not be made until more data on the ecological implications of the disposal of contaminated spoils were available. To demonstrate the lack of knowledge in this area, we have summarized a number of the major conclusions made by Swiss et al. (1980) below:

Organo Halogens

"Unfortunately, virtually nothing is known about the availability to benthic infauna of organohalogens adsorbed to sediments."

Mercury and Mercury Compounds

"Unfortunately, nothing was found about the appropriateness of the regulated limit of 0.75 milligrams per kilogram for mercury and mercury compounds in the solid phase of a waste..."

and "...no information was found to indicate the possible effect such a level of mercury might have on biota, or why this level was chosen in the first place."

Cadmium

"There is relatively little information on the long-term effects of cadmium on marine ecosystems. However, since this element is toxic to and accumulates in marine organisms, potential for ecosystem damage exists."

Persistent Plastics

"The present regulation seems to be completely arbitrary, there is no literature available to justify an increase or decrease in this level."

The major finding of the review by Swiss et al. (1980) was that there was limited scientific information about the direct interactions between sediment contaminants and benthic organisms, and that future research related to the ODCA and supported by RODAC should be directed toward this issue. This conclusion has also been reached by a number of other researchers in the field. For example, Hirsch et al. (1978) concluded that there was little or no correlation between bulk sediment heavy metal content and environmental impact, and recommended development of site-specific toxicity evaluation procedures using whole sediment bioassays. In an extensive review of the impacts of dumping in the Great Lakes, the Board of the International Joint Commission (1978) expressed similar concerns, stating that research results "have shown no relationship between bulk chemical content for sediment and the adverse effect that may result from open-water disposal of that sediment". And "...in other words, dredged material may be classified as "polluted" on the basis of bulk analyses, while in fact few of the contaminants may be available to the environment." Studies which have attempted to devise reliable chemical methods to predict biological or ecological effects of contaminants in marine sediments have had limited success (e.g. Hall and Bindra, 1979; Luoma and Bryan, 1978) due to the extreme complexity of the predictive relationships involved (Burton, 1979).

Predictive relationships become even more difficult to compute when more than one contaminant is present, as is invariably the case in the "real world". It is generally agreed that no adequate chemical procedures exist for assessing the biological or ecological effects of spoil disposal, and that biological testing is required to assess the potential impacts of contaminated spoil to biota (US EPA/COE, 1977). Steps to incorporate biological testing into dumping regulatory/permit programs have been taken in the United States, and examples of these efforts are summarized below.

2.3 Recent Legislation and Permit Requirements in the United States

2.3.1 Marine Protection Research and Sanctuaries Act

In accordance with Section 103 of Public Law 92-532, the Marine Protection, Research and Sanctuaries Act passed in 1972 provided that any proposed dumping of dredged material in ocean waters must be evaluated for potential environmental impacts by the use of criteria published by the Environmental Protection Agency (EPA) in the Federal Register. The criteria adopted (Federal Register 142, No. 7, 11 January 1977) were notable in their requirement for extensive use of bioassay testing of dredged material, and for the publication of an Implementation Manual describing specific evaluative approaches and procedures. The Implementation Manual (United States Environmental Protection Agency/Corps of Engineers, 1977) outlined procedurally sound, routinely implementable guidelines for compliance with the technical requirements for ocean dumping permits. Detailed guidelines were provided for sediment and water sample collection; preparation and preservation of samples; chemical analyses; and, bioassay methodology for liquid, suspended particulate and solid phases which included testing for bioaccumulation potential. As Section 103 was designed to regulate and limit adverse ecological effects of ocean dumping, the Register emphasized evaluative techniques such as bioassays which were felt to provide relatively direct estimations of the potential for environmental impacts.

2.3.1.1 Types of Bioassay Tests

Although the Implementation Manual dealt extensively with testing of separate phases of ocean dumped material, it was generally felt that the greatest potential for impact was in the more highly contaminated solid phase to which bottom-dwelling species would be exposed for the longest time. The manual conluded "...therefore, unless there is a reason to do otherwise, the major evaluative efforts should be placed on the solid phase."

Two main types of bioassays with test substrates were recommended:

i) solid phase bioassays to assess mortality (after 10 days) in select benthic species
ii) tests to assess bioaccumulation potential

Solid Phase bioassays carried out on a number of different types of contaminated sediments from the Pacific Region such as Vancouver Harbour (McGreer et al., 1981), and False Creek (Reid et al., 1981) have shown these substrates are not generally toxic to benthic test species. However, the same studies indicated there was a potential for bioaccumulation of sediment associated contaminants, and this aspect would appear to be of the greatest concern for ocean dumping in the Pacific Region.

The bioaccumulation tests recommended in the Implementation Manual (U.S. EPA/COE, 1977) were intended to assess the potential for long term contaminant accumulations in the marine food web, and an experimental exposure time of 30 days was recommended. If longer term tests were required, it was recommended that the bioaccumulation studies be conducted in the field.

The section of the Implementation Manual (U.S. EPA/COE, 1977) dealing with the methodology guidelines for conducting the bioaccumulation potential tests is included in Appendix I of this report. A number of specific requirements for conducting the tests have been outlined including such important items as the minimum quantity of biological material required for chemical analysis, suitable biological species for test organisms, sampling design, references for acceptable methods of chemical analysis, and specifics with respect to data analysis and interpretation including recommended statistical procedures. The role of bioaccumulation testing in the permit evaluation/decision making matrix is illustrated in Figure 1.

2.3.1.2 Interpretation of Results

In recommending the use of bioassay tests with dredged materials, the US EPA/COE committee recognized that bioassay results could not predict environmental effects precisely, that they were qualitiative at best, and that results would be subject to some additional interpretation. Laboratory studies cannot duplicate the dynamic conditions found in the "real" environment, but can be used as screening tools to indicate the potential for environmental impacts. The Implementation Manual (U.S. EPA/COE, 1977) used mortalilty as an "end point" for acute toxicity bioassays as it was easy to understand the "significance" to the organism. However, even with mortality, it was not possible to predict the true ecological meaning of the bioassay results (i.e. the significance of the death of a certain percent of a particular species in any natural population). Instead, the Implementation Manual took the view of environmental protection that any "statistically significant" difference in mortality (or other biological paramater such as level of bioaccumulation of a contaminant) between organisms exposed to a dredge spoil and a control was a potential cause for concern, and thus undesirable.

Tests which yielded statistically significant results were not intended to be interpreted as having "failed" but rather having raised a "red flag" concerning disposal of that particular material (R. Peddicord, pers. comm.). A guiding principle in interpreting the tests has been that the Corps is charged only with not making dumpsites "worse" environmentally than existing conditions. Thus, disposal in an existing dumpsite or site already receiving input of contaminants poses a different situation than dumping in a relatively pristine area. In this regard the use of "control" and/or "reference" sediments for comparison with test dredgeate material in the various bioassays takes on a special meaning. "Control" sediments from a healthy area are used to indicate mortality (or uptake, etc.) due to the health of test organisms, and other factors related to laboratory test conditions. "Reference" sediments are used to indicate test results which are statistically, significantly different for the dredged material. Where an active dumpsite is used for disposal, statistically significant differences between a test material and a reference sediment may not occur that often.

Additional facts may also be considered in making a decision about any one permit application, especially where a degree of bioaccumulation is indicated (e.g. see pp. G14-15 in Appendix

1). Experimentation with new methods for accurately assessing "safe" or "permissable" levels for contaminants in ocean dumped material is currently an area of active research (e.g. Engler et al., 1981; Suszkowski and Manksy, 1981).

2.3.2 EPA-Guidelines for Specification of Disposal Sites for Dredged Spoil Material

Recent legislation published in the Federal Register (1980 a,b) by the United States Environmental Protection Agency outlines guidelines for specification of disposal sites for dredged material, and testing requirements for selection of disposal sites under Section 44 of the Clean Water Act (1975) which applies to all waters of United States of America. A number of key points included in this legislation are worthy of comment.

