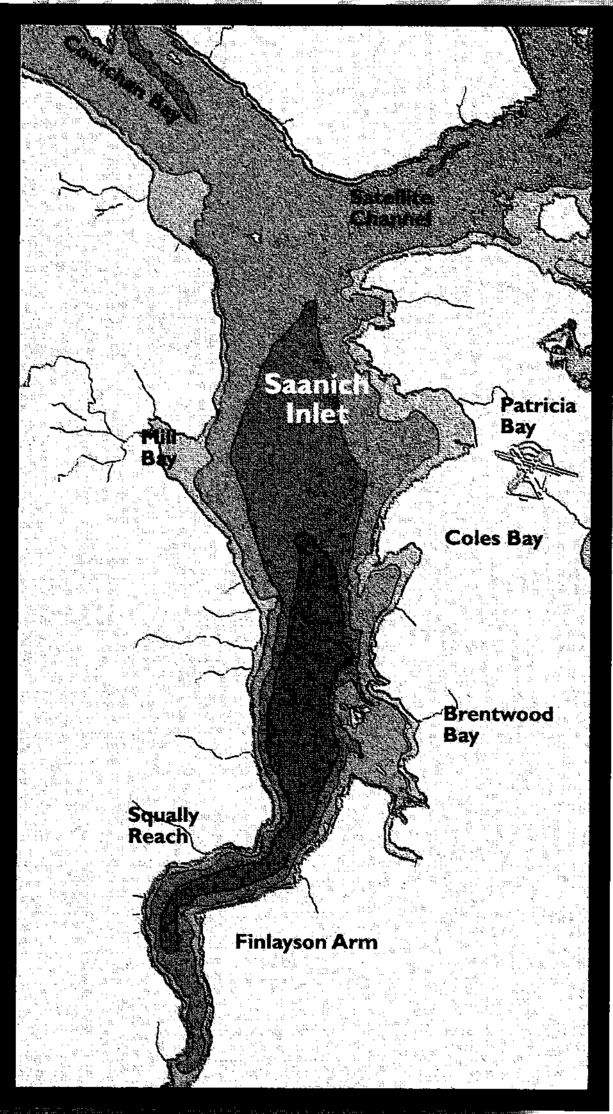
Saanich Inlet Study



Synthesis Report: Technical Version

Province of British Columbia
Ministry of Environment, Lands and Parks

Cover Design: DoMo Communications
Management

Coast Salish Design: "Thunderbird & Salmon"
Roddy Albert Modeste Sr.
Malahat First Nation

Saanich Inlet Study reports available from:

Ministry of Environment, Lands and Parks
Environmental Protection Department
Water Quality Branch
Third Floor, 765 Broughton Street
Victoria, BC V8V 1X4
Tel.: (604) 387-9500
Fax: (604) 356-8298

Also available online at http://www.env.gov.bc.ca/epd/epdpa/wq/saanich/sis.html

Canadian Cataloguing in Publication Data

Main entry under title:
Saanich Inlet study. Synthesis report: technical version

Includes bibliographical references: p.
ISBN 0-7726-2758-4

1. Hydrology - British Columbia - Saanich Inlet. 2. Water Quality - British Columbia - Saanich Inlet. 3. Water - Pollution - British Columbia - Saanich Inlet. 4. Saanich Inlet (B.C.) I. EVS Consultants Ltd. II. Sea Science (Firm) III. Frank Gobas Environmental Consulting. IV. BC Environment. Water Quality Branch.

GB708.B7S323 1996 553.7'2'0971128 C95-960511-8

SAANICH INLET STUDY

SYNTHESIS REPORT:
TECHNICAL VERSION

April 1996

Ministry of
Environment,
Lands and Parks

BC Environment

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix A Saanich Inlet Study Component Reports

Appendix B Model Parameters of the Environmental Fate and Food-Chain Bioaccumulation Models

Appendix C Phytoplankton Composition of Saanich Inlet

Appendix D Carbon/Nutrient Model Description and Results

ACKNOWLEDGEMENTS

The Ministry of Environment, Lands and Parks (MELP) gratefully acknowledges the generous and dedicated support and advice of the agencies, organizations and individuals who contributed to the Saanich Inlet Study (SIS).

We wish to thank the individuals and representatives of non-government organizations who participated in the SIS Advisory Committee. These volunteers provided essential advice and challenged the Study Team to take a broad ecosystem approach. The Study process provided valuable opportunities for scientists and lay people to exchange views and information and to engage in stimulating discussion. In particular, the efforts of many people from the local First Nations greatly enhanced the SIS participants' understanding of aboriginal values and concerns.

The support and cooperation of the Institute of Ocean Sciences (Fisheries and Oceans Canada) in terms of providing facilities, staff time and substantial resources in conducting oceanographic sampling and assisting with public education has been critical to the Study.

We would like to thank the many scientists and experts from the University of Victoria, the Capital Regional District, the Cowichan Valley Regional District, and the Greater Victoria Water District who contributed considerable time, effort, and expertise as members of the SIS Technical Committee.

We would like to acknowledge and thank the hundreds of people who attended the open houses, provided input and advice, and expressed their concerns about the future of Saanich Inlet.

In preparing the final SIS Synthesis Reports (Technical and Summary Versions), the Study Team and the consultants retained by the Ministry received considerable review comments and advice from the SIS Committees and others representing a broad diversity of opinion and various fields of expertise. Ultimately, the Ministry bears responsibility for ensuring that the Study process led to a set of products that is both balanced and accurate.

Saanich Inlet Study Advisory Committee

Association for the Protection of Rural Central Saanich
Clarence Bolt

Citizens' Association to Save the Environment (CASE)
Derek Mallard

First Nations of South Island Tribal Council
Chief Cyril Livingstone

Georgia Strait Alliance
Laurie MacBride

Greater Victoria Water District
Jack Hull

Mill Bay Community League
Doug Allan, Ted Mills

Saanich Inlet Enhancement Society
Lena Lee, Michael Scott

Sidney Environmental Advisory Committee
Richard A. Bailey

Steering Committee to Save Saanich Inlet and Malahat Mountain
Mark Horne, Patricia Sloan

Tsartlip Village
Chief Simon Smith, Chris Tom

Urban Development Institute
Tony Lloyd

BC Marine Awareness Society
Oliver Brost, Darrell Bainbridge

Cowichan Valley Regional District
Mike Renning

Friends of South Cowichan
Anne Bomford

Goldstream Volunteer Salmonid Enhancement Society
Bob Peers

Malahat First Nation
Randy Daniels, Russell Harry,
John Wagner, Rod Modeste

Recreational Fishing Consultant
Jim Gilbert

Saanich Inlet Protection Society
Francis Pugh

Sierra Club of Western Canada
Bruce Cumming

Tourism Victoria
Bill Turner

Tseycum Village
Chief Vern Jacks, Tom Sampson

Victoria Golden Rods & Reels Society
Albert (Rolly) Thorpe, Allan King,
Stewart Reeder, Arnold Smith

Saanich Inlet Study Technical Committee

BC Environment,
Vancouver Island Region
Lloyd Erickson

Cowichan Valley Regional District
Derek York

First Nations of South Island Tribal Council
Chief Cyril Livingstone

Fisheries & Oceans Canada,
Pacific Biological Station
Glen Jamieson

Greater Victoria Water District
Jack Hull

University of Victoria
Louis Hobson, Verena Tunnicliffe

Capital Regional District
Laura Taylor

Environment Canada
Dave Walker

Fisheries & Oceans Canada,
Institute of Ocean Sciences
Bill Crawford, Dario Stucchi,
Frank Whitney, Bob Wilson

Fisheries & Oceans Canada,
West Vancouver Laboratory
Colin Levings

Tseycum Village
Chief Vern Jacks

Saanich Inlet Study Team, BC Environment

Prad Kharé	Director, Water Quality Branch Advisory Committee Chair
Ben Kangasniemi	Study Manager Technical Committee Chair
Alan M. Calder	Study Coordinator

DOCUMENT CREDITS

This report was written by a multidisciplinary team of scientists lead by EVS Environment Consultants. The authors utilized the findings of the six component reports listed in Appendix A as well as other information including input from the Advisory and Technical Committees. Authorship of the individual sections is as follows:

Section 1	Introduction	Beth Power (EVS)
Section 2	Water Values - A Human Perspective	Beth Power (EVS)
Section 3	Human Water Uses	Beth Power (EVS)
Section 4	Saanich Inlet Mass Balance Model	Susan Davidson (Sea Science) and Beth Power (EVS)
Section 5	Physical Oceanography	Susan Davidson, Scott Tinis and Jennifer Shore (Sea Science)
Section 6	Sediment Transport	Susan Davidson (Sea Science)
Section 7	Chemical Contaminants	Frank Gobas and Michael Z'Graggen (Frank Gobas Environmental Consulting)
Section 8	Bacterial Contaminants	Susan Davidson (Sea Science)
Section 9	Nutrients, Oxygen and Phytoplankton	Tim Parsons (UBC) and Tom Kessler (Kessler and Associates)
Section 10	Marine Life	Gary Mann (EVS)
Section 11	Geographical Summary of Saanich Inlet	Beth Power and Paul Kennedy (EVS)
Section 12	Major Findings, Conclusions and Recommendations	Beth Power (EVS)

Prad Kharé, Ben Kangasniemi and Alan Calder of the Water Quality Branch (BC Ministry of Environment, Lands, and Parks) assisted in preparing this document and were responsible for the overall management and coordination of the Study. Patricia Howie (Woodward Environmental Management), Michael Z'Graggen, Margot Daykin and John Nelson (EVS) provided valuable input and review comments. Paul Kennedy (EVS) produced the maps and Vickie Duff (EVS) produced the document.

1. INTRODUCTION

1.1 Background

Saanich Inlet is a glacially-formed fjord, 28 kilometres in length, located near the south eastern tip of Vancouver Island (Figure 1-1). The mid-channel of the inlet represents a jurisdictional boundary between the Cowichan Valley Regional District (CVRD) on the west and the Capital Regional District (CRD) on the east. The Saanich Inlet area is rich in ecological, cultural and recreational values and has approximately 40,000 residents within its watershed. An overview map of Saanich Inlet showing the watershed area and various features is provided in Figure 1-2.

The Bamberton lands fall within the CVRD and consist of approximately 650 ha (1560 acres) located thirty-two kilometres north of Victoria on the western slopes of Saanich Inlet in the vicinity of Bamber Creek. The historical zoning and use of these lands are industrial as reflected in the CVRD Official Settlement Plan. In October 1993, upon considering re-zoning of the Bamberton lands from "Industrial Use" to "Residential Use" to enable development of a town accommodating up to 12,500 people, the CVRD sought approval for bylaw and zoning amendments by the Minister of Municipal Affairs. Under the Municipal Act, the Minister has the option of approving a bylaw with or without conditions, rejecting the bylaw, or asking for more information. Prior to making a decision on the proposed bylaw changes, the Minister of Municipal Affairs retained consulting engineer Douglas MacKay to coordinate an independent evaluation of the bylaw amendment request and to examine issues raised by the proposal for urban development of the Bamberton lands.

In his final report, MacKay recommended that the bylaws not be amended until the Ministry of Environment, Lands and Parks carried out a comprehensive examination of the assimilative capacity of Saanich Inlet sufficient to assess a permit application for the treatment and discharge of sewage from the proposed development (Section 1.6). It was further recommended that the bylaw changes not be approved until a growth management strategy was developed by the CVRD with linkages to the CRD in sufficient detail to provide a regional context for appropriate development of the Bamberton lands.

Upon receipt and consideration of the MacKay report and recommendations (MacKay, 1994), the Minister of Municipal Affairs reserved judgment on the bylaw amendment until:

a) The Ministry of Environment, Lands and Parks (MELP) completed a technical assessment of the capacity of Saanich Inlet to assimilate discharges of treated sewage and stormwater from surrounding urban development without environmental degradation; and

b) the CVRD has made significant progress towards development of a growth strategy for the regional district.

In July 1994, the Province of British Columbia announced three separate but coordinated review processes.

- Saanich Inlet Study
- CVRD Regional Growth Management Study
- Provincial Environmental Review Process

The Environmental Review Process is following the procedures set out in the B.C. Environmental Assessment Act. Under the Act, environmental, economic, social, health, cultural, and heritage effects of the proposed development are to be assessed. The results of the Saanich Inlet Study, in addition to the Regional Growth Management Study, will contribute to baseline information considered under the Provincial Environmental Review of the Bamberton Development Proposal.

1.2 Approach of the Saanich Inlet Study

The Water Quality Branch, Ministry of Environment, Lands and Parks is responsible for conducting the Saanich Inlet Study. Major support in planning and implementing the study has been provided by the Institute of Ocean Sciences (Fisheries and Oceans Canada). To ensure broad input to the study from the stakeholders (i.e., public, First Nations, the federal government, regional government and the scientific community), a public Advisory Committee and a Technical Committee were established to help guide in the study (see acknowledgements for details).

The Advisory Committee provided input from a broad spectrum of stakeholders who were invited to comment on the procedures used to meet the study objectives and on draft findings. The Technical Committee was composed of scientific and technical experts from government agencies and universities who were invited to provide information, assistance and scientific advice. A list of all the representatives is provided in the acknowledgements.

During the initial meetings of these two Committees, the study terms of reference were discussed and finalized as follows:

> *"The purpose of the study is to determine the sensitivity of Saanich Inlet to contaminants and marine habitat disturbances from urban and rural development, and to determine the capacity of the inlet to assimilate these contaminants and marine habitat disturbances without environmental degradation. Contaminants to be considered include those associated with sewage effluents, urban and rural storm drainage and agricultural runoff."*

Under the Saanich Inlet Study, a series of complementary projects were conducted, as described in Appendix A. These included oceanographic studies, water and sediment quality investigations, intertidal surveys, workshops and open houses. Figure 1-3 depicts the study process and the sequence of activities leading to this report. The authors want the readers to recognize that this report and the conclusions and recommendations presented here contain only some highlights from the Saanich Inlet Study, which is essentially a baseline study. This report does not fully describe the depth of information in some areas and the lack of detail in other areas. Readers are urged to review the reports described in Appendix A for more detail on specific topics.

1.3 Concept of Assimilative Capacity

Assimilation refers to processes which include dilution, inactivation, metabolism, and breakdown. These may be physical, chemical or biological processes. Assimilation is used here in a very broad sense and is intended to apply to the resilience of natural systems as well. Assimilative capacity is the threshold beyond which natural processes cannot accept wastes and disturbances without environmental degradation.

Assessment of assimilative capacity and sensitivity for Saanich Inlet was a three stage process:

1. *Measures of environmental quality were selected* in context with water values and uses. In Saanich Inlet, there are numerous and broadly reaching water values and uses (Sections 2 and 3) for which protection is desired. Therefore, a number of measures of environmental quality were selected in the early stages of the Saanich Inlet Study (i.e., contamination by chemicals, bacteria, and nutrients and assessment of marine life status).

2. *For each measure of environmental quality, criteria or conditions where environmental quality is degraded or diminished were defined (i.e., assimilative capacity exceeded for that component).* Where possible, these are linked to degradation of water uses or marine resources. For each measure of environmental quality (Sections 7 to 10), comparisons of the present status to the criteria are made. This information is also summarized geographically (Section 11).

3. Finally, the information compiled for each component is integrated in a discussion of overall assimilative capacity (Section 12). The Advisory Committee strongly recommended that the final assessment of assimilative capacity be integrated, as it would be inappropriate to make a final determination of assimilative capacity based on any one measure alone; therefore, (1) cumulative effects are discussed in Chapter 12, and (2) the summary version of the Saanich Inlet Synthesis report focuses on overall assimilative capacity.

In fulfilling the terms of reference for the study, the concept of assimilative capacity is applied as an aid in describing and, in some cases, quantifying the sensitivity of Saanich Inlet to human influences. It is not applied for the purpose of promoting the use of the environment for disposal of wastes. The study has taken a broad ecosystem approach in that water and sediment contaminants, nutrient enrichment, sensitive biota, critical habitat, public values and First Nations values throughout the watershed have been considered. The present state of these resources and values has been assessed and their sensitivity or capacity to sustain further perturbations determined. It is not within the scope of the study to recommend the degree to which any remaining assimilative capacity can be exploited.

1.4 Concept of Precautionary Principle

In this assessment of assimilative capacity, the "precautionary principle" was applied, which is defined by MELP as: *"Where there are threats of serious or irreversible damage, the lack of full scientific uncertainty shall not be used as a reason for postponing measures to prevent environmental degradation"* (MELP, 1995a).

In preparation of this report, there was much discussion about the use of models (Section 4) and the need for assumptions and how this relates to the precautionary principle. Models help build on existing data, organize information and describe processes. Science also uses models to make predictions, which was necessary because one of the objectives of the Saanich Inlet Study was to assess assimilative capacity. Given this objective, models were used in combination with other approaches to predict the consequences of addition of various environmental stresses. To examine different scenarios, various model assumptions were selected. The important point is that the assumptions are grounded in reality or were selected using the precautionary principle, so that model predictions are "worst case".

For example, the oceanography model used assumptions that likely over-estimate water residence times. Therefore, modelled sediment chemistry, which uses the oceanography model results, is likely to be higher than would actually occur. The level of conservativeness is proportional to the degree of uncertainty in the nutrient model. For instance, as our understanding of nutrient systems in Saanich Inlet is relatively good, the assumptions that were made were more realistic.

Each technical section includes subsections which describe the assumptions made and our certainty in the work done on each component, as well as any certainty and data gaps. This information was used to describe the level of confidence in the findings of the Saanich Inlet Study.

It is recognized that there are limitations in the time-scales that humans are capable of understanding. Ecological systems are naturally variable and change over time, and not all change is "bad". From a geological time scale perspective our data go back only months, years, and in some cases, decades to describe Saanich Inlet. The oral history of First Nations provides information on a somewhat longer time scale. Clearly Saanich Inlet was not always as we see it today, and as recently as the last ice age was buried under a glacier, nearly devoid of plants and animals.

However, world-wide effects such as global warming and ozone depletion are rapidly being recognized as important factors that add uncertainty to decision-making. Models used by the Intergovernmental Panel on Climate Change (IPCC) estimate that the observed doubling of CO_2 concentrations from pre-industrial levels could increase average global temperatures by 0.8 to 3.5°C by the year 2100 (Anon., 1995). The IPCC suggests that global warming will lead to major alterations in weather systems. Some climate change models suggest a rise in average temperature of 7°C in the winter and 4°C in the summer for B.C. over the next 100 years. Related to this, rising sea level could cause major coastal flooding and erosion, damaging estuaries, property, and other coastal resources. Should these model predictions hold, the implications for the ecology of coastal areas such as Saanich Inlet will be profound.

Policymakers are faced with responding to the risks posed by anthropogenic emissions of greenhouse gases in the face of significant scientific uncertainties (IPCC, 1995). It is appropriate to consider these uncertainties in the context of information indicating that climate-induced environmental changes cannot be reversed quickly, if at all, due to the long time scales associated with the climate system. Policymakers will have to decide to what degree they want to take precautionary measures by mitigating greenhouse gas emissions and enhancing the resilience of vulnerable systems by means of adaptation. Delaying such measures may leave a nation or the world poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences (IPCC, 1995). Climate change and a rise in sea level or changes in storms or storm surges could result in the erosion of shores and associated habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, a change in the pattern of chemical and microbiological contamination in coastal areas, and increased coastal flooding (IPCC, 1995).

The approach used in the Saanich Inlet Study assumes that conditions in Saanich Inlet do not change dramatically. It was not designed to evaluate the impacts of large-scale (e.g., global warming, ozone depletion) or catastrophic events (e.g., earthquakes, turbidity currents, landslides, inversions of the bottom anoxic layer in Saanich Inlet).

1.5 Approach of Synthesis Report

It is important to recognize that this document is not a prescription for Saanich Inlet's health; the correct analogy is closer to a diagnosis of its present state and sensitivities. This study synthesizes available information and makes judgements to describe the sensitivity of Saanich Inlet to the best of the Study Team's ability.

The approach taken to the Saanich Inlet Synthesis Study can be described at two levels: baseline and interpretation. This report takes the findings of approximately ten baseline investigations conducted under the Saanich Inlet Study, conducts various analyses of assimilative capacity in some key areas and then synthesizes the information into an overall interpretation of the assimilative capacity and sensitivity of Saanich Inlet.

The Ministry of Environment, Lands and Parks strategic vision is: "An environment that is naturally diverse and healthy, and enriches people's lives" (MELP, 1995a). This view is fundamental to the approach taken in this study. The study team has sought to identify sensitive biota and habitats, and has estimated quantities of contaminants and nutrients that would pose a risk to the ecosystem or to human uses or values of Saanich Inlet. Where environmental problems were found to exist, remedial actions are recommended.

Land use and resource management decisions must be guided by knowledge of what kinds of activities and disturbances the inlet is most sensitive to. This knowledge allows decisions to made regarding solving the most important existing problems and helps in aiming preventative actions in the most productive manner.

It is important to recognize that the synthesis report is essentially a series of static snapshots of what in nature is a dynamic process involving not only marine life, but also terrestrial, atmospheric and anthropogenic physical and chemical processes. This underlies the importance of synthesizing all sources of information, including anecdotal and qualitative information, to describe the changes in Saanich Inlet over recent history. This synthesis is an ambitious undertaking, in that it is one of the first attempts to bring together in one report such a wide range of information. In the process we believe we have created a document that is more than the sum of its parts. As Saanich Inlet is one of the best studied fjords on the B.C. coast, we have the opportunity to use this information to make wise decisions about its management.

For specific components of the Saanich Inlet Study, the approach selected was chosen to suit the subject of interest. A number of discussions with the Advisory and Technical Committees focused the application of qualitative and quantitative methods to determine the assimilative capacity and sensitivity of Saanich Inlet. It was decided that:

- The method selected for a specific component should suit the subject.
- More than one method could be applied to assess the assimilative capacity or sensitivity for any one component of the Saanich Inlet Study and that these methods should be summarized in the report for each component.
- Qualitative and quantitative methods were considered to have equal weight and provide complementary information. *Essentially, the total is believed to be greater than the sum of its parts.*

For example, to synthesize information on chemical contaminants in Saanich Inlet, quantitative modeling methods were applied. Chemical investigations tend to be data-intensive and therefore, methods to assess assimilative capacity involve numerical models. However, to synthesize information on cultural use, qualitative approaches were used to assess sensitivity, relying largely on oral history of First Nations, the Report on First Nations Consultation (Simonsen et al., 1995) and the Open House Report (Howie, 1995). Some components used a combination of quantitative and qualitative methods; for example, descriptions of Saanich Inlet use for recreational purposes are described qualitatively and quantitatively (e.g., results of questionnaires were tabulated). Together, these methods allow a determination of assimilative capacity related to recreation. In the end, the various approaches taken to assess each component of Saanich Inlet were integrated to assess the assimilative capacity and sensitivity of Saanich Inlet to the various stressors on a geographical site-specific basis.

The process of preparing the Saanich Inlet Study Synthesis Report should be viewed as one of the deliverables. The interaction and cooperation between scientists and lay people greatly strengthened the study. Public input and involvement on the committees and open houses demonstrated there exists a feeling of stewardship for the resource - Saanich Inlet. It is hoped that those involved will continue to share the responsibility of ensuring corrective and protective action follows this study.

1.6 Regulatory Background on Wastewater Discharge to Saanich Inlet

The MacKay report (1994) charged the Saanich Inlet Study with carrying out an examination of the assimilative capacity of Saanich Inlet sufficient enough to assess a permit application for treatment and discharge of sewage from the proposed development. By implication, this means examining the potential impacts of a point source discharge for wastewater (i.e., a sewage outfall). Therefore, the Province included bacteria (Section 8) and nutrient (Section 9) modelling components in the Terms of Reference for the Saanich Inlet Synthesis Study, as these are two key issues related to sewage discharge, among others. It is important to put these examinations in the regulatory context for wastewater discharge to Saanich Inlet, as outlined below. These present regulatory policies have been driven by both (1) a lack of appropriate information to assess the potential effects of effluent discharge into the inlet, and (2) public opposition to wastewater discharge in Saanich Inlet.

The Province of B.C. has informally discouraged point source discharges into Saanich Inlet, based on a precautionary approach in the absence of detailed information. This position is recognized and supported by both the Capital and Cowichan Valley Regional Districts (the Ministry of Environment, Lands and Parks Vancouver Island Regional Office [Finnie, pers. comm. 1995], the CRD [Taylor, pers. comm. 1995], and the CVRD [York; pers. comm. 1995]).

The only authorized point source discharge into Saanich Inlet is a secondary treated sewage discharge from Brentwood College School into Mill Bay (Waste Management Permit No. PE-1640) which was recently upgraded to include the hydroxyl process. A maximum discharge of 105 m^3/day was first authorized on December 11, 1973. Authorized maximum discharge concentrations of suspended solids and BOD are 60 mg/L and 45 mg/L, respectively.

Point source discharges to Saanich Inlet were addressed in a 1966 study of sewage disposal in the greater Victoria area cited by the CRD. The study recommended that untreated sewage not be discharged to Saanich Inlet. This recommendation was adopted as operational practice and has evolved into the CRD's present position that the discharge of treated sewage into the inlet is considered inappropriate. However, this issue has not been considered by the CRD board and the position is therefore not considered formal CRD policy.

The Cowichan Valley Regional District's official position regarding the discharge of point source wastes into Saanich Inlet is contained in the current Official Settlement Plan for Mill Bay/Malahat, Electoral Area "A", which was originally approved in 1986. Policy 4.15 of the Settlement Plan states that the "emission of effluent from sewer outfalls into marine waters, within Electoral Area "A", shall be prohibited. Over time, those existing sewer systems with outfalls into the waters of the Mill Bay/Malahat area should be upgraded or eliminated so that the discharge of effluent into the marine environment may be discontinued." Tertiary treatment was not considered at the time the Official Community Plan was prepared, but that does not preclude future consideration (Johnson, pers. comm. 1995).

The Province's position stems from the Pollution Control Board's refusal (believed to be a decision of the Board on December 13, 1966) to allow the Corporation of the District of Central Saanich to discharge sewage into Brentwood Bay (Saanich Inlet). Rationale for this position was based on a lack of understanding at the time for how a sewage discharge would impact a confined anoxic fjord. Concerns included the potential impacts of the discharge on the balance of the inlet ecosystem, and on the anoxic layer itself (a fresh water effluent discharge at depth might cause vertical displacement of the anoxic layer, putting fish and other marine organisms at risk). The Pollution Control Board's refusal to authorize Brentwood Bay's sewage discharge into Saanich Inlet forced connection of the discharge to the Central Saanich sewerage system and conveyance to the Central Saanich sewage treatment plant (i.e., the sewage is pumped across the Saanich Peninsula for discharge into Haro Strait).

1.7 Document Organization

This document is organized into a total of 14 sections. Sections 2 to 3 set the scene from the human perspective in terms of values and specific uses. Sections 4 to 6 describe the oceanographic and sedimentation processes required to support analyses of assimilative capacity present in the following sections. Sections 7 to 9 describe the detailed quantitative analyses used to estimate assimilative capacity for chemical contaminants, bacterial contamination and nutrients. Section 10 focuses on marine biota and presents the status of marine species and key habitats; the sensitivity of key species and habitats is described and recommendations for remedial action and protection are given. Section 11 takes key findings presented in the report and integrates them from a geographical perspective. Section 12 summarizes the major findings, conclusions and recommendations. A glossary to define language (Section 13) and references cited in the document (Section 14) are provided.

Figure 1-1 Saanich Inlet general setting. Contours are marked every 100 m (Source: Drinnan et al., 1995).

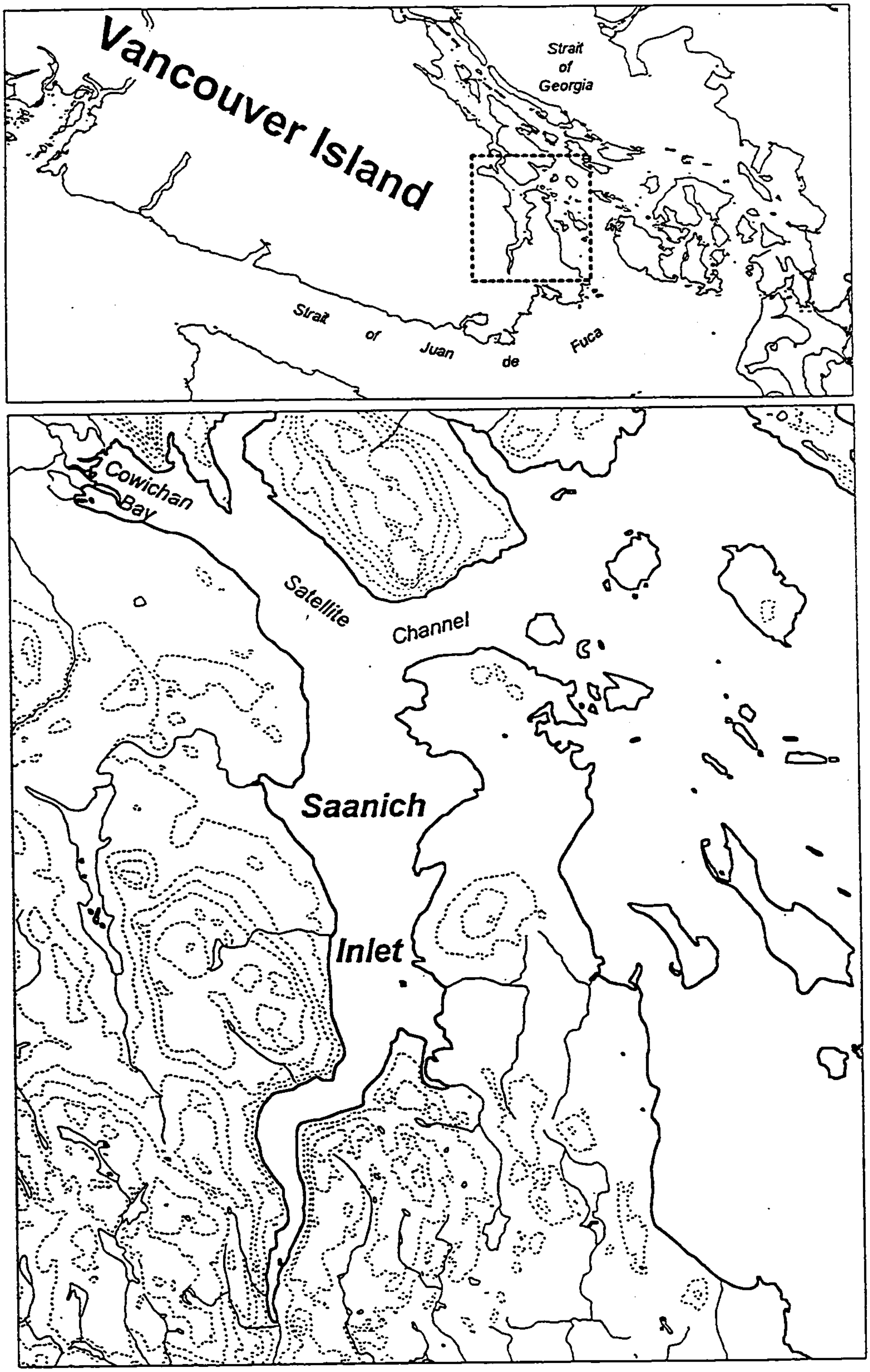


Figure 1-2 Saanich Inlet watershed area.

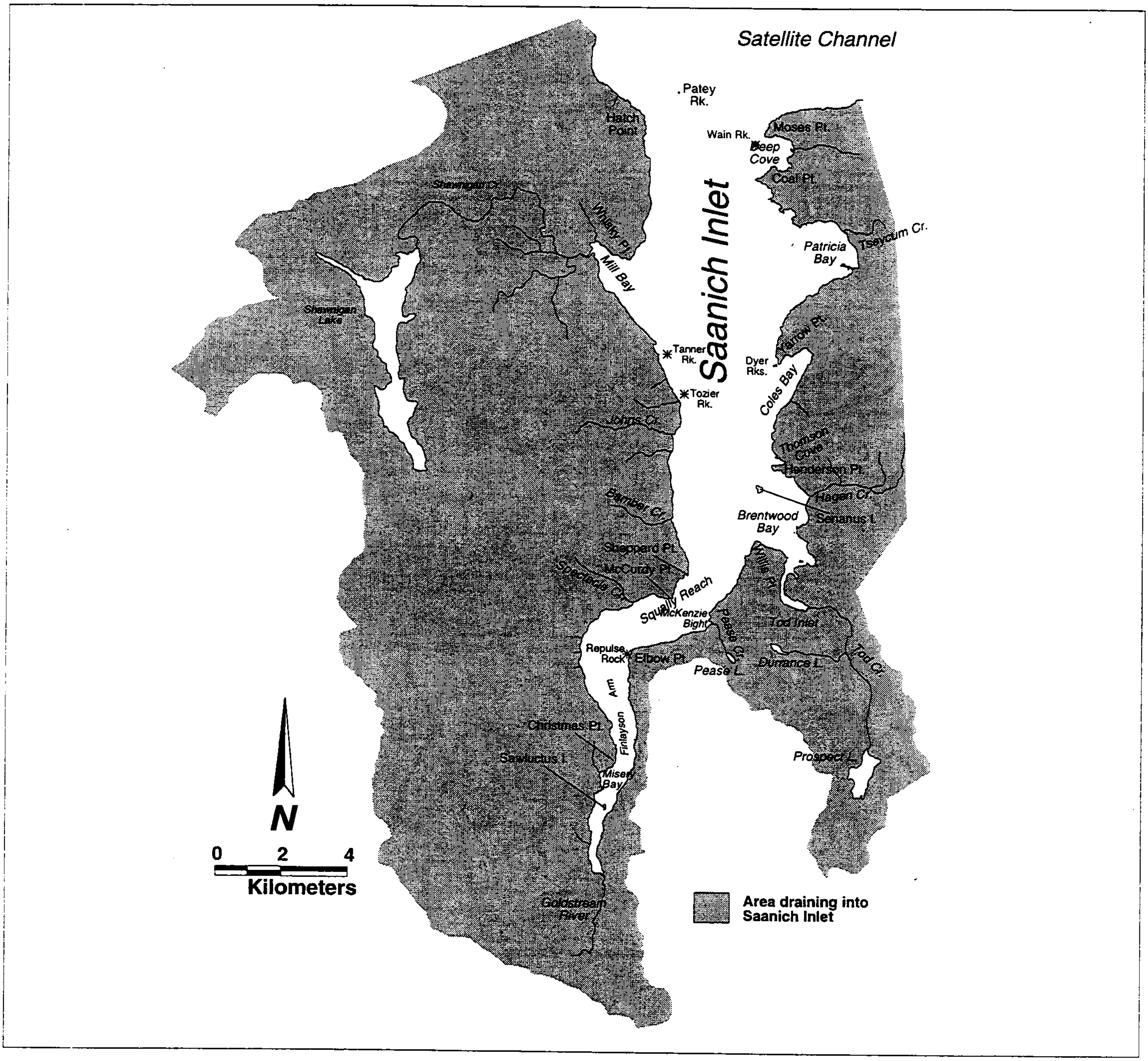
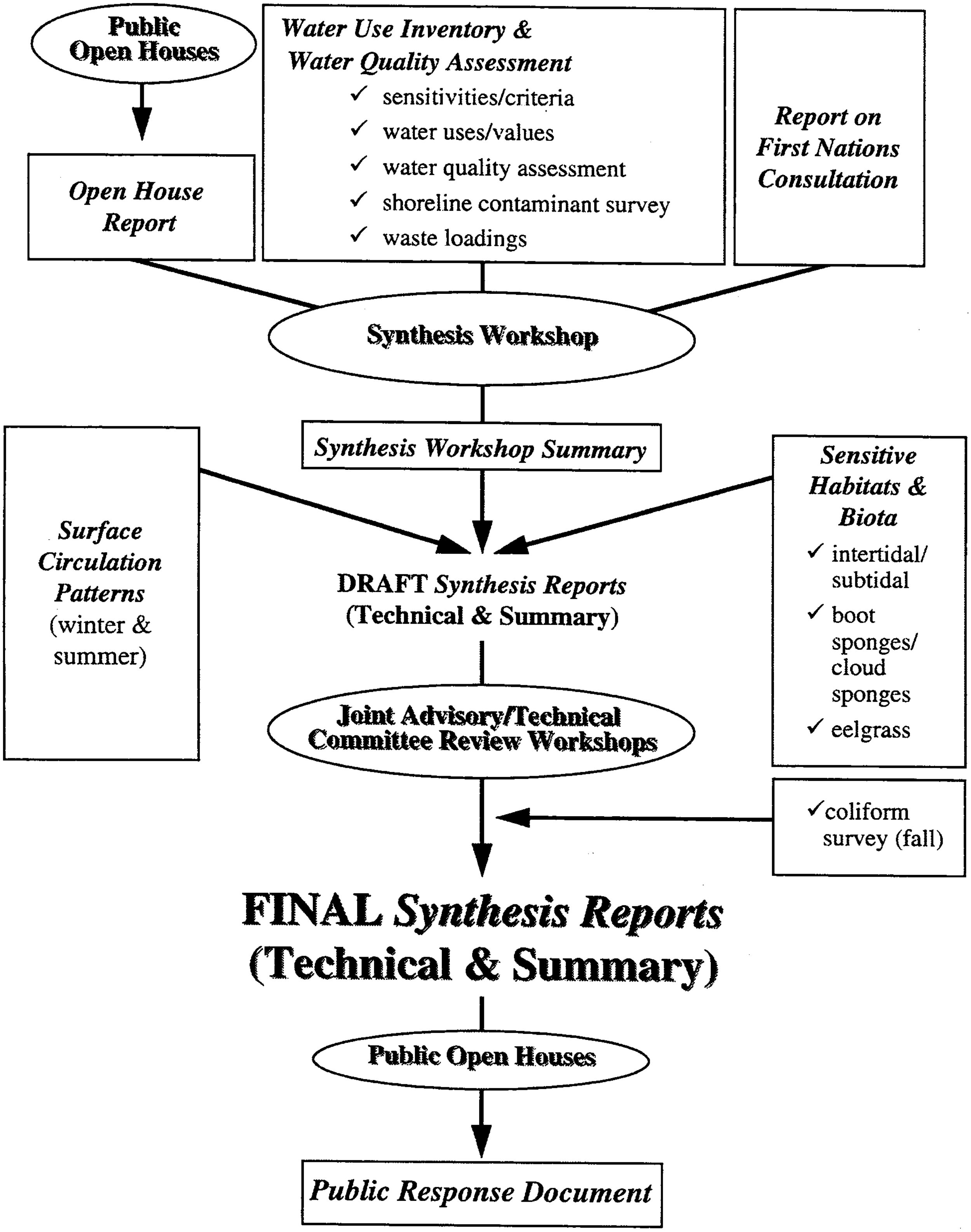


Figure 1-3 Saanich Inlet components and process



2. WATER VALUES - A HUMAN PERSPECTIVE

2.1 Overall Background

For the purposes of this document, "water value" is regarded as the human affinity for water and its environs. The quantitative and scientific analysis which comprises the majority of the Saanich Inlet Study cannot be considered outside of the subjective human context of public values. The intrinsic non-human values are reflected in other sections. In preparing the Saanich Inlet Study Synthesis report, it became apparent that consideration of human water use alone (i.e., in the standard way of addressing recreation and fishing in general as outlined in Drinnan et al. [1995]), was not enough to capture the importance of Saanich Inlet to the people who live on and value the inlet's environment. Therefore, this section on water values for humans was added to attempt to characterize this important aspect of Saanich Inlet. Water uses are defined and discussed in the following section (Section 3).

Human values for Saanich Inlet span a range of perspective and levels of emotion. Comments from the initial January 1995 Saanich Inlet Study Open Houses mention "feeding the soul", and discussions with First Nations representatives leave one with a feeling of their close association with the water.

Standardized methods to measure the loss of human values as a result of degradation do not exist. Most often, this question does not get posed until thresholds or boundaries have already been crossed. To some degree, this has happened in the communities surrounding Saanich Inlet.

We have not attempted to develop a method to measure the sensitivity of human values to degradation of Saanich Inlet. Rather, we summarize what we have heard and reviewed, to ensure these views are a part of the overall assessment of Saanich Inlet. Information was compiled from the following sources:

- Questionnaire results from Open House consultations and Open House report
- Report on First Nations Consultation
- Discussions with Saanich Inlet Advisory Committee members over the course of this study
- Copies of official community plans (OCPs) and other planning documents for jurisdictions bordering on Saanich Inlet

- Interviews with representatives of local First Nations

Based largely on the Open House Consultations and discussions with people who live near Saanich Inlet, water values are discussed from two overlapping perspectives:

- Cultural and aesthetic values
- Environmental values

2.2 Cultural and Aesthetic Values

For the purposes of this document, cultural value is regarded as the affinity humans feel for Saanich Inlet, as related to their cultural identity. The term "cultural" refers to First Nations cultures that live on the shores of Saanich Inlet, but the "westcoast" culture developed by more recent inhabitants is also dependent to some extent on Saanich Inlet. For instance, the lifestyle of some inhabitants is dependent on aesthetic values such as "solitude" and "wilderness". These kinds of terms were used at the Open Houses, indicating the importance of Saanich Inlet to the local residents from all cultural backgrounds. Therefore, water values to both First Nations and westcoast culture are discussed, recognizing they share some common ideas. As described by a Saanich Inlet Study participant: *"Saanich Inlet has been and continues to be essentially linked to our sustenance, both physical and spiritual. Its health is central to our present and future."*

2.2.1 First Nations Culture

First Nations people populated Saanich Inlet from one end to the other and right around all of the shores and bays (Poth, 1983; Simonsen et al., 1995). There were three main nations that lived in Saanich Inlet at one time or another during the year: Saanich, Malahat and Cowichan. Saanich people also inhabited many of the Gulf Islands and most of the San Juan Islands.

Since the Saanich people named the places they knew and used, the place names represent the extent of traditional territory (Poth, 1983). A review of place names described in Poth (1983) and Simonsen et al. (1995) demonstrates the cultural uses and values of Saanich Inlet by First Nations. Place names identify historical resource use and areas within the inlet of contemporary significance to local First Nations. Translation from the Saanich language to English presents some difficulties because a language is a way of thinking, or viewing the human experience of the world, as much as it is a way of communicating (Poth, 1983). In the early stages of the preparation of this document, discussions with First Nations representatives made it clear that the oral history of the First Nations was an important record of the status and history of Saanich Inlet.

With respect to religious worship within the inlet, some physical features appear to be important. As described in Simonsen et al. (1995), Saanich Inlet as a whole is considered by many to be a sacred place. Claxton and Elliott (1994; as cited in Simonsen, 1995), state: *"...To have connection to the land, according to ancient beliefs and teachings, is the Saanich identify."*

Loss of Privacy and Solitude

Based on discussions with First Nations representatives and Simonsen et al. (1995) there is a general invasion of privacy at sacred places and other traditional-use areas. These areas are largely documented in text and maps presented in Simonsen et al. (1995). It should be noted that archaeological sites are protected by law and unauthorized disturbances to such areas is an offence.

An issue of concern is the desecration of grave islands within Saanich Inlet. Virtually every small rocky outcrop and island within the inlet was used as a grave site by either the Saanich or Malahat Nations. Children were told not to put their canoes up on the small islands within the inlet out of respect for the island graves (Simonsen et al., 1995). These graves sometimes consisted of canoes which were placed on the islands (Appendix B from Simonsen et al., 1995). When the Mill Bay ferry service began, a directional flag was erected on Senanus Island, which was perceived by some individuals as an insensitive measure. A general consensus among First Nations representatives consulted by Simonsen et al. (1995) is that the preservation of important ceremonial areas must be given a high priority by First Nations.

With regard to solitude, this intangible feeling is inversely proportional to the number of residents in the vicinity of Saanich Inlet. As population levels rise, particularly since settlement by Europeans and others, solitude becomes threatened. Cultural solitude for many First Nations individuals has been degraded or lost.

Loss of Access to Cultural Sites

Many sites of cultural interest to First Nations are located near commercial or residential development and have been directly impacted by activity. In some cases, entire sites have been destroyed. Comments in some site records indicate that 10 to 90% of intact deposits have been destroyed by either natural or human processes (Simonsen et al., 1995).

Traditional structure of Saanich culture is threatened due to the loss of cultural traditions associated with natural resource use, spiritual activities and lost opportunities for aboriginal youths to experience traditional activities.

With respect to the waters of Saanich Inlet (see Section 3.2), water quality concerns (e.g., bacterial contamination) of Saanich Inlet restricts swimming by First Nations and others. Before water quality was considered degraded, youths partaking in initiation ceremonies would swim in Saanich Inlet early each morning.

Some religious ceremonies of the Saanich and Malahat involve ritual bathing in fresh water tributaries in order to gain power and strength for cleansing purposes (Simonsen et al., 1995). However, as a result of urban development there has been a loss of sacred bathing pools in tributaries to Saanich Inlet. This is due to lack of access and to low or no flow conditions in some tributaries. Ritual bathing still occurs in some parts of the Saanich Inlet watershed.

There is a role for traditional knowledge in the expression of societal values (Environment Canada, 1994a). The level of interest shown by First Nations representatives in the Saanich Inlet Study is indicative of the value they place on Saanich Inlet. As their culture has been and is so closely tied to the water, it is the observation of the study team that their tolerance for environmental degradation is low.

2.2.2 Westcoast Culture

It is difficult to describe what westcoast culture and related aesthetic values really mean, but they are a defining part of living on the coast. The water is a strong attraction for many inhabitants in B.C., as evidenced by human population distribution, historical and present day. Many facets of the westcoast culture (e.g., recreational pursuits) are closely linked to the specific features of the surrounding natural environment. However, the natural environment is also recognized as an essential source of spiritual well-being, providing a sense of serenity and natural beauty.

It is also realized that a resource (i.e., Saanich Inlet) can have value for any given individual even if it is not "used". Although difficult to monetize, a variety of economic instruments have been developed which strive to quantify such non-consumptive uses. In other words, value can be assigned to Saanich Inlet for just knowing that it exists. This fact has been demonstrated in natural resource damage case law in the U.S. Citizens are interviewed to determine how much they would pay to halt damage or return a habitat to health. An average value is determined, and this is multiplied by the number of people in the community to determine a total value of the resource for just knowing that it is healthy. Value due to lost use (e.g., fishing or recreational pursuits) or depreciated property values is also additive.

Saanich Inlet Study Open House participants reported having been interested in Saanich Inlet for an average of 22 years (this period ranged from 1-75 years). Overall, the natural beauty, scenery, views, and plant and animal life were reported as being more highly valued than recreational uses (e.g., boating, fishing, hiking, etc.) (Howie, 1995).

