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United States
Environmental Protection
Agency
Water Division

Region 10
1200 Sixth Avenue
Seattle WA 98101

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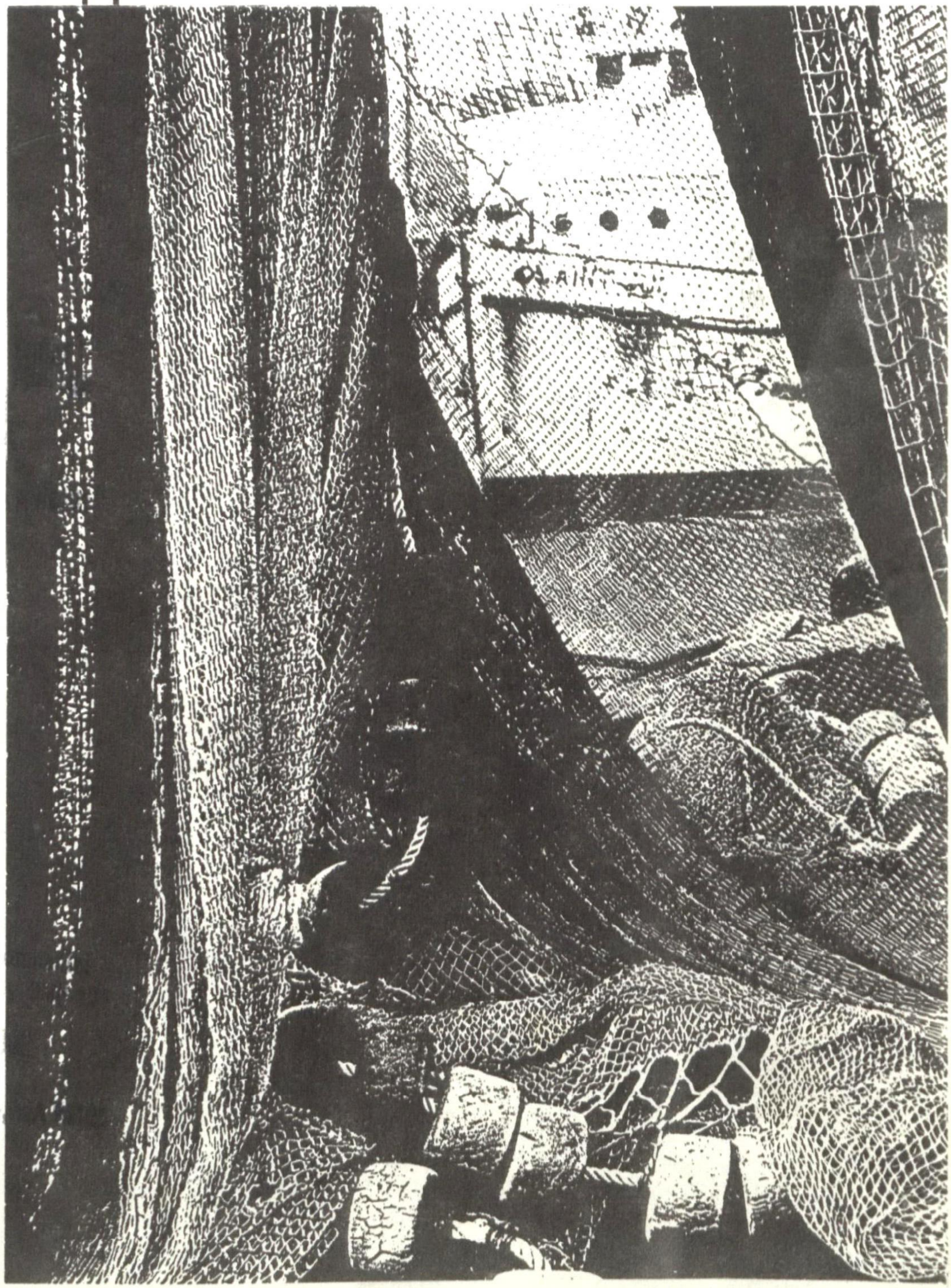
EPA

Water Quality Management Program For Puget Sound

Part II
Proposed Approach and Technical Support Effort



U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION X
1200 SIXTH AVENUE
SEATTLE, WASHINGTON 98101

REPLY TO
ATTN OF:

Dear Reader:

The Environmental Protection Agency and Washington Department of Ecology are developing a unified water quality management program for Puget Sound. This is the second of three reports addressing management needs and strategies. Part I described the roles of management agencies and evaluated their information needs in light of available data about the condition of Puget Sound waters and factors affecting water quality (EPA 910/9-83-106A, 1983).

Part II outlines the major unified program planning elements: (1) the proposed management approach, and (2) needed technical investigations and activities. Chapters 1, 2, 3 and 9 describe the proposed management program. Chapters 4 through 8 describe technical work needed to support the proposed program.

We want Part II to inspire thoughtful discussion and constructive ideas from the diverse audiences concerned about Puget Sound water quality. To be an effective management strategy, the proposed program must gain support from the interested and regulated public, the technical and scientific community, and regulatory agency staff. Given the diversity of interests, the depth of analysis or specific proposals in Part II may not satisfy every reader. We are trying to work with this diversity in developing the management program.

EPA and WDOE want an evaluation of the proposed management approach and priorities, and the validity of technical support work outlined in Part II. We also need comments about proposed priorities within and among major technical work categories. A series of workshops will be held in late January to discuss the proposals in Part II. The public and affected users of Puget Sound as well as scientific, technical, and regulatory communities will participate. A schedule for the workshops, showing the closing date for written comments, is attached.

We intend recommended management and technical support programs to be affected by discussions in these workshops and to mirror the diversity of public, technical, and management audiences. The final report (Part III, to be published in April 1984) will describe the recommended management strategy and a program of technical support work. It will guide EPA and WDOE funding decisions, regulatory actions and interagency coordination.

This letter is your invitation to review Part II and participation in one of the upcoming workshops. We look forward to having your ideas and reactions.

Very truly yours,

Gary O'Neal
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Puget Sound Coordinator
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WATER QUALITY MANAGEMENT PROGRAM FOR PUGET SOUND: PART II, PROPOSED APPROACH AND TECHNICAL SUPPORT EFFORT

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7 December 1983

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Management Approach

Effective water quality management practices are predicated on: 1) full knowledge of current environmental conditions, and 2) the ability to predict environmental impacts of programs and decisions implemented by management agencies. Water quality managers need data that demonstrate the linkage between pollutant loadings and adverse effects of pollutants on biota and on beneficial uses of resources. Data that demonstrate these linkages are sparse. The objectives of this report are: 1) to recommend a management approach that will improve data availability and usefulness, 2) to describe the research needed to bridge critical data gaps, and 3) to recommend improvements in on-going environmental quality monitoring programs.

The principal management question is: What is the cumulative effect of pollutant discharges on the ecological health of Puget Sound and on beneficial uses derived from the Sound? Two observations are readily apparent as this principal question is considered. First, the question and the approach to answering it are complex, and an individual's expertise and responsibilities are often narrowly focused or limited to specific kinds of data. The complexity of the situation, coupled with the limitations of a single-issue approach, have impeded remedial actions. The effective approach must therefore occur within a holistic, interdisciplinary framework. Second, the complexity of the question requires breaking down the necessary research into manageable units of effort. A compartmentalized approach is acceptable as long as the various activities are designed, coordinated, performed, and interpreted within the holistic framework. An active, interdisciplinary, interagency forum must coordinate this approach to accomplish effective water quality management of Puget Sound.

Management priorities (e.g. funding) should focus on immediate problems based on best available data, theoretical considerations, reasonable judgments, and public concerns. Several high priority management objectives and needs can be identified based on existing knowledge of Puget Sound water quality problems. In Puget Sound, high priority should be given to highly toxic synthetic organic compounds and diseased fish in urban embayments, impacts on bottom sediments from municipal and industrial wastes, and decertification of shellfish growing areas. Specific management objectives should include: defining existing and developing water quality problems; identifying pollutants of greatest concern; evaluating risk to human health and marine organisms from exposure to toxicants; determining the fate of pollutants discharged into Puget Sound; and identifying environmental conditions that precipitate management action. Within these management objectives, priority also is given to obtaining data from urban embayments and the Central Basin on pollutant loading, deposition and retention of pollutants within these areas, and identifying biological and potential public health problems associated with pollutants.

Recommended Studies

Studies that are needed immediately to obtain critical data are generally classified as mass loading, transport and fate, or biological effects studies. Work funded by EPA and WDOE is currently underway on certain aspects of toxic contamination of urban/industrial bays, bacterial contamination of Puget Sound shellfish, and program management and coordination.

Prior to implementation of mass loading studies, a preliminary list of high priority chemical compounds must be developed. The preliminary list developed for Puget Sound includes: pesticides, PCBs, halogenated aliphatics (e.g. CBDs), monocyclic aromatics, polychlorinated dibenzofurans (PCDFs), polycyclic aromatic hydrocarbons (PAHs), and selected heavy metals. This preliminary list must be modified as new data are obtained on loading, accumulating levels in the environment, and potential biological effects.

MASS LOADING

Sources and amounts of pollutants discharged to Puget Sound are not quantitatively or qualitatively well understood. Loading data are essential for water quality management of specific geographical areas (e.g. urban embayments) and of Puget Sound as a whole. Recommended studies that pertain to critical data gaps in mass loading are:

- Development of high priority pollutant lists for local geographical areas.
- Analysis of CSO effluent volume and composition.
- Documentation of pollutant loading from urban rivers.
- Documentation of pollutant loading from industrial discharges.
- Documentation of pollutant loading from urban runoff.
- Documentation of pollutant loading from municipal treatment plants.
- Documentation of pollutant loading from atmospheric flux.

- Identification of problems associated with septic tank leachate.

- Review of historical spills, dumps, and locations of contaminated sediments (including dredge spoils).

Quantification of pollutant loadings will enable water quality managers to focus management effort on major inputs of pollutants. Management effort then will be allocated more effectively. Mass loading data also significantly influence the focus and design of transport and fate, and biological effects studies.

TRANSPORT AND FATE

Once pollutants have entered Puget Sound, knowledge of the transport and fate of these pollutants is essential to the prediction of impacts. Mathematical models that represent a vertically and horizontally dynamic system are needed to describe water circulation and areas of sediment deposition in Puget Sound. As knowledge of pollutant fate processes is gained, the information may be used to refine water circulation models. Recommended transport and fate studies include:

- Development of a circulation model for Puget Sound.

- Development of a circulation model for the Central Basin and urban embayments.

- Analysis of pollutant reactions at the freshwater/saltwater interface.

- Analysis of distribution and fate processes for pollutants in sediments.

- Development of a solids settling model.

- Estimation of advection of organic compounds.

- Description of organic pollutant fate processes.

Understanding pollutant transport and fate processes is essential for water quality managers who regulate activities and implement abatement programs. Detrimental impacts are expected to concentrate in areas that accumulate pollutants; the ability to predict depositional areas is necessary to identify geographical areas requiring special attention.

BIOLOGICAL EFFECTS

Critical information that links pollutants with adverse impacts on biota is sketchy or has not been developed. Effort is focused on two broad management needs: linking pollutants to observed biological effects, and developing action level criteria germane to management decisions. Four important data gaps have been identified:

- Pollutant uptake and bioaccumulation mechanisms, and primary pathways of exposure.
- Statistical relationships between sediment contamination, body burdens of toxicants, and biological conditions (e.g. disease).
- Causal relationships between contamination and demersal fish diseases.
- The effects of sediment contamination and organic enrichment on benthic invertebrate community structure.

Recommended biological studies that address these data gaps and help establish action levels are:

- Correlations between elevated body burdens of toxicants in English sole, elevated levels of toxicants in the environment, and the occurrence of pathological conditions.
- Long-term bioassays with young-of-the-year English sole to investigate the mechanisms of bioaccumulation and possible cause of disease.
- Effects of sediment contamination and organic enrichment on benthic invertebrate communities.
- Analysis of toxicant bioaccumulation and occurrence of disease in sport-caught rockfishes from urban embayments.
- Toxicant bioaccumulation in market squid in urban embayments.

Initially, major emphasis is placed on identifying linkages between pollutant levels and adverse biological effects that may not be cause-effect linkages. Action levels can be identified based on these linkages, assuming that pollutant levels are indicators of potential biological impacts. Data from the initial work provide a basis for focusing and designing follow-on studies that examine cause-effect relationships.

Recommended Improvements in Monitoring Activities

Monitoring programs are necessary to identify change in environmental conditions in Puget Sound. A review of current monitoring efforts in Puget Sound reveals the need for a comprehensive monitoring program that would provide water quality managers with a means of detecting and documenting changes in the enviroment, including those resulting from the cumulative actions taken in Puget Sound.

A comprehensive monitoring program must be able to show trends in pollutant levels in the water column, sediment, and biota. In addition, pathological conditions that are implicated as pollutant-induced, and composition of the Puget Sound biological community must be monitored in appropriate locations and in a manner reflecting management concerns and beneficial uses at these locations. Several existing programs, such as WDOE marine monitoring and Metro's TPPS and Seahurst baseline programs, provide a substantial foundation for the recommended comprehensive program.

In addition to the comprehensive monitoring program, several additional activities for coordinating ongoing monitoring efforts are recommended. These consist of:

- Briefing meetings between monitoring agencies.
- Development of a monitoring manual.
- Calibration of analytical labs and techniques.
- Development of a Puget Sound data base.
- Standardization of names of Puget Sound taxa.

These activities would improve the usefulness of data from the various monitoring agencies, with the net result of increased efficiency in the overall monitoring effort.

Recommended changes to existing monitoring programs are aimed at improving their value to water quality managers and at incorporation into the comprehensive monitoring program.

Interim Management Approach

Until sufficient data are obtained by the recommended research effort, water quality managers must make decisions based on existing data. Reasonable judgments based on the best available data can be used to develop a "preponderance of evidence" approach to decision making. This approach requires knowledge of current pollutant loadings and of the accumulating pollutant reservoir. The interim approach is based primarily on chemical data and biological testing of current pollutant loadings and the accumulating reservoir of pollutants. Management decisions can be made at any point in the process of evaluating current discharge practices and the accumulating reservoir of pollutants. For example, discovery in effluent of a chemical compound known to be acutely toxic or carcinogenic at low concentrations may indicate a need to control or abate discharge of the compound. However, the decision is best supported by additional data on occurrence in the environment and associated biological effects. The interim program will evolve into the overall management approach as data are obtained that link specific pollutants to observed biological effects.

Chapter 1

INTRODUCTION

Purpose and Objectives

The perception of Puget Sound as a relatively pristine body of water has changed during the last few years, and this change has stimulated intensive effort to maintain the Sound as a high quality environment. Changes in the quality of Puget Sound resulting from the inflow of pollutants have evoked an effort by the Environmental Protection Agency (EPA), in association with the Washington State Department of Ecology (WDOE) to develop a more comprehensive, coordinated water quality management program specifically designed for Puget Sound. The first phase of this work effort required the coordinated compilation of data and information from numerous interacting agencies and individuals. The report resulting from the first phase (Jones & Stokes Associates, Inc. 1983) describes the roles of agencies participating in water quality management, the data presently needed to make management decisions, and the data available for decision-making.

It is generally accepted that effective water quality management practices are predicated on having adequate knowledge about environmental conditions and the capability to predict the cumulative environmental impacts of regulatory actions. This knowledge and capability is becoming even more critical to regulatory processes as pollutants increase in complexity and distribution. The regulatory process is significantly impaired by the lack of germane data linking controllable pollutant loadings with adverse effects in biota and the beneficial uses of resources. Furthermore, the regulatory process is hampered by insufficient capability to use data to predict the results of regulatory actions. These factors make it difficult to even judgmentally project the remedial effects of possible regulatory actions.

Analysis of this situation demonstrates the immediate need to implement a holistic, well coordinated water quality management program for Puget Sound. Many of the activities that must be initiated to implement such a program are identified in this report, which was formulated using the following objectives:

- Emphasize the importance of building holistic, ecological conceptualizations into water quality R&D and management activities.

- Provide a working document for the use of water quality managers, technical experts, and citizens groups that focuses attention on the need, objectives, and scope of data requirements.

- Recommend new management directions and activities that will improve data availability, quality, and application.

- Outline the research required to bridge the most critical data gaps and to formulate predictive models.

- Recommend changes in on-going programs that will provide more valuable data to decision makers.

These objectives are critical to understanding the purpose of the report. This report provides a framework for community discussion of the direction of EPA/WDOE-supported research, investigation, and monitoring during the next few years. A third and final report will include and be responsive to the community input received during these discussions.

Summary of Data Availability

The findings of the first phase of work (Jones & Stokes Associates, Inc. 1983) are summarized in Appendix A.

Available data do not clearly link specific pollutants to adverse impacts on biota or beneficial uses; nevertheless, the evidence indicates a positive association between industrialization/urbanization and adverse changes in the ecology of and beneficial uses of some areas in Puget Sound. Several key topics have been identified that require urgent action for long-term management of water quality in Puget Sound. Critical data needs are:

- Sources and amounts of high priority pollutant inputs.

- Descriptions of the environmental fates of pollutants, including modeling to predict solids deposition areas, predict relationships between dissolved pollutants and suspended solids, and predict pollutant transfer to organisms.

- Biological effects of high priority pollutants.

- Information on long-term trends.

Until major gaps in our understanding of these topics are bridged, water quality managers are faced with the knowledge that regulatory decisions cannot focus on specific agents that cause adverse impacts on biota or beneficial uses. There is, therefore, uncertainty that decisions will be as effective and efficient as one may desire.

General Approach to Water Quality Management in Puget Sound

Wastewater, groundwater, and surface runoff discharged to Puget Sound may contain pollutants that are toxic or otherwise harmful to fish and wildlife, and thus potentially harmful to humans who take food, economic, or recreation benefits from the Sound. The principal question is: What is the cumulative effect of pollutant discharges on the ecological health of Puget Sound and on beneficial uses derived from the Sound? This broad question can be divided into more specific ones concerned with geographical locations (e.g., Elliott Bay), species (e.g., English sole), beneficial uses (e.g., shellfish harvesting), and so on. The specific questions pertinent to Puget Sound are outlined in Chapter 2. Factual responses to inquiries about pollution of the Sound require information and data relevant to many questions. Very often these data are complex and extremely expensive to obtain; moreover, the scientific and engineering community has not discovered, in many situations, how to ask the essential questions.

NEED FOR HOLISTIC APPROACH

The general need for technical data and information in water quality management is accepted by almost everyone. The gathering of specific kinds of data, however, is often limited by an individual's knowledge (expertise) and responsibilities, and falls short of the general need. To compensate for this, a holistic approach is needed. The principal consideration in preparing this report was obtaining critical data needed to protect and maintain beneficial uses of resources by water quality managers operating within the holistic framework outlined by Figure 1-1. The approach strives to link pollutant loadings to adverse effects on biota and beneficial uses of resources.

USEFULNESS OF COMPARTMENTALIZED APPROACH

Documenting linkages between pollutant sources and measurable adverse effects on beneficial uses requires many areas of technical (scientific) expertise. From a practical standpoint, it is necessary to divide the research into manageable units of effort. Figure 1-1 portrays a process, but it is possible to recognize steps in the process. A compartmentalized approach is acceptable as long as the various research efforts are designed, carried out, and interpreted within the holistic framework.

Figure 1-2 is a schematic illustration of how the Puget Sound ecosystem can be divided into manageable units (compartments) for research and investigative effort. A systematic

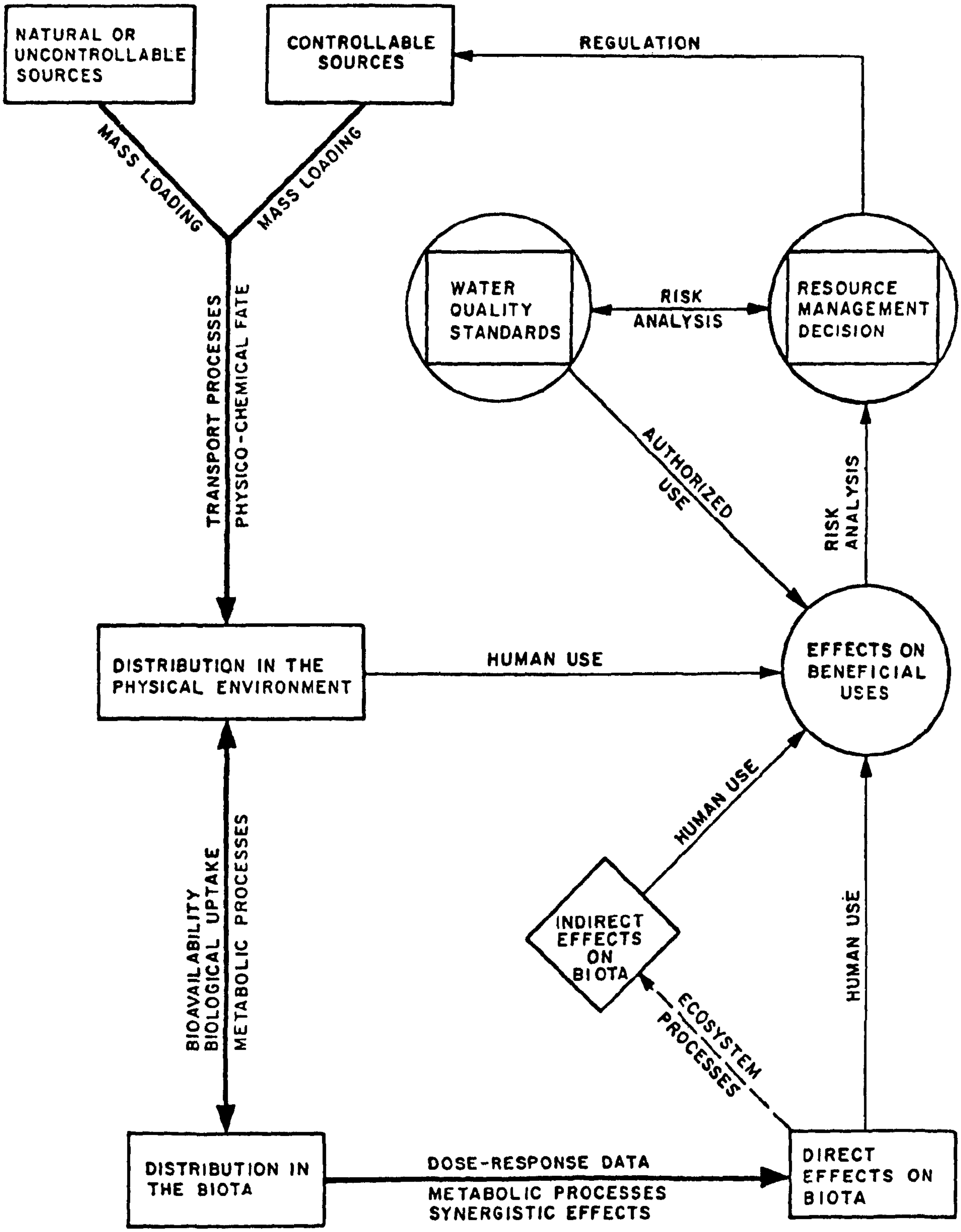


Figure 1-1. Diagram of Linkages Between Data Needed for Water Quality Management Decisions

NOTE: Boxes and bold arrows represent descriptive compartments and processes which can be quantified. Ecosystem processes (broken arrow) and indirect effects (diamond) are open to scientific analysis but rarely quantifiable. The circles and remaining arrows represent compartments or processes that are defined or implemented within the social framework (modified from White and Lockwood, in press).

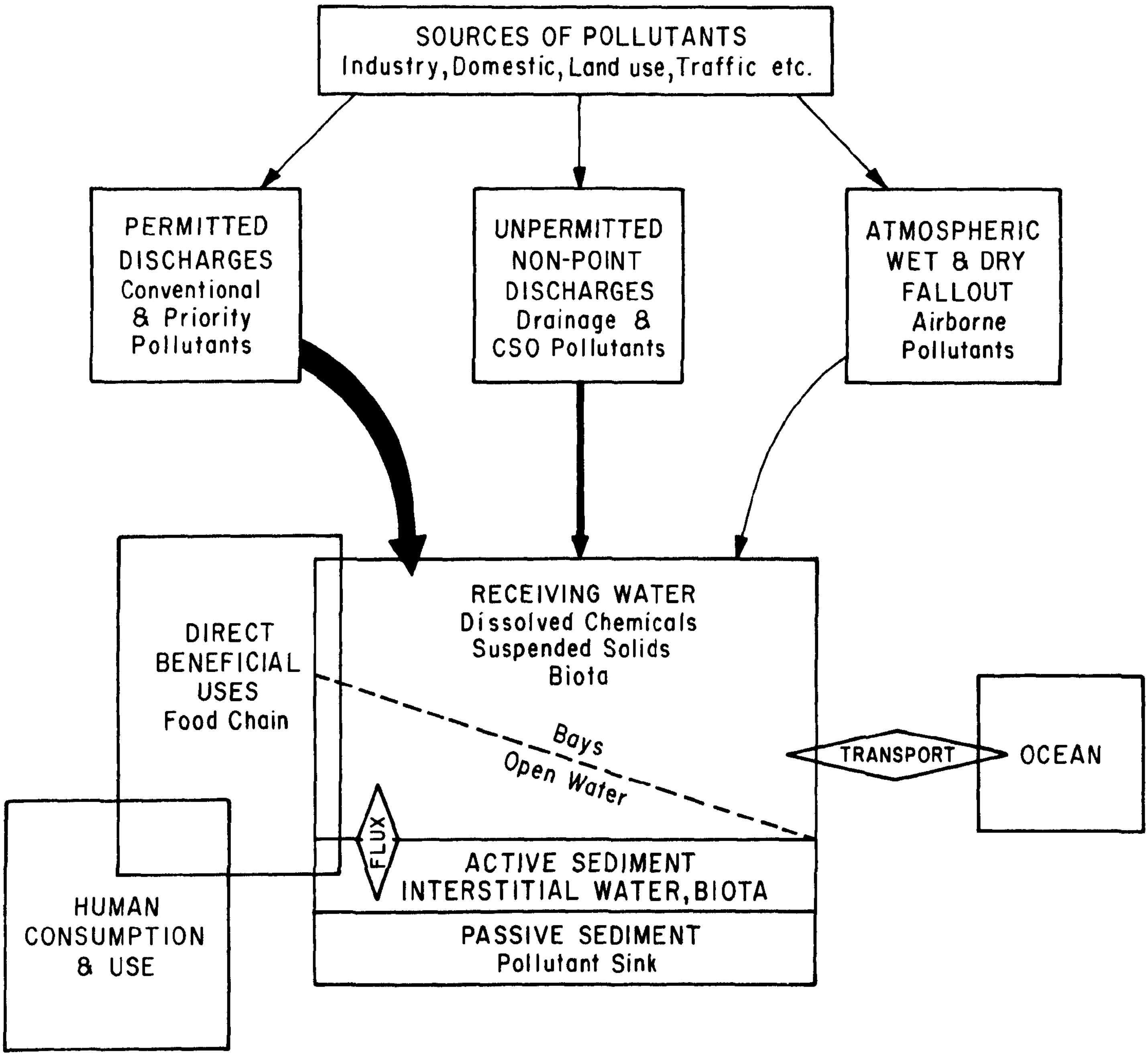


Figure 1-2. Schematic Illustration of Interrelated But Distinct Subject Areas That Must be Considered in the Systematic Analysis and Management of Puget Sound Water Quality

analysis of water quality concerns occurs in each compartment (Figure 1-2) as a result of one or more recommendations presented in this report.

Initially, pollutants that are considered potentially harmful to the Sound must be identified and classified according to their presence and documented level of risk to biological systems. In Chapter 4 of this report a preliminary list of pollutants that represent the highest level of risk to biota using the Sound is identified. The locations and amounts of high risk substances discharged from both permitted and nonpermitted sources must be known to help develop plans and implement actions that will produce effective abatement. Chapter 5 identifies methods for refining the preliminary list and acquiring an accurate accounting of mass loading for high priority pollutants and certain other substances.

Many toxic chemicals discharged to the Sound are either bound to particulate matter or will be bound in a relatively short period, and eventually will be deposited in the sediments. Some dissolved chemicals may be accumulated by biota, and some of the adsorbed load may redissolve as ionic conditions change. Until accurate estimates of mass loading and mass accumulation in bottom sediments are made, the proportional fates of specific, relatively conservative pollutants will be left to speculation. Chapter 6 recommends methods of describing how dissolved pollutants and suspended solids move through Puget Sound. Studies are also designed to examine the fate of pollutants in sediments as well as in other environmental compartments of Puget Sound.

The pathways for chemicals to move from discharge to sediment, biota, or the ocean require identification and description. A high priority is placed on gaining knowledge about the transfer of pollutants from sediment to biota and also on the resulting effects on biota. It is recommended for the near term that two general types of studies be done: 1) screen biota for bioaccumulation of selected pollutants, and 2) test biota to identify pathologies associated with or perhaps caused by the bioaccumulation of specific pollutants (Chapters 7 and 8). A logical outcome of these studies is the establishment of sediment and body burden standards for selected toxic substances.

A comprehensive long term monitoring program is required to record ecological changes that are attributable to water quality management actions. Intensive monitoring of areas receiving the greatest loads of pollutants is expected to yield the most obvious positive effects of toxic substance source control and treatment. Monitoring of other areas must occur, however, to register environmental changes that may result from the total pollutant load and the movement of substances from one area to another (Chapter 8). Human food, e.g., clams, fish, and waterfowl, must be monitored to assure safety of the public.

Management decisions must be made before many of the recommended studies yield data that can be used as regulatory tools. Therefore, an interim approach to water quality management is proposed (Chapter 9). This approach will allow decisions to be made based on a "preponderance of evidence" format, until such time as cause-and-effect relationships between pollutants and impacts on beneficial uses are defined.

INSTITUTIONAL CONSIDERATIONS

The prevailing passive system of communicating ecological data is inefficient and ineffective relative to the needs of all concerned parties. If each party conducting an in-depth analysis of a complex problem must continue to ferret out diverse pieces of information from numerous sources scattered throughout the Puget Sound area, large amounts of time, human resources, and money are unnecessarily diverted from the productive tasks of new data collection, analysis, and communications. This problem is correctable by establishing a central library for all Puget Sound data resources, published and unpublished, based on automatic data processing principles with an index of materials accessible to off-site computer terminals. It also should be required that any reports produced with public money be deposited in the library. Moreover, such a library should be staffed to assist users of its resources.

Collection of sound ecological data for management of water quality based on a holistic viewpoint requires that agencies and individuals recognize their common goals and need for coordinated effort. Coordination of related activities generally does not occur unless accomplished by regulations, a Memorandum of Understanding (MOU), or recognition of mutual interests. Projects and programs are often developed by individuals and small groups in response to their particular needs, which may be either specific and narrow in scope, or broad enough to affect other projects and programs. Many opportunities to gain data and understanding from such work are lost if peers and interested parties are not included in study planning and design.