2.3.2.1 Rationale Used in Preparing Guidelines

Variations in the nature/characteristics of dump sites throughout the country were considered to be so great that it was unrealistic to arrive at numerical criteria or standards for toxic or hazardous substances on a nationwide basis. Therefore, guidelines concentrated on outlining specific tools to be used in evaluating and testing the impact of dredged material rather than listing numerical pass-fail criteria. The legal position with respect to the guidelines from EPA are given under Section 307 (a) 1 which states in part that "...toxic (restricted) substances are assumed to be present in the aquatic environment unless demonstrated not to be, and that such pollutants are biologically available unless demonstrated otherwise." Since this basis for the guidelines could result in testing of a countless number of substances every time a discharge was proposed, a process was included called "reason to believe " (Section 230.22(b) which stated that when toxic contaminants were considered not to be present in dredged material, no testing was requried. This process allowed for a reasonable number of contaminants thought to be present in a dredge material to be analyzed and tested. The guidelines require the determination of the degree to which material to be discharged will introduce, relocate, or increase contaminants. The guidelines further specified that determination should consider: i) the material to be discharged; and ii) the availability of the contaminants to biota.

The guidelines defined a contaminant as "...a chemical or biological substance in a form which can be incorporated into, onto or be ingested by and that harms aquatic organisms, consumer required organisms or users of the aquatic environment, and includes but is not limited to substances on the list of toxic pollutants" (Section 307(a)(1))-Federal Register January 31, 43 FR4109). The guidelines stressed that potential biological and ecological impacts of contaminants should consider release of contaminants which adversely affect adults, juveniles, larvae or eggs of biota or have undesirable effects on biological communities, causing accumulation or production of toxics or render organisms unfit for human consumption.

2.3.2.2 Evaluation Procedure

The evaluative procedures suggested by EPA for evaluation and testing are shown in Figure 2.

The EPA guidelines stated that, where prior evaluations or scientific testing and research was available, this information should be used in making a determination as to whether or not materials should be dumped. Where an initial evaluation (i.e. chemical) indicated the presence of sufficiently large numbers of chemicals to render impractical the identification and effects of all contaminants by chemical testing, they stressed the need to look at biological effects through the use of bioassay testing, including long-term cumulative effects on aquatic ecosystems (i.e. bioaccumulation).

As test procedures are commonly done in the laboratory and not the field, they were considered only generally predictive of what may actually occur at the disposal site, and results of laboratory tests were not considered to be the sole determinant granting a disposal permit.

The testing requirements also commented on the need to undertake proper chemical analysis of the samples including use of recommended extractants and solvents for determining the availability of contaminants from the dredged material. Comments were made on the particular problems with analysis of organic compounds, and the rapid advances being made in this field with respect to new analytical techniques and instrumentation. The selection of proper techniques which would permit effective extraction for the specific contaminants in a reproducible manner was advised.

2.4 Practical Considerations

An important consideration in performing the type of bioassays previously described is that they require considerable expertise in conducting biological evaluations, a continuing effort to collect or culture stocks of all the recommended test species, and continued maintenance of organisms in good health in the laboratory for the ongoing evaluations. The US EPA/COE Implementation Manual (1977) recognized these requirements and concluded "...these considerations argue against obtaining services of a different group to conduct each evaluation. It is highly recommended that a few groups with demonstrated bioassay capabilities be selected, with each group conducting evaluations for a number of permit applications. This will enable these groups to develop adequate culturing and maintenance capabilities and the expertise and familiarity with the procedures required to consistently conduct them properly, and to provide the most reliable results at the least cost per evaluation." This procedure has been followed by the Corps of Engineers, and from an initially large number of organizations which were tested, the Corps has settled on approxiamtely 10 firms in the United States which they feel are reliable to conduct the biological tests they require (R. Peddicord, pers. comm.).

A second consideration alluded to above is that of cost. Biological evaluations, especially those requiring replication for statisitcal comparison or long-term cumulative studies with concomitant chemical analyses are more costly than simple bulk chemical analysis of dredged material. However, if costs are kept in line with the size of the proposed dredging/disposal operation, the additional monies required by a permit applicant to supply the required biological information should not be onerous. For example, on large, major projects such as the recent 35 million dollar dredging contract to expand the Robert's Bank Superport, provision for 1/2 of 1% of the dredging contract price to provide appropriate bioassay data would have yielded 175,000 dollars for such studies. This practice, of having the proponent provide funding for appropriate monitoring studies has been successfully carried out by the Environmental Protection Service, Atlantic Region (A. McIver, pers. comm.). Where the scope of dredging is much smaller but is repeated on a routine basis, as is common in the Pacific Region, an initial study might include both biological and chemical testing to characterize the dredge spoil. Subsequently, a reduced program (e.g. chemical analysis only) could be undertaken to monitor changes in the nature of the material to be dredged over time.

3.0 PARAMETERS USED IN CANADIAN OCEAN DUMPING PERMIT EVALUATIONS

3.1 Current Parameters

The parameters currently listed for storage in the System 2000 Ocean Dumping Data Base are given below. The list is comprised of Schedule I and II substances from the Ocean Dumping Control Act (1975), and a number of additional chemical and physical parameters for characterizing the dredged material.

1. Organohalogens
2. Mercury
3. Methylmercury
4. Cadmium
5. Oil and grease
6. Organic material extractable hydrocarbons removed
7. Organic material with non-hydrocarbons removed
8. Aliphatic and alicyclic fraction of hydrocarbons
9. 2-3 ring aromatic hydrocarbons
10. Polynuclear aromatic hydrocarbons
11. Plastics
12. Arsenic
13. Lead
14. Copper
15. Zinc
16. Organo-silicon
17. Cyanides
18. Fluorides
19. Pesticides
20. o,p DDE
21. p,p DDE
22. Berylium
23. Chromium
24. Nickel
25. Vanadium
26. Turbidity
27. Percent light transmission
28. Suspended solids
29. Volatile solids
30. Total dissolved solids
31. Temperature (°C)
32. Percent salinity
33. pH
34. Biological oxygen demand
35. Dissolved oxygen
36. Chemical oxygen demand
37. Oxygen saturation
38. Oxygen uptake rate/unit volume
39. Total nitrogen
40. Nitrate
41. Nitrite
42. Ammonia
43. Total phosphorus
44. Depth (m)
45. Depth (cm)
46. Net bottom velocity
47. Total organic carbon
48. Percent moisture content
49. Particle size distribution
    Clay Gravel
    Silt Rock
    Mud Wood
    Sand
50. Other (unspecified)

3.2 Common Parameters Used by RODAC - Pacific Region

Approximately twenty percent of the total number of permits issued by RODAC Pacific Region were selected at random to provide information on which parameters had been most frequently monitored, and to evaluate trends in the monitoring data from selected sites. The frequency with which each parameter was measured from 1976 to 1980 was assessed as an indication of its relative importance in the Pacific Region (Table 3). In the 57 permits examined, only 15 parameters of the 50 listed in the System 2000 Data Base had been monitored. Of the 15 which were monitored mercury, cadmium, PCB's, and particle size distribution were measured in 100% of the 1980 permit applications examined. The only other organic contaminant analyses were for pentachlorophenols monitored in one ocean dumping permit from 1976, and petroleum hydrocarabons in 1979. Loss on ignition which was measured in 87% of the permits in 1976 has been gradually replaced by the more precise total organic carbon (TOC) method. The use of oxygen uptake as a monitoring parameter was consistent over the 5 year period examined, as was particle size distribution. Other parameters such as petroleum hydrocarbons, iron and arsenic were not monitored on a regular basis for ocean dumping in the Pacific Region.

3.3 Trends Apparent in Monitoring Data from Selected Sites in the Pacific Region

As part of our assessment of the parameters currently being used to assess the effects of ocean dumping, we were asked to identify any spatial or temporal trends in sediment chemical data from the various dredge and dump sites. The following section provides a brief overview of some of the trends which were apparent on a site by site basis.

3.3.1 Dredge sites

High levels of chemical contaminants have been found in dredge spoil from False Creek (Bay Forest Products), and from Squamish - Woodfibre (Weldwood, Rayonier and MacMillan Bloedel plants). These dredge sites have been monitored on a regular basis, and thus were selected for evaluation of spatial and temporal changes in sediment trace metal and PCB levels.