To demonstrate the will of each community with respect to issues that have the potential to impact Saanich Inlet, selected text from Official Community Plans (OCPs) for jurisdictions bordering Saanich Inlet and comments from other correspondence have been compiled in Table 2-1. Based on the high level of involvement in the Saanich Inlet Study and in feedback from the Open Houses, the enjoyment of Saanich Inlet has become impaired for some residents in the Saanich Inlet watershed.

2.3 Environmental Value

By environmental value, we mean the value that society places on the Saanich Inlet environment. Based on Howie (1995) and various OCPs, public opinion seems to be that water quality and marine life are more sensitive to change and a greater cause for concern than loss of human uses. Environmental value is embedded in a number of scientific measurements that we can make to describe the environmental quality of Saanich Inlet. Such measurements are described in Sections 5 to 10. In meeting some of the environmental quality criteria, human values and uses may also be implicitly protected. For example, sediment criteria values are designed to protect aquatic life. MELP policy is that where uncertainty exists, the precautionary principle should be applied.

Habitat conservation was the primary recommendation of the recent report on Shared Marine Waters (British Columbia/Washington State Marine Science Panel, 1994). Drinnan et al. (1995) describe "special habitats" within Saanich Inlet which are relatively rare in B.C. Unusual/unique species records are also summarized, demonstrating unusual environmental values in Saanich Inlet. During the Council of Resources and the Environment (CORE) process for Vancouver Island, the majority of Saanich Inlet was designated as "regionally significant land". This means that it is a corridor of land that links protected areas and has special significance because of its sensitive environmental, recreational and cultural values. There has been a recent shift in environmental management and the desires of society towards preservation of biodiversity. The vision of the Ministry of Lands and Parks is: *"An environment that is naturally diverse and healthy,* *and enriches people's lives."* (MELP, 1995a). This recognizes that there is an intrinsic value in the environment. The Canadian Biodiversity Strategy (Biodiversity Working Group, 1994) notes that governments cannot act alone to ensure the conservation of biodiversity and the sustainable use of biological resources, and calls for support at the individual level. Strong linkages between biodiversity issues and atmospheric change were emphasized at the Earth Summit in 1992, when the Convention on Biological Diversity and the Framework Convention on Climate Change were signed by most of the United Nations countries. In Canada, the effect of human settlement on biodiversity is evident in the southern part of the country, where development has been concentrated, including Southern Vancouver Island. This is also discussed in Section 10 in the context of marine life.

In many jurisdictions, there has been a shift towards more holistic "ecosystem" or "watershed" management approaches. Goals and objectives for ecosystem health are established and these take into account the will of local communities. To some degree this has been done under the auspices of the Saanich Inlet Study and through preparation of OCPs, as described previously.

Table 2-1 Compilation of comments from OCPs, newsletters and correspondence.

Jurisdiction	Relevant Text from Document	Reference
Mill Bay	OCP participants most commonly mentioned the following values and themes: •maintain rural character of the area •stop suburban/commercial sprawl & highway strip development •allow only environmentally-sensitive development •protect the land base of agriculture & the forest industry •encourage economic development (local industry, small business & tourism) •solve sewage problems •increase greenspace designation, parks, pedestrian something & recreation facilities	Mill Bay Messenger (June 1995)
Cobble Hill	The community plan provides guidelines for the management of shore zone areas by encouraging water surface uses where they are co-ordinated with upland uses and where they are compatible with other water surface uses.	Cobble Hill OCP (undated)
	There are several areas in Cobble Hill which represent a significant public resource simply because of their high visibility.	
Mill Bay/Malahat	Environmental Protection •The preservation or improvements of the air and water resources through the upgrading of waste disposal methods within the Regional District. •To control land uses in areas subject to floods, landslides or other anticipated disasters in order to protect life and property. Recreation Areas •To encourage and assist in providing where possible, the recreational areas for the Region's citizenry and visitors. •To conserve open space, protect natural and scenic features and preserve wildlife resources.	Mill Bay/Malahat OCP (May, 1986)

Table 2-1 (continued)

Mill Bay/Malahat (continued)	One of the Electoral Area's greatest assets is its physical resource base, including productive agricultural holdings, forested uplands, scenic coastal areas, and other natural landscape features.	Mill Bay/Malahat OCP (May, 1986)
	The unique natural environment of the Cowichan Valley is a major contributing factor to the quality of life and the visual attractiveness of the area for residents and visitors.	
	As the degree of human activity intensifies, so does the threat of permanently altering and destroying valuable environmental features. It is essential to understand the sensitivities of these resources so that future development may be accommodated without disrupting the area's healthy, liveable and aesthetically pleasing natural setting. Equally essential is the need to preserve those precious features which recall the past. It is not the intent of this plan to prohibit development, but instead to guarantee compatibility with the environment.	
	Environmental resources of critical concern include: a) *Environmentally sensitive areas* which support important plant and animal communities. b) *Hazard lands* which pose a possible threat to human life or property. c) *Recreational resource* areas which offer significant outdoor recreational potential. d) *Scenic views and landscapes* which are distinctively representative of the region and the settlement area. e) *Heritage sites* which provide a valuable record of human settlement and activity significant to the study of local history.	
	To buffer watercourses, lakes, and other wetlands from undesirable forms of development so as to maintain their environmental quality and aesthetic appeal. To recognize the importance of the marine and foreshore environment to the quality of life of Mill Bay residents and to protect them from detrimental use and the negative aspects of indiscriminate development.	

Table 2-1 (continued)

Mill Bay/Malahat (continued)	POLICY 4.19: Development of hazard lands shall be prohibited unless supported by an environmental assessment and a sealed engineering study guaranteeing that the development will not result in the detriment of the environment, possible property damage or loss of life on the site or in the surrounding area.	Mill Bay/Malahat OCP (May, 1986)
	The overwhelming views along the Malahat, the pastoral valleys and rolling hills, the forested mountain slopes and the magnificent variations along the coastline offer a vast repertoire of scenic delights. The scenery is a major factor in attracting both tourists and residents to the area and it must be treated as a resource.	
The Corporation of the District of Central Saanich	The Capital Regional District be advised that Central Saanich Council is opposed to the notion of discharging wastewater and storm water into the Saanich Inlet;	Various correspondence on letterhead (1991 - 1992)
	...that Council advise the Provincial and Federal Governments, and all other levels of Government adjacent to the waters of the Inlet, that Council is supportive of the efforts to establish National Marine Park (Reserve) status for the waters of Saanich Inlet.	
	Accordingly, the Council respectfully requests the Government of Canada to apply its support for the concept of protecting biodiversity and rare species to the Saanich Inlet and adjacent lands by designating this area as protected.	
The Corporation of the District of Central Saanich	MOVED BY ALDERMAN TOBIN SECONDED BY ALDERMAN BOX That it be recommended to Council, that with respect to the preservation of the Saanich Inlet, the Environmental Advisory Committee be requested to assess the proposed W3 (Water) Zone for Tod Inlet for possible designation as an ecological sanctuary. CARRIED UNANIMOUSLY	Planning and Zoning Committee Meeting Minutes (June 8, 1992)

Table 2-1 (continued)

The Corporation of the District of Central Saanich	WHEREAS the District of Central Saanich has supported the action of the Saanich Inlet Protection Society in their efforts to protect the waters of Saanich Inlet; AND WHEREAS the Saanich Inlet is a unique and special body of water with limited flushing capability; THEREFORE BE IT RESOLVED THAT the District of Central Saanich requests the Provincial Minister of Environment, Lands and Parks to protect the waters of the Saanich Inlet by declaring the Inlet a Provincial Marine Park; AND BE IT FURTHER RESOLVED THAT the Provincial Ministry of Environment, Lands and Park work with those governments adjoining the Inlet, to develop a management plan.	Resolution #233.93 (February 15, 1993)
Province of B.C., Minister of Municipal Affair (Darlene Marzari)	...protection of the quality of inlet waters remains a paramount consideration.	Letter to President of the Citizens Association to Save the Environment (June 30, 1994)

3. HUMAN WATER USES

3.1 Background

For the purposes of this document, "water use" is regarded as human requirements of a water resource. Use of water by non-human organisms is covered elsewhere (Section 10). Human interaction with marine water has a history as long as our existence on earth. Human use of water spans from marine resource consumption to recreation to commerce.

In Saanich Inlet, the earliest human use reported was by the aboriginal Coastal Salish people. Their use of Saanich Inlet continues to the present day. Human use has intensified in the past century, with a wider range of water uses and higher rates of use.

Public input on values and uses for Saanich Inlet were not restricted to water uses; however, for the purposes of this document, only water-based uses will be discussed. Section 2 discusses some of the "bigger picture" values for the Saanich Inlet area and the human water uses here should be viewed in that context. The reader is referred to Saanich Inlet Study component reports for complete documentation of public and First Nations input on uses and values (Howie, 1995; Simonsen et al., 1995).,

Human use of Saanich Inlet spans a range of activities. Based largely on the January 1995 Open House consultations, the various water uses include:

- First Nations marine resource use.
- Recreational use.
- Educational use.
- Commercial use.

Standardized methods to determine the sensitivity of all aspects of these uses to degradation do not exist. There are, however, several repeatable scientific methods to employ in determining the status of recreational uses. These are utilized elsewhere in this report (Sections 7 to 10). In this chapter a purely qualitative approach is used. Around the world, these kind of determinations are made on a site-specific basis and reflect the societal goals of the humans that live around and use the water. Most often, questions about assimilative capacity and sensitivity do not get posed until human thresholds or boundaries have already been crossed. To some degree, this has happened in the communities surrounding Saanich Inlet.

To describe the present status and sensitivity for Saanich Inlet with respect to each water use listed above, key indicators were identified. For each water use, the study team reviewed the same information considered in Section 2, including:

- Questionnaire results from Open House consultations and resultant report.
- Report on First Nations Consultation.
- Discussions with Saanich Inlet Advisory Committee members.
- Copies of official community plans and other planning documents for jurisdictions bordering on Saanich Inlet.
- Discussions with representatives of First Nations (October 1995).

Findings are described for each water use in the following sections. It is recognized that there are a wide range of opinions about the status of Saanich Inlet, with respect to environmental degradation. Coming to a single determination on assimilative capacity and sensitivity of human water uses may not be possible, as "the answer" depends largely on opinion. Despite this constraint, it is important to try to describe the status of Saanich Inlet, for in doing so we begin to think about how to manage and remedial any existing problems that are identified and to prevent further degradation.

3.2 First Nations Marine Resource Use

Traditionally, First Nations people traveled through their territories to visit other groups, fish and gather food, particularly in the summer. One of the unique characteristics of any culture is their food - the First Nations that used Saanich Inlet depended on the inlet for food and materials (e.g., fish, clams, crabs, mussels, sea urchins, seaweed, ducks, and seabird eggs; see Simonsen et al., 1995 for full species list).

The people were seagoing, relying on the sea for transport, trade, resource harvesting and other cultural activities. To some extent that is still true today. First Nations paddlers from Saanich Inlet are active in paddling races, training on Saanich Inlet on a regular basis. There is a strong desire to collect food locally from the sea.

Archaeological sites are described in Simonsen et al. (1995) and these provide an historical record of cultural use of Saanich Inlet. The record documents extensive seasonal and related resource use of Saanich Inlet.

Today, the First Nations communities on the shores of Saanich Inlet include: Malahat, Tsartlip, Pauquachin, Tseycum and Tsawout. In 1846, the Treaty of Washington established a United States - British border, which caused an artificial boundary for First Nations (Simonsen et al., 1995). In 1852, Sir James Douglas made an agreement with the Saanich which entailed purchase of much of the lands surrounding Saanich Inlet. Incorporation of Indian Reserves caused drastic changes in the cultural patterns of the inlet's First Nations. Although it is stipulated within the Douglas treaties that the Saanich not be withheld from their hunting and fishing activities, the creation of Indian reserves facilitated change due to the encroachment of non-natives within traditional resource harvesting locations (Simonsen et al., 1995). The Douglas treaties specify that First Nations are "at liberty to hunt over unoccupied lands", and "to carry on fisheries as formerly".

Traditional uses such as food collection and natural resource utilization are limited in three main ways:

1. Access is limited.
2. Resource quantity is limited.
3. Resource quality is degraded.

Taken in combination, this is clear indication that, for these uses, Saanich Inlet is degraded past the threshold of assimilative capacity. Access by First Nations is limited by private ownership of land, land alienation and a perception that foreshore areas are private. Reductions in resource quantity are well documented (Drinnan et al., 1995) and summarized in Section 10. Degraded resource quality is evidenced by bacterial contamination (e.g., 12 of 15 traditional shellfish beds closed for harvesting due to fecal coliform contamination; see also Section 8) and also observations by First Nations representatives that marine resources are of poorer quality than they once were (Calder and Mann, 1995).

We have attempted to summarize the status of First Nation resource uses in Table 3-1. Where a use is lost, assimilative capacity has been exceeded. This provides a useful summary, but does run the risk of over-simplification.

In conclusion, it was generally observed by all First Nations contacted by Simonsen et al. and by the study team that they traditionally relied almost exclusively on the natural resources of Saanich Inlet and surrounding upland areas for their food, economy and well-being. A common thread in listening to representatives of First Nations is the large amount of change in Saanich Inlet that has occurred in a relatively short time period. It is clear that resource uses are sensitive to further urbanization. The assimilative capacity for aboriginal food resources, particularly shellfish, has been exceeded.

3.2.1 Recreational Use

3.2.1.1 Background

Howie (1995) identified a number of recreational uses for Saanich Inlet. Looking at the use of Saanich Inlet over the year prior to the January 1995 Open House and over the lifetime of questionnaire respondents, it is clear that hiking or walking; wildlife viewing; and beachcombing or picnicking are very popular activities (Table 3-2). While some wildlife viewing takes place beneath or on the water, the top three recreational activities in Saanich Inlet take place on the shoreline or in the surrounding upland area. The results of the questionnaire may indicate a trend of decreasing activity in swimming and fishing and an increase in power boating (Howie, 1995). Recreational fishing and shellfish harvesting are described in greater detail in Section 10.

When asked what uses or values of Saanich Inlet were most sensitive to change, the majority of respondents perceive that water quality and marine life were more sensitive than recreation and tourism. This opinion is supported by environmental criteria which generally demonstrate aquatic life as the most sensitive indicator of environmental quality. Chemical criteria are used to assess environmental status and prevent pollution. Biological criteria would be more direct but are not yet well developed. Refer to Sections 7 and 8 for application of environmental criteria as another method of assessing environmental status.

Howie (1995) documents where recreational activities most often take place. Brentwood Bay, Mill Bay and the Goldstream Estuary are the three most popular areas. Tod Inlet, Pat Bay, Coles Bay and the Bamberton area were also identified as popular areas.

3.2.1.2 Sensitivity and Assimilative Capacity

By default, assimilative capacity has been exceeded if a water use, such as recreational use, is impaired. To evaluate impairment, the Open House Report (Howie, 1995) was reviewed. Due to the general nature of the questionnaires, it is usually not possible to discuss impairment of recreational uses in a geographically-specific manner. The following questions from the Open House Report provided information to evaluate impairment:

- What changes have you experienced in Saanich Inlet?

- How have these changes affected your activities in the inlet?
- What potential changes or trends in Saanich Inlet cause you concern?
- What uses or valued characteristics of Saanich Inlet do you believe are most sensitive to change?
- What changes would you like to see in Saanich Inlet in the future?

As much as possible, responses were linked to recreational uses. Responses summarized below were taken from the Open House Report, unless indicated otherwise:

Hiking/walking/beach access

- More apt to be "runoff" beach front by newly arrived home owners than before
- Many waterfront properties have small docks and jetties many of which, apparently, are built without a permit; these foreshore structures may have minimal direct impact, however one consequence is that they restrict beach access to First Nations (Simonsen et al., 1995)

Wildlife viewing

- Loss of marine organisms and plant life over intertidal areas
- Not heard sea lion for past two years
- No longer conduct intertidal biology walks due to loss of organisms

Swimming

- No longer swim
- There have never been any swimming beach closures in Saanich Inlet

Power boating

- Increase in power boats, water skiing, skidoo-type boats (could be taken to mean degradation or enhancement)
- Increase in power boating
- Concerned about increase in boating traffic

Fishing

- Reduced fishing success
- Stopped collecting shellfish in about 1975
- Loss of the sports fishery
- Bivalve shellfish growing criterion for coliforms is exceeded in many areas of Saanich Inlet and as a result most of the shellfish beds are closed for harvesting (Drinnan et al., 1995).
- Many of the shellfish closures were initiated in 1987, with re-evaluation surveys annually since 1990 (Drinnan et al., 1995)

Kayaking/canoeing/rowing

- Less inclined to kayak in some areas

Sailing

- Still use it a great deal for sailing

SCUBA diving

Certain dive sites have become degraded over the years in terms of species numbers or abundance (Drinnan et al., 1995)

Water Skiing

- Waterskiing occurs in Tod Inlet, one of the few protected waterways near Victoria. This activity takes place in spite of a posted five knot speed zone (Drinnan et al., 1995)

Most of these uses are water-based (i.e., use the water itself). It is recognized that there are some uses that are dependent on Saanich Inlet in some way, but are not water-based (e.g., hiking/walking, photography, drawing/painting).

The difficult issue to address is how much impairment of recreational uses is "too much" (i.e., exceeding assimilative capacity). How many opinions and what degree of degradation is considered adequate to determine whether a recreational use is degraded. There are some that would say one opinion is enough and others that would say a majority. This level of information is not available nor would it be practical to procure.

Based on the information available from public consultation, the relative level of degradation for the most common water-based recreational uses is described in Table 3-3. From this assessment, environmental degradation of Saanich Inlet is evidenced by impairment of fishing (for more detailed discussion, see Section 10). Also, there is a perception that swimming use is degraded, although coliform criteria for swimming, using regulatory guidelines, are not exceeded. To a lesser degree, impairment of wildlife viewing, kayaking/canoeing and SCUBA diving are also indicative of exceedance of the assimilative capacity of Saanich Inlet.

3.3 Educational Use

Saanich Inlet has been visited by oceanographic cruises since the 1930s. The inlet's proximity to the University of B.C., the Fisheries Research Station at Departure Bay (Nanaimo) and the University of Washington gave scientists close access to the fjord (Drinnan et al, 1995). Later siting of the Institute of Ocean Sciences in Sidney and the opening of the University of Victoria increased the number of interested scientists and students.

A number of the parks near Saanich Inlet have marine foreshore areas. Goldstream Provincial Park has an interpretive centre that is well used for education purposes related to Saanich Inlet. The newly created Gowlands Commonwealth Legacy Park is a significant educational resource.

Educational uses are somewhat sensitive to further urbanization of Saanich Inlet. This relates largely to stresses being placed on the subjects of study. Also, a component of environmental education is the principle of sustainable environment itself, and as such, Saanich Inlet is a case study.

3.4 Commercial Use

Industrial uses of Saanich Inlet include the occasional deep sea anchorage of vessels waiting to dock at Cowichan Bay or Crofton, and the Hatch Point bulk oil storage facility that receives weekly deliveries by barge of petroleum products for distribution. The Institute of Ocean Sciences is located in Patricia Bay and has a high degree of ship movement (Drinnan et al., 1995). There is also a floatplane base in Patricia Bay, with a commercial operator running approximately 1000 flights per year. There are a number of small marinas in Saanich Inlet, with the greatest concentrations in Brentwood Bay (see maps in Section 11).

The cement plant at Bamberton is no longer operating. However, damage to the bottom habitat adjacent to the plant has been documented through SCUBA and submersible dive logs, and from sediment chemistry data (Drinnan et al., 1995). Also, there is a cement storage facility owned by Tilbury Cement south of Bamberton, where dry cement is transhipped.

There is only one effluent permit issued under the B.C. Waste Management Act. Brentwood College at Mill Bay operates a small sewage treatment plant employing the hydroxyl treatment system discharging up to 105 m^3/day via a submarine outfall in Mill Bay. This plant was very recently amended to this new process. There are no industrial discharges to the inlet or heavy industrial activities in the watersheds.

Commercial use from a fisheries perspective is discussed in Section 10. A number of commercial operations have operated in Saanich Inlet over the years, but due to low abundance, regulation and, in the case of shellfish, degraded environmental quality, commercial activities are now limited.

3.5 Overall Water Values and Uses

It is a paradox that the values and uses of Saanich Inlet that attract humans can suffer degradation due to influx of humans and related pressures on the inlet. Water uses can be, of themselves, deleterious to Saanich Inlet. Decreases in the quality of water uses (e.g., fishing) may in part be a result of overuse of Saanich Inlet (e.g., overfishing). However, there are water uses (e.g., shellfish consumption) that are degraded due to an exceedance of the assimilative capacity of Saanich Inlet.

Consideration of water values (Section 2) and water uses (Section 3) lays the groundwork for selection of benchmarks for environmental health in Saanich Inlet. The water values and uses describe the expectations of the communities surrounding Saanich Inlet.

Table 3-1 Status of First Nations marine resource uses of Saanich Inlet based on consultations with First Nations.

First Nations Subsistence Uses (Marine)	Present Status[1]
Salmon	degraded
Herring	lost
Rockfish	good/degraded
Lingcod	degraded
Bivalves (clams, mussels, oysters)	lost
Crab	good
Ducks	degraded
Sea lettuce	degraded

[1] Present status:
good = use not significantly degraded
degraded = use significantly degraded
lost = no use possible (degraded past assimilative capacity)

Table 3-2 Results of short-form questionnaire used at Saanich Inlet Study Open Houses, showing recreational uses of Saanich Inlet (Source: Howie, 1995).

Rank	Took Part In Past Year	No. of Responses	% of Total	Took Part In Lifetime	No. of Responses	% of Total
1	Hiking or Walking	676	82%	Hiking or Walking	763	93%
2	Wildlife viewing	648	79%	Wildlife viewing	731	89%
3	Beachcombing, picnicking	556	68%	Beachcombing, picnicking	683	83%
4	Swimming	313	38%	Swimming	525	64%
5	Power boating	269	33%	Power boating	468	57%
6	Fishing	252	31%	Fishing	435	53%
7	Kayaking/canoeing/ rowing	250	30%	Kayaking/canoeing/ rowing	432	53%
8	Sailing	164	20%	Sailing	323	39%
9	SCUBA diving	45	5%	SCUBA diving	108	13%
10	Water skiing	36	4%	Water skiing	102	12%
11	Windsurfing	12	1%	Windsurfing	45	5%
12	Other Sports	8	1%	Other Sports	9	1%
13	Photography/Video Production	5	1%	Photography/Video Production	7	1%
14	Drawing/Painting	4	0%	Drawing/Painting	4	0%
15	Research	3	0%	Research	3	0%
16	Other	3	0%	Other	3	0%

Table 3-3 Status of water-based recreational uses of Saanich Inlet based on public consultation.

Water-based Recreational Use	Present Status[1]
Wildlife viewing	good
Swimming	degraded
Power-boating	good
Fishing	degraded
Kayaking/canoeing/rowing	degraded
Sailing	good
SCUBA diving	degraded
Water skiing	good
Windsurfing	good

[1] Present status:
good = use not significantly degraded
degraded = use significantly degraded
lost = no use possible (degraded past assimilative capacity)

4. SAANICH INLET MASS BALANCE MODEL

4.1 Background

Early in the formulation of this phase of the Saanich Inlet Study, it was determined that both a qualitative and quantitative approach would have to be taken to meet the objectives of this investigation (Section 1). The present section provides background information on one of the main models used. The approach to this model is called "mass balance" and is described further in Section 4.2.

The model described herein was the basis for modelling efforts for:

- Physical oceanography (Section 5).
- Sediment transport (Section 6).
- Chemical fate in environmental media (Section 7).
- Chemical fate in food web (Section 7).

The framework that links these modules is described in Section 4.3. It is important to note that different models were used to support the assessment of assimilative capacity for coliform bacteria (Section 8) and for nutrients/oxygen (Section 9). Models used to investigate these issues are described in the relevant sections.

4.2 Mass Balance Modelling Approach

A mass balance modelling approach was selected to meet the stated objectives of the project; the rationale for this approach is described in this section.

In the mass balance modelling approach, a key component of each individual module is the application of the equation of conservation of mass (also known as the continuity equation in hydrodynamics). In simple terms, the quantities of any material entering the Saanich Inlet system must equal the quantities leaving the system, minus the quantities retained, transformed or degraded. This principle applies equally well to all types of materials, including water, sediment and tissues of biota.

Thus, the application of a mass balance model becomes, at its simplest, a basic "bookkeeping" exercise where each model constituent (water, sediment and contaminants) is tracked through the environmental system of interest (in this case, Saanich Inlet). Once the appropriate mass balance formulation has been determined for each constituent, the mass balance model, as a whole, can become a surrogate for the natural system. The mass balance model can be used to simulate the response of the natural system to changes in contaminant loadings, and to aid in the prioritization of sites for remediation (U.S. EPA, 1993). In the case of this study, the mass balance model approach was employed to assess the sensitivity and estimate the assimilative capacity to contaminant inputs.

The development and application of a mass balance modelling system involves several main components:

- The division of the study area into representative subcompartments or boxes.
- The mathematical representation of the relevant physical, chemical and biological transport, transformation and decay processes.
- The definition and quantification of the inputs (also known as loadings or boundary conditions) to the ecosystem of interest. In Saanich Inlet, hypothetical loadings which could exceed environmental criteria were projected for various scenarios.

The definition and quantification of the loadings can be subdivided into fluid (fresh and salt water components), sediment and contaminant sources.

The mathematical representation of the relevant physical, chemical, and biological processes leading to the transport and transformation of contaminants is handled separately within each module (or sub-model) of the mass balance modelling system. The mathematical representation of these processes is implicitly tied to the way in which the study area is divided into boxes (discretization); both the mathematical formulations and level of ecosystem discretization are reflected in the level of complexity of the model system or individual module.

Generally speaking, a range of levels of complexity can be used to represent the relevant processes within each module. As stated in the ARCS report (U.S. EPA, 1993): "The degree of complexity required depends on the physics of the system, factors affecting the transport and transformations specific to the contaminants of concern, and the management questions the mass balance modelling study will address. The degree of complexity used in particular studies is often dictated by the time and funding available."

As a broad-based classification, modelling approaches can be subdivided into those that are driven by data and *in situ* measurements, and those that are driven by detailed knowledge of the processes that are to be included in the model. For some processes, such as many aspects of fluid flows, the physics driving the flows are relatively well understood. When adequate field measurements are also available, the modeller has the choice between data-driven methods and knowledge-driven methods, and can choose the appropriate model formulation based on the other factors outlined above.

However, for many other processes relevant to the fate of marine contaminants (i.e., deposition and erosion of cohesive sediments, decay of fecal coliforms, metal speciation) the appropriate level of knowledge is not available and models must rely on a data-driven approach. The data and knowledge bases for each of the individual modules of the proposed modelling system are described in this report.

The time- and length-scales relevant to the particular problems under consideration affect both the mathematical representation of the dominant processes and the division of the study area into representative subcompartments:

- *Near-Field*

  If , for example, the primary focus of the proposed modelling efforts was to be on the localized regions surrounding discharge outfalls, then the time-scale of concern would be on the order of several minutes to several hours, with the corresponding length-scale on the order of tens to hundreds of metres.

- *Far-Field*

  If , for example, the intent is to examine long-term responses of the inlet as a whole to changes in contaminant loading, then the relevant time-scale might be on the order of months to years, with the associated length-scale on the order of hundreds of metres to kilometres.

Each of these types of problems requires a different approach to both the mathematical formulation of the relevant processes and the division of the study area into representative subregions. In the near-field scenario, the hydrodynamic module would be formulated based on plume theory, where the advection and dispersion of the contaminants in the vicinity of the outfall is largely governed by the characteristics of that discharge. The currents in the receiving waters (resulting from tides, wind-induced flows, etc.) would be represented as steady flows in the plume model (appropriate for short-time scales). Plume modelling would be performed for a representative range of receiving water conditions. A typical spatial scale used for this type of model would be on the order of tens of metres. For some issues addressed in this evaluation (specifically, coliform bacteria and nutrients), a near-field approach was used, as it was most appropriate. This is discussed further in those sections.

For the far-field scenario, the long-term fate of contaminants is largely determined by the mean circulation patterns in the receiving waters, which themselves could be driven by geostrophic and tidal forcing, storm events and the effects of surface winds, and estuarine flow patterns. A very different approach is required from that described for the near-field problem. A range of numerical formulations are available to explicitly model various combinations of these current components; all of these formulations are based on detailed solutions of the equation for conservation of momentum coupled with the continuity equation.

In summary, the modeller has the choice between a variety of approaches for the formulation of a model. The choice of the appropriate level of model complexity, as reflected in the mathematical formulation of the relevant processes and the discretization of the study area, will depend on a number of factors such as:

- The management questions the mass balance modelling study is meant to address.
- The amount and types of pre-existing data available for the study area of concern.
- The degree to which the details of the various processes are understood.
- The time and funding available to study the area of concern.

4.3 Saanich Inlet Model Framework

The model system used as one of the tools to support this study follows the general concepts of a mass balance modelling approach using a box model formulation. This approach is widely accepted and has been used in similar applications in areas such as Halifax Harbour, Nova Scotia (Halifax Harbour Task Force, 1990), and in the Great Lakes (e.g., Diamond et al., 1994; U.S. EPA, 1993). The main physiographic regions (or subbasins) of Saanich Inlet were used to divide the inlet into boxes (Figure 4-1). These boxes were further subdivided into vertically-layered boxes, as described in Section 5.

As much as possible, application of the mass balance modelling approach involves quantification of the sources, transport and fate of contaminants in Saanich Inlet. The components of this modelling approach are illustrated in Figure 4-2. The typical steps in such a modelling approach are: (1) predicting water and sediment transport; (2) using the predicted water and sediment transport, along with estimates or projections of contaminant loadings, to estimate the chemical concentrations in water and sediments; and (3) using the predicted or threshold (e.g., criteria) contaminant concentrations in water and sediments to estimate the transfer of contaminants through the food web and their accumulation in important biological receptors (e.g., fish and shellfish). To apply the model system to Saanich Inlet, the approach was to characterize the system, run the model, and then evaluate the model predictions.

The Saanich Inlet model system consists of a linked series of individual modules, each of which represent a sub-set of the physical, chemical and biological processes that affect contaminant concentrations in the water column, in suspended sediments and seabed sediments, and in marine biota. Four individual modules were included in the modelling system:

- Hydrodynamic module
- Sediment transport module
- Environmental fate module
- Food web bioaccumulation module

Each of these modules will be summarized briefly in the following paragraphs and described in more detail as individual sections of this report.

Hydrodynamic

Contaminants discharged into marine waters are generally associated with significant flows of fresh (rather than saline) water, particularly for point source discharges. At least in the short-term, the fate of dissolved contaminants is largely governed by the advection and mixing processes affecting these fresh water inputs. Even in the long-term, much of the variability of contaminant concentrations in the water column can often be explained by water transport alone (U.S. EPA, 1993). The hydrodynamic module represents the transport of water masses from compartment to compartment within Saanich Inlet (Section 5).

Sediment Transport

Significant quantities of both organic and inorganic solids are added to Saanich Inlet in association with sources such as rivers and storm drains, runoff and the Fraser River plume. In marine waters, a large source of organic suspended solids may also be attributed to primary productivity (Petrie and Yeats, 1990). Since many contaminants preferentially adsorb onto fine, suspended solids, the transport, deposition and potential resuspension of sediments is an important factor in contaminant fate assessment. The sediment transport module represents the movement and deposition of sediments entering the Saanich Inlet system (Section 6).

Environmental Fate

Chemical contaminants discharged into the inlet are originally associated with either the operationally defined dissolved or particulate portions of the discharge. Contaminants can move from compartment to compartment in the inlet through the associated hydrodynamic and sediment transport processes, but are also subject to volatilization, sorption from the water column onto suspended sediments, diffusion between the water column and the seabed and transformation, degradation, and decay processes. The environmental fate module integrates the effects of all of these processes (Section 7).

Food Web Bioaccumulation

In addition to the physical and chemical processes affecting the distribution of chemical contaminants in the marine environment, contaminants can move through the food web through a variety of processes including ingestion, gill exchange and excretion. The food web bioaccumulation module can help assess contaminant concentrations in phytoplankton, pelagic and benthic invertebrates, and fish (Section 7).

Figure 4-1 Box boundaries for Saanich Inlet hydro-dynamics model.

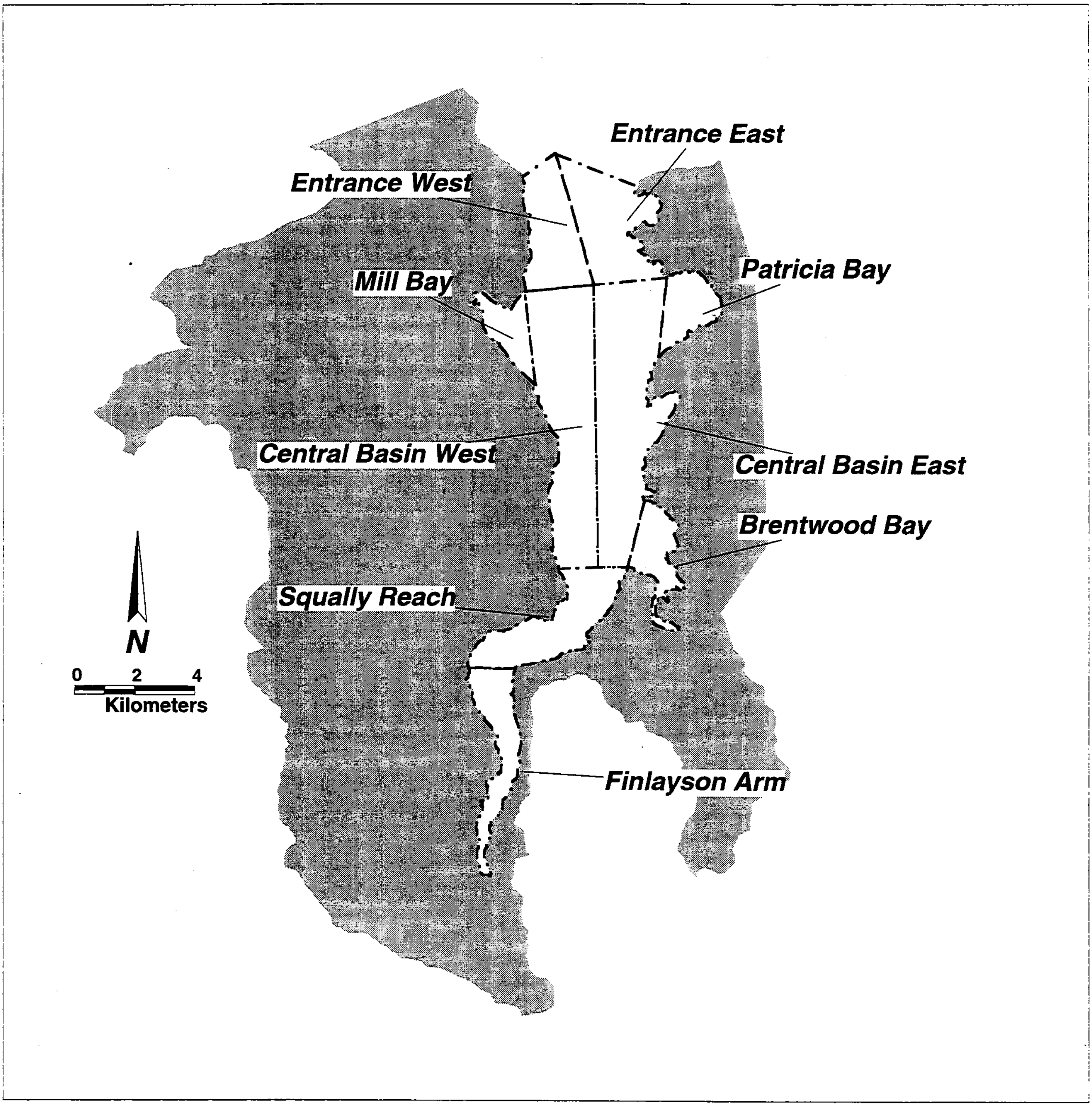
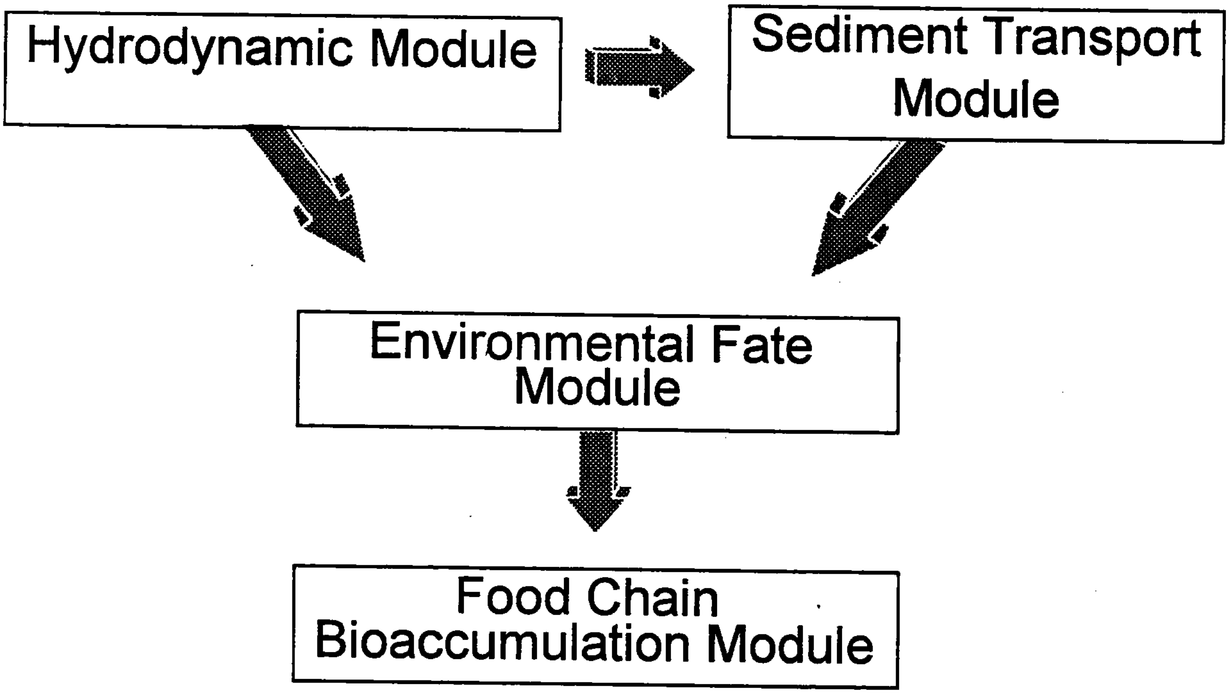


Figure 4-2 Saanich Inlet model showing individual modules.



5. PHYSICAL OCEANOGRAPHY

As described in Section 4, the fate of materials, such as contaminants, that enter Saanich Inlet, is strongly affected by the movement of water masses within the inlet. This is true for short-term, near-field processes such as plume dispersion in the vicinity of an outfall, as well as for long-term, far-field processes related to the dispersion of dissolved and suspended materials throughout Saanich Inlet. Thus, the physical oceanography of the inlet must be considered in the assessment of the fate of materials entering Saanich Inlet, and in the assessment of the assimilative capacity of the inlet for contaminants.

The overall framework of the modelling system used for the oceanography and sediment transport components of this work is described in Section 4. The oceanographic module is the first component of the Saanich Inlet model and has been designed to represent the long-term movement of water masses throughout the inlet. The results of the oceanographic module are then used as input parameters for the sediment transport (Section 6) and environmental chemical fate modules (Section 7). Since the primary focus of the oceanographic module is the long-term exchanges between the various regions of Saanich Inlet, modelling efforts have focused on representing mean circulation patterns.

The following sections describe the major features of Saanich Inlet as they relate to oceanographic processes, the major physical processes leading to transport and mixing of inlet waters, and the development, application and results of the oceanographic module used in this work.

5.1 Background

5.1.1 Physiography

Saanich Inlet is located on southern Vancouver Island, forming the division between the Saanich Peninsula and the main body of the Island (Figure 1-1). The inlet is oriented in a north-south direction, with the mouth of the inlet at the northern end. Saanich Inlet is isolated from the waters of the Strait of Georgia to the north and Juan de Fuca Strait to the south by the many intervening Gulf Islands.

The inlet is long and narrow, extending roughly 28 km from the head at the Goldstream River to the mouth at the junction with Satellite Channel (Figure 1-2). The main body of the inlet averages about 3 km in width over the northern and central regions, narrowing in a southward direction through Squally Reach and Finlayson Arm to a typical width on the order of 500 m at the southernmost end. Several coastal embayments (Deep Cove, Patricia Bay, Mill Bay, Coles Bay and Brentwood Bay) adjoin the main body of the inlet over the central and northern portions.

As for most coastal fjords, the waters of Saanich Inlet are consistently deep throughout the main body of the inlet. Figure 5-1 and Figure 5-2 show the variation in water depth along an approximate inlet centreline; the deep central basin is clearly evident, with a maximum water depth of roughly 225 m. Moving northwards from the deep central basin, water depths decrease to about 70 m at the entrance to the inlet. These relatively shallow water depths persist through the Gulf Islands, forming an extended sill separating the deep waters of Saanich Inlet from the deep ocean waters in Haro Strait (Figure 5-3 and Figure 5-4). The coastal embayments are significantly shallower than the deep central basin in Saanich Inlet, with maximum water depths ranging from about 40 m in Mill Bay to 100 m in Brentwood Bay.

The southern reaches of Saanich Inlet are bordered by steep rocky slopes, low peaks and ridges, while the northern reaches are bounded by lower, gently sloping terrain, particularly on the eastern side. Much of the surrounding watersheds are forested, with low levels of development. However, agricultural development on the Saanich Peninsula is significant.

The cross-sectional shape of the inlet is generally steep-sided and flat-bottomed, particularly in the southern reaches. The coastal embayments are generally quite broad and flat in cross-section, with the seabed sloping gently towards the main channel.

5.1.2 Oceanographic Processes

The circulation patterns in coastal fjords such as Saanich Inlet are typically influenced by a variety of oceanographic processes acting over a range of time scales. These include tides, winds and density-driven processes. The estuarine circulation, although relatively weak in Saanich Inlet when compared with many coastal estuaries, still plays an important role in driving the mean circulation patterns in the inlet.

The relative importance of each of these mechanisms in driving the circulation within the inlet varies from area to area. For example, the relatively strong tidal currents in Satellite Channel are expected to have more of an influence on the waters near the mouth of Saanich Inlet, whereas intrusions of dense ocean water from Haro Strait appear to be the major mechanism leading to flushing of inlet waters below sill depth.

5.1.2.1 Tides

Tides in Saanich Inlet are mixed semi-diurnal, with generally two large and two small exchanges per day. Tidal ranges are fairly consistent throughout the inlet, although previous measurements have suggested some spatial variations, possibly in response to meteorological forcing (Drinnan et al., 1995). At Patricia Bay on the east side of Saanich Inlet, the tidal ranges for mean and large tides are 2.4 and 3.9 m, respectively.

Tidal currents in the inlet are generally quite weak, being less than 5 cm/s in the main body of the inlet. Tidal currents are stronger over the sill, with measurements at mooring A (Figure 5-3) showing tidal currents of roughly 10 to 15 cm/s (Stucchi and Giovando, 1983). It should be remembered that tidal currents are oscillatory in nature, often with relatively small net water movements. The present project is concerned primarily with processes affecting the mean, long-term circulation in the inlet, thus it is the residual tidal currents that are of interest.

5.1.2.2 Estuarine Circulation

Estuaries are coastal regions characterized by fresh water loading, where the loading rate is high enough to result in dilution of seawater through mixing with fresh water. Since fresh water is lighter than seawater, the fresh water entering an estuary tends to form a surface layer flowing outwards overtop of the heavier marine water. As the fresh water flows away from its source, it mixes with the underlying seawater, leading to a brackish surface layer which increases in depth and salinity with distance away from the point of discharge. Entrainment of salt amplifies the river flow such that the flux of water leaving the estuary at the surface may be several times the initial fresh water influx. This process is illustrated in Figure 5-5.

As underlying saline water is entrained into the outward-flowing surface layer and carried out of the estuary, it must be replaced by a compensating volume of water flowing into the estuary, creating a net inflow at depth of saline water and a two-layer circulation system. This estuarine circulation pattern represents average flow conditions; although instantaneous flows may be in the opposite direction, on average, there will be a net outflow at the surface coupled with a net inflow at depth. It is this long-term mean circulation pattern that the oceanographic model is designed to capture.

The estuarine circulation pattern in Saanich Inlet is complicated by two factors: the total fresh water inflow to the inlet is low, particularly in the summer months, and the major sources of fresh water to the inlet are not located at the head of the inlet. The impact of these factors on circulation patterns in the inlet will be discussed in more detail later in this report.

5.1.2.3 Deep Water Renewal Events

The estuarine circulation pattern shown in Figure 5-5 primarily affects the waters above the sill depth, with the sill acting as a wall limiting exchange between the deep bottom waters in the inlet and the open ocean. The Saanich Inlet sill begins at the northern end of the inlet and effectively extends eastward through Satellite Channel to Swanson Channel, where water depths reach a minimum of 65 m over the outer sill region (Figure 5-4). Water depths then increase rapidly to over 200 m in Haro Strait, which is itself connected to the Pacific Ocean through Juan de Fuca Strait.

The waters of Haro Strait show a discernible annual cycle, with summer conditions characterized by annual minimum salinities in the surface waters (0 - 40 m) together with annual maximum salinities in the deepest waters (200 - 300 m). The minimum surface salinities occur as a result of the spring freshet in the Fraser River (Figure 5-6), where maximum flow rates occur from late May through early July. The maximum salinities in the deep waters are due to the seasonal influx of upwelled water from the west coast flowing into Juan de Fuca Strait and eventually into Haro Strait (Anderson and Devol, 1973; Stucchi and Giovando, 1983).

Superimposed on the annual cycle in the salinity structure of the waters in Haro Strait is a fortnightly cycle related to variations in tidal mixing. The lowest surface salinities, coupled with high deep water salinities and a strong vertical salinity gradient, have been seen to occur between neap and spring tides at the southern end of Haro Strait. Higher surface salinities, lower deep water salinities and a relatively weak vertical salinity gradient are seen after spring tides (Stucchi and Giovando, 1983). A similar cycle in salinity has been observed at Mooring A near the entrance to Saanich Inlet (Figure 5-3), with higher salinity water present at sill depth during neap tides.

The deeper waters of Haro Strait are considered to be the source of renewal water for the deep basin in Saanich Inlet. The waters below sill depth in Saanich are flushed only by density flows, occurring when the salinity at the mouth of the inlet exceeds that of the deep waters inside the inlet. For this to occur, deep water from Haro Strait must be mixed upwards and transported inwards across the outer sill and into Satellite Channel to the mouth of Saanich Inlet. This process appears to be both driven by and limited by fortnightly variations in tidal mixing.