An active, interdisciplinary forum is needed to review and critique project and research design as well as resulting data and reports. This process is especially important for publicly-funded projects and research oriented toward water quality management. Such a group should include representatives of all appropriate technical disciplines, management agencies, dischargers, governmental bodies, consultants, and public groups willing to responsibly participate in such a forum. Independent operation as a grant-funded, nonprofit corporation directed by several major funding entities may serve the public and effectively avoid single issue biases.

Chapter 2

MANAGEMENT PRIORITIES, OBJECTIVES, AND NEEDS

The fundamental objective of resource managers is to protect and maintain beneficial uses of the resource. As described in the first phase of work (Jones & Stokes Associates, Inc. 1983), society plays the major role in defining beneficial uses. To a great extent, society also plays a major role in defining adverse impacts on beneficial uses. The major role of scientists is to provide data and guidance on how to protect and maintain beneficial uses.

Before specific management objectives can be identified, managers must have adequate knowledge of the current status of the resource. Although by no means complete or conclusive, scientific data exist (Jones & Stokes Associates, Inc. 1983) that permit reasonable judgments on the status of water quality problems in Puget Sound.

Current Status of Water Quality Problems in Puget Sound

TEMPERATURE, DISSOLVED OXYGEN, SALINITY, AND pH

Temperature, dissolved oxygen, salinity, and pH may be altered by human activities near or on localized shallow marine embayments with poor flushing characteristics. In Puget Sound, these water quality problems are primarily limited to tributary water estuaries, e.g. the lower Duwamish River. There is little evidence to indicate that these are serious water quality problems in Puget Sound, nor is there reason to believe they will become problems in the near future, other than in localized areas.

NUTRIENTS

Nutrient loading to Puget Sound can be beneficial if the resulting increase in plant productivity contributes to larger stocks of valuable fish, shellfish, or wildlife. Ecological systems are generally resilient and able to accommodate mild fluctuations in nutrient levels. Excessive nutrients can result in excessive plant productivity, which then may lead to oxygen depletion in poorly flushed water as plant material decays. Changes in nutrient balance may alter plant and phytoplankton species composition, replacing nutritious or valuable species with less nutritious or noxious species.

Data from Puget Sound (Jones & Stokes Associates, Inc. 1983) reveal that nutrient loading can become, or is, a problem in relatively shallow, poorly flushed embayments of Puget Sound (e.g. Budd Inlet). There is no current evidence to indicate that adverse impacts result from nutrient loading to the Central Basin. This situation could change at some time in the future as population growth occurs in the Puget Sound watershed and greater quantities of wastes are produced.

BACTERIA AND VIRUSES

Bacteria are a food source for shellfish and are generally harmless, but fecal bacteria are used as an indicator of the potential presence of harmful viruses and other pathogens associated with human waste. The Washington Department of Social and Health Services (DSHS) has decertified commercial shellfish growing areas because of unacceptable levels of fecal coliform bacteria in the water. In rural areas, unacceptably high fecal coliform bacteria in the water is likely to be caused by nonpoint sources such as overloaded septic tank leach fields, livestock, or wildlife. In urban areas, shellfish are exposed to potentially harmful pathogens found in untreated domestic wastewater. Shellfish in urban areas are also exposed to toxicants, but few toxic organic compounds have action level criteria established for shellfish. The absence of fecal coliforms in water near urban areas does not mean that shellfish from these areas are uncontaminated by pollution.

SEDIMENTATION AND DREDGE SPOIL DISPOSAL

Organisms that live in depositional environments or in estuaries typically adapt to sedimentation. Sedimentation and dredging activities become a pollution problem when:

- Toxic compounds are adsorbed to sediments or settling solids.
- Changes in sediment type alter the benthic community.
- Erosion or deposition results in habitat loss for important species.
- Spawning in nearshore habitats is impeded by siltation.
- Navigation or port facilities are impaired.

Sediment currently is of most concern in Puget Sound as a pollutant carrier, in habitat alteration, and in the issue of navigation and dredge spoil disposal. Best Management Practice (BMP) improvements in agriculture, silviculture, and construction may alleviate some sedimentation concerns; however, increased population and urbanization can act to offset this gain. Disposal of contaminated dredge spoils in some areas is a special case of pollution by heavy metals and organic compounds.

HEAVY METALS

Heavy metals locked within mineral matrices are of little concern as pollutants. Many marine organisms can detoxify heavy metals over a wide range of environmental concentrations through the activities of certain enzymes, such as metallothioneins. Problems may arise when uptake of heavy metals exceeds the capacity of natural detoxification mechanisms. The toxic effect of heavy metals is most often shown to be sublethal (e.g. Sanders et al. 1983). It is difficult to identify lethal or pathological effects at concentrations typically encountered in marine waters.

Heavy metal pollution occurs in Puget Sound. Significant sources include runoff from highways and parking lots, shipping and shipyards, and industry. Elevated levels of heavy metals (relative to presumed nonpolluted areas) have been found in sediments of most urbanized embayments and harbors. Anthropogenic metal loading to Puget Sound has probably occurred since the turn of the century. However, even in areas displaying high sediment contamination by heavy metals, body burdens of most resident organisms appear to be no more than two- or three-fold greater than those of organisms collected in presumed nonpolluted areas. As a result, correlations between body burdens of heavy metals and the incidence of pathological conditions are inconclusive.

NATURALLY-OCCURRING HYDROCARBONS

Many petroleum and combustion hydrocarbons are naturally occurring organic compounds. The former can enter ecosystems through natural seeps, and the latter through forest fires. Many organisms have evolved tolerance mechanisms to at least low environmental levels of these compounds. Input to Puget Sound increased dramatically with the advent of industrialization and the use of combustion engines. Measurable concentrations of some of these compounds are found in sediments of Puget Sound. Some are also found in tissues of organisms residing in Puget Sound, but many of these compounds are also readily metabolized. It is rarely clear whether metabolization results in detoxification, or in more toxic byproducts. Some of these compounds are carcinogenic, mutagenic, or teratogenic, and clearly require consideration as a priority water quality problem.

SYNTHETIC HYDROCARBONS

This is a category of compounds for which organisms rarely have evolved defensive or detoxification mechanisms. This fact alone qualifies these compounds as candidate water quality problems of highest priority. Diversity and production of these compounds have increased dramatically since World War II. Within the last decade, a number of these compounds have been shown to be toxic, carcinogenic, mutagenic, and teratogenic at low concentrations. Lipophilic compounds have been found in tissues of organisms from urbanized areas at levels as high as one or two orders of magnitude greater than in tissues of organisms from presumed nonpolluted areas.

Priorities for Water Quality Management

Marine pollution is a relatively new subject area with many unanswered questions. As a technological frontier, vast amounts of money and time could be spent investigating and researching the field. Unfortunately, only limited resources are available, and decisions cannot be postponed until "all the evidence is in." Management effort and resources should focus first on water quality problems that require immediate attention, and secondarily on problems that may develop if present practices do not change. Decisions must be made on best available data, theoretical considerations, and reasonable judgments.

Organisms and ecosystems are capable of adjusting to certain environmental levels of most naturally occurring pollutants. This indicates that adverse impacts in most of these categories may be reversible on some reasonably short time scale. Clear exceptions are those water quality problems related to input of synthetic organic compounds, especially those that are lipophilic and hazardous to human health or marine life at low concentrations. Elevated levels of naturally-occurring organic compounds and the occurrence of synthetic organic compounds in biota and sediments of Puget Sound are high priority management issues, particularly since many of these compounds are known or suspected carcinogens, mutagens, or teratogens at low concentrations. Further analysis of existing data indicates that most water quality concerns occur in urbanized embayments, particularly around the Central Basin. These geographic areas should receive high priority in locating sites for research, investigations, or monitoring.

In setting priorities, water quality managers must not only consider technical information provided by scientists, they also must consider public use of the resources. In Puget Sound, the current, major water quality concerns for the public (based on frequency of news coverage) are: incidence of diseased fish in urban embayments, health risks and aesthetic impacts resulting from discharge of municipal wastes, and decertification of shellfish growing areas.

Management Objectives and Data Needs

In reviewing current status of water quality in Puget Sound and the concerns that must be considered in establishing priorities for water quality management, management objectives become apparent. Key objectives are:

- Define the nature and extent of existing and developing water quality problems in Puget Sound.

- Identify pollutants of greatest concern in Puget Sound.

- Determine whether marine organisms that support beneficial uses of Puget Sound are at unacceptable risk due to exposure to toxicants, particularly those toxicants known to be acutely toxic, carcinogenic, mutagenic, or teratogenic at low concentrations.

- Determine the fate of pollutants discharged to Puget Sound.

- Identify environmental conditions that indicate when action must be taken as provided by federal and state laws and their implementing regulations.

Other objectives may be identified for localized areas of Puget Sound, and still others will arise as knowledge of the Puget Sound ecosystem expands.

Data needs are broadly described and briefly outlined in Chapter 1, and by Jones & Stokes Associates, Inc. (1983). Specific data needs, based on current status of water quality and management priorities, can be briefly summarized as follows:

- For urban embayments:

  - What are pollutant loadings into the bay from various point and nonpoint sources?

  - What are the depositional areas for contaminated sediments?

  - What is the extent of pollutant retention within the bays?

  - What biological problems are occurring in bays that can be associated with pollutants?

  - What action levels could be developed to judge the significance of existing or proposed discharges, or of existing contaminated deposits?

- For the Central Basin:

  - What are the loadings from major urban embayments?

  - What are the depositional areas for contaminated sediments?

  - Are there biological problems in the Central Basin associated with pollutants?

- What are the trends in water quality, contaminated sediment, and biota?

- What action levels could be developed to judge the significance of existing or projected levels of toxic pollutants?

Each of these needs will be addressed by recommended studies or monitoring programs described in subsequent chapters of this report.

Types of Solutions

Solutions to water quality problems can arise in either the technological or the social/political arena. In many cases, a solution may require effort in both arenas.

Regulatory action by water quality management agencies influences and is influenced by activities in both arenas (Jones & Stokes Associates, Inc. 1983). As new information is made available, certain regulatory actions (e.g. revision of permit conditions and limitations, improved surveillance and enforcement activities) can be modified within a reasonably short time under existing regulations. The principal purpose of the recommendations in this report is to provide water quality managers with improved technological tools to analyze and regulate controllable sources of pollutants to the Sound. Data and analyses stemming from these studies will reduce data gaps that presently make it difficult to negotiate permit conditions and implement pollution abatement programs.

In the social/political arena, the role of water quality managers and regulatory agencies is focused primarily on data collection and dissemination, and enforcement as appropriate. Following public education, some of these solutions can be implemented as enforceable regulations in relatively short time periods. Examples of regulatory changes include:

- Revision of construction codes.
- Implementation of or changes in land use ordinances.
- Improved coordination between regulatory agencies.

Other solutions are long term in nature and may be difficult to accomplish by regulatory action. Examples include:

- Change in disposal practices by homeowners and other individuals handling small quantities of hazardous materials.

- Lifestyle changes resulting in reduced demand for hazardous materials.

- Population growth management.

Although these are important and valuable steps to solving many water quality problems, it is impractical to presume that these alone will resolve urgent management concerns or prevent water quality degradation. At the present time, technological solutions implemented through regulatory authority (and resulting from research effort) will play a major role in abating or preventing water quality degradation.

Chapter 3

INTEGRATION OF DATA

The recommendations in this report appeared in draft form in March 1983. At that time, EPA and WDOE funded selected components through interagency agreements. Work on these components is now underway. These funded components continue to appear in this report as elements of recommended studies. The work effort and expected products of on-going work are summarized below. Collectively, the funded components provide a major step in identifying problem areas and addressing some of the more urgent data needs. Following this summary, the remainder of this chapter describes priorities among the recommendations, and how the resulting data address the management objectives and needs outlined in Chapter 2.

Products of Current EPA/WDOE-Funded Research

TOXIC CONTAMINATION OF THE URBAN-INDUSTRIAL BAYS

A major portion of this effort is to develop better understanding of the nature and extent of toxic chemical contamination of the bottom sediments of bays near the major urban-industrial areas of Puget Sound. Current work in this area can be classified and described under the following three components: problem definition, criteria development, and toxicant source and loading analysis.

Problem Definition. Five bays were selected for priority attention: Commencement Bay, Elliott Bay, Port Gardner, Sinclair Inlet, and Bellingham Bay. Four "baseline" bays were chosen to represent relatively undeveloped, uncontaminated areas of Puget Sound: Case Inlet, Dabob Bay, Sequim Bay, and Samish Bay. Level of effort is more intense in areas such as Sinclair Inlet, Bellingham Bay, and Port Gardner where existing data are sparse, and less intense in Commencement Bay and Elliott Bay where a number of studies recently have been conducted.

An initial screening survey is underway to characterize the physical, chemical, and biological conditions of the four baseline bays and Port Gardner, Sinclair Inlet, Bellingham Bay, and the Four Mile Rock dredge spoil disposal site (in Elliott Bay). Approximately 20 surface sediment samples will be collected in each bay and analyzed to determine sediment grain size and concentrations of selected metals, carbon tetrachloride extractable organic matter, and organic carbon. Amphipod bioassays will also be conducted on the same samples.

The results of these initial screening analyses will be used to select approximately 10 sites in each urban-industrial bay and five sites in each baseline bay for more detailed chemical and biological analysis. Oyster larvae bioassays, benthic biology recruitment tests, more detailed amphipod bioassays, a broad range of detailed chemical analyses, and biological community structure analyses will be conducted on samples from each selected site. These analyses will proceed through the summer of 1984.

Samples of bottomfish and shellfish will be collected from the sites selected after the initial screening survey. These samples will be analyzed to define the incidence of fish and shellfish abnormalities and disease. Similar work will be done in each of the four baseline bays and in Sinclair Inlet, Bellingham Bay, and the Four Mile Rock area of Elliott Bay. This information will supplement previous work in Commencement Bay, inner Elliott Bay, and Port Gardner. The field work is to be conducted in the fall of 1983. The pathological analyses will be incorporated with the results of the chemical and biological analyses, and published in the fall of 1984.

Finally, an effort to assess the degree of human exposure to potentially contaminated fish and shellfish from the urban-industrial areas of Puget Sound is being undertaken by the Washington Department of Social and Health Services (DSHS) under a grant from WDOE. The "catch and consumption" survey will supplement a similar study of the Commencement Bay area by the Tacoma-Pierce County Health Department. The DSHS survey includes a review of available Department of Fisheries sport fishing and shellfish harvest data for the Puget Sound area, and field interviews with sport fishermen in the Seattle, Everett, Bremerton, and Bellingham urban areas. Surveys will continue through the spring of 1984, and analysis of the survey results is expected by the summer of 1984. A more detailed, two-year study designed to complement the DSHS work is being undertaken by the National Oceanic and Atmospheric Administration (NOAA).

Criteria Development. There is a need to understand the potential significance of elevated levels of various chemicals in the bottom sediments of Puget Sound. Although the results of this work will be applicable throughout Puget Sound, initial effort is focused on Commencement Bay. A detailed literature review and evaluation of the properties of these chemicals and groups of chemicals will be conducted to establish their potential bioavailability and toxicity in the marine biological system. Approximately 15 to 20 chemicals known to exist and judged to be most significant in Commencement Bay will be reviewed and ranked in importance. The chemical and toxicological literature review of priority toxicants from Commencement Bay is expected to be completed in the spring of 1984.

Another activity designed to help further understanding of the significance of marine sediment contamination involves spiking sediment samples with selected chemicals in various concentrations, and determining the resulting biological effect through use of amphipod bioasssay techniques. The degree of biological uptake of these chemicals and their effect on a tolerant benthic polychaete also will be determined. If successful, this work will determine which chemicals and groups of chemicals are most important in causing biological stress, and at what concentrations they produce adverse biological effects. Commencement Bay sediments and chemicals will be used in this work. The expected completion date is the summer of 1984.

The Northwest and Alaska Fisheries Center is also attempting to identify which chemicals are causing biological problems in Puget Sound. Under this two-year effort, sediment samples from two areas that are known to be highly contaminated, the Hylebos Waterway of inner Commencement Bay and the West Waterway of inner Elliott Bay, will be separated into a number of chemical fractions. These fractions will be used in a series of bioassay techniques, including the amphipod and oyster larvae bioassays, to determine their biological effects. Through this process, the relative significance of various chemical groups should become more apparent. EPA's Marine Science Center in Newport and the National Marine Fisheries Service will share sediment samples, biological and chemical analyses, and technical expertise.

Eventually, development of sediment quality criteria or standards may be necessary to establish a specific basis for remedial action and toxicant control policies. For this reason, an effort is underway to evaluate a range of possible approaches to establishing such sediment-related criteria or standards. Various alternative methodologies, their associated data requirements, and relative utility in the regulatory process will be examined. This work is expected to be completed in the spring of 1984.

Toxicant Source and Loading Analysis. Part of the work currently funded by WDOE in the nearshore areas of Commencement Bay is directed toward source identification and analysis. Several major studies of a similar nature have also been completed by Seattle Metro in Elliott Bay. This kind of information will also be developed in the Port Gardner/Everett area. Additional source-related work also may be necessary in Bellingham Bay and Sinclair Inlet. The work planned in the Port Gardner/Everett area is designed to identify all existing sources of toxicants, and to develop estimates of toxicant loading to Port Gardner. Where adequate site-specific data on hydrology or chemical characteristics are not available, appropriate data from other regional or national studies will be evaluated and extrapolated to the Everett area. Gaps or inadequacies in existing data will be identified. The effect of these deficiencies on the toxicant loading estimates also will be evaluated. The processes of toxicant deposition in Port Gardner and transport of toxicants out of the area will also be examined by using mass balance techniques and sedimentation rate analyses. These analyses will require collection of a series of deep sediment cores in the area and chemical analysis and lead-210 age-dating of the cores to determine the history of sediment deposition and contamination over time. Completion of the analysis is expected in late fall of 1984.

BACTERIAL CONTAMINATION OF SHELLFISH

WDOE undertook a major new initiative in the fall of 1983 to develop a coordinated, intergovernmental shellfish program. This effort, a part of the WDOE/EPA Puget Sound water quality management program, is being staffed and funded largely by WDOE.

Burley Lagoon, Minter Bay, and their associated watersheds are being studied in detail. Land use patterns, fecal coliform bacteria sources, and fecal coliform bacteria concentrations in feeder streams, receiving waters, sediment, and oyster tissues will be determined under various streamflow conditions. Flushing action and exchange processes in the bay will also be evaluated to determine if they affect bacterial concentrations.

Burley Lagoon and its associated watersheds were selected for a basin planning effort to be conducted by Pierce County and Kitsap County, with funding provided by WDOE. Existing land use and runoff control regulations and ordinances will be evaluated and modified as necessary to establish effective regulatory controls. The work effort is expected to be completed by summer of 1984.

WDOE is considering the merits of establishing a "no major additional discharge" policy that could apply to domestic sewage treatment plant discharges, industrial discharges, and stormwater discharges to areas with substantial shellfish resources. This effort will involve evaluation of the alternative forms such a policy might take, and development of a methodology for determining those geographic areas to which such a policy should be applied. These evaluations are expected to be completed by mid-1984.

PROGRAM MANAGEMENT AND COORDINATION

A brief evaluation of the management structure and problem-solving approaches employed in the recently completed Chesapeake Bay water quality program was undertaken in order to learn from that work. In addition, an identification of the major regulatory decisions facing various agencies in the Puget Sound region and an evaluation of the decision processes is currently underway. This work will be completed in the fall of 1983.

An evaluation of several institutional options for coordinating and managing policy level direction of Puget Sound water quality management activities also has been initiated. The results of this work will be helpful in understanding future institutional needs and may prove useful in helping to define the direction and role of the newly established Puget Sound Water Quality Authority. This same effort will identify and evaluate options for improving interagency coordination in the development of program plans and proposals for project-level investigations, and in the implementation of specific projects and activities. Both of these evaluations are expected by spring of 1984.

Priorities for Recommended Studies

Studies in Chapters 5-7 are designed to provide information that water quality managers must have to evaluate current environmental conditions and impacts of regulatory decisions. The recommendations do not provide answers to all questions relevant to water quality impacts. There are many questions that are technically interesting and for which answers would be useful to water quality managers. The recommendations provided in Chapters 5-7 are considered high priority needs as determined through an initial screening process. Furthermore, the studies have been selected because the results are likely to provide technically sound data that can be used to predict water quality impacts and make management decisions.

Highest priority is given to those studies that are deemed urgent or critical in meeting management needs. Recommendations are classified by the general categories of mass loading, transport and fate, and biological effects of pollutants. Within each category, some recommended studies are judged more critical to decision making than others. Table 3-1 summarizes the types of recommended studies and their relative priority based on need for data within each category. Monitoring program recommendations are not included in Table 3-1, but are treated separately in Chapter 8.

Since the results from each study should be used to focus or interpret results from other studies, (the holistic approach), the timing of each study is also important. Table 3-2 is an effort to rank the recommended studies as a function of timing priority, i.e. how the various studies should be phased. It should be noted that timing priority in Table 3-2 may not reflect the overall need to fill specific information gaps as in Table 3-1. As decisions are made on which studies should be undertaken, consideration should be given to the need for the data (Table 3-1), and how the information from that and other studies can be integrated (Table 3-2).

Monitoring programs (Chapter 8) will provide some data for use in the recommended studies (Chapters 5-7). Although the use of these data is encouraged, it should be noted that the purpose of a monitoring program is to document environmental conditions over time; therefore, the use of these data should be considered carefully. In many respects, it is more likely that the outcome of the recommended studies will influence the design and focus

Table 3-1. Recommended Studies by Type and Approximate Degree of Priority Based on Need for Data to Eliminate or Reduce Significant Information Gaps

Highest Priority	Moderate Priority	Lower Priority
<u>Mass loading</u>	<u>Mass loading</u>	<u>Mass loading</u>
High-priority pollutant lists	Urban runoff	Septic tank leachate
CSO effluent	Municipal treatment plant survey	Historical spills
Rivers discharging into urban embayments	Atmospheric flux	
Industrial survey		
<u>Transport and fate</u>	<u>Transport and fate</u>	<u>Transport and fate</u>
Compartmental distribution and fate in sediments	Advection of organic compounds	Whidbey Basin model
Reactions at freshwater/saltwater interface	Organic pollutant fates	Southern Puget Sound model
Model of Puget Sound		Hood Canal model
Model of Central Basin		Bellingham Bay model
Solids settling model		
<u>Biological effects</u>	<u>Biological effects</u>	
Body burdens, sediment concentration, and incidence of disease	Benthic invertebrate communities	
English sole bioassays	Squid survey	
Rockfish survey		

Table 3-2. Recommended Studies Ranked by Approximate Degree of Priority Based on Timing, i.e., Need for Data to Complement Ongoing or Subsequent Studies

Study	Timing Priority
High priority pollutant lists	1
CSO effluent	1
Industrial survey	1
Rivers discharging into urban embayments	1
Urban runoff	1
Municipal treatment plant survey	1
Body burdens, sediment concentration, and incidence of disease	1
English sole bioassays	1
Rockfish survey	1
Squid survey	1
Compartmental distribution and fate in sediments	1
Reactions at freshwater/saltwater interface	2
Atmospheric flux	2
Solids settling model	3
Model of Puget Sound	3
Model of Central Basin	3
Benthic invertebrate communities	4
Advection of organic compounds	5
Organic pollutant fates	5
Septic tank leachate	5
Historical spills	6
Whidbey Basin model	7
Southern Puget Sound model	7
Hood Canal model	7
Bellingham Bay model	7

of monitoring programs. Major exceptions include mass loading data obtained from monitoring programs.

Meeting Priority Data Needs

Specific data management needs were summarized in Chapter 2. In addition, an effort has been made in Chapters 5-8 to describe how each recommendation meets certain management needs. The following is a brief outline of how the recommendations fit in with the management needs outlined in Chapter 2. Names of study recommendations are abbreviated as in Table 3-1 and 3-2. Full technical descriptions are found in Chapters 5-8.

INFORMATION REQUIRED FOR URBAN EMBAYMENTS

What are the Loadings into the Bay From Various Sources? This information will be obtained from a combination of recommended studies and recommended monitoring effort. Recommended mass loading studies (Chapter 5) that will provide these data are:

- CSO effluent
- Industrial survey
- Rivers draining into urban embayments
- Urban runoff
- Municipal treatment plant survey
- Atmospheric flux.

Some of this work is already underway in Commencement Bay, Elliott Bay, and Port Gardner. Concurrent development of area-specific high priority pollutant lists will greatly benefit from these studies as well as help identify the pollutant species needing quantification in these studies.

Existing monitoring efforts are generally inadequate for meeting this management need, or these data would already have been available. Some information can be provided by the 301(h) monitoring program, but only with reference to municipal dischargers. Metro's TPPS program will provide some mass loading data for large CSOs in the Duwamish estuary, Elliott Bay, and Lake Washington Ship Canal. The Renton treatment plant also currently contributes to Elliott Bay. With implementation of recommended changes, the PSAPCA and NPDES monitoring programs could provide much of the necessary data, and will be particularly valuable in identifying trends.

What are the Depositional Areas for Contaminated Sediments? Recommended studies (Chapter 6) that will identify these areas are:

- Model of Central Basin coupled with the model of Puget Sound (the latter used to define boundary conditions)
- Reactions at freshwater/saltwater interface
- Solids settling model.

Probable depositional areas also can be identified by examining existing sediment maps, as discussed in the recommended comprehensive monitoring program. Some intensive monitoring programs may have also obtained some useful data, and should be reviewed.

What is the Retention of Pollutants Within the Bays? Recommended studies (Chapter 6) that will help determine the retention time are:

- Model of Central Basin coupled with the model of Puget Sound
- Reactions at freshwater/saltwater interface
- Solids settling model
- Compartmental distribution and fate in sediments
- Advection of organic compounds
- Organic pollutant fates
- Historical spills.

The on-going literature review of toxic compounds in Commencement Bay will provide some of these data. The existing WDOE marine monitoring program can provide some information on this subject once transport and fate processes have been described by the above studies. The monitoring programs proposed under the 301(h) program may provide some useful data, as long as the discharges occur into bays and not into the Central Basin or other large basins of Puget Sound.

What Pollutant-Associated Biological Problems are Occurring in Urban Bays? It is generally assumed that some of the fish diseases now observed in urban embayment populations are caused by pollution. An immediate need is better documentation of the relationship between chemical and biological information. Following this initial effort, there is a need to address causal mechanisms. Studies that will address these needs (Chapter 7) are:

- Body burdens, sediment levels, and incidence of disease in English sole
- English sole bioassays
- Rockfish survey
- Squid survey
- Benthic invertebrate communities.

Data from intensive monitoring surveys and Metro's TPPS study can be used to identify some problems. Data from intensive surveys cannot always be used to correlate pollutant levels with observed effects, let alone identify causal mechanisms. Whether Metro's TPPS study will be able to provide some of these data remains to be seen. The 301(h) monitoring program may be able to identify water quality problems if they result from these discharges, but causal mechanisms are unlikely to be identified. The same limitation applies to the comprehensive monitoring program outlined in Chapter 8. Work currently underway by EPA will provide useful data on the relationship between sediment contamination and the incidence of disease.

What Action Levels Could be Developed? Water quality criteria have been established by EPA for certain chemical compounds. Action is taken to prevent these compounds from exceeding levels in the water column that are presumed to be hazardous to aquatic life or human health. Similar action levels for concentrations in sediment or biota may be necessary for compounds found at hazardous levels in sediment or biota, even though at low concentrations in the water column. This management need will require data from recommended studies and monitoring. Preliminary planning work is currently underway. The studies listed in the previous data need (biological problems) will provide data that can be used toward reaching this objective. In particular, the English sole bioassays, the field study on English sole, and sediment bioassays conducted as part of the benthic invertebrate communities study will be of value. To a limited extent, the comprehensive monitoring program, the Basic Water Monitoring Program (BWMP), and the shellfish PSP and coliform bacteria monitoring programs (Chapter 8) can provide useful data in noting what levels of pollutants are associated with certain biological effects. Additional data could be provided by the 301(h) monitoring programs, if these programs are implemented as recommended.

INFORMATION REQUIRED FOR THE CENTRAL BASIN

What are the Loadings From Major Urban Embayments? This data need can be addressed by the work outlined for the retention of pollutants within the bays.

What are the Depositional Areas for Contaminated Sediments? This data need can be approached with the same effort outlined for urban embayments.

Are There Biological Problems in the Central Basin? Most of this information will come from a comprehensive monitoring program (Chapter 8). In particular, the recommended sediment and bioaccumulation elements of the comprehensive monitoring program will ascertain whether organisms in the Central Basin are being exposed to accumulating amounts of toxicants or are building up body burdens of compounds that either can be associated with or lead to adverse impacts on beneficial uses. At present, benthos and demersal fish are prime candidates for a comprehensive monitoring program. There is no existing evidence that primary producers or pelagic species have been adversely impacted in urban embayments or in the Central Basin. NOAA is currently investigating toxicant concentrations in birds and mammals of Puget Sound. Whether any species other than benthos and demersal fish require monitoring will not be clear until this NOAA study is completed.

What are the Trends in Water Quality, Contaminated Sediments, and Biota? Most of these data will be provided by long-term monitoring effort because the data need is time dependent. Existing programs that could be used in providing some information are the BWMP, the WDOE marine water monitoring program, and the shellfish PSP monitoring program. However, as now operated, these programs leave major issues and large areas of the Sound unaddressed. Part of this missing coverage could be remedied by implementation of the recommended changes to these programs (Chapter 8). However, the best way to meet this objective is to implement the recommended sediment and bioaccumulation elements of the comprehensive monitoring program. These two elements, in association with the WDOE marine water monitoring program, will fulfill this management need.

What Action Levels Could be Developed? In many respects, the data obtained to identify probable action levels in urban embayments will be applicable to identifying probable action levels in the Central Basin. Before this management need can be further addressed, it must first be determined whether biological problems occur outside of the urban embayments.

Chapter 4

RECOMMENDED HIGH PRIORITY POLLUTANTS

Many chemical compounds are discharged to Puget Sound. Some of these are very toxic in small quantities, others are not known to be toxic. Before mass loading studies can be planned and conducted (Chapter 5), the list of chemical compounds targeted for evaluation must be shortened to a manageable length. For the most part, the existing data (Jones & Stokes Associates, Inc. 1983) are only sophisticated enough to identify groups of organic compounds and heavy metal elements that are likely candidates. These are identified in this chapter. Work is recommended in Chapter 5 to refine this preliminary list to specific chemical isomers or chemical species in different areas of Puget Sound.