3.3.1.1 False Creek - Bay Forest Products

Table 4 lists sediment levels of PCB's and metals reported from sampling at this dredge site for permits 169, 368, 611 and 766, covering the years 1977-1980. Over this period there was an apparent decline in cadmium and zinc, and an increase in PCB levels. However, a major difficulty in comparing data from one year to the next is that samples of different depths were collected on each occasion. In addition, the sampling method was not specified in each instance.

3.3.1.2 Weldwood - Squamish

Mercury, cadmium and PCB levels recorded in permits 12, 460 and 830 (1876-1980) are given in Table 5. Sampling sites varied from one permit to the next, and the limited amount of data at any one site did not allow meaningful conclusions concerning trends to be drawn.

3.3.1.3 Rayonier - Woodfibre

Mercury levels found in Rayonier dredge spoil during the term of permits 20, 343, 588 and 819 (1976-1980) are given in Table 6. The apparent decline in mercury levels with time may be a result of the reduction in the number of samples and sampling sites monitored in permits since No. 343, at which time an extensive survey was taken. Also, where chemical detection limits were greater than the concentration of contaminant in the spoil, results were reported as "less than...", and true values could not abe compared.

3.3.1.4 MacMillan Bloedel - Squamish

Table 7 shows sediment mercury, cadmium and PCB levels recorded in permit applications 233, 417 and 816 covering the period 1976-1980. Data for this site indicated a well-defined decrease in mercury levels with time. PCB levels also declined but the data were limited. Trends in much of the data were difficult to assess levels of contaminants in sediments were ofsten less than analytical detection limits.

In summary, there is evidence of decreasing levels of heavy metals with time at certain dredge sites, notably cadmium and zinc at False Creek, and mercury at MacMillan Bloedel -Squamish. In most other cases, no well-defined trends were apparent. The lack of details on sampling procedures, and changes in sampling sites/depth from one year to the next reduced the ability to accurately compare contaminant levels over time. Moreover, data were often from single grab samples, with no replication which would allow statistical comparisons.

3.3.2 Dump Sites

Point Grey was the only dumpsite which provided sufficient monitoring data for which changes in the degree and extent of chemical contamination over a period of time could be accurately determined. An environmental assessment report by Packman (1980) examined metal concentrations from core and grab samples taken at more than 30 stations in the vicinity of the Point Grey dump site in 1975 and 1978. Analysis from the 1980 monitoring program (unpublished data) have also been included.

Average surface sediment concentrations of Cu, Hg, Pb and Zn reported in each year are given below:

	Metal (ppm)			
Year	Cu	Hg	Pb	Zn
1975	46	0.10	18	102
1978	40	0.55	19	101
1980	53	0.19	79*	118

* "Using a more efficient analytical technique" (Packman, 1980).

Cadmium levels were below the analytical detection limit of 2.0 ppm in all three years. The data indicated increases in copper and zinc levels, and a decrease for mercury. Although the levels of some heavy metals (e.g. Cu, Zn, Pb) had apparently increased over time at stations surrounding the dump site, this was considered to be an indication of substantial dumping outside the confines of the designated dumpsite rather than any spreading of contaminated spoil (Packman, 1980). It should be noted that Point Grey is an active dumpsite, and values reflect continuous addition of new materials.

As time series data at dumpsites are limited, more studies are required to adequately assess changes in contaminants and other parameters. Ideally, such studies should be undertaken at a site which is no longer active, to provide a degree of control for parameters under study. Care should be taken to ensure precise position fixing, and comparable methodologies including sample depth and analytical techniques. Sufficient replication to establish statistical confidence limits is also recommended. Since funding for research is often limited, intensive monitoring of a few select dumpsites would appear to be the most cost-effective approach.

3.4 Comments on the Analysis and Interpretation of Commonly Measured Parameters

In reviewing ocean dumping permit/monitoring data from the Pacific Region, a number of observations were made with respect to measurement and interpretation of parameters. A brief summary of these observations is provided below.

3.4.1 Sampling Methods

Sampling methods varied considerably not only from one site to another but from one sampling occasion to another at any one site. Adoption of standard procedures would greatly assist in comparing data collected at different times. A review of different techniques (e.g., cores, grabs etc.), and a discussion of the advantages and disadvantages of each is provided by Walton (1978). No specific requirement for the depth of sample taken for analysis is listed in the current System 2000 Ocean Dumping Data Base computer profile. Depth is an important parameter, and should be specified in cm, and not given simply as "surface" or "subsurface."

3.4.2 Sample Analysis

Input to the System 2000 computer Data Base presently requires the name of the analyst (C114), and the analytical method used (C115). However, one parameter not specifically requested is the size-fraction of sediment analyzed.

In the Pacific Region, chemical data have been collected on different sediment size - fractions from bulk samples to the < 63 μm (silt/clay) sieve fraction. This has been particularly true for mercury. As mercury (and other trace contaminants) are generally found in greater concentrations in smaller sized particle fractions, it was once believed that analysis of the finer fractions only would be more "accurate" in assessing contamination of dredge spoil. However, the percent composition of this fine fraction in the total spoil was not addressed. Since the maximum concentrations of Schedule I Substances listed in the Ocean Dumping Control Regulations are for the "solid phase" of the dredged material, bulk analysis should be used for chemical analyses in the future.

3.4.3 Chemical Analysis

Advances in analytical methodology, particularly in the field of organohalogen compounds are occurring with increasing frequency. With the number of methods currently available for analyzing chemical contaminants, some degree of standardization with respect to analysis of dredge spoils is desirable. Although the computer Data Base provides a section for stating the analysis used, no recommended methods are given. This can result in a series of different procedures being used to analyze the same contaminant(s) at one site from one study to the next. It would be useful to prepare a list of recommended analytical methods for each contaminant in this regard. A list of references of acceptable methods could be circulated with the permit application. Such a procedure has been followed in the United States (US EPA/COE, 1977). Approval of a preferred method would require a consensus of regional RODAC members. The methods for consideration could be selected from among those already published elsewhere (e.g. US EPA/COE, 1977; Walton, 1978; Department of the Environment; 1979; EPA, 1980). Recommended analytical methods should also be established for new compounds which are added to the list of prohibited substances.

In addition to recommended analytical methods for each contaminant, acceptable procedures for sample preparation, calculation of detection limits, and reporting format should be supplied. Examples of inadequate detection limits (i.e. limits above the maximum allowable concentration under the ODCA) were also noted in a review of permit and monitoring data from the Prince Rupert area (McGreer et al., 1980). When the analyatical detection limit is above that prescribed in the ODCA, an accurate determination of the suitability of the material for ocean disposal can not be made.

Inconsistency in reporting analytical data on a wet weight or dry weight basis was also noted. As values in the scientific literature are also not reported in any consistent manner, it would seem that determination on a wet weight basis, together with the percent moisture content would be most convenient. Conversion to a dry weight basis could then be made and reported when desired.

Report format for chemical analysis should include estimates of precision (i.e. confidence limits) for the values reported, and accuracy based upon comparison with an approved standard. The precision, sensitivity, and accuracy should be part of the information included with the permit and supplied to the computer Data Base.

3.4.4 Mercury

Although mercury was the most frequently analyzed metal in the Pacific Region, analytical reports showed that a number of different methods for sample preparation and instrumentation techniques (e.g. atomic absorption; ultra violet) have been used. Standardization of methods, and reporting of the sensitivity and precisions of the methods used would be desirable.

3.4.5 Volatile Solids

A variety of methods using different ignition temperatures and times have been used in reporting volatile solids. As this term is often equated with volatile organic matter, a standardized method (e.g. APHA, Standard Methods, 1975; Holme and McIntyre 1971) should be adopted. Alternatively, the more precise Total Organic Carbon (TOC) technique should be employed.

3.4.6 Oxygen Uptake Rate/Unit Volume

Different procedures and apparatus have also been used to report the rate of sediment oxygen uptake. Data have been reported as mg O_2/h; mg O_2/24h; mg O_2/g sediment; and mg O_2/cc sediment depending upon the method employed. Oxygen uptake rate can be used to assess the instantaneous rate of oxygen consumption of spoil being dumped or the long-term effect of dumped material with a high oxygen demand. In the latter case, the uptake rate/surface area of spoil may be a more suitable unit of measurement. Where a measure of oxygen uptake for permit approval is requried, appropriate guidelines for determination should be distributed to the applicant.