Measurements of the properties of the deep water in Saanich Inlet over the period from 1966 through early 1973 have shown a distinct annual cycle in salinity, temperature and dissolved oxygen levels at 100 m (Pickard, 1975), with salinity and temperature values peaking in the fourth quarter. These measurements indicate that renewal of waters at 100 m in Saanich Inlet occurs on a yearly basis. However, the corresponding measurements at 200 m water depth clearly indicate renewal events during only three of the six years, with renewal during the remaining three years uncertain.

Anderson and Devol (1973) estimated renewal volumes for 1962 and 1969 based on a deep water nitrate budget; their results indicate 64% of the water below 150 m was replaced in 1962, with 33% replaced in 1969. Renewal flows were found to occur primarily during the months of August and September, when salinities in bottom waters are highest at the mouth of Saanich Inlet.

Observations from 84 m water depth at Mooring A (Stucchi and Giovando, 1983) show three distinct renewal events, occurring at the ends of the months of August, September and October, 1978. Renewal events typically lasted for 8 to 10 days each month, with tidal period variations in inflow speed, salinity and temperature. The vertical extent of these renewal events within the waters of the inner basin is unclear; however, monthly dissolved oxygen profiles at Station S5 do not indicate renewal of the bottom waters during this time period (Stucchi and Giovando, 1983). The observed events in 1978 may represent mid-depth renewals rather than full renewals extending to the bottom of the deep basin in Saanich Inlet.

5.1.2.4 Circulation Patterns in Saanich Inlet

Previous studies of the circulation patterns in Saanich Inlet are limited, having primarily consisted of drogue studies and limited current meter deployments. Drogue deployments have been summarized by Drinnan et al. (1995); only the more recent studies will be discussed here.

Sets of depth-integrating 'holey-sock' drogues were deployed in Saanich Inlet during June and September of 1990, for periods ranging from 24 to 52 hours. The drogue tracks are shown in Figure 5-7 and Figure 5-8 for the June and September deployments, respectively. During June, drogues were deployed in the central regions of the inlet near Coles Bay and Brentwood Bay. These drogues showed a consistently southerly movement over several tidal cycles, with average speeds ranging from 2.4 to 7.3 cm/s.

During September (Figure 5-8), the drogues were deployed primarily in the northern third of the inlet, between Mill Bay and Pat Bay. Although directions of movement were varied and again did not appear to be correlated with the tides, several features of the circulation in this region are evident. The drogue deployed on the west side of the inlet near Mill Bay moved steadily to the south, while those deployed on the east side showed a strong, although more varied, movement to the north. Drogues deployed near the centre of the inlet showed a more varied pattern, although a net movement from the west to the east side of the inlet is suggested. Average speeds ranged from 2.4 to 5.2 cm/s.

Two recent drogue studies have been completed in Saanich Inlet, with the intent of monitoring water movements within the coastal embayments as well as in the main body of the inlet (Cross and Chandler, 1996). In December of 1994, drogues were deployed at two depths (3.5 m and 12.5 m) over two five-day periods in the main body of the inlet.

The surface drogues deployed during the first five-day period showed a strong movement out of the inlet, with all drifters leaving the inlet on the eastern side (Figure 5-9). The only observed drift reversals were on 7 December, when wind conditions were reported as relatively calm (less than 5 knots). Otherwise, winds were generally from the south and east. The sub-surface drifters showed much weaker and less coherent movements, with some drifters moving to the south while others moved northwards.

During the second five-day deployment, surface drogue movements were more complex, with apparent southerly movements during the first day or two followed by generally northerly drift patterns. Again, drift reversals, perhaps in response to tides, seem to be limited to days with calm wind conditions. The near-surface drogues also seemed to show a general southerly movement for a day or two, followed by a northerly drift pattern.

Drogues were also deployed during these time periods in Brentwood Bay, Mill Bay and in the Bamberton nearshore zone. Surface drogues (1.0 m) in Brentwood Bay showed variable movement and a tendency to circulate within the bay, particularly during the second deployment period. However, all drogues leaving the bay did so in a northward direction. All but one sub-surface (10.0 m) drogue remained within Brentwood Bay.

Drifters in Mill Bay showed a stronger tendency to leave the bay relatively quickly, including both surface and near-surface drogues. The primary drift direction was to the southeast, although other directions were also observed along with some recirculation in the shallower areas. Drift directions were strongly parallel to the shoreline near Bamberton, with both southward and northward movements observed for surface and near-surface drogues.

A similar drogue study was conducted during July of 1995 (Cross and Chandler, 1996), with drogues deployed in the main body of Saanich Inlet and in Brentwood Bay, Mill Bay and Pat Bay. The drogues in the main body of Saanich Inlet were tracked for two five-day periods, with surface drogues at 1.5 m water depth and sub-surface drogues at 12.5 m.

During the first week, surface drogues were deployed near the mouth of Pat Bay. Although all drogues showed a net movement northward out of the inlet on the east side, drift patterns were highly variable, as were drogue speeds. A sub-surface drogue deployed near Elbow Point in Squally Reach showed variable movement, but remained trapped in that area for the entire five-day period. A second sub-surface drifter deployed just north of the entrance to Mill Bay showed a net slow southward movement, although with several reversals in direction. Sub-surface drogues deployed near the centre of the inlet showed slow net northerly movements, although with several flow reversals.

During the second five-day period, surface drifters deployed between Mill Bay and Pat Bay showed the marked influence of a counter-clockwise circulation pattern in the centre of the inlet (Figure 5-10). This pattern was also seen in one of the sub-surface drogues. While the drift patterns seem to reflect a tidal influence, little net movement was seen over the five-day period. At the same time, a surface drogue deployed in Squally Reach remained in that region for several days before exiting the inlet quickly on the eastern side, bypassing the central gyre. It should be noted that tidal ranges were higher during the first five-day period than during the second five-day period, and that winds were minimal during the entire study.

The Brentwood Bay drifters again showed variable movement and a tendency to circulate within the bay, with drogues leaving the bay in a northward direction. Drifters left Mill Bay relatively quickly, although drifters left the bay both to the southeast and to the northeast, perhaps reflecting the stage of the tide at the time of drogue deployment. Those in Pat Bay showed a more variable movement pattern and longer residence times, again leaving the bay primarily in a northerly direction.

This brief summary indicates that near-surface water movements within Saanich Inlet are highly variable, probably due to no clear dominance of any single oceanographic process. The short-term drogue movements appear to show the influence of both tidal fluctuations and wind forcing. Although the drifter patterns require further detailed study, several main features of circulation within the inlet can be discerned:

- In general, drifters seem to move southward on the western side of the inlet and northward on the eastern side, with stronger drift speeds on the eastern side.
- Some net movement from west to east in the centre of the main body of the inlet has been observed.

- The coastal embayments have relatively long residence periods, particularly Brentwood Bay.
- A convergence zone seems to exist near Squally Reach.
- A central, counter-clockwise surface gyre is apparent in the centre of the inlet, at least during the summer season, when the estuarine flow system is relatively weak.

The design of the oceanographic module, as described in the following sections, will be based on some of these features of the observed circulation patterns in Saanich Inlet.

5.2 Approach

The oceanographic module developed to represent the mean circulation patterns in Saanich Inlet is based on a mass balance approach as described in Section 4. The oceanographic module is data-driven, and relies heavily on *in situ* measurements of water column properties in the inlet. This type of model is commonly referred to as a box model, in that the water body of concern is divided into a relatively small number of sub-areas, or boxes, representing water masses of similar characteristics. The inlet waters are sub-divided into boxes in both the horizontal direction, such as the separation between Brentwood Bay and the main body of Saanich Inlet, and in the vertical direction, such as the division between the waters above and below sill level in the inlet.

5.2.1 Oceanographic Module Formulation

The volume fluxes between the different regions or boxes of the inlet are determined through the simultaneous solution of the equations for conservation of volume and conservation of mass for a chosen tracer. For model box j, these equations can be expressed as:

Conservation of volume:
$$\sum_{i=1}^{n} Q_{ij} - \sum_{k=1}^{m} Q_{jk} = 0 \qquad (5\text{-}1)$$

Conservation of mass (tracer):
$$\sum_{i=1}^{n} C_i Q_{ij} - \sum_{k=1}^{m} C_j Q_{jk} = 0 \qquad (5\text{-}2)$$

where Q_{ij} represents the advective and diffusive fluxes of water from box i to box j and C_i is the tracer concentration in box i. The above equations assume steady-state conditions. Applying these equations to the total number of modelling boxes results in a simple system of linear equations which can then be solved for the unknown set of Q values.

For Saanich Inlet, salt has been chosen as an appropriate tracer based on the conservative nature of salinity, the available data, and the strong relationships between estuarine circulation patterns, deep water renewal events and the salt content of the water column. Although other tracers such as temperature could be used to balance the conservation equations, the boundary conditions for temperature (solar radiation flux along the inlet) are not well known.

In order to develop a box model for Saanich Inlet, the waters of the inlet must be sub-divided into boxes representing water masses of similar characteristics. This division is based on a number of factors:

- Logical physical boundaries
- Changes in the processes generating ocean currents
- Amount and spacing of available data
- Observed changes in water column properties

The physical boundaries affecting division of the inlet into boxes are apparent from an examination of the shape of the inlet (Figure 4-1). The coastal embayments adjoining the main body of the inlet (Deep Cove, Patricia Bay, Mill Bay, Coles Bay and Brentwood Bay) appear as distinct water bodies from a physiographic perspective, as do the southern portions of the inlet as represented by Squally Reach and Finlayson Arm.

The oceanographic processes and circulation patterns in Saanich Inlet have been discussed in the previous material. Available observations indicate that, although the circulation in the inlet is weak and variable, several distinct regions do exist. Drinnan et al. (1995) suggest that the inlet should be sub-divided into at least three regions:

- The northern end, where circulation patterns are strongly affected by tidal currents in Satellite Channel, with inflow on the west side and outflow on the east side
- The central portion, where surface currents are more variable and may show longer-period movements in either direction
- A southern portion, with reduced circulation and flushing

In addition, vertical divisions are required in order to separate the more active surface waters from the deep basin, where renewal events appear to occur on a seasonal basis as discussed previously.

The division of Saanich Inlet into boxes should also be based on spatial variations in the properties of the water column. In order to use the box modelling approach, it will be assumed that the salinity in each box is homogeneous, (i.e., that one salinity value can be used to represent the waters of each box). This implies that the time required to mix each box is short compared to the time scale for substantive exchanges between boxes. This assumption may not be valid for the deep waters of Saanich Inlet, where box volumes are large and vertical mixing is limited. In order to form boxes that represent relatively homogeneous regions, spatial variations in salinity measurements must be examined as part of the inlet sub-division process.

Salinity values in Saanich Inlet are influenced by the fresh water inflows, which in turn carry a strong seasonal signal. The fresh water inflows and their seasonal variations are discussed next, followed by a summary of the salinity data used in this project.

5.2.2 Fresh Water Loadings To Saanich Inlet

Saanich Inlet is atypical of most British Columbia fjords in that the majority of fresh water input does not come from a single source at the head of the inlet. For Saanich Inlet, one of the largest sources of fresh water to the inlet is the combined outflow from the Cowichan and Koksilah Rivers. The outflow from these rivers enters the inlet at the mouth, after mixing with the marine waters of Satellite Channel. Other major sources of fresh water to Saanich Inlet include Shawnigan Creek, discharging into the inlet at Mill Bay, and the Goldstream River at the head of the inlet. Smaller and non-point sources of fresh water entering the inlet include minor creeks, with both gauged and ungauged streams, and direct precipitation on the surface waters of the inlet. The location of the various sources of fresh water to Saanich Inlet are shown in Figure 1-1, with the characteristics of the various sources described in the following sections.

5.2.2.1 Cowichan and Koksilah Rivers

The Cowichan River has a drainage basin of over 800 km^2, and discharges into Cowichan Bay on the eastern shore of Vancouver Island, roughly 10 km to the northwest of the entrance to Saanich Inlet. The drainage basin includes the mountainous regions in the centre of Vancouver Island; discharge from the Cowichan River is modulated by both the natural effects of Cowichan Lake and man-made flow control structures.

The Koksilah River has a drainage area of roughly 300 km^2, and discharges into the Cowichan River before it enters Cowichan Bay. The discharge from the Koksilah reflects natural flow conditions as there are no control structures on the river.

Mean monthly discharge data for the Cowichan and Koksilah Rivers have been obtained from Environment Canada for the period covering 1970 through 1993. Cowichan River flow rates were measured near Duncan, with Koksilah flows measured at Cowichan Station, upstream from the confluence with the Cowichan. The Cowichan River discharges a mean annual flow of roughly 50 m^3/s, with the Koksilah River discharge significantly lower at 9 m^3/s.

The combined discharge for the Cowichan and Koksilah Rivers is shown in Figure 5-11, with mean, maximum and minimum monthly flow rates for the period covering 1970 through 1993. This figure shows the strong seasonal cycle in the discharge pattern, with flow rates reaching and exceeding 100 m^3/s during the period from November through February. Flow rates decrease gradually in the spring and summer months, reaching roughly 20 m^3/s by June and a minimum of 6.7 m^3/s in August. The fall increase in discharge is relatively sudden, with average monthly flow rates of 11, 24 and 94 m^3/s in September, October and November, respectively.

The seasonal variation in discharge rates reflects the strong influence of rainfall events on river flows. Since there are no major snow packs in the drainage basins of either the Cowichan or Koksilah Rivers, a strong spring freshet is absent from the record. This pattern should be compared with rivers such as the Fraser, where the flow rate in the months of May and June exceeds that in the winter months by as much as an order of magnitude (Figure 5-6).

Although the combined discharge from the Cowichan and Koksilah Rivers provides the largest single source of fresh water to the region, not all of this discharge enters Saanich Inlet. Estimates of the proportion of the discharge from this source entering the inlet are discussed in Section 5.2.5.

5.2.2.2 Shawnigan Creek

The largest point source of fresh water directly entering Saanich Inlet is provided by Shawnigan Creek. Shawnigan Creek drains a watershed of roughly 92 km^2 and discharges into the west side of Saanich Inlet at Mill Bay, approximately 6 km south of the mouth of the inlet. The discharge from the creek is regulated by the upstream influence of Shawnigan Lake.

Discharge data for Shawnigan Creek were obtained from Environment Canada for the period from 1974 through 1993 and are plotted in Figure 5-12. The mean annual monthly discharge rate for Shawnigan Creek is 1.9 m^3/s, with discharge varying from a high of 5.3 m^3/s in December to a low of 0.03 m^3/s in September. Shawnigan Creek is essentially dry for the months of August and September, and has very low flow from May through July. This seasonal cycle is similar to that described above for the Cowichan and Koksilah Rivers.

5.2.2.3 Goldstream River

The third largest source of fresh water to Saanich Inlet is the Goldstream River, entering the inlet at the southernmost end of Finlayson Arm. Discharge from a significant portion of the Goldstream watershed is used by the Greater Victoria Water District as part of the water supply for the City of Victoria, however a minimum flow is always maintained in order to maintain spawning habitat in the river (Hull, pers. comm. 1995).

Discharge information for the Goldstream River for the period from 1973 through 1986 were measured by the Water Management Branch of the B.C. Ministry of Environment, Lands and Parks. Mean monthly flow rates for this period are plotted in Figure 5-13, showing a high of 2.0 m^3/s during December and a low of roughly 0.3 m^3/s in the months of May and June. The annual average monthly discharge rate for the Goldstream River is 0.9 m^3/s.

5.2.2.4 Minor Creeks and Streams

Much of the fresh water directly entering Saanich Inlet comes from the many small streams and creeks distributed along both sides of the inlet. With the exception of Tod Creek (Figure 5-13), discharge data from these sources were not available for use in this project.

Tod Creek flows into Tod Inlet, an arm of Brentwood Bay on the west side of Saanich Inlet. The drainage basin for Tod Creek is surprisingly large, with a surface area of 23 km^2. The watershed contains three lakes: Prospect Lake, Durrance Lake and Quarry Lake.

Although discharge from the creek was metered from 1982 through 1992, measurements were obtained only from April through September and data represent discharge from only one portion of the watershed (roughly 38%). Estimates of the mean monthly discharge from the entire Tod Creek watershed for a full year have been developed by the Water Survey Branch of the MELP and supplied to the study team (Blecic, pers. comm. 1995). These estimates range from a maximum of 0.8 m^3/s during the month of December to a minimum of roughly 0.01 m^3/s during the summer months, and indicate an average annual monthly discharge of 0.3 m^3/s. These data are plotted in Figure 5-13, together with the discharge data for the Goldstream River.

The remainder of the small streams and creeks discharging into Saanich Inlet can be grouped by watershed area, as shown in Figure 5-14. Of the six areas shown, runoff data are unavailable for four watersheds (Boatswain Bank, West Side, Southeast Side, and Saanich Peninsula). For the purposes of this project, estimates of the discharge from these regions have been developed from precipitation and watershed characteristics for each region.

Total monthly precipitation data covering the time period from 1970 through 1992 were obtained from Environment Canada for the stations marked on Figure 5-14. A simple model was used to convert precipitation and watershed areas to estimates for the runoff from non-point sources in the boxes. Fresh water fluxes were taken as a product of the relevant watershed area, precipitation rates from the closest available precipitation stations, and runoff coefficients developed by McRae Engineering Ltd. for the CRD (Humphrey, pers. comm. 1995). Mean monthly fresh water inputs by region as calculated in this manner are plotted in Figure 5-15, and summarized in Table 5-1.

Runoff coefficients differ for summer (April through September) and winter (October through March) seasons and for various land use classifications. Boatswain Bank, West Side and Southeast Side watersheds represent combined forest and residential land types, while Saanich Inlet is mainly agricultural land.

5.2.2.5 Direct Precipitation

The mean annual precipitation at the various recording stations around Saanich Inlet is shown in Figure 5-15. These stations together average 1058 mm of rainfall per year. Considering that the surface area of Saanich Inlet is 70 km^2 (Drinnan et al., 1995), the contribution of fresh water to the inlet through direct rainfall is roughly equivalent to an average annual input of 2.3 m^3/s. When compared to the other fresh water sources in Saanich Inlet, it can be seen that the input through direct precipitation contributes approximately the same amount of fresh water to Saanich Inlet as does the discharge from Shawnigan Creek.

When estimating the contribution of precipitation over land to the fresh water flows into Saanich Inlet (Section 5.2.2.4), it is clear that data from the nearest monitoring station should be used to estimate the rainfall over a given land area. However, it is not clear how precipitation data measured over land should be used to estimate rainfall over water, particularly when topographical effects on the rate of precipitation may be significant. In order to estimate the mean monthly input through direct precipitation on the water surface of Saanich Inlet, the monthly precipitation data from the recording station at Victoria International Airport were used. This monitoring station is close to the main body of Saanich Inlet and is located in a relatively flat area. The annual mean precipitation measured at the airport station is also the lowest of all the monitoring stations surrounding the inlet, thus providing a conservative estimate of the direct rainfall over the water surface of the inlet. Mean monthly inputs from direct precipitation, averaged over the period from 1970 through 1993, are plotted in Figure 5-14.

5.2.2.6 Summary of Fresh Water Inputs to Saanich Inlet

The contributions of fresh water to Saanich Inlet through the various sources described above (excluding the Cowichan and Koksilah Rivers) are summarized in Table 5-2. This table clearly illustrates several interesting characteristics of Saanich Inlet. Firstly, the direct fresh water input to the inlet is low, reflecting the small drainage basins surrounding the inlet. Secondly, the major sources of fresh water are distributed around the inlet rather than concentrated at the head, with more of the fresh water entering the western side than the eastern side. These two factors contribute to the complex circulation patterns observed in the inlet, as described in Section 5.1.2.4.

5.2.2.7 Seasonal Regimes

Seasonal variations in the oceanographic processes in Saanich Inlet must be considered in order to develop representative modelling scenarios for the contaminant fate modelling system and to divide the inlet into boxes representing homogeneous water masses. The fresh water flow into Saanich Inlet drives the long-term estuarine circulation patterns within the inlet, while the fresh water content in the adjoining channels has a strong effect on the occurrence of deep-water renewal events. Hence, the division of the yearly cycles into characteristic "seasons" has been based mainly on variations in the fresh water discharge rates.

Figure 5-11, Figure 5-12, Figure 5-13 and Figure 5-15 show the annual cycle in mean monthly discharge rates for the combined Cowichan and Koksilah Rivers, Shawnigan Creek, Goldstream River, minor creeks and streams, and precipitation falling directly on the surface waters of the inlet. Each of these figures show a strong seasonal cycle, with maximum flows during the winter months from November through February, and minimum flows during the summer months from May through September.

For the purposes of this project, the annual cycle has been divided into five periods, or "seasons":

- Winter, represented by the high flow months of November through February

- Spring, a transition period between the wet and dry seasons, represented by the months of March and April

- Summer, the low flow season of May, June and July

- Summer Renewal, with low fresh water inputs plus deep-water renewal events, assumed to occur primarily in August and September

- Fall, characterized by moderate fresh water inflows during the month of October

5.2.2.8 Long-term Variability In Regional Fresh Water Discharge (1960-1993)

Previous work has suggested that long-term cycles in precipitation may be an important factor affecting stream discharges in southern Vancouver Island (Hull, pers. comm. 1995). Long-term studies of the infilling of the water supply reservoir for the City of Victoria have indicated the presence of an approximate 10-year cycle in stream flows leading into the reservoir.

To examine the long-term variability of runoff in the Saanich Inlet region, the combined discharge of the Cowichan and Koksilah Rivers from 1960 to 1993 was filtered using a 3-year running mean. With this filter, cycles of greater than 3 years in length are more easily visible than when looking at raw monthly data. The filtered river discharge is shown in Figure 5-16.

The variability seen in Figure 5-16 indicates an 8- to 10-year cycle in the discharge of the Cowichan-Koksilah River system. Two particular time periods are of interest: the years from 1976 to 1978, representing the period covered by much of the oceanographic data used in this study; and present-day conditions.

Figure 5-16 shows that the 1976 to 1978 time period coincides with one of the notable dry periods over the 33 year record, making this time period extremely useful for examining low flow conditions (i.e., low flushing conditions). It is unclear from recent precipitation and stream flow data if present-day conditions reflect those of the 1976 to 1978 time period. Figure 5-16 indicates a peak river discharge around 1990, with declining discharge levels through 1993. Monthly river flow data were not available for 1994 and 1995. However, precipitation data recorded at Victoria International Airport indicate that 1994 was close to an average year, with total precipitation roughly 5% higher than the long-term average value. It is not known if the 8- to 10-year cycle in discharge observed in the record from 1960 to 1993 will persist into the future. Thus, predictions of future flow conditions cannot be made.

5.2.3 Salinity Data

Spatial variations in water column properties, particularly salinity, are an important factor in the division of Saanich Inlet into representative boxes. The maximum number of model boxes is limited by several factors, including the amount of data available. Each physical box must contain salinity data representing each season of interest; ideally, enough data would also be available for each box such that the averaging process would remove any variations induced by the tidal cycle.

Water column measurements for Saanich Inlet are available from a variety of sources, including early measurements described by Herlinveaux (1962), Institute of Ocean Sciences (IOS) data collected from 1976 to 1978 and in 1983, data collected by the University of British Columbia covering the period from 1977 through 1989, and recent measurements collected by Aquametrix Research Ltd. (Cross and Chandler, 1996).

A general summary of the water column structure in Saanich Inlet is presented by Drinnan et al. (1995). Wide variations in temperature and salinity are apparent in the surface waters, with lowest temperatures and salinities in winter, and the highest values in the summer season. This cycle reflects the relatively high input of fresh water to the inlet during the winter months. Measurements deeper in the water column show the same seasonal signal, although the fluctuations in temperature and salinity decrease with increasing water depth. Properties of the deep basin waters (ca. 200 m) are very constant, with the exception of dissolved oxygen concentrations.

Recent data described by Cross and Chandler (1996) show some interesting spatial variations in water properties. The data collected in December of 1994 show a cold, brackish layer on top of warmer saline water everywhere in the area except in the middle of Satellite Channel. The brackish layer appears to deepen with distance down Saanich Inlet from the head, at the same time becoming colder and less saline on the surface (Drinnan et al., 1995), following the classical estuarine circulation pattern shown in Figure 5-5. A cross-inlet transect from Mill Bay to Patricia Bay indicates colder, near-surface water on the east side of the inlet, with warmer, deeper (> 10 m) water on the same side.

For the purposes of the box model, a data set with good spatial and seasonal coverage of the inlet is required. These requirements are best met by the data collected by the IOS (Coastal Zone Oceanography Section, 1980), covering the time period from April 1976 through November 1978. CTD and dissolved oxygen profiles were collected at 6 stations within the inlet and 3 stations outside of the inlet, at approximately monthly intervals. Station locations for this data set are shown in Figure 5-3.

Although the IOS data set provides a good picture of the longitudinal variations of water column properties in Saanich Inlet, information about cross-channel variations is limited. Two joint surveys by Aquametrix Research Ltd. and IOS were conducted to address this concern (Cross and Chandler, 1996); the first survey measured winter conditions in December of 1994 while the second survey measured summer conditions during July 1995. Data from these surveys were used to determine cross-channel salinity variations and embayment box salinities. Station locations for the December and July surveys are shown in Figure 5-17 and Figure 5-18, respectively.

5.2.4 Box Model Structure for Saanich Inlet

As discussed in Section 5.2.1, the sub-division of the waters of Saanich Inlet into boxes is based on a combination of logical physical boundaries, the physical oceanography of each region, the amount and spacing of available data and observed changes in water column properties. The structure of the box model developed for Saanich Inlet is shown in plan view in Figure 5-19.

Saanich Inlet has been divided into 9 regions in the horizontal direction:

Entrance (East and West): This region lies over the sill at the mouth of Saanich Inlet, thus having significantly shallower waters than in the adjoining Central Basin regions. The Entrance region has been further sub-divided into west and east boxes in order to reflect the previous observations that fresh water from the Cowichan River system enters Saanich Inlet on the western side, with strong surface outflows observed on the eastern side of the inlet. Deep Cove, on the eastern side of the Entrance region, has been considered as part of the eastern box rather than as a separate region.

Central Basin (East and West): The Central Basin is the largest region of Saanich Inlet, extending from Willis Point in the south to Whiskey Point in the north. The east and west sides of the Central Basin have been separated into distinct water masses based on previous observations of cross-channel variations in the surface water properties. All three embayment regions used in this project open into the Central Basin.

Squally Reach: Squally Reach is the upper part of the lower arm of Saanich Inlet, and is significantly narrower than the Entrance and Central Basin regions. The reach runs from Elbow

Point in the south to Willis Point in the north, where it meets the waters of the Central Basin. Squally Reach has no major point source of fresh water.

Finlayson Arm: Finlayson Arm lies south of Elbow Point, and represents the southernmost end of Saanich Inlet (head of the inlet). The major source of fresh water to Finlayson Arm is the Goldstream River. From an oceanographic perspective, Squally Reach and Finlayson Arm are very similar, but there appears to be a consistent estuarine signature in their respective salinities, suggesting that the entire region south of Willis Point constitutes an estuary, partially-decoupled from the rest of the basin region.

Mill Bay: Mill Bay is the smallest of the three embayments identified for this modelling project, and is the only embayment on the western side of Saanich Inlet. The largest point source of fresh water directly entering Saanich Inlet is Shawnigan Creek, discharging into Mill Bay.

Brentwood Bay: Brentwood Bay joins the eastern box of the Central Basin near the southern end of the Central Basin. For the purposes of this project, Brentwood Bay includes Tod Inlet. The bay has two point sources of fresh water: Tod Creek and Hagan Creek. Brentwood Bay represents the most densely populated area adjoining Saanich Inlet.

Patricia Bay: Patricia Bay (commonly known as Pat Bay) lies to the north of Brentwood Bay, on the eastern side of the Central Basin. The Institute of Ocean Sciences is located on the shores of Pat Bay, which also borders on the Victoria International Airport.

In the vertical direction, the main body of Saanich Inlet has been sub-divided into three layers. The surface layer has been chosen to represent the outwardly flowing brackish layer that is an integral part of the estuarine flow pattern shown in Figure 5-5. As the brackish layer moves outward from the sources of fresh water (primarily Finlayson Arm and the coastal embayments), the surface layer thickens slightly. It should be noted that, even though the volume flux of the fresh water entering the box is amplified several times as it leaves the box, the layer thickness does not increase proportionally: most of the increase in volume flux is accounted for by an increase in the surface layer velocities.

Surface layer box depths are 5 m in Finlayson Arm, 8 m in the three embayments of Mill Bay, Brentwood Bay and Pat Bay, and 10 m in the main body of Saanich Inlet and in Squally Reach. These depths have been determined from a review of the salinity profiles in each region.

In an estuarine flow system, the thin, outwardly-flowing, brackish surface layer is coupled with a thicker, slower, deeper layer providing the compensating inflow of saltier water (Tinis, 1995; Baker, 1992). This lower layer has been defined to extend from the bottom of the surface layer to sill depth (assumed at 80 m) for the main Saanich Inlet boxes; and from the bottom of the surface layer to the seabed for the coastal embayment boxes.

The deep basin waters in the main channel of Saanich Inlet are represented by an additional four boxes extending from 80 m to the seabed. These boxes are located in Finlayson Arm, Squally Reach and the east and west sides of the Central Basin. The box bottom has been set at 225 m for these boxes, with the exception of Finlayson Arm, where an average maximum depth of 180 m has been assumed.

As a consequence of the three-dimensional nature of this box arrangement, it is difficult to present a flat paper view representing the model structure. A schematized version of the box model is shown in Figure 5-19, with plan views of each of the three layers of boxes together with vertical cross-sections of various regions of the inlet. In this figure, each square or rectangle represents one model box (box dimensions are not to scale).

The fresh water inflows to Saanich Inlet are represented as circles, with the total fresh water inflow to each model box in the surface layer given in subsequent figures showing model results. The fresh water inflows represent the sum of all fresh water inputs entering that model box from the sources described previously in Section 5.2.2. Inflows of marine water to Saanich Inlet are shown as ellipses and include an inflow of surface water on the western side of the inlet and the renewal water assumed to flow directly into the bottom box on the eastern side of the Central Basin. The circles and ellipses represent the flow boundary conditions that must be specified in order to run the oceanographic model.

Figure 5-19 also shows the assumed directions of flow between the various model boxes as used in the current project. The model system as presented contains 22 model boxes; applying equations 5-1 and 5-2 to each model box leads to a system of 44 linear equations. The model system can then be solved for a maximum of 44 unknown fluxes. Ideally, the exchanges between each of the boxes should be two-way in both vertical and horizontal directions; however, this creates an unsolveable model system with a total of 86 unknown values.

To restrict the number of unknown fluxes to 44 (the total number of linear equations) and thus create a solvable system of equations, many of the horizontal fluxes have been restricted such that flow is permitted in only one direction (i.e., some of the horizontal fluxes have been assumed to be zero). For a classical two-layer estuarine system, this procedure is quite simple, in that flow is consistently down-inlet in the surface layer from the head of the inlet to the mouth, and consistently up-inlet in the bottom layer.

However, the longitudinal splitting of the Central Basin and Entrance boxes in the Saanich Inlet model presents two challenges: firstly, the direction of the horizontal fluxes in the surface layer was not immediately obvious and had to be established using other than the classical estuarine flow pattern assumptions. Secondly, some of the unknown fluxes still had to be specified in order to create a solvable system of equations.

The directions for the horizontal fluxes in the surface layer have been based on the previous observations of flow patterns in the inlet. For the lower reaches of the inlet and the coastal embayments, the flow direction was taken to be consistent with that of a positive estuary, with surface flow in the outwards direction. The previous studies described in Section 5.1.2.4 suggest that the flow in the surface layer of the main channel is generally cyclonic in nature, moving southwards on the western side of the inlet and northwards on the eastern side. A net movement from west to east in the Central Basin has also been observed.

The flow directions shown in Figure 5-19 have been set to match these observations of surface layer flows. With the surface layer flow directions established, the lower layer fluxes were set by necessity (conservation of volume) to be opposite in direction to those at the surface. However, the oceanographic model formulation still requires additional fluxes to be specified in order to create a solvable model system.

Several of these fluxes have been set to zero: the horizontal fluxes connecting Central Basin West and Squally Reach in the upper and lower layers, and the horizontal fluxes connecting the Entrance East and West boxes. The closing of the connection between the Central Basin West box and the Squally Reach box has been based on anecdotal evidence suggesting a zone of little net water movement; available data also indicated that the lower reaches were somewhat isolated in an oceanographic sense from the main channel.

The remaining fluxes required to run the oceanographic model were prescribed at the surface boundary between Satellite Channel and the Entrance West box, and between the Entrance West and Central Basin West boxes. The rate of inflow to the deep basin boxes during the summer renewal season must also be determined in order to run the model for the months of August and September. The calculation of these flux values will be described in the following section.

5.2.5 Model Parameters

The approach taken in the application of the box model to Saanich Inlet has differed from many previous box modelling studies (e.g., EVS et al., 1995; Petrie and Yeats, 1990; ASA Consulting

Ltd., 1986), in that averaging of salinity data on a seasonal basis prior to performing model runs was not feasible for Saanich Inlet. The variability of the salinity data at a single station in Saanich Inlet was found to be quite large, even when data sets were first sorted by season. Because the salinity gradients in Saanich Inlet are normally quite small, the averaging of the data sets prior to model implementation often had the net effect of erasing the spatial gradients that were present in individual data sets.

To avoid this difficulty, the seasonal averaging approach was modified such that model runs were performed for each individual data set (i.e., for each cruise). The model results were then grouped *a posteriori* into seasonal bins. Since the model is linear, the salinities and resulting fluxes from individual model runs could then be averaged together, with the results representative of mean conditions.

Box salinities for each model box have been determined by vertically integrating the appropriate salinity profile and dividing by the height of the box. It should be noted that the salinity data used for this project were obtained from stations located along a rough centreline of the inlet as shown in Figure 5-3. Thus, two related issues remain: how to specify the salinities on both sides of the Central Basin and Entrance Boxes, and how to specify the salinities in the coastal embayment boxes (Mill Bay, Brentwood Bay and Pat Bay).

Data from the joint IOS and Aquametrix surveys (Cross and Chandler, 1996) were used to examine cross-channel salinity gradients and embayment box salinities. The station locations shown in Figure 5-17 and Figure 5-18 show three cross-channel transects: the S4 stations, with one end in Coles Bay; the S5 stations between Mill Bay and Pat Bay; and the S6 stations across the mouth of Saanich Inlet. These transects were used to determine typical cross-channel salinity gradients for both winter and summer conditions. Salinities in the Mill Bay and Patricia Bay boxes were determined from the salinity profiles measured at each end of the S5 transect, using the layer depth determined from the data within each respective embayment. Brentwood Bay salinities were assumed to be equal to those of Pat Bay. Cross-channel salinity gradients were less in the summer than in the winter months, reflecting the lower fresh water input to the inlet during summer.

The above analyses determined that the typical surface cross-channel salinity gradient between the east and west Central Basin boxes was approximately 0.2 parts per thousand (ppt) for summer conditions and 0.3 ppt for the winter season, with stronger gradients between the Entrance boxes (Figure 5-20 through Figure 5-25). These cross-channel gradients were then applied to the averaged salinities from the CTD stations located along the inlet centreline. Salinity transects across the inlet were not available for spring, summer renewal and fall conditions. For the purposes of this project, the winter season gradient was applied to all winter, spring and fall model runs, with the summer season gradient used for the summer and summer renewal seasons. However, the cross-channel gradients used in the summer and summer renewal seasons were also scaled up or down on a cruise-by-cruise basis to reflect the large variations in longitudinal salinity gradients in the inlet during these seasons. An example of the resulting box salinities, drawn as a profile line from the head of Finlayson Arm to the mouth of the inlet, is shown in Figure 5-20 for average conditions during the winter season (November through February).

The model also requires fresh water inputs to each surface box to be specified as input parameters. As discussed in Section 5.2.2, fresh water inputs to Saanich Inlet have been estimated from a combination of available discharge measurements (Shawnigan Creek and Goldstream River) and precipitation-based estimates. Since model runs were performed for each individual monthly survey rather than by using salinity data averaged on a long-term, seasonal basis, the fresh water inflows have also been separately estimated for each individual cruise used in the oceanographic model.

As described previously, two additional fluxes must be prescribed for all model runs. These fluxes have been chosen as the surface boundary flux between Satellite Channel and the Entrance West box, and the surface flux between the Entrance West and Central Basin West boxes. The surface boundary flux between Satellite Channel and the Entrance West box has been based on the combined outflow from the Cowichan and Koksilah Rivers, using the following approach.

It has been assumed that the discharge from the Cowichan/Koksilah system follows the typical positive estuarine flow pattern, with outward flow in the surface layer and inward flow in the deeper layer. The surface layer is fresher than the deeper layer, with salinities increasing in the seaward direction. A simple two-box, two-layer system representing this flow pattern is shown in Figure 5-21. Applying equations 5-1 and 5-2 to such a flow system yields the following result for Q_{OUT}, the seaward flux in the surface layer.

$$Q_{OUT} = \left(\frac{S_{IN} - S_{FRESH}}{S_{IN} - S_{UPPER}} \right) Q_{FRESH} \qquad (5\text{-}3)$$

The fresh water amplification factor, representing the increase in volume flux of the river discharge as it flows seaward in the estuary, is given by the term in brackets in equation 5-3.

The amplification factor, as it applies to the combined discharge from the Cowichan and Koksilah Rivers, has been calculated at the mouth of Saanich Inlet. The salinity at Station 6A (Figure 5-17) has been used to represent the salinity in the upper layer (S_{UPPER}), the salinity in the lower Entrance West box has been used to represent the salinity of the inward flow in the deep layer (S_{IN}), and the salinity of the Cowichan/Koksilah discharge (S_{FRESH}) has been assumed to be zero. When multiplied by the discharge from the Cowichan and Koksilah Rivers (Q_{FRESH}), an estimate of the seaward flux of brackish water exiting from Cowichan Bay is obtained.

It has been assumed that very little of the water exiting from Cowichan Bay moves northward through Sansum Narrows and that the Cowichan River water is well-distributed (but not uniformly mixed) across Satellite Channel. Based on consideration of the geometry and relative orientations of Satellite Channel and Saanich Inlet, lower and upper bounds of 25% and 50%, respectively, have been estimated for the portion of the total brackish outflow that enters Saanich Inlet from Cowichan Bay. Model sensitivity to this value is discussed in Section 5.3.2.

In a similar manner, the amplification factor between the Entrance West and Central Basin West boxes have been determined using the above boundary influx values and the respective box salinities. This flux was found to be consistently 10% higher than the boundary inflow to the surface Entrance West box.

The last remaining boundary value that must be specified in order to run the oceanographic model is the rate of inflow to the deep basin boxes during the summer renewal season. The average renewal flux can be calculated from estimates of renewal volumes and flushing periods provided by Anderson and Devol (1973). Assuming that flushing starts at the beginning of August, calculated fluxes range from 59 to 162 m^3/s.

Stucchi and Giovando (1983) observed renewal fluxes occurring in periodic pulses lasting from 8 to 10 days, separated by periods of no renewal flow. While inflow speeds were on the order of 0.1 m/s, inflows were slowed, or even arrested, on the ebb tide. Inflows were seen to extend from the seabed upwards about 10 to 14 m into the water column, with the top of the inflowing layer at roughly 72 m. Assuming an average inflow velocity of 0.05 m/s, an average inflowing layer depth of 8 m and a layer width of 1000 m (reflecting roughly that portion of the cross-section at Station A where water depths exceed 72 m), leads to a renewal pulse flux of 400 m^3/s. As this flux typically lasts for a 9-day period out of each renewal month, average monthly fluxes can then be estimated to be about 120 m^3/s.

The inflow of renewal water is assumed to occur primarily over the eastern side of the sill, where the deepest water depths can be found. In the oceanographic model, renewal water flows into the Central Basin East box. Again, certain of the fluxes between the four bottom boxes must be prescribed to maintain a solvable set of equations for the summer renewal season. It has been assumed that the directions of the fluxes between the bottom boxes are as shown in Figure 5-19, with the total renewal influx divided between the four deep basin boxes on a volumetric basis. Hence, the horizontal fluxes between the deep basin boxes are simply pre-determined percentages of the total renewal flux.

The salinities in the bottom boxes were also found to be equal, with the exception of a small decrease of 0.1 ppt in the bottom waters of Finlayson Arm. The salinity of the renewal water has been set at 31.2 ppt, based on observations at Mooring A (Stucchi and Giovando, 1983). The oceanographic model then solves for the vertical fluxes between each bottom box and the overlying box in the lower layer.

5.3 Findings

Of the total of 30 cruises for which CTD data were available, model runs were completed for 17 cruises. Of the remaining 13 cruises, 3 were rejected due to bad or incomplete data sets. Data from six of the cruises showed no significant salinity gradient in the inlet, with the remaining four indicating a negative salinity gradient in the surface waters of Saanich Inlet (Table 5-3). Results for the 17 cruises where modelling was possible are described next, followed by some discussion of the conditions for which the oceanographic box model as developed during this project was not appropriate.

5.3.1 Model Results

As discussed in Section 5.2.2.7, the annual cycle in Saanich Inlet has been sub-divided into five periods, or "seasons", based primarily on variations in average monthly fresh water inflow to the inlet:

- Winter: November, December, January, February
- Spring: March and April
- Summer: May, June and July
- Summer Renewal: August and September
- Fall: October

Model runs have been performed separately for each individual month of data to preserve the relatively small salinity gradients normally present in Saanich Inlet. Fresh water inflows have been estimated for each individual month, using historical stream flow and precipitation records. Thus, the fresh water flows corresponding to each individual modelling month do not necessarily correspond to the average seasonal conditions. This factor was considered in the grouping of model results into seasonal bins (e.g., a particularly wet March might have been grouped with the winter runs rather than the spring runs).

Figure 5-22 shows the model results for winter conditions, where the rate of direct fresh water input to Saanich Inlet has been estimated at 14.4 m^3/s. Fresh water inflows, salinities and fluxes between model boxes are shown. All flow rates are in m^3/s and all units for salinities in ppt. In a similar manner, model results for the spring, summer and summer renewal seasons are shown in Figure 5-23 through Figure 5-25. Total direct fresh water inputs to the inlet for these seasons are 5.6 m^3/s for spring, 1.7 m^3/s for summer and 2.9 m^3/s for the summer renewal season.

No model runs were possible for the month of October, representing the fall season, since salinity data were not available for that month. However, the fresh water inflows to Saanich Inlet during the fall season are very similar to those during the spring season, so the spring modelling results have also been used to represent fall conditions in the inlet.

A comparison of Figure 5-22 through Figure 5-25 shows that the circulation within Saanich Inlet is strongest in the winter season and weakest in the summer and summer renewal seasons, reflecting the strong influence of fresh water inflow rate on the estuarine flow pattern in the inlet. Both horizontal and vertical fluxes are generally stronger on the eastern side of the inlet than on the western side, probably as a consequence of the assumed connection between the Squally Reach box and the Central Basin East model box.

The results of the model runs for the summer renewal season are shown in Figure 5-25. These runs were performed using an average renewal flux of 50 m^3/s, the maximum value that could be used without causing failure of the box model. Surprisingly, the renewal flux acted to decrease both the horizontal and vertical exchange rates from those predicted for the slightly drier summer months of May through July. The circulation in the inlet slows as a result of the salt added to the system through the renewal water; fresh water must then be retained in the lower and upper layers of the model system in order to compensate for the saltier influx in the bottom waters while maintaining the observed salinity gradients.

This slowing of the circulation in the system during the summer renewal season may be an artifact of the box model assumption of fixed box depths. If the renewal influx to the bottom box was assumed instead to raise the depth of the boundary between the bottom and lower boxes, no fluid exchanges would occur between the two layers. This situation would be analogous to the summer conditions with no renewal influx, and the box model would predict larger horizontal and vertical fluxes. In reality, a combination of the two processes probably occurs.

Based on the results of the oceanographic model, the residence times for the various model boxes have been computed. Residence time is an indication of the average time that water is resident within each box; it is defined as the volume of the box divided by the sum of all outflowing fluxes. Annual average residence times are defined as the volume of each box divided by the average annual flux out of that box.

Table 5-4 shows a wide range of residence times for the various regions of Saanich Inlet. The residence times in the entrance boxes are surprisingly low, indicating rapid flushing. Residence times increase with distance up the inlet away from the mouth, particularly in the lower layer. Residence times are longest in the deep bottom waters, reflecting the limited flushing occurring only during the summer renewal season.

5.3.2 Sensitivity Analyses

For a complex box model such as that described here for Saanich Inlet, many of the fluxes must be predetermined in order to reduce the number of variables such that the model system can be solved. Many exchanges have been set to zero through limiting flows between model boxes to only one possible direction, with the flow direction chosen to be consistent with a typical estuarine circulation pattern and the observed salinity gradients in the inlet.

Three additional fluxes were prescribed in order to run the box model: the brackish water inflow of surface waters at the mouth of the Entrance West box, the surface exchange between the Entrance West and the Central Basin West boxes, and the deep water renewal flux for the summer renewal season. The total brackish water outflow from the Cowichan River in Satellite Channel has been estimated using the amplification factor approach as described in Section 5.2.5; model runs used the assumption that 50% of the brackish water outflow in Satellite Channel entered the mouth of Saanich Inlet.

To test the model sensitivity to this flux, model runs were repeated assuming that only 25% of the brackish outflow enters the mouth of Saanich Inlet. In all cases, the circulation in the embayments and south of Squally Reach was unaffected, since these regions are essentially decoupled from the circulation in the main body of Saanich Inlet. The circulation in the Central Basin and Entrance boxes was strongly affected, with the resulting fluxes reduced by 40 to

50%. Hence, an independent assessment of the mean surface inflow to Saanich Inlet would assist in model calibration. It should be noted that the Fraser River may also be responsible for a large amount of brackish water in Satellite Channel during spring and summer months.

The model results were found to be extremely sensitive to estimates of the renewal flux. Four data sets were available for the summer renewal months of August and September (Table 5-3); all four cruises gave reasonable model results when run without the renewal flux. When the renewal flux was added to the system, the model failed for two of the data sets at renewal flux values less than 50 m^3/s. The remaining two data sets provided reasonable model results using flux values up to a maximum of 50 m^3/s.

Several factors may be involved in the model sensitivity to renewal fluxes. Firstly, estimates of the renewal flux are uncertain, and should be considered as order of magnitude estimates only. Secondly, the available data sets may not correspond to periods where renewal processes were active, hence the model should not be expected to yield reasonable results with a renewal flux added. Finally, the box model structure, with the boundary between the intermediate and deep layers set at 80 m, is such that some of the renewal flux may actually be flowing into the lower layer of boxes rather than into the bottom layer.

In its present formulation, the box model is entirely driven by salinity gradients induced by fresh or brackish waters flowing into the inlet. The estimation of these inflows is detailed in Section 5.2.2. Accurate measurements of discharge from many of the small streams and creeks entering the inlet were not available; flow estimates were based on precipitation data and watershed characteristics. Inflows from small creeks and streams are particularly important to the circulation between the coastal embayments and the main body of Saanich Inlet.