Selection Criteria

The EPA priority pollutant list identifies 126 hazardous compounds, chosen primarily because of their toxicity, persistence, ability to bioaccumulate, scale of production, and chance for release to the nation's environment. The EPA list was used primarily as a starting point for development of a preliminary list of high priority pollutants. Priority pollutant compounds were reviewed (Jones & Stokes Associates, Inc. 1983) to determine those most likely to be of concern based on their structural and behavioral characteristics. Local information was then reviewed to ascertain which of these compounds were highly concentrated or widespread in Puget Sound, or implicated as likely causes of observed biological effects. Characteristics evaluated include:

- Acute and sublethal toxicity, including known or suspected carcinogenicity, mutagenicity, and teratogenicity.
- Ability of organisms to detoxify or adapt to known levels of pollutant in the environment.
- Tendency for persistence in the aquatic environment.
- Tendency to bioaccumulate and pose health hazards to the organism or to higher trophic level organisms.
- Degree of contamination relative to expected background levels and to other polluted areas.

- Spatial extent of contamination within Puget Sound.
- Number and type of environmental compartments (water, sediment, biota) known to display elevated concentrations.

Selection of High Priority Pollutants

Based on the above criteria, the following preliminary list was developed for Puget Sound:

- Pesticides: DDT and its metabolites DDD and DDE; possibly aldrin and its metabolite dieldrin, and endrin.
- Polychlorinated biphenyls: particularly the more heavily chlorinated tetrachloro- through nonachlorobiphenyls.
- Halogenated aliphatics: particularly chlorinated butadienes (CBDs); possibly tri- and tetrachloroethylene.
- Monocyclic aromatics: particularly chlorinated benzenes.
- Polychlorinated dibenzofurans and pentachlorophenol.
- Polycyclic aromatic compounds: particularly naphthalenes, fluoranthenes, benzo[a]- and dibenzo[a]anthracene, benzo[a]pyrene; possibly pyrene.
- Heavy metals: lead, mercury, silver, copper, arsenic, cadmium; possibly selenium.

The above list is not meant to be exhaustive, nor is it final. In fact, refinement is recommended in Chapter 5. The list should be modified as new data are obtained. These compounds were chosen on the basis of their existing or potential impact in the aquatic environment; compounds typically existing as air pollutants were not considered except as they impact water. A number of other compounds are potential candidates for listing because of their toxicity and/or ability to bioaccumulate, but available data on distribution, sources, and concentration are limited. Absence of information does not necessarily indicate lack of a problem; in many cases it may indicate a lack of sampling. Additional information is likely to result in additions to or deletions from the above list. As noted in Chapter 3, EPA has already begun to work on this data need.

RATIONALE FOR PESTICIDES

Most priority pollutant pesticides are now either banned or severely restricted in usage. Input can be expected to continue to decrease. However, some compounds are still of concern; current concentrations in the environment may pose significant hazard to marine biota. The potential hazard of certain banned compounds may not decrease for some time, primarily because of their persistence, continuing high levels in Puget Sound sediments or biota, and bioaccumulative ability. Metabolites of these compounds also are often very toxic, and little is known of their distribution, metabolic pathways, or concentrations.

The primary pesticide of concern appears to be DDT and its metabolites DDD and DDE. DDT was banned in the United States in 1972, so input should be decreasing. All three compounds are listed as priority pollutants by EPA, and are classified by Chapman et al. (1982a) as Category 1 compounds because of their persistence, bioaccumulative ability, and nonvolatility. They are also considered to be Category 1 pollutants of concern by Konasewich et al. (1982) based on wide distribution and relatively high concentrations in Puget Sound. In most areas of the world, DDE is the predominant form in sediments. However, DDT appears to be the predominant form in Puget Sound sediments, indicating either recent input of DDT or lack of metabolic activity in the sediments. Dry weight samples of biota from Commencement and Elliott Bays show considerably higher concentrations than other areas of Puget Sound, indicating that contamination results from localized sources.

Aldrin and dieldrin were banned from usage in the United States in 1974, and endrin was banned in 1979 (Frandsen pers. comm.). Input of these compounds should therefore be decreasing. All three compounds are classified as EPA priority pollutants. Chapman et al. (1982a) classify aldrin as a Category 2 compound (persistent, bioaccumulative and volatile), and dieldrin and endrin as Category 1 compounds (persistent, bioaccumulative and nonvolatile). Konasewich et al. (1982) consider dieldrin and endrin as Category 5 compounds (those which are toxic, but for which additional information is required).

Aldrin is readily metabolized to dieldrin, which tends to persist in the marine environment. It is therefore likely that dieldrin, not aldrin, is of greater long-term concern. Dieldrin is one of the most persistent of the organochlorine pesticides (Callahan et al. 1979) and is also considered a potential carcinogen (Sittig 1980). Bioaccumulation factors of 60,000 and 2,700 have been noted for snails and fish, respectively (Callahan et al. 1979).

Little information on local distribution or concentration is available. Low levels of aldrin and endrin have been detected in Puget Sound sediments (Konasewich et al. 1982). Aldrin and dieldrin have been detected in West Point treatment plant effluent, even though banned. Aldrin and dieldrin are extremely toxic to most forms of life, including molluscs and other invertebrates (Sittig 1980). EPA (1980) criteria for aldrin state that levels in water are not to exceed a value of 1.3 ppb; criteria for dieldrin are 0.0019 ppb (24-hour average), not to exceed 0.71 ppb.

Endrin is isomeric with dieldrin. It is persistent and highly toxic in the marine environment; toxicity to pink shrimp has been noted at 0.037 ppb. Chronic toxicity to mammals is also greater for endrin than for other organochlorine pesticides. EPA (1980) water quality criteria for saltwater organisms are 0.0023 ppb (24-hour average), not to exceed 0.037 ppb. Endrin is readily bioaccumulated, and has been reported to reach concentration factors of 6,400 in marine fish (Sittig 1980).

Data for aldrin, endrin, and dieldrin are limited, and it is not now possible to accurately assess their importance in Puget Sound. Because of their toxicity and persistence, it is believed that initial work on Puget Sound biota and pollutants should include these three pesticides to determine their degree of presence and the extent of their local hazard.

RATIONALE FOR POLYCHLORINATED BIPHENYLS

Although their production has been terminated, polychlorinated biphenyls (PCBs) are EPA priority pollutants and are considered Category 1 pollutants by Chapman et al. (1982a) because of their persistence, bioaccumulative ability, and nonvolatility. Konasewich et al. (1982) also consider PCBs to be pollutants of concern based on their widespread dispersion and predominance in Puget Sound sediments and biota. They are also considered to be of primary concern in this study because of the unknowns regarding their metabolites and reactions in seawater, and because of their potential health effects. Levels in Commencement and Elliott Bay biota range up to 0.850 and 2.1 ppm wet weight, respectively, for English sole muscle; much higher levels are found in liver tissue (Malins et al. 1982). In comparison, current United States and Canadian guidelines for consumption of PCBs in fish are 5 ppm and 2 ppm wet weight, respectively.

RATIONALE FOR CHLORINATED BENZENES

The main monocyclic aromatic hydrocarbons of concern appear to be the chlorinated benzenes. Of these, chlorobenzene, three dichlorobenzenes, trichlorobenzene, and hexachlorobenzene are EPA priority pollutants. Chapman et al. (1982a) rank all of these as Category 2 pollutants (persistent, bioaccumulative and volatile), with the exception of hexachlorobenzene, which is ranked as a Category 1 pollutant (persistent, bioaccumulative, and nonvolatile). Konasewich et al. (1982) consider these compounds to be pollutants of concern based on their toxicity and widespread distribution in Puget Sound. These compounds, and particularly hexachlorobenzene, are identified as high priority pollutants in this study for the same reasons. Sediment analyses from Hylebos Waterway, Old Tacoma, and Elliott Bay identify several hundred organic compounds; tri-, tetra-, penta-, and hexachlorobenzenes are all present, often in fairly high concentrations relative to the other organic compounds in the area. Concentrations of hexachlorobenzene were particularly high. This compound was found in 59 of 61 areas sampled throughout Puget Sound. Concentrations reach 1,300 ppm in Commencement Bay sediments (Malins et al. 1982). Levels in Commencement Bay biota were also relatively high in comparison to other areas (Konasewich et al. 1982). Although no EPA water quality criteria guidelines have been established for chlorinated benzenes, acute and chronic toxicity levels of 160 and 129 ppb, respectively, are noted for saltwater biota (EPA 1980).

RATIONALE FOR CHLORINATED BUTADIENES

Halogenated aliphatic compounds are generally volatile, but two of those classified by EPA as priority pollutant compounds tend to be persistent, bioaccumulative and nonvolatile. Of these two, only hexachlorobutadiene (HCBD) appears to be present in Puget Sound in high concentrations, although sampling has been limited (Konasewich et al. 1982). HCBD is considered a Category 1 pollutant by Chapman et al. (1982a) based on its persistence, bioaccumulative ability and nonvolatility. Konasewich et al. (1982) classify chlorinated butadienes (CBDs) in general as pollutants of concern based on their presence in all compartments of the Puget Sound ecosystem. The group as a whole is considered to be of high priority in this study because a number of volatile CBDs and their isomers are widely distributed and are often found in high concentrations in Puget Sound. Furthermore, low levels have been shown to produce chronic effects on biota. HCBD, for example, is considered fetotoxic, nephrotoxic, neurotoxic, and carcinogenic (EPA 1980). Tri-, tetra-, and pentachlorobutadiene reach levels of 1,000-4,000 ppm in Hylebos Waterway sediments. Dichlorobutadiene is also present but appears to be approximately two orders of magnitude less in concentration (Malins et al. 1982) and probably exhibits lower toxicity than the others because it has fewer chlorines. Dry weight concentrations of total CBDs in Commencement Bay sediments have reached 20,000 ppb (Malins et al. 1982) and concentrations in English sole livers of Hylebos Waterway have been noted at 8600, 410, 220, and 10 ppb for the hexa-, penta-, tetra-, and trichlorinated butadienes.

RATIONALE FOR CHLORINATED ETHYLENES

Several chlorinated ethylenes (ethenes) are listed as EPA priority pollutants. Although Chapman et al. (1982a) classified these compounds as Category 4 pollutants (persistent, nonbioaccumulative, and volatile), Callahan et al. (1979) have noted that several of these compounds are known to bioaccumulate. Konasewich et al. (1982) consider chlorinated ethylenes as Category 1 pollutants because concentrations in water, particularly in Hylebos Waterway, indicate discharges of these compounds are continually occurring. Chlorinated ethylenes are considered in this report as possibly high priority pollutants because little is currently known about levels in sediment and biota, and potential effects on biota. Concentrations in water at Hylebos Waterway are high (3 ppb) relative to concentrations reported elsewhere in marine waters (0.01 ppb). Although this level in water is as much as three orders of magnitude lower than EPA (1980) guidelines, these data suggest that concentrations in sediments and biota may be higher than elsewhere in the marine environment because of continued input.

RATIONALE FOR POLYCHLORINATED DIBENZOFURANS AND PENTACHLOROPHENOL

Polychlorinated dibenzofurans (PCDFs) are not considered EPA priority pollutants, but Konasewich et al. (1982) consider them pollutants of concern because of their toxicity and potentially widespread distribution. Because their structure indicates they are persistent, bioaccumulative, and nonvolatile, they would be considered Category 1 compounds under the system developed by Chapman et al. (1982a). PCDFs are also closely related to the chlorinated dibenzodioxins, which are among the most toxic compounds known. Omission from the EPA priority pollutant list often means that the compound will be overlooked or appear less important; preliminary efforts in pollutant detection often focus primarily on the EPA priority pollutants. This may be the reason that little local information is available now for these compounds.

Hexa-, penta-, and tetrachlorodibenzofurans have been detected in Puget Sound sediments, although levels were not quantified (Malins et al. 1980). Malins et al. (1982) also noted low concentrations of dichlorodibenzofurans in a subsequent analysis of Tacoma sediments. Although reports concerning the presence of PCDFs are few, there is a potential for widespread distribution because these compounds are present as occasional contaminants in PCB and pentachlorophenol (PCP) formulations.

PCP is widely used as a wood preservative and in pulpmills, sawmills, and lumber terminals. A major PCP producer is located in Tacoma. An EPA priority pollutant, it is a possible precursor of PCDFs and is highly toxic to a variety of organisms. It is adsorbed by organic matter and known to bioaccumulate. Some continuing sources have also been identified, but a few preliminary analyses of sediments have generally shown no observable concentrations. It seems likely that PCDFs and PCP are potentially widely present, but quantification is needed.

Toxicity of PCDF compounds varies, depending on the number and position of the chlorine atoms. Certain compounds have been shown to be highly toxic to birds and mammals, although information concerning aquatic organisms is lacking. As these compounds appear to be highly bioaccumulated, consumers of contaminated aquatic organisms could potentially be affected. The most immediate data requirements concern identification of the isomers present, and the need to determine their distribution and concentrations. PCP and its degradation products should also be examined more closely.

RATIONALE FOR POLYCYCLIC AROMATIC HYDROCARBONS

Nearly all of the polycyclic aromatic hydrocarbons (PAHs) are of concern. Sixteen compounds are listed on the EPA priority pollutant list, but a very large number of related compounds have been noted in Puget Sound. All PAHs listed as priority pollutants are considered Category 1 pollutants (persistent, bioaccumulative, and nonvolatile) by Chapman et al. (1982a). On the basis of their characteristics and distribution, naphthalene, chlorinated and brominated naphthalenes, the fluoranthenes, benzo[a]- and dibenzo[a]anthracene, benzo[a]-pyrene, and other halogenated PAHs are all considered Category 1 pollutants by Konasewich et al. (1982). Many PAHs are carcinogenic. They are widespread throughout Puget Sound, but reach particularly high concentrations in Commencement and Elliott Bays.

It is difficult to evaluate the relative importance of many compounds in this group because data concerning distribution, concentration, and environmental compartment are limited, so that existing data may not be representative. Information concerning behavior of some compounds is also limited. This group was considered to be of primary concern in this study based on: large number of compounds observed; distribution; concentration in sediments, suspended matter, and water; structure; properties; and health effects. Additional sampling will undoubtedly indicate the presence of other PAH compounds in Puget Sound. PAHs chosen as high priority pollutants correspond fairly closely to those chosen by Konasewich et al. (1982), and include fluoranthenes, naphthalenes and selected anthracenes and pyrenes.

Fluoranthene compounds are numerous and widely dispersed. Sampling of sediments at only three sites (Old Tacoma, Hylebos Waterway, and Seattle Pier 54) indicated the presence of fluoranthene, approximately nine types of chlorofluoranthenes/ pyrenes, and at least six other types of fluoranthenes/pyrenes, methyl fluoranthenes/ pyrenes, and benzofluoranthenes. Fluoranthene and benzofluoranthene appear to be the most highly concentrated of these compounds, with concentrations ranging from 1-8 ppb in sediments for all three areas tested (Malins et al. 1980). They are considered carcinogens and/or co-carcinogens, and have been found to be present in a number of Puget Sound organisms, as well as in sediments, suspended particulates, and the water column.

Naphthalene compounds are numerous and in high concentrations in Commencement and Elliott Bay sediments. Naphthalene, eight chlorinated naphthalenes, and at least 12 other naphthalene compounds have been noted at only three sample sites by Malins et al. (1982). Naphthalenes are widely distributed, and have been found in sediment, water, and biota in areas from Port Susan to Case Inlet. In general, the chlorinated naphthalenes were noted at concentrations an order of magnitude less than that of other naphthalene compounds, but they are more prone to bioaccumulation because of their chlorine content.

Naphthalene is acutely toxic to invertebrates (Sittig 1980), and concentrations may be approaching levels observed to affect benthos populations. Armstrong et al. (1979 in Konasewich et al. 1982) suggest that levels as low as 2 ppm in sediments can affect biota. Naphthalene compounds in Old Tacoma and Seattle Pier 54 were found to total approximately 2 ppm and 3.6 ppm, respectively (Malins et al. 1980).

Anthracene compounds are also numerous and of conspicuously high concentration in sediments. Anthracene, benzo[a]- and dibenzo[a]anthracene, five chlorinated/brominated anthracenes, and six additional anthracene/phenanthracene compounds were noted by Malins et al. (1980) in the sediments at three locations tested. There is widespread distribution of benzo[a]anthracene in both sediments and biota from Case Inlet to Seattle. Concentrations of chlorinated anthracenes were two to three orders of magnitude below levels of other anthracene compounds. Benzo[a]-anthracene was particularly highly concentrated, ranging from 2-7 ppm in the Tacoma area and at Seattle Pier 54. Dibenzo[a]-anthracene was found less frequently and at an order of magnitude less concentration in sediments (Malins et al. 1980). However, as it contains one more ring than benzo[a]anthracene, it is likely to be more highly bioaccumulated (Callahan et al. 1979). Both compounds are considered likely to be carcinogens (Konasewich et al. 1982).

Benzo[a]pyrene and pyrene appear widespread, and were noted in concentrations ranging from 0.3-2.0 ppm and 2.0-10.0 ppm, respectively, in Tacoma and Seattle waterfront sediments by Malins et al. (1980). Benzo[a]pyrene is a recognized carcinogen and has been found in numerous locations in the sediment, water column, and various invertebrates.

RATIONALE FOR SELECTED METALS

High concentrations of metals have been noted in sediments, water column, and biota, but no data exist to determine whether heavy metals are adversely affecting biota. As elements, metals will not degrade, and most are bioaccumulated, often as essential nutrients. Toxicity is a function of the chemical species in which the metal occurs. Identification of which chemical species should be listed as high priority pollutants is one of the more urgent data needs for heavy metals. Continued metal input is expected, although improved effluent treatment practices have decreased heavy metal mass loading compared to that of 10 years ago.

Lead. Lead is an EPA priority pollutant and is considered by Chapman et al. (1982a) as a Category 1 pollutant based on its persistence, bioaccumulative ability and nonvolatility. Konasewich et al. (1982) and Crecelius (pers. comm.) also consider it as one of the heavy metals of greatest concern. Lead concentrations are elevated in sediments, water, and biota, and lead has been observed in high concentrations in nearly all urban areas. Highest concentrations have been noted in the lower

Duwamish River and Hylebos and City Waterways in Tacoma. Local concentrations in sediments have been noted to reach 790 ppm (Malins et al. 1980). Lead is also bioaccumulated, and concentration factors of greater than 2,500 have been noted for the mussel *Mytilus edulis* (Konasewich et al. 1982). Local concentrations in biota have been noted to reach 22.9 ppm (Malins et al. 1980). Although EPA water quality criteria guidelines have not been established for saltwater biota, acute and chronic toxicity levels for marine organisms are noted at 450 and 25 ppb, respectively (EPA 1980).

Mercury. Mercury is an EPA priority pollutant, and is considered a Category 1 pollutant by Chapman et al. (1982a); a pollutant of concern by Konasewich et al. (1982); and the metal of greatest concern by Crecelius (pers. comm.). It is persistent, bioaccumulative, and one of the few heavy metals known to biomagnify. Concentration factors of 100,000 and 1,670 have been observed in marine invertebrates and fishes, respectively (Callahan et al. 1979).

Mercury is elevated in Puget Sound water, sediments, and biota; it has been observed at concentrations of >1 ppm in sediments of Sinclair Inlet and Bellingham, Elliott, and Commencement Bays (Malins et al. 1982). Concentrations in Puget Sound bottomfish, salmon, and dogfish have been noted at 74, 77, and 970 ppb, respectively (Dexter et al. 1981). Mercury is of concern because of possible effects to consumers of Puget Sound biota.

Mercury has been estimated to have five times the toxicity of lead (Schroeder *in* Konasewich et al. 1982). EPA (1980) criteria guidelines recommend a maximum concentration in water of 0.025 ppb (24-hour average), never to exceed 3.7 ppb, for marine life.

Silver. Silver is an EPA priority pollutant, and is considered as a Category 1 pollutant by Chapman et al. (1982a), and a pollutant of concern by Konasewich et al. (1982) and Crecelius (pers. comm.). Dexter et al. (1981) believed data on silver to be limited and of unknown quality. It is persistent, bioaccumulative, and elevated in local water, sediment, and biota. Silver concentrations are highest in Sinclair Inlet and City and Sitcom Waterways in Tacoma. Concentrations from 1,000 to 11,000 ppb have been observed in dry weight sediments from a number of diverse areas (Malins et al. 1980). Silver is bioaccumulated primarily through the water, and concentrations have been noted to reach 6,070 ppb in local biota (Konasewich et al. 1982). Silver is considered to be one of the most toxic metals, and very low levels have been shown to affect aquatic organisms. A maximum concentration in water never to exceed 2.3 ppb is recommended by EPA (1980) for saltwater life. No 24-hour criteria are available.

Copper. Copper is an EPA priority pollutant, and is considered a Category 1 pollutant by Chapman et al. (1982a), and a pollutant of concern by Konasewich et al. (1982) and Crecelius (pers. comm.). It is persistent, bioaccumulated, and elevated in local sediments and water. There is also limited evidence for its bioaccumulation in demersal fishes. Accumulation of copper has been noted in fish (liver) and invertebrates to levels of 17.6 ppm and 79.7 ppm, respectively (Malins et al. 1980). Dry weight sediment concentrations of 1,600 ppm have been noted; in comparison, EPA guidelines within the Great Lakes consider dry weight sediments in excess of 50 ppm copper as "heavily polluted" (Konasewich et al. 1982).

Copper (as cupric ion) is very toxic to marine biota. Konasewich et al. (1982) report 96-hr LC50 values as low as 5 ppb total dissolved copper. Marine invertebrate larvae are particularly sensitive, but sensitivity is widely variable among species. EPA (1980) guidelines specify a maximum 24-hour average of 4 ppb total dissolved copper, never to exceed 23 ppb. Sanders et al. (1983) tested crab larvae at total dissolved copper concentrations between 0.57 and 1270 ppb, resulting in a calculated cupric ion concentration of 0.003-10 parts per trillion. Survival and duration of the larval stage did not change over the range of test conditions, but larval growth decreased at total copper concentration above 60 ppb. In Puget Sound, total dissolved copper ranges from 0.1 to 3 ppb (Schell 1976).

Arsenic and Cadmium. Some controversy exists over the importance of arsenic and cadmium as toxic pollutants in Puget Sound. Both are EPA priority pollutants and are considered Category 1 pollutants by Chapman et al. (1982a) because of their persistence, bioaccumulative ability, and nonvolatility. Konasewich et al. (1982) consider them compounds of concern. Crecelius (pers. comm.) believes they are not of great concern because neither appears to be affecting Puget Sound biota at the present time. Dexter et al. (1981) believe data on cadmium are of uncertain quality.

Arsenic is a known human carcinogen, but this has not been shown for animals. There is evidence that suggests bioaccumulation in demersal fishes. Little is known about arsenic concentrations in or effects on marine biota (Sittig 1980; Konasewich et al. 1982). The primary anthropogenic source is the ASARCO smelter. Highest levels of arsenic are found in the vicinity of ASARCO and in sediments of Quartermaster Harbor. It reaches concentrations up to 10,000 ppm in localized areas near the source (Konasewich et al. 1982). EPA (1980) water quality criteria for arsenic include a saltwater acute criterion of 508 ug/l and state that the criterion should be lower among species more sensitive than those tested. No chronic criterion is given.

Cadmium levels in Elliott Bay sediments reach at least 18 ppm, and exceed "heavily polluted" levels designated for Great Lakes harbors (Konasewich et al. 1982). Cadmium is also elevated in sediments of Commencement Bay (up to 16 ppm), and Budd Inlet (up to 11 ppm) (Dexter et al. 1981), but little concentration data from water column or biota are available. Cadmium is also strongly bioaccumulated through both food and water and is relatively mobile in the environment (Callahan et al. 1979), so it is bioavailable for many organisms. Concentration factors of 250,000 and 3,000 have been noted for marine invertebrates and fish, respectively, (Callahan et al. 1979) in other areas. Low levels are capable of causing chronic effects; 6.5 ppb and 5 ppb have been shown to affect mysid shrimp respiration and brood formation. Existing levels also exceed concentrations shown to affect burrowing in some clam species (Konasewich et al. 1982). EPA (1980) Water Quality Criteria guidelines for cadmium are 4.5 ppb for a 24-hour period, not to exceed 59 ppb at any time.

Selenium. Selenium is an EPA priority pollutant, and is considered to be a Category 1 pollutant by Chapman et al. (1982a) because of its persistence, bioaccumulative ability, and nonvolatility. Local researchers have varying opinions concerning selenium. Dexter et al. (1981) believe selenium data are unreliable; Konasewich et al. (1982) consider selenium to be a pollutant of concern; and Crecelius (pers. comm.) believes it is not a problem. It is highly elevated in Puget Sound sediments, and concentrations as high as 113 ppm in dry weight sediments have been noted (Konasewich et al. 1982). There appear to be few data for water column and biota. However, selenium is acutely toxic to aquatic invertebrates and fishes (Sittig 1980); the EPA (1980) criterion for protection of saltwater life is 54 ppb (24-hour average), not to exceed 410 ppb (recoverable inorganic selenium).

Chapter 5

RECOMMENDED MASS LOADING STUDIES

A review of the existing pollutant loading data (Jones & Stokes Associates, Inc. 1983) revealed that pollutant loading from many sources is poorly understood, both qualitatively and quantitatively. Without accurate knowledge of pollutant contributions from various sources, efficient and effective pollution control decisions cannot be made. Therefore, additional mass loading studies are needed to quantitatively determine the significance of the different sources of pollutants.

The list of high priority pollutants presented in Chapter 4 generally provides the focus for the effort in the following studies. Exceptions to this are noted as appropriate. In all cases, mass loading studies must evaluate the chemical species, or isomeric forms in which pollutants occur. Furthermore, the data must distinguish between pollutants in the dissolved and particulate state to the extent that this information may be obtained.

Data from mass loading studies significantly influence the focus of studies on transport and fate processes (Chapter 6) and biological effects (Chapter 7) by identifying those pollutants that should be investigated and where. Mutual feedback between mass loading and biological effects studies is generally practical because many of the studies are internally subdivided into phases. Progress and results of early phases help define or focus the work effort in later phases.

The purpose of a mass loading study must be clearly defined before initiation of the program. Each study must provide data that will meet one or more of the following data needs:

- What are the high priority pollutants in given geographical (water mass) areas, based on suspected biological effects and suspected quantities discharged or retained in the area?
- What are the major sources of high priority pollutants?
- What are the loadings of high priority pollutants for each identified or suspected source?

The mass loading studies presented below will provide a better definition of the magnitude of the various pollutant sources to Puget Sound. These mass loading studies should provide information that will enable water quality managers to compare relative mass loadings among various sources, and make cost-effective decisions regarding any necessary control measures or remedial actions.

High Priority Pollutant Lists by Geographic Area

Need. The list of high priority pollutants identified in Chapter 4 is a preliminary list based on existing information developed for Puget Sound as a whole. The Sound is sufficiently large and the range of human activities sufficiently diverse that large quantities of certain pollutants may be found only in localized areas of the Sound. Furthermore, the speciation of these compounds can alter toxic effects, and may vary from area to area. There is a need to refine the preliminary list of high priority pollutants to provide water quality managers with a list of pollutant species, isomers, and their metabolites that would be most appropriate for monitoring or research analyses in localized areas.

Objectives.

1. Develop a semiquantitative estimate of pollutants entering localized areas of Puget Sound.
2. Identify the chemical species, isomers, and degradation products of priority pollutants in various areas of Puget Sound.
3. Conduct a literature review to identify respective toxicological effects.
4. Refine the list of high priority pollutants by area as other mass loading studies are conducted.
5. Develop open file reports on high priority pollutants by geographic area.

Methodology. The preliminary high priority pollutant list in Chapter 4 represents a starting point for the development of more refined lists for localized areas of Puget Sound. Pollutants listed in Chapter 4 should not be deleted from the regional lists of high priority pollutants unless it can be shown that mass loading is minimal and the toxicity of the chemical species, isomer, or degradation products does not warrant high priority status in a given localized area. This list may be further modified pending the outcome of studies conducted for EPA Office of Policy and Research Management on the pulp and paper mill industry (Woods pers. comm.). Similar evaluations should be conducted if and when comparable data are obtained for other industries, and as data are obtained from mass loading studies.

Semiquantitative estimates of pollutant loadings into regional areas of Puget Sound can be developed using existing monitoring data obtained by major dischargers and published national average concentrations for discharger SIC numbers (SCS Engineers 1981). Alternative strategies may need to be developed for small municipal dischargers that have not been required to monitor concentrations of priority pollutants in the effluent but receive industrial wastes. These estimates can be used to establish and refine regional lists of high priority pollutants.

A literature review should be conducted to document estimated toxic risk for each chemical species, isomer, or byproduct, perhaps in the manner described by Klapow and Lewis (1979) and illustrated in Figure 5-1.

The list or lists of high priority pollutants should be developed as open file reports, i.e., constantly amended as new information is obtained by water quality managers.

Benefits to Water Quality Managers. The development of regional (localized) lists of high priority pollutants will help focus localized monitoring and research efforts on those pollutants. These lists also can be used to focus source investigation activities and transport/fate studies. The lists provide flexibility in establishing monitoring programs and permit conditions from area to area.