3.4.7 Particle Size Distribution

Present requirements of the System 2000 Data Base for particle sizing consist of classifying sediments into clay, silt, mud, sand, gravel, rock and wood fractions. The Data Base requires results to be expressed as percent dry weight, however, the Act requires the percentage by volume of each fraction. According to the Wentworth Classification sediment fractions are graded as:

Gravel	> 2,000	µm
Sand	2,000 - 63	µm
Silt	63 - 3.9	µm
Clay Colloids	< 3.9	µm

References to Rock and Mud in the Data Base are more general descriptions for the material. "Mud" can be defined as the combined silt/clay fraction. A sediment can be classified as mud where this fraction (< 63 µm) represents 50% or more of the sediment.

Analytical results for particle size in RODAC permit files are reported in a number of different ways. Frequently, sediments are subdivided into other fractions than those required, or not classified into percent sand, silt, etc. As the computer Data Base accepts the Wentworth series noted above, it would be useful to have all results reported in this way.

3.4.8 Wood

Wood is classified as one sediment "fraction " under particle size distribution by the System 2000 Data Base. The Data Base input requires percent wood expressed as dry weight. Most commonly in the Ocean Dumping Permits reviewed, percent wood was determined only for wood particles > 2 mm in size. Smaller wood particles were not quantified.

As wood wastes make up such a significant part of the materials requiring ocean dumping in the Pacific Region, a more precise determination should be required. A separate subsample of the spoil should be collected for wood content. It would be useful to determine the percent of "floatable" and "non-floatable" wood fractions. These could be dried for percent weight determinations. An estimate of the size fractions could be obtained by measuring larger pieces (>

2mm), and by sieving the remainder (< 2mm) through Wentworth sieves and determining the percent of dry weight. At present not enought is known about the impacts of wood wastes on bottom dwelling species to interpret the biological significance of dumping material of different size fractions. However, continued ocean dumping research on impacts of wood similar to that carried out by Chang and Levings (1976), may lead to better defined critera for permissible wood content of dredge spoil.

4.0 RECOMMENDATIONS

Information presented in this report provides a current review of the criteria being used to assess ocean dumping applications. From the tests which are now routinely required before issuing dumping permits, and the concerns expressed for impacts of ocean dumping of contaminated materials, the following recommendations for future monitoring have been put forward:

1. Establish standard procedures for sample collection including vessel position fixing, sampling gear, sample depth, method of preservation and sediment fraction to be analyzed.

2. Establish recommended methodology/protocols for conducting chemical, physical and biological testing including recommended test species. Emphasis should be placed on recommending existing methods where possible, rather than developing new methodology to enable comparison with values in the scientific literature. Test species, and physical/chemical conditions should be appropriate to the Pacific Region.

3. Incorporate relevant data on methodology into format of System 2000 Ocean Dumping Data Base where no provision presently exists (e.g. detection limits claimed for analysis employed).

4. Conduct studies to monitor long-term changes in biological, chemical and physical features, and impacts from continued dumping at active dumpsites. – D.F.O.

5. Incorporate bioassay testing, particularly tests such as bioaccumulation to assess long-term, cumulative effects on disposal of contaminated material to the marine environment.

6. Continue to support fundamental research into "cause and effect" relationships between disposal of various types of dredge material and potential for biological impacts. In particular, research into long term biological effects of sediment associated chemical contaminants, and the effects of wood wastes on biota would appear to be priorities in the Pacific Region.

7. Undertake studies to relate different methods of chemical analyses and extraction procedures to bioavailability for contaminants of concern in various types of dredge spoil materials.

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FIGURES

FIGURE 1

Sequence of testing and evaluation procedures (from EPA/COE Implementation Manual, 1977)

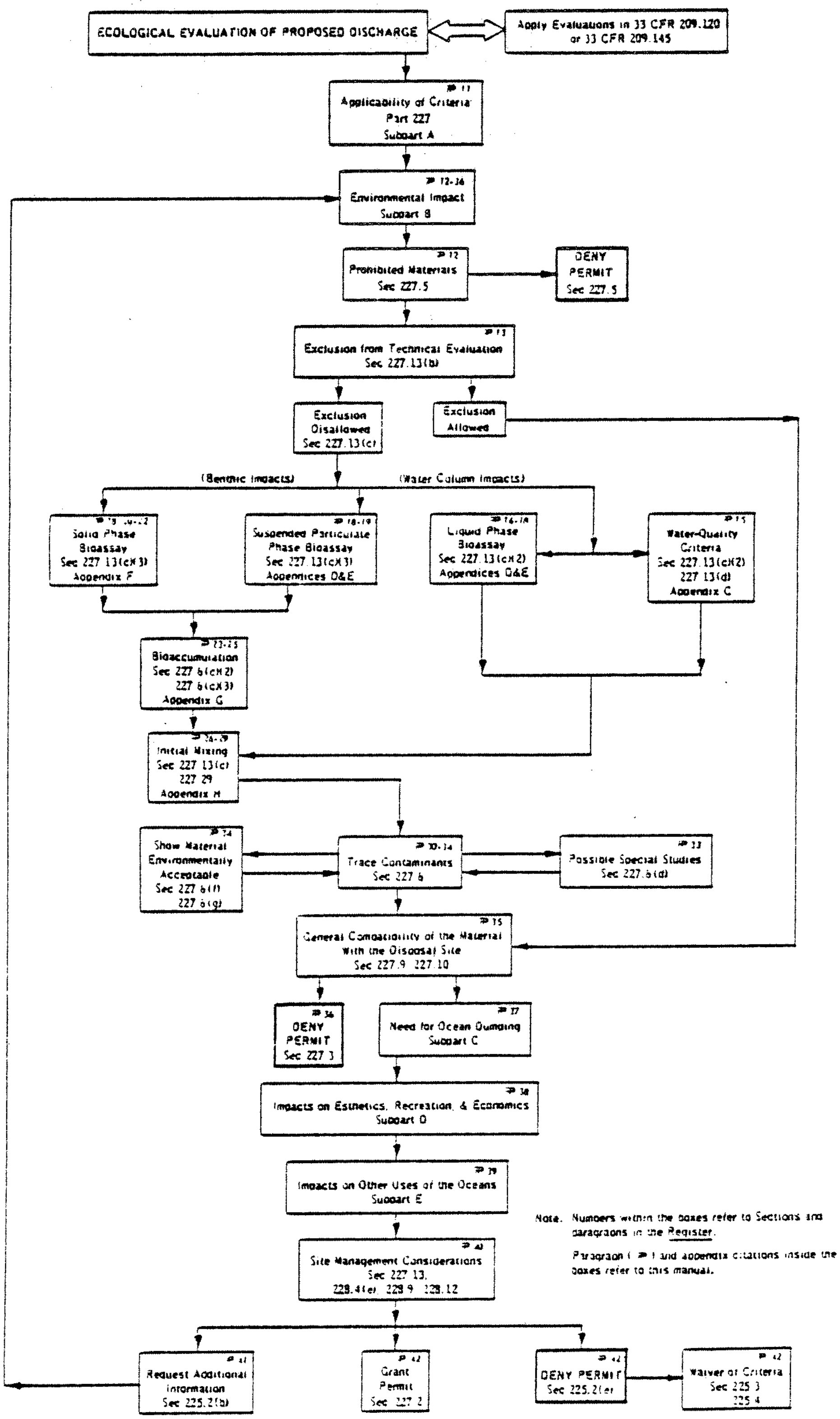
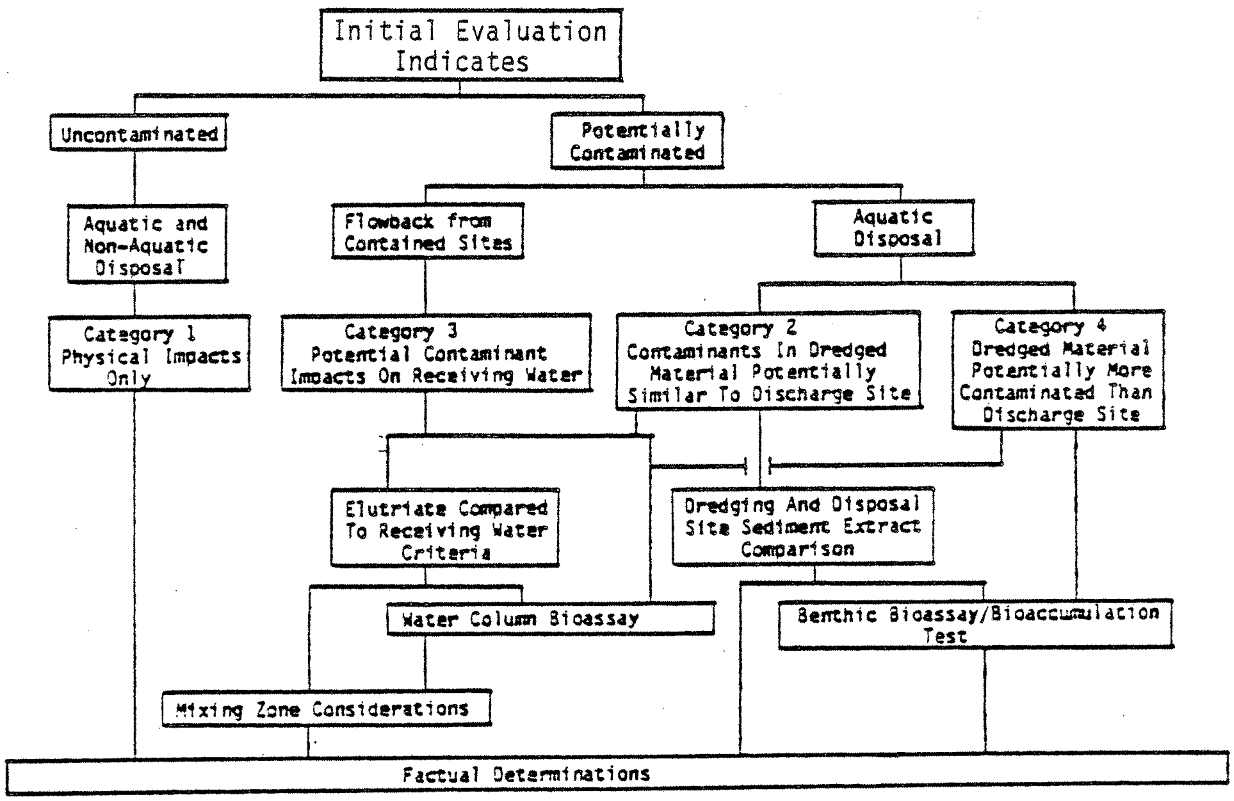