The model results were also tested for sensitivity to changes in the rate of fresh water inflow to the inlet. The coastal embayments are very sensitive to changes in fresh water inputs, with an increase or decrease of 50% in the fresh water inflow to an embayment reflected in a corresponding 50% increase or decrease in the fluxes between the embayment and the main body of the inlet. This direct relationship reflects the fact that circulation in the embayments (as represented by the box model) is essentially decoupled from the flows in the main body of the inlet. Finlayson Arm and Squally reach showed a similar response to changes in fresh water inputs.

The fluxes in the central channel were much less sensitive to changes in the fresh water loading rate, showing changes ranging from 1 to 10% for a 50% increase in fresh water inflows during average summer conditions, and changes ranging from 7 to 16% for a similar 50%

increase in fresh water inflows during average winter conditions. Thus, the circulation in the main body of Saanich Inlet is much more sensitive to the brackish influx at the mouth of the inlet than to changes in the direct local fresh water inputs.

The model runs within each season (i.e., winter, spring, summer and summer renewal; Figure 5-21 through Figure 5-25) have been compared in order to assess the variability in model fluxes. This comparison has shown that for the winter runs (4 cruises) model fluxes varied by as much as 110% from the average, with typical variability on the order of 50%. Spring (6 cruises) and summer (3 cruises) model runs showed similar variability. Summer renewal (4 cruises) model runs indicated slightly lower variability in the model results.

5.3.3 Model Limitations

The oceanographic model presented in this report reflects, within the limitations of the box modelling approach, a compilation and integration of currently available information on the circulation and flushing of Saanich Inlet. Many of the uncertainties in the box model reflect uncertainties in the current state of knowledge regarding oceanographic processes in the inlet.

In particular, there are few actual measurements of mean currents within the inlet, except for the drifter studies described earlier in this report. However, drifter movements are indirect measures of mean circulation patterns and speeds, in that they are strongly affected by short-term processes such as tides and winds, and deployment periods are often not frequent enough or of sufficient duration to resolve mean circulation patterns. This is particularly evident for summer conditions, when mean circulation patterns in the inlet appear to be highly variable.

Several limitations to the box model approach as applied here have also become apparent during the course of this project. These include:

- The lack of measurements of fresh water inflows to the various regions of the inlet, particularly the coastal embayments.
- Limited data sets that could be used to typify average conditions for each identified season, particularly the summer, summer renewal and fall seasons.
- Weak and variable tracer (fresh water) inputs during the summer months (May through September).

- The complex, three-dimensional structure of the box model requires that many exchanges between boxes be restricted in direction and that additional fluxes be prescribed.

Of these limitations, the first three would likely apply to any modelling exercise where the density structure of the water column were to be included. However, the limitation of weak and variable tracer inputs during certain seasons has particular impact on the box modelling approach, since it relies on gradients in tracer concentrations to drive the model. This limitation is particularly evident for six of the data sets that could not be used in this modelling exercise.

Six of the 30 CTD data sets available for use in this project showed no significant salinity gradients within Saanich Inlet (Table 5-3). Of these six, four represented conditions during the summer or summer renewal seasons (September of 1977 and 1978, May and July, 1978). It should be noted that these years represent the driest portion of the long-term cycle apparent in fresh water discharge (Figure 5-16). The remaining two data sets lacking significant salinity gradients (November 1976 and October 1978) show the definite effects of wind mixing in the salinity profiles at each station.

The final model limitation listed above, the restriction of possible flow directions between the various model boxes, was necessitated in order to reduce the number of variables in the model system such that a unique solution to the model equations (Equations 5-1 and 5-2) became possible. While the flow directions built into the model system have been based on available knowledge of circulation patterns within the inlet, these assumptions were not appropriate for four of the data sets examined during this project.

The salinity profiles measured during the December 1976, July 1977 (two cruises) and November 1977 cruises show a negative salinity gradient in the surface waters of Saanich Inlet, with the lowest salinities at the mouth of the inlet. The negative gradients observed during the two winter cruises may reflect the impact of high discharges from the Cowichan and Koksilah Rivers during these time periods, when large amounts of relatively fresh water in Satellite Channel may act to block the outflow of saltier surface waters from within Saanich Inlet. The negative gradients observed during July may reflect the effects of the Fraser River freshet on the waters of Satellite Channel.

5.3.4 Considerations for Model Improvement

The assumptions, results and limitations inherent in this modelling exercise have been fully discussed in the preceding material in this report. In order to refine the predictions of the oceanographic model, the following would be required:

- Fresh water inputs to the inlet should be more accurately quantified, particularly for the coastal embayments of Mill Bay, Brentwood Bay and Patricia Bay. The rate of flushing of these embayments is directly proportional to the rate of fresh water inflow (Equation 5-3 and Table 5-4).

- Independent estimates of the mean currents within Saanich Inlet should be obtained. The recent current meter deployments should provide some information that could be used to calibrate or verify the model predictions. The magnitude of tidal residuals is of particular interest. Additional current meter deployments elsewhere in the inlet would also provide useful information for any modelling exercise. The recent drifter observations (Cross and Chandler, 1996) would also benefit from more detailed analyses, particularly in terms of correlations with winds and tides and a thorough comparison of winter and summer conditions.

- Better estimates of the renewal fluxes, duration, frequency and extent of impact on the bottom waters of Saanich Inlet would aid in the modelling of flows during the summer renewal season. The particular mechanisms by which renewal water flows into the bottom boxes should also be investigated (i.e., mixing versus upward displacement).

- The formulation of the oceanographic model could be refined through the consideration of a second tracer, such as temperature. Although beyond the scope of this project, addition of a second tracer to the modelling database would perhaps allow the restrictions on flow directions to be reduced or even eliminated. In particular, inclusion of a two-way flow between the Central Basin boxes may more accurately represent the gyre observed during the July 1995 field program.

- Finally, more synoptic data sets with good spatial and seasonal coverage of the inlet would allow model predictions to be refined in the future.

The efforts required to modify or improve the predictions of the oceanographic model must be considered in terms of the overall goals of this project, to determine the assimilative capacity of Saanich Inlet for various contaminants. Thus, before further efforts are put into refining the oceanographic model, the magnitude and relative importance of uncertainties in the other components of the contaminant fate modelling system should also be considered.

5.4 Model Certainty

In general, the processes leading to flushing of the waters in Saanich Inlet appear to be fairly weak, particularly for the waters of the deep central basin. Due to the generally weak and variable forcings, the relative magnitudes of the various oceanographic processes remains somewhat unclear. Nevertheless, the oceanographic model developed for this project has focused on development of a model system that reflected, as far as possible, the state of knowledge with respect to mean circulation patterns within the inlet at the time of model development.

The model has several limitations, which are discussed fully in the previous material and summarized here. A primary limitation of the model is the inability to represent processes other than estuarine circulation, and to deal with conditions where salinity gradients in the inlet either do not exist or are contrary to the assumed direction of flow. Insignificant or negative salinity gradients were found to exist either in summer months, when brackish water from the Fraser River freshet is present at the mouth of the inlet, or during early winter, when discharge from the Cowichan and Koksilah Rivers is high. During these times, flushing of the inlet may be minimal, or flow directions may be reversed from those assumed in the oceanographic model.

The oceanographic model described in this section was developed in the early stages of this project (Summer 1995), as it provides the foundation from which the sediment transport and contaminants models are built. Since that time, ongoing work at the Institute of Ocean Sciences has provided additional insights (Winter 1996) into the oceanographic processes active in Saanich Inlet. Current measurements on the east and west sides of the inlet (Stucchi, pers. comm. 1996a) between the S5 and S6 transects have confirmed the net inflow on the west side of the inlet, and net outflow on the east side. Further analyses of water properties throughout the inlet have indicated that flushing of the inlet in the summer months is largely driven by fortnightly variations in the tidal cycle, a process that is not reproduced by the oceanographic model.

The question remains as to the accuracy and reliability of the model results for predicting water circulation in the inlet. The model results from the spring and winter seasons are considered to be the most reliable, since the estuarine flow pattern is most firmly established during these periods. The main factor affecting the variability in the model predictions for the main body of the inlet is the quantity of brackish inflow at the mouth, while the coastal embayments and Finlayson Arm are most sensitive to the rate of local fresh water input.

Model results for summer and summer renewal seasons are considered significantly less reliable, particularly with respect to flushing of the embayments. Recent evidence suggests that flushing of the embayments during the summer months is not primarily driven by estuarine circulation; other processes such as wind-driven and tidal mixing may dominate. The residence times given in Table 5-4 for the summer and summer renewal seasons are probably too long, perhaps by an order of magnitude in embayments (i.e., Mill Bay, Patricia Bay and Brentwood Bay, Squally Reach). Reasonable values are now thought to be on the order of a few weeks (Stucchi, pers. comm. 1996b) for the surface waters of the embayments.

Table 5-1 Average annual flow rates for four ungauged watersheds draining into Saanich Inlet.

Watershed	Watershed Area (km^2)	Precipitation Station	Runoff Coefficient, Summer	Runoff Coefficient, Winter	Average annual flow rate (m^3/s)
Boatswain Bank	22	Cherry Point	0.40	0.75	0.46
West Side	62	Shawnigan Lake	0.475	0.775	1.7
Southeast Side	14	Victoria Highland	0.475	0.775	0.36
Saanich Peninsula	43	Victoria International Airport	0.10	0.75	0.71

Table 5-2 Sources of fresh water to Saanich Inlet.

Source	Average Annual Flow Rate (m^3/s)
Shawnigan Creek	1.9
Goldstream River	0.92
Minor creeks and streams:	
Tod Creek	0.30
Boatswain Bank Watershed	0.46
West Side Watershed	1.7
Southeast Side Watershed	0.36
Saanich Peninsula	0.71
Direct Precipitation	2.3

Table 5-3 Summary of Saanich Inlet CTD cruises, 1976-1978.

Cruise Number	Month	Status
7624	April 1976	Used for modelling
7625	May 1976	Used for modelling
7626	July 1976	Poor data
7627	Aug 1976	Used for modelling
7628	Sept 1976	Used for modelling
7629	Nov 1976	Well-mixed to 15 m, no surface gradient
7630	Dec 1976	Negative gradient
7721	Mar 1977	Used for modelling
7722	Apr 1977	Used for modelling
7723	May 1977	Used for modelling
7724	May 1977	Used for modelling
7725	July 1977	Weak, negative gradient
7726	July 1977	Weak, negative gradient
7727	Aug 1977	Used for modelling
7728	Sept 1977	No significant gradient
7729	Nov 1977	Negative gradient
7730	Dec 1977	Used for modelling
7820	Jan 1978	Used for modelling

Table 5-3 (continued)

Cruise Number	Month	Status
7821	Feb 1978	Used for modelling
7822	Mar 1978	Used for modelling
7823	Apr 1978	Used for modelling
7824	May 1978	No significant gradient
7825	June 1978	Used for modelling
7826	July 1978	No significant gradient
7827	Aug 1978	Incomplete data
7828	Sept 1978	No significant gradient
7829	Oct 1978	Incomplete data
7830	Sept 1978	Used for modelling
7831	Oct 1978	Well-mixed to 10 m, no surface gradient
7832	Nov 1978	Used for modelling

Table 5-4 Residence times in Saanich Inlet (days).

Box	Season					
	Winter	Spring	Summer	Summer Renewal	Fall	Annual Average
Entrance West Surface	0.5	0.7	0.8	1.4	0.7	0.7
Entrance West - Lower	1.9	2.5	4.7	18	2.5	2.9
Entrance East - Surface	0.3	0.5	0.9	1.4	0.5	0.5
Entrance East - Lower	1.5	2.4	5.2	18	2.4	2.6
Central Basin West - Surface	1.3	2.3	2.7	4.8	2.3	2.1
Central Basin West - Lower	4.8	7.4	13	43	7.4	8.0
Central Basin West - Bottom	-	-	-	510	-	3040
Central Basin East - Surface	1.4	2.5	3.5	5.6	2.5	2.3
Central Basin East - Lower	5.6	8.9	17	50	8.9	9.5
Central Basin East - Bottom	-	-	-	170	-	1010
Squally Reach - Surface	9.2	18	38	27	18	16
Squally Reach - Lower	55	109	222	189	109	97
Squally Reach - Bottom	-	-	-	310	-	1840
Finlayson Arm - Surface	5.2	11	17	11	11	8.5
Finalyson Arm - Lower	68	146	225	133	146	112
Finlayson Arm - Bottom	-	-	-	250	-	1520
Mill Bay - Surface	2.0	5.0	24	74	5.0	4.4
Mill Bay - Lower	5.8	14	68	209	14	13
Brentwood Bay - Surface	27	49	259	147	49	51
Brentwood Bay - Lower	112	203	1028	624	203	210
Patricia Bay - Surface	30	75	170	88	75	56
Patricia Bay - Lower	87	221	471	252	221	160

Figure 5-1 Saanich Inlet bathymetry: plan view.

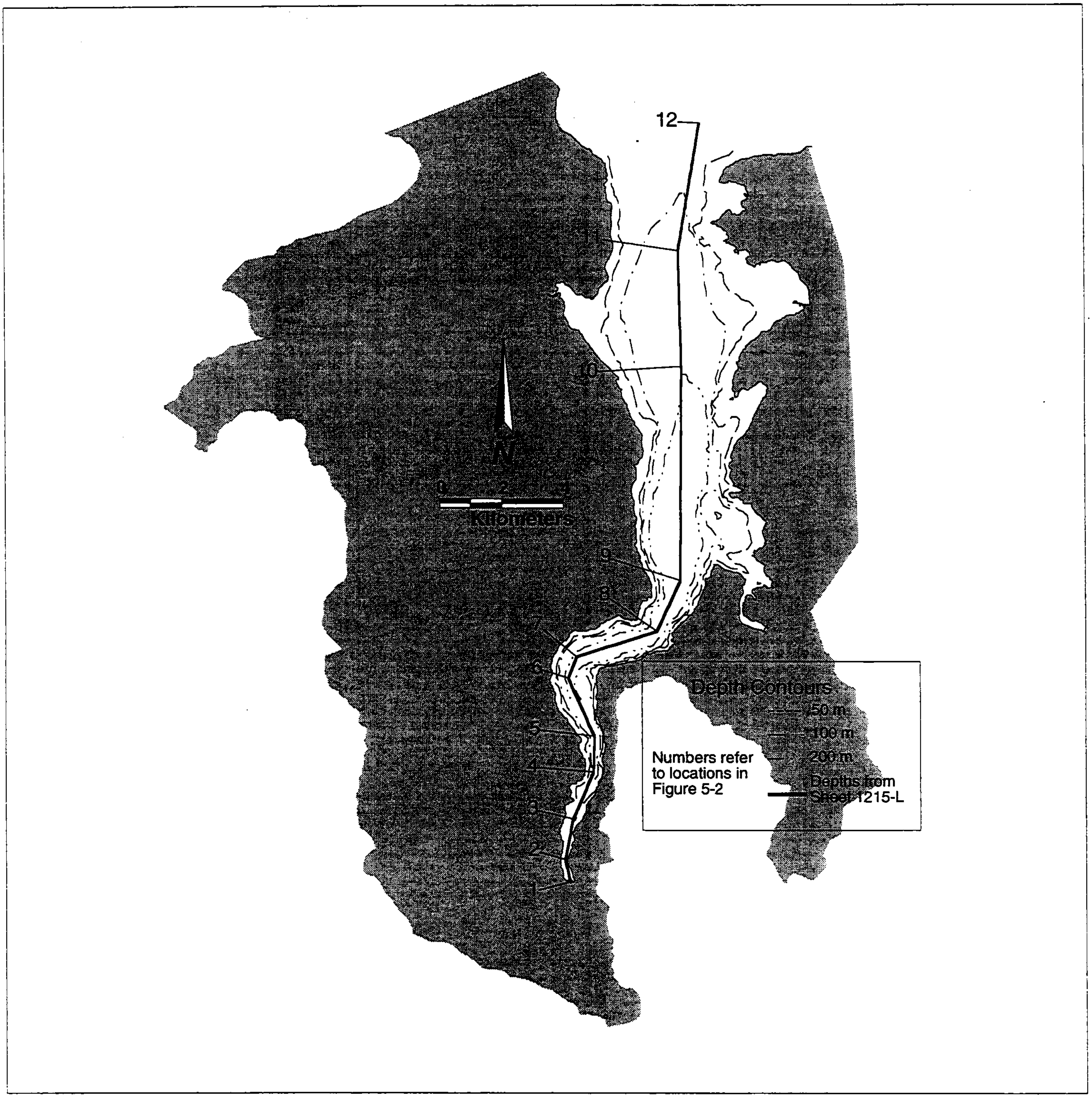


Figure 5-2 Saanich Inlet bathymetry: section (after Drinnan et al., 1995).

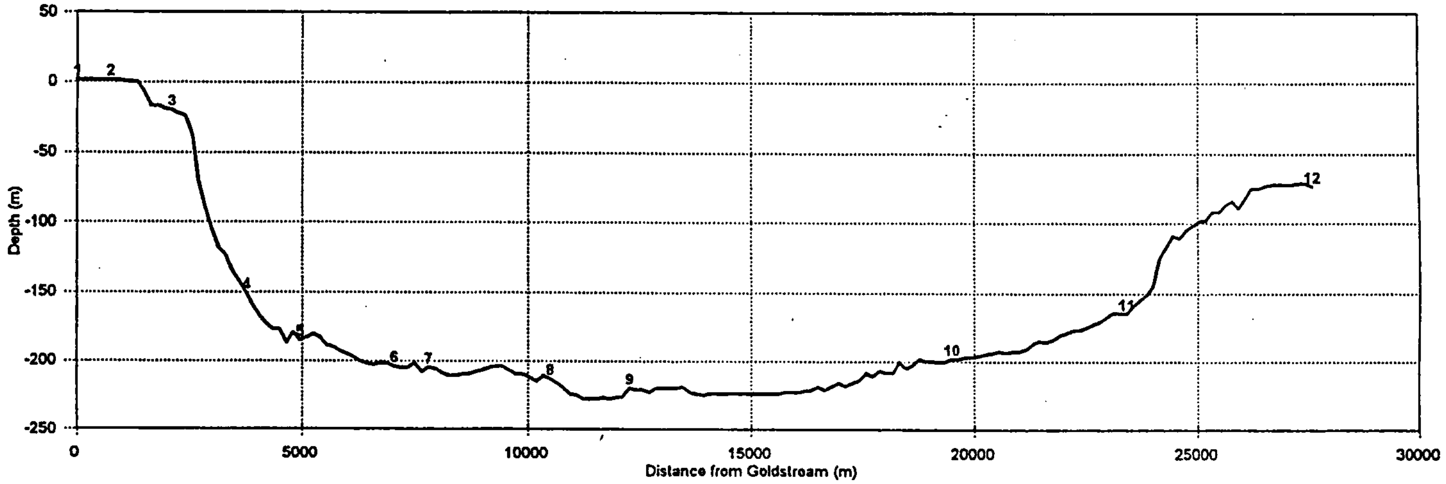


Figure 5-3 CTD station locations and site of mooring A (Source: Stucchi and Giovando, 1983).

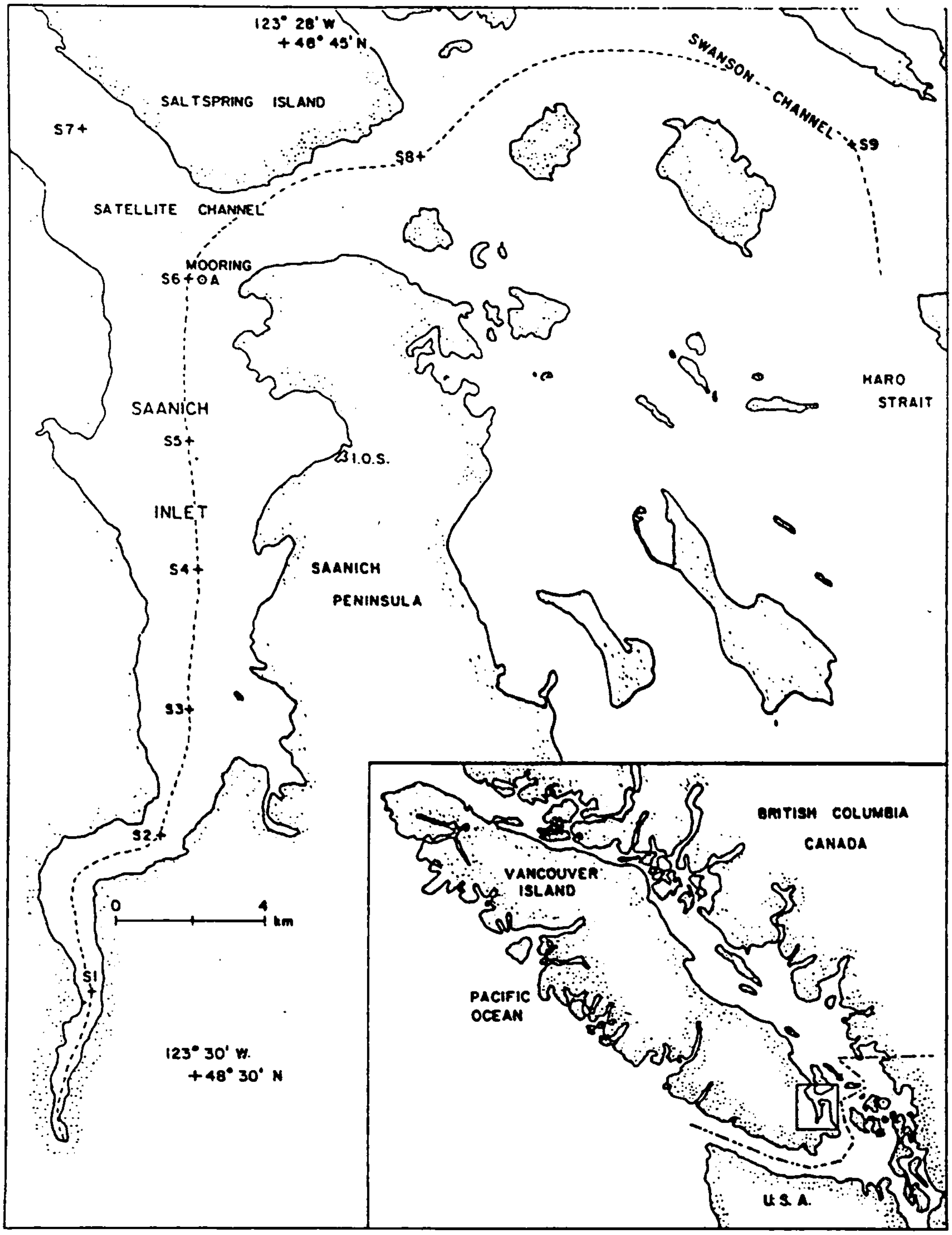


Figure 5-4 Bathymetry from Saanich Inlet to Haro Strait (Source: Stucchi and Giovando, 1983).

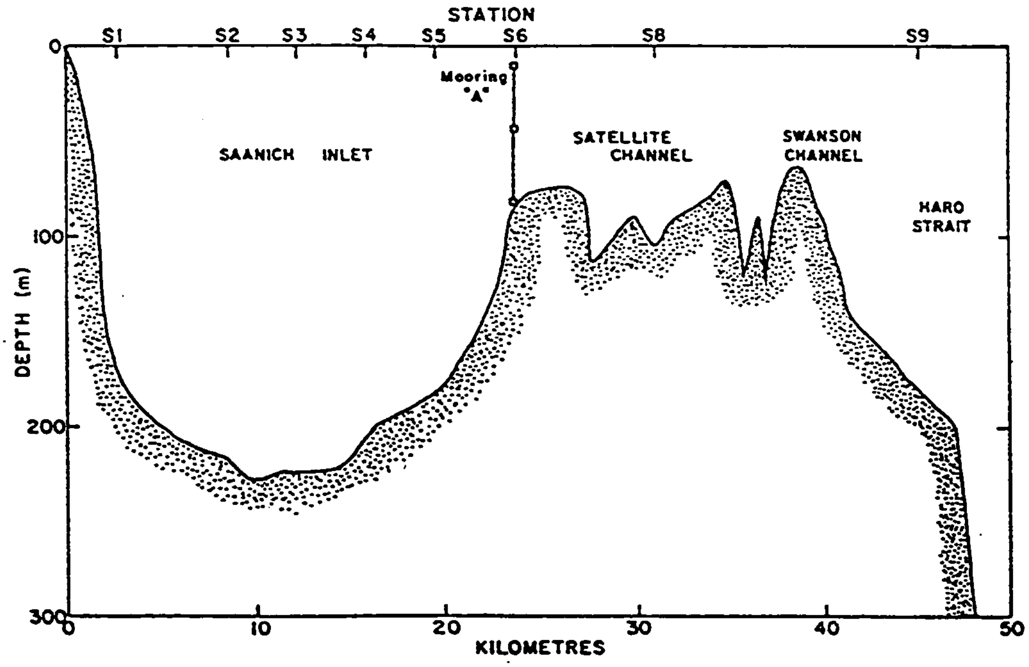


Figure 5-5 Estuarine circulation in a typical British Columbia inlet (Source: Thomson, 1981).

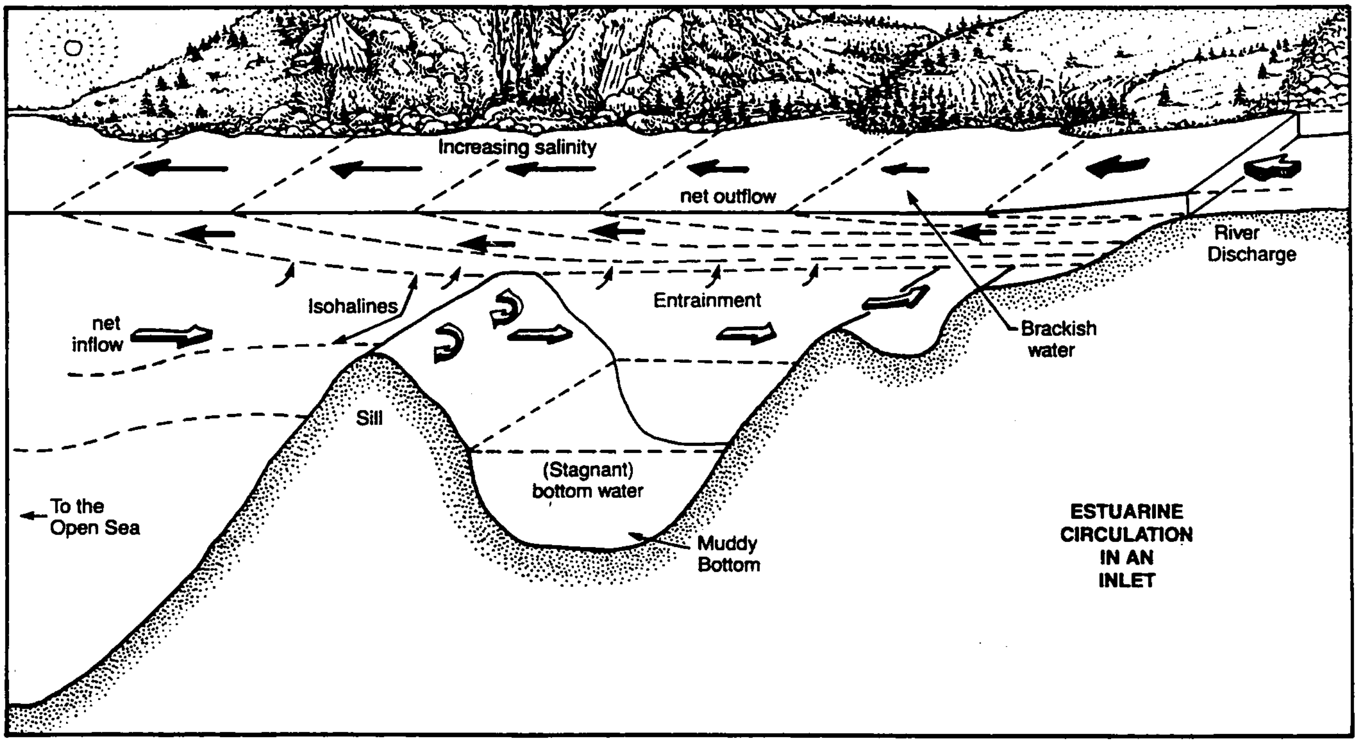
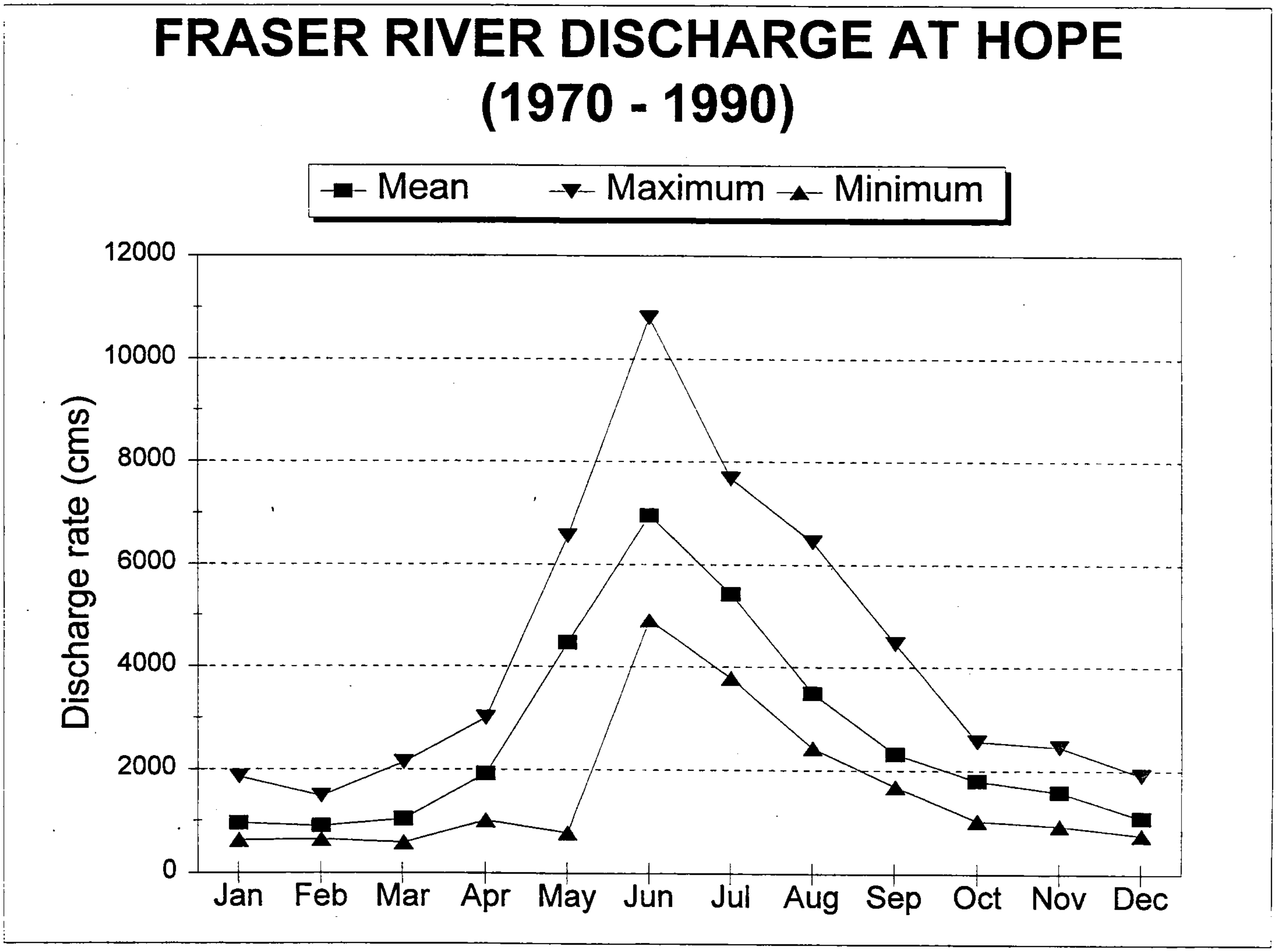


Figure 5-6 Mean, maximum and minimum monthly discharge rates for the Fraser River at Hope.



Note: cms - cubic metres per second

Figure 5-7 Loran-C Drogue tracks: June, 1990 (Source: Drinnan et al., 1995).

Figure 5-8 Loran-C Drogue tracks: September, 1990 (Source: Drinnan et al., 1995).

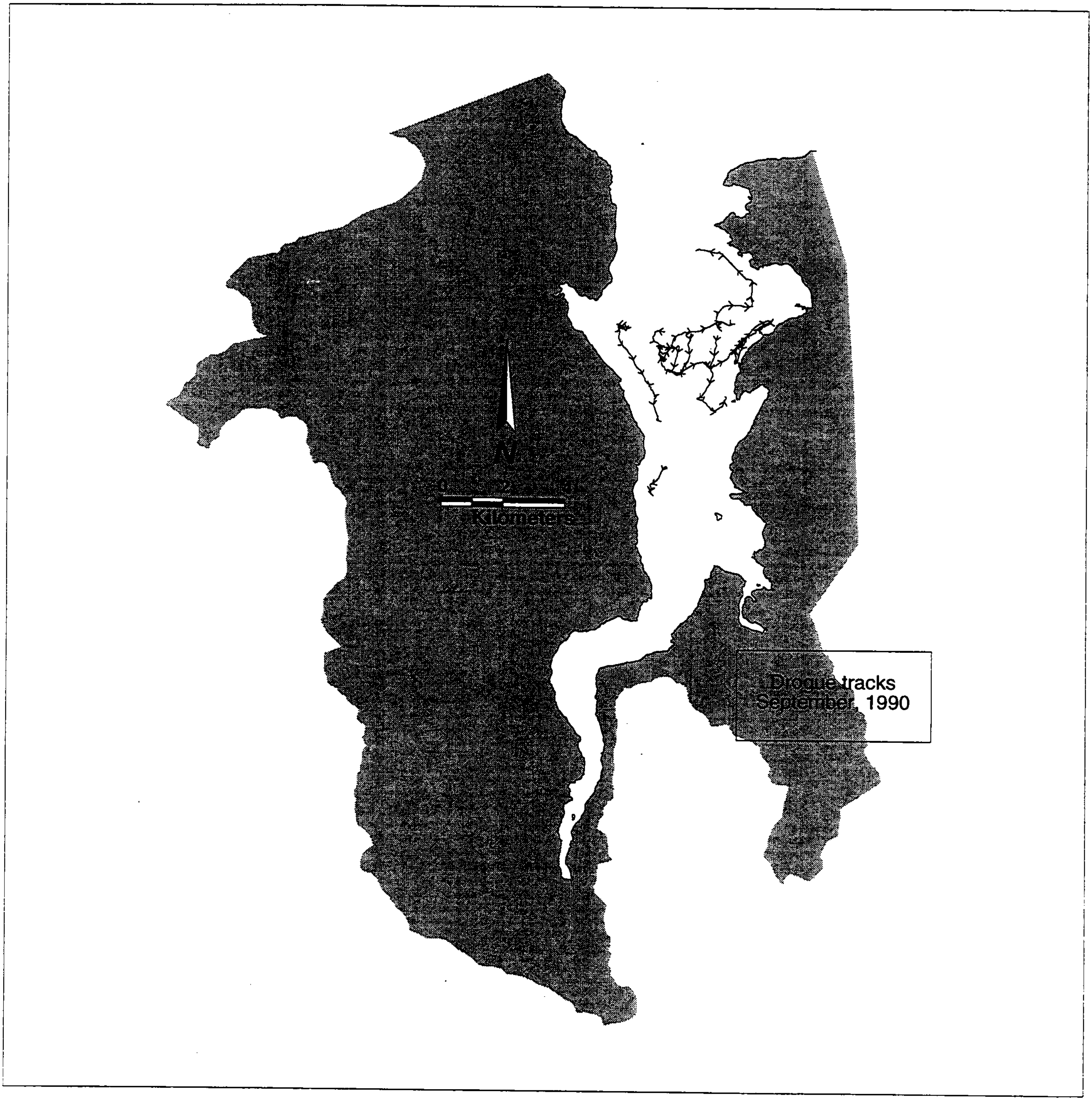


Figure 5-9 Surface drogue movements, December 1994; only selected drogue movements are presented, others are found in Cross and Chandler (1996).

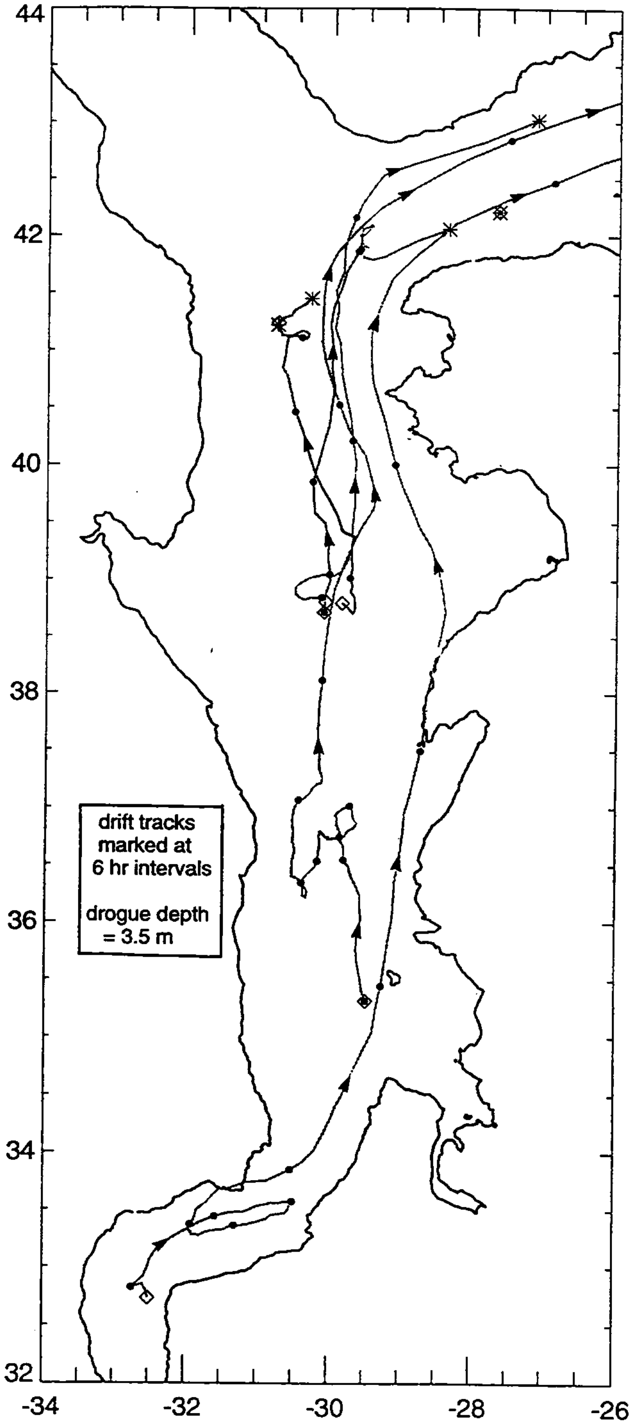


Figure 5-10 Surface drogue movements, July 1995; only selected drogue movements are presented, others are found in Cross and Chandler (1996).

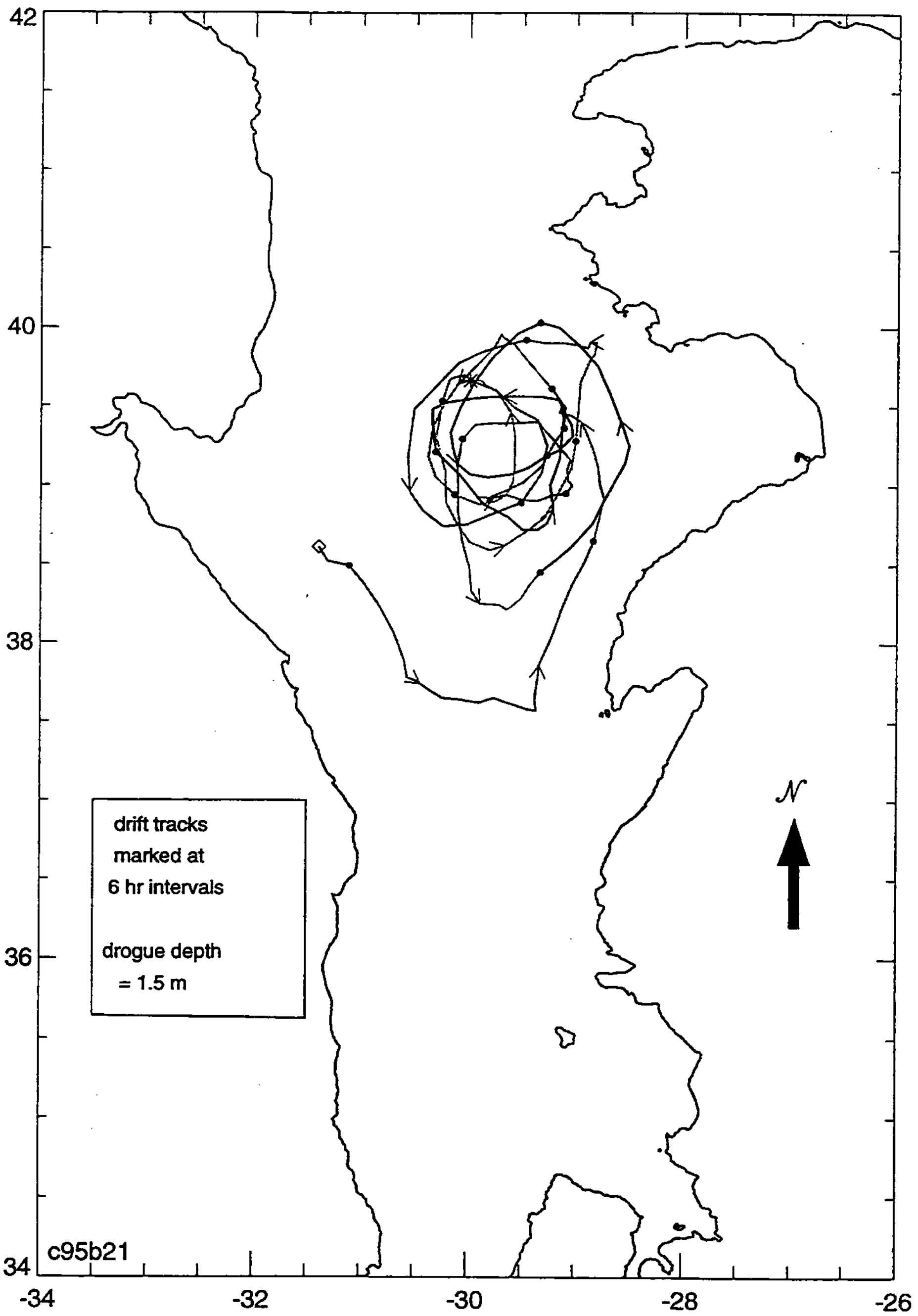


Figure 5-11 Mean, maximum and minimum monthly discharge rates for the Cowichan and Koksilah Rivers.

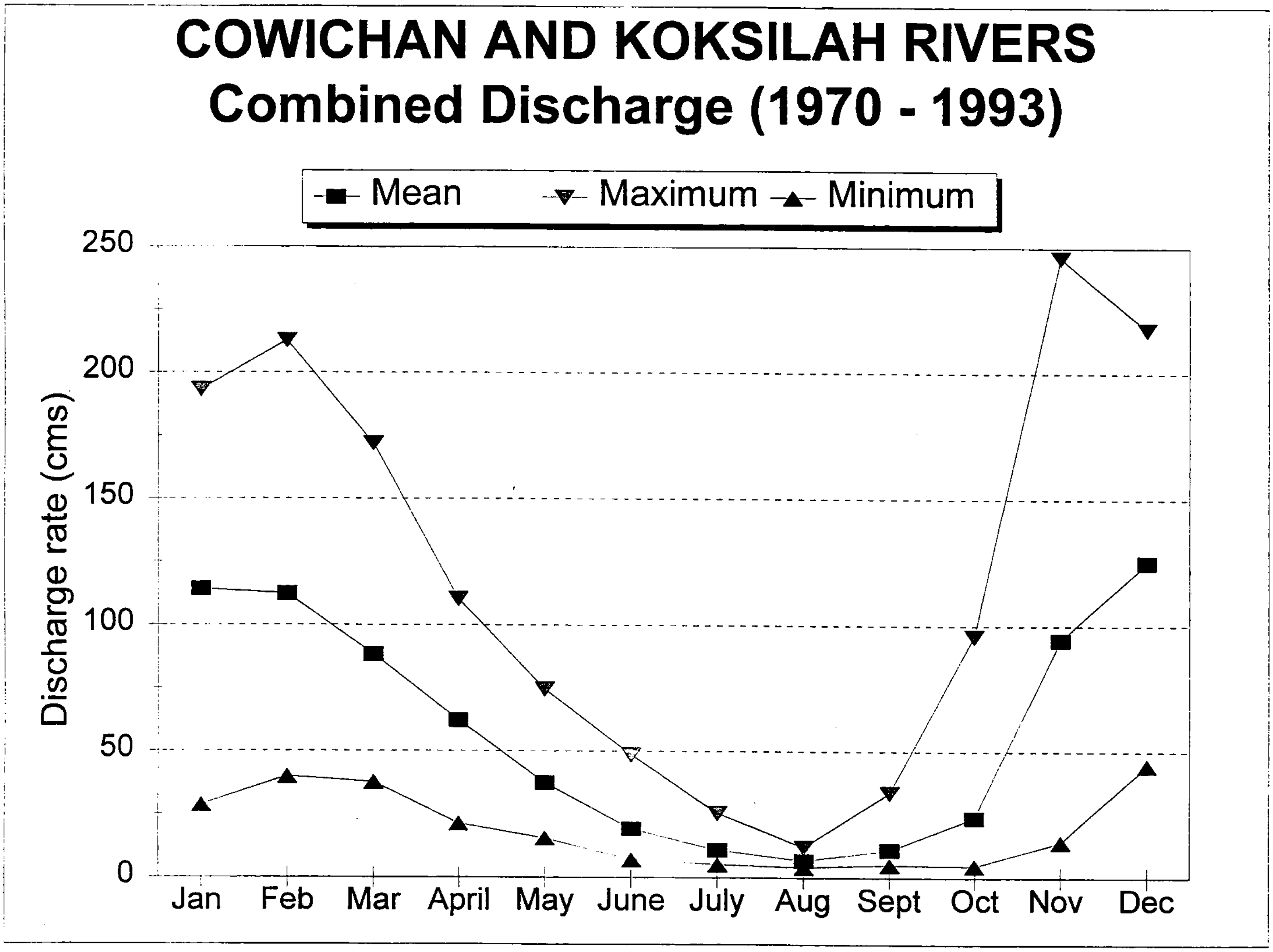


Figure 5-12 Mean, maximum and minimum monthly discharge rates for Shawnigan Creek.