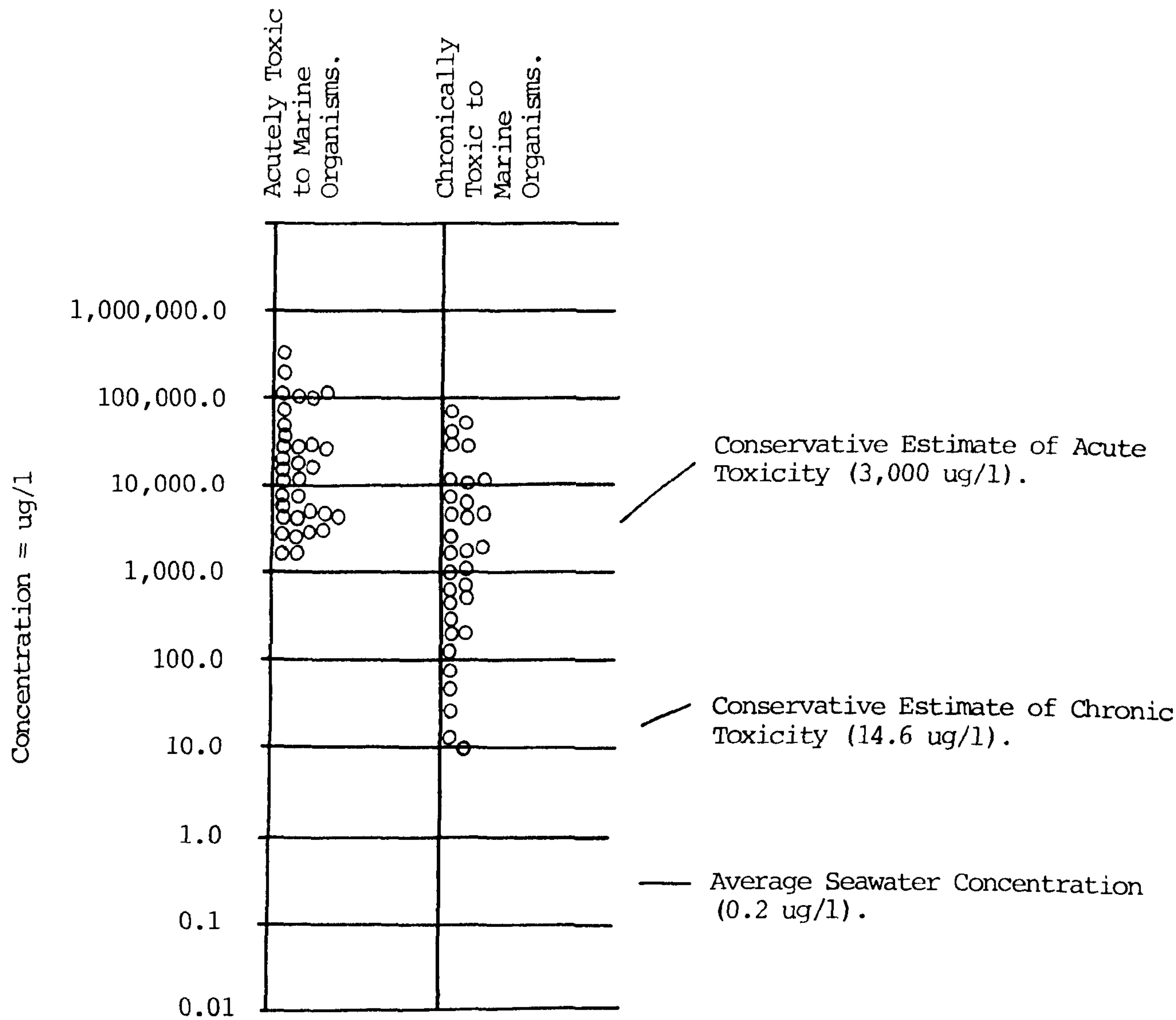
CSO Effluent

Need. Nine cities that discharge to the study area have combined storm and sewer systems; six of these (Bellingham, Bremerton, Everett, Olympia, Port Angeles, Seattle Metro) discharge into confined urban embayments. These systems contain emergency overflow stations that provide a means to bypass the treatment plant, i.e. discharge without treatment, during periods of heavy rainfall. The pollutant loading from combined sewer overflows (CSOs) is potentially significant during large storm events. Limited information currently exists on discharge quality and volumes. Seattle Metro is conducting a local CSO study as part of their TPPS program, and recent facility plans of Metro and Bremerton have quantified CSO flows and frequency of flow events (Kievit pers. comm.). Pollutant concentration information is needed to enable water quality managers to calculate mass loading of pollutants from CSOs by area, and to evaluate any need for control measures.

Objectives. Estimate the loading of priority pollutants from CSOs to Puget Sound on an annual or seasonal basis.

Methodology. The design of this study must be directed toward characterization of CSO flows that would allow a loading approximation without detailed monitoring of each CSO. CSOs to

Figure 5-1. Example of Toxicity Data Plotted for a Chemical Species



Source: Modified from California State Water Resources Control Board 1983.

be evaluated by this study must discharge into urban embayments at a frequency of at least one discharge in two years, (i.e. discharge during a median flow event). If significant variation in volume and pollutant composition is found or expected between CSOs, classes of CSOs may need to be distinguished and characterized. Variations could result from differences in system contributors, tributary land uses (industrial, commercial, or residential), and frequency and duration of overflow.

A review of Metro's CSO study is needed to determine whether meaningful variations in effluent composition exist between CSOs and whether classes were (or can be) distinguished. If classes of CSOs are distinguishable, other areas with CSOs should be characterized to determine appropriate CSO classification. Loading estimates should be made based on appropriate Metro pollutant analysis data, site-specific historical records of actual overflows, or precipitation records and system capacity.

If Metro's data do not allow distinctions between classes of CSOs, a characterization study is needed. The study involves selecting areas with differing land uses and system contributors, and monitoring the volume and composition of discharge from CSOs. These results would then be used to estimate the CSO loading to specific areas of Puget Sound.

Benefits to Water Quality Managers. The study would provide an estimate of the mass loading and relative contribution of designated pollutants to urban embayments from CSO sources. The water quality manager will be able to determine whether CSOs represent major sources of certain pollutants and, therefore, whether control of this or other sources would be appropriate and cost-effective.

Rivers Discharging into Urban Embayments

Need. Rivers discharging into urban embayments are subject to potentially significant pollutant loadings as the river flows through the urban area. Both point and nonpoint pollution sources can be numerous. Rivers draining urban areas are, in most cases, draining into urbanized harbors, bays, or other subareas of Puget Sound that typically have water quality problems. Current pollutant loading data for Puget Sound rivers draining urban areas usually encompass only conventional pollutants and heavy metal parameters. Urban rivers normally contain higher levels and a wider variety of pollutants than rivers draining rural watersheds. Data are needed to estimate the contribution of organic priority pollutants to urban embayments from riverine discharges. Recent EPA programs in the Elliott and Commencement Bay areas may significantly reduce the effort required by this study on the Duwamish and Puyallup Rivers.

Objectives. Determine pollutant loadings from rivers draining urban areas.

Methodology. Rivers which discharge to urban embayments or drain large urban areas are listed in Table 5-1. Water quality sampling should occur near the mouths of these rivers. The stations should reliably represent net river discharge. Factors that should be considered include: location of major confluences; depth; distance from riverbank; tide-induced upstream movement of water and its effect on the transport of dissolved pollutants and suspended particulates, and spatial relationship to nearby dischargers. The duration and frequency of sampling should allow for determination of seasonal variances.

The following information sources should be used to select the pollutants that will be quantified:

- The list of high priority pollutants described in Chapter 4.
- Loading data from major upstream dischargers.
- Previous special studies that may reflect water quality conditions in the river or watershed.
- An initial pollutant scan to verify or add to the list of high priority pollutants.

Pollutant loading measurements should include those pollutants occurring in the soluble and suspended particulate state. In addition, all conventional water quality parameters should be analyzed because of their importance in fate and transport processes of pollutants. (See General Requirements in Chapter 8).

Benefits to Water Quality Managers. The data from this study will determine the relative contribution of rivers to the pollutant load in urban embayments. The data can also be used as a preliminary estimate of the potential role of many nonpoint pollutant sources resulting from land uses on the watershed. A comparison of the magnitude of river contribution to other source contribution is needed to identify any appropriate corrective measures.

Depending on the results of this study, several other phases may be considered for implementation. First, a more detailed investigation on sources of pollutant loading to the river may be needed to decrease the river's contribution of pollutants to urban embayments. Second, smaller streams which also drain urban areas may need to be analyzed if significant river-related loadings are indicated. Third, if the riverine load is determined or suspected to be significantly influenced by natural pollutant sources or human activities in rural areas, analysis of nonurban rivers may be necessary to quantify riverine loading.

Table 5-1. Rivers Discharging to Urban Embayments or Draining Urban Areas

River	City	Receiving Water
Whatcom Creek	Bellingham	Bellingham Bay
Snohomish River	Everett	Everett Harbor
Lake Washington Ship Canal	Seattle	Central Basin
Duwamish River	Seattle	Elliott Bay
Puyallup River	Tacoma	Commencement Bay
Deschutes River	Olympia	Budd Inlet

Finally, the data may indicate whether a long-term monitoring program is warranted.

Industrial Survey

Need. The existing NPDES effluent limitations and monitoring requirements of industrial dischargers are usually limited to conventional pollutants. Few data exist on concentrations of priority pollutants or other toxic chemical compounds that could occur in the discharge. These data are needed to accurately obtain a loading estimate that could be used by water quality managers.

Objectives.

1. Determine the possible pollutants in effluents from NPDES-permitted industrial dischargers.

2. Estimate loadings for these pollutants.

Methodology. WDOE should identify probable constituents in industrial waste streams based on published national average concentrations for SIC numbers (SCS Engineers 1981), EPA Form 3510-2C (currently used for NPDES renewals), and the Industrial Waste Survey conducted for the Department of Energy (URS Company 1980). Based on these data sources and actual concentrations reported in discharger monitoring reports (DMRs), mass loading of high prority pollutants should be estimated for specific areas of the Sound.

It should be noted that level of treatment and local variations in industrial plant operations may greatly affect a pollutant's concentration, but that using the average concentration provided by SCS Engineers (1981) will yield an approximate value of loading to specific water bodies. Areas with high estimated loadings should be investigated in more detail with a quantitative pollutant scan of appropriate discharges.

Benefits to Water Quality Managers. This study would identify probable pollutants and loadings from various industrial dischargers. It would help refine localized lists of high priority pollutants, and determine relative contribution of pollutants from industrial discharges. This information would be useful in evaluating currently identified problem areas. The survey would provide a means of focusing on probable pollutants in a certain area so that selective monitoring of pollutants and appropriate dischargers could occur if deemed necessary. Also modifications to NPDES permit limitations and requirements could be made to stabilize or abate the discharge of identified problem pollutants.

Urban Runoff

Need. Urban areas have many nonpoint pollution sources that are likely contributors of pollutants to urban runoff. Except for cities with combined sanitary and storm sewers, urban runoff flows into Puget Sound without any treatment. In many cases, storm drains empty directly into Puget Sound as hundreds of nonpermitted point sources. WDOE has developed an Urban Stormwater Management Plan (Grace 1983) that includes issuing general permits for stormwater discharge in an area. Some data on pollutant loading may be generated by implementation of this plan, but will not appear for some time. The pollutant loading from this source is potentially significant; quantification of pollutant loading is needed to determine if corrective measures should be implemented. A study is in progress by the City of Bellevue that addresses loadings from urban runoff, and may be transferable to other Puget Sound areas.

Objectives.

1. Based on the Bellevue report and other appropriate data, estimate the pollutant loading from urban areas that would be expected to have similar runoff characteristics.

2. Collect data as needed from other urban areas to allow estimates of mass loading from storm drain discharges.

Methodology. Site characteristics of urban areas around Puget Sound would be evaluated relative to factors influencing urban runoff parameters. The evaluation should include local land uses, upwind air pollution point sources, annual average precipitation, and drainage programs. Data from the Bellevue study would be used to estimate pollutant loading to urban embayments for comparable urban areas. For urban areas that are determined to be significantly different from the Bellevue sites, a comparison with other areas in Metro's Toxicant Pretreatment Planning Study (TPPS) program or in the National Urban Runoff Program (NURP) should be made. Appropriate estimates of pollutant loading for comparable Puget Sound urban areas would then be made. If significant urban areas of Puget Sound cannot be assumed to be similar to other areas that have been studied, runoff analyses must be performed to estimate the pollutant loading from these areas.

Benefits to Water Quality Managers. The approximate loadings from urban runoff could be compared with other known sources. This would determine to what extent corrective measures are needed. The data will help determine whether there is a need to evaluate local stream quality, because of potential similarities to urban runoff.

Municipal Treatment Plant Survey

Need. Approximately 75 municipal wastewater treatment plants discharge to Puget Sound. Effluent composition is a function of: number, size, and type of contributors to the system; degree of pretreatment of industrial wastes; and treatment capabilities of the plant. Due to the variety of inputs to a sewer system, many different pollutants may be present in the effluent. In most cases, information is not available for parameters other than conventional pollutants. Metro treatment plants and some of the other municipal plants that have applied for 301(h) waivers have limited data on priority pollutant parameters. If mass loading of pollutants is to be accurately assessed, there is a need for data from all municipal dischargers. The need for this study and the level of effort required will depend on the quantity and quality of data provided with 301(h) waiver applications.

Objectives. Quantify pollutant loading from municipal treatment plants.

Methodology. Sample collection and analysis should be performed on the effluent from municipal treatment plants after all treatment processes, including chlorination, have occurred. Sample collection and analysis should follow prescribed methods that are the same for all dischargers. Treatment plants that process only domestic wastewater and discharge small volumes of wastewater initially need not be included in this study. If the study indicates that homeowner discharge of toxic materials may be a major source contribution, the study should be revised to include all municipal dischargers. The study should include an analysis for both wet and dry periods. Initially, a qualitative pollutant screening should be conducted to identify any priority pollutants that occur in the effluent. Quantitative analyses can be restricted to high priority pollutants and to other selected pollutants identified in the qualitative screening.

Benefits to Water Quality Managers. The municipal effluent stream is the final discharge point for many dischargers. Because of the variety of pollutants that may be present in a municipal effluent stream, the loading from each municipal discharger is an important and highly variable element in understanding total Puget Sound loadings. The data resulting from this study will permit water quality managers to identify appropriate places to implement cost-effective corrective measures. These data will be helpful in comparing the relative contribution of municipal dischargers during the evaluation of Section 301(h) waiver applications.

Atmospheric Flux

Need. The atmosphere is the receiving body for many types of emissions. Pollutants are transported and sometimes transformed within the air column, and may be deposited directly to Puget Sound waters or onto adjacent lands. Pankow et al. (1982) indicate that a wide variety of organic compounds are present in the atmosphere. Current data on pollutant concentrations are limited to some heavy metals, conventional air pollution parameters, and parameters influencing acid rain. The magnitude of the pollutant loading from the atmosphere is unknown at this time. It is expected that loadings of certain pollutants in certain areas would be significant. An ongoing Metro study is investigating the atmospheric contribution of heavy metals to the Central Basin of Puget Sound. An ongoing Bellevue study includes a partial analysis of dry and wet atmospheric fallout. The data from these studies may be useful in design of this program.

Objectives.

1. Identify and, if possible, estimate concentrations of high priority pollutants in the atmosphere and in air fallout residue.

2. Estimate magnitude of dry, wet, and gaseous contribution to Puget Sound.

3. Determine areas of most likely significant contribution.

Methodology. A review of existing PSAPCA data and data soon to be released by Metro and Bellevue on air pollutants, concentrations, and deposition rates would be the first step in this study. This would include a review of sampling and monitoring techniques and selection of parameters. An initial analysis from one or more known areas of poor air quality would help establish a list of high priority pollutants. The station network design should consider local wind patterns, large point sources, direct input to Puget Sound, and existing air quality monitoring stations.

Benefits to Water Quality Managers. The study would provide a better understanding of this source and its impact on Puget Sound. If significant quantities of pollutants of concern are inputted from the atmosphere, a further study may be necessary to pinpoint originating sources.

Septic Tank Leachate

Need. WDOE and DSHS have decertified certain shellfish growing areas because of violations of fecal coliform standards.

Although it is suspected that septic tank leachate may be the problem source in some of these areas, confirmation and location of the problem source is needed.

Objectives. Locate septic tank leachate plumes that could contaminate shellfish.

Methodology. EPA Region 5 has successfully used a septic leachate detector system (Kratzmeyer pers. comm.). The instrument is portable, can be used on a small boat, and is operated by two people. The system used by Region 5 would work in relatively calm marine waters. The machine detects the presence of organic materials, but does not discriminate between natural organics and leachate. As a result, false positive readings may occur. False and real positives can usually be distinguished by drilling shallow test wells along the shoreline every 6-7 meters and testing groundwater.

Benefits to Water Quality Managers. Identification of sources of fecal coliform input would allow adequate control measures and recertification of local shellfish growing areas.

Historical Spills, Dumps, and Locations of Contaminated Sediments

Need. Large pollution inputs have occurred during accidental spills and as a result of previous waste and dredge spoil disposal practices. PCBs in the Duwamish estuary, Commencement Bay's chemical dumpsite, and the Four Mile Rock dredge spoil disposal site in Elliott Bay are examples of past events that continue to impact water quality. The persistence of many pollutants requires that such historical events and their locations be summarized. Since areas with contaminated sediments may be a significant pollutant source, knowledge of these locations and their present influence on water quality is needed to determine the relative level of impact of past events and current practices.

Objectives.

1. Summarize spill events that included large inputs of persistent pollutants (PCBs, pesticides, heavy metals, radioactive wastes, and chlorinated hydrocarbons) and locate continuing sources of leachate.

2. Determine if leachate or sediments at these locations continue to contribute to water quality problems in Puget Sound, and estimate relative contribution where appropriate.

Methodology. This study should draw on existing records and data as its main source of information. Some limited sediment sample collection and analysis may be necessary to verify existing conditions. Major data sources include investigations under Superfund, the Resource Conservation and Recovery Act (RCRA), and WDOE hazardous waste investigations.

Benefits to Water Quality Managers. This study would provide a comprehensive documentation of events, locations, and pollutants involved. The data would provide a framework for comparing the relative impact of historical and current practices, and identify potential clean-up areas.

Chapter 6

RECOMMENDED STUDIES OF TRANSPORT AND FATE PROCESSES

A major information need is knowledge of the dispersion, transport, and fate of dissolved pollutants, contaminated sediments, and suspended solids released from rivers and waste outfalls. Other water quality parameters of potential interest include dissolved oxygen (DO), biochemical oxygen demand (BOD), temperature, salinity, pH, and nutrients. A second major information need is the ability to predict the effects of altered management practices on these dymanic processes.

Mathematical hydrodynamic simulation models are recommended as the best approach for predicting pollutant fates under various waste management alternatives. Such models, coupled with appropriate data on pollutant fate processes, must be capable of answering the following important water quality management questions:

1. What is the retention time for pollutants in the water column of urban embayments?

2. What fraction of the pollutant load is deposited in the sediments of urban embayments?

3. Where are the depositional environments in urban embayments?

4. What pollutant load of each urban embayment is contributed to Puget Sound as a whole?

5. Where are the depositional environments in Puget Sound?

Although questions 1-4 are concerned primarily with processes occurring within embayments, larger-scale circulation patterns influence these processes. Pollutant fate in embayments is highly dependent on the degree of water exchange at the system boundaries. Application of circulation/water quality models to embayments requires that boundary conditions either be specified, or be predicted by a larger-scale hydrodynamic model. If a large-scale model is not used to define boundary conditions, a localized modeling effort would require an intensive oceanographic field study to empirically determine boundary flow. The most cost-effective and reasonable approach to assessment of pollutant transport and fate is to first develop systemwide predictive capabilities. A generalized system model would be modified (as needed) and applied to the entire Sound to define overall transport processes, interbasin transfer, and boundary conditions at subsystems of concern. More detailed models could then be applied to major Puget Sound basins (e.g., Central Basin) to predict specific circulation and depositional patterns. Finer grids could be used in areas such as Commencement Bay to predict localized pollutant transport.

Puget Sound is a highly complex system, exhibiting both horizontally and vertically oriented physical processes. Many of the physical processes are variable over time, requiring a model capable of accounting for dynamic processes occurring in the Sound. As a result, the selected model should meet the following criteria.

- Must be hydrodynamic, rather than hydrostatic.

- Must be capable of simulating both vertical and horizontal physical processes.

- Must conserve mass.

- Must be theoretically sound, particularly for certain physical processes for which hydrostatic approximations are necessary.

- Must operate with a flexible grid system, i.e., can optimize the trade-off between spatial resolution and cost of use by allowing less detail in noncritical areas and larger element spacings in deeper water.

- Must be available (nonproprietary) and manageable by EPA/WDOE personnel.

It is currently recommended that the study area be limited to the Puget Sound area south of Deception Pass and the northern end of Admiralty Inlet, including the Whidbey, Southern, Central, and Hood Canal Basins. The San Juan Island Passages, the Strait of Juan de Fuca, and the Strait of Georgia do not warrant inclusion at this time. Waste inputs to the marine environment from these areas represent only a small fraction of the total waste loading, and inclusion of these areas in the modeling effort would substantially increase complexity without significantly increasing predictive capability.

Studies of transport processes can be initiated with little input from other studies, but the results initially will be limited to describing the movement of water within Puget Sound. Once data are available on fate processes, particularly in reference to pollutant reactions at the freshwater/saltwater interface and solids settling patterns, the water circulation models can be used to predict how and where specific pollutants will be distributed in Puget Sound.

Puget Sound Circulation Model

Need. No model that has been applied to Puget Sound adequately describes overall circulation patterns, fate processes of solids, or interbasin transfer on a Sound-wide basis (Jones & Stokes Associates, Inc. 1983). A model that can describe these features is needed to provide system-wide information for use in more detailed formulations and to assess the sensitivity of model results to variations of important driving variables and boundary conditions.

Objectives. Develop a working, predictive model, including calibration and verification, for use by EPA in a comprehensive modeling program.

Methodology. Although the ideal model would be a 3-dimensional representation of the entire system, the costs of such a model would be prohibitive, especially for long-term transient simulations. Fortunately, however, because of the generally narrow and deep nature of Puget Sound, a 2-dimensional, laterally averaged approximation is justified.

The model by Najarian et al. (1981) was identified in an earlier work effort (Jones & Stokes Associates, Inc. 1983) as the optimum existing technique for application to Puget Sound. Adaptation to Puget Sound requires work effort that is designed to:

- Provide descriptions of overall circulation patterns, mixing processes and net mass transport throughout Puget Sound. Model results should aid in locating areas of complex hydrodynamic processes requiring additional field data and detail in the sub-basin models.

- Provide insight into the sensitivity of the model calculation to variation of parameters and approximations of important processes such as sill zone circulation, solids processes, and water reflux coefficients.

- Determine boundary conditions required to drive the sub-basin models. Boundary conditions of particular importance include interbasin exchange of water and pollutants, water reflux, and net mass transport between basins.

A more technical description of the methods is provided in Appendix B.

Benefits to Water Quality Managers. The model can be used to supply general information such as net circulation patterns, mass transport, and boundary conditions. The data provided by the model can also be used to drive more detailed sub-basin models.

Central Basin Circulation Model

Need. Although laterally averaged models are sufficient for a Sound-wide application, they may not always be appropriate when examining the localized effects of rivers or waste discharges, especially when large lateral gradients in water quality are expected. The Central Basin receives wastes from multiple discharges along its shores, is relatively wide in certain areas, and exhibits complex net transport vertically throughout the basin, and horizontally around Vashon Island. Thus, a more complex 3-dimensional model is needed for prediction of circulation patterns and water quality characteristics in the Central Basin.

The development of a 3-dimensional, leveled model of the Central Basin, extending approximately from the Tacoma Narrows on the south to the entrances to Admiralty Inlet and Possession Sound on the north, is recommended. This model should be capable of predicting circulation patterns, mixing processes, solids transport and accumulation, and other water quality variables on a local basis. Specific areas of interest (e.g. Elliott and Commencement Bays) may be considered on a smaller-scale basis by adjusting the grid elements and time steps. The model by Sheng and Butler (1982) is recommended for adaptation to the study area (Jones & Stokes Associates, Inc. 1983).

Objective. Provide finer spatial resolution in the Central Basin where the largest fraction of wastes is discharged.

Methodology. Modifications to the model by Sheng and Butler (1982) include incorporation of desired variables (e.g. density modifiers and suspended solids) into the conservation of mass equation and the equation of state. Associated sources, sinks, and decay or settling rates must also be included in the formulation. These data will be provided by other recommended studies that address these processes.

The 3-dimensional, leveled model allows for grid flexibility to adequately represent sub-areas requiring greater detail. The most appropriate approach for model simulation would be to apply the 3-dimensional model in a "nested" fashion. The more detailed "nested" grid would extend only to the mouth of the bay, where it would be "coupled" to the less detailed version of the Central Basin 3-dimensional model for boundary condition specification. A second approach would simply involve refinement of the grid elements of the Central Basin model in the local areas of interest; however, this would always require running the entire Central Basin model, which may not be necessary or cost-effective depending on the specific study objectives.

Existing field observations are quite extensive for all modeling variables of interest in the Central Basin except for sedimentation and settling rates for solids and associated pollutants. Two independent data sets describing local phenomena and water quality characteristics are required for calibration and verification procedures.

Model calibration, verification, and sensitivity analyses recommended for this model are similar to those described in Appendix B.

Benefits to Water Quality Managers. This model is expected to be the most valuable one to water quality managers because of its flexibility and ability to model localized areas of Puget Sound. Once the systemwide model is developed to provide necessary data for boundary conditions and necessary fate processes are identified, the Central Basin model can predict the retention time of pollutants in urban embayments, areas of deposition of pollutants in urban embayments and the Central Basin, and the loadings from major bays to the Central Basin.

Pollutant Reactions at the Freshwater/Saltwater Interface

Need. Many pollutants reach Puget Sound in a freshwater medium, e.g. rivers, surface runoff, rainfall, and most municipal and industrial discharges. When pollutants carried by freshwater contact saltwater, a number of changes in chemical behavior and speciation (and therefore activity) occur because of changes in dissolved materials, pH, temperature, density, and a number of other factors. Some pollutants are likely to flocculate and settle out; others are likely to be released into the water column from suspended particulates and become more available to biota. Little information is available concerning fate processes of most pollutants in estuaries and other areas of freshwater/saltwater mixing. These data are needed to improve reliability of transport model predictions. The data also will help explain how pollutants act in the marine environment and become either available to biota or locked up in sediment sinks.

Objectives.

1. Determine reactions and compartmental shifting of pollutants in the freshwater/saltwater mixing zone.
2. Determine the extent of floc formation and its role in pollutant transport.
3. Determine effects of the freshwater/saltwater interface on chemical speciation.

Methodology. The study should combine data from the literature, field investigations, and rigorously controlled laboratory studies that reflect field conditions. A first step in this direction has been described by Curl (1982). The design of the study should provide data that can be used to generally describe speciation, flocculation, and compartmentalization of pollutants in a variety of freshwater/saltwater interfaces, including estuaries and point source discharge mixing zones.

The study should be conducted on the high priority pollutants identified in Chapter 4. Pollutant ionic state or isomer must be determined as appropriate. Distribution between the dissolved and suspended particulate state must be identified and flocculation rates assessed. The influence of DO, pH, conductivity, salinity, temperature, total dissolved and total suspended solids, and total organic carbon content on speciation, flocculation, and compartmentalization must be assessed.

All sample collection, preservation, and analyses should follow approved standard methods and be subject to EPA approval prior to sample collection. Analyses should be conducted by an EPA-certified laboratory.

Benefits to Water Quality Managers. The data will assist water quality managers in predicting whether the pollutant load will remain in a given area and whether the pollutant load will exist in a form that is likely to result in significant biological activity. These data are needed as input to the transport models so that depositional rates and environments can be reliably predicted.

Compartmental Distribution and Fate Processes for Pollutants in Sediments

Need. The fate of toxicants in marine waters is poorly understood. Sediments are a major sink for many pollutants, but mobilization from sediments (at least of metals) has been identified as one of two significant exchange processes within Puget Sound (Dexter et al. 1981). There is also some indication (e.g. data on DDT/DDE ratios) that degradation processes in Puget Sound sediments vary. However, microbial activity and sediment chemistry have not been researched, and concurrent data on the levels of toxicants in sediment interstitial water, the water column (dissolved and particulate phases), and biota have not been obtained. Compartmental distribution and exchange of pollutants in Puget Sound is therefore neither quantified nor well documented. These data are needed to understand the fate of toxicants in urban embayments and Puget Sound.

Objectives.

1. Determine the relationship between pollutant concentrations in sediment, biota, and dissolved and particulate water column fractions for specific types of sediments.

2. Determine processes and reactions in sediments affecting fluxes between environmental compartment and/or bioavailability of contaminants.

3. Obtain site-specific information on fate processes for two of the major embayment environments of Puget Sound.

Methodology. The study initially should encompass Commencement and Elliott Bays. Several sampling areas should be located in heavily polluted areas in each bay as well as in offshore deeper waters. The dredge disposal site in Commencement or Elliott Bay should also be considered for inclusion in the study. Because pollutant adsorption is affected by sediment grain size and organic content, areas of different sediment characteristics should be considered to provide a wider range of information. If possible, the study should include a site known to become anaerobic on a seasonal basis.

Sampling and analysis should include all high priority pollutants identified in Chapter 4 of this report. The study design should address the potential benefit (versus cost) of sampling twice - once during winter and once during summer.

The water column (just above the bottom, for both dissolved and particulate phases), bottom sediments (top layer), and benthic infauna should be analyzed to determine concentrations of high priority pollutants. Pollutant species (ionic state or isomer) should be determined when possible or applicable because this often determines mobility and toxicity.

In situ water column analyses should also be made to determine DO, pH, conductivity, salinity and temperature. Laboratory analyses should include total dissolved and total suspended solids for water. Sediment should be analyzed to determine composition, volume, activity of microbial organisms, and redox conditions. Sediment grain size, total organic carbon content, reduced sulfur content, pH, Eh, oxygen concentration, and any other factors believed necessary to define/understand sediment processes should also be analyzed. Data collection and analysis should follow recognized standard procedures. Analysis should be completed by an EPA-certified laboratory.

Upon completion of data collection and analysis, a report should be prepared that: 1) describes speciation and compartmentalization for each pollutant in each sediment type; 2) describes sediment and water column characteristics at each location; and 3) discusses reactions occurring within each sediment type and the degree to which these are responsible for pollutant biotransformation or mobilization from sediments to water column or interstitial water.

Benefits to Water Quality Managers. An understanding of fate processes in the marine environment, particularly the microbial and chemical activity in the sediments, is basic to understanding bioavailability to organisms and transport of pollutants via release to the water column. Understanding of sediments in at least two of the most contaminated embayments will provide important information on biotransformation/biodegradation ability, which in turn will help to determine long range assimilative capacity in these embayments. These data will be of value in developing action levels for sediment contamination, predicting the potential for toxic effects, identifying trends in pollutant accumulation and flux, and predicting loadings from major bays into the Central Basin.

Solids Settling Model

Need. Several models are available that describe particle settling in marine waters. In general, these models either simply assign a settling velocity to the particles, or compute a velocity based on Stoke's Law and include this component in the transport equations. The difficulty with either approach is that particle-particle interactions are ignored. Particles with diameters below about 10 um often coagulate to form larger particles. The two dominant parameters controlling coagulation in waste plumes are particle concentration (after initial dilution) and turbulence of the receiving water (Morel and Schiff 1980). Thus, the size of fine organic particles is not conservative and is subject to coagulation, which is controlled by the stochastic process of particle collision.

It is not clear whether coagulation processes must be included in the Puget Sound water quality model. Previous models, such as Hendricks (1978), have obtained reasonable results without directly modeling coagulation processes. It may be only necessary to use particle settling velocities in the water quality model that reflect speeds of coagulated particles. Two approaches are thus available: 1) develop particle settling algorithms that describe coagulation processes or, 2) develop a test to measure settling velocities representative of coagulated particles.

Particle settling velocity is usually measured in a column of water under quiescent conditions and with little concern for the initial concentration of particles in the test column. This procedure is not adequate because initial particle concentration and turbulence must adequately simulate coagulation processes in Puget Sound.

Objectives.

1. Describe coagulation and settling characteristics of solids in seawater.

2. Determine whether the Puget Sound water quality model should use measured settling velocities or incorporate a coagulation algorithm to describe particle settling.

Methodology. A literature review should be performed on algorithms that were developed to describe particle coagulation processes and on settling velocity measurements techniques under controlled turbulence conditions. Contact should also be made with NOAA, EPA, and the Southern California Coastal Water Research Project (SCCWRP) to review ongoing studies.