FIGURE 2

EPA Testing Flow Chart (from Federal Register, 1980b)



TABLES

TABLE I

LIST OF SCHEDULED SUBSTANCES UNDER THE OCEAN DUMPING CONTROL ACT

SCHEDULE I

PROHIBITED SUBSTANCES

1. Organohalogen compounds.
2. Mercury and mercury compounds.
3. Cadmium and cadmium compounds.
4. Persistent plastics and other persistent synthetic materials.
5. Crude oil, fuel oil, heavy diesel oil, and lubricating oils, hydraulic fluids and any mixtures containing any of them.
6. High-level radioactive wastes or other high-level radioactive matter that may be prescribed.
7. Substances in whatever form produced for biological and chemical warfare.

SCHEDULE II

RESTRICTED SUBSTANCES

1. Arsenic and its compounds.
2. Lead and its compounds.
3. Copper and its compounds.
4. Zinc and its compounds.
5. Organosilicon compounds.
6. Cyanides.
7. Fluorides.
8. Pesticides and their by-products not included in Schedule I.
9. Beryllium and its compounds.
10. Chromium and its compounds.
12. Vanadium and its compounds.
13. Containers and scrap metal.
14. Radioactive wastes or other radioactive matter not included in Schedule I.
15. Substances that by reason of their bulk would interfere with fishing.

TABLE 2

SCHEDULED FACTORS TO BE TAKEN INTO ACCOUNT UNDER THE OCEAN DUMPING CONTROL ACT

SCHEDULE III
FACTORS TO BE TAKEN INTO ACCOUNT IN GRANTING PERMITS

1. CHARACTERISTICS AND COMPOSITION OF SUBSTANCE

(1) Total amount and average composition of substance dumped (e.g. per year).
(2) Form (e.g. solid, sludge, liquid or gaseous).
(3) Properties: physical (e.g. solubility and density), chemical and biochemical (e.g. oxygen demand, nutrients) and biological (e.g. presence of viruses, bacteria, yeasts and parasites).
(4) Toxicity.
(5) Persistence: physical, chemical and biological.
(6) Accumulation and biotransformation in biological materials or sediments.
(7) Susceptibility to physical, chemical and biochemical changes and interaction in the aquatic environment with other dissolved organic and inorganic materials.
(8) Probability of production of taints or other changes reducing marketability of resources (fish and shellfish).

2. CHARACTERISTICS OF DUMPING SITE AND METHOD OF DEPOSIT

(1) Location (e.g. co-ordinates of the dumping site, depth and distance from the coast) and location in relation to other areas (e.g. amenity areas, spawning nursery and fishing areas and exploitable resources).
(2) Rate of disposal per specific period (e.g. quantity per day, per week, per month).
(3) Methods of packaging and containment, if any.
(4) Initial dilution achieved by proposed method of release.
(5) Dispersal characteristics (e.g. effects of currents, tides and wind on horizontal transport and vertical mixing).
(6) Water characteristics (e.g. temperature, pH, salinity, stratification, oxygen indices of pollution-dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD)-nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity).

TABLE 2 (CONT.)

(7) Bottom characteristics (e.g. topography, geochemical and geological characteristics and biological productivity).

(8) Existence and effects of other dumpings that have been made in the dumping site (e.g. heavy metal background reading and organic carbon content).

(9) In issuing a permit for dumping, consideration should be given whether an adequate scientific basis exists for assessing the consequences of such dumping, as outlined in this Schedule taking into account seasonal variations.

3. GENERAL CONSIDERATIONS AND CONDITIONS

(1) Possible effects on amenities (e.g. presence of floating or stranded material, turbidity, objectionable odour, discoloration and foaming).

(2) Possible effects on marine life, fish and shellfish culture, fish stocks and fisheries, seaweed harvesting and culture.

(3) Possible effects on other uses of the sea (e.g. impairment of water quality for industrial use, underwatercorrosion of structures, interference with ship operations from floating substances, inteference with fishing or navigation through deposit of waste or solid objects on the sea floor and protection of areas of special importance for scientific or conservation purposes).

(4) The practical availability of alternative land based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

TABLE 3

OCEAN DUMPING PARAMETERS MOST FREQUENTLY MONITORED (%) IN PERMITS FROM RODAC PACIFIC REGION

	Year				
Parameter	1976	1977	1978	1979	1980
Hg	13	50	33	100	100
Cd	0	21	0	73	100
Cu	0	21	0	45	20
Pb	0	21	0	36	20
Zn	0	21	0	45	20
As	0	0	0	9	0
Fe	0	7	0	0	0
PCP	7	0	0	0	0
PCB's	0	57	50	100	100
petroleum hydrocarbons	0	0	0	9	0
volatile solids (=loss on ignition)	87	86	92	36	0
O_2 uptake	80	71	92	64	60
total organic carbon	0	7	17	27	60
moisture	0	20	50	58	60
particle size	87	100	100	64	100
no. of Permits examined	15	14	12	11	5