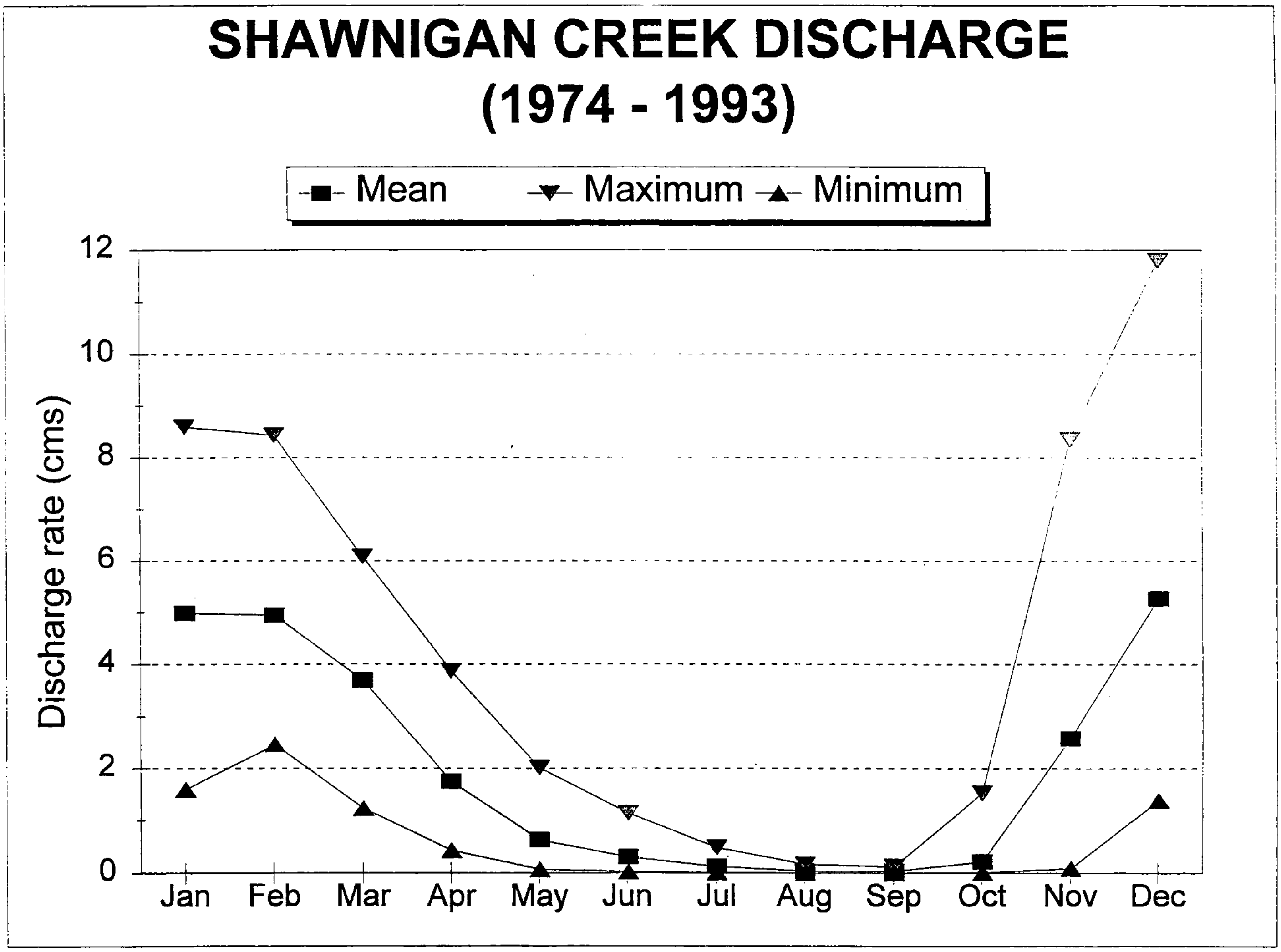


Figure 5-13 Mean, maximum and minimum monthly discharge rates for the Goldstream River (1973-1986) and Tod Creek (estimate).

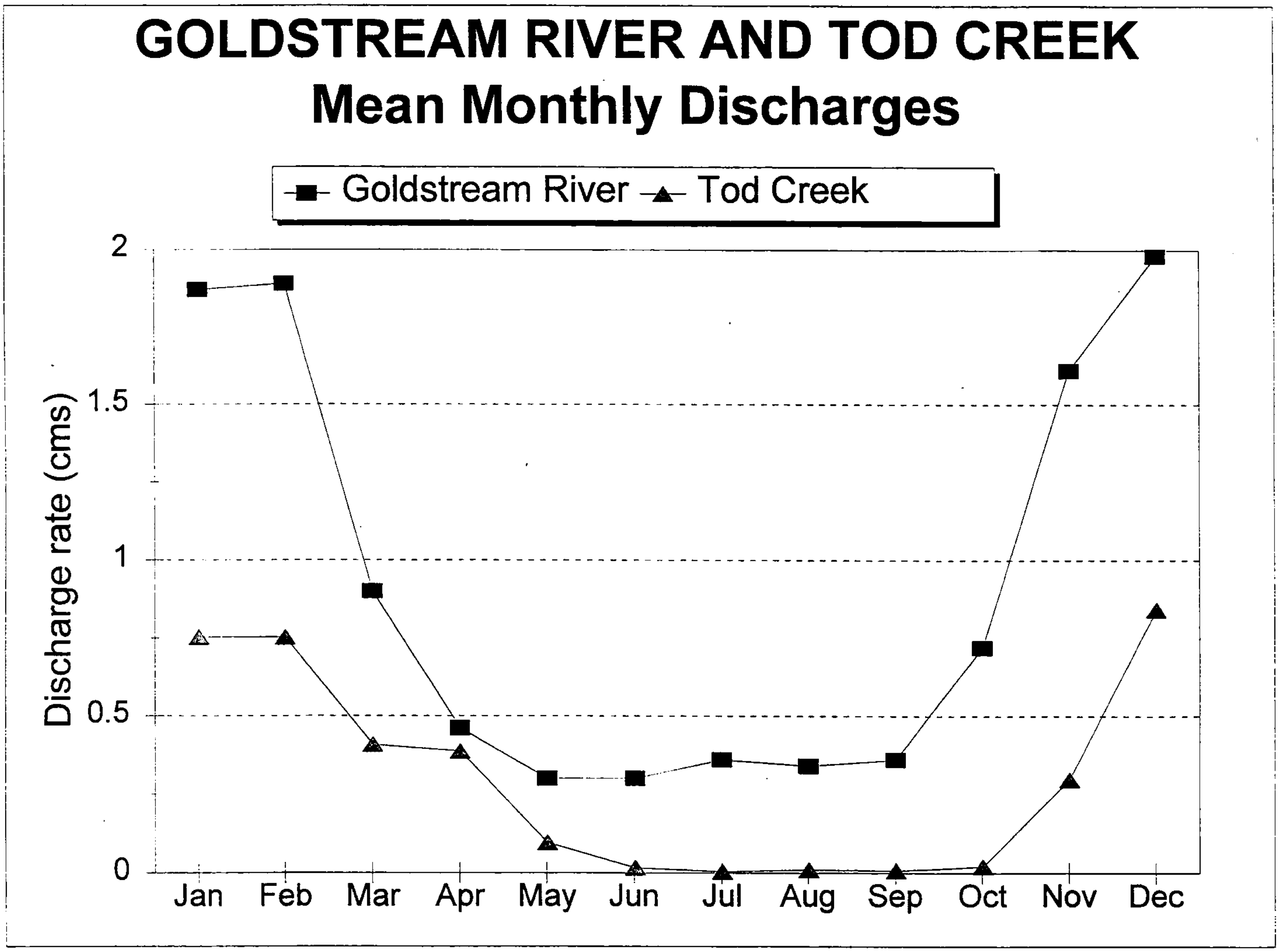


Figure 5-14 Watershed boundaries and precipitation stations with annual mean precipitation (Source: Drinnan et al., 1995).

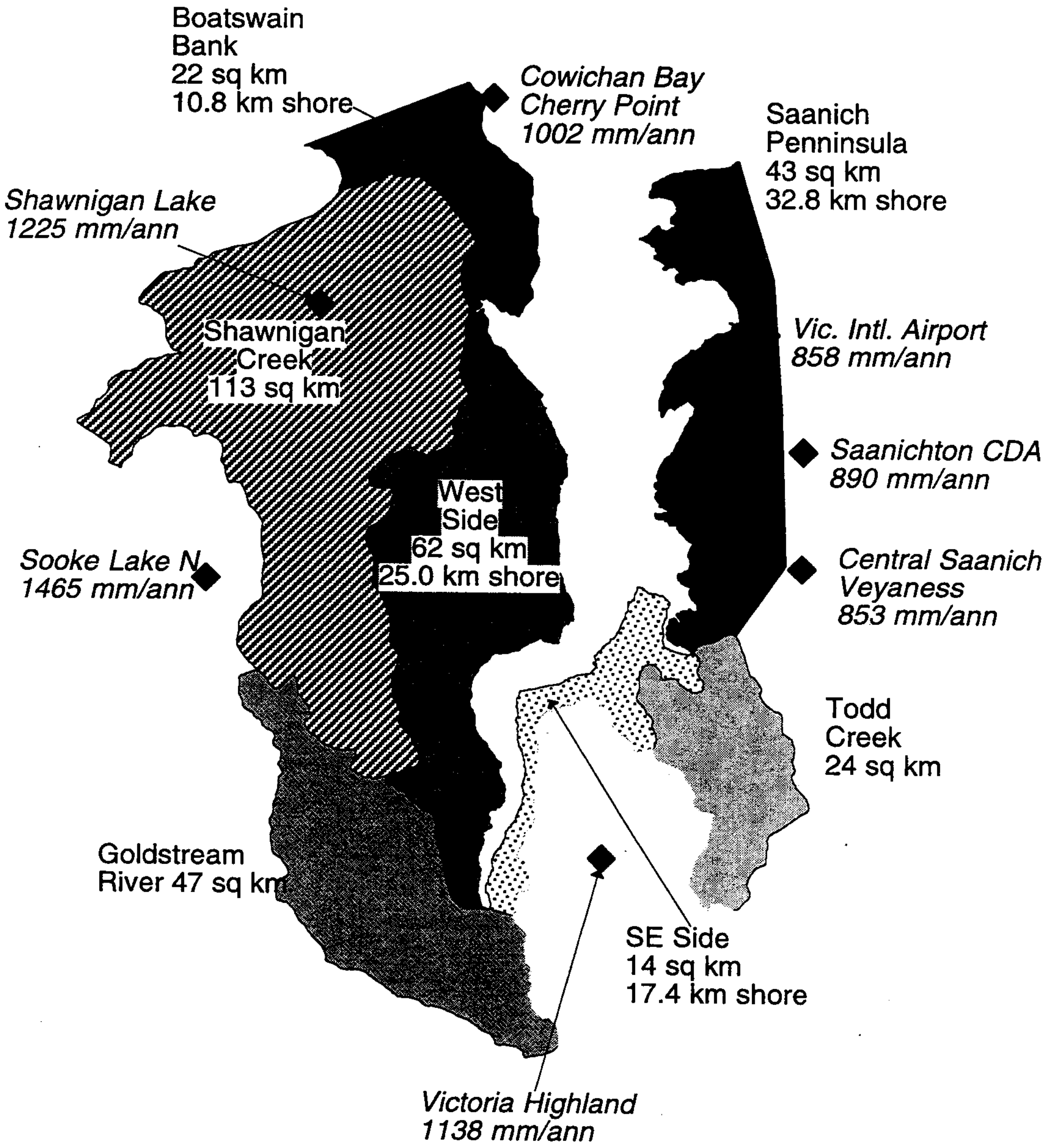
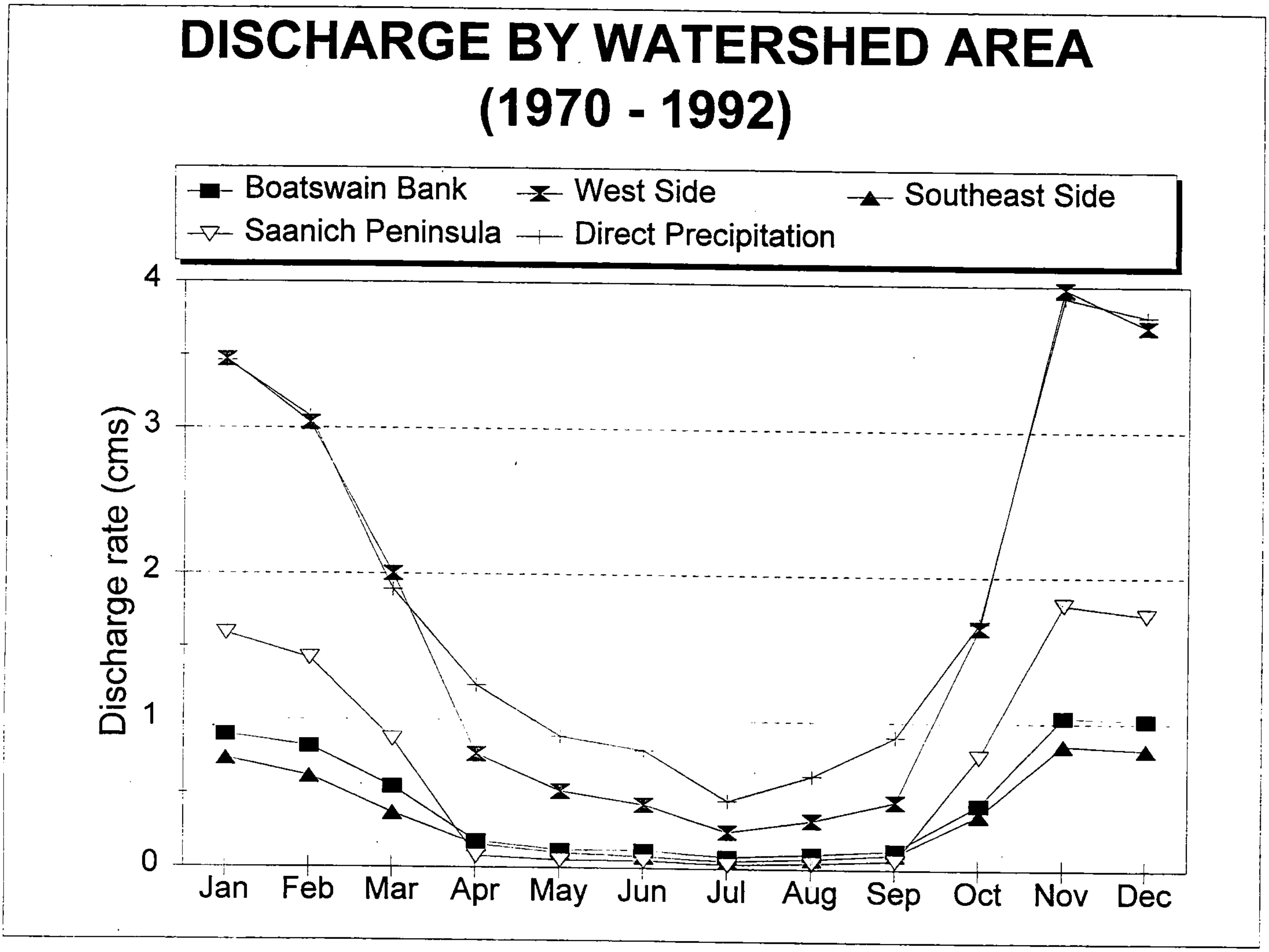
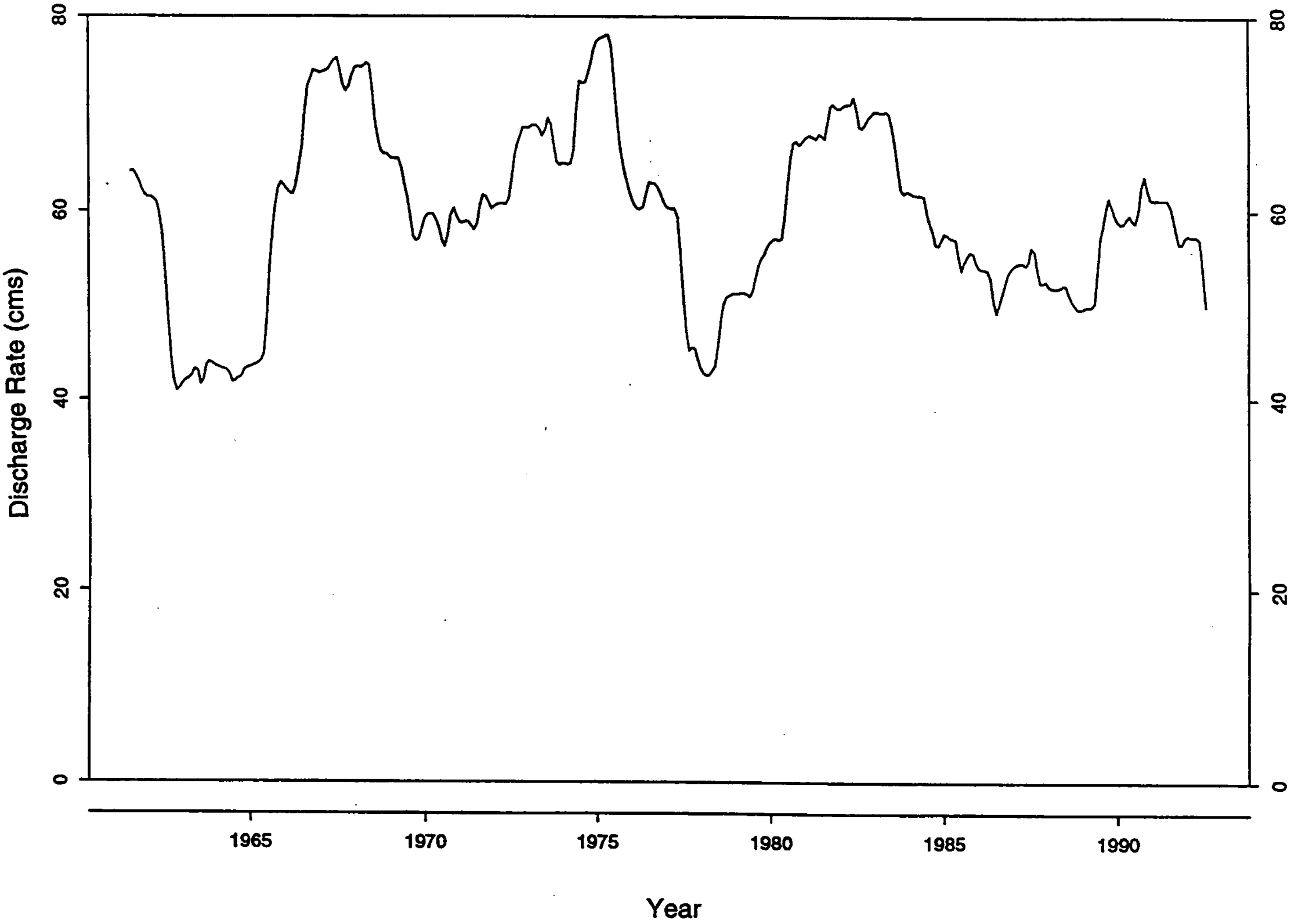


Figure 5-15 **Estimates of mean monthly discharges from unmetered streams and creeks and direct precipitation on the water surface of Saanich Inlet.**



Note: cms - cubic metres per second

Figure 5-16 Long-term cycles in discharges from the Cowichan and Koksilah River System, plotted using a 3-year running mean.



Note: cms - cubic metres per second

Figure 5-17 Station locations for CTD profiles, December 1994 survey (Source: Cross and Chandler, 1996).

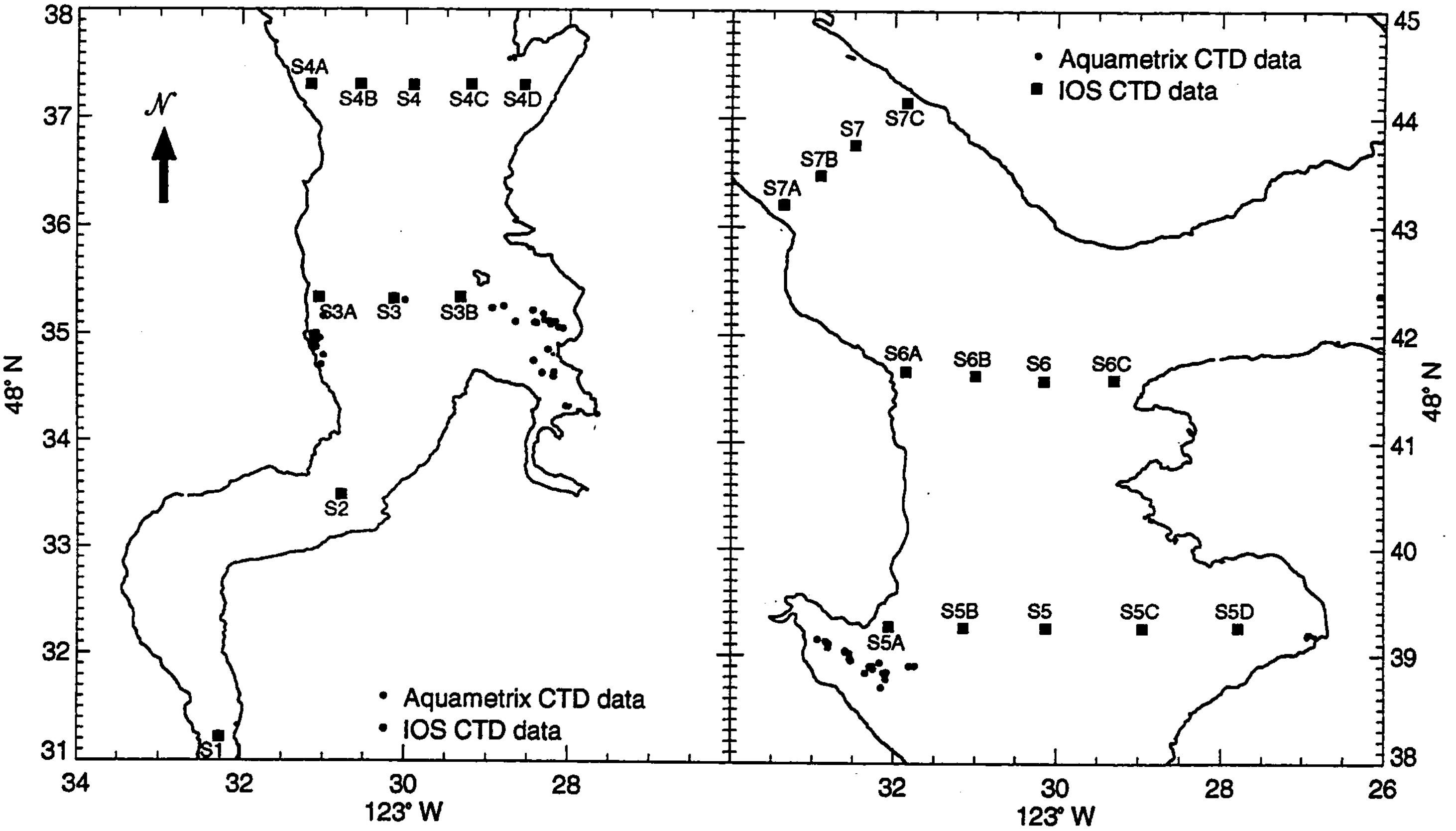


Figure 5-18 Station locations for CTD profiles, July 1995 (Source: Cross and Chandler, 1996).

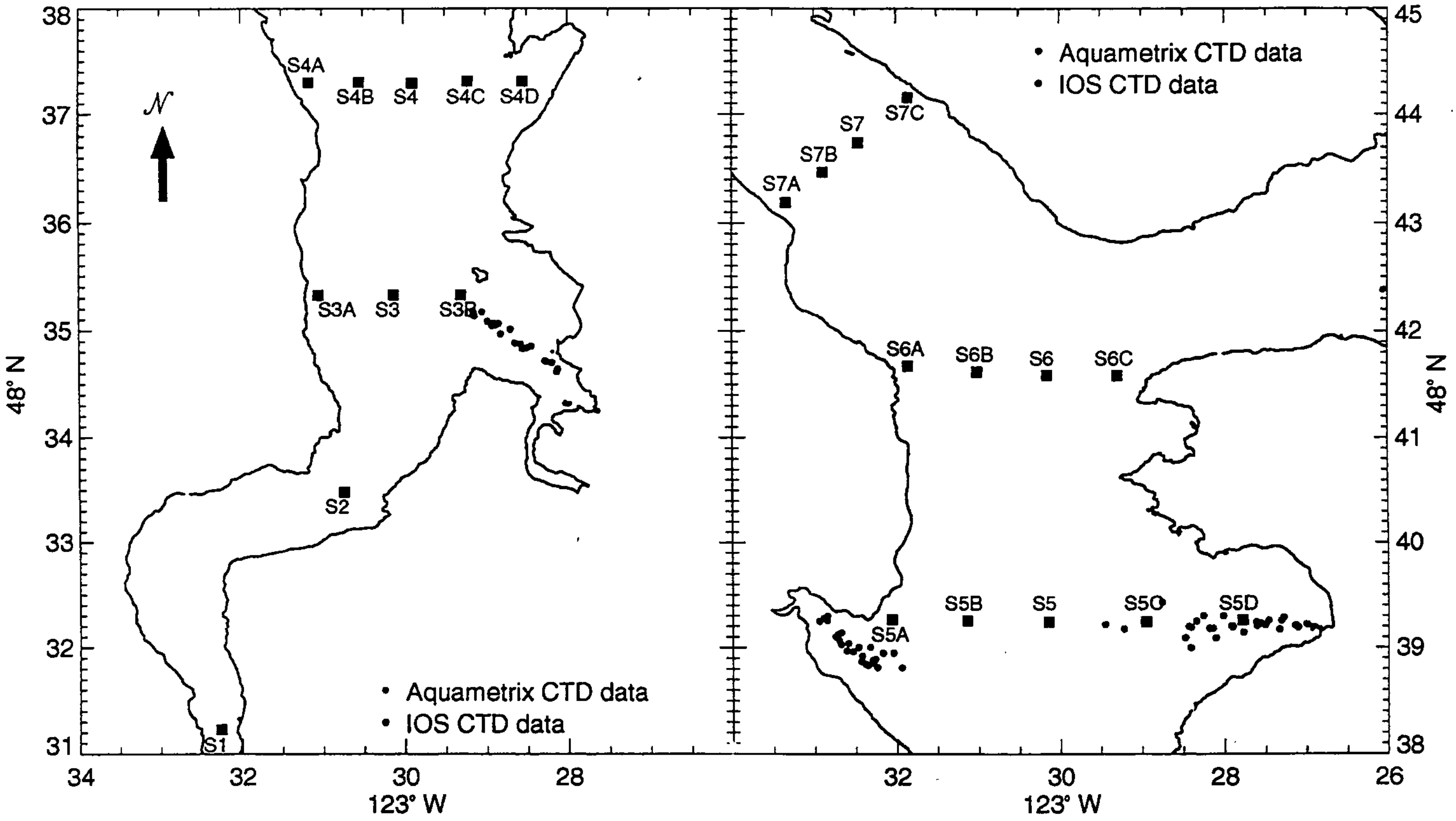


Figure 5-19 Schematic view of box model structure for Saanich Inlet: (a) surface layer, (b) lower layer, (c) deep basin boxes, (d) vertical sections (see text for detailed explanation).

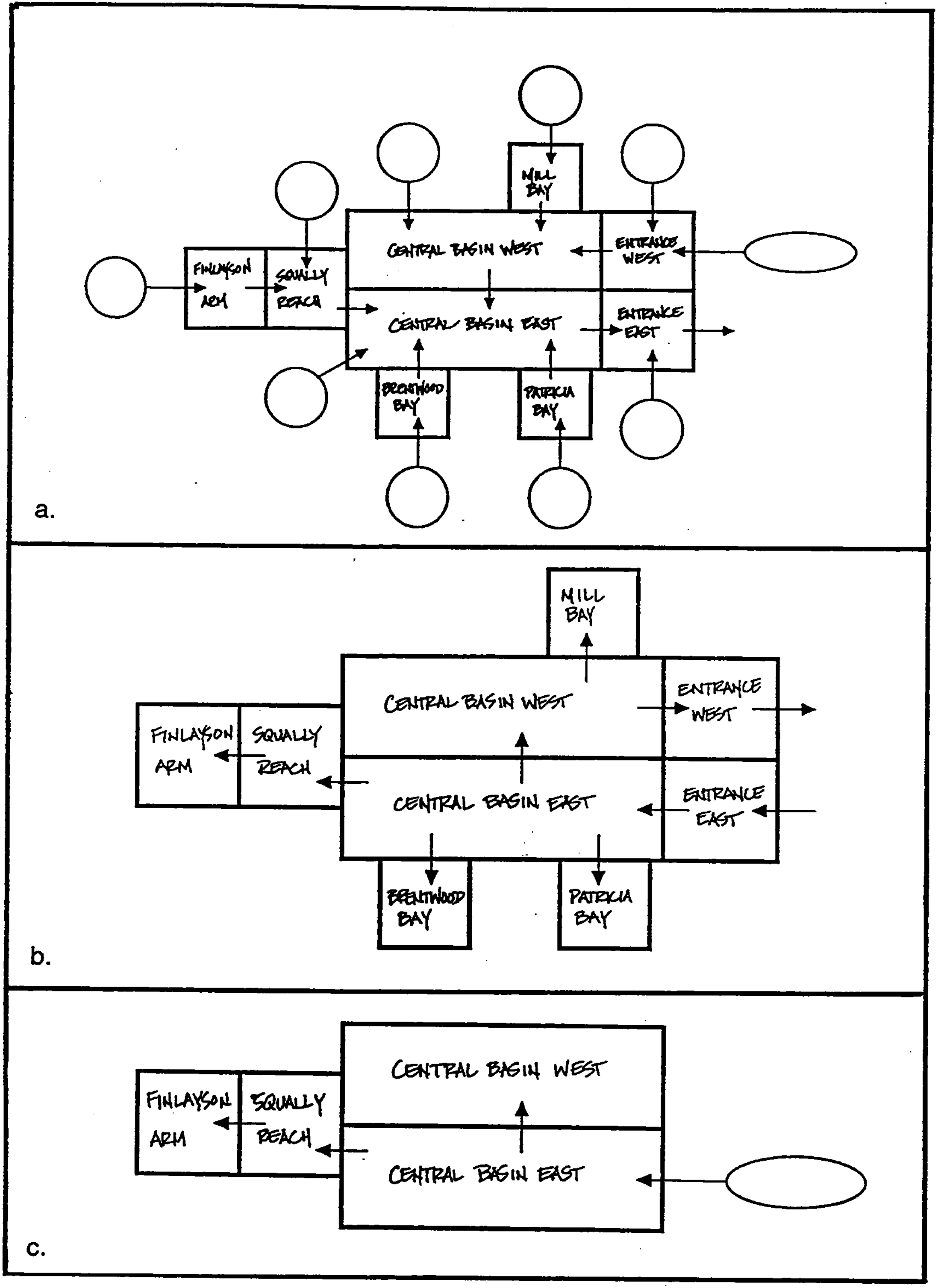


Figure 5-19 (continued)

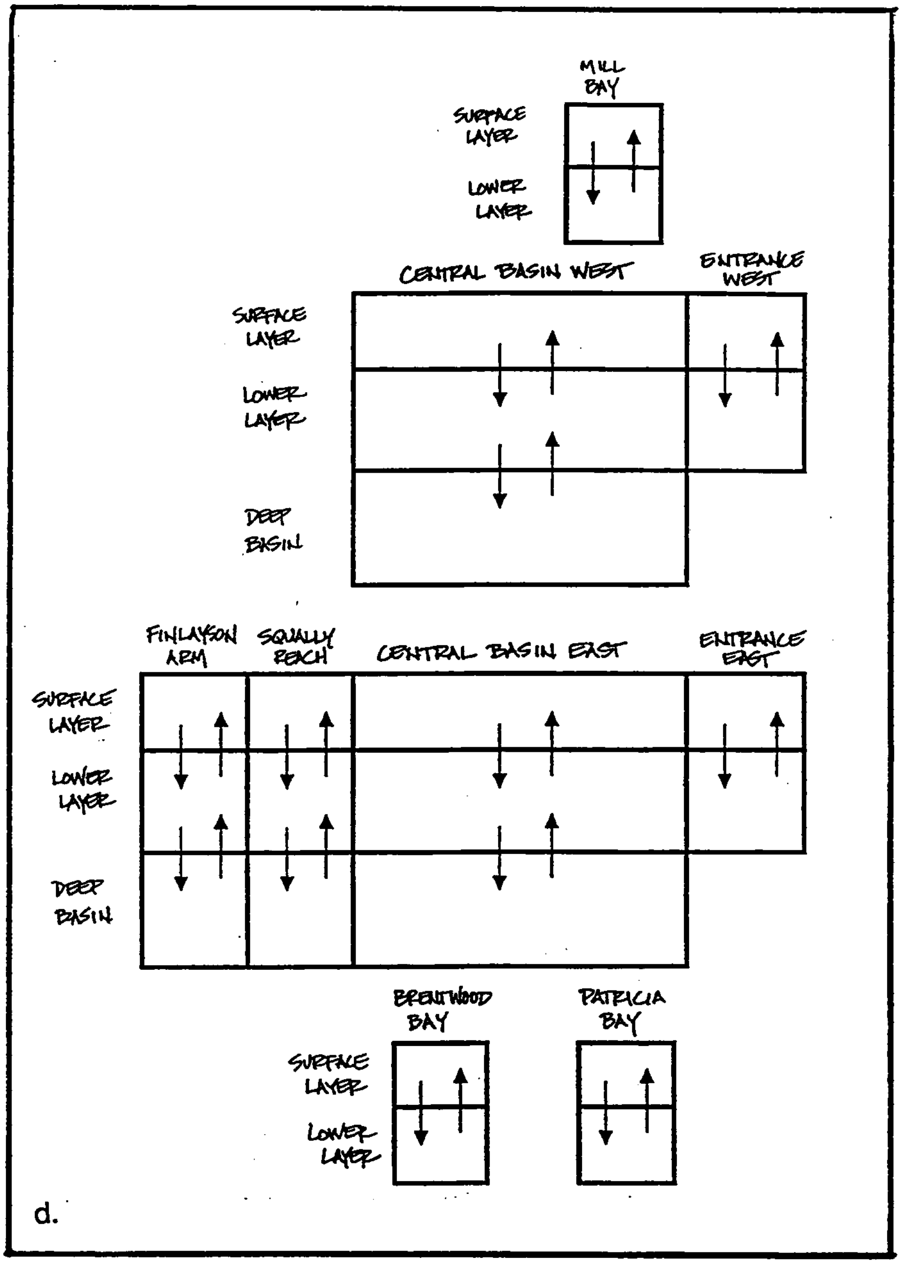


Figure 5-20 Salinity gradients in the main channel of Saanich Inlet for average winter flow conditions.

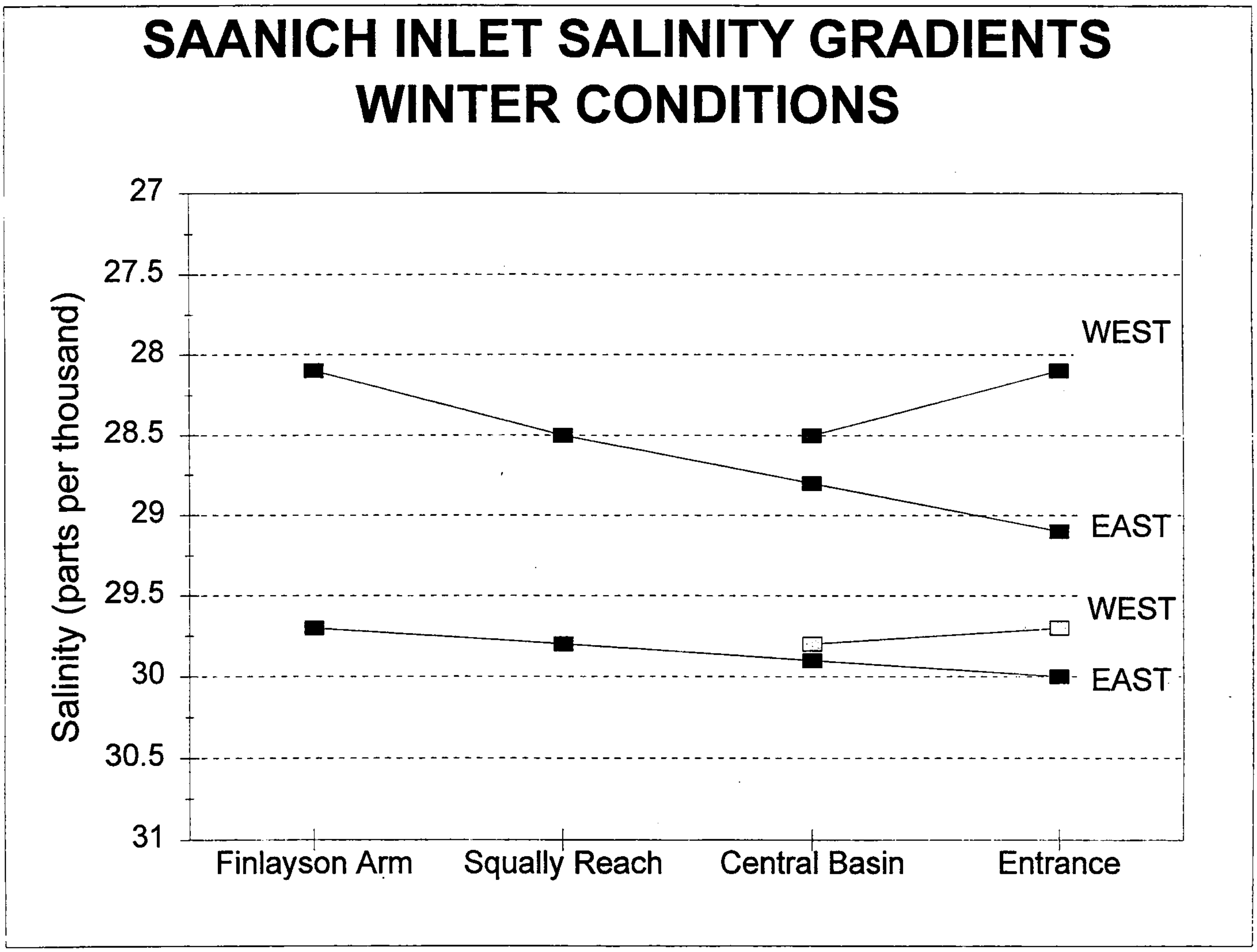
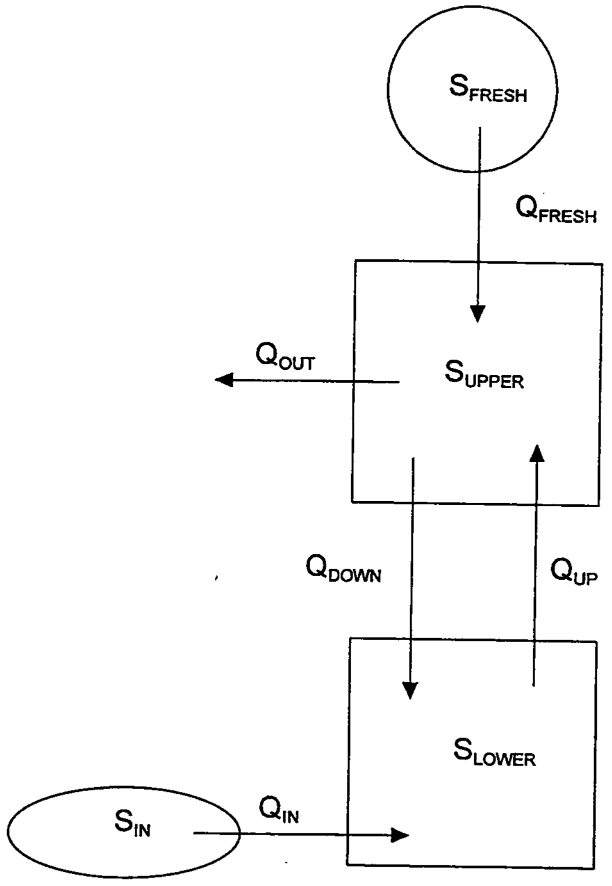


Figure 5-21 Schematization of a positive estuarine flow system in a two-layer model.



S_{FRESH}	Salinity of fresh water entering the upper box (assumed zero)
S_{UPPER}	Salinity of marine waters in upper box
S_{LOWER}	Salinity of marine waters in lower box
S_{IN}	Salinity of deep marine water entering inlet at the mouth

Q_{FRESH}	Flow rate of fresh water entering the inlet
Q_{DOWN}	Downward exchange rate of water from upper to lower box
Q_{UP}	Upward exchange rate of water from lower to upper box
Q_{IN}	Rate at which deep marine water enters inlet
Q_{OUT}	Rate at which surface waters flow out of the inlet

Figure 5-22 Oceanographic model results for winter conditions. Salinities are shown in lower left corner of each model box (ppt) with flow rates near the end of each corresponding arrow (m^3/s). Fresh water inflows are shown within each circle (m^3/s), marine water inflows within each ellipse (m^3/s).

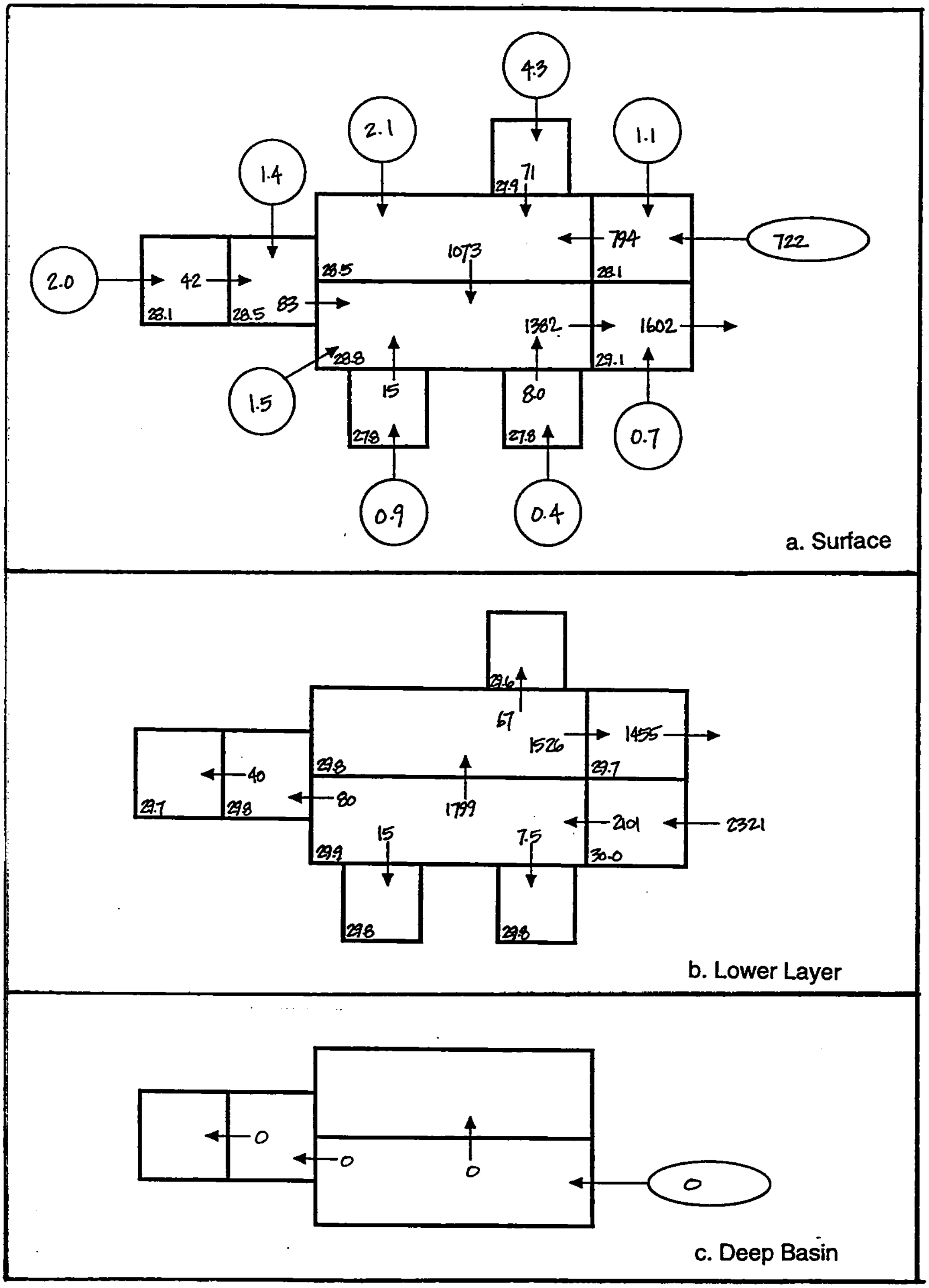
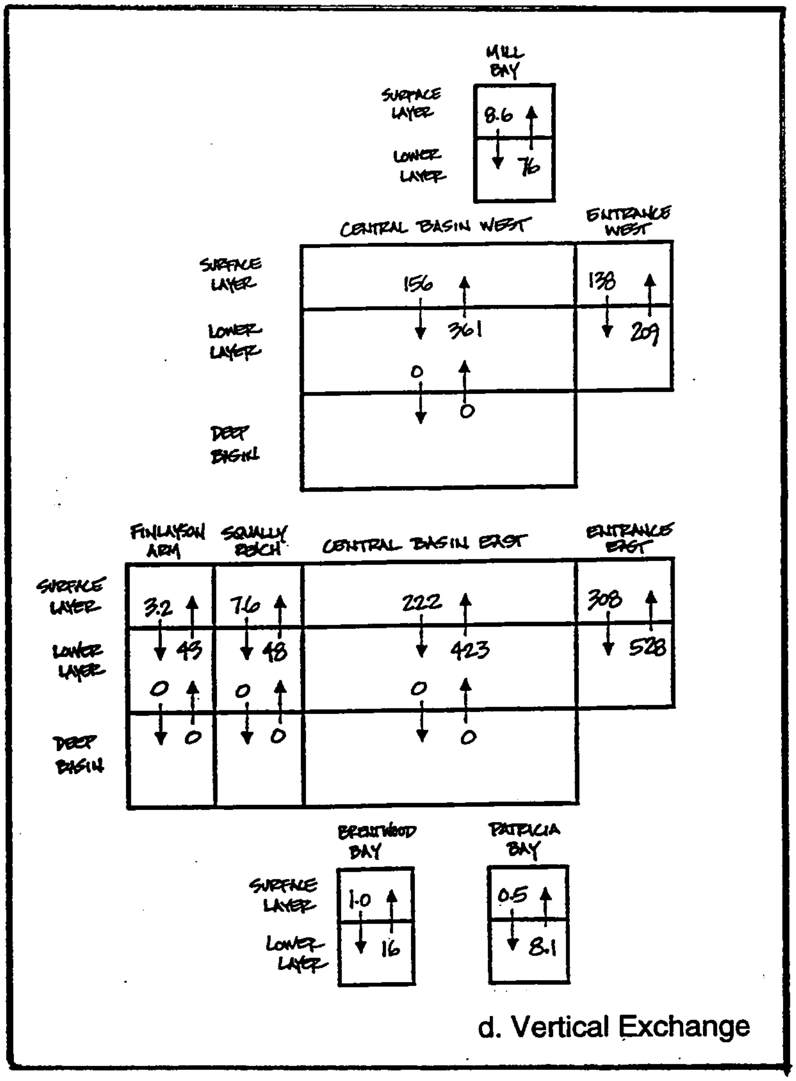


Figure 5-22 (continued)



d. Vertical Exchange

Figure 5-23 Oceanographic model results for spring conditions. Salinities are shown in lower left corner of each model box (ppt) with flow rates near the end of each corresponding arrow (m^3/s). Fresh water inflows are shown within each circle (m^3/s), marine water inflows within each ellipse (m^3/s).