The decision to adopt the coagulation algorithm or settling velocity approach should be made based on cost differences in subsequently using the model and the expected accuracy of results. If adopted, the algorithm will be based on equations developed in the literature with minor modifications made as necessary. Similarly, the specifications of the settling velocity procedure, if adopted, will be based on existing literature and will specify the apparatus, procedure, and test data presentation.

Benefits to Water Quality Managers. The data developed with this model are needed as input to the transport models so that depositional rates and environments can be reliably predicted.

Advection of Organic Compounds

Need. Past mass balance studies and estimates of transport and dispersal through advection have concentrated primarily on nutrients or heavy metals. There is little information concerning concentrations, transport, and dispersal of organic priority pollutants. Most organic compounds are expected to adsorb readily to particulates. Larger particulates are likely to settle in the vicinity of the discharge in the absence of turbulence or strong currents, but any suspended particulate matter and associated pollutants at embayment mouths have the potential for advection to adjacent water masses. There is a need to determine whether advection plays a significant role in the distribution of organic priority pollutants in Puget Sound.

Objectives.

1. Determine the extent to which organic priority pollutants are transported by advection in various Puget Sound basins.

2. Evaluate the need for additional organic pollutant monitoring in ambient waters.

Methodology. Sampling should be programmed around a "worst case" advection scenario. Water samples should be obtained during periods of strong flow in the following areas: at the mouth of Bellingham Bay, Skagit Bay, Everett Harbor, Elliott Bay, Commencement Bay, Budd Inlet, and Sinclair Inlet; mid channel of Puget Sound off West Point; and mid channel of Hood Canal off King's Spit. Only a single sampling is anticipated at each location. If measurable quantities of organic priority pollutants are found, it may be desirable to sample additional areas such as Seahurst, Admiralty Inlet, Tacoma Narrows, Saratoga Passage, and other major passages.

Water samples should be taken on an outgoing tide, both a few feet below the surface and at mid-depth if possible, to allow for differences due to water layering. Current speed and direction should also be measured at each sampling depth.

An analysis should be made for all the high priority organic pollutants identified in Chapter 4 of this report. Organic compounds are expected to exist primarily adsorbed to particulates, with the exception of chlorinated ethylenes (found primarily in the dissolved fraction). Sample collection should follow approved standard procedures, and analyses should be conducted by an EPA-certified laboratory.

Benefits to Water Quality Managers. The study will allow a preliminary determination of whether significant organic pollutant advection exists between water masses. This information is also necessary for pollutant mass balance determinations within individual areas and for development of pollutant transport models. In addition, it will allow an assessment as to which, if any, of the high priority pollutants should be added to the existing WDOE marine monitoring program.

Organic Pollutant Fate Processes

Need. Any analysis of the fate of organic pollutants must recognize that their behavior is often highly nonconservative. Incorporation of a conservative pollutant into a water quality model is relatively simple; the model must keep track of all sources of the pollutant and the advective dispersion of the pollutant throughout the modeled system. Incorporating nonconservative organic priority pollutants into a water quality model is a much more complex process. In addition to advective transport, many organic pollutants are subject to chemical and microbial degradation, photodecomposition, and volatilization. For example, tetrachloroethylene degrades to tri-chloroethylene, cis-1,2-dichloroethylene, vinyl chloride, 1,1-dichloroethylene, and trans-dichloroethylene. As a further complication, most organic compounds readily adsorb to particle surfaces. Thus, a water quality model of organic priority pollutants must model the compounds partitioning between the dissolved and the adsorbed (or solid) state. If partitioning and chemical transformations are included, a water quality model can then simulate organic pollutant advective transport in the dissolved state and dispersion and settling of adsorbed pollutants, as well as take into account degradation and evaporative losses.

Objectives. The general objective of this study is to review the literature on partitioning coefficients and rate coefficients for degradation and evaporation processes for organic and inorganic priority pollutants. Specific objectives are:

1. Compile available coefficients for evaporation, chemical and microbial degradation, photodecomposition, solubility, octanol-water partitioning, and solids-water partitioning for high priority pollutants in Puget Sound.

2. Determine which processes are most significant in modifying pollutant concentrations.

3. Estimate the percentage of each high priority pollutant expected to be adsorbed onto particulate matter in Puget Sound.

4. Determine which pollutants should be included in the water quality model.

5. Develop algorithms to describe the behavior of high priority pollutants in Puget Sound, if appropriate.

Methodology. Konasewich et al. (1982) present an evaluation of the processes affecting the transport and distribution of chemical pollutants in Puget Sound. The report reviews available data on rates of photodecomposition, evaporation, chemical degradation (hydrolysis), sediment adsorption, and other processes for a large number of organic and inorganic pollutants. Callahan et al. (1979) also provide a great deal of information. The literature should be reviewed to determine whether additional rate coefficients are available for the preliminary list of high priority pollutants identified in Chapter 4 of this report.

The available coefficients for processes affecting organic and inorganic pollutant concentration will be presented with emphasis given to the solids-water partitioning coefficient for the high priority pollutants identified in Chapter 4. A sensitivity analysis will then be performed to determine the processes that are most significant in determining pollutant concentrations in Puget Sound. Recommendations will then be made to include organic pollutants in the Puget Sound water quality model or to simply consider all, or some percentage, of each pollutant to be irreversibly adsorbed onto particle surfaces.

Benefits to Water Quality Managers. The study will determine the feasibility of incorporating high priority organic pollutants into the Puget Sound water quality model.

Other Basin Models

Highest priority for water quality modeling is currently focused on the Central Basin. Recommendations for modeling other basins are provided in Appendix C.

Chapter 7

RECOMMENDED BIOLOGICAL IMPACT STUDIES

Jones & Stokes Associates, Inc. (1983) identified several categories of biological data that were necessary to link pollutants with adverse impacts on biota. Critical information needs include: bioavailability and bioaccumulation of toxicants; distribution of toxicants in biota; metabolic processing of pollutants; and dose-response relationships. Existing data sources were then reviewed for pertinent data on fishes, benthic invertebrates, and plankton. The analysis of these data left major questions unanswered in all of these types of biological data.

A "shopping list" of needed data is easy to compile if no consideration is given to the importance of the data or to the priorities inherent in its collection. It is difficult to assign priorities to projects, knowing that the resources available for supporting these studies are limited. The recommendations in this chapter focus on two broad management needs: linking pollutants to observed biological effects (particularly sublethal effects), and providing data that can be used to develop action level criteria for future management activities. In Chapter 9, an interim approach is proposed for making decisions, using other kinds of biological data (focusing on acute toxicities). The data obtained in the interim and the data obtained through studies recommended in this chapter together provide a comprehensive, increasingly sophisticated, systematic analysis of biological effects of pollution.

It appears that benthic organisms and demersal fish demonstrate suspected pollution-induced diseases or population changes more often than pelagic biota. Therefore, recommended studies should focus on benthic and demersal species. Exposure of benthic biota to pollutants can be by way of contaminated sediments, contaminated food, or contaminated water. The recommended studies, therefore, should test hypotheses that would examine which of these pathways leads to pollutant-induced disease or population changes.

Once significant exposure pathways are identified, it becomes possible to identify pollution concentrations that can be used by water quality managers to predict the impacts of changes in waste management and to establish action level criteria. Concentrations of toxicants in the water column are often transient and require frequent measurement. Concentrations in sediment and biota, on the other hand, integrate pollutant levels over time. Concentrations in biota are particularly useful indicators of bioavailability of compounds that are not readily metabolized or depurated. It is unlikely that water quality criteria alone will be effective in managing water quality in Puget Sound. Management decisions may need to be based on toxicant concentrations in sediments, or even in biota. The key to this is linking these levels with documented adverse impacts on biota or beneficial uses. Ideally, the linkage should be cause-effect, based on specific pollutants. This goal is pursued by recommendations in this chapter. At the same time, practical considerations indicate that decisions must also be made when adverse impacts cannot be directly related to specific causal agents. Therefore, priority must be given to determining whether statistically significant relationships occur between incidence of disease and body burdens of toxicants or concentrations of contaminants in sediment.

The following topics have been identified as the most important data gaps at the present time:

- What are the mechanisms of uptake and bioaccumulation of toxicants? Is the primary pathway of bioaccumulation through direct contact with or uptake from the sediments, from the water column, or through ingestion of contaminated food?

- Are observed body burdens statistically correlated with levels of sediment contamination? Is there a significant correlation between observed biological conditions (e.g. disease) and body burdens or sediment contamination?

- What role does exposure to toxicants, either in sediments or in prey organisms, play in the induction of disease among demersal fish species?

- What role do sediment contamination and organic enrichment play in the structuring of benthic invertebrate communities?

Major emphasis on biological effects studies has been placed on the relationship between levels of pollutant in sediments and biota and the incidence of disease. Consequently, major feedback should occur between the studies of biological effects and the study of compartmental distribution of pollutants and fate proceses within sediments (Chapter 6).

Key Species and Biological Communities

Before describing recommended studies designed to address these questions, consideration must be given to the selection of key species and biological communities to be used. Previous studies in Puget Sound have involved a wide variety of organisms or community types. The studies recommended in this chapter, however, have been directed toward only a limited number of organisms in Puget Sound. Because of cost constraints, laboratory or field investigations cannot be conducted on all possible organisms that are potentially affected by a pollutant source.

A list of species or biotic assemblages that are most appropriate for future study of pollutant impacts in Puget Sound has been developed (Table 7-1). The following criteria have been used in selecting key species for the recommended studies:

- Trophic importance.
- Commercial/recreational importance.
- Numerical abundance.
- Susceptibility or sensitivity to pollutant effects.
- Probability of exposure to pollution.
- Use in previous studies.
- Adaptability to laboratory conditions.

There is a trade-off between selecting organisms that are susceptible to pollutants and organisms that are likely to be exposed to pollutants. Ideally, consideration should be given to testing a variety of organisms. When funding resources are limited, a practical alternative is to select a species that occurs in polluted areas and is also known to demonstrate pathologies or other biological phenomena suspected to be pollution-induced.

The list in Table 7-1 should not be considered as all inclusive, but should primarily serve as guidance for those species that may be most appropriate. The recommended studies in this chapter include English sole as the recommended test organism. For any site-specific study, the local fauna should be evaluated for their appropriateness. Alternatives can be selected from Table 7-1. If none of these species is appropriate because of habitat or faunal differences, alternative species should be selected based on the previously listed criteria.

English sole and Dungeness crab are common in Puget Sound, have been used in previous studies, and are adaptable to laboratory conditions. Moreover, English sole prefer depositional environments and are therefore frequently exposed to impacts from contaminated sediments, and display pathological conditions thought to be induced by pollution.

Filter-feeding bivalve molluscs have been shown to be valuable organisms for assessing the potential for bioaccumulation of toxic substances. The bay mussel is commonly used in

Table 7-1. Recommended Species for Future Studies

Fishes
English sole (*Parophrys vetulus*)
Starry flounder (*Platichthys stellatus*)
Epibenthic Invertebrates
Dungeness crab (*Cancer magister*)
Bay mussel (*Mytilus edulis*)
Pacific oyster (*Crassostrea gigas*)
Infaunal Invertebrates
Macoma spp.
Littleneck clam (*Protothaca staminea*)
Butter clam (*Saxidomus giganteus*)
Amphipod (*Rhepoxynius abronius*)
Polychaetes (*Capitella capitata* and *Abarenicola pacifica*)

testing bioavailability of toxicants. The Pacific oyster is included in the recommended species list because of its past use in the oyster larvae bioassay, a technique that has undergone considerable development as a sensitive toxicity test.

Infaunal invertebrate communities are highly susceptible to sediment-related impacts. The use of infaunal assemblages is recommended because of their trophic importance. Compared to fish or plankton populations, it is relatively easy to quantitatively sample infauna and assess temporal and spatial changes in response to environmental perturbations. Many infaunal species are also well suited for use in laboratory bioassays. Many amphipods are important in structuring infaunal communities and as food for fishes. They are also relatively sensitive to the magnitude of sediment deposition and to sediment contamination when compared to other infaunal groups such as molluscs and polychaetes. Thus, the continued use of amphipods in assessing effects in indigenous assemblages and for use in bioassays is recommended. The phoxocephalid amphipod (*Rhepoxynius abronius*) has been used in previous studies and, although bioassay techniques may require further development, its use is recommended for future research programs. Infaunal species (e.g., *Macoma* spp. or *Abarenicola* spp.) may also be of value in assessing bioaccumulation or in conducting life cycle or sublethal bioassays.

Body Burdens, Sediment Concentrations, and Incidence of Disease

Need. A considerable body of data indicates that certain pathological conditions among demersal fish species occur in higher prevalence in polluted urban estuaries than in less polluted areas of Puget Sound. While the etiology of these pathological conditions is unknown, these data suggest that these conditions may be initiated by or associated with exposure of fishes to environments contaminated with various organic toxicants and heavy metals. There is a definite need to determine whether accumulation of toxicants in the sediments directly or indirectly affects benthic biota or can be associated with pathological conditions.

Previous investigators (e.g. Sherwood and McCain 1976; Malins et al. 1982) have assumed a linkage between the toxicants and pathological conditions, and have attempted to examine the body burdens of suspect toxicants in diseased fish and compare these with body burdens of healthy fish. All such attempts to date have been inadequate, however, at least partially because of the small numbers of fish examined. Furthermore, certain organic pollutants found in the habitat (e.g., polycyclic aromatic hydrocarbons) can be metabolized by fishes and, therefore, may not be found in high concentrations in fish tissues even if they are the causative agent for the observed disease. To ascertain whether there are significant correlations between the occurrence of pathological conditions in these fishes and environmental levels of toxicants, it will be necessary to: 1) collect and analyze sufficient numbers of diseased and healthy fish, along with other data from polluted and known unpolluted areas, so that appropriate statistical tests can be applied to the data; 2) identify pollutant loads in the environment as well as in body tissues.

Objectives.

1. Determine whether statistically-significant correlations exist between the occurrence of fish disease, high body burdens, and environmental concentrations of certain toxicants.

2. Determine whether sediment concentrations of certain toxicants can be used to predict the incidence of disease or bioaccumulation.

Methodology. Past studies of fish pathology in Puget Sound have concentrated on two flatfish species, English sole (*Parophrys vetulus*) and starry flounder (*Platichthys stellatus*). English sole from the polluted urban estuaries of Puget Sound have been shown to have a higher prevalence of disease, especially liver neoplasms (McCain et al. 1982), and are therefore recommended for this study.

Sufficiently large numbers of English sole should be collected in trawls in areas of known sediment contamination so that there is a reasonable expectation of obtaining a substantial number of diseased specimens. It would be desirable to collect fish from various urban areas (e.g., Hylebos Waterway, Commencement Bay, Duwamish River, Sinclair Inlet, Port Gardner) as well as from several control areas far removed from anthropogenic sources of pollutants (e.g., Hood Canal, San Juan Islands, or outside of Puget Sound if necessary). Thorough quantitative analysis of sediment constituents must occur at all sampling stations. Sampling effort can be reduced if this study is combined with field work conducted on effects of contaminated sediments on benthic invertebrate communities.

Considering the very low prevalence of most diseases in areas far removed from known sources of chemical contaminants, it is unlikely that significant numbers of diseased fish would be collected from the control areas. The concentrations of toxicants in healthy fish from these areas may be compared, however, with the concentrations in apparently healthy fish from the contaminated urban areas. These data will help determine whether body burden or sediment contamination is a better predictive indicator of the incidence of pathological abnormalities. Furthermore, the data may later be useful in addressing the potential existence of a time lag between exposure and appearance of pathological symptoms.

All specimens should be examined both macroscopically and microscopically for the presence of fin erosion, skin tumors, and liver abnormalities. Work in the North Sea indicates that bottom fish that contain body burdens of certain chemicals are unable to produce viable gametes (von Westernhagen et al. 1981). NOAA is sponsoring a study of the ability of Platichthys stellatus in San Francisco Bay to produce viable gametes and embryos (Mearns pers. comm.). Progress of this study should be monitored. If the effort seems warranted, tests of reproductive success of English sole should follow protocols being developed at Lawrence Livermore Laboratories (Spies pers. comm.). Past studies (Malins et al. 1980, 1982; McCain et al. 1982) have shown that other pathological abnormalities (e.g., lesions of the gill, kidney, spleen, and gall bladder, as well as certain cardiac abnormalities) either occur at low frequencies, or the geographical distributions of fish with these conditions are not clearly associated with polluted urban areas. Hence it is unlikely that sufficient numbers of fish with these conditions would be collected for analysis of these pathological abnormalities.

Replicate fish from each area should be selected at random from each group of fish with a specific disease type. Many fish may have symptoms of more than one disease (e.g., both skin tumors and hepatomas), and hence could serve as samples for more than one analysis. Tissue samples (at a minimum, muscle and liver tissue) should be taken from each fish for chemical analysis. It should be noted that the fish must be of sufficient size so that a sample of the liver may be analyzed microscopically for lesions and leave enough tissue (i.e., several grams at a minimum) for chemical analyses. The chemical analyses should include those organic toxicants and metals deemed to be of primary concern based on sediment chemistry. Replicate fish should also be selected at random from the group of fish having no disease symptoms, and then should be similarly analyzed. Data from all analyses should be normalized to eliminate age and size differences between fish. Furthermore, tissue concentrations of lipophilic compounds should be normalized for percent lipid content of the tissues. Stomach content of test fish also should be analyzed to evaluate potential dietary influences on fish condition.

Statistical analysis of the resulting data should be designed to detect significant correlations between the occurrence of a specific disease and tissue or sediment concentrations of toxicants identified in the sediment analyses. Particular attention should be given to possible correlations between the occurrence of liver abnormalities and elevated liver concentrations of the pollutants.

Benefits to Water Quality Managers. This study is designed to quantitatively identify reasonable relationships among the kinds and amounts of toxicants in sediments or in English sole, and the incidence of specific pathological abnormalities. Such correlations should not necessarily be taken as proof that a given toxicant was responsible for initiating the disease, but they, in conjunction with other related studies, may suggest which chemical contaminants are most likely associated with the initiation of these diseases. Furthermore, the study will ascertain whether levels of sediment contamination or body burdens of toxicants are adequate indicators of the incidence of pathological abnormalities. The results of this work are essential to the design of laboratory tests to examine cause-effect relationships. These data will help identify biological problems associated with pollutants now occurring in urban embayments, and also can be used to determine whether action levels can be established for pollutants in sediments or English sole. As noted in Chapter 3, work is currently underway on elements of the recommended study.

Long-Term Bioassays with Young-of-the-year English Sole

Need. Ample evidence exists to indicate that demersal fish species inhabiting polluted urban areas of Puget Sound have higher concentrations of certain organic toxicants in their tissues than do similar fish in less polluted areas of the Sound (e.g., Malins et al. 1980, 1982; Gahler et al. 1982). A considerable body of data also indicates that these same demersal fish species display higher prevalences of a number of pathological conditions in the urban areas than in background or control regions of Puget Sound (e.g., McCain et al. 1982). While in each case the end result is clearly defined, the mechanisms are largely unknown. In the case of bioaccumulation, it is not known whether the primary pathway is uptake from the water, contact with sediments, or ingestion of contaminated food. In the case of the various pathological conditions (e.g., fin erosion, skin tumors, hepatomas, and other liver abnormalities), their etiology is as yet undetermined. In each case, sampling natural populations of these fishes is not likely to reveal the exact mechanisms of these phenomena. Laboratory experimentation, combined with field data collected as part of the preceding recommendation, is probably the only way to resolve some of these difficult questions.

McCain et al. (1982) exposed English sole to contaminated sediments from the Duwamish River and to control sediments from the Snohomish River for 3 months in a laboratory bioassay. In a separate experiment, they exposed English sole to contaminated sediments from the Duwamish River and to control sediments from Port Madison for 2 months. There were no significant differences in mortality or histopathological changes between fish exposed to contaminated and presumed control sediments in either experiment. McCain et al. (1982) noted that in each experiment, the so-called control sediments were found to be contaminated. The Port Madison sediments had high concentrations of chlorinated butadienes, while the Snohomish River sediments had high concentrations of PCBs and pesticides. They concluded that if similar experiments were to be conducted in the future, the control sediment should be free of such contaminants, even if it is necessary to search beyond Puget Sound for uncontaminated sediment.

McCain et al. (1982) also concluded that the length of exposure in these experiments may not have been sufficiently long to permit the development of various histopathological conditions observed in naturally-occurring English sole in contaminated environments such as the Duwamish River. It is also possible that the Duwamish sediments used were not highly contaminated, since they were collected in the upper portion of the industrialized part of the Duwamish River, rather than in the lower portion where the concentrations of certain synthetic organic compounds are known to be higher. Sherwood and Mearns (1977) found that 13 months were needed before symptoms of fin rot appeared in mid-sized Dover sole. Enlargement of the liver and fin rot appeared much more quickly in young-of-the-year, perhaps because of the increased surface:volume ratio (Mearns pers. comm.).

An additional problem with these experiments to date is that all fish were fed relatively uncontaminated food organisms collected in nonurban areas, whereas naturally-occurring fish may ingest contaminated prey in the polluted urban estuaries, such as the Duwamish River. If food is the primary pathway for uptake of these substances, especially those important in the initiation of disease, this may explain the failure to induce histopathological conditions in the experimental fish exposed to contaminated sediments.

Despite past failures to induce pathological conditions in demersal fish species exposed to contaminated sediments, or to elucidate the dominant pathway of pollutant uptake, the experimental technique still holds promise for the investigation of these subjects. Attention must be given, however, to experimental design in order to maximize the power of discrimination among the possible alternatives.

<u>Objectives</u>.

1. Ascertain the primary pathway of bioaccumulation in demersal fishes.

2. Investigate the possible role of contaminated sediments and/or food in the initiation of various pathological conditions in those fishes.

<u>Methodology</u>. It is recommended that further experimentation be conducted along the lines of McCain et al. (1982), but with important refinements. It is suggested that the recommended bioassays be separated into two phases: a pilot or preliminary phase in which the efficacy of the procedures will be tested using only Duwamish River sediment and control sediment; and a second phase in which the procedures, if deemed to be appropriate will be applied to the testing of contaminated sediments from other areas of Puget Sound. The question of whether contaminated

food plays an important role in bioaccumulation or disease induction should be answered during the pilot study so that this aspect may be included or reduced in scope in later studies as appropriate.

McCain and co-workers at the Northwest and Alaska Fisheries Center in Seattle will soon begin a series of bioassays using English sole to test the toxicity and bioaccumulation potential of contaminated sediments from the Duwamish River, relative to control sediments collected from Hood Canal. In a sense, the studies recommended herein are modifications of the studies about to be undertaken by McCain and co-workers.

It is recommended that the proposed exposure time of young-of-the-year be increased from 4 months to a minimum of 6 months. In order to determine the magnitude of sediment contamination required to elicit a given response, it is recommended that similar bioassays be conducted using dilutions of the contaminated sediment with control sediment so that young-of-the-year fish are exposed to 100, 30, 10, and 1 percent contaminated sediment, as well as to control sediment (0 or <<1 percent contamination). Parallel bioassays should be conducted with one group receiving only uncontaminated food (e.g., amphipods, the deposit-feeding clam Macoma spp., and/or the filter-feeding clam Protothaca staminea) and the other fed with contaminated food. All food items should be subsampled and chemically analyzed to verify purity/contamination. Hence, in the pilot study there will be a minimum of 10 separate treatments: five concentrations of contaminated sediments (including control sediment) and exposure to either contaminated or uncontaminated prey. Prey species should be the same for all treatments.

A sufficiently large number of English sole should be used in each treatment so that even with a certain amount of mortality, a reasonable number of replicate fish (e.g., 5-10) may be sacrificed at regular intervals (e.g., monthly) throughout the course of the bioassays, for assessment of any histopathological changes and for measurement of the bioaccumulation of pollutants. If, after this initial pilot study, it is apparent that the ingestion of contaminated prey has little influence on either mortality, bioaccumulation, or disease induction, then bioassays in the second phase of this study may omit the additional complication of having to obtain or prepare a contaminated food supply for the fish. If, on the other hand, it appears that the observed effects are significantly enhanced by the use of contaminated food, then subsequent bioassays using sediments from other areas of Puget Sound should include the feeding of contaminated prey to the English sole. Recommended areas for the collection of contaminated sediments include the Hylebos Waterway, Commencement Bay, Sinclair Inlet, and Port Gardner.

Testing organisms on clean sediments spiked with certain toxicants at concentrations similiar to urban embayments may be very useful in interpreting the results of this study. Testing spiked sediments may clarify etiology of some of the observed pathologies, and will be valuable background information for establishing links between biological effects and specific pollutants at environmental concentrations.

Benefits to Water Quality Managers. The experimental design will provide data that will identify the route of biological uptake of toxicants. This information will help focus subsequent work on pollutant effects on the marine communities. By exposing the fish to serial dilutions of contaminated sediments, insight will be gained into the potential benefits of reducing sediment concentrations of suspect toxicants. Action level criteria may be tentatively identified as well. The experiment is not designed to address causal agents in disease induction; however, the data will be useful in generating hypotheses and in association with other research activity.

Benthic Invertebrate Communities

Need. The deposition of solids from waste discharges has a high potential for impacting benthic invertebrate communities because these organisms live in direct contact with bottom sediments. Studies of animal-sediment interactions have demonstrated that the physical and chemical characteristics of marine sediments play a key role in structuring marine benthic communities (Gray 1974). Studies by McGreer (1982) in the Fraser River Delta (north of Puget Sound) indicated that the degree of copper contamination was the major factor affecting distribution of the infaunal bivalve *Macoma balthica*. The benthos may also be important in affecting the distribution of contaminants in sediments by processes such as bioaccumulation, biodegradation, and bioturbation (Swartz and Lee 1980; Lee and Swartz 1980). The macroinvertebrate benthos are also important from a trophic perspective since they are key food items for many demersal fishes and may form key links in detrital food webs.

Past studies in Puget Sound have provided limited evidence for determining how benthic community structure is affected by toxicants near waste discharges (e.g., sewage and pulp mill) or contaminated areas (Commencement Bay waterways). Seattle Metro's TPPS program is conducting work of this nature around the West Point sewer outfall. In some cases, these effects were attributed to toxic influences of contaminated sediments. Laboratory sediment bioassays have also identified a number of areas in Puget Sound where sediments are associated with acute mortalities in benthic infaunal species. However, interpretation of results from these studies has been controversial. Major limitations of some studies are:

- Restricted spatial extent.
- Incomplete taxonomic identification.

- Lack of concurrent measurement of physical-chemical sediment characteristics.
- Potentially significant differences in experimental protocol and statistical treatment of data.
- Sampling in areas that may not receive significant inputs to the sediments because of good flushing characteristics around the outfall.

Because of these limitations, the currently available information does not provide for an adequate characterization of existing effects of various waste discharges on benthic communities. From a predictive standpoint, the available data are also insufficient for establishing a relationship between the degree of sediment modification by contamination (e.g., change in copper content) or organic enrichment, and the resultant changes in abundances of key species or overall community structure. It is not anticipated that these problems will be readily resolved. Nevertheless, there is a need to understand how benthic communities respond to toxicants in the environment. A survey based on consistent sampling and analytical methods is needed. The resulting data can be used to focus on more detailed investigations and to assist in the generation of testable hypotheses. Some elements of this work plan are in progress (Chapter 3).

Objective.

1. Document benthic community structure in contaminated areas and in reference areas.
2. Examine effects of organic enrichment, changes in sediment particle sizes, and toxicants on benthic biota.
3. Compare results of field surveys and results of laboratory bioassays, and determine whether bioassay results can be used to predict responses of indigenous organisms.
4. Develop qualitative and, if possible, quantitative relationships between the degree of sediment modification and the response of benthic invertebrate organisms.

Methodology. The recommended study can be accomplished by a coordinated effort involving laboratory and field investigations. The overall study approach would involve a synoptic sampling of sediments at a variety of locations throughout the Puget Sound system. During program design, consideration must be given to the flushing characteristics of the discharge location. Examples of generic kinds of sampling areas include:

- Near sewage discharges (both large and small discharges, in both erosional and depositional habitats).

- Near industrial discharges (pulp mill, ASARCO smelter).

- Areas subject to complex industrial contamination (e.g., Duwamish Waterway, Hylebos Waterway).

- Deep water areas potentially subject to sediment deposition.

- Reference areas (several kinds, in areas far from contaminant sources).

Much of the sampling effort can be reduced if this study is combined with the field study on English sole.

The following types of samples would be collected at each site:

- Three-to-five replicate samples for characterization of infaunal communities.

- One subsample for analyses of metals.

- One subsample for analyses of organic contaminants.

- One sample for use in determining grain size and in sediment bioassays.

The infaunal samples should be screened with a 0.5-mm mesh sieve, but no larger than 1-mm mesh. The study program should include a brief analysis of the information loss resulting from selection of 1-mm mesh screen. Organisms should be identified to the lowest practicable taxa, generally to species.

Biological field data should include:

- Species richness, evenness (J), and Shannon-Wiener diversity (H').

- Abundance of dominant species.

- Abundance of major taxonomic groups (e.g., Amphipoda, Echinodermata).

- Infaunal Trophic Index (ITI).

The analytical approach should attempt to relate observed biological conditions to sediment variables. Analytical techniques may include simple and multiple regressions, classification analysis, principal component analysis, and multiple discriminant analysis.

Sediment bioassays should be conducted on sediments from at least 10 selected sites. Experimental protocol and design should be appropriate for statistical analyses of the data. The selected sites should represent the major contaminated areas of Puget Sound and at least two reference areas. Consideration should be given to the sediment bioassays described in Chapter 9. At a minimum, the bioassays should include an acute toxicity test, (perhaps with the amphipod *Rhepoxynius abronius*), and use of a more sensitive test such as sperm or oyster larvae bioassays For each site, bioassays should be conducted on full strength sediment and on three dilutions (30, 10, and 1 percent) with sediment from an uncontaminated reference site. Control bioassays should also be conducted on the reference sediment.

Benefits to Water Quality Managers. The results of the sediment bioassays should be compared with the abundances of major organism groups as sampled in the field survey. Emphasis should be placed on a determination of how the relative sediment toxicity correlates with sediment chemistry, grain size, and abundance of indigenous species. If such relationships can be established, the results of serial dilutions of contaminated sediment can be used to predict the response of benthic communities to future changes in the degree of sediment contamination.

Rockfish Survey

Need. A study is needed to determine whether sport fish associated with artificial reefs and fishing piers in urban areas bioaccumulate toxicants and display pathological conditions typically associated with polluted environmental conditions. Previous investigations have collected and examined primarily demersal fishes that inhabit the soft bottom of urban bays, rather than fishes that inhabit urban rocky reef habitats. Gahler et al. (1982) have examined a few nondemersal fish from Commencement Bay, but the sample size was inappropriate for drawing conclusions.

Objectives.

1. Determine whether rockfish in urban areas have accumulated toxicants and display pollution-associated pathological conditions.