TABLE 4

CONTAMINANT LEVELS (ppm) IN DREDGE SPOIL BAY FOREST PRODUCTS - FALSE CREEK

		Permits (1977-1980)				
		169	368		611	766
			Depth			
Parameter		Top 6"	Surface	4' depth	Not recorded	Not recorded
Hg	mean	0.42	0.9	0.5	1.84	0.41
	min	0.15	0.6	0.5	0.41	0.34
	max	0.62	1.2	0.5	5.6	0.47
Cd	mean	5.7	3.6	1.7	1.38	2.0
	min	5.0	3.0	1.5	0.6	1.0
	max	6.5	4.0	2.0	2.4	2.8
Cu	mean	61	94.3	48.4	102	79
	min	55	93.0	47.5	43	48
	max	70	96.5	50.0	201	114
Pb	mean	126	142	22.6	168	78
	min	92	131	20.0	66	190
	max	158	155	26.0	312	135
Zn	mean	1073	714	120	559	488
	min	760	680	117	308	314
	max	1310	745	124	989	578
PCB's	mean	No Data	0.32	0.01	0.12	2.09
	min		0.09	0.01	0.07	1.29
	max		0.63	0.01	0.18	3.89

TABLE 5

CONTAMINANT LEVELS (ppm) AT WELDWOOD DREDGE SITE

Parameter		Permits (1976-1980) 12	460	830
Hg	Mean	1.10	~0.135	1.01
	Min.	0.24	<0.01	0.02
	Max.	4.94	0.44	2.60
Cd	Mean	No Data	No Data	<0.5
	Min.			<0.5
	Max.			<0.5
PCBs	Mean	No Data	~0.03	~0.013
	Min.		<0.02	<0.01
	Max.		0.05	0.038

TABLE 6

MERCURY LEVELS (ppm) AT RAYONIER DREDGE SITE

Parameter		Permits (1976-1980) 20	343	588	819
Hg Levels (ppm)	Avg.	No Data	~0.08	<0.05	<0.05
	Min.		0.04	<0.05	<0.05
	Max.		0.21	<0.05	<0.05

TABLE 7

CONTAMINANT LEVELS (ppm) IN MacMILLAN-BLOEDEL DREDGE SPOILS

Parameter		Permits (1976-1980) 233	417	631	816
Hg	Avg.	1.08	1.0	0.53	0.11
	Min.	1.08	0.8	0.37	0.07
	Max.	1.08	1.2	0.68	0.15
Cd	Avg.	No Data	No Data	No Data	<0.5
	Min.				<0.5
	Max.				<0.5
PCB	Avg.	No Data	0.007	<0.005	<0.005
	Min.		0.005	<0.005	Trace
	Max.		0.009	<0.005	0.005

APPENDIX I

"Guidance for Assessing Bioaccumulation Potential"
(from EPA/COE Implementation Manual, 1977)

APPENDIX G: GUIDANCE FOR ASSESSING BIOACCUMULATION POTENTIAL

Introduction

1. The ocean disposal criteria require that the potential for bioaccumulation of contaminants from dredged material be evaluated in the technical assessment of permit applications. This requires predicting whether there will be a cause-and-effect relationship between an animal's presence in the area influenced by the dredged material and a significant elevation of its tissue content or body burden of contaminants above that in similar animals not influenced by the disposal of dredged material. That is, it must be predicted whether an animal's exposure to the influence of the dredged material is likely to cause a meaningful elevation of contaminants in its body.

2. A variety of laboratory research methods for measuring bioaccumulation are presently undergoing modification and evaluation as regulatory tools. All such methods require one month or more for completion and provide no quantitative method for considering field conditions such as mixing in the interpretation of the results, as required by the Register. Field sampling programs overcome the latter difficulty since the animals are exposed to the conditions of mixing and sediment transport actually occurring at the disposal site in question. The former difficulty is also overcome if organisms already living at the disposal site are utilized in the bioaccumulation studies. The use of this approach for predictive purposes is technically valid only where there exists a true historical precedent for the proposed operation being evaluated. That is, it can be used only in the case of maintenance dredging where the quality of the sediment to be dredged is considered not to have deteriorated or become more contaminated since the last dredging and disposal operation. In addition, the disposal must be proposed for the site at which the dredged material in question has been previously disposed or for a site of similar sediment type supporting a similar biological community.

3. Considering these limiting conditions and following the

procedure given below, it is possible to assess bioaccumulation by animals that have spent major portions of their life in or on a sediment very similar to the sediment in question under the physical and chemical conditions actually occurring at the disposal site. Caged animals of suitable species may also be placed at appropriate stations in and around the disposal site, but this will require a substantial exposure time before analysis. If the conditions discussed above cannot be met in the field, a general approximation of bioaccumulation potential may be obtained as described later in this appendix from animals used in the suspended particulate or solid phase bioassays.

Field Assessment of Bioaccumulation Potential

Apparatus

4. The following is a general description of the major items required. Additional miscellaneous equipment will have to be furnished.

- a. A vessel capable of operating at the disposal site and equipped to handle benthic sampling devices. Navigation equipment must be sufficient to allow precise positioning.
- b. Sampling devices such as a Smith-MacIntyre or other benthic grab. Corers are less satisfactory since they sample a smaller surface area and have a greater penetration than is needed.
- c. Stainless steel screens of 1-mm mesh to remove animals from the sediment.
- d. Tanks sufficient for transporting the animals to the laboratory in collection site water.
- e. Laboratory facilities for holding the animals prior to analysis.
- f. Chemical and analytical facilities as required for the desired analyses.

Species selection

5. The species selected for analysis must occur in sufficient numbers for collection of an adequate sample at all stations. The same species must be collected at all stations since comparisons of bioaccumulation cannot be made across species lines.

6. For each species at each station, a minimum of several grams

of tissue, as indicated in the references given in paragraph 20, must be collected to provide sufficient sample to allow measurement of chemical concentrations. In samples that do not contain sufficient tissue, it will be impossible to quantify the amount of contaminant present. Since data in the form of "concentration below detection limits" is not quantitative, it is vital that sufficient tissue to allow definitive measurement of concentration be collected for each species at each station. It is also important that exactly equal masses of tissue be analyzed for each station. If possible, several samples of sufficient size for analysis should be collected at each sampling station in order to provide a statistical estimate of variability in tissue content of the contaminants of concern. The collection of more than one sample per station, however, may prove impossible in practice if small organisms must be used or if suitable organisms are not abundant at the disposal site. In such cases the use of caged animals, as discussed in paragraph 10, may be advisable.

7. It is desirable to select the largest appropriate species so as to minimize the numbers and collection effort required. However, highly mobile epifauna (such as crabs, lobsters, shrimp, and fish) should not be used, since their location when collected cannot be related to their body burden at the time of collection in any potential cause-and-effect manner. Therefore, relatively immobile species that are fairly large, such as bivalves, some gastropods, large polychaetes, etc., are the most desirable organisms. Any relatively immobile species collectable in sufficient numbers at all stations may be used, but the required collection effort increases sharply as organism size decreases.

Sampling design and conduct

8. Sufficient tissue to obtain definitive body burden values must be collected from each of at least three stations within the disposal site boundaries and from each of at least six stations outside the disposal site. The stations outside the site must be located in areas with a substrate sedimentologically similar to that within the disposal site. These stations outside the disposal site will serve two purposes. If the direction of net bottom transport at the site is known, at least

three stations should be located in a substrate similar to that within the site and in the path of transport away from the site. The data from these stations will provide an indication of uptake of any contaminants transported out of the disposal site. At least three stations must also be located in an uncontaminated sediment sedimentologically similar to that within the site, but in a direction opposite that of the net bottom transport. Data from these sites will provide a reference level of contaminants in tissues to which those levels found in and downstream from the disposal site may be compared. If the direction of net bottom transport is not known, at least six stations surrounding the disposal site should be established in sediments sedimentologically similar to those within the disposal site.

9. In all cases it is mandatory that several stations be sampled, rather than collecting all of the animals at one station. This will provide a measure of the variability that exists in tissue concentrations in the animals in the area. Samples from all stations should be collected the same day if possible and in any case within four days.

10. If caged animals placed around the disposal site are utilized instead of free animals living there naturally, all the considerations of paragraphs 8 and 9 must be evaluated in selecting the sampling stations, including the sedimentological similarity of the substrate at all stations. The cages must be designed and positioned such that the animals are able to burrow or establish their natural relationship to the sediment in order to truly evaluate the influence of the dredged material on bioaccumulation potential. Cages should not be constructed of metal or coated with material that may leach the contaminants of concern. They must be anchored and marked on the surface so that they can be reliably located and recovered.