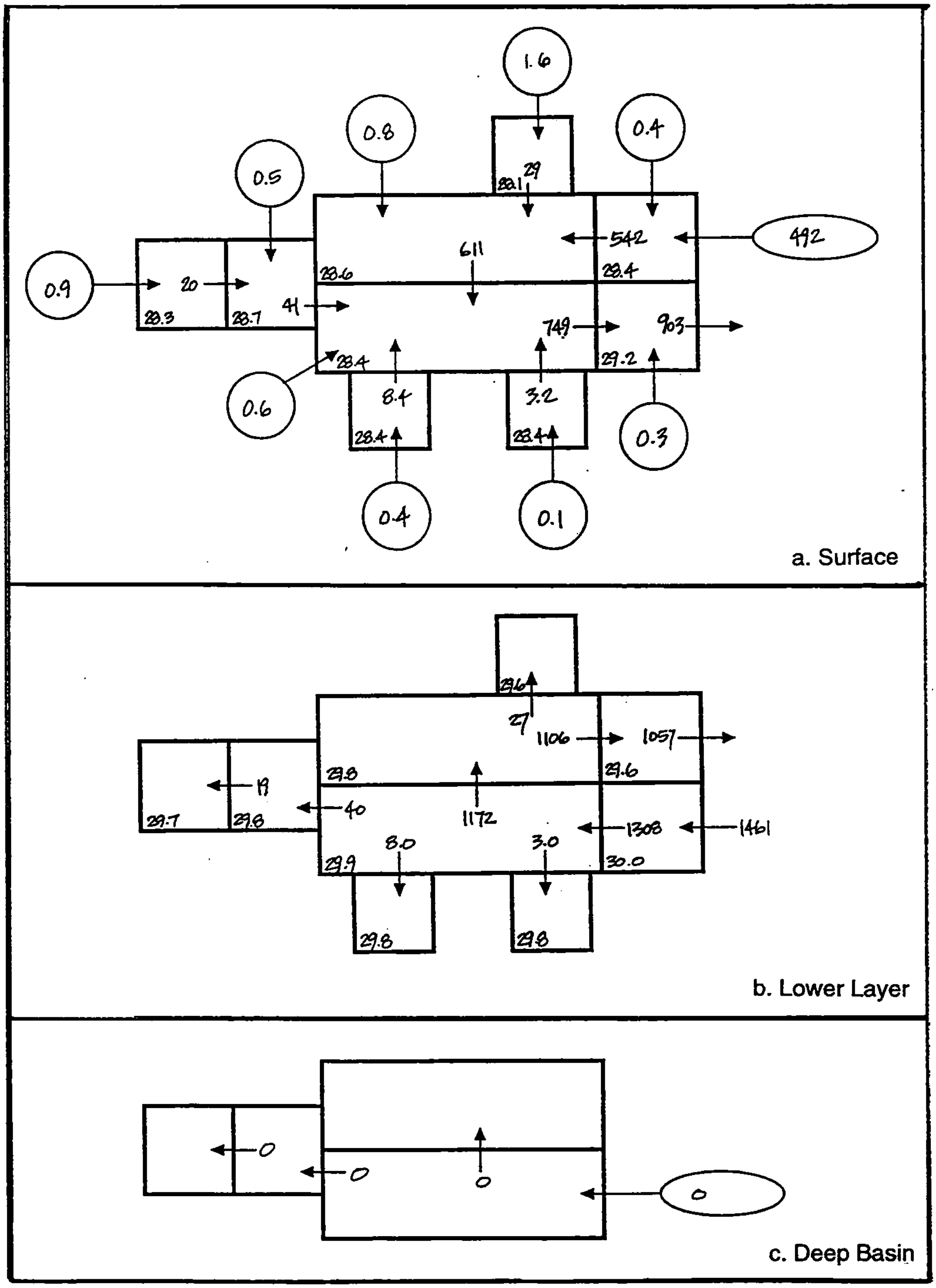
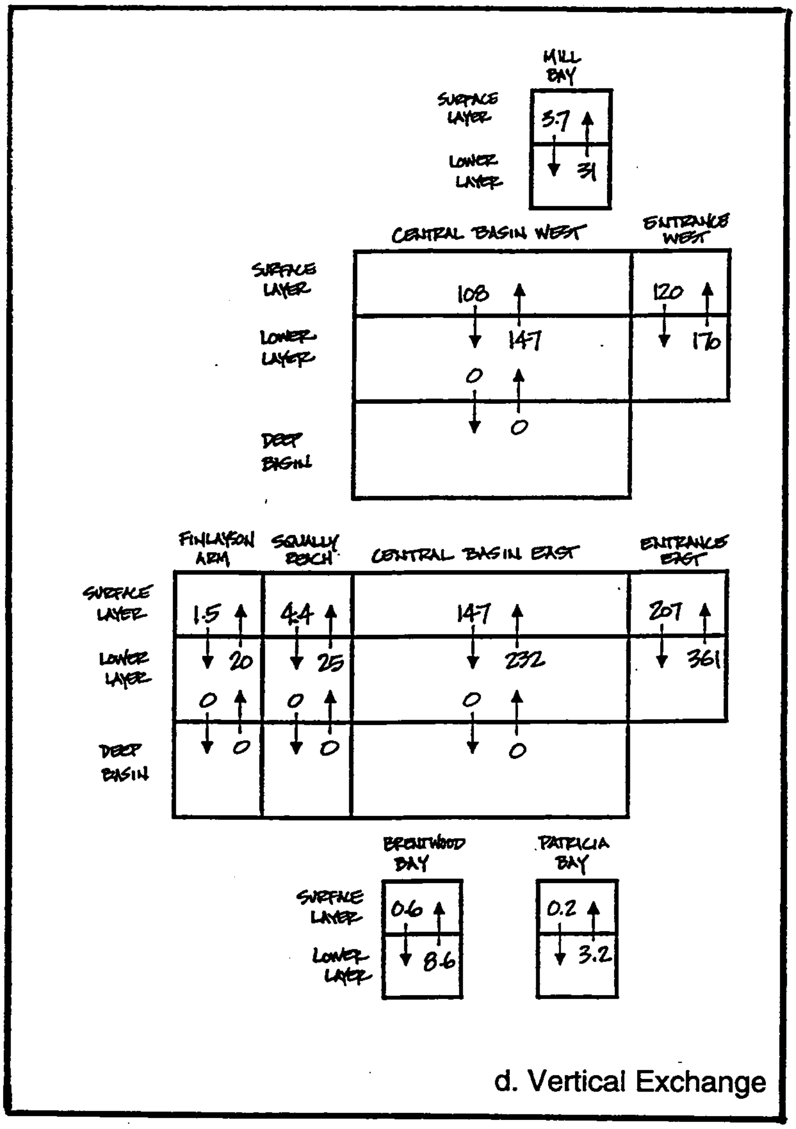


Figure 5-23 (continued)



d. Vertical Exchange

Figure 5-24 Oceanographic model results for summer conditions. Salinities are shown in lower left corner of each model box (ppt) with flow rates near the end of each corresponding arrow (m³/s). Fresh water inflows are shown within each circle (m³/s), marine water inflows within each ellipse (m³/s).

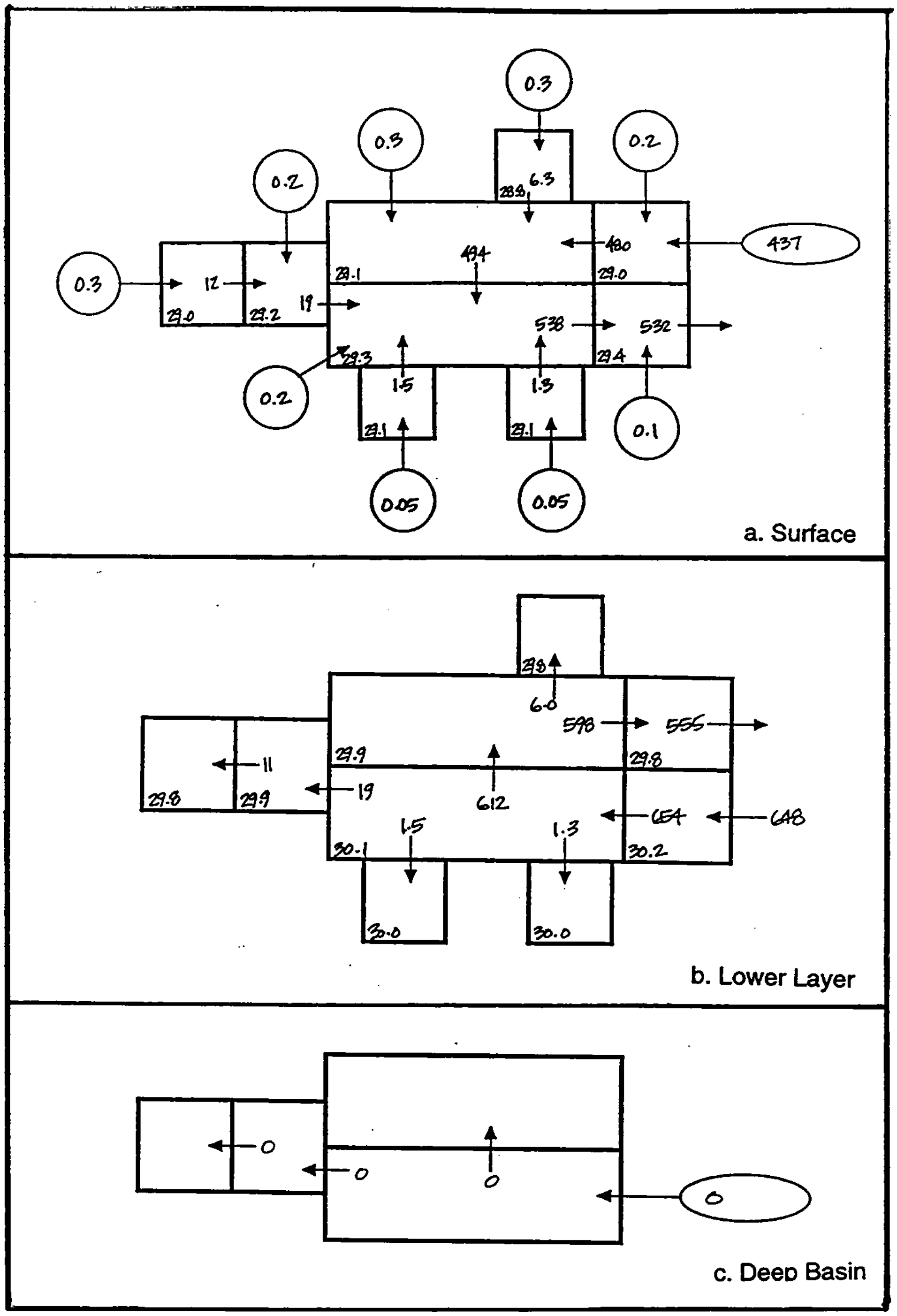
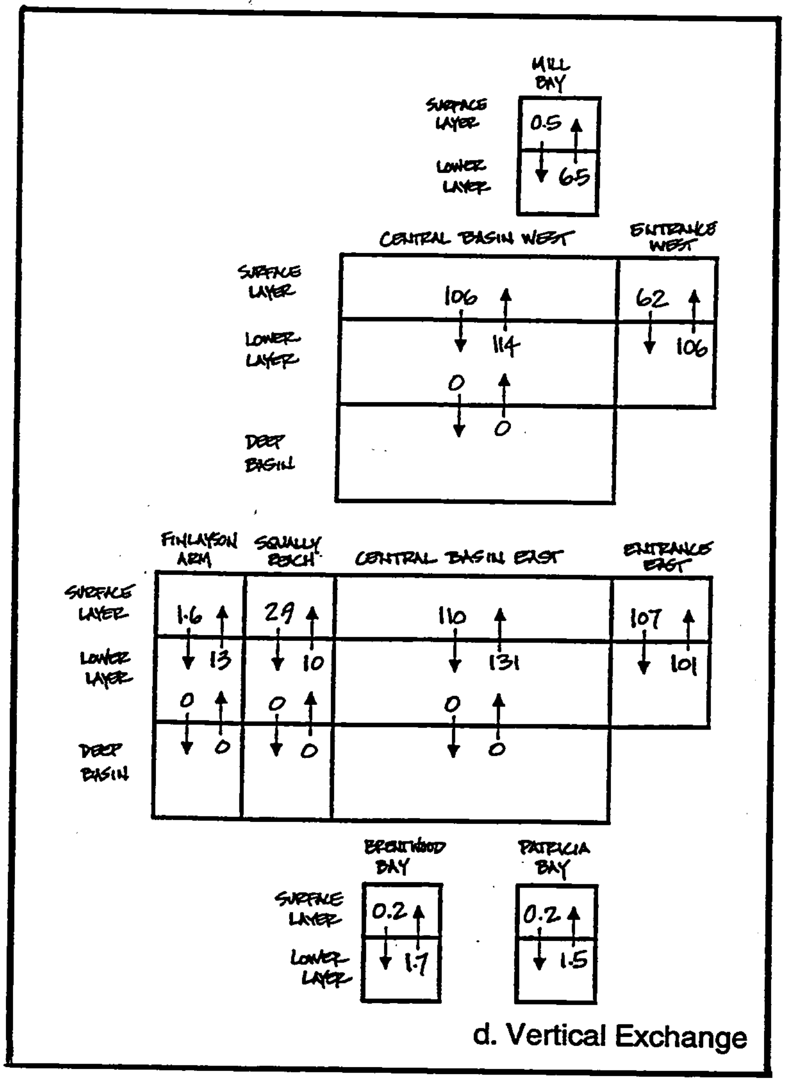


Figure 5-24 (continued)



d. Vertical Exchange

Figure 5-25 Oceanographic model results for summer renewal conditions. Salinities are shown in lower left corner of each model box (ppt) with flow rates near the end of each corresponding arrow (m^3/s). Fresh water inflows are shown within each circle (m^3/s), marine water inflows within each ellipse (m^3/s).

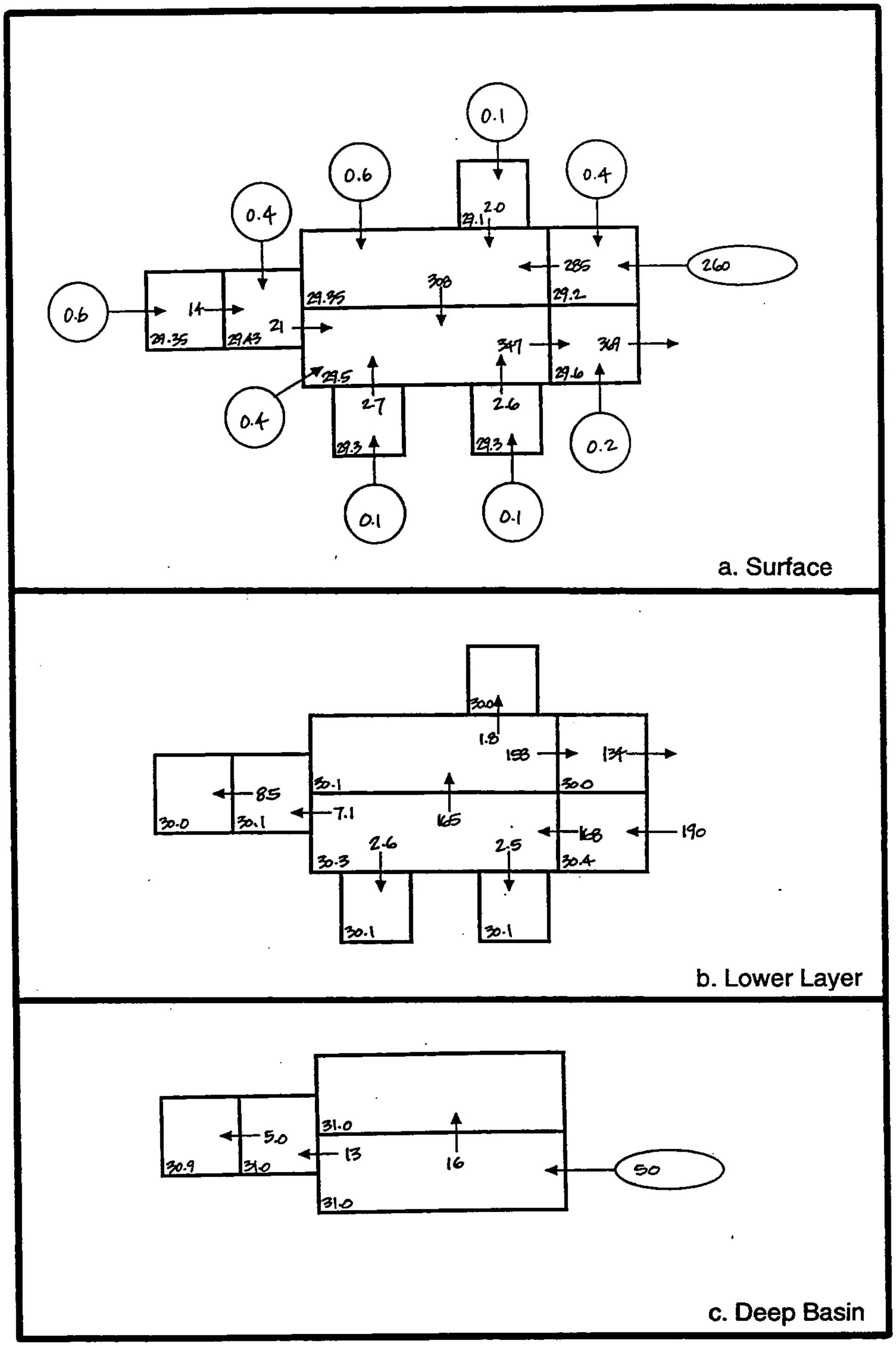
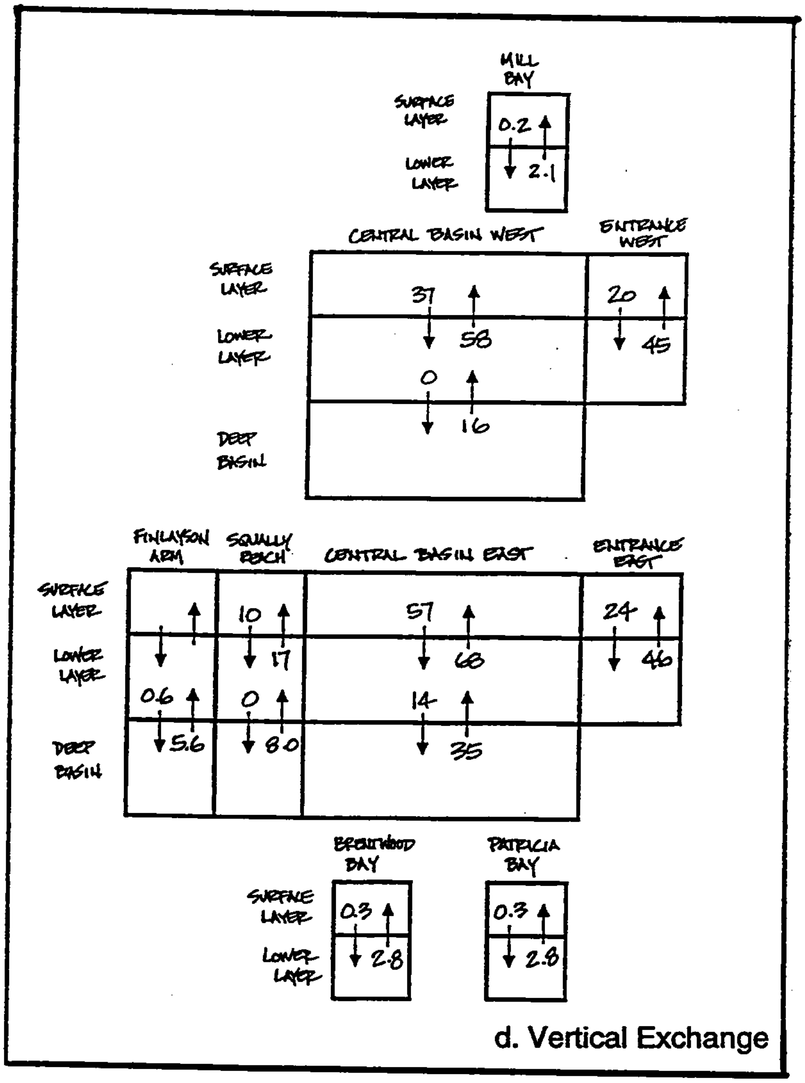


Figure 5-25 (continued)



d. Vertical Exchange

6. SEDIMENT TRANSPORT

Sedimentary processes in Saanich Inlet relate to two aspects of this study. Firstly, the sediment transport model is an integral part of the Saanich Inlet mass balance model described in Section 4 of this report. Sediments, both as suspended material in the water column and as part of the seabed, play an important role in determining the fate of contaminants in the marine environment. Many contaminants preferentially adsorb onto fine suspended solids, eventually incorporating into seabed deposits. The transport, deposition and potential resuspension of sediments are important factors in the assessment of the fate of contaminants entering the Saanich Inlet system.

Secondly, increases in the suspended sediment concentrations in the waters of the inlet or increases in the seabed sedimentation rate may have adverse affects on the marine habitat and on some biota. Anecdotal evidence suggests that episodic events of increased turbidity in the inlet may be related to land development activities. Issues related to sedimentary processes in the inlet as they affect habitat and biota are discussed in Section 10 of this report.

6.1 Background

Saanich Inlet extends into two physiographic regions: the Victoria Highland region, typified by low mountains, and the Nanaimo Lowlands region, characterized by gently rolling hills and flat plains (Drinnan et al., 1995). Much of the southern end of the inlet is surrounded by exposed bedrock, while bedrock is overlain by Quaternary sedimentary deposits in the watersheds to the north and east of the inlet. These Quaternary deposits were formed during the last ice age, when a glacier moved southwards from the Cowichan Valley into Saanich Inlet and across the Saanich Peninsula.

Many previous studies have focused on the sediments underlying the deep basin in Saanich Inlet. Cores collected during the 1960s by the University of Washington were found to consist of alternating dark and light laminae (Gross et al., 1963; Buddemeier, 1969), each with distinct characteristics. The light laminae consist mainly of diatoms deposited during spring and summer plankton blooms in the surface waters (Gross et al., 1963; Sancetta and Calvert, 1988; Whitney and Wong, 1984), while the dark laminae are dominated by fine, terrigenous sediments deposited mainly during fall and winter. The organic carbon content of bottom sediments increases in an up-inlet direction, ranging from less than 2% over the sill region to more than 4% in Finlayson Arm at the head of the inlet (Francois, 1988).

The varved sequences in the bottom sediments of Saanich Inlet are found interbedded with massive units ranging from several centimetres to several tens of centimetres in thickness. The massive units are thought to have been formed by sediment gravity flows, triggered by earthquake events and occurring on average, about once every 100 years (Bobrowsky and Clague, 1990; Blais, 1992).

Gucluer and Gross (1964) identified five sources of suspended solids to the waters of Saanich Inlet: marine plankton, suspended sediments entering at the mouth of the inlet, solids associated with the direct fresh water discharges to the inlet, shoreline erosion and the discharge from the Bamberton cement plant. The effects of the discharge from Bamberton were found to be largely limited to the local vicinity of the plant site; this source is assumed to be insignificant at present since the cement plant is no longer in operation. Shoreline erosion, although it provides a source of coarse material to the nearshore zones, is not thought to be a major source of suspended materials to the inlet as a whole. The remaining three sources will be discussed in more detail in the next section of this report.

Since contaminants are strongly associated with the fine sediment fractions, the sediment transport model has been developed to focus on the dynamics of suspended solids within the inlet. Seabed processes such as sediment resuspension and bedload transport play a relatively minor role within Saanich Inlet, and are limited to shallower shoreline areas with mobile seabed deposits. The following section describes the mathematical formulation of the sediment transport model, including a discussion of the suspended solids loadings to Saanich Inlet.

6.2 Approach

The sediment transport module has been based on the mass balance approach described in Section 4.2 of this report, and uses the conservation of mass equation for each model box:

$$\sum_{j=1}^{n} C_j Q_{ij} - \sum_{k=1}^{m} C_i Q_{ik} + P_i - E_i \qquad (6\text{-}1)$$

where C_i and C_j represents the concentration of suspended sediments in box i and box j, respectively, Q_{ij} represents the transports of water from box i to box j and includes external source terms, P_i represents the sum of all internal transformations affecting sediment concentrations within each box, and E_i represents the transports across the boundaries of box i that are not accompanied by fluid transport. The above equation assumes steady-state conditions; applying this equation to each model box leads to a simple system of linear equations which can then be solved for the unknown C_i values.

In order to run the sediment transport module, appropriate formulations for the internal transformation (P_i) and boundary transport (E_i) terms must be developed for each model box. The main internal transformation of interest to this project is the *in situ* production of organic matter in the surface waters of the inlet through photosynthesis (primary production). Estimates of primary productivity are discussed in Section 6.2.1.3.

The E_i term in equation 6-1 represents the transports of suspended solids across the boundaries of box i that are not directly associated with fluid movement. This terms is used to represent the effects of gravity on sediment movement. As suspended materials are transported away from their source by the circulation of water masses in the inlet, they also fall through the water column, eventually depositing onto the seabed. The downward flux of sediments across the bottom of each model box has been parameterized as:

$$E_i = C_i V_{fi} A_i \tag{6-2}$$

where V_{fi} represents the fall velocity for the suspended solids in box i and A_i represents the plan area of box i through which downward sediment fluxes are assumed to occur.

As described in Section 5 of this report, the waters of Saanich Inlet have been sub-divided into boxes representing water masses of similar characteristics. This subdivision has been based on logical physical boundaries, changes in the processes that generate ocean currents and spatial gradients in water column properties. The sediment transport module uses the same box structure as that developed for the oceanographic module, reflecting the assumption that sedimentary processes are largely governed by water movements.

The sediment transport model also requires the volume exchanges between model boxes (Q_{ij}) and the external sediment inputs to each box, or sediment loadings, to be specified as input data. The volume exchanges between model boxes have been determined through the oceanographic modelling described in detail in Section 5; the sediment loadings to Saanich Inlet are described in the following sections.

6.2.1 Sediment Inputs to Saanich Inlet

As described previously, the three major sources of suspended materials to Saanich Inlet are suspended solids entering at the mouth of the inlet, direct inputs associated with the fresh water discharges to Saanich Inlet and *in situ* productivity. Seasonal variations in the relative magnitudes of these sources are apparent. Additional sources of suspended materials to the inlet include the inflow to the lower layer at the mouth of the inlet, and the deep water renewal events. The following material summarizes the magnitudes and characteristics of each of these sources.

6.2.1.1 Local Streams and Rivers

The direct sources of fresh water to Saanich Inlet have been summarized in Section 5.2.2. These sources include Shawnigan Creek, Goldstream River, Tod Creek and the many small creeks and streams entering the inlet. Of these, Shawnigan Creek represents the largest single source, with an annual average flow rate of 1.9 m^3/s (Table 5.2).

Concentrations of suspended solids are not routinely monitored for any of the direct sources of fresh water entering Saanich Inlet. In order to provide an estimate of suspended sediment concentrations in these streams and creeks, data from other watersheds on the eastern side of Vancouver Island have been obtained through MELP (Nijman, pers. comm. 1995) and reviewed for application to this project.

Suspended sediment concentration data were supplied for the Cowichan and Koksilah Rivers, two sites on the Nanaimo River and the Oyster River near the city of Campbell River. Of these sites, only the Cowichan, Koksilah and Oyster River stations had data for each month of the year. Data were extremely limited, with a maximum of 24 readings for any one month over the period of record. As a result, data variability is relatively high, particularly in the winter months when rainfall events are likely to have a strong impact on concentrations of suspended solids.

A comparison between the Cowichan, Koksilah and Oyster River stations showed that concentrations in the Cowichan and Koksilah Rivers were very similar for much of the year, with significantly higher sediment concentrations in the Cowichan River during the months of November through February. Oyster River data were somewhat similar to the Cowichan data, although with higher solids concentrations in the months of October and February.

The data from the Cowichan River were chosen for use in this project, primarily due to the proximity to Saanich Inlet and the general similarity between data sets. A formal comparison between suspended sediments loads from the Cowichan watershed and those watersheds surrounding Saanich Inlet would require a far more detailed assessment than that completed here, and would involve comparison of land uses, watershed areas, precipitation characteristics, river and land slopes, etc. Although information is limited, the available data can be used to qualitatively estimate the order of magnitude of the suspended solids loadings to Saanich Inlet.

The suspended solids concentration data from the Cowichan River have been averaged over the seasons as previously defined for this project (winter, spring, summer, summer renewal and fall). The results indicate concentration levels of 20, 4, 2, 2, and 2 mg/L for winter, spring, summer, summer renewal and fall seasons, respectively. These concentration values have been used to calculate the suspended solids loadings for all creeks and streams flowing directly into Saanich Inlet (including ungauged streams), with the exception of the Goldstream River. Approximately 40% of the Goldstream River watershed is used to supply drinking water to the City of Victoria (Hull, pers. comm. 1995); hence, a significant portion of the suspended load is likely to be retained within the reservoir system. Anecdotal evidence also suggests that the waters of the Goldstream River are extremely clear, even during heavy rainfall events. Thus, suspended sediment concentration values for the Goldstream River have been taken as one-half the values given above.

The many lakes in the watersheds surrounding Saanich Inlet (e.g., Shawnigan Lake) may also act as sediment traps, reducing the sediment load to marine waters. This process may also be significant in the Cowichan watershed, from which the data used to estimate sediment loads to Saanich Inlet were obtained.

6.2.1.2 Cowichan River and Satellite Channel

Many previous studies of Saanich Inlet have identified the discharge from the Cowichan River as the major source of sediments to Saanich Inlet. Measurements of deposition rates in the inlet (see Drinnan et al., 1995 for a summary) have shown that accumulation rates are roughly 6 times higher at the mouth of the inlet than at the head, suggesting that the main source of sediments to the inlet is through the waters of Satellite Channel. The greater dominance of terrigenous sediments towards the mouth of the inlet indicate that the Cowichan River may indeed be a major source of sediments to Saanich Inlet. However, discharge from the Fraser River and sediments resuspended from the bed of Satellite Channel may also contribute to the sediment load entering the inlet at the mouth.

Unfortunately, measurements of suspended sediment concentrations at the mouth of Saanich Inlet are limited. Previous studies have focused on longer-term deployments of sediment traps at various depths and locations in Saanich Inlet. Although providing valuable information on the characteristics of suspended solids within the inlet, these data cannot be used as direct measurements of suspended solid concentrations in the water column.

Direct measurements of suspended solid concentrations within the water column in Saanich Inlet are limited to four depth profiles taken at the centre of the inlet near Pat Bay, in March, May, August and November of 1984 (Whitney, pers. comm. 1995a). These profiles show extremely low concentrations of suspended solids, ranging from 0.1 to 0.9 mg/L with a mean value of 0.3 mg/L (Drinnan et al., 1995).

Turbidity measurements at the entrance to Saanich Inlet show peaks occurring at about sill depth and at the surface during certain times of the year (Whitney, pers. comm. 1995b). The peak in turbidity at sill depth occurs on the neap tide during the summer months, when the currents into the inlet are at their strongest as a result of renewal events. Surface peaks in turbidity occur during the winter months, reflecting the discharge from the Cowichan River, and perhaps during the summer months when the Fraser River water is present in the region. Again, the surface peaks in turbidity tend to be associated with the neap tide, when vertical mixing in Satellite Channel is reduced and vertical stratification of the water column is preserved. The levels of suspended solids in the water column associated with these turbidity peaks are not known.

The sediment transport model requires suspended solid concentration values to be specified as boundary conditions for the three inflows at the mouth of Saanich Inlet: the surface inflow on the western side of the inlet (surface Entrance West box), the mid-depth inflow on the eastern side of the inlet (lower Entrance East box) and the deep inflow of renewal water on the eastern side during the summer renewal season (deep Central Basin East box). The suspended solid concentrations assumed for each of these inflows are shown in Table 6-1 for each of the five modelling seasons.

The concentration values shown in Table 6-1 show the same seasonal pattern as indicated by the Cowichan River data, with highest concentration values in the winter months, intermediate values in the spring, and consistently low values throughout the summer, summer renewal and fall seasons. The higher values assumed for the lower layer inflow during the summer, summer renewal and fall seasons reflect the observations of higher turbidity levels in the lower water column, while the winter values reflect the influence of the relatively high Cowichan River sediment discharge on both surface and deeper waters.

6.2.1.3 Primary Productivity

Suspended solids are produced within the waters of Saanich Inlet through photosynthesis in the upper euphotic zone. Monthly measurements of primary production have been supplied by Frank Whitney of the Institute of Ocean Sciences; these measurements are from the centre of

Saanich Inlet in the vicinity of Patricia Bay. Averaging the productivity measurements over the modelling seasons gives values of roughly 2 mg C/(m^3 x day) for the winter season, 6 mg C/(m^3 x day) for spring and 8 mg C/(m^3 x day) for the summer, summer renewal and fall seasons. Production has been assumed to be limited to the upper 4 m of the water column during the winter months, 8 m during spring and to extend downwards to a depth of 16 m during the summer, summer renewal and fall seasons. For modelling purposes, the suspended solid load created through primary productivity has been added to the surface layer boxes only.

Production values have been multiplied by a factor of 2.0 to convert from total carbon productivity to suspended solids, and by the surface area of each box to determine loading rates. Although there is some evidence that productivity is higher at the mouth of the inlet than towards the head, a spatially uniform rate has been used for this first-order model for simplicity.

6.2.1.4 Summary of Suspended Solids Loadings to Saanich Inlet

The annual loadings of suspended sediments to Saanich Inlet from the three sources described above are summarized in Table 6-2. The inflows of marine water at the mouth of Saanich Inlet can be seen to dominate over all other sources, supplying roughly 95% of the total annual load of suspended solids to Saanich Inlet. This load has been estimated from assumed rather than measured concentration values, and uses the fluid fluxes as determined from the results of the oceanographic model (Section 5). Both the concentration values and the oceanographic fluxes represent unverified data which include large uncertainties; thus, the magnitude of this sediment load is also uncertain. However, reducing this load by an order of magnitude would still result in the inflows at the mouth providing roughly 70% of the total load of suspended solids to the waters of Saanich Inlet.

The suspended solids in the marine inflows include both terrigenous and biogenic materials, with the balance between the two varying on a seasonal basis. It is likely that a significant portion of this material is biogenic, particularly during the summer months when a frontal zone of high productivity is present at the mouth of Saanich Inlet (Parsons et al., 1983).

The contribution of local streams and rivers and *in situ* productivity to the overall sediment budget in Saanich Inlet are roughly equal, with the exception of Mill Bay where the discharge from Shawnigan Creek dominates over primary productivity. However, these sources combined contribute only 5% of the total estimated suspended solids loadings to Saanich Inlet.

6.2.2 Model Parameters

The sediment transport model as formulated above (Equations 6-1 and 6-2) has one adjustable parameter: the fall velocity, V_{fi}. The fall velocity (i.e., the rate at which suspended material falls through the water column) is determined by the particle size of the suspended sediments, particle shape, specific gravity and the composition of the suspended materials. Due to the complex inter-relationships between these parameters, and considering the importance of floc formation in the marine environment, the fall velocity is a difficult parameter to specify accurately based on simple sediment characteristics alone. Instead, the fall velocity is often used as an adjustable parameter to be set to a value that minimizes the differences between model predictions and *in situ* observations (e.g. Petrie and Yeats, 1990; EVS Consultants et al., 1995). *In situ* observations typically include either concentrations of suspended solids or net seabed siltation rates.

For Saanich Inlet, a fall velocity of 2.0 m/day has been specified for all model runs, for all model boxes. This value is comparable to the 2.2 m/day used by Petrie and Yeats (1990) in their modelling of Halifax Harbour, although it is somewhat higher than the value of 0.9 used for Burrard Inlet (EVS Consultants et al., 1995). The value of 2.0 m/day has been chosen such that the results of the sediment transport model match the observed pattern of deposition rates in the inlet.

6.2.3 Model Assumptions and Limitations

The sediment transport model described in this report reflects a compilation and integration of the available information on sedimentary processes in the inlet at the time of model development. Since that time, additional data have become available that are pertinent to this effort. These data will be discussed in more detail in Model Certainty (Section 6.3.3).

The sediment transport model represents a simple mass balance formulation for Saanich Inlet, and relies heavily on available measurements of the relevant parameters. The major limitations of this model are:

- Transport of fine sediments is largely governed by the water movements and circulation patterns in the inlet. Thus, uncertainties in the fluxes predicted by the oceanographic model will be propagated through to the sediment transport model.

- The loadings of suspended solids to the inlet are not well understood. No measurements are available for suspended solids loadings from rivers and streams flowing directly into Saanich Inlet, or from exchanges with the waters of Saanich Inlet.
- Measurements of concentrations of suspended solids in the waters of the inlet are limited; the available data (Drinnan et al., 1995) appear to be extremely low.

The model formulation uses a constant fall velocity for all solids suspended in the water column, and for all areas of the inlet.

6.3 Findings

6.3.1 Model Results

The results of the sediment transport model simulations for winter, spring, summer, the summer renewal season and fall are shown in Figure 6-1 through Figure 6-5. These figures follow a similar format to that used in Section 5 to present the results of the oceanographic model, where each square represents one model box. External inputs to the inlet are represented as circles or ellipses, with circles corresponding to sediment inputs associated with fresh water sources, and ellipses corresponding to marine water sources.

Figure 6-1 through Figure 6-5 show the predicted suspended solids concentrations in the water column for each model box for each of the five seasons. These values are shown in the lower left hand corner of each model box and have units of mg/L. The horizontal fluxes of suspended solids between model boxes and crossing the boundaries of Saanich Inlet are shown beside each arrow indicating flow direction. All sediment fluxes are shown in units of grams per second (g/s). The rate of creation of suspended solids through primary productivity is shown within the small circle inside each model box, again in units of g/s.

A comparison of Figure 6-1, representing winter conditions, and Figure 6-3, showing summer conditions, gives a clear picture of the seasonal variation in the composition of suspended solids loadings to Saanich Inlet. Although the relative amounts of biogenic versus terrigenous materials in the boundary influx at the mouth of Saanich Inlet are unknown, the remaining sources show that terrigenous inputs dominate during the winter months. Conversely, primary productivity (shown in the small circles within each model box) is one to two orders of magnitude greater than the inputs from terrigenous sources during the summer months.

6.3.2 Model Verification

The model results show that concentrations of suspended solids in the water column are highest during the winter months, and lowest during the summer and summer renewal seasons. During the winter, suspended solids concentrations in the surface layer vary from a minimum of 0.06 mg/L in Finlayson Arm to a maximum of 2.7 mg/L in the Entrance West box. Concentrations in the surface layer were found to increase from the head of the inlet to the mouth, probably as a result of the dominant loading at the mouth of the inlet. Concentrations were also higher on the western side of the inlet than on the east, reflecting the stronger loading on the western side (boundary inflow and Shawnigan Creek). Surface layer concentrations in Brentwood Bay and Pat Bay were relatively low, at 0.3 and 0.2 mg/L, respectively. In the lower layer, concentrations ranged from 0.9 mg/L to 3.1 mg/L, again increasing towards the mouth of the inlet. Suspended solids concentrations in the deep basin boxes varied between 2.3 to 6.6 mg/L.

In the summer months, suspended solids concentration values were lower for all model boxes, ranging from 0.02 to 0.9 mg/L in the surface waters, 0.2 to 1.7 mg/L in the lower layer, and 0.5 to 3.0 mg/L in the deep basin boxes. Model results showed the same spatial patterns as for winter, with higher concentrations towards the mouth of the inlet, on the western side in the surface layer, and on the eastern side in the lower layer and in the deep basin boxes. The model also predicts that suspended solids concentrations should increase with depth in all areas of the inlet.

The suspended solid concentration values predicted by the sediment transport model are somewhat higher than previous observations, where measurements in the central basin area ranged from 0.1 to 0.9 mg/L throughout the year. However, these observations represent a very limited number of measurements, and indicate unusually low suspended solids concentrations in the water column. Recent measurements by Frank Whitney of the Institute of Ocean Sciences (Whitney, pers. comm. 1995c) have become available since the completion of this modelling exercise; these data indicate sediment concentrations ranging from 0.5 to 5 mg/L.

As described previously in Section 6.2.2, the fall velocity used by the model has been adjusted such that the model results match the observed pattern of sediment deposition in the inlet. Previous estimates of sedimentation rates in the inlet are summarized in Drinnan et al. (1995); these range from 0.8 to 1.7 cm/yr, or, as dry weight accumulations, from 420 to 2700 g/m^2/yr. Siltation rates are lowest at the head of the inlet in Finlayson Arm, and increase towards the mouth. Previous estimates of siltation rates in Saanich Inlet are given in Table 6-3 and plotted in Figure 6-6.

Siltation rates as predicted by the sediment transport model are given in Table 6-4, on a season by season basis and as annual averages. The model predictions show that sedimentation rates in the main channel of Saanich Inlet increase from the head of the inlet at Finlayson Arm, through Squally Reach to the Central Basin boxes, before decreasing in the Entrance boxes over the sill region. This pattern largely reflects the spatial variations observed in the above measurements. Predicted annual average siltation rates for the main channel boxes range from 830 $g/m^2/yr$ in Finlayson Arm to 3024 $g/m^2/yr$ in the Central Basin East box. Bearing in mind the spatial variability and errors associated with the measurement of siltation rates, these values represent a good match to the observed values. The associated siltation rates range from 0.4 to 1.4 cm/yr, based on a sediment density of 2.2 g/cm^3 and a seabed porosity of 0.9.

The sediment transport model predicts an annual average siltation rate of 0.5 cm/yr in Mill Bay and 0.2 cm/yr in both Brentwood and Patricia Bay. Although it has been suggested that the coastal embayments are erosional rather than depositionary environments, the lack of large or long period waves within Saanich Inlet suggests that erosional effects are confined to a relatively thin margin around the edge of each bay. Shoreline erosion is likely to occur in response to occasional storm events, rather than on a relatively continuous basis such as is associated with sediment deposition. Since the model considers average effects over the total area of each box, it is quite possible that, while the edges of the embayment boxes are erosional, the average condition over the entire box is one of net deposition. The contaminant fate model (Section 7) does, however, incorporate the effects of sediment resuspension along the shoreline of Saanich Inlet.

6.3.3 Model Certainty

Section 6.2.3 discussed the assumptions and limitations of the Saanich Inlet sediment transport model. Since the development of this model and the writing of the draft Saanich Inlet Synthesis Study report, additional information has become available that sheds some insights into the reliability of the mass balance model components.

As discussed throughout this section, there are four main areas of uncertainty associated with the Saanich Inlet sediment transport model: the rates of exchange between the various water masses in the inlet, the loadings of suspended solids, the concentrations of suspended materials in the water column and the model formulation. Further analyses of the water column data collected in the summer and fall of 1995 have indicated that the residence times predicted by the oceanographic model for the coastal embayments seem to be low, particularly for the summer and summer renewal seasons.

Predicting the impacts of an increased flushing rate on the results of the sediment transport model is difficult due to the nonlinearities in the model formulation. In order to assess this factor, a model run was repeated for the average summer conditions with the horizontal fluxes between the coastal embayments and the central basin boxes increased by one order of magnitude. Suspended solids loadings and sediment fall velocity were maintained at the values specified earlier in this report. Results of this model run showed a slight increase in suspended sediment concentrations in the surface waters of the coastal embayment boxes, with a greater increase in the lower layers. The siltation rates in the coastal embayments increased by factors of 1.7 in Brentwood Bay, 2.3 in Pat Bay and 4.7 in Mill Bay. Suspended solids concentrations and siltation rates remained essentially unchanged in the rest of Saanich Inlet.

Revised data obtained since the completion of the work described here indicate that the estimates of suspended solids loadings from primary productivity used in this study are probably low, perhaps by as much as an order of magnitude. Increasing the magnitude of the productivity source by one order of magnitude would increase the total estimated loading of suspended solids to the inlet by roughly 20%; this increase is considered to be well within the uncertainty associated with the overall loadings estimates used for this study. Any further studies should re-evaluate suspended solids loadings from primary productivity.

Recent measurements of suspended solid concentrations in the waters of Saanich Inlet indicate levels of about 0.5 to 5.0 mg/L for the surface waters during summer conditions. Model predictions for the summer season range from 0.02 to 0.9 mg/L, with the lowest values in Finlayson Arm, Squally Reach and the coastal embayments (Mill Bay, Brentwood Bay and Patricia Bay). The values predicted by the model appear to be low, by up to one order of magnitude, particularly for the coastal embayments and the waters at the head of the inlet. As shown above, increasing the rate of flushing of these areas of the inlet leads to only small changes in the suspended solids concentrations in the surface waters.

The sedimentary processes in Saanich Inlet include two separate sub-systems: those affecting sediments of biogenic origin and those affecting terrigenous sediments. Recent work has shown that roughly 26% of the suspended particulate organic carbon in the water column is grazed daily during July and excreted as fecal pellets (Whitney, pers. comm. 1995b); these fecal pellets have a fall velocity on the order of 100 m/day. The fall velocity of 2.0 m/day used in this model represents an integrated value with contributions from both the biogenic and terrigenous sedimentary sub-systems. Based on the new evidence with respect to the relative importance of each sedimentary sub-system, a higher fall velocity may be justified.