2. Determine whether rockfish in urban areas warrant inclusion in future monitoring or research programs.

Methodology. Although public fishing areas exist at essentially every urban area, the Old Town dock in the western portion of Commencement Bay and the Seattle public fishing pier in Elliott Bay are recommended as initial test locations. Both locations are in large urban areas, readily accessible to many fishermen, and are near an artificial reef. A relatively pristine reef habitat, perhaps in the San Juan Islands, is suggested as a control location. Quillback rockfish (*Sebastes maliger*) and copper rockfish (*Sebastes caurinus*) are recommended as test species because of their abundance, widespread distribution, and fairly sedentary nature (Buckley pers. comm.).

Before sampling the rockfish, divers should assess the size, number and distribution of the rockfishes expected to be sampled. Based on their observations, samples of rockfish should be taken by hook and line, monofilament gill or trammel net, spearfishing, localized use of quinaldine, or any combination of the above. Spearfishing and quinaldine may work best for younger fishes.

Rockfish sampling should be sufficiently extensive to allow statistical comparisons of toxicant accumulation between urban and control sampling areas. Since bioaccumulation will increase with exposure time until a steady state is reached, the age of each rockfish should be determined as an indication of relative length of exposure. It should be noted in sampling design that quillback or copper rockfish give birth in April or early May to pelagic young that may or may not settle out within the birth area (Moulton 1977). It is likely that sufficient numbers of young rockfish will not appear on the reef until one year of age and, for this reason, the initial toxicant uptake by juvenile fish cannot be examined.

Statistical analysis should begin with the comparison of body burdens as a function of lipid content in three age groups of fish: young (<4 years), middle age (4-8 years) and old (≥ 9 years) fish. Researchers should note that the methodology of rockfish age determinations is being reviewed (Bargmann pers. comm.). If a relationship between age and toxicant body burden does exist, the statistical tests between urban and control sampling areas should be conducted for each age group. If no relationship exists, then the data may be pooled. Testing for bioaccumulation between three age groups will require more fish to be analyzed than if the data were pooled. The list of high priority pollutants identified in Chapter 4 of this report should be included in the analysis. Any observable fish diseases should be identified and compared to catch location, age, and toxicant accumulation.

After completion of the toxicant bioaccumulation assessment at Commencement and Elliott Bay public fishing areas, a decision can be made to continue or forego a similar investigation at other urban fishing areas. Urban fishing areas, e.g. near Everett or Bellingham Bay, may provide additional information on the question of human ingestion of rockfish containing toxic compounds.

Benefits to Water Quality Managers. These data will help characterize the extent of pollution impacts on sport fish in urban areas. Rockfish and groundfish (e.g. English sole) occupy different habitats and feed on different organisms in the same water body. If the data indicate that body burdens of pollutants in rockfish are substantially different from body burdens of groundfish in the same area, one can develop laboratory and field studies that would help identify the linkage between exposure pathway and uptake mechanism.

Squid Survey

Need. A recent investigation of the Southern California Bight indicates squid may be particularly susceptible to bioaccumulation of certain heavy metals. In comparison to 17 pelagic species off Southern California, market squid (*Loligo opalescens*) contained some of the highest concentrations by wet weight of Ag, Cd, Cu, Zn, and Se (Schafer et al. 1981). In contrast, organic contaminants such as PCB and DDT and other metals such as As, Cr, Mg, Pb, and Ni were comparable to or below those concentrations reported for other pelagic species. An explanation for the relatively high concentrations of particular metals found in squid is not available. Relatively low levels of PCB and DDT contamination are also surprising because squid have a fairly high lipid content relative to other pelagic species, and should readily bioaccumulate lipophilic halogenated compounds.

Within the last four years market squid have become an increasingly popular sport species in Puget Sound, especially in urban areas where lights attract squid to the surface. Squid may be commercially harvested in the near future (Goodwin, pers. comm.). Because squid is an increasingly popular food source and is a species with potentially high bioaccumulation ability for some pollutants, data are needed to determine whether toxicant concentrations in squid from urban embayments pose a hazard to human health.

Objectives. Determine whether squid in urban areas have accumulated toxicants at levels posing hazards to human health.

Background. Although squid surveys have not been conducted in Puget Sound, squid are found throughout most of Puget Sound and are generally captured at night by fishermen utilizing a light source as an attractant. Sport fishing for squid occurs from October to February and spawning of two-year-old squid occurs from January to May (Goodwin pers. comm.). Squid spawn in a variety of locations, in water as shallow as 6-18 m in depth (Goodwin pers. comm.) and may even spawn on pier pilings in urban areas such as Elliott Bay (Chew pers. comm.). Squid egg cases are deposited on solid substrate in Puget Sound (Goodwin pers. comm.) and on mud and sand substrate in California (Ally pers. comm.). Deposition of egg cases on contaminated substrate may provide a source for toxicant bioaccumulation. It is generally believed that squid return to spawn at the location of hatching, but investigations have not confirmed this hypothesis. After spawning, the two-year-old squid die.

Methodology. Market squid should be sampled from one or two urban embayments for comparison to squid from a reference location. Two recommended test locations are the Seattle public fishing pier in Elliott Bay and the Old Town Dock in Commencement Bay. The use of a squid jig and a fishing pole should be sufficient to capture squid.

Sufficient numbers of squid should be obtained for statistical comparisons between test and control groups. Since age, i.e. exposure time, may affect bioaccumulation results, the squid should be divided into two distinct size classes, if possible, and then tested for toxicant bioaccumulation. If age does have an effect on bioaccumulation, then test and control groups should be compared at each age class. If age does not have an effect on bioaccumulation, then the age classes may be pooled. The list of high priority pollutants identified in Chapter 4 of this report should be included in the analysis.

Benefits to Water Quality Managers. These data will help determine whether the developing squid fishery could be impacted by existing waste management practices. In particular, levels of toxicants can be identified, and associated risk to human health can be estimated.

Chapter 8

RECOMMENDATIONS FOR MONITORING PROGRAMS

Approach to Monitoring Programs

There is a continuous need to measure and record water quality characteristics of Puget Sound to provide knowledge about trends. The general purpose of a monitoring program is to detect and track changes in specific environmental conditions over time. Confusion between monitoring programs, investigations, and research activities frequently occurs. Investigative activity and research (hypothesis testing) are only secondary aspects of a well-designed monitoring program. Water quality monitoring typically provides data relevant to achievement of regulatory standards, long-term characterization of an environmental parameter, or input to specified data programs.

The purposes of a monitoring effort obviously affect the type of program and selected methodologies. Water quality managers typically have one of two objectives in mind when implementing a monitoring program. In some cases, the purpose is to monitor a wide array of parameters to see how the environment changes over time. In other instances, the purpose is to focus on a specific problem or activity and see how the environment responds over time. In all cases, the initial step in monitoring is to clearly state the questions that the monitoring program must answer. It is particularly important that the questions be well defined and specific. For example, it is difficult to design a long-term monitoring program that will answer the question whether arsenic is affecting biota until the question is broken down into specific questions that are amenable to measurement. Once specific questions and subsidiary objectives are defined, water quality analysts can determine how the needed data are to be obtained, interpreted, and reported.

Two major weaknesses of monitoring programs are: failure to consider the time element, and failure to distinguish between the two types of monitoring programs identified above. Too often a wide array of environmental data are collected and then analyzed to try and determine if certain waste discharge practices are harming the environment. No initial effort is made to ascertain whether the observed data can clearly answer the question. Frequent failure to link monitored parameters to questions about waste discharges leads to unnecessary regulatory and public confusion.

General Requirements of Monitoring Programs

Water quality conditions occur as a result of complex chemical/physical/biological processes peculiar to the ecosystem. The relationship of water quality conditions to beneficial uses is also a function of these complex processes. Consequently, to achieve a monitoring objective it is necessary to understand what the influencing or controlling factors may be so that these can be incorporated into the monitoring program. One does not usually monitor ammonia, for example, without also monitoring pH and temperature. The following is a brief summary of parameters and processes that should be considered in developing a monitoring program. In all cases, a competent statistician must be consulted consulted during the planning stage to ensure that sampling design and data analysis are amenable to statistical treatment.

MONITORING SPECIFIC POLLUTANTS

Physical conditions such as pH and salinity significantly alter speciation of most heavy metals and isomerization of many organic compounds. Whether the pollutant occurs in the dissolved or particulate state also has a major bearing on the ecologic impact of the pollutant. If pollutants are adsorbed to particulates, their availability to biota may be influenced by whether they are associated with organic or inorganic fractions of suspended solids. Depending on specific questions addressed by a monitoring program, the sampling program may need to analyze such associations.

There are theoretically sound arguments that organisms stressed by low dissolved oxygen or other suboptimum conditions in the habitat may be more susceptible to the effects of pollutants; therefore, dissolved oxygen, pH, salinity, temperature, total suspended solids, and turbidity should be standard parameters analyzed in any receiving water monitoring program. Similarly, pH, Eh, and sulfide in the interstitial water of sediments can play major roles in the bioavailability and ecological impact of pollutants in sediments.

MONITORING PLANKTON

Meteorological conditions, nutrient availability, and microscale current patterns play major roles in the structure and functioning of plankton communities. Taxonomic information is also important, since the structure of plankton communities is significantly affected by interspecific competition in response to local, small-scale variations in environmental parameters.

MONITORING BENTHOS

Benthic communities are significantly influenced by organic content, grain size, and chemistry of sediments and interstitial water. Proper taxonomic identification is also important, especially for organisms that greatly influence community structure or serve as major food sources for bottom-feeding fish. If the examined pollutants are known to be lipophilic, the percent lipid content of the biota and sediment is needed to adequately interpret bioaccumulation and uptake data.

MONITORING FISH

One of the most challenging aspects of monitoring fish populations is determining whether the sampled fish are resident or transient in the study area. If it is not known whether the species under investigation are resident populations, the monitoring program must include tagging studies or similar methods to examine residence time in the study area. The sex and age class or size class of organisms should be noted, especially if it is suspected that one age class may be more susceptible than another, or if the examined pollutants are lipophilic and could be associated with yolk material. The percent lipid content of tissues or whole organisms is also needed to adequately interpret the susceptibility of species to pollutant uptake and bioaccumulation. Environmental conditions (salinity, habitat type, temperature) known to influence distribution of fishes should be documented in addition to those parameters affecting speciation, molecular state, and activity of the pollutants included in the monitoring program.

Comprehensive Monitoring Program for Puget Sound

RATIONALE

There is a need to know whether pollutant levels in Puget Sound are increasing over time, and whether biological effects are occurring that may be reasonably linked to changes in water quality. Most existing or proposed monitoring programs are either very localized in scope, or encompass a narrow set of environmental parameters. There is no existing comprehensive program that monitors trends in pollutant levels and biological responses to pollutants in Puget Sound as a whole. There is a need for such a program to provide water quality managers with a mechanism to detect impacts resulting from the cumulative actions taken in the Sound.

The comprehensive program must address the following questions:

- What are the trends for pollutant levels in the water column?
- What are the trends for toxicants in the sediment?
- What are the trends for body burdens of toxicants in biota?

- What are the trends for diseases or other pathological conditions implicated as being pollutant-induced?

- How are biota changing in Puget Sound over time?

Note that the last two questions do not address the causes of changes in biota. The purpose of the comprehensive monitoring program is to detect changes in environmental conditions. If changes are detected, additional data analyses or work will be required to ascertain whether these changes may be linked to pollutants or to some other environmental parameter or event. Furthermore, it should be noted that many of the recommended studies in Chapters 5-7 will provide useful baseline data in these subject areas. However, a monitoring program is needed to describe trends in these subject areas.

Monitoring concentrations of pollutants in the water column and sediments must be carried out on a Sound-wide basis. Concentrations in water are useful to water quality assessment, but are susceptible to short-term, intermittent fluctuations and must therefore be interpreted carefully. The biota selected for monitoring will vary to a certain extent between different areas of Puget Sound. Monitoring concentrations of toxicants in biota should occur on a Sound-wide basis, but selection of species must consider: 1) role in the ecological community of the area, 2) exposure to pollutants, and 3) role in beneficial uses of Puget Sound resources. Ideally, the monitored species will rate highly in all three of these categories.

EXISTING PROGRAMS THAT PROVIDE A BASE FOR EXPANSION

There are a number of existing data acquisition programs (Table 8-1) that can be integrated with minimal recommended modifications into an initial comprehensive monitoring program. These programs include WDOE marine monitoring, Metro's TPPS program and baseline Seahurst study, the mussel watch conducted as part of WDOE Basic Water Monitoring Program, and DSHS paralytic shellfish poison and fecal coliform monitoring programs. The recommended changes to each of these are discussed later in this chapter.

Several aspects of the WDOE marine monitoring program would significantly contribute to the comprehensive program:

- The 44 stations provide a reasonable coverage of Puget Sound (Figure 8-1).

- Considerable background data on conventional pollutant parameters and heavy metal concentrations in the water column have been collected to date.

- The program currently operates smoothly and consistently, although the absence of data from winter months is a serious shortcoming.

Table 8-1. Monitored Resources and Monitoring Activities in Puget Sound

	Monitoring Agency								
Monitored Resource	WDOE	EPA	METRO	DSHS	COE	WDF	DNR	NMFS	PSAPCA
Source management & control	State hazardous waste program	RCRA regulations	Pretreatment studies						
Permitted discharges	NPDES program	National standards of performance; toxic & pretreatment effluent standards; local 301(h) waivers			Dredge spoil disposal				Atmospheric
Nonpermitted discharges	Basin management plans (Section 208)	Delegated to WDOE	Basin management plans (Section 208)						
Rivers and streams	Major rivers		Service area rivers						
Nearfield receiving water		Local 301(h) waivers*	West Point outfall		Dredge spoil disposal				
General receiving water	44 marine water stations								
Sediments		Local 301(h) waivers	West Point outfall		Dredge spoil disposal				
Uptake & bioaccumulation			West Point outfall	PSP & coliforms in shellfish & growing water					
Habitat & biota	Permit review	Permit review; local 301(h) waivers*	West Point outfall	Shellfish beds		Permit review		Permit review	
Status of beneficial uses				Shellfish resources	Navigation resources	Fishery resources	Shellfish resources	Fishery resources	
Atmospheric fallout									Nonorganic pollutants
Management & operations	DMRs, inspections, permitting	Delegated to WDOE		Processing plant inspection					

*May vary widely; most 301(h) wiaver applications are under review.

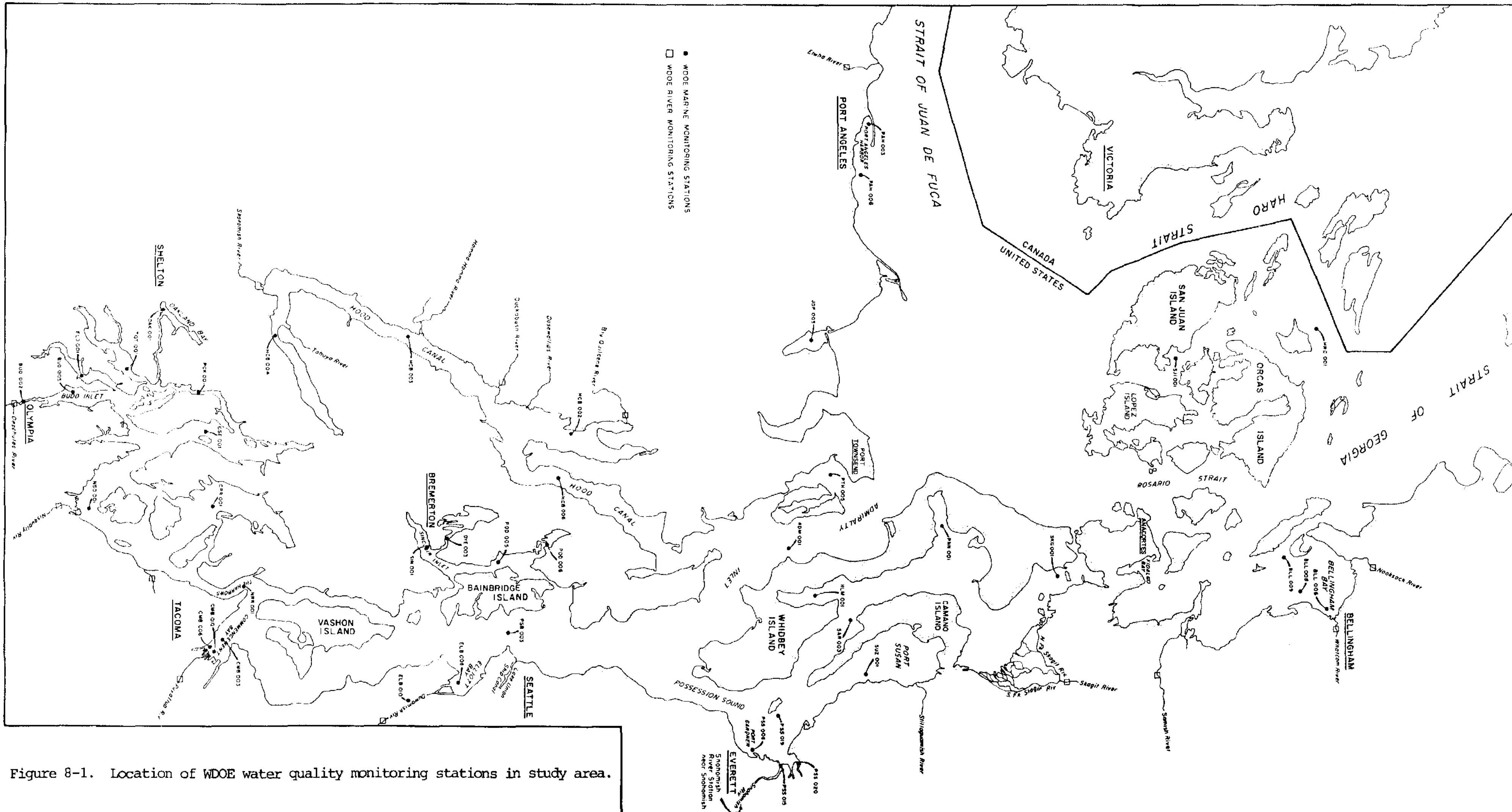


Figure 8-1. Location of WDOE water quality monitoring stations in study area.

- The program is directed by a public agency.
- Data storage and access is systematized.

Seattle Metro is conducting extensive research in the Central Basin as part of the TPPS program and the Seahurst baseline study. These studies cannot be considered as monitoring programs, but they provide important baseline data for a relatively large area of the Central Basin.

The other existing monitoring programs (Table 8-1), while not extensive, add data on pollutant loading or biological communities and organisms. These programs could be integrated into the comprehensive monitoring program. Furthermore, work underway by EPA and WDOE (Chapter 3) will provide valuable data for beginning the program. Monitoring also will be implemented in the near future as part of the 301(h) waiver program. The 301(h) monitoring program could potentially provide a substantial amount of data for review and evaluation if waivers are granted in Puget Sound. Areal coverage and value of the data depend on the number of applications that are approved and the monitoring program that is developed for each discharger. Applications have been received from dischargers located in most areas of Puget Sound, except Hood Canal and the San Juan Islands. The proposed generic monitoring program (Table 8-2) indicates that a broad set of environmental categories could be included in the majority of the monitoring programs. Wide variations or substantial deviations from the generic model would seriously handicap the value of these data for comprehensive monitoring program purposes.

OUTLINE OF THE COMPREHENSIVE MONITORING PROGRAM

The following is a brief outline of the recommended comprehensive monitoring program. It is organized by subject area. It is anticipated that not all elements will be included in a comprehensive program. The following is presented for consideration in final program design.

Trends in Pollutants in the Water Column. This element should be carried out throughout Puget Sound. The recommended design is basically that of the WDOE marine water quality monitoring program. Consideration should be given to the following changes:

- Monthly sampling should also occur during winter months, at least at the stations south of Admiralty Inlet.
- General requirements of monitoring programs, as described earlier, must be reviewed to identify additional parameters that must be measured.
- Heavy metals must be included in the program.

Table 8-2. Proposed Generic 301(h) Waiver Monitoring Program for Small Dischargers (<5mgd) During 5-Year Life of Waiver

Environmental Compartment	Approximate Frequency	Approximate Number of Stations	Parameters
Effluent	Weekly, at minimum	1	Conventional pollutants
Effluent	Once in 4th yr [1]	1	Priority pollutants and pesticides
Receiving water	4 times per yr [2]	5 at 5m depth intervals	DO, pH, temperature, salinity, turbidity, and Secchi disc
Receiving water	4 times per yr [2]	7	Fecal coliform
Benthos	Initially and in 4th yr	5	Grain size, volatile solids, community structure analysis
Sediment	Once in 4th yr	2	Priority pollutants and pesticides occurring in the effluent
Animal tissues [3]	Once by 4th yr	2	Priority pollutants in the effluent
Fishes	At least once in 4th yr	2	Compared to reference community

NOTES: [1] During dry weather.

[2] Every other month, Spring-Fall.

[3] Livers from flatfish, if high concentrations found in sediment or effluent.

- High priority organic compounds should be included if it can be shown that levels are detectable in the water column (see recommended study in Chapter 6).

- Water column analysis for pollutants should differentiate between dissolved constituents and suspended particulates.

Trends for Toxicants in the Sediment. This element should be carried out throughout Puget Sound. Sediments are functionally divided into three major strata, two of which may not be long-term sinks for pollutants. A top, thin layer may be subject to frequent resuspension and movement resulting from currents. In most cases, this layer is only a few (1-3) cm deep. A second, middle layer is not readily disturbed by current activity, but is subject to biological reworking and (in some areas) to infrequent, unusual, or seasonal events resulting in large-scale sediment transport. The depth of this layer is highly variable. In deep water, it may extend to a depth of 10-15 cm, but in shallow water erosional areas the depth may be greater. A third, deeper layer is generally stable and represents a permanent or long-term pollutant sink. Concentrations of toxicants in the upper two layers reflect ambient or recent water quality conditions, and should be monitored. Concentrations in the deeper layer reflect historic water quality conditions.

Data exist that can be used initially to design this monitoring program. Broad-scale maps of sediment types have been prepared by the Washington Department of Fisheries (WDF) as part of a survey of mariculture sites. Metro, as part of the TPPS program and the Seahurst baseline study, has examined concentrations of heavy metals and organic priority pollutants in sediments from the Central Basin, and will release these data soon. These data include concentrations in deep sediment layers, which need not be sampled again. A number of intensive surveys have been conducted by various agencies that have included analyses of bottom sediments in local areas. Additional work is underway by EPA (Chapter 3).

The data sources and maps described above can be used to identify likely station locations, especially in the Central Basin. Sampling stations should be established in an array of sediment types in urban embayments. To the extent possible, station locations should correspond with established WDOE marine monitoring stations. The recommended minimum array of stations is found in Table 8-3. Samples should be collected at the sediment surface and at a depth of 10 cm at each station once every 3 years. Sediment samples should be analyzed for interstitial Eh, pH, sulfide concentration, organic content, and concentrations of all heavy metals, and designated high priority organic pollutants (Chapter 4).

In areas potentially subject to estuarine influence, salinity range should also be determined, and sampling frequency initially should document seasonal changes in sediment characteristics.

Table 8-3. Locations of Recommended Sampling Stations

General Sampling Area	Specific Sampling Site
URBAN	
Port Angeles Harbor	PAH 003[a]
Bellingham Bay	BLL 006[a]
Port Gardner	PSS 008[a]
Elliott Bay	Duwamish Head No. 10[b]
Sinclair Inlet	Point Turner No. 3[b]
Commencement Bay	Old Tacoma No. 13[b]
Budd Inlet	Olympia Shoal No. 3[b]
NONURBAN	
Admiralty Inlet	ADM 001[a]
Port Susan	SUZ 001[a]
Nisqually Reach	NSO 001[a]

[a] Designations correspond to existing monitoring site for the State Surface Water Quality Program.

[b] Designations correspond to those used by Malins et al. (1980, 1982).

The sampling frequency can be adjusted as sediment dynamics near the estuary are determined. Sediment traps should be deployed at selected locations to monitor sediment settling rates over time and the types and quantities of toxicants adsorbed to the settling material.

Trends for Biota. Details of this element will vary between different regions of Puget Sound. Monitoring trends in body burdens of toxicants, incidence of disease or other pathological conditions thought to be related to pollution, and species composition in Puget Sound are closely related topics. Sampling and analysis in some cases will simultaneously address more than one of these topics, therefore, the recommended programs are combined here and presented as one unit. It is not intended that every species in Puget Sound be monitored. The following suggestions should be considered if organisms from one of the following groups are included in the program for a particular area. Furthermore, it should be noted that there is a two-fold purpose to this element of the program: 1) develop an "early warning" system for detecting potential biological problems, and 2) monitor trends in selected biota.

Rooted Vegetation. Effort should be made to monitor populations and body burdens. Sampling populations should occur once a year in the latter half of the growing season. Monitoring stations should be located in selected urban embayments and in at least two areas displaying little pollution. Relative abundance, percent cover, or an appropriate measure of distribution should be noted. Chemical analyses for high priority pollutants (Chapter 4) should occur once every two years.

Plankton. Effort should be made to monitor populations. Sampling should occur at least once a year, preferably quarterly, at WDOE marine monitoring stations (Figure 8-1) representing urban embayments and major basins. In addition to the general requirements described earlier in this chapter, monitoring should include levels of chlorophyll *a* and primary productivity.

Benthos. Effort should be made to monitor populations, body burdens, and incidence of pathological conditions. Sampling for population monitoring should occur at least once a year in the late summer or fall. Recommended locations should correspond to sediment monitoring stations (Table 8-3). Community analyses must take into account the general requirements described earlier, and the procedures outlined earlier in a recommended study on benthic communities (Chapter 7).

Body burdens of toxicants should be measured once every two years. The organisms chosen should include a range of feeding types and species of commercial or recreational importance. Species for consideration include: a mobile epibenthic predator such as Dungeness crab (*Cancer magister*), a filter-feeding bivalve such as the littleneck clam (*Protothaca staminea*) or the butter clam (*Saxidomus giganteus*), and a deposit-feeding bivalve (e.g. *Macoma* sp.) or polychaete (e.g. *Abarenicola* sp.). All high priority pollutants (Chapter 4) for the area should be measured. Data are needed on sex, size, weight, and lipid content of the organisms examined. Complementary data on bioaccumulation may be provided by WDOE's BWMP.

Pathological examinations should be limited to crustaceans once every two years. Emphasis should be placed on parasitic infections and lesions of the exoskeleton, gills, hepatopancreas, and excretory organs. Routine monitoring of tissue abnormalities in bivalves is not recommended because only necrosis of the digestive tubules has been observed in Puget Sound (Malins et al. 1980, 1982). Consideration may be given to examining parasitic infections of bivalves.

To minimize variation in the data, all sampling should occur at the same time of year, and a standard size range or age class of each species should be chosen. Enough specimens should be collected to ensure an acceptable level of precision in measured parameters. A pilot study may be necessary to determine minimum sample sizes. It is recommended that technicians follow standard EPA analytical methods. Handling of biological specimens and histopathological techniques should follow methods used by Malins et al. (1980, 1982). Technicians performing histopathological analyses should be trained by qualified personnel and follow standardized procedures. Similar recommendations apply to fish and marine birds and mammals.

Fish. Effort should be made to monitor populations, body burdens, and incidence of pathological conditions. Recommended locations should correspond to sediment monitoring stations (Table 8-3). Population monitoring should occur at least once a year, and take into consideration reproductive condition or recruitment to the population. In addition to the general requirements described earlier, appropriate data to calculate catch-per-unit-effort must be reported.

Tissue levels of high priority pollutants should be determined in demersal species (e.g. English sole) annually. A wide spectrum semiquantitative pollutant scan should be conducted on selected species every other year. To the extent possible, analysis should focus on a particular size range or age class. In all cases, data should be normalized to percent body lipid content.

At each annual sampling period, selected representatives of all species should be visually examined for gross pathological conditions. Examination of fin rot, skin, and liver lesions or tumors, and parasitic infections should occur once every two or three years.

Marine Birds and Mammals. Population monitoring of marine birds can be obtained from data generated by local birdwatching groups, e.g. Christmas bird counts by the Audubon Society. Once every two or three years, body burdens of high priority pollutants should be examined in resident adult birds and in yolk material.

Monitoring of marine mammal populations should be limited to population censuses and observations of birth defects during the pupping season. Monitoring of body burdens or pathological conditions should include apparently healthy, as well as moribund or dead individuals, or should not be attempted at all.

Recommended Ancillary Activities

BRIEFING MEETINGS BETWEEN MONITORING AGENCIES

Semiannual briefing meetings are recommended for representatives of all agencies carrying out monitoring efforts. Potential agencies that would be involved include EPA, WDOE, Metro, COE, NOAA, DSHS, USGS, and PSAPCA. Other resource agencies (e.g. USFWS and WDF) may also benefit from participation. The purpose of the meetings would be to communicate the monitoring progress made since the last meeting and outline future work efforts. This would provide an understanding of the total monitoring being done in Puget Sound. The scheduling of meetings should consider the various fiscal years of the agencies so that activities of other agencies could be considered in budget preparation. One useful outcome of the meetings would be an updated list of Puget Sound monitoring programs. This could be included as an appendix in the monitoring manual proposed in the next section.

DEVELOPMENT OF A MONITORING MANUAL

The development of a procedural manual would provide guidance and develop a framework of uniformity between programs. The manual would include acceptable methods for sample collection and storage, analytical techniques, quality assurance, and data reporting for specific substances. It is recommended that such a manual be developed and made available to all groups performing monitoring programs in Puget Sound. A periodically updated appendix of the ongoing monitoring programs and contact persons would provide a useful reference. It is recognized that in certain cases monitoring programs are inflexible in that methodologies may be specified by regulations. Suggestions as to major topics to be covered in the manual follow.

Recommended Procedures. The recommended procedures section should contain a description of the elements of a monitoring program, questions that should be considered during program design, and recommended procedures for sample collection and analysis. For example, elements of a monitoring program would possibly include:

- Statement of objectives.

- Explanation of how methods will meet objectives.
- Design of program.
- Data verification procedures.
- Data analysis procedures.
- Data reporting procedures.

Questions to be addressed during program design could include:

- What are the program objectives?
- How can the program be designed to provide input to other programs?
- How can the program be designed to use data from other programs?
- Are background data or controls necessary to obtain meaningful data?
- Will the collected data meet the program objectives?
- Are there any site-specific features that could influence the program?

The recommended procedures for sample collection and analysis could reference other manuals such as Standard Methods for the Examination of Water and Wastewater. This section should stress the importance of documenting the procedures followed for data collection and analysis. This documentation should accompany the data.

Data Presentation. Standardized data presentation would greatly facilitate the combination and analysis of data from different monitoring programs. The manual should recommend units of measure, and methods for summarization, storage, and distribution of the data. Units of measure should be consistently metric (including flow data).

The presentation of the data in summary documents with statistical information is normally more meaningful than raw data. The manual should recommend that summary documents be required as part of the monitoring program. Annual or seasonal summary periods with means, ranges, standard deviations, sample number, and confidence levels could be included as appropriate. If more detailed information is required, the complete data set should be stored where it can be easily retrieved. The manual should discuss the various storage media and the advantages and disadvantages of each. Examples of storage media that could be included are computer tape on agencies' systems, STORET, microfiche, bound documents, and loose-leaf documents.