11. When the collection vessel has been positioned, repeated collections are made at the same spot until an adequate sample is obtained. The sediment obtained by the sampler is hosed through 1-mm stainless steel screens, and the retained individuals of the desired species are placed in holding tanks. In all cases no animal with any indication of injury should be retained.

12. Return the animals to the laboratory, being careful to label the samples clearly and keep them separated and to maintain nonstressful temperature and dissolved oxygen levels. In the laboratory, maintain the samples in clean water in separate containers. No sediment is placed in the containers and the animals are not fed. Any organisms that die must be immediately discarded. Fecal material is siphoned from the aquaria twice daily until little more is produced, indicating that all material has been voided from the digestive tracts. This probably will be completed within 2 to 3 days after collection, and sooner with small animals. A more desirable procedure, if animals are large enough to make it practical, is to excise the digestive tracts soon after collection rather than allowing the animals to excrete their contents. It is necessary to empty or remove the digestive tracts since material therein may well contain inert constituents and the contaminants of concern in forms that do not become biologically available during passage through the digestive tract. Such material would also probably be unavailable while passing through the digestive tract of any predator that might have ingested the animals being analyzed. Therefore, since the digestive tract content has not been incorporated into the tissue, it would give an artificially high indication of bioaccumulation if it were included in the analysis.

13. The shells or exoskeletons of molluscs or crustaceans are removed and not included in the analysis. These structures generally contain low levels of contaminants and would contribute weight but little contaminants if they were included in the analysis. This would give an artificially low indication of bioaccumulation.

Analysis and interpretation

14. Preparation and analysis of tissues are by the procedures given in the "Chemical Analysis" section of this appendix. The section on "Data Analysis and Interpretation" gives guidance on these matters.

Laboratory Assessment of Bioaccumulation Potential

Sampling design and conduct

15. This approach should be taken only in those cases where a true historical precedent for the proposed operation does not exist (as discussed in paragraph 2). The considerations of paragraphs 5, 6, and 7 should be kept in mind when selecting bioassay species to be used for laboratory assessments of bioaccumulation potential.

16. Animals from solid or suspended particulate phase bioassays may be used, but it is considered unlikely that important bioaccumulation would occur at the disposal site from the latter phase, since animals would be exposed to it for such short periods due to dilution. At the end of the bioassay, surviving animals from the replicate controls are treated in a manner corresponding to the separate reference samples in the field assessment outlined earlier. Survivors from the replicate sediment-exposure aquaria correspond to the samples from the disposal site. In the case of suspended particulate bioassays, survivors from the first replicate of all test medium concentrations are pooled to make one sample corresponding to a disposal site sample; survivors from the second replicate of all test medium concentrations are pooled to make the second disposal site sample, etc.

17. At the end of the bioassay, each sample is placed in separate aquaria in clean, sediment-free water to void the digestive tracts, as discussed in paragraph 12. Each replicate from the bioassay is treated as if it was a sample from the field assessment discussed earlier. If very small animals are to be analyzed, more than the minimum number specified for the bioassay may have to be used, or more replicate aquaria may be established in the bioassay. The considerations of paragraph 13 also apply to bioassay organisms used in assessing bioaccumulation potential.

Analysis and interpretation

18. Preparation and analysis of tissues are by the procedures given in the "Chemical Analysis" section of this appendix. The section on "Data Analysis and Interpretation" gives guidance on these matters.

Chemical Analysis

Constituents to be assessed

19. The chemical constituents to be assessed for bioaccumulation are those constituents deemed critical by the District Engineer and Regional Administrator after considering known inputs to the sediment to be dredged. The following constituents, discussed in Section 227.6 of the Register, are of particular concern and should be assessed for bio-accumulation whenever the District Engineer and Regional Administrator have any reason to believe they may be of concern in the sediment in question.

- a. Organohalogen compounds (PCB's, DDT, etc.)
- b. Mercury and its compounds
- c. Cadmium and its compounds
- d. Petroleum hydrocarbons
- e. Known or suspected carcinogens, mutagens, or teratogens. (This is a very poorly defined group of materials for which specific analytical procedures are not generally available.)

Procedures

20. Referenced standard procedures for specific constituents are given in Table G1. These references should be consulted for detailed guidance on amount of tissue required for analysis of each constituent of concern, methods of sample preparation and analysis, and data presentation.

Data Analysis and Interpretation

21. Complete tissue concentration data for all samples should be presented as in Table G2. A separate analysis must be conducted for each chemical constituent and each animal species. This example utilizes laboratory bioaccumulation data from analyzing the survivors of the hypothetical solid phase bioassay presented in Appendix F. The control and the dredged material samples from three sites were each replicated five times, corresponding to the five replicates used here.

Table G1

Procedural References for Analytical Methods for Tissue Analyses of Organic Materials

Material	Reference 1	Reference 2	Other References
BHC	Sections 211, 212	Section 5A	
Heptachlor	" " "	"	3, 4
DDD, DDE, DDT	" " "	"	5, 6, 7
Chlordane	" " "	"	8
Dieldrin	" " "	"	7
Endrin	" " "	"	9
Toxaphene	" " "	"	4
PCB	Sections 211, 212, 251	"	10
Mirex	Sections 211, 212	"	11
Methoxychlor	" " "	"	
Mercury and its compounds			12
Cadmium and its compounds			12
Petroleum hydrocarbons:			
Aliphatic			13
Aromatic			13

Table G2

Hypothetical Results* of a Laboratory Assessment of Bioaccumulation Potential

Replicate (n = 5)	Tissue Concentration, ppm (wet wt) Control	Dredged Material Sample 1	2	3
1	0.15	0.27	0.25	0.15
2	0.08	0.42	0.38	0.12
3	0.38	0.24	0.52	0.24
4	<0.05	0.37	0.47	0.14
5	0.23	0.49	0.61	0.30
sum of data, ΣX =	0.89	1.79	2.23	0.95
mean, $\bar{X} = \frac{\Sigma X}{n}$ =	0.18	0.36	0.45	0.19
sum of squared data = ΣX^2 =	0.2287	0.6839	1.0703	0.2041
corrected sum of squares, $CSS = \Sigma X^2 - \frac{(\Sigma X)^2}{n}$ =	0.0703	0.0431	0.0757	0.0236
variance, $S^2 = \frac{CSS}{n-1}$ =	0.0176	0.0108	0.0189	0.0059

* The constituent measured and the animal species used in the assessment must be identified.

Small organisms were used; in one case, tissue concentration of the constituent of concern was below detection limits. Such data are nonquantitative and cannot be used in statistical analyses. However, the arbitrary but environmentally protective assumption made in such cases is that the actual concentration in the sample was only slightly less than the detection limit, and the detection limit is used as if it was the datum.

22. To determine whether there is an indication of bioaccumulation potential, it is necessary to make statistical comparisons of the tissue concentrations in the controls to those in animals exposed to the dredged material. It is possible that in some cases the mean tissue concentration in one or more of the dredged material samples may be less than or equal to that in the controls. Such cases have been documented and in no way reflect adversely on the quality of the evaluation, but simply

give no indication of bioaccumulation potential for the constituent, species, and sediment sample in question.

23. If tissue concentration in any of the dredged material samples is higher than that in the controls, the data must be compared statistically. An analysis of variance (ANOVA) is used to compare the mean tissue concentration in animals from the reference substrate control to the mean tissue concentration in animals exposed to each dredged material sample. Before an ANOVA can be performed, it is necessary to use Cochran's test to determine whether the variances of the data sets are homogeneous. This is determined by calculating the C-value, defined as the ratio of the largest variance to the sum of all the variances. In this case:

$$C = \frac{S^2_{max}}{\Sigma S^2} = \frac{0.0189}{0.0532} = 0.3553 \qquad \text{(G1)}$$

where

S^2_{max} = largest variance among the data sets

ΣS^2 = sum of all the variances

The calculated C-value is evaluated by comparing it to the C-value given in the table in Enclosure 1 to Appendix D. In the table, k is the number of treatment means summed in the denominator (4 in this case) and ν is one less than the number of observations contributing to each variance (5 - 1 = 4 in this case). Therefore, the tabulated value for C in this example is 0.6287.