In summary, the sediment transport model for Saanich Inlet contains many areas of uncertainty: the rate of flushing of the coastal embayments, the total loads of suspended solids entering the inlet, particularly at the mouth, the seasonal and spatial variations in suspended solids concentrations in the water column; and the appropriate fall velocity for the suspended materials. If one were to consider all these effects cumulatively, then the certainty of the model would be very low. It should be remembered, however, that model results were calibrated using available estimates of siltation rates in the main body of the inlet. Thus, the confidence level in this parameter is moderate to high, depending on location within the inlet. However, the estimates of suspended solids concentrations in the surface waters of the inlet appear to be low, perhaps by as much as one order of magnitude.

6.4 Considerations for Model Improvement

The sediment transport model as presented here represents a simple mass balance formulation for Saanich Inlet. Although the model results agree well with the available seabed siltation rates, there are several areas of uncertainty associated with the model predictions. These include: the water movements in the inlet, the sediment loadings, the concentrations of suspended solids in the water column and the model formulation.

The fate of fine sediments entering Saanich Inlet is largely determined by the circulation patterns within the inlet. The modelling and prediction of the mean circulation patterns in Saanich Inlet are described in Section 5 of this report. Although the oceanographic model reproduces many of the known features of the circulation system, the model incorporates many assumptions which are, at present, unverified. Validation of the assumptions contained in the oceanographic model formulation would require further data collection and analyses (Section 5.3.4).

As described in Section 6.2.1, the loadings of suspended solids to Saanich Inlet are largely unknown. Of the three main sources of suspended materials (local rivers and streams, primary productivity and boundary inflows), the boundary inflows provide the vast majority of the sediment load to Saanich Inlet. However, the concentration and composition of suspended solids in the water column at the entrance to the inlet are largely unknown. It is strongly recommended that suspended solids concentrations in the waters at the mouth of the inlet be measured, and the composition (biogenic vs. terrigenous) composition of the suspended materials be determined.

Similarly, few measurements of the concentrations of suspended solids in the water column throughout the inlet are available. Measurements covering seasonal variations as well as spatial variations in the inlet would provide additional information that could be used to validate the sediment transport model. Measurements of siltation rates in the coastal embayments would be useful for validation of the model predictions in these regions of the inlet. The frequency, duration and extent of resuspension events along the shorelines should also be assessed.

The present formulation of the sediment transport model is relatively simple, in that one fall velocity is used to represent all the sediments in the inlet. In reality, suspended materials are composed of a variety of sizes and types of materials, each falling through the water column at different rates. Previous studies (Whitney, pers. comm. 1995c) have indicated that the sedimentary processes in Saanich Inlet can be subdivided into two separate systems, representing solids of biogenic and terrigenous origin. The terrigenous sediments are generally composed of fine silts and clays, and have a relatively slow fall velocity. Conversely, a large percentage of the biogenic solids in the upper water column are processed through grazing and excreted as fecal pellets, falling relatively rapidly through the water column. A more complex sediment transport model could be developed to separately model these two systems, however, the relative loadings from each source must be determined before this could be effectively implemented.

Table 6-1 Assumed concentrations of suspended solids in marine water inflows at the mouth of Saanich Inlet (mg/L).

Inflow	Winter	Spring	Summer	Summer Renewal	Fall
Surface Entrance West	3.0	2.0	1.0	1.0	1.0
Lower Entrance East	3.0	2.0	2.0	2.0	2.0
Deep Summer Renewal	-	-	-	1.0	-

Table 6-2 Annual loadings of suspended solids to Saanich Inlet (tonnes per year).

Model Box	Local Streams	Boundary Influx	Renewal Events	Primary Productivity	**TOTAL**
Entrance East	157	107,723	-	263	**108,177**
Entrance West	246	33,805	-	208	**34,225**
Central Basin East	334	-	264	1076	**1,674**
Central Basin West	468	-	-	779	**1,247**
Squally Reach	311	-	-	395	**706**
Finlayson Arm	225	-	-	219	**444**
Mill Bay	940	-	-	96	**1,036**
Brentwood Bay	199	-	-	261	**460**
Patricia Bay	87	-	-	151	**238**
TOTAL	**2967**	**141,528**	**264**	**3,448**	**148,207**

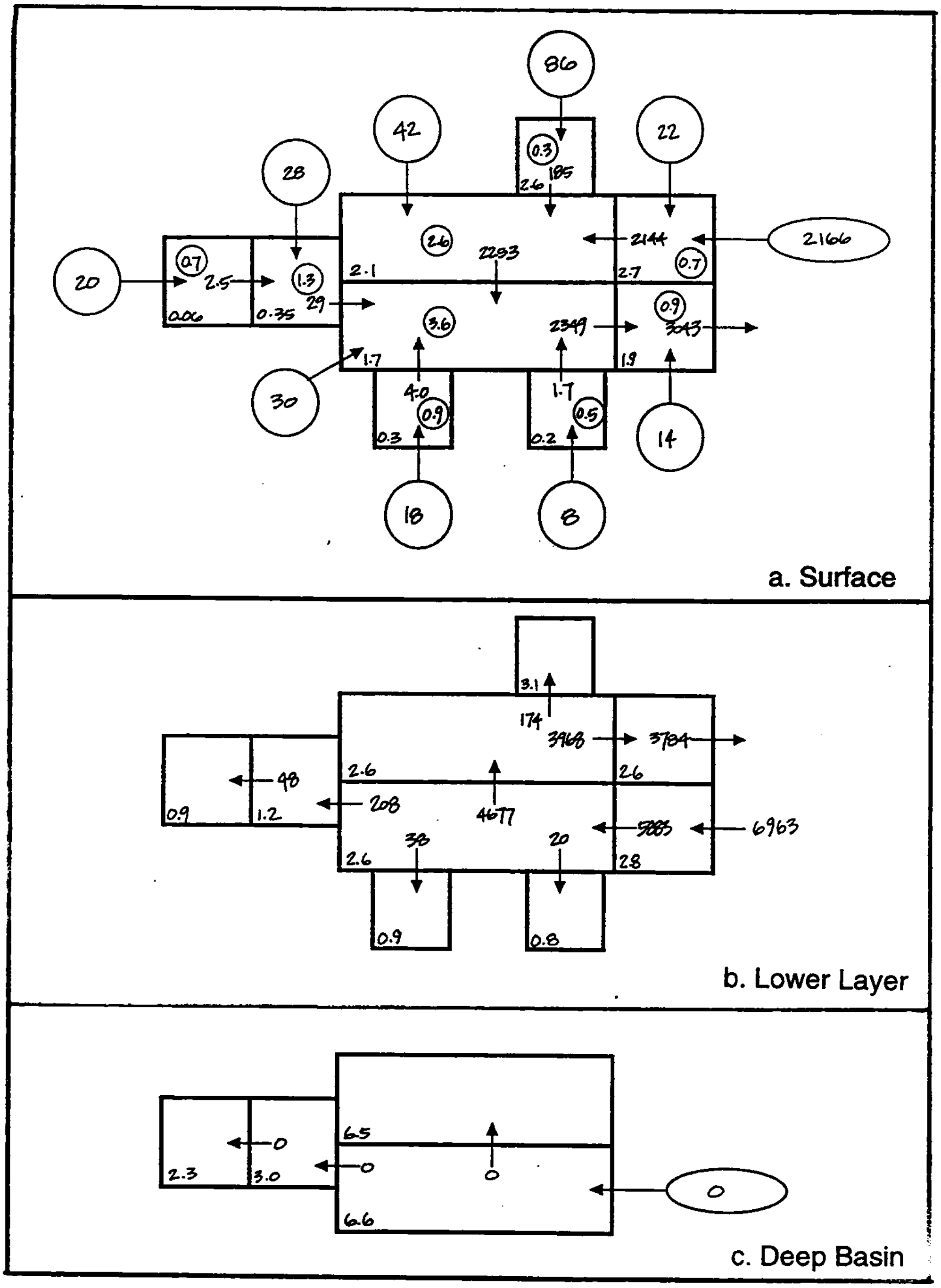
Table 6-3 Siltation rates in Saanich Inlet (after Drinnan et al., 1995).

Station	Distance from head (km)	Sedimentation rate ($g/m^2/yr$)
CP4	5.7	420
SN 0.8	6.5	950
SI-3	8.7	930
1	10.9	900
G	15.7	1440
SI-7	18.3	2700
SI-9	20.5	2570

Table 6-4 Sedimentation rates in Saanich Inlet, model predictions.

Model Box	Winter ($g/m^2/yr$)	Spring ($g/m^2/yr$)	Summer ($g/m^2/yr$)	Summer Renewal ($g/m^2/yr$)	Fall ($g/m^2/yr$)	Annual Average ($g/m^2/yr$)	Annual Average (cm/yr)
Finlayson Arm	1676	364	386	444	554	830	0.4
Squally Reach	2185	801	510	503	874	1139	0.5
Central Basin West	4735	2695	1821	1093	2477	2859	1.3
Central Basin East	4808	2841	2185	1093	2768	3024	1.4
Entrance West	1894	1020	728	510	874	1136	0.5
Entrance East	2040	1311	1238	1020	1311	1484	0.7
Mill Bay	2258	947	328	189	852	1087	0.5
Brentwood Bay	634	226	189	189	306	351	0.2
Patricia Bay	583	175	204	211	270	330	0.2

Figure 6-1 Sediment transport model results for the winter season (see text for explanation of figure).

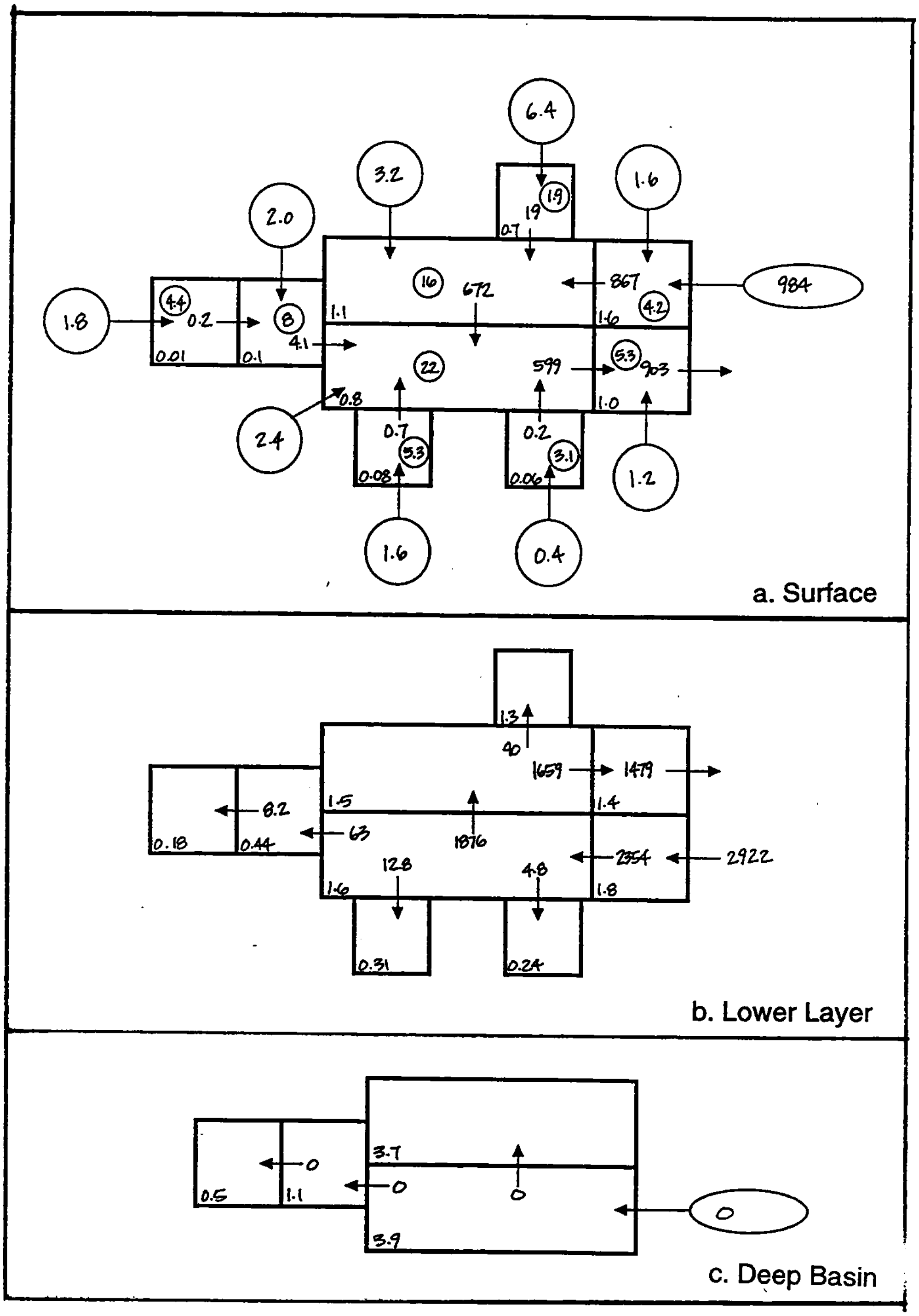


a. Surface

b. Lower Layer

c. Deep Basin

Figure 6-2 Sediment transport model results for the spring season (see text for explanation of figure).



a. Surface

b. Lower Layer

c. Deep Basin

Figure 6-3 Sediment transport model results for the summer season (see text for explanation of figure).

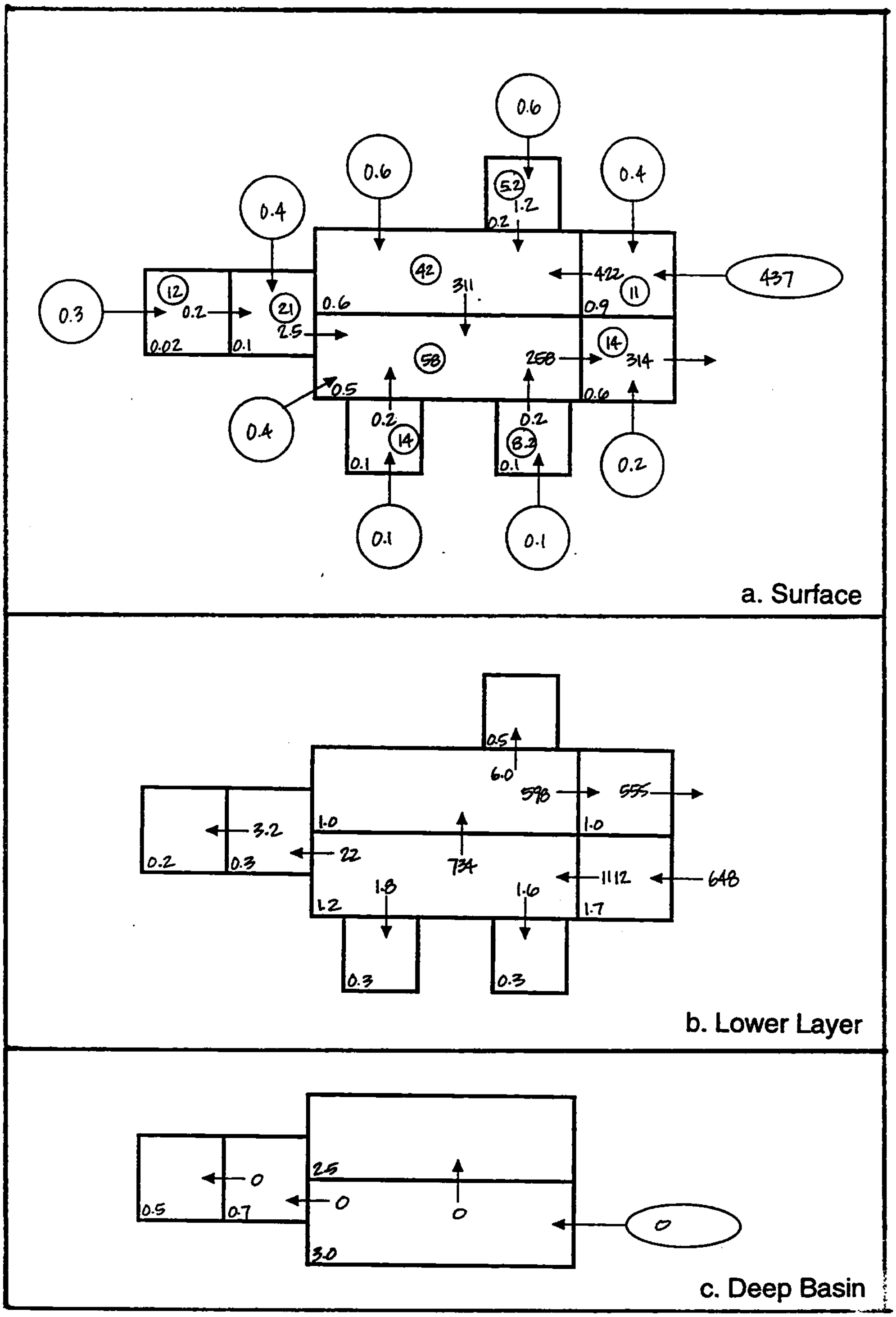


Figure 6-4 **Sediment transport model results for the summer renewal season (see text for explanation of figure).**

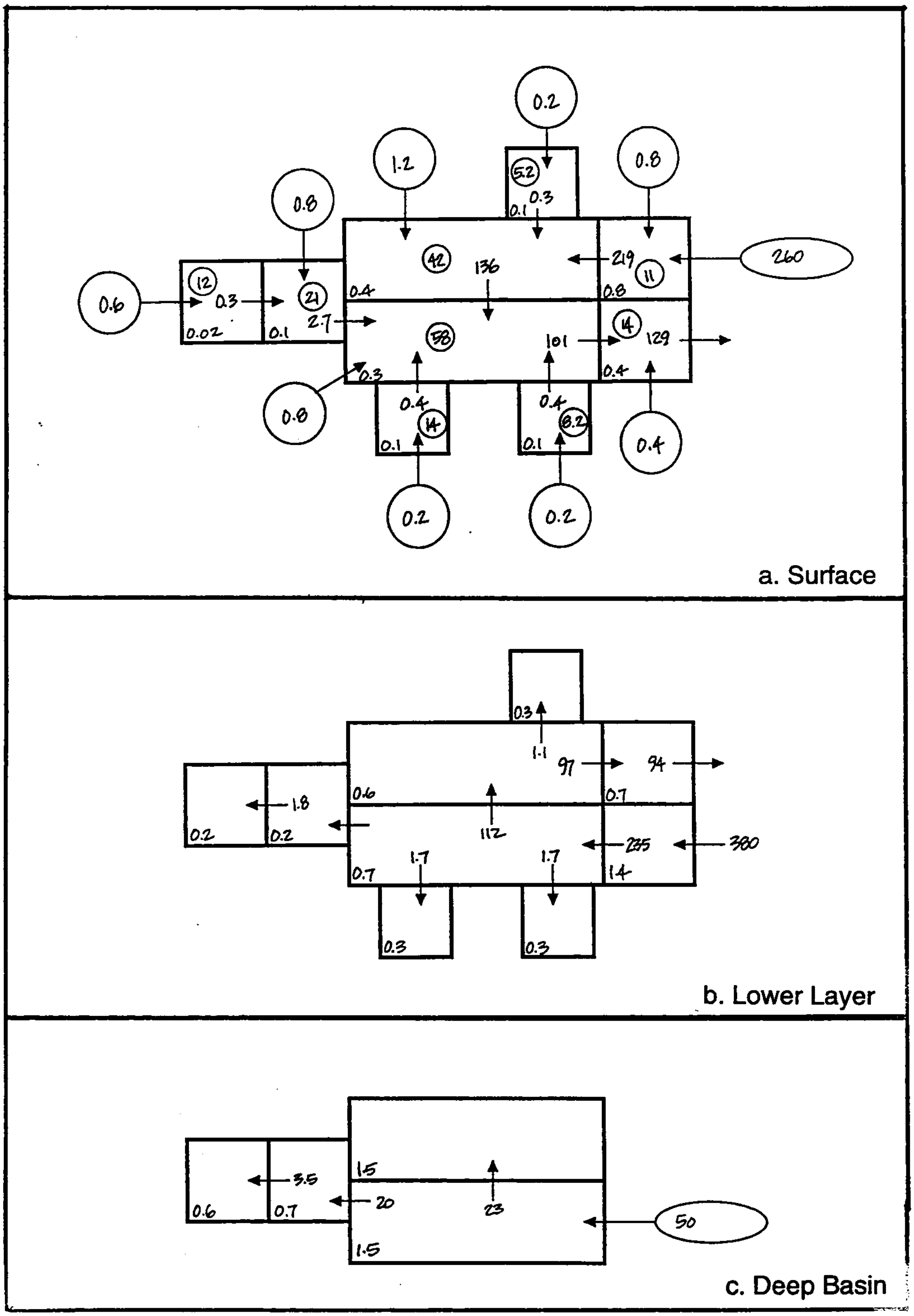
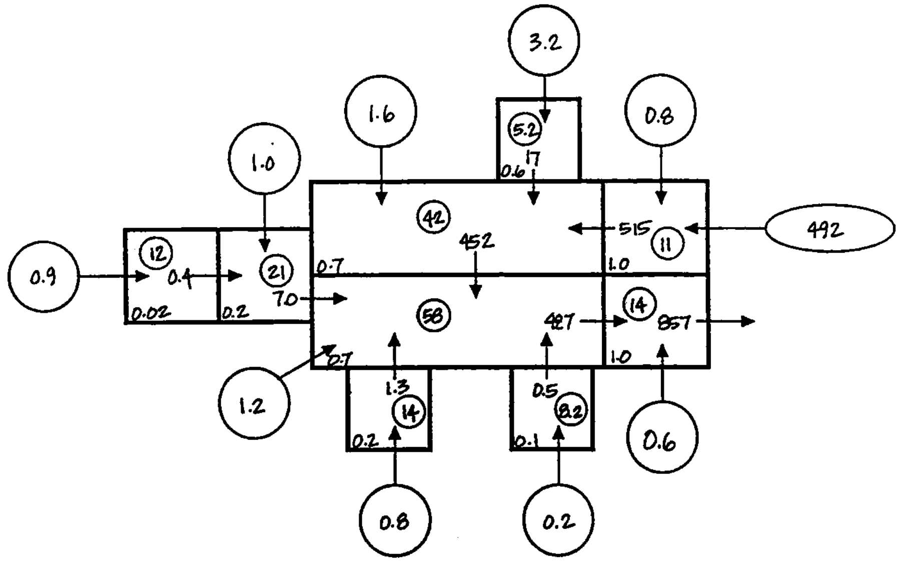
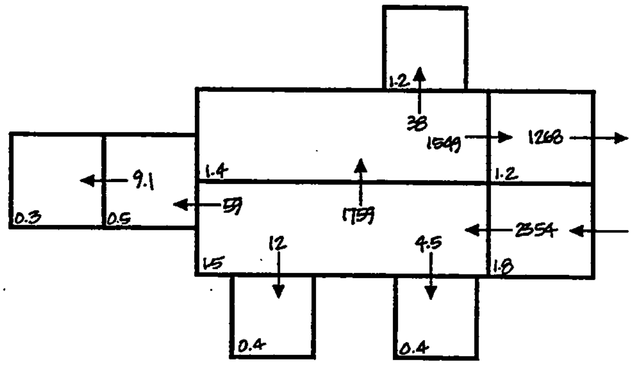


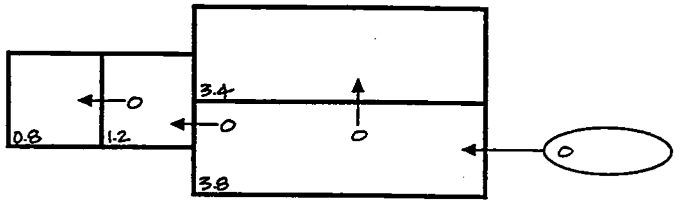
Figure 6-5 Sediment transport model results for the fall season (see text for explanation of figure).



a. Surface

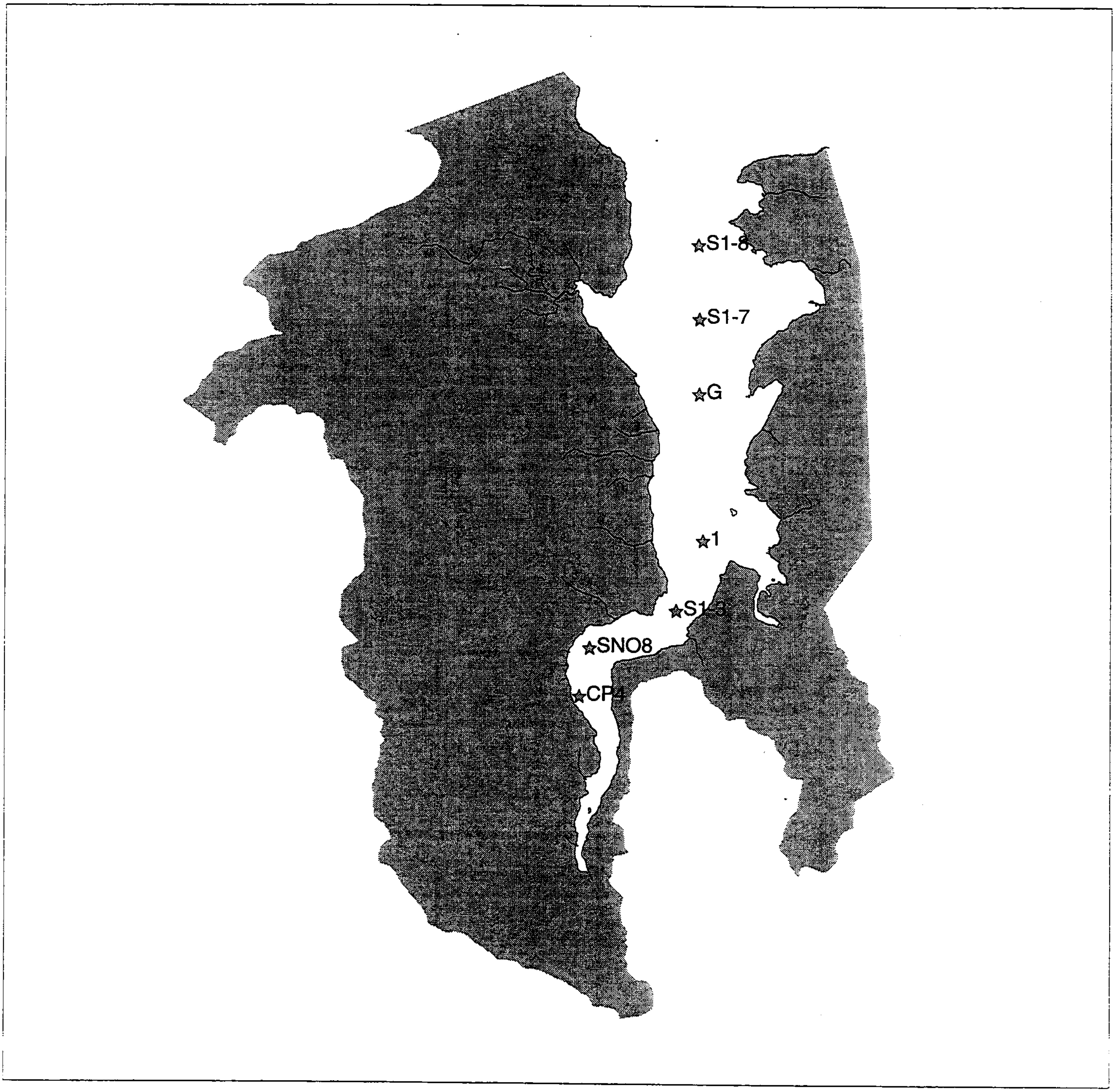


b. Lower Layer



c. Deep Basin

Figure 6-6 Station locations for siltation estimates given in Table 6-3.



7. CHEMICAL CONTAMINANTS

7.1 Background

Chemical contaminants are defined as concentrations of chemical substances found in environmental matrices (i.e., water, sediment, biological tissue) which exceed typical background concentrations. The source of such substances is activities related to urban, rural and agricultural releases - both point and non-point source. Water quality and waste loadings in Saanich Inlet are reviewed in Drinnan et al. (1995) and reference should be made to this document for background information on chemical contaminants.

For chemical contaminants in aquatic systems, two matrices usually act as the "canary in the coal mine" - sediments and biological tissues. This is because many chemicals that are typically of concern tend to accumulate in these matrices. For most chemical contaminants, information about the concentrations in the water of Saanich Inlet are unavailable because routine monitoring is not conducted as there are no significant point sources in the area. Generally, chemical contaminant concentrations in the water column are near analytical detection limits. For that reason, much of the available information on water quality in Saanich Inlet is based on contaminant concentration in sediments.

There is some information on sediment contamination (largely collected under the Saanich Inlet Study; Drinnan et al., 1995), with a focus on areas that have the highest likelihood of receiving contaminants resulting from human activities in Saanich Inlet. There are few data sets describing chemical contamination in biological tissues. As discussed in this section, data on contaminant loading rates to Saanich Inlet do not exist. Therefore, we have also conducted calculations of what the contaminant loadings are expected to be.

This section focuses on the inlet itself (i.e., marine data), as opposed to the tributaries. Drinnan et al. (1995) reviews the environmental quality of the Saanich Inlet by a screening level investigation. Sample collection sites are shown in Figure 7-1. In summary, Airport Creek and Hagan Creek has intermittent exceedances of water quality criteria for some metals. Tod Creek sediments were noted to exceed MELP sediment quality criteria. Information for other creeks indicated water quality values below MELP criteria; it should be noted that there are a number of tributaries for which limited data exist. The pattern of findings outlined in Drinnan et al. (1995) for tributaries to Saanich Inlet suggests that they are loading sources to the inlet. In this study, we evaluated existing information on chemical contaminant concentrations in Saanich Inlet and we conducted calculations of the contaminant inputs that are expected to meet various water quality criteria, including sediment and fish tissue criteria. Finally, we compared estimated chemical input levels in areas of Saanich Inlet to water quality criteria to evaluate whether the assimilative capacity of Saanich Inlet has been exceeded for chemical contaminant inputs.

7.2 Chemical Contamination Of Saanich Inlet

The extent of knowledge of chemical contamination in marine waters of Saanich Inlet is summarized in Table 7-1. It illustrates that there are a number of contaminants that are present at elevated levels in Saanich Inlet. The contaminants for which data exist can be classified in two groups. The first group are referred to as "metals" and include substances such as mercury, copper and lead. The other group of chemical contaminants is referred to as polycyclic aromatic hydrocarbons (PAHs), which include substances such as benzo(a)pyrene (a potent carcinogen), anthracene, pyrene and others. Although the actual sources of these contaminants in the Saanich Inlet are unknown, it is expected that these pollutants originate from a variety of sources such as storm water runoff, agricultural runoff, seepage from landfills and septic fields, marinas, and spills of fuels and oils. There may also be natural sources since some metals are natural constituents of soils and sediments. There are also natural sources for the PAHs, such as forest fires, but the elevated levels found in Saanich Inlet are indicative of local human activities. There is a shortage of marine data regarding other groups of chemical contaminants which are generally associated with human activity, such as pesticides, PCBs and dioxins. Pesticide measurements in six tributary (i.e., fresh water) sediments showed concentrations below detection limits in five of the creeks, but pp-DDE and pp-DDT concentrations in Tod Creek exceeded MELP criteria. PCB and dioxin data for fresh water and marine sites in Saanich Inlet were not available.

To evaluate whether marine sediment concentrations are particularly "high or low", the observed concentrations are compared to sediment quality criteria. Sediment quality criteria are recommendations regarding "safe" levels of contaminants for the protection of a given water use (MELP, 1995b). When possible, the working and approved sediment quality criteria derived by the MELP were used. For those substances for which the MELP has not derived sediment quality criteria, sediment quality criteria derived by Environment Canada (1994b) were used.

The observed concentrations of individual chemicals were divided by the corresponding sediment quality criteria to derive a ratio that represents the extent to which observed concentrations exceed sediment quality criteria (Table 7-1). Ratios less than one represent no exceedance of the criteria (i.e., observed concentrations are less than the sediment quality criteria). Ratios greater than one reflect chemical concentrations in the sediments that are greater than the sediment quality criteria. The extent of exceedance of the sediment quality criteria is illustrated in Figure 7-2.

Table 7-1 and Figure 7-2 illustrate that contaminant concentrations in sediments from the Gold Stream Estuary did not exceed the sediment quality criteria for the chemicals that were investigated. Sediment quality criteria were exceeded in Tod Inlet for mercury, dibenzo(a,h)anthracene, benzo(a)pyrene, acenaphtylene, chrysene, pyrene, naphthalene and phenanthrene. In Brentwood Bay, sediment quality criteria were exceeded for copper, lead, mercury, zinc, PAHs, benz(a)anthracene, dibenzo(a,h)anthracene, chrysene, pyrene, benzo(a)pyrene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene and phenanthrene. Figure 7-2 illustrates that exceedance of the sediment quality criteria is greater in Brentwood Bay than in the Goldstream Estuary and Tod Inlet. The maximum level of exceedance of sediment quality criteria was 147 fold for phenanthrene, a polycyclic aromatic hydrocarbon.

These results indicate that Tod Inlet and Brentwood Bay have received and may still be receiving inputs of some chemical substances that exceed the approved and working sediment quality criteria. Mercury and PAHs appear to be of greatest concern since concentrations exceeded sediment quality criteria most often. The conclusion from this review of chemical concentration measurements in Saanich Inlet sediments is that there are some locations in Saanich Inlet that contain sediment concentrations of some chemical substances that do not meet the existing approved and working sediment quality criteria.

7.3 Assimilative Capacity of Saanich Inlet for Chemical Contaminants

There is a toxicological principle that states that the “dose makes the poison”, which is true for a number of chemicals where the risk increases with exposure. The essence of this principle is that most chemical substances, whether they are kitchen salt, chlorine, zinc or copper, have the potential to exert adverse effects, but that it is the “dose” or simply the amount of the substance that is absorbed by the organism which determines whether adverse effects occur. This principle, dating back to the 17th century, can also apply to ecotoxicological effects of chemicals in the natural environment. When applied to chemicals in natural ecosystems like Saanich Inlet, the “dose” refers to the input or the emission of the substance into the ecosystem. The “poison” refers to any adverse effects that may occur such as reduction in reproductive success, tumor incidence in fish or human health risks from the consumption of local fish.

Some groups of chemical substances, in particular cancer causing substances, are believed to be able to produce adverse effects at all possible "doses", including extremely low intakes. However, the probability or risk that the adverse effect (e.g., tumors or lesions) occurs is related to the level of intake by the organism or human. If the intake level is high, then there is a high probability or risk that the effect will occur. If the intake level is low, then the probability that the effect will occur is low. If intake levels are extremely low, then the probability of an effect occurring is also extremely low and it may be so low that it is essentially insignificant when compared to other risks that organisms and humans are exposed to.

The consequence of this toxicological principle is that there are certain levels of chemical input that will not produce an adverse effect or cause a significant risk for an adverse effect to occur. However, when a certain critical chemical input is exceeded, adverse effects can occur or there may be a significant probability that an adverse effect will occur. The level of chemical input in the Saanich Inlet ecosystem that will not result in an adverse effect or cause a significant probability for an adverse effect to occur, will be referred to in this study as the assimilative capacity of the Saanich Inlet ecosystem for a given chemical substance[1]. This means that for this component of the study, assimilative capacity represents a chemical input or emission level, which can be expressed in units of grams of chemical contaminant per day.

Knowledge of assimilative capacity is a crucial piece of information for managing the health of the ecosystem because it can be used to evaluate whether actions that are associated with the discharge of contaminants can be expected to result in a potential environmental or human health threat. For example, existing chemical inputs through leaching, surface-runoff or direct discharge can be directly interpreted in terms of their potential to cause contaminant concentrations that are a threat to ecosystem or human health by simply comparing the existing chemical input levels to the assimilative capacity. In a similar fashion, the impacts of future development and associated chemical contaminant inputs can be assessed and possibly prevented by ensuring that expected chemical contaminant inputs do not exceed the assimilative capacity. The merit of defining the assimilative capacity is that it provides insights into whether human activities in the inlet will result in future problems and what actions need to be taken, on an ecosystem level, to prevent deterioration of water quality.

---

[1] In the scientific literature, "assimilative capacity" usually refers to the capacity of the ecosystem to remove chemicals from the ecosystem. The term "carrying capacity" is reserved for the maximum level of chemical input that the ecosystem can sustain. Throughout this report, the term "assimilative capacity" will refer to the maximum level of anthropogenic input that the Saanich Inlet ecosystem can sustain. See also Section 1.3 which defines assimilative capacity in the context of the Saanich Inlet Study.

One argument against applying the concept of assimilative capacity is that "some level of pollution may be accepted". In fact, knowledge of assimilative capacity does not prevent efforts to phase out all possible contaminant sources. However, it is important not to view the assimilative capacity as a license to pollute up to some accepted level. Thus, it should be viewed as a tool for an ecosystem based management of human activities. Absence or ignorance of the limits of Saanich Inlet to assimilate human contaminants is likely to result in the continuation of the practices responsible for ecosystem degradation.

Another argument against the definition of the assimilative capacity for Saanich Inlet is the lack of data and the uncertainty associated with the definition of "safe" environmental concentrations and the calculations used to determine the assimilative capacity. The uncertainty may be perceived to be so great that it is better to ignore the existence of an assimilative capacity for Saanich Inlet and to adopt a "zero-tolerance" approach with respect to pollutants. This precautionary approach is appealing but often impractical because human activity (e.g., boating, urban runoff, marinas) will always be associated with contamination, yet there is no mechanism to determine whether these activities are a potential threat to the ecosystem or whether their impact is significant.

Further, if point-source discharges were proposed for Saanich Inlet, this chemical contaminant model could be used to look at the far-field implications of the action. The chemical concentrations in the effluent would need to be known to predict loadings. Other aspects of the environmental impact of such a proposed discharge are discussed in Sections 7.1 and 8.1.

7.4 Methodology

The assessment of the assimilative capacity of ecosystems for chemical contaminant inputs involves three steps.

1. The first step involves the definition of "safe" levels of contaminants in the various media of the ecosystem. The "safe" level is the concentrations that is known or expected not to cause adverse effects in the ecosystem or to cause a significant probability for an adverse effect to occur.

2. The second step involves the derivation of the relationship between chemical input levels and resulting chemical concentrations in the various media (e.g., water, sediments, fish) of the ecosystem. The relationship between chemical input levels and resulting concentrations is unique for each ecosystem.

3. The maximum chemical input level that will result in “safe” concentrations is determined. This chemical input level can be viewed as the maximum chemical input level that can be considered “safe”. This chemical input level is referred to in this study as the assimilative capacity.

The first step of defining “safe” concentrations of chemical contaminants in environmental media has been carried out by MELP as well as many other regulatory agencies. The “safe” concentrations in aquatic ecosystems like Saanich Inlet are referred to by MELP as water quality criteria. These water quality criteria are defined as “safe levels of contaminants for the protection of a given water use” (MELP, 1995b). The BC water quality criteria for various chemical contaminants are published in MELP (1995b). This document contains “approved” as well as “working” water quality criteria. Working water quality criteria are criteria that have not yet met final approval by the BC Ministry. Water quality criteria are expressed in terms of concentrations of an individual chemical substance in water, sediments and, in some cases, the edible tissue of living organisms. In this study, the BC Water quality criteria are used as the basis for deriving the assimilative capacity of Saanich Inlet for chemical inputs. As a result, the assimilative capacity of Saanich Inlet for chemical contaminants is defined as the maximum chemical input level (in grams/day) that is expected to meet the BC water quality criteria in all parts of Saanich Inlet. Note that this measure of assimilative capacity applies for one measure only, as discussed in Sections 1 and 12.

To determine the relationship between chemical input levels and chemical concentrations in the various environmental media of Saanich Inlet, a simulation model was developed that predicts the behaviour of chemical substances in the inlet. This model is based on the best available scientific knowledge of the hydrodynamic conditions of Saanich Inlet (Section 5), the sediment dynamics in the inlet (Section 6), the transport and transformation of chemical contaminants in the inlet and the uptake, bioaccumulation and trophic transfer of the contaminants in the food-chain of Saanich Inlet. The general box model is described in Section 4.

The final step in the assessment of the assimilative capacity of Saanich Inlet for chemical contaminants is to use the relationship between chemical input levels and resulting concentrations to derive the maximum chemical input levels that are expected to meet the MELP water quality criteria. This process is discussed in Section 7.3.

7.4.1 Selection of Chemical Contaminants for Study

Due to the considerable effort that is required to derive the assimilative capacity of Saanich Inlet for contaminant inputs, the assessment of the assimilative capacity was limited to four chemical substances, namely mercury, benzo(a)pyrene, phenanthrene and anthracene. These chemical substances were selected because they are associated with the human activity present in Saanich Inlet. In addition, the consumption of mercury contaminated fish and crab by local residents is a potential human health concern in the areas of Saanich Inlet that contain the highest mercury concentrations. Benzo(a)pyrene is of concern because it is a well known carcinogen. Phenanthrene and anthracene exceeded MELP water quality criteria the most (i.e., up to 147 fold), and thus are likely the contaminants of greatest concern. Also, for the purpose of this study, it was important to select chemical contaminants, for which ambient concentration data exists and for which the MELP has developed water quality criteria. Although this study is limited to only four substances, the methodology that is applied in this study can be used to assess the assimilative capacity for other substances. However, there are limitations to modelling some metals (Section 7.4.4.3) which was also a factor in selection of the indicator substances for this study.

7.4.2 Defining "Safe" Concentrations

Table 7-2 lists the "safe" concentrations that were selected to derive the assimilative capacity of mercury, benzo(a)pyrene, phenanthrene and anthracene in Saanich Inlet. The sediment quality criteria for anthracene and phenanthrene refer to sediments in fresh water systems since corresponding sediment quality criteria for marine sediments have not yet been derived by the MELP. We will assume in this study that fresh water sediment quality criteria apply to the marine sediments of Saanich Inlet, which is a reasonable assumption for PAHs; for those PAHs for which the MELP has derived both fresh water and marine sediment quality criteria, fresh water and marine sediment quality criteria are identical. Sediment quality criteria for PAHs are dependent on the organic carbon content of sediments. The criteria values defined by MELP (1995b) are based on an organic carbon content of 1%. Since the organic carbon content of Saanich Inlet sediments is between 2 to 4.5%, the original criteria values were modified as required. The sediment quality criteria for PAHs shown in Table 7-1 and Table 7-2 reflect these changes.

7.4.3 Developing the Relationship Between Chemical Input Levels and Resulting Concentrations in Saanich Inlet

To determine the relationship between chemical input levels and chemical concentrations in the various environmental media of Saanich Inlet, we developed a simulation model that predicts the behaviour of chemical substances in Saanich Inlet. This model is divided in two sub-models. The first sub-model is an environmental fate model which describes the relationship between chemical contaminant input levels and resulting chemical contaminant concentrations in the water, sediments and suspended sediments throughout Saanich Inlet. The second sub-model is a bioaccumulation and trophic transfer model which relates the concentrations in water, sediments and suspended solids to concentrations in the organisms of the Saanich Inlet food-chain. A description of the models and an explanation of the model's assumptions is presented in the following sections.

7.4.3.1 Environmental Fate Model

The purpose of the Saanich Inlet environmental fate model is to establish a quantitative relationship between the combined input or emission levels of various contaminants into the inlet and the resulting concentrations of these contaminants in water, sediment and suspended solids of the various parts of the inlet. The chemical input-concentration relationships are established by solving a series of mass-balance equations for each section or compartment of Saanich Inlet.

Each of the mass-balance equations consists of a simple inventory of chemical transport into and chemical transformation (i.e., reaction) and transport out of each section of the inlet. The mass-balance approach assumes that the rate of transport into each compartment is equal to the rates of chemical transport and transformation out of the compartment. This is a situation that is achieved when contaminant input levels and transport rates are constant over a prolonged period of time.

To derive mass-balance equations, the inlet was subdivided both vertically and horizontally into a series of interconnected compartments, as is described in Section 5. This compartmentalization of the inlet enables the environmental fate model to assess contaminant concentrations as a function of location within the inlet and water depth. Contaminants enter each compartments through inflow of water and suspended solids from an adjacent compartment, or from point sources (e.g., sewage treatment effluent) and non-point sources (e.g., surface runoff). Bed sediment transport was considered to an insignificant route of compartment-to-compartment chemical transport in the inlet. In each compartment, contaminant transport and transformation takes place as a result of (1) water inflow and outflow from and to neighbouring compartments, (2) volatilization, (3) sorption to suspended sediments, (4) diffusion between water and sediments, (5) settling of suspended sediments, (6) resuspension of bed sediments, (7) deposition (or sediment burial) and (8) degradation in water and sediments (Figure 7-3). The rate of each of these processes is characterized by a rate constant with units of 1/day.

The rate constants were derived from a combination of hydrodynamic calculations, chemical specific properties and a series of site-specific parameters. Methods used by the model to assess rate constants and concentrations are listed in Appendix B. The chemical properties were taken from Howard (1991), Lymann et al. (1990), and MacKay et al. (1992-1994) and are listed in Appendix B. The Henry Law Constant was corrected for the ambient temperature to represent seasonal variations in volatilization rates. The water and sediment degradation rate constants were taken from MELP (1995b) and Howard (1991). Although the true values of these degradation rates are largely unknown, they are generally recognized to be small in aquatic systems compared to other chemical fate processes. Hence, the uncertainty in the values of the degradation rates has little effect on the outcome of the model calculations. Data regarding the sediment dynamics in the Saanich Inlet were taken from the sediment transport model presented in Section 6.

To represent seasonal variations in the model, the rate constants were derived on a seasonal basis. Hence, the mass-balance equations were also solved on a seasonal basis, resulting in estimates of chemical concentrations for the fall, winter, spring, and two periods in the summer. As explained in Section 5, the summer season was divided in two parts to represent water renewal events.

Contaminant concentrations in the water and bed sediments were derived by an Euler-type numerical integration of the mass balance equations for the water and sediments. The simulations were performed until 99.9% of steady-state was achieved.

7.4.3.2 Bioaccumulation and Trophic Transfer Model

The purpose of the food-chain bioaccumulation model is to relate chemical concentrations in the water and sediments to chemical concentrations in organisms of the aquatic food-chain in Saanich Inlet. By combining the food-chain bioaccumulation and environmental fate models, it is possible to predict chemical contaminant concentrations in Saanich Inlet biota in each compartment if chemical contaminant input levels to the inlet are known. Alternatively, it is possible to use the results of the model to determine the magnitude of the maximum contaminant inputs that will meet fish tissue criteria, human consumption guidelines or other environmental quality criteria and standards that may apply.

The food-chain bioaccumulation model consists of several sub-models characterizing chemical bioaccumulation in phytoplankton, pelagic invertebrates (i.e., copepods and euphausiids), various species of benthic invertebrates (i.e., polychaetes, blue mussel, Dungeness crab, prawns, and amphipods), and several species of fish (i.e., Pacific herring, English sole, lingcod, juvenile salmon, quillback rockfish, and spiny dogfish). The individual sub-models are linked together through feeding interactions to represent trophic interactions in the Saanich Inlet food-chain. Trophic interactions are important because diet is an important source of contaminants for fish and other organisms.