Advantages might include retrieval speed, selective retrieval, availability, storage space, and flexibility. The distribution of the summary documents should be recommended by the manual. Agencies that have expressed interest in a data summary and appropriate libraries should be notified of the availability of summary documents.

Recommended Parameters for Special Types of Studies. This section of the manual would discuss the major types of monitoring programs and the parameters which should be included in the programs. Many of these parameters are discussed in this chapter as general requirements of monitoring programs. The major types of programs may be cataloged as: mass loading, receiving water quality, sedimentation and sediment composition, biological, and hydrological.

CALIBRATION BETWEEN ANALYTICAL LABS AND TECHNIQUES

There are several analytical chemistry labs in the Puget Sound area. A calibration and comparison of analytical techniques between the major labs is recommended. This would allow different data sets to be properly compared and combined. Identical samples could be submitted for analysis along with a procedural questionnaire to be completed by lab personnel. A comparison and evaluation could be prepared and appended to the monitoring manual discussed earlier.

DEVELOPMENT OF A PUGET SOUND DATA BASE CENTER

A large volume of information on Puget Sound exists but is scattered among numerous agencies and libraries. The establishment of a Puget Sound Data Base Center is recommended. This center would collect reports, summary documents, maps and other forms of information concerning the Puget Sound environment. This collection would be very useful to managers and researchers in that a significant amount of information on Puget Sound would be available at one location. If document copies are not available for the center, a computerized location catalog could be developed as part of the Center's resources.

Locating this center within an existing facility would be more cost effective than setting up a new library. It also would allow researchers easy access to related information.

TAXONOMIC STANDARDIZATION

Because of the diffuse nature of the taxonomic literature and the inherent difficulties in identifying many benthic invertebrate species, taxonomic standardization is an important part of a regional biological monitoring program. Past studies of benthic invertebrate communities in Puget Sound have varied considerably in their level of taxonomic detail, from identification of only Infaunal Trophic Index (ITI) taxa (generally at family level) to species-level identifications.

Although some biotic groups have been subjected to attempts at regional standardization (e.g. Staude 1980), most have not.

It is expected that sampling of benthic infaunal assemblages will be an important component of regional 301(h) monitoring programs. Such monitoring programs may be conducted by individual dischargers or by their consultants. In addition, benthic infauna have been monitored in industrialized areas by NOAA, and should be an important group in a comprehensive monitoring program for Puget Sound. If such data are to be of value in comparing existing biological conditions, the taxonomic identities of species should be consistent among monitoring organizations.

The objectives of a taxonomic standardization program would include:

- Improvement of the overall level of taxonomic expertise in the Puget Sound area.
- Standardization of names used for each Puget Sound species.

These objectives could be accomplished by the following activities:

- Compilations of the taxonomic literature on Puget Sound species.
- Development of taxonomic keys for select taxonomic groups.
- Publication of a list of taxonomic experts for each taxa.
- Maintenance of a centralized reference collection of species organized by taxon.
- Periodic meetings of regional taxonomists to discuss specific problems, compare identifications, and attend presentations by local experts.

Evaluation of Existing Monitoring Programs

In this section, existing monitoring programs are evaluated for their ability to address the needs of water quality managers (Chapter 2) and to fit in with objectives of the proposed comprehensive monitoring program. Specific objectives originally giving rise to the program are not included as evaluation criteria. It may be that a program is quite suitable for its original purpose, but unsuitable for the criteria used here. Programs that provide useful data as currently implemented or proposed are presented first, followed by programs with recommended changes.

INTENSIVE SURVEYS

Background. WDOE, EPA, and the COE conduct a number of intensive surveys directed toward assessing specific problem areas. The studies are generally short term and site-specific, and address such problems as assessing effects of an outfall, determining wasteload allocations, or evaluating effects at a dredge spoil disposal site. WDOE's Ecological Baseline and Monitoring (ECOBAM) program, the longest intensive survey, lasted approximately 7 years and terminated last year. This study of Everett Harbor evaluated water quality changes in the harbor as a result of the upgrading of pulp and paper industry discharges. WDOE also monitored biota by use of live box fish assays and settling plates (primarily to determine diversity and biomass) (Bernhardt pers. comm.; Determan pers. comm.). EPA and WDOE recently conducted a joint investigation of Everett Harbor that analyzed sediments for priority pollutants and investigated abnormalities in fish. Other areas that have also been studied include Commencement Bay and the Duwamish Waterway.

Value to Water Quality Managers. Intensive surveys are useful to the manager responsible for remedial actions for a problem. Because of their specificity and generally short duration, these surveys should not be considered an integral part of a regional monitoring network, but may provide valuable information for designing a monitoring program. Furthermore, the surveys provide data that address some of the management needs. No changes are recommended for short-term problem-solving surveys due to the purpose and goals of these surveys.

METRO SEAHURST BASELINE STUDY

Background. Metro is conducting a baseline study near the proposed Seahurst outfall. The study includes investigation of the water column, oceanography, subtidal and intertidal habitat, microbiology, virology, and fisheries. Work is being conducted throughout the southern half of the Central Basin.

The water column study investigates temperature, salinity, oxygen, nutrients (nitrogen, phosphorus, and silica), chlorophyll, particulate matter, zooplankton, phytoplankton, and phytoplankton productivity. The intertidal and kelp bed study characterizes the infauna, epifauna, microflora, and macroflora. The sediment samples are analyzed for metals, toxic organic compounds, petroleum hydrocarbons, and nutrients. Organisms collected with the sediments are also identified. Bacteria and virus levels in water, sediment, and shellfish are also examined. The fisheries study includes collections and health determinations of pelagic and demersal fish.

Value to Water Quality Managers. The results from this baseline study will partially meet some of the identified water quality needs for the Central Basin of Puget Sound. This baseline study can be used in the future to assess trends in species composition and environmental levels of pollutants in the Central Basin.

METRO TOXICANT PRETREATMENT PLANNING STUDY

Background. This 3-year Metro program ended in September 1983. One of its objectives has been to identify the sources of toxic pollutants entering Metro wastewater treatment plants. During the study, representative industries were screened for all priority pollutants and for other compounds of possible interest that are present in concentrations of 1 ppb or greater. A list of compounds of concern is being generated from this effort, and is expected to contain approximately 25 compounds (Simmler pers. comm.). Information was also gathered on mass loading of pollutants from riverine input and surface runoff. The study also examined concentrations of toxicants in sediments of the Central Basin off the Seattle metropolitan area. Bioassays were also conducted on sediments from selected stations.

Value to Water Quality Managers. Mass loading data and sediment chemistry analyses will be valuable to water quality managers as background data necessary for monitoring program design. Chemical analyses conducted on sediments from the Central Basin will be of use in monitoring trends in contamination levels. In combination with the Seahurst baseline study, sediment chemistry of the Central Basin is documented for a wide area. Analysis of deep cores provides background data that need not be sought in the comprehensive monitoring program. The bioassay results should be used with caution. They indicate areas where more thorough analysis may be appropriate.

PUGET SOUND AIR QUALITY MONITORING

Background. The Puget Sound Air Pollution Control Agency (PSAPCA) has established several air quality stations in Pierce, King, Snohomish, and Kitsap Counties. Parameters potentially impacting Puget Sound through wetfall and dryfall and monitored by PSAPCA include suspended particulates, nitrogen oxides, hydrocarbons, and lead. Most organic priority pollutants are not monitored. Measurements of concentration in the atmosphere are taken several times a month and summarized in an annual report. Two other air pollution agencies monitor air quality in other counties adjacent to Puget Sound, but their programs are not as extensive as PSAPCA's.

Value to Water Quality Managers. The transport of pollutants in the air and the pollutant flux into the Sound has not been quantified for most pollutants. The PSAPCA monitoring program provides a mechanism for further investigation and quantification of this nonpoint pollutant source. It will not be useful to water quality managers until data are available that document the contribution of airborne pollutants to mass loading in Puget Sound and its subareas. A study (recommended in Chapter 5) to examine loading from the atmosphere is necessary before appropriate changes in the program can be identified.

PROPOSED 301(h) MONITORING PROGRAMS

Background. Several municipal wastewater treatment plants have applied for waivers from secondary treatment, as allowed by Section 301(h) of the Clean Water Act (CWA). If the waiver is granted, the applicant must "establish a system for monitoring the impact of the discharge on a representative sample of aquatic biota" (P.L. 95-217). EPA Region 10 has developed a generic monitoring program that would be required of applicants with discharges less than 5 mgd (Table 8-2). The generic 301(h) monitoring program is proposed as an initial guideline; substantial modifications for each discharger may occur, depending on the volume, quality, and location of a discharge. More extensive monitoring programs will be developed for larger discharges. A much larger and more detailed program has already been developed for Metro's West Point treatment plant, if their application is approved.

The proposed monitoring programs would sample six environmental compartments: effluent, receiving water, benthic populations, sediment, animal tissues, and fishes. Monitoring of these compartments would be conducted at established times within the 5-year duration of the waiver. The proposed frequency and parameters are summarized in Table 8-2.

Currently, 301(h) waiver applications have been received from 28 municipalities with discharges in the Puget Sound study area. These applications are being reviewed on a case-by-case basis by EPA and WDOE. Individual monitoring programs would be developed as each waiver application is approved.

Value to Water Quality Managers. Data gathered during the proposed 301(h) monitoring programs may be used in addressing some identified water quality management needs for Puget Sound as a whole. Furthermore, major elements of the comprehensive monitoring programs are reflected in the generic 301(h) monitoring program. Knowledge of deposition areas, environmental trends, and health of the biota could result from the monitoring surveys. Significantly more information will result from larger, more detailed programs.

The real value of these programs to water quality managers will largely depend on the implementation schedule and the completeness of the data requested from the various dischargers. The application review process is time consuming and waivers will be issued as they are approved. This will stagger monitoring effort schedules among dischargers and could complicate the integration of resulting data sets. This potential problem would be alleviated by preplanning schedules and program content within the total program rather than by individual discharger. The initial guideline for program design appears useful with the possible exceptions of surveying priority pollutants in the effluent and bioaccumulation in animal tissues. It is impossible to determine trends when sampling frequency is limited to only one event. The sampling frequency for monitoring receiving water is designed to monitor during periods when volume of riverine discharge is less likely to obscure discharge effects. The drawback of this sampling regime is that marine water quality parameters during winter remain unknown because the existing WDOE marine monitoring program does not operate in winter months.

NPDES MONITORING AND ANALYSIS

Background. The NPDES permit program is designed to abate, and eventually eliminate, discharge of pollutants that would significantly degrade the water quality of the receiving waters. WDOE is responsible for the administration of Washington's program and issues discharge permits on a case-by-case basis. Based on established effluent and receiving water quality criteria and the permit application, WDOE establishes permit conditions. Effluent parameters to be monitored, data collection and analysis techniques, monitoring frequency, and reporting schedules are specified as permit conditions. Monitoring is carried out by the permit holder with the results filed at the appropriate regional WDOE office as discharge monitoring reports (DMRs).

Recommended Changes. Recommendations for this program include administrative changes, a list of additional permit conditions to be considered before permit renewal, and DMR storage procedures.

A major problem identified in the administration of the program is the expiration of permits and the delay in renewal. A discharger is required to notify WDOE prior to the current permit's expiration date. If a permittee submits a letter confirming that no changes in the discharge are expected during the next 5 years, the permittee is not required to submit a reapplication form (Springer pers. comm.). In such cases, due to limited agency resources, the permit is extended until action is taken by WDOE or until the discharger notifies WDOE of pending changes (Kievit pers. comm.).

As NPDES permits are renewed or extended, it is recommended that the following permit conditions be considered as local additions to the national requirements, as appropriate:

- Require submittal of an additional checklist that identifies and estimates concentrations of all pollutants that may occur in the discharge. Existing forms do not contain requirements for analysis of most priority pollutants or pollutants of local concern (e.g. PCDFs).

- Require continuous measurements of the discharge volume.

- Require monitoring of effluent using standard methods specified in Chapter 9.

- Require scheduled composite sample monitoring of high priority pollutants (listed in Chapter 4) that are identified as potentially occurring in the effluent.

- Require use of a standardized report form that establishes common terminology and units.

- Require annual summaries of DMRs, with appropriate statistical information.

These modifications of the present system should improve the quality of mass loading information gathered under the NPDES program. The changes also will provide useful information to Puget Sound water quality managers on trends in mass loadings from point sources.

After WDOE receives a DMR, the information should be entered into a data base on the WDOE computer system. This would greatly ease data retrieval and expedite use of the data. Also, permit compliance verification with automatic noncompliance notices could be incorporated into the computer program. Annual summaries by dischargers would not be necessary if DMR data are stored in an accessible automatic data system.

Value to Water Quality Managers. The NPDES monitoring program should provide pollutant source data from numerous point discharges to Puget Sound. These data can be used to determine relative pollutant loadings and tentatively identify problem areas. It also can be used to evaluate pollutant source control and pretreatment programs and to evaluate the proportional significance among several discharges of the same pollutant. At the present time, it is difficult to identify toxic constituents in the wastestream of most permittees, and loading measurements are very rare.

WDOE RIVER MONITORING

Background. The WDOE surface water quality monitoring program has been ongoing for several years under authority of RCW 90.48.250. The program includes a large network of fresh and saltwater monitoring stations. A discussion of the marine monitoring program is given in the next section. The objectives of the surface water quality monitoring program are:

1. Obtain long-term water quality data to document maintenance of water quality classification.

2. Provide a regular check for problem identification and subsequent investigation (Haines pers. comm.).

The freshwater network is composed of 94 river stations. Included in this network is the Basic Water Monitoring Program (BWMP) and 23 federally operated stations. WDOE monitors the freshwater stations monthly for temperature, dissolved oxygen, pH, specific conductivity, nitrogen (nitrate, nitrite, ammonia), phosphates (ortho and total), fecal coliform, turbidity, color, and suspended solids. A few stations are also used to monitor COD, water hardness, and total and dissolved cadmium, chromium, copper, lead, mercury, and zinc. The U.S. Geological Survey (USGS) monitors the federal stations every other month for the above list of parameters and silver, arsenic, barium, cobalt, iron, manganese, selenium, calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, silica, alkalinity, sodium absorption ratio, fecal streptococcus, dissolved solids, total and dissolved organic carbon, phytoplankton, and chlorophyll. COD is not included and some variation in parameters occurs between USGS stations. Monitoring of BWMP stations is divided between WDOE and USGS. WDOE obtains USGS data on request, and stores all data on the WDOE computer and on EPA's STORET system. At the end of the year, a summary of water quality data and flow data is compiled by WDOE.

Recommended Changes. It is recommended that selected high priority pollutants (Chapter 4) be included in the analyses at each station at least over the course of one year, to provide baseline information and identify potential problem areas. Sampling for these pollutants could then be reduced to those areas where problems are shown to exist.

Value to Water Quality Managers. The data gathered on rivers discharging to Puget Sound can be used in determining pollutant loading. The data also can be used to identify loading trends. Correlations between loadings and upstream land uses may be used for future land use planning and predicting water quality impacts.

WDOE MARINE WATER MONITORING

Background. Monitoring of the 44 marine stations of WDOE's surface water quality monitoring program follows a different procedure from the river stations discussed above. The objectives are the same for this part of the program. Four marine stations are designated as part of the BWMP network. All monitoring is conducted by WDOE. Grab samples are collected monthly from April through October. During poor weather months (winter) sampling is not attempted because WDOE uses small seaplanes for transportation and sample collection. Summer storms may also prevent sample collection. Marine water is normally analyzed for conventional pollutants including: coliform bacteria, turbidity, salinity, conductivity, pH, nitrogen (nitrate, nitrite, ammonia), and phosphates (ortho and total). At some stations sulfite waste liquor, chlorophyll a, and/or arsenic are also monitored. Samples are collected on the surface and at 10 m; occasionally a 30 m sample is also collected. Fecal coliform is only analyzed in the surface water sample. The data are reviewed by WDOE and stored on the WDOE computer and in the EPA STORET system.

Recommended Changes. The recommended changes to this program would greatly improve the value of this program to water quality managers.

- Monitor during the winter months, at least at all stations in Puget Sound south of Admiralty Inlet. The winter months are needed to establish accurate annual trends and to identify seasonal variations. Freshwater flow and sediment transport are very significant during these months (Fredriksen, 1970) and may affect the marine water quality in Puget Sound. Surface vessels may be needed to collect and transport samples to shore.

- Include measurement of high priority heavy metals. Inclusion of the heavy metal parameters would provide background data for detection of water quality changes and better data for estimating mass balance of these pollutants. Monitoring should distinguish between chemical species and metals in the dissolved and particulate state.

Value to Water Quality Managers. This program establishes a means for long-term observation of the water quality of Puget Sound as a whole. This data base should be used in monitoring environmental trends as well as existing conditions. The program is currently hampered by failure to monitor during the winter, as well as failure to monitor heavy metal concentrations.

USGS RIVER MONITORING

Background. USGS conducts two monitoring programs that are of interest to Puget Sound water quality managers: continuous flow gaging stations, maintained on the larger rivers; and the water quality monitoring done in conjunction with WDOE river monitoring. The flow gaging program is part of the National Water Data System operated by the USGS. Program objectives are to collect hydrological data to determine annual variations in national conditions and long-term changes in streamflow. Almost all stations are gaged continuously with record tapes changed every other month. The flow record often covers a number of years but may not be continuous in terms of time or location. Data are published annually by water year and stored on computer.

Recommended Changes. Changes that could yield valuable data for Puget Sound water quality managers are presented below.

- Establishment of additional gaging stations is recommended for rivers that are not gaged downstream of major confluences, such as the Stillaguamish River. Ideally, all stations would be located near the river mouth but upstream from the zone of significant tidal influence. This would provide more useful flow data for mass loading and hydrological studies. These data are currently computed by routing down flow data from the upstream gaging station.

- Gaging stations and WDOE water quality monitoring stations should coincide to the maximum extent possible. Flow data and water quality data could then be used with greater confidence to calculate mass loadings.

Value to Water Quality Managers. This program contributes useful data that complement the WDOE program by measuring or computing flow data and adding water quality monitoring stations.

BASIC WATER MONITORING PROGRAM

Background. As part of the Basic Water Monitoring Program (BWMP) conducted by WDOE, intertidal populations of mussels (*Mytilus edulis*) are collected once per year for analysis of the pollutants listed in Table 8-4. The BWMP is part of a national program coordinated by EPA. Mussels are collected during a low-tide period in late summer or early fall. The locations of sampling stations for previous study years are shown in Table 8-5. Note that during 1982, only the Commencement Bay station was sampled. In the future, it is likely that four stations will be sampled each year, including City Waterway in Commencement Bay (Joy pers. comm.).

Recommendations. Because the BWMP is part of a nationwide program, minor, but important, modifications are recommended.

- It is recommended that the same sites be sampled every year. Some consideration should be given to addition of sampling stations near urban areas other than Tacoma, e.g., Elliott Bay and Everett Harbor.

- Consistency of sampling and analytical methods should be maintained among states and over time within the state. The BWMP should follow national guidelines (EPA 1977) for station location, sampling methods, and data reporting. As national guidelines permit, mussels should be collected from the same tidal height each time. The results of the California "mussel watch" program show that concentrations of cadmium, chromium, aluminum, iron and manganese in mussel tissue vary in

Table 8-4. Pollutants Monitored in Mussel Tissue by WDOE

Metals
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Zinc
Pesticides
Aldrin
Chlorodane (4 isomers)
DDD
DDE
DDT
Dieldrin
Endrin
PCBs
1221
1232
1242
1248
1254
1260
Others
α-BHC (hexachlorocyclohexane
γ-BHC " (lindane)
Hexachlorobenzene
Pentachlorophenol

SOURCE: Joy pers. comm.

Table 8-5. WDOE Sampling Stations, Basic Water Monitoring Program

Year	Stations				
	Kayak Point Port Susan	Pulali Point Hood Canal	City Water Way Commencement Bay	Carr Inlet near Cromwell	S. Heron Island Case Inlet
1979		x			
1980	x	x		x	x
1981	x	x	x		x
1982			x		

SOURCE: Yake pers. comm.

relation to tidal height (Stephenson et al. 1979; Mearns pers. comm.).

- Only 11 of the high priority pollutants recommended for study (Chapter 4) are presently monitored by the BWMP (PCBs are counted as a single pollutant). Monitoring of all recommended high priority pollutants should be considered.

- Consideration should be given to transplanting mussels from a clean area to a BWMP location and vice versa. These mussels would be exposed for 10 weeks and analyzed for body burdens of toxicants. Comparison of field populations with transplanted test organisms will provide more useful data on trends.

Value to Water Quality Managers. This program has the potential of yielding useful data on the biological uptake of pollutants, which would be useful in addressing some of the identified water quality management needs. Furthermore, the data can be used to identify trends in water quality parameters. The data collected to date have been sparse, but could be used with caution for local trend analyses. This particular program offers opportunities to compare Puget Sound data with other national program data.

SHELLFISH PSP MONITORING PROGRAM

The Washington Department of Social and Health Services (DSHS) conducts an ongoing monitoring program for paralytic shellfish poison (PSP) in Puget Sound. Additional information on the distribution and abundance of the causative organism *Gonyaulax catenella* and related toxin levels in shellfish is available from short-term investigations by Nishitani et al. (1979) and Nishitani and Chew (1979, 1980). Since these latter studies are not being continued as full-scale monitoring efforts, the following sections address only the DSHS shellfish PSP monitoring program.

Background. The Washington Department of Health (now part of DSHS) began testing for PSP toxin levels in shellfish in the 1930s, but a PSP monitoring program was not developed until 1957 (Nishitani and Chew 1982). Under the current program, DSHS is responsible for coordinating sampling of shellfish, and measuring amounts of PSP in the tissues. Most of the common species of edible shellfish are included in the program, e.g., bay mussel (*Mytilus edulis*), butter clam (*Saxidomus giganteus*), littleneck clam (*Protothaca staminea*, *Tapes japonica*), and Pacific oyster (*Crassostrea gigas*). Other shellfish such as scallop (*Pectin* spp.), cockle (*Clinocardium nuttallii*), soft shell clam (*Mya arenaria*) and Olympia oyster (*Ostrea lurida*) are occasionally tested for PSP. Sampling of recreational shellfish beds is conducted by county health departments, whereas commercial shellfish samples are sent to the DSHS laboratory by the commercial operators (Lilja pers. comm.). Most county health districts depend partly or entirely on public volunteers for collection of shellfish. According to Food and Drug Administration (FDA) regulations, harvesting areas must be closed when toxin levels reach 80 ug/100 g of shellfish tissue. Counties are responsible for closing recreational harvesting areas. DSHS orders the closure of commercial beds when necessary. At a particular site, closures may apply to only one or two species of shellfish, while other species with acceptable levels of PSP continue to be harvested. Contaminated shellfish are generally those species that feed extensively on phytoplankton.

Tests for PSP in commercial shellfish areas are generally conducted on a biweekly basis from April through October. Certain commercial beds, which are harvested year round, are tested on a regular basis throughout the year (Lilja pers. comm.). Testing schedules for recreational harvesting areas vary greatly, depending on the potential for contamination, the relative number of users, the perceptions of the agency responsible, and the capacity of the state testing laboratory. When high levels of PSP are discovered in either a sport or a commercial shellfish area, an intensive sampling schedule is often initiated, e.g., weekly or occasionally more frequently.

PSP sampling areas are located throughout Puget Sound, with a total of over 100 stations (Table 8-6). Approximately 60-70 percent of the samples come from recreational harvesting areas (Lilja pers. comm.). Some of the large bays (e.g., Dungeness Bay, Sequim Bay) have more than one sampling site. Each site within a larger bay is not tested during each sampling period. For recreational shellfish areas, the location of sites tested vary greatly over time in relation to site use, potential contamination, and submission of samples by public volunteers. Permanent sampling locations have been established in commercial shellfish areas. In addition, occasional testing of noncommercial mussels (Mytilus edulis) in Southern Puget Sound is conducted as part of an "early warning system." However, concentrations of Gonyaulax and high levels of PSP toxin have never been observed in the southern basin.

The present method of detecting PSP is the standard mouse bioassay (AOAC 1975). The mouse bioassay is the only method presently approved by FDA (Nishitani and Chew 1982). Since it is an expensive, time-consuming test, the present capacity of the monitoring program is limited by laboratory capabilities (Lilja pers. comm.; Stott pers. comm.). Alternatives to the mouse bioassay, including rapid commercial assays using High Pressure Liquid Chromatography or field colorimetric tests, are being developed, but none is presently available for use as a standard technique in monitoring programs (Shimizu and Ragelis 1979; Sullivan pers. comm.). Alternative bioassay methods are now being researched in various labs. Two that show promise are a housefly bioassay, under development at the University of Southern California (Ross pers. comm.), and an antibody bioassay, under development by Biometrics Systems Inc. (Guire pers. comm.).

Table 8-6. Locations of Shellfish Testing Areas, PSP Monitoring Program.

Commercial Harvest Areas

Dungeness Bay
Sequim Bay
Discovery Bay
Port Townsend Bay
Kilisut Harbor
Mystery Bay
Scow Bay
Oak Bay
Colvos Rocks
Port Gamble Bay

Penn Cove
Race's Lagoon
Port Susan Bay
Skagit Bay
Similk Bay
Samish Bay

Portage Bay
Hale Passage
Lummi Bay
Drayton Harbor
Point Roberts

Ship Bay - Orcas Island
Eastsound - Orcas Island
Hunter Bay - Lopez Island
Westcott Bay - San Juan Island
Open Bay - Henry Island

Agate Passage
Brownsville
Liberty Bay

Sport Harvest Areas

<u>Clallam County</u>

Dungeness Bay
Sequim Bay
Port Williams
Gray Marsh
Diamond Point - Discovery Bay

<u>Jefferson County</u>

Discovery Bay
Kilisut Harbor
Port Townsend Bay
Oak Bay
Thorndyke Bay
Bywater Bay

<u>Mason County</u>

Stretch Island
Hartstene Island Bridge
Budd Inlet
Henderson Inlet
Nisqually Reach

<u>Pierce County</u>

Dupont Dock
Ketron Island
Fox Island Bridge
Titlow Beach
Point Defiance
Browns Point
Gig Harbor
Mayo Cove
Vaughn Bay

<u>King County</u>

Alki Point
Fauntleroy
Normandy Park
Seahurst Park
Dash Point
Redondo
Carkeek Park
Quartermaster Harbor

Sport Harvest Areas

<u>Kitsap County</u>

Foulweather Bluff
Hansville
Kingston
Suquamish
Agate Passage
Fletcher Bay
Manitou Beach
Fay-Bainbridge State Park
Eagle Harbor
Yukon Harbor
Illahee State Park
Blake Island
Miller Bay
Dyes Inlet
Murden Cove
Skiff Point
Manchester State Park

<u>Snohomish County</u>

Mukilteo
Edmonds
Warm Beach
Hat Island

<u>Island County</u>

Penn Cove
Doublebluff Beach
Columbia Beach
Holmes Harbor
Baby Island
Satchet Head
Camano Island State Park
Manaco Beach
Ala Spit
Woodland Beach - Camano
Snatelum Point
Useless Bay
Cultus Bay
Elger Bay
Harrington Lagoon

<u>Skagit County</u>

Guemes Island - Burrows Bay
Sinclair Island
Similk Bay
Samish Bay
March Point
Hat Island
Cypress Islnad

<u>Whatcom County</u>

Chuckanut Bay
Birch Bay
Larabee State Park
Drayton Harbor
Bellingham Bay
Cherry Point
Sandy Point

<u>San Juan County</u>

Cattle Point - San Juan
Garrison Bay - San Juan
Spencer Spit - Lopez
Mackaye Harbor - Lopez
Shoal Bay - Lopez
Mud Bay - Lopez
Fisherman Bay - Lopez
Squaw Bay - Shaw
Pile Point - San Juan
Guthrie Cove - Orcas
Decatur Island - South En
Sucia Island - West Side
Buck Bay - Orcas
Mitchell Bay - San Juan

SOURCE: Lilja pers. comm.

Recommendations. For the most part, the existing sampling program is adequate; the current program has an excellent record for protecting the public. Since the beginning of the program in 1957, there have been no reported cases of PSP from shellfish commercially harvested in Washington (Nishitani and Chew 1982). However, the program is not formalized. Formalization of a specific sampling strategy and concurrent measurement of water quality parameters are recommended.

In addition to the current data reports, the following data analyses are recommended:

- Minimum, mean, and maximum PSP level for each shellfish species at each site.
- Correlation analyses of water quality parameters (e.g., salinity, nutrient levels, temperature of surface water) with PSP levels for selected primary sites.
- Time series comparisons of PSP levels at adjacent sites to identify spatial and temporal progression of high PSP incidence.

Data analyses should be directed not only at immediate monitoring requirements (i.e., protection of the public through harvest closures), but also at potential predictive models that might allow accurate forecasts of PSP incidence.

Value to Water Quality Managers. The cause of *Gonyaulax catenella* blooms and resulting levels of the toxin is not clearly understood. If a water quality parameter is linked to the blooms, this data base would provide substantial information on water quality trends. Until such a link is determined, the PSP monitoring program data are limited to public health objectives. If measurement of some water quality parameters were added at the time of collection, these data could be used in establishing associated water quality conditions and trends.

SHELLFISH COLIFORM BACTERIA MONITORING PROGRAM

Background. DSHS is responsible for monitoring the quality of shellfish from commercial harvest areas. The program is primarily oriented toward commercial clams, mussels, and oysters. DSHS only occasionally tests recreational shellfish samples collected by county employees or volunteers.

The shellfish/coliform monitoring program is part of the National Shellfish Sanitation Program, a cooperative venture among federal, state, and industry representatives since about 1925 (Stott pers. comm.). The program in Washington state monitors fecal coliform bacteria in the water column and in shellfish at commercial growing areas. Shellfish tissue samples are examined weekly at processing plants, and additional monitoring is performed at the wholesale and retail levels (Lilja pers. comm).

The field program does not maintain a routine sampling schedule. Rather, intensive field surveys are conducted over a 4-10 day period in each area during the time of expected poor water quality. Commercial growing beds covered by the coliform monitoring program include those monitored for paralytic shellfish poisoning (PSP) (Table 8-6) as well as other harvest areas in Hood Canal and Southern Puget Sound (Lilja pers. comm.). The field surveys form the basis for classifying growing areas according to recommended guidelines established by the National Shellfish Sanitation Program. These guidelines have been adopted by the state and are based on coliform bacteria concentrations in the water column. There are no established federal criteria for bacteria concentrations in shellfish tissue in the field (Stott pers. comm.), but state guidelines for tissue contamination have been developed. Growing areas are classified as certified, conditionally certified (e.g., area may be open only part of the season), and closed.