24. Since the calculated C-value is smaller than the tabulated C-value, the calculated value is not significant at the 95-percent confidence level, and the variances may be considered homogeneous. If the calculated C-value is larger than the tabulated C-value, the variances are not homogeneous. In such cases, before any ANOVA calculations are performed, a transformation should be performed on all data in order to achieve homogeneity of variances. The transformation is performed on each datum by obtaining the natural logarithm of (X + 1), where X is the datum. Recalculate the C-value using the transformed data. If

variances are now found to be homogeneous, use the transformed data in all ANOVA calculations. If the variances are still nonhomogeneous, an approximate test of the equality of means given by Sokal and Rohlf in their Box 13.2[14] should be used.

25. ANOVA equations and calculations for the data of Table G2 are given in Table G3. The values on the third line of the table (Total) should be the same whether they are calculated by the equation or obtained by summing the corresponding treatment and error values, thus providing an easy means of checking the accuracy of the calculations. The calculated F-value is evaluated by comparison with the tabulated F-value[15] at the 0.05-probability level with the appropriate degrees of freedom (df). The df's are those given for the treatments and error, respectively, in Table G3. The tabulated F-value with 3 and 16 df's is shown at the bottom of Table G3. Since the calculated F-value exceeds the tabulated value, there is a statistical difference between mean tissue concentrations among the four sets of data. If the calculated F-value had been equal to or less than the tabulated value, there would be no statistical differences between tissue concentration in the reference substrate controls and any of the dredged material samples. In that case, the analysis would be complete at this point with no indication of potential bioaccumulation from the dredged material in question.

26. When the calculated F-value exceeds the tabulated value, it is then necessary to determine which dredged material means differ significantly from the reference substrate control mean. This may be done by the Student-Newman-Keuls multiple-range test given by Sokal and Rohlf in their Box 9.9.[14] Least significant ranges (LSR) used in this process are the product of the pooled standard error of the group mean $S_{\bar{X}}$ and the studentized ranges Q given in Rohlf and Sokal's Table U.[15]

$$S_{\bar{X}} = \sqrt{\frac{\text{MS error}}{n}} = \sqrt{\frac{0.0133}{5}} = 0.0516 \qquad \text{(G2)}$$

where the terms are taken from Table G3.

27. At the 0.05 level of significance, the Q and LSR values for K = 2, 3, and 4 items are:

Table G3

ANOVA Equation and Calculations for the Data of Table G2

Source of Variation	df Equation	df Value	Sum of Squares SS Equation	SS Value	Mean Square MS Equation	MS Value	F Equation	F Value
Treatments†	(a-1)	3	$\Sigma \frac{(\Sigma X)^2}{n} - \frac{(\Sigma\Sigma X)^2}{\Sigma n}$	0.2573	$\frac{SS_{treatment}}{a-1}$	0.0858	$\frac{MS_{treatment}}{MS_{error}}$	6.45*
Error	a(n-1)	16	ΣCSS	0.2127	$\frac{SS_{error}}{a(n-1)}$	0.0133		
Total	(an)-1	19	$\Sigma(\Sigma X^2) - \frac{(\Sigma\Sigma X)^2}{\Sigma n}$	0.4700				

† Number of treatments a = 4

* $F_{.05(3,16)} = 3.24$

		K		
		2	3	4
Q(Rohlf and Sokal, Table U[15])	=	2.998	3.649	4.046
$S_{\bar{X}}$ (equation G2)	=	0.0516	0.0516	0.0516
LSR = $QS_{\bar{X}}$	=	0.1547	0.1883	0.2088

28. The multiple-range test is completed by arranging the four treatment means in increasing order and then comparing the difference between means with the LSR for the number of means K in the range separating the two being compared. That is, for two adjacent means K = 2 and for comparing means separated by one mean, there is the intervening mean and the two being compared, so that K = 3. It is necessary to compare each dredged material mean to the control mean but not to compare treatment means among themselves. Such comparisons between treatment means are not necessary for permitting decisions, but could provide useful managerial information by distinguishing sediments with high bioaccumulation potential from those with a lesser but still statistically significant bioaccumulation potential. The comparison of treatment means to the control for the above example is given in the following tabulation.

Treatment Means from Table G2			
$\bar{X}_{control}$	$\bar{X}_3$	$\bar{X}_1$	$\bar{X}_2$
0.18	0.19	0.36	0.45

K	LSR	Mean Comparison: Difference Between Means
2	0.1547	$\bar{X}_3 - \bar{X}_c$ = 0.19 - 0.18 = 0.01 n.s.
3	0.1883	$\bar{X}_1 - \bar{X}_c$ = 0.36 - 0.18 = 0.18 n.s.
4	0.2088	$\bar{X}_2 - \bar{X}_c$ = 0.45 - 0.18 = 0.27*

Note: Entry of n.s. indicates difference is not significant at the 0.05-probability level; * indicates difference is significant

29. When the difference between two means is greater than the LSR, the difference between those means is statistically significant at the 0.05-probability level. Therefore, the multiple-range test has shown

that the mean tissue concentration of the constituent of concern in animals exposed to dredged material sample 2 is statistically higher than the corresponding concentration in animals exposed to the control sediment. Tissue concentrations of this constituent in animals exposed to dredged material samples 1 and 3 were not statistically higher than in the control animals.

30. The ANOVA calculations and mean comparison given above may be used for data analysis in all cases involving two or more treatments, provided that the same number of samples occurs in each treatment. The ANOVA calculations for studies in which the same number of samples does not occur in each treatment are given by Sokal and Rohlf in their Box 9.1.[14] Unequal numbers of replicate samples may occur in field evaluations where the direction of net bottom transport is not known and samples outside the disposal site are located in all directions from the site. In such cases, those stations outside the site having the highest tissue concentrations cannot arbitrarily be assumed to lie in the direction of net bottom transport, unless this is also indicated by independent evidence. Otherwise the only analysis possible is to compare the mean tissue concentration at the stations within the disposal site to the pooled mean tissue concentration at all stations outside the site. That is, two samples containing different numbers of observations will be compared. When the direction of net bottom transport is known, three mean tissue concentrations will be compared. These will be from samples within the site, samples outside the site in the direction of net bottom transport, and samples outside the site and not influenced by net transport from the site.

31. In the example given in paragraphs 21 through 29, by comparison to the control animals, animals in one of the dredged material samples had elevated tissue concentrations of the constituent of concern, and those in the other two samples did not. Therefore, there is a potential for bioaccumulation of this chemical by this species of animal from sediments at one site in the dredging area.

32. At present there are very little data for marine species upon which to base an evaluation of the meaning of a specific concentration

of a particular contaminant in the species in question. The only such levels that are fixed from a regulatory viewpoint are those levels set by the Food and Drug Administration for fish and shellfish for human consumption. Therefore, this guidance recommends the environmentally protective approach of assuming that any statistically significant differences in tissue concentrations between control and exposed organisms are a potential cause for concern. It should be kept in mind, however, that at present tissue concentration of most constituents in most species cannot be quantitatively related to biological effects. Therefore, in making the final assessment of bioaccumulation, the District Engineer and the Regional Administrator must objectively consider the magnitude of bioaccumulation shown, the toxicological significance of the material(s) bioaccumulated (i.e., arsenic would be of greater concern than iron), the proportion of sediment sampling sites which produce uptake, the number of different constituents bioaccumulated from the sediment in question, the position in human and nonhuman food webs of the species showing uptake, the presence of motile species at the site that might serve as transportation vectors removing bioaccumulated materials from the disposal area, and other factors relevant to the particular operation in question.

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*Volume I (2nd Edition, 1968, and subsequent revisions) contains directions and associated background information for multi-residue methods used by FDA to analyze food and feed samples collected under its surveillance programs. Volume II (1967 and subsequent revisions) contains methods that can be used to analyze for single compounds. Each volume is revised continuously to reflect appropriate changes and additions to the methodology and information.

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