Recommended Changes. The DSHS monitoring program for coliform bacteria in shellfish is part of an established national program. Significant improvement of the local program would result from:

- Establishment of empirical relationships between water column concentrations of bacteria and tissue levels.
- Coordination with the PSP monitoring program by measuring *Gonyaulax catenella* concentrations in water samples collected for the coliform program.
- Establishment of a formal sampling and classification program for recreational harvest areas.

Value to Water Quality Managers. The major benefit to the comprehensive monitoring program is the documentation of trends in shellfish contamination by bacteria. These trends will demonstrate the effectiveness of WDOE programs to control bacterial contamination in shellfish growing areas.

Chapter 9

INTERIM APPROACH TO WATER QUALITY MANAGEMENT

Rationale

Water quality managers must bridge major gaps in the data needed to link pollutants to observed environmental degradation and adverse impacts on Puget Sound resources. It may be a few years before recommended studies provide data that will bridge the more critical gaps. It may be even longer before specific chemical pollutants can be identified as causal agents and environmental action levels established.

The water quality manager meanwhile must rely on existing data and acceptable investigative tools. Such data are useful as long as one interprets the results as warning signals. Discovery of high sediment concentrations of toxicants and pathological conditions in biota is evidence that demands a closer evaluation of the quality of the environment and current waste management practices. Best available data and reasonable judgments can be used to develop a "preponderance of evidence" approach to decision making.

This approach requires simultaneous investigations of two features of the environment: current loading of pollutants, and the accumulating reservoir of pollutants. Information on both features is needed. For example, current pollutant loading may not directly affect biota, but may be contributing to adverse impacts resulting from accumulating contaminants.

Evaluation of current input and accumulating materials must include both chemical analyses and bioassays. Acute response bioassay results must be interpreted with care. They should not be considered as the final product of any survey, or as direct proof of adverse impact in the environment. Rather, these tests should be seen as warnings that adverse biological effects may occur. Management decisions can be made based on data from any one of the steps described below, but decisions must take into account information provided at all steps in the process. For example, discovery in effluent of a chemical known to cause cancer at low concentrations may warrant development or implementation of the best available technology (BAT) that is economically feasible to control the discharge, even though acute response bioassays do not indicate lethality. In the same way, discovery of high sediment contamination by a carcinogenic compound may indicate a need to stabilize or reduce concentrations in the environment by reducing input, even though current input of the compound alone may be unlikely to cause detectable effects.

As noted in Chapter 7, the interim management program is a valuable part of the Puget Sound water quality management program. The biological tests conducted here, in association with the recommended biological studies of Chapter 7, will provide data bridging critical gaps in the linkage of pollutants to biological effects. The interim approach will gradually change as data are obtained from the work described in Chapter 7. The interim approach is based on reasonable judgments applied to information obtained from chemical analyses, acute response bioassays, and other available data. As the recommended studies are completed, a more sophisticated approach can be taken as linkage between pollutants and specific biological effects (particularly sublethal effects) are identified.

Current Discharge Practices

POINT SOURCE

Evaluation of a point source discharge should include the following steps: 1) Identify concentrations of pollutants and waste flow volumes in the discharge. 2) Perform biological tests on the discharge. 3) Enact, continue or expand appropriate BAT as necessary. 4) Continue chemical and biological monitoring on a regular basis to help identify any change in discharge toxicity that may require further action.

Step one is necessary to identify any compounds that can produce significant biological effects at the concentrations present. It also identifies compounds that concurrently should be monitored in sediments and biota. Highest priority should be given to synthetic organic compounds that are known or suspected to be acutely toxic, carcinogenic, mutagenic, or teratogenic at low concentrations (e.g. at tens of parts per million or lower).

Step two provides an assessment of the potential toxicity of the discharge using sensitive indicator organisms in short-term acute response bioassays. Sublethal and chronic effects (e.g. life cycle and reproductive effects) are presumed to result from long-term, low-level exposures to substances identified as acutely toxic. Sublethal effects are a major concern; however, experiments designed to directly measure such effects are difficult to perform, expensive, long term, and poorly validated. These features cause long-term chronic effect bioassays to fall more into basic research rather than as field investigative tools, thus, the interim reliance on acute response techniques. The selected bioassay(s) must, in order to be useful in an interim management context, meet the following criteria:

- Since seawater chemistry may alter toxicity of some discharges, the bioassay should be conducted on marine or anadromous species in seawater. To prevent osmotic shock, freshwater effluent should be tested at a concentration no greater than 10 percent, or should be mixed with ocean salts.

- The test organism(s) must demonstrate the best possible compromise of the following traits: sensitivity, availability, and adaptability to handling and bioassay conditions. Also, the life history and ecology of the test organism(s) should be well documented.

- The bioassay technique(s) should be standardized, accepted, and well validated.

- The test should require a minimum of special equipment or skills.

- Costs should be relatively low for the quality of data obtained.

- The bioassay should define a discrete endpoint for analysis.

- Results should be statistically interpretable (i.e. from a well controlled experimental design).

Bioassays selected using these criteria will best meet immediate management needs by effectively serving, in conjunction with the chemical characterization, as a warning sign identifying particular toxic conditions requiring careful review.

At this time, bioassays potentially appropriate for toxicity investigations and monitoring include:

- The Pacific oyster embryo bioassay (Woelke 1972; ASTM 1980).

- A mussel larvae bioassay following the same methods (ASTM 1980).

- The sperm cell toxicity bioassay (Dinnel et al. 1982; Stober & Chew 1983).

- A modified Ames test (Dexter & Kocan 1981).

- A mysid shrimp bioassay (EPA/COE 1977; Petrazzuolo 1983).

- Bioassays using larvae of other crustaceans such as Dungeness crab or pandalid shrimp.

All of these are relatively short-term tests having discrete endpoints, generally accepted methodologies, and well-developed protocols which thus far have seen relatively wide use.

Generally, it is recommended that the Pacific oyster larvae bioassay be the minimum required biological test for effluent monitoring under these interim water quality management procedures. The organism and test presently are ranked as best meeting the criteria set forth above. The sperm cell bioassay (Dinnel et al. 1982; Stober & Chew 1983) should be given serious consideration as a possible replacement to the oyster larvae bioassay once it becomes better validated and more widely accepted. This test exhibits similar, or more sensitivity to a wide variety of toxicants compared to the oyster larvae bioassay. It can be performed, analyzed, and results interpreted and available in one day. A further advantage is that the reading of the results is less subjective than for oyster larvae. WDOE's Industrial Section currently uses a salmonid bioassay, using 65 percent effluent in freshwater (Springer pers. comm.). The test could be modified by using post-smoltification fish in seawater, however, consideration should be given to the relatively more sensitive bioassays listed above.

Step three is a decision stage. Either steps one or two can dictate establishment, continuance, or expansion of BAT or best control technology (BCT), depending on the situation. The results of chemical analyses of sediments from the receiving area must also be considered in the decision. Current discharge practices may not be harming exposed organisms directly, for example, but they may be exacerbating conditions caused by historical practices.

Step four (continued chemical and biological monitoring) could be required if there were the possibility that the composition or toxicity of the discharge would change. Monitoring would provide information on the success of management decisions.

NONPOINT SOURCE

The relative importance of nonpoint source input of pollutants, especially toxicants, to Puget Sound is difficult to determine. Little information is currently available (Jones & Stokes Associates, Inc. 1983). However, even for purposes of interim management, it is important to know as much as possible about nonpoint source contributions so that the effectiveness of potential management actions can be predicted. This approach is also a major part of the longer term water quality management plan for Puget Sound (Chapter 5). The scope of the problem is initially reduced in magnitude by treating riverine input to Puget Sound as if it were a point source. If the data indicate major pollutant contributions from rivers, evaluation of the relative contribution of point and nonpoint sources becomes important as a subsequent work effort in the watershed.

Effort to identify and reduce the potential for nonpoint source contamination should be directed as follows: 1) Inventory inputs of toxicants, and describe and quantify the constituents at different times of the year. 2) Determine relative contributions by input types. 3) Estimate the relative need for and practicality of remedial action (i.e. whether the source is controllable). 4) Implement remedial action as possible. These steps are more fully described in Chapter 5.

Without supporting effort on nonpoint sources, point source dischargers could face costly regulation with no benefit to the receiving environment, because local nonpoint inputs are major contributors of the target pollutant. The data obtained from the recommended approach will allow comparison of the relative importance of current point and nonpoint discharges to potential water quality problems.

Accumulating (Sediment) Contamination

Evaluating the effects of historical and steadily accumulating contamination is as necessary to water quality management as evaluating the importance of present discharges. As a reservoir of adsorbed toxicants, sediment acts as an integrator of present and historical water quality conditions. Sediments highly contaminated from past practices may adversely affect resident biota, and these effects could be exacerbated by new inputs of pollutants.

Several steps may be required when assessing toxicants accumulating in the sediments. These steps include: 1) Conduct physical and chemical analysis of the sediments likely to be influenced by a discharge of interest, or at suspected sites of high contamination. 2) Identify toxicants likely to be the most critical based on their chemical and biological properties. 3) Survey the biota found in the area of the sediment samples, including species composition, chemical body burdens, and histopathological screening if appropriate. 4) Perform biological tests on the sediments. 5) Compare results from chemical and biological analyses of current inputs (point and nonpoint sources) to the sediment analyses. 6) Enact, continue, or expand BAT, BCT, or best management practices (BMP) as necessary to stabilize or reduce loading. 7) Monitor sediment and local biota, and continue biological testing, if required, to help assess the effectiveness of management actions.

Just as during evaluation of present discharges, management decisions can be made at various steps along this procedure, depending on results. Significant findings from either the chemical or biological analyses alone could dictate specific actions. The most responsible and defensible management actions will come only after consideration of results from analyses on both current inputs and the store of accumulated contaminants.

It should be noted that elements of this work effort are now underway Chapter 3).

Ideally, one would like to be able to answer three major questions regarding the potential toxicity of any contaminanted sediment to aquatic life. These include:

1. Is the sediment toxic?

2. Are chemical compounds that are associated with sediments taken up by organisms?

3. Can chemicals in sediments and taken up by organisms cause any adverse biological effects?

Research into these questions has been identified earlier in this report as being a priority for further funding. Meanwhile, the state of the art does not seem to be such that bioassays designed to identify sublethal or chronic effects can be used as regulatory tools. Management should, therefore focus for now on results from acute bioassays, coupled with physical and chemical data on the sediments themselves.

Protocols have been developed to study the potential for acute sediment toxicity (EPA/COE 1977; Pequegnat et al. 1981; Pierson et al. 1982b; and Petrazzuolo 1983). These protocols differ in some of the specifics, but all generally assess potential sediment toxicity through the testing of three "phases" of material prepared from the bulk sediment samples. These are: Solid Phase (SP), Suspended Particulate Phase (SPP), and Liquid Phase (LP) preparations. SP, SPP, and LP preparations have been used in acute toxicity tests with a variety of indicator organisms and methodologies. Guiding principles in conducting sediment bioassays are:

- Sediments should be tested as Solid Phase (SP), Suspended Particulate Phase (SPP), and Liquid Phase (LP) preparations, with appropriate methodologies and species as outlined below.

- Bioassays should utilize established, standardized, well-validated methodologies. Utilization of or research into new techniques is not appropriate to these interim recommendations. Although such investigations should be encouraged, and indeed actively funded, they should not detract from efforts required for interim monitoring and management.

Those tests that have been or can easily be applied to Puget Sound organisms, and that best meet the criteria given earlier in this chapter, are summarized below relative to each phase.

SOLID PHASE ACUTE BIOASSAYS

Biological testing performed with solid phase sediment samples is subject to two major confounding factors that can affect interpretation of the results. First, benthic organisms generally have very specific substrate preferences. The degree to which these "preferences" may actually be requirements is not well quantified for species that have been used thus far in sediment bioassays. The testing of several different sediments using a single test species without the use of rigorous controls and appropriate validating experiments usually yields uninterpretable data. Second, fine sediments tend to accumulate toxicants to higher levels than coarser sediments receiving the same exposure, primarily because of the difference in surface area available for adsorption. Clearly, sediment grain size can have a two-fold role in influencing the outcome of sediment bioassays.

For these reasons, some specific recommendations are made below which, together with good laboratory practices, are necessary for data analysis and interpretation.

- Ideally, sediments would be tested fresh; however, there are situations where this is impractical. If bioassay test data are to be compared, the methods should be standardized. Under these constraints, the optimum compromise is that all sediments (including controls) should be stored frozen, and bioassays should begin no later than 48 hours after the initiation of thawing.

- All bioassays should include clean control (reference) sediment, native control sediment (from which the test organisms were collected, if appropriate) and a toxic (negative) control sediment. Toxic (negative) control material can be sediment known to be contaminated and to produce quantified, repeatable, acute effects on the test organisms, or can be manufactured by spiking separate samples of the clean control (reference) sediment with a standardized preparation of a toxicant, as methods for such spiking become accepted and the results repeatable. If spiking is done, a spiked native sediment control should also be included. Control sediments (toxic and clean reference) could be kept as large stocks for use in various bioassays, adding to the comparability between studies.

Several investigators have used gammarid amphipods under various methodologies to assess acute toxicity of sediments in Puget Sound (Swartz et al. 1982; Pierson et al. 1982a, 1983; Chapman et al. 1982b; Stober & Chew 1983). Gammarid amphipods bury themselves in the substrate and are small and easily collected in numbers sufficient for testing. Much debate centers around the appropriateness of the various methodologies, species used, interpretations of data, and the importance of controlling for potential confounding factors such as particle size. Until a scientific consensus can be reached regarding methodologies and interpretations, the water quality manager is faced with a choice for solid phase testing: either amphipod bioassays should be performed in the interim and the data archived for possible re-evaluation later, or some other more appropriate organism should be tested in the solid phase. Presently, there is no other organism that has been shown to be any more "ideal" for SP testing than an amphipod species. Chapman et al. (in press) have used *Capitella capitata*; the species should be given consideration if the methodology can be proven to be more appropriate and acceptable to the scientific community.

Since the results of any SP bioassay could be affected by a variety of sediment parameters, as much information as possible about any of these parameters is required. In this way, future research into the importance of these potentially confounding factors can be used to reevaluate already collected data, and reperforming tests may not be necessary. The following information must be recorded on sediments used in any SP bioassay:

- Particle size analysis on all controls and test sediments.
- Eh, pH, and ammonia concentration determinations, at least at the beginning and end of the test period.
- Chemical analysis on all control and test sediments.

SUSPENDED PARTICULATE PHASE ACUTE BIOASSAYS

SPP bioassays expose organisms to fine particulates and any chemical contaminants bound to those particulates. Continuous-flow experiments are most appropriate for SPP testing and for use with larger organisms such as fishes and nonlarval bivalves or crustaceans. Sublethal indices (e.g. growth of young mussels) are easier to test for in continuous-flow SPP bioassays than with other phase testing. However, sublethal tests are difficult to interpret and usually involve a high degree of variability. The criteria for use as an interim management tool are again best met by performing short-term acute SPP bioassays on sensitive organisms.

Continuous-flow SPP bioassays have most often been performed using smolts of various salmonid species. Smolts are relatively more sensitive to pollutants and pollution-related stresses than other salmonid life-history stages, but they are not among the more sensitive species that could be used. The importance of salmonids to the culture and economy of the Pacific Northwest, together with their availability and the vast amount of experience workers have had in handling these organisms, makes them appropriate for use in the testing program. It is necessary, however, to ensure that the salmonids have actually undergone successful smoltification prior to beginning any bioassay performed in saltwater. This can be accomplished by using species that are adapted to osmoregulation in seawater essentially from hatching, i.e. pink (*Oncorhynchus gorbuscha*) or chum (*O. keta*) salmon. Individuals of these species can be tested when much smaller than other salmonids, thus allowing larger sample sizes and better resolution of effects. If smolts of another salmonid species are used, plasma sodium analyses, minimally, should be performed prior to and for at least 3 days following seawater entry, to ensure that successful smoltification has indeed taken place.

LIQUID PHASE ACUTE BIOASSAYS

LP bioassays can provide indications of the potential acute toxicity of soluble chemical contaminants in the sediment. Several organisms and techniques have been utilized and have gained general acceptance, or have become sufficiently validated to allow consideration of their use in a management context at this time. These include many of the same organisms and tests outlined for the monitoring of effluent discharges. The same criteria for their use apply.

Compatibility between results from biological tests applied to discharges and to sediments is necessary; therefore, the Pacific oyster larvae bioassay should be used at this point as well. The sperm cell bioassay may be able to replace the oyster larvae bioassay in the near future.

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APPENDIX A

Summary of Findings from First Phase of Work

This appendix is a brief summary of the findings of the first phase of work (Jones & Stokes Associates, Inc. 1983). The report described water quality management programs and data needs, and evaluated the ability of existing data to meet data needs of water quality managers.

Management Programs

Water quality managers have the necessary regulatory tools to respond to, prevent, and abate pollution once it becomes reasonably evident that a discharge/activity has an adverse effect on beneficial uses or resources. Although a comprehensive water quality management structure is operating in Puget Sound, it is not fully integrated and coordinated with respect to the acquisition and use of data and information. In particular, research and monitoring efforts between, and occasionally within, management agencies are not coordinated.

Data Needs for Water Quality Management

Water quality management is normally accomplished by various statutory permit/enforcement programs. Ideally, water quality management decisions should be made with full knowledge of the direct and cumulative impacts expected to result from each decision. Knowledgeable decisions require data of several kinds: location and type of pollutant sources; quanitity of each potential pollutant discharged; physical, chemical, and biological processes affecting pollutant transport and environmental fate; and toxicity/dose-response data for key species likely to be affected. This information will allow a reasonable determination of the maximum loading a system can absorb before an unacceptable biological impact occurs.

Because many ecosystem impacts are difficult to observe or quantify, the term "unacceptable impact" is most effectively defined as impairment of a designated beneficial use, or alteration in the ability of certain organisms to survive, grow, and reproduce. These represent key starting points in impact assessment and resource management.

The data base should have two key features: it should contain data that can demonstrate relationships between pollution and effects on biota and beneficial uses; and it should be based on a coordinated multidisciplinary (holistic) approach so that data are compatible and consistent from study to study. Ideally, the data should link specific pollutants to observed adverse impacts.

Available Data

MASS LOADING OF POLLUTANTS

With the exception of effluent analyses done as part of the 301(h) waiver applications for municipal discharges and as NPDES permit compliance monitoring by a few selected industrial dischargers, there are few data to describe sources and mass loading of priority pollutants to Puget Sound. Loading for nonpoint sources is not documented, partly because nonpoint discharges are not permitted sources, but primarily because their diffuse nature does not easily lend itself to source identification, characterization, quantification, or monitoring.

POLLUTANT TRANSPORT

The objectives of a modeling effort for Puget Sound are to identify depositional areas for contaminated solids (fate of solids) and to determine retention time of dissolved pollutants and suspended solids (interbasin transfer, overall circulation patterns, fate of solids). Although major concern is focused on urbanized embayments, because of known or suspected pollution-related impacts on beneficial uses, an overall Puget Sound model is necessary to supply important general information on net circulation, mass transport, and boundary conditions to drive more detailed subarea models.

Major limitations of models that have been or are currently being applied to Puget Sound include:

- Dimensionality - Many of the models use 1-dimensional formulations which represent over-simplified systems.
- Spatial Resolution - Some of the formulations utilize grids to break up the study area into workable units. Many of the models lack grid flexibility. Detailed information in certain areas is required, thus, lack of grid flexibility severely limits the applicability of some models.
- Site-Specificity - Some of the models are site-specific. The assumptions and basic equations used in the models are only applicable to a certain area or water body type.
- Verification and Calibration - Many of the models lack adequate calibration and verification.

Three options exist for future modeling effort in Puget Sound: revise an existing model of Puget Sound; modify and adapt a model developed for a different water body; or develop a new model. All require data for model development and calibration. A substantial amount of data for use in circulation modeling is available for many physical/chemical parameters in Puget Sound, although it is not presented in an organized, comprehensive format. The state-of-the-art model review identified a model by Najarian et al. (1981) as the optimum existing technique for application to Puget Sound as a whole. A model by Sheng and Butler (1982) was identified as the optimum existing technique for adaptation to the Central Basin. The latter is a 3-dimensional leveled model that provides flexibility in grid layout. Both models would not require major modifications for application to Puget Sound.

FATE AND DISTRIBUTION OF POLLUTANTS

A review of literature on properties, fates, sources, and distribution of the 126 EPA "priority pollutants", petroleum hydrocarbons, polychlorinated dibenzofurans, and particulates in Puget Sound reveals numerous data gaps for most of these pollutants. Behavior of many compounds, and even whole groups, is not well understood. Behavior of an entire group often must be inferred from behavior of a single compound, or of related compounds, because compound-specific data are not available. In addition, reactions are often site-specific, and much of the known fate information is based on reactions in a freshwater environment. Interactions in the marine environment in general, and in Puget Sound in particular, are not well understood.

The lack of data on properties, sources, fates, and distribution of many compounds does not mean that decision makers are completely without information in these areas. Sufficient data exist to permit reasonable judgements regarding properties, fates, and probable distribution in the Sound. Certain compounds appear to be of greater concern than others based on their acute and chronic toxicity, their tendency for persistence and bioaccumulation, and the degree and extent of local contamination Many of the priority pollutants do not appear to be of local concern, while other pollutants not considered as EPA priority pollutants have greater local impact based on their prevalence and properties. Compounds of most concern appear to be DDT/DDE, PCBs, chlorinated aliphatics (including chlorinated butadienes [CBDs]), polychlorinated dibenzofurans, polycyclic aromatic hydrocarbons (particularly naphthalenes, fluoranthenes, benzo(a)anthracene, benzo(a)pyrene, and possibly pyrene and chrysene) and, to a lesser extent, heavy metals. Others, such as aldrin/ dieldrin, are of potential concern, but additional data are needed to determine their status.

BIOLOGICAL EFFECTS OF POLLUTANTS

For the Puget Sound region, the most intensively studied biological effects include organism abundances, toxicity, and bioaccumulation. There is little or no information concerning potential biological effects on behavior and reproduction. Fishes have received the greatest study effort; however, considerable work has also been conducted on assessment of toxicity using benthos and plankton.

Studies have produced several kinds of information, including:

- Identifying (or failing to identify) effects on indigenous biota.
- Identifying tissue contamination and abnormal pathological conditions in organisms inhabiting industrialized areas.
- Identifying probable relationships between contaminated sediments and bioaccumulation, disease, and mortality of Puget Sound organisms.

Although effects on biota (e.g., fin erosion, bioaccumulation) have been implicated in field studies, information on quantitative cause-and-effect relationships is lacking. For example, apparent effects of the West Point sewage discharge have been detected in local infaunal communities. However, the available information does not adequately characterize the cause(s) of the observed effects, and is clearly inadequate in establishing a quantitative cause-and-effect relationship.

Studies of bioaccumulation have demonstrated that various contaminants (e.g., PCBs, CBDs, and several metals) occur in elevated concentrations in Puget Sound biota. However, information on uptake routes, intertrophic transfer, and depuration rates is generally lacking. Moreover, quantitative relationships between sediment or water concentrations and organism tissue levels also are unavailable. In comparing body burdens of certain compounds in fish from urbanized areas and fish in areas presumed to be nonpolluted, conflicting data are usually observed. Much of the confusion is due to improper or unverified reference sites. However, the general condition is that heavy metals are on the order of two- or three-fold greater in tissues of fish from urban areas, whereas some synthetic organic compounds may be as high as one or two orders of magnitude greater, relative to presumed nonpolluted reference sites.

It is known that certain synthetic organics are toxic to many organisms at low concentrations. Data from the literature indicate that PCBs are taken up from sediments and from the water column, and that PCBs induce some of the pathological conditions observed in urbanized embayments of Puget Sound. These latter observations, although obtained in laboratory conditions, are indirect evidence that PCBs may be causing some of the observed pathologies of fishes. This does not, however, constitute evidence that PCBs are the only causal agent for fish abnormalities in Puget Sound.

Overall, past studies in the Puget Sound region have served to identify the nature and location of probable biological effects. Although some cause-and-effect relationships are suggested by available data, additional studies will be required for the determination of quantitative relationships that are useful for predictive purposes.

Monitoring Programs

The main function of monitoring programs is to identify trends. Common limitations to existing monitoring programs make it difficult to use these data to evaluate environmental conditions, identify trends, or predict impacts of water quality management decisions. Private studies often tend to provide more in-depth data, but only for localized areas and over short durations, which makes trend determinations difficult. However, because of their greater detail, short-term studies may ultimately provide data of greater value than that provided by routine water column monitoring of a few selected conventional parameters. Value of these studies would be enhanced if collection and analysis procedures are standardized to allow comparison of study results over time.

APPENDIX B

Methods for Adapting Models to Puget Sound

The following is a brief outline of steps necessary to adapt the model of Najarian et al. (1981) to Puget Sound.

Modification of the Najarian et al. (1981) model formulation, required for adaptation to Puget Sound. Modifications include incorporation of desired variables, (density modifiers, temperature, and suspended solids processes), into the conservation of mass equation and the equation of state. Associated sources, sinks, and decay or settling rates must also be included in the formulation. These data will be provided by other recommended studies that address solids processes in detail, including settling characteristics, possible algorithms, and the relationship between organic constituents and suspended solids (sediment contaminant coefficients).

Selection of temporal and spatial resolution requirements including specification of the time step and grid configuration. For any model there is a tradeoff between spatial resolution, time step, and the cost of running the model. The Najarian et al. (1981) model uses a semi-implicit finite difference integration scheme that allows significantly larger time steps in the dynamic integration. This is useful when dealing with water bodies of extreme depth, as found in certain basins of Puget Sound. In addition, this model allows for network branching to account for multiple, interconnected channels. Therefore, appropriate model resolution based on water quality conditions and waste sources, as well as hydrodynamic processes, can be selected to provide various levels of needed detail.

Collection of existing data for calibration and verification procedures. Two independent data sets are needed for this task. Additional field observations are required to adequately represent suspended solids and may be needed to describe sill zone processes, depending on model sensitivity results. Measurement of sedimentation rates by sediment traps is considered to be the appropriate method of collecting model calibration and verification data. A program of sediment trap deployment throughout the Sound would be needed.

Calibration of the model. Calibration of the model involves "tuning" the various empirically based coefficients on a site-specific basis using one of the independent data sets. These coefficients are influenced by system geometry, local eddy behavior, bottom irregularities and vertical, sill zone mixing. Thus, before application to Puget Sound, site-specific calibration will be required.

Verification and application of the model. Once the model coefficients are calibrated, the model is verified using a different, independent set of prototype conditions to determine whether the model accurately reproduces these observations. After verification procedures have been completed, the model may be used in a predictive capacity to calculate net transport, general circulation, and boundary conditions for the sub-basin models.

Sensitivity analysis of the model. Sensitivity studies should be performed to separately investigate the response of the model to variation in the forcing mechanisms thought to govern circulation in Puget Sound. Sensitivity studies will ensure that the model is properly "debugged" and that there are no discrepancies in the representation of physical phenomena. These studies will offer insight into the understanding of the various forcing functions (tides, winds, density, etc.) and indicate needs for additional field data in on-going model testing.

The first set of sensitivity tests should be made for tidal simulation in order to estimate the approximate bottom friction coefficients. For these initial tests, density variations will be ignored. A systematic series of model simulations will be made varying the bottom friction coefficients to determine the sensitivity of system response in terms of tide amplitudes and phase variations throughout. Preliminary adjustment of bottom friction coefficient will be made by comparing model results to available in situ data.

The next set of sensitivity studies will investigate the role of density-induced circulation on system-wide net flows. The model will be run "diagnostically" by specifying the density variations throughout from available prototype data, probably on a seasonal average basis, as permitted by available data sources. The results of these tests will be a series of runs showing the capability of the model to simulate the net, long-term seasonal circulation induced by the large-scale horizontal and vertical density structure of the Puget Sound system.

Next, sensitivity studies of model response to vertical eddy viscosity and diffusivity formulations and magnitudes will be performed to assess the impact of various treatments on model predictions. Empirically derived formulations related to such parameters as depth, winds, vertical stratification, and water velocity will be obtained from the literature, and will be updated based on analysis of on-going model calibrations against field data.

Finally, given a definition of the bottom friction and vertical eddy viscosity formulations, a series of wind driven simulations will then be performed. These studies will quantify the response of channel waters to wind forcing and document the response times that characterize the system.

APPENDIX C

Other Basin Models

Whidbey Island Basin Model

A separate 3-dimensional model of the Whidbey Island Basin is considered of secondary priority. It would extend from Possession Sound on the south to Deception Pass on the north. The model recommended is that by Sheng and Butler (1982), for the same reasons as outlined for the Central Basin (Chapter 6).

Skagit Bay and Port Susan are areas within the Whidbey Island Basin that receive major river discharges, as well as exhibit extensive tidal flat areas. For these areas, a 2-dimensional, vertically averaged model with flooding and drying capability should be applied (Taylor and Pagenkopf 1981), with appropriate boundary conditions supplied from either the laterally averaged model, or a 3-dimensional model of Whidbey Island Basin.

Southern Puget Sound Model

Southern Puget Sound is defined as that portion of Puget Sound south of the Tacoma Narrows. This water body exhibits vigorous tidal mixing, and receives freshwater runoff from the Deschutes and Nisqually Rivers. Despite strong tidal mixing, this water body exhibits local stratification near river mouths and seasonal stratification in many areas due to the significant depths that exist. In view of the channelized network nature of this system, as well as the extreme depths of the main channels, the best modeling approach is application of the 2-dimensional, laterally averaged model by Najarian et al. (1981).

Budd and Totten Inlets represent the irregular network of shallow channels that connect to Southern Puget Sound through Pickering and Dana Passages around Hartstene Island. This portion of southern Puget Sound is very shallow, and exhibits local water quality stresses as evidenced by high algal and zooplankton productivity. The MIT-DNM 1-dimensional network model (Harleman et al. 1977) is ideally suited for representation of this subsystem, because of its shallow, channelized nature.

Hood Canal Model

Hood Canal is also, by nature of its long, deep, and narrow channels, most appropriately represented by the 2-dimensional, laterally averaged model by Najarian et al. (1982). Furthermore, Hood Canal normally exhibits distinct stratification due to numerous rivers that discharge into this basin along its length. The main features of hydrodynamics within Hood Canal are therefore oriented along the vertical and longitudinal axis of the system.

Bellingham Bay Model

Bellingham Bay is a separate, semi-enclosed basin bordering on the Strait of Georgia. This basin exhibits wide variability in depth, with extensive tidal flat areas that alternately flood and dry over the tidal cycle. Bellingham Bay receives major freshwater runoff from the Nooksack and Samish Rivers. Because of the relatively shallow nature of the system, as well as the tidal flats, the most appropriate circulation model for application to this area would be a 2-dimensional, vertically averaged model with the capability to simulate flooding and drying effects accurately and economically. Such a model is the finite-difference model by Taylor and Pagenkopf (1981), which could be applied to the system without modification.