Since the number of resident species in Saanich Inlet is very large, it was impossible to include every species in the model. Instead, we selected representative species for each of the major trophic levels based on ecological importance, and the extent of biological data available. Data availability was an important criterion because the food-chain model requires information regarding the feeding characteristics of the organisms, weights, lipid contents and other data to parameterize the model. The trophic levels and biological species that were included in the model can be found in Table 7-3, and a conceptual diagram of the Saanich Inlet food-chain is shown in Figure 7-4. The structure of the food-chain was assumed to be identical for all parts of the Saanich Inlet. This simplification appears to be reasonable in the absence of more detailed data regarding food-chain interactions in the inlet.

The food-chain bioaccumulation model was based on the steady-state bioaccumulation model developed by Gobas (1993) and recent work on the bioaccumulation of chemicals in benthic invertebrates reported by Morrison (1995). The original model developed by Gobas (1993) has been applied to a variety of chemicals and to various ecosystems. The model has been formally reviewed by the U.S. EPA and has now been formally adopted to aid in the development of water quality criteria in the U.S. (EPA-822-R-94-002).

Although a truly time-dependent version of the food-chain bioaccumulation model was not applied in this study, seasonal variations in the bioaccumulation behaviour were approximated by conducting simulations of the steady-state model with parameters that are characteristics for the various seasons. For instance, water temperature, concentrations of suspended solids and water flows differed between fall, winter, spring and two periods during the summer season. In this way, it was possible to simulate seasonal variations in chemical contaminant concentration throughout the year.

Bioaccumulation in phytoplankton and pelagic invertebrates was represented by equilibrium partitioning with the freely dissolved or bioavailable chemical concentration in the overlying-water (Gobas et al., 1991). Bioavailable chemical concentrations were determined from site-specific data regarding dissolved organic carbon concentrations, according to methods reviewed and adopted by the U.S. EPA and summarized in U.S. EPA (1994).

Bioaccumulation in benthic invertebrates was described by a mass-balance expression including contaminant uptake and elimination via the respiratory surface or gills and dietary uptake and fecal elimination. The expressions used for benthic invertebrates were based on the recent work by Morrison (1995). The benthic invertebrate model was based on recent experimental and field work in Howe Sound and Lake Erie. It is an improvement over the simpler equilibrium based model (DiToro et al., 1991; Gobas et al., 1989), which has been used by several authors as well as by Gobas (1993) and Gobas et al. (1995).

The model describing contaminant bioaccumulation in fish consisted of a whole-fish mass balance equation which included uptake via the gills and through the ingestion of food and elimination via the gill, through fecal excretion and by metabolic transformation (Figure 7-5). The rate of each of these processes was represented by a first order rate constant. Fish weights and lipid content are important parameters in the model, as uptake and elimination rates as well as food digestion parameters are estimated from these parameters and temperature.

Although many marine fish species are migratory in nature, the model did not consider these spatial movements to keep the model calculations sufficiently simple. In addition, there is limited data regarding the migration routes of most of the species used in the model. The model assumed that fish remain in the inlet long enough for chemical concentrations to reach steady-state levels which is consistent with the precautionary principle. Therefore, if fish spend significant periods of time in "less polluted" waters outside the inlet, the model is expected to overestimate contaminant concentrations.

Model Parameterization

The individual sub-models of the Saanich Inlet food-chain model were relatively simple to parameterize. The most important parameters are the lipid content, body weights and dietary compositions for each of the fish species. Since biological data for Saanich Inlet are very limited, it was necessary to use data from other geographical locations to parameterize the food-chain bioaccumulation model.

Data regarding the lipid contents of the organisms are listed in Appendix B. Unfortunately, data regarding the body lipid content of some species was not available. In those cases, the body lipid content was estimated from the lipid contents of particular tissues of the fish. For instance, the lipid contents of lingcod and rockfish were taken from the lipid content of the liver tissue. The lipid content of liver tissue may overestimate whole body values for these fish because sluggish bottom feeding fish (e.g., sharks, cod, haddock etc.) tend to store lipids in their livers, while more active species such as herring, mackerel, and salmonids tend to store lipids in their muscle tissue (Sargent, 1976). Lipid content values for spiny dogfish were unavailable. Therefore, an estimated value of 15% was used based on scientific judgement.

Body weights for each of the fish species are listed in Appendix B. These typical sizes were derived from information in Black (1984), Schmitt et al. (1994), Hart (1973), and Livingston and Goiney (1983).

Feeding Interactions

The individual sub-models were linked through predator-prey relationships to represent the trophic interactions in the Saanich Inlet food-chain. The diet of each fish species was derived from stomach content data (Appendix B). Since the diets of some fish species are very diverse (e.g., dogfish are known to eat at least 27 species of fish), it was necessary to simplify the diet by grouping prey species in classes of biological similarity which were represented by a single species. For example, sandlances and other forage fish were grouped together with pacific herring, and medium sized benthic crustaceans (e.g., cumaceans) were grouped together with prawns.

Pacific herring are the most ecologically important forage fish species in the Georgia Basin (Schmitt et al., 1994). Herring populations in Saanich are discussed in Section 10. Herring are important prey for several fish species (e.g., salmonids, dogfish, hake and pollock), birds (e.g., cormorants and gulls), and marine mammals (e.g., seals and sea lions). Stomach contents of herring collected from the Strait of Juan de Fuca (Cross et al., 1978) and Burrard Inlet (Howard Paish and Associates, 1975) indicate that herring consume primarily calanoid copepods, but supplement their diet with larger zooplanktivorous species and epibenthic invertebrates. Based on these data the dietary proportions shown in Appendix B were used.

English sole are bottom fish that feed extensively on small benthic invertebrates such as gammarid amphipods, shrimp, mysids, cumaceans, polychaetes and bivalves (Kravitz et al., 1976). English sole are often collected as part of water quality monitoring programs.

Lingcod are solitary bottom-dwelling predators that feed primarily on fish (i.e., herring, sand lance and bottom-dwelling fish), but supplement their diet with invertebrates (Hart, 1973; Rosenthal, 1980). Since stomach content data were unavailable for Saanich Inlet, the dietary proportions were derived from stomach content data for lingcod taken from Queen Charlotte Straits (Black, 1984). Lingcod are further discussed in Section 10.

The diet of juvenile salmonid species (e.g., Chinook, Chum, and Pink Salmon) consists almost entirely of benthic and pelagic invertebrates (Clark, pers. comm. 1995).

The quillback rockfish consumes primarily benthic invertebrates such as small crustaceans and polychaete worms. The dietary proportions were derived from data provided by Rosenthal (1980).

Spiny dogfish is a very slow-growing and long-lived species of shark that is abundant throughout the Georgia Basin. Dogfish are considered omnivorous, opportunistic feeders that feed on a wide variety of fish and shellfish (Schmitt et al., 1994; Feder, 1980a). Young dogfish consume mostly invertebrates, but as age advances, the diet changes to mainly fish and large invertebrates. The dietary proportions shown in Appendix B were derived from Jones and Geen (1977) for dogfish caught in British Columbia.

7.4.4 Model Assumptions

A number of key assumptions were required to model the fate of contaminants in Saanich Inlet either due to our need to make predictions, lack of data, gaps in our knowledge of certain physical and biological processes, and the need to limit the scope of the modelling exercise. The first key assumption is that chemical concentrations in Saanich Inlet are relatively stable over the longer term, or at "steady-state". The second key assumption is that chemical concentrations are uniform in each box. This second assumption is inherent in the box model approach used for the hydrodynamic calculations (Section 4). Essentially, these two key assumptions reflect the temporal and spatial scale of the modelling approach. The final assumption places bounds on the types of chemicals which can be modelled using this approach.

7.4.4.1 Steady-state Assumption (Mass-Balance)

The Saanich Inlet environmental fate model is based on a series of mass-balance equations describing the net movement of individual chemicals in and out of the water and sediments of each compartment. The model assumes the rate of chemical inputs into each compartment and individual medium (e.g., sediment, water or fish) equals the rate of chemical output. This situation is achieved when contaminant loadings and transport rates are constant over a prolonged period of time.

The length of time required for the mass-balance to apply is different for the various parts of the Saanich Inlet. It also varies among the seasons and it is dependent on the specific chemical contaminant. Due to the truly time-dependent nature of the model calculations used to derive the mass-balance for each contaminant, it is possible to assess the time required to reach steady-state. The estimated time required to reach 95% of steady-state is illustrated in Table 7-4 for the various chemical contaminants and locations in the Saanich Inlet. The time to reach steady-state during each of the seasons ranges between a minimum time of 4 to 5 months to a maximum of 17 years. The corresponding residence times are three fold lower than the times to achieve 95% of steady-state and hence range between 1 to 2 months and 5 to 6 years. It should be noted that these residence times of the contaminants are not the same as those of the water (hydraulic residence time) as the removal of chemical substances and water are controlled by different processes.

Table 7-4 shows that, in all cases, the duration of the season is too short to reach steady-state. The effect of this on the calculations of the assimilative capacity for Saanich Inlet is that the seasonal variability is being overestimated by the model which is consistent with the precautionary principle. This means that there is likely to be less season-to-season variability in the chemical contaminant concentrations in Saanich Inlet than the model calculations suggest. The seasonally averaged and hence more realistic estimates of the time periods required to reach 95% of steady-state in Saanich Inlet are illustrated in Table 7-5. Table 7-5 shows that it will require several years up to decade before chemical contaminant concentrations in Saanich Inlet have fully responded to a change in chemical input level.

Although the steady-state assumption appears to be a reasonable assumption for assessing the long term response to contaminant inputs in the Saanich Inlet, it is important to stress that the model is <u>not</u> expected to give accurate predictions of contaminant concentrations during periods when contaminant loadings are changing rapidly. Under conditions of rapidly changing chemical input levels, it is important to conduct the model simulations on a time dependent basis. Although this can be done with the current model, the results presented in this report do not represent the time-dependent calculations needed to predict the time response of contaminant concentrations to rapidly changing loadings. As no chemical loading information is presently available for Saanich Inlet the rate of inputs over time and space is unknown. This would benefit from site-specific source information.

7.4.4.2 Spatial Resolution

Another important assumption of the model is that the water and sediment subcompartments are completely mixed. This means that the model predicts contaminant concentrations that are the same throughout the entire compartment. There is ample evidence indicating that in the immediate vicinity of contaminant point sources, the contaminant concentrations can be much greater than in locations further away from the point source. In the Saanich Inlet model, the concentrations in each subcompartment are "averaged" over the entire area of the subcompartment. This means that the model cannot distinguish between differences in concentrations within a subcompartment. The model does distinguish between differences in concentrations between the various water layers within a compartment.

The main purpose of this model is to provide a comprehensive basin-wide, "ecosystem" level assessment of the fate of contaminants in Saanich Inlet (i.e., far-field). To achieve this goal as discussed in Section 4, the model sacrifices the detailed spatial resolution that is required to simulate chemical concentrations in the immediate vicinity of the point sources (i.e., near-field). A greater spatial resolution can be achieved within the existing modelling framework by further subdividing the Saanich Inlet compartments. It is should be stressed that adding compartment requires the collection of additional information, which is currently not available. Detailed spatial resolution can be achieved by choosing an alternative modelling framework with respect to the hydrodynamics. A "plume model" approach such as used in Sections 8 and 9 is better suited for predicting contaminant concentrations in the vicinity of point sources than the "box model" approach that was followed in this study. The limitation of plume models is that they cannot be applied to the whole inlet and they are unable to address non-point sources, which are the primary concern in Saanich Inlet. In addition, "plume models" are unable to incorporate bioaccumulation and food-chain transfer phenomena.

7.4.4.3 Chemical Substances

Model calculations were performed for four chemical substances - anthracene, benzo(a)pyrene, phenanthrene and mercury. It is possible to use the same model to make additional model calculations for other organic substances (e.g., organic pesticides, PCBs, dioxins, DDT, DDE, petroleum hydrocarbons, etc.) as long as the appropriate chemical property data are used. However, at present, it is not possible to conduct model simulations for metals other than mercury which is an important model limitation. In order to conduct model simulations for mercury, the rate constants were calculated using a different methodology than that used for the organic substances. The sub-models used to characterize the environmental fate of mercury are characteristic for mercury only and cannot be used for other metals because of the differences in water chemistry among metals.

7.4.5 Assessment of the Assimilative Capacity of Saanich Inlet for Chemical Contaminants

The assimilative capacity of Saanich Inlet should be thought of as its overall sensitivity to a variety of stressors. However, for specific stressors such as chemical contaminants, it is useful for management purposes to look at the assimilative capacity for chemicals alone. To assess the assimilative capacity of Saanich Inlet for chemical inputs, model simulations were conducted for scenarios where, for each of the four chemical substances that were investigated in this study, a chemical input level of 1 gram per day (g/d) was introduced in each of the compartments of Saanich Inlet, namely Finlayson Arm, Central Basin East, Central Basin West, Entrance East, Entrance West, Patricia Bay, Brentwood Bay, Mill Bay and Squally Reach. Based on these scenarios, the steady-state chemical concentrations in water, sediments, suspended sediments, Dungeness crab and other organisms listed in Table 7-3, were predicted for each subcompartment, and within each subcompartment for each layer of Saanich Inlet. These calculations were repeated for each of the seasons to derive the season-to-season variability in the concentrations.

The model calculations produce a mass balance for each compartment of the inlet. An example of such a mass balance is illustrated in Figure 7-6. The mass balance is essentially an accounting system of the amounts of contaminant entering and leaving individual parts of the Saanich Inlet ecosystem. This helps to determine which natural processes are the most important in terms of delivering and removing contaminants from the inlet. The arrows refer to transport and transformation of the contaminant in units of g/d. The dominant processes are responsible for the greatest transport of the contaminant control to a large extent the behaviour of the contaminant in that part of the inlet. Figure 7-7 illustrates the important roles of water movement and sediment transport on the behaviour of contaminants in the inlet.

The end result of these simulations is a set of simple linear equations for each of the chemical contaminants, environmental media, Saanich Inlet subcompartments and seasons which relate the chemical input level to the resulting concentrations. For example, for the West Central Basin of Saanich Inlet, the relationship between the concentration of benzo(a)pyrene in sediments and the chemical loadings (LD) from Finlayson Arm (FA) , Central Basin East (CBE), Central Basin West (CBW), Entrance East (EE) , Entrance West (EW), Squally Reach (SR) , Mill Bay (MB), Brentwood Bay (BB) and Patricia Bay (PB) during the winter is given by:

$C_{sediment}$ =

$$6.89.10^{-8} \times LD(FA) + 2.42.10^{-7} \times LD(MB) + 1.01.10^{-7} \times LD(BB) + 5.34.10^{-8} \times LD(PB) + 1.31.10^{-7} \times LD(SR) + 2.50.10^{-7} \times LD(CBW) + 1.60.10^{-7} \times LD(CBE) + 2.13.10^{-7} \times LD(EW) + 7.35.10^{-8} \times LD(EE)$$

Where:

$C_{sediment}$ = concentration of benzo(a)pyrene in sediments (g/kg dry sediment)

LD = chemical loading to each subcompartment

By simply entering the chemical input levels from the various locations it is possible to derive the concentration of benzo(a)pyrene in the sediments of the West Central Basin of Saanich Inlet under winter conditions. If these calculations are repeated for all seasons, a range of concentrations is derived. This range of concentrations reflects the seasonal variations in the concentrations. As discussed in Section 9.2.2. this range of concentrations may somewhat exaggerate the variability in actual concentrations.

The chemical input-concentration relationship also illustrates that, theoretically, there is an infinite number of combinations of chemical input levels that may produce a particular concentration. From this it may appear that it is impossible to derive a chemical input level that will represent the assimilative capacity for the inlet. In practice, however, the situation is much simpler. The results of model simulations for all parts of Saanich Inlet demonstrate that there are certain areas within the inlet, namely Mill Bay, Patricia Bay, Brentwood Bay and Squally Reach, that are more affected by chemical input levels than other areas. For example, based on the same loading scenario, the concentration of benzo(a)pyrene in Mill Bay sediments may be 5 mg/kg, whereas it is only 0.55 mg/kg in sediments of the West Central Basin. The situation further simplifies because within each of the so-called "most impacted" areas of Saanich Inlet, the chemical contaminant concentration is largely dependent on the chemical input levels entering the area itself. This is illustrated by the relationship between the concentration of benzo(a)pyrene in the sediments of Brentwood Bay and the chemical loadings from Finlayson Arm (FA), Central Basin East (CBE), Central Basin West (CBW), Entrance East (EE), Entrance West (EW), Squally Reach (SR), Mill Bay (MB), Brentwood Bay (BB) and Patricia Bay (PB) :

$C_{sediment}$ =

$$7.17.10^{-8} \times LD(FA) + 1.39.10^{-7} \times LD(MB) + 5.89.10^{-5} \times LD(BB) + 5.1.10^{-8} \times LD(PB) + 1.40.10^{-7} \times LD(SR) + 1.46.10^{-7} \times LD(CBW) + 1.70.10^{-7} \times LD(CBE) + 1.25.10^{-7} \times LD(EW) + 7.82.10^{-8} \times LD(EE)$$

Where:

$C_{sediment}$ = concentration of benzo(a)pyrene in sediments (g/kg dry sediment)

LD = chemical loading to each subcompartment

This relationship shows that benzo(a)pyrene inputs from Brentwood Bay have a much greater impact on the benzo(a)pyrene concentration in the sediments of Brentwood Bay, than comparable input levels from other locations in Saanich Inlet. For example, to produce the same sediment concentration in Brentwood Bay, benzo(a)pyrene inputs in Mill Bay need to be 420 times and in Patricia Bay 1150 times greater than the benzo(a)pyrene inputs from Brentwood Bay. Assuming that the discrepancy between chemical loadings is among the potential locations for chemical inputs in Saanich Inlet, it is possible to simplify the chemical input-concentration relationship. This is illustrated below for the concentration of benzo(a)pyrene in the sediments of Brentwood Bay:

$$C_{sediment} = 5.89.10^{-5} \times LD(BB)$$

Where:

$C_{sediment}$ = concentration of benzo(a)pyrene in sediments (g/kg dry sediment)

LD = chemical loading to each subcompartment

This relationship can readily be used to assess which input level of benzo(a)pyrene would result in a particular concentration. For example, to meet the MELP sediment quality guideline of 0.12 mg/kg, benzo(a)pyrene inputs into Brentwood Bay should not exceed $0.00012/5.89.10^{-5}$ or 1.3 grams per day.

This methodology was applied to all chemical substances and for those media for which "safe" concentrations were derived in Table 7-2. The "safe" concentrations were entered in the chemical input-concentration relationships to derive the maximum chemical contaminant input levels that meets the "safe" concentrations in each of the four areas that were identified as potential locations for chemical contaminant inputs. Since there are chemical input-concentration relationships for each of the seasons, a range of maximum chemical input levels is produced. The maximum and minimum values of these maximum chemical input levels, which are referred to as the assimilative capacities, are listed in Table 7-6 and Table 7-7.

Table 7-6 illustrates the maximum chemical input levels of four chemical substances in Finlayson Arm, Central Basin East, Central Basin West, Entrance East, Entrance West, Squally Reach, Mill Bay, Patricia Bay and Brentwood Bay that are expected to meet the MELP sediment quality criteria. The range of assimilative capacities reflect the season-to-season variability in the chemical input-concentration relationships. If MELP sediment quality are met in each of these areas, then the sediment quality criteria are expected to be met throughout Saanich Inlet. Given the uncertainty inherent in this model, what is important is the relative values for chemical inputs that are predicted to exceed criteria. Mill Bay, Brentwood Bay, Finlayson Arm and Squally Reach are the most vulnerable to the chemical contaminants modelled here.

Table 7-7 illustrates the maximum chemical input levels of mercury that are expected to meet the MELP sediment quality criteria, the "maximum" and "30 day average" water quality criteria and the fish tissue guideline for "high" and "low" fish consumption rates. The assimilative capacity based on the rate of fish consumption by humans was derived by assuming that people consume Dungeness crab tissue only. The range of assimilative capacities reflect the seasonal variability in the chemical input-concentration relationships.

Figure 7-8 illustrates the assimilative capacity of Brentwood Bay for mercury derived based on different MELP water quality criteria. It shows that depending on the water quality criteria selected for the derivation of the assimilative capacity, estimates of the assimilated capacity can differ by more than 3 orders of magnitude. The main reason for this large discrepancy is that the criteria for water, sediments and fish tissue guidelines are derived individually and afford different levels of protection to different receptors. The lowest assimilative capacity of approximately 0.1 g/day mercury is derived when using criteria for the consumption of fish products.

In summary, there are some locations in Saanich Inlet that contain concentrations of some chemical substances in marine sediments that do not meet the existing MELP approved and working sediment quality criteria. Mercury and the PAHs appear to be the chemical contaminants that most often exceed chemical criteria. This indicates that Tod Inlet and Brentwood Bay have received and may still be receiving inputs of some chemical substances that are large enough that the MELP approved and working sediment quality criteria are exceeded in these locations. However, there is insufficient information available to evaluate how wide-spread the exceedance of B.C. water quality criteria is within the Inlet.

The assimilative capacity of Saanich Inlet for several chemical contaminant inputs was determined and Mill Bay, Brentwood Bay, Finlayson Arm and Squally Reach were found to be the most vulnerable to the chemical contaminants. The assimilative capacity was defined as the maximum chemical input levels (in grams/day) that will meet the MELP water quality criteria in all locations of Saanich Inlet. If the assimilative capacity is exceeded, it is expected that MELP water quality criteria will not be met.

7.4.6 Assimilative Capacity in Relation to Historic Chemical Input Levels

The chemical input-concentration relationships that were used to assess the assimilative capacity can also be used to make an estimate of previous chemical input levels if observed chemical contaminant concentration data are available. Such data are available for Brentwood Bay and Tod Inlet. The data consist of chemical contaminant concentrations in sediments. These data were earlier presented in Table 7-1. The chemical input levels that were responsible for these concentrations can be derived under the assumption that chemicals entered Brentwood Bay and Tod Inlet "slowly" over a prolonged period of time rather than in a single "sudden" event (e.g., spill). Under that assumption, chemical input levels can be "back-calculated" from the observed concentration data.

The resulting chemical input levels for Brentwood Bay are listed in Table 7-8 and are graphically presented in relation to the assimilative capacities in Figure 7-8. Similar data for Tod Inlet are illustrated in Figure 7-9. It should be stressed, however, that there is insufficient information regarding the spatial distribution of the chemical concentrations in Brentwood Bay. If the sediment concentrations that were used to derive the chemical input levels represent a "hotspot" with exceptionally high concentrations, then the calculated chemical input levels may overestimate the actual chemical input levels since the model assumes a uniform distribution of the concentrations in the sediment over the entire area of the Brentwood Bay compartment. Figure 7-8 illustrates that in Brentwood Bay the assimilative capacity is presently exceeded for all of the chemical substances that were investigated as part of this study. This suggests that reductions in contaminant loadings would be required to meet the MELP sediment quality criteria and the assimilative capacity in Brentwood Bay. Figure 7-9 illustrates that in Tod inlet, historic chemical input levels may have been close to the assimilative capacity with the exception of anthracene. For anthracene, the historic chemical input level was less than the assimilative capacity.

7.5 Model Certainty

The ability of the model to reliably predict the assimilative capacity of Saanich Inlet for contaminants depends primarily on the accurate representation of the processes governing the fate of contaminants in aquatic systems and certainty in the magnitudes of "safe" concentrations developed by MELP.

As the hydrodynamic and sediment transport models made conservative assumptions, the water and sediment residence times are likely to be shorter than model results show. As a result, the chemical fate model is also conservative, and it is used in combination with protective environmental quality criteria. Therefore, the level of certainty is adequate to use the chemical fate model results in the context of the Saanich Inlet Study.

7.5.1 Model Calculations

It is customary to compare model predictions against actual observations to verify whether model predictions are realistic. To accomplish this, data are required concerning the quantities of chemical contaminants entering Saanich Inlet, and chemical concentrations in various environmental media. This is because the main purpose of the chemical fate model is to relate chemical contaminant emissions to resulting concentrations in water, sediment and organisms of Saanich Inlet. However, data regarding contaminant inputs into the Saanich Inlet do not exist and, although ambient concentrations are available for some environmental media and for some contaminants, the data set is limited and does not provide a sufficient data base for the verification of the model. For instance, chemical concentrations in sediments were provided by Drinnan et al. (1995) for only a few marine areas (i.e., Tod Inlet, Brentwood Bay, and Goldstream Estuary), and within these areas only a few measurements were taken (e.g., metal and PAH concentrations in Tod Inlet are based on 3 samples taken in 1995). These measured concentrations are assumed to be representative of concentrations in the various boxes of Saanich Inlet. Considerable uncertainty exists regarding these estimated loadings since they are based on such limited data sets (Figure 7-8 and Figure 7-9), but the uncertainty errs on the side of caution as the data used are likely taken near sources. The data gaps for contaminant inputs to Saanich Inlet and contaminant concentrations in environmental media are the most significant limitations to the interpretation of the results of the chemical contaminant modelling effort. However, when additional data become available, it would be possible to formally test the capability of the model to predict ambient contaminant concentrations from contaminant inputs into the inlet and to further assess the assimilative capacity.

Although at the current time it is not possible to quantitatively validate the performance of the chemical fate model, a qualitative assessment of the certainty of the model itself can be conducted based on experience regarding the ability of models similar to the one used in Saanich Inlet. The original bioaccumulation model developed by Gobas (1993) has been formally reviewed by the U.S. EPA and is currently being used to develop water quality criteria. A variation of the model has also been used to assess the fate of PAHs and mercury in Burrard Inlet (EVS et al., 1995). The contaminant fate modelling work in the Burrard Inlet suggests that 95% of the model predictions of ambient contaminant concentrations are typically within a factor of two to three of the actual concentrations. Unlike the Saanich Inlet study, chemical inputs to the inlet had been estimated, and a fairly extensive database with contaminant concentrations in sediments and biota was available to verify model predictions. Considering that the natural variability in contaminant concentration measurements, which can also be a factor of two to three, this level of uncertainty is reasonable. However, it should be kept in mind that any uncertainty in the hydrodynamic and sediment transport models may be propagated to the contaminant fate model because the three models are linked.

7.5.2 Safe Concentrations

The assessment of the assimilative capacity of inlet for contaminant inputs uses MELP criteria for water, sediments and fish tissue to estimate acceptable loadings. Any uncertainty in these "safe" concentrations must be considered in interpreting the results of this study, even though they are independent of model calculations. The MELP process used to derive "safe" ambient concentrations of contaminants is an elaborate process which is largely based on an extensive literature survey of toxicological data. Typically a "no-effect or low-effect" concentration for a contaminant is identified and then a safety factor is applied to produce a "safe" concentration. The safety factor introduces some conservatism in the derivation of the "safe" concentration. Therefore, it should be noted that the methodology used by MELP to derive "safe" concentrations is prone to an *overestimation* of what constitutes a "safe" concentration (Walker, 1996). Hence, although there may be some uncertainty in the estimate of the "safe" contaminant concentrations, it will err on the side of precaution.

As a result of the uncertainty in the assessment of the assimilative capacity, it is unwise to interpret the assimilative capacities calculated as part of this study as specific "threshold" values. Instead, they should be viewed as a "indicator" values of the range of contaminant concentrations that, if exceeded, may be associated with significant impacts on the aquatic ecosystem and human health. Considering that the available data suggest that the assimilative capacity has been exceeded for some contaminants and in some parts of the inlet, the criteria can further be used to develop target values for remediation and impact assessment of proposed future developments. Well-designed monitoring studies would confirm whether contaminant concentrations are causing significant impacts when the "assimilative capacity" and "safe" concentrations have been reached. These monitoring studies are the "safe guard" required to adapt management strategies to impacts that were not foreseen as part of this study.

Table 7-1 Reported concentrations of various contaminants in marine sediments (Drinnan et al., 1995) from three locations in Saanich Inlet in relation to the approved and working sediment quality criteria, reported by MELP (1995b) or criteria developed by Environment Canada (1994b). Criteria exceedance refers to the extent to which observed concentrations exceed the sediment quality criteria. Values below 1.0 refer to conditions where chemical contaminant concentrations in sediments are below the sediment quality criteria. Values above 1.0 represent the extent to which the observed chemical contaminant concentration in the sediments exceed the sediment quality criteria.

					Observed Concentrations (µg/g)			Criteria Exceedance[c]		
Group	Chemical Contaminants	Criteria[a,b]	Units	Source of Criteria	Goldstream Estuary	Tod Inlet	Brentwood Bay	Goldstream Estuary	Tod Inlet	Brentwood Bay
Metals	Arsenic	33	µg/g	MELP 1995b	10	19	12	0.30	0.58	0.37
	Cadmium	5	µg/g	MELP 1995b	1	3	2	0.20	0.67	0.40
	Chromium	52.3	µg/g	Env. Can 1994b	23	16	24	0.44	0.31	0.47
	Copper	70	µg/g	MELP 1995b	17	40	193	0.24	0.57	2.76
	Lead	30.2	µg/g	Env. Can 1994b	10	25	131	0.33	0.84	4.34
	Mercury	0.15	µg/g	MELP 1995b	0.05	0.21	1.01	0.33	1.42	6.73
	Nickel	30	µg/g	MELP 1995b	17	17	23	0.57	0.57	0.77
	Zinc	120	µg/g	MELP 1995b	41	89	248	0.34	0.74	2.07
PAHs	LPAH[d]	7400-16650	µg/kg	MELP 1995b	12	197	5593	0.003	0.11	3.40
	HPAH[e]	2400-5400	µg/kg	MELP 1995b	72	887	14767	0.06	1.7	27.7
	Benz(a)anthracene	400-900	µg/kg	MELP 1995b		74	940		0.83	10.6
	Dibenzo(a,h)anthracene	12-28	µg/kg	Env. Can 1994b		12	115		4.34	41.6
	Chrysene	400-900	µg/kg	MELP 1995b		106	1770		1.2	19.9
	Pyrene	310-689	µg/kg	Env. Can 1994b		143	3700		2.1	54.5
	Benzo(a)pyrene	120-270	µg/kg	MELP 1995b		71	837		2.66	31.5
	Acenaphthene	300-675	µg/kg	MELP 1995b		7	41		0.11	0.61
	Acenaphthylene	12-26	µg/kg	Env. Can 1994b		8	76		3.06	29.3
	Anthracene	1200-2700	µg/kg	MELP 1995b		30	2420		0.11	9.06
	Fluoranthene	4000-9000	µg/kg	MELP 1995b		160	4330		0.18	4.88
	Fluorene	400-900	µg/kg	MELP 1995b		14	440		0.16	4.95
	Naphthalene	20-45	µg/kg	MELP 1995b		47	50		10.6	11.3
	Phenanthrene	80-180	µg/kg	MELP 1995b		94	2610		5.24	147

[a] Sediment quality criteria for anthracene, phenanthrene, fluoranthene and benzanthracene refer to sediments in fresh water systems, because corresponding sediment quality criteria for marine sediments have not been derived by the MELP. The range shown for each PAH is indicative of the Threshold Effects Level (TEL) and the Probable Effects Level (PEL).

[b] Sediment quality criteria are reported for sediments with an organic carbon content ranging between 2% (in embayments) and 4.5% (in basin), which is typical for Saanich Inlet sediments

[c] Exceedance of MELP sediment quality criteria in based on sediments with an organic carbon content of 2%. For definition, see table caption. Shaded values show exceedances of criteria values.

[d] Low molecular weight PAHs.

[e] High molecular weigh PAHs.

Table 7-2 MELP (1995b) water quality criteria used to derive the assimilative capacity of selected chemical contaminants in Saanich Inlet.

Chemical Contaminant	Criteria[a,b]	Units	Source	Type of Water Quality Criteria
Mercury	0.15	µg/g sediment	MELP 1995b	Sediment Quality
	0.02	µg/L water	MELP 1995b	30-day average water quality
	2	µg/L water	MELP 1995b	maximum water quality criteria
	0.5	µg/g wet weight	MELP 1995b	fish tissue guideline based on fish intake less than 210 g/day
	0.1	µg/g wet weight	MELP 1995b	fish tissue guideline based on fish intake less than 1050 g/day
Benzo(a)pyrene	120-270	µg/kg sediment	MELP 1995b	Sediment Quality
Anthracene	1200-2700	µg/kg sediment	MELP 1995b	Sediment Quality
Phenanthrene	80-180	µg/kg sediment	MELP 1995b	Sediment Quality

[a] Sediment quality criteria for anthracene, phenanthrene, fluoranthene and benzanthracene refer to sediments in fresh water systems, because corresponding sediment quality criteria for marine sediments have not been derived by the MELP.

[b] Sediment quality criteria are reported for sediments with an organic carbon content of 2 to 4.5%, which is typical for Saanich Inlet sediments

Table 7-3 **Biological species included in the food-chain bioaccumulation model.**

Trophic Level	Species
Phytoplankton	Diatoms
Pelagic Invertebrates	Copepod (*Pseudocalanus* spp. and *Calanus* spp.) Euphausiid (*Euphausia* spp.)
Benthic Invertebrates	Prawn (*Pandalus platyceros*) Dungeness Crab (*Cancer magister*) Mussel (*Mytilus edulis*) Amphipod (*Gammarus* spp.) Annelid worm (Polychaeta and Oligochaeta)
Fish	Pacific Herring (*Clupea harengus pallasi*) English Sole (*Parophrys vetulus*) Lingcod (*Ophiodon elongatus*) Juvenile Salmonid (*Oncorhynchus* spp.) Quillback Rockfish (*Sebastes maliger*) Dogfish (*Squalus acanthias*)

Table 7-4 Estimates of the time (years) required for some chemical contaminants to reach 95% of a true steady-state in various locations of Saanich Inlet during the various seasons. Only minimum (Min) and maximum (Max) times are presented.

Chemical	Range	Finlayson Arm	Squally Reach	Mill Bay	Central Basin (W)	Central Basin (E)	Brentwood Bay	Patricia Bay	East Entrance	West Entrance
Phenanthrene	Min	5	5	0.5	6	5	1	1	1	1
	Max	13	13	4	12	12	9	7	5	5
Benzo(a)pyrene	Min	4	4	1	3	3	4	5	3	2
	Max	12	13	15	15	14	17	16	15	13
Anthracene	Min	3	3	0.4	3	3	1	1	1	1
	Max	5	5	3	4	4	4	4	3	3
Mercury	Min	1	2	0.4	2	2	2	2	0.4	0.4
	Max	5	5	6	6	6	6	6	5	3

Table 7-5 Estimates of the seasonally corrected times (years) required for some chemical contaminants to reach 95% of a true steady-state in various locations of Saanich Inlet.

Chemical	Finlayson Arm	Squally Reach	Mill Bay	Central Basin (W)	Central Basin (E)	Brentwood Bay	Patricia Bay	East Entrance	West Entrance
Phenanthrene	9	9	1.3	9	9	5	4	3	3
Benzo(a)pyrene	9	9	5	7	7	10	11	7	6
Anthracene	4	4	1.1	4	4	3	3	2	2
Mercury	3	4	2.6	4	4	4	3	2.1	1.7

Table 7-6 **Estimated assimilative capacities (kg/day) of four chemical contaminants in various areas of Saanich Inlet. The assimilative capacity represents the maximum chemical input level that will meet the MELP sediment quality criteria. See Section 7.4 for explanation.**

Chemical	Finlayson Arm	Mill Bay	Brentwood Bay	Patricia Bay	Squally Reach
Phenanthrene	0.03 - 0.19	0.014 - 2.2	0.010 - 0.31	0.0049 - 0.08	0.22 - 0.84
Benzo(a)pyrene	0.0004 - 0.0015	0.00015 - 0.031	0.00036 - 0.0020	0.00018 - 0.00058	0.028 - 0.049
Anthracene	1.6 - 7.0	0.22 - 24	0.36 - 3.5	0.14- 0.84	17 - 64
Mercury	0.00033 - 0.0015	0.00016 - 0.010	0.00046-0.0018	0.00022-0.00072	0.21 - 0.71

Chemical	Central Basin West	Central Basin East	Entrance West	Entrance East
Phenanthrene	4.6 - 7.1	5.1 - 13	6.8 - 23	18 - 46
Benzo(a)pyrene	0.38 - 0.59	0.50 - 0.92	0.82 - 2.0	1.5 - 5.5
Anthracene	220 - 490	0280 - 540	130 - 420	290 - 860
Mercury	0.13 - 0.94	0.24 - 4.3	6.8-29	3.4- 14

Table 7-7 Estimated assimilative capacity (kg/day) of some areas of Saanich Inlet for inputs of mercury. The assimilative represents the maximum chemical input level that will meet various MELP sediment quality criteria. See Section 7.4 for explanation.

Medium	Criteria	Criteria Value[1]	Range	Estimated Assimilative Capacity (kg/day)								
				Finlayson Arm	Mill Bay	Brentwood Bay	Patricia Bay	Squally Reach	Central Basin West	Central Basin East	Entrance West	Entrance East
Water	30-day average	2.0E-05	Min	0.0026	0.0024	0.0041	0.0053	0.16	0.16	0.3	5.9	19
			Max	0.0040	0.0095	0.0070	0.0082	0.45	0.87	4.0	22	72
	Maximum	2.0E-03	Min	0.26	0.24	0.41	0.53	16	16	30	5900	1900
			Max	0.40	0.95	0.70	0.82	45	87	400	2200	7200
Sediments		0.15	Min	0.00033	0.00016	0.00046	0.00022	0.21	0.13	0.24	6.8	3.4
			Max	0.00056	0.00099	0.00085	0.00036	0.71	0.93	4.3	29	14
Crab Tissue	Low Consumption[2]	0.5	Min	0.00068	0.00025	0.00072	0.00035	0.42	0.25	0.5	12	6
			Max	0.0031	0.016	0.0027	0.0011	1.4	1.8	8.6	40	24
	High Consumption[3]	0.1	Min	0.00014	0.000049	0.00014	0.000069	0.084	0.05	0.1	2.4	1.2
			Max	0.00061	0.0032	0.00055	0.00022	0.28	0.36	1.7	8	4.8

[1] Water quality criteria are reported in units of mg/L, sediment criteria in units of mg/kg, and consumption criteria in units of mg/kg wet weight.

[2] Criteria value corresponds to a fish consumption rate less than or equal to 210 grams/week.

[3] Criteria value corresponds to a fish consumption rate less than or equal to 1050 grams/week.

Table 7-8 Estimates of the historic input levels (kg/day) of four chemical substances in Brentwood Bay in relation to Brentwood Bay's assimilative capacity (kg/day). The assimilative capacity is defined as the maximum chemical input level that will meet the MELP sediment quality criteria.

Chemical	Assimilative Capacity (kg/day)	Estimated Historic Input Level (kg/day)
Phenanthrene	0.01 - 0.1	1.5 - 15
Benzo(a)pyrene	0.00038 - 0.0020	0.012 - 0.063
Anthracene	0.36 - 3.5	3.3 - 31
Mercury	0.00046 - 0.00085	0.0031 - 0.0057

Figure 7-1 Chemical contaminant collection sites, March 1995 survey (Source: Drinnan et al., 1995).

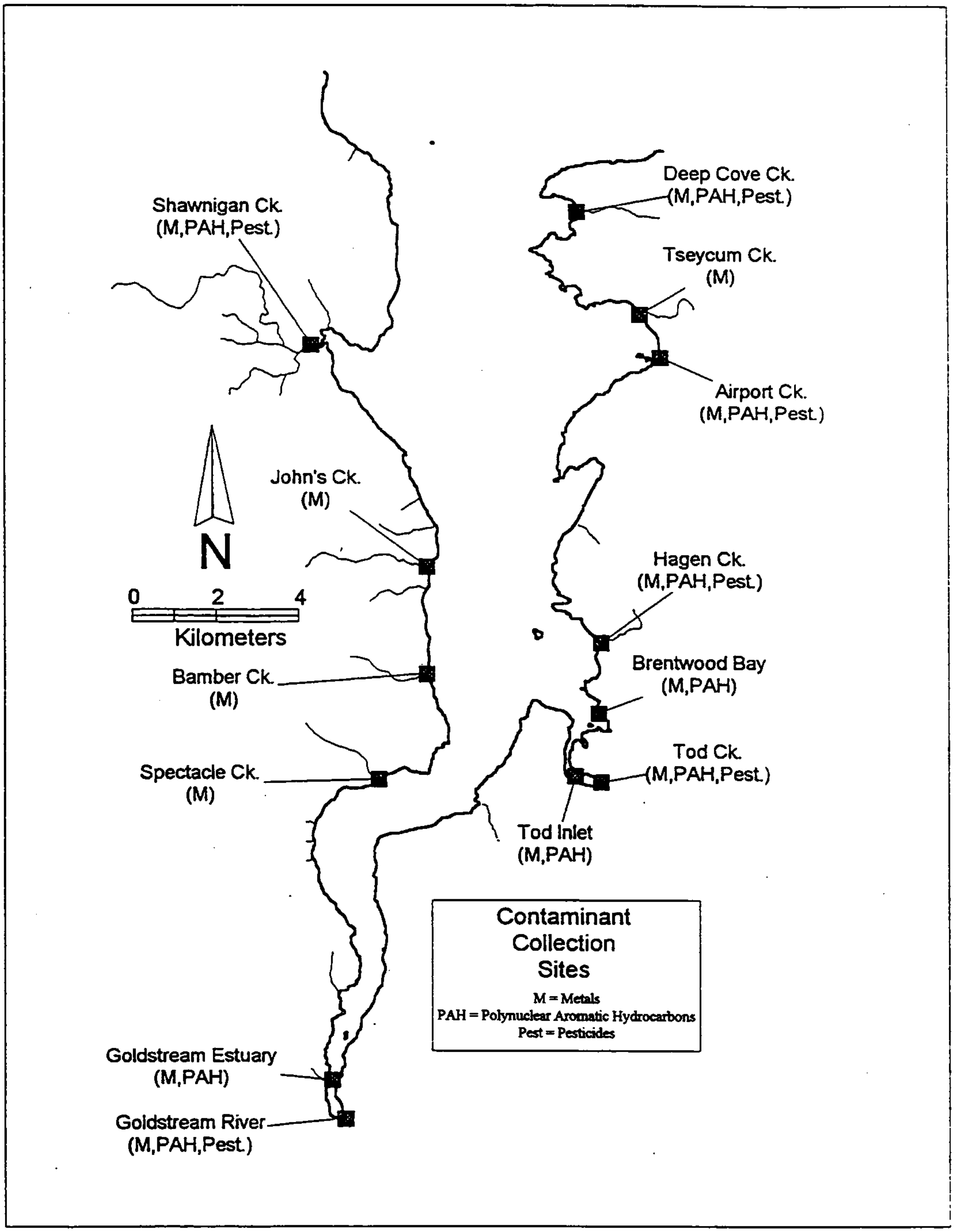


Figure 7-2 Extent to which observed concentrations of various chemical contaminants in sediments from three locations in Saanich Inlet exceed the MELP sediment quality criteria. Values greater than 1.0 refer to concentrations that exceed the sediment quality criteria (e.g., a criteria exceedance of 20 means that sediment concentrations are 20 fold greater than the corresponding sediment quality criterion).

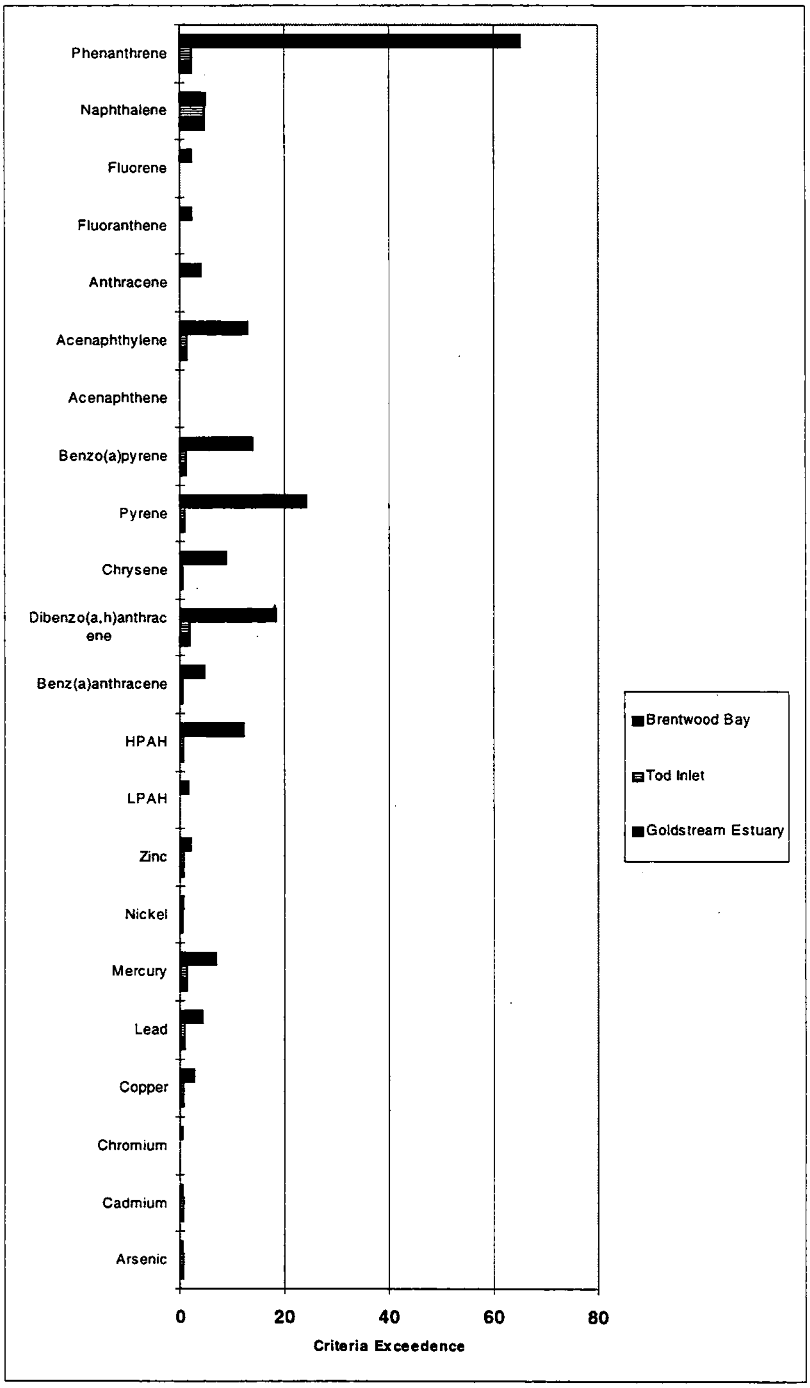


Figure 7-3 Schematic diagram of the environmental fate processes included in the environmental fate model for Saanich Inlet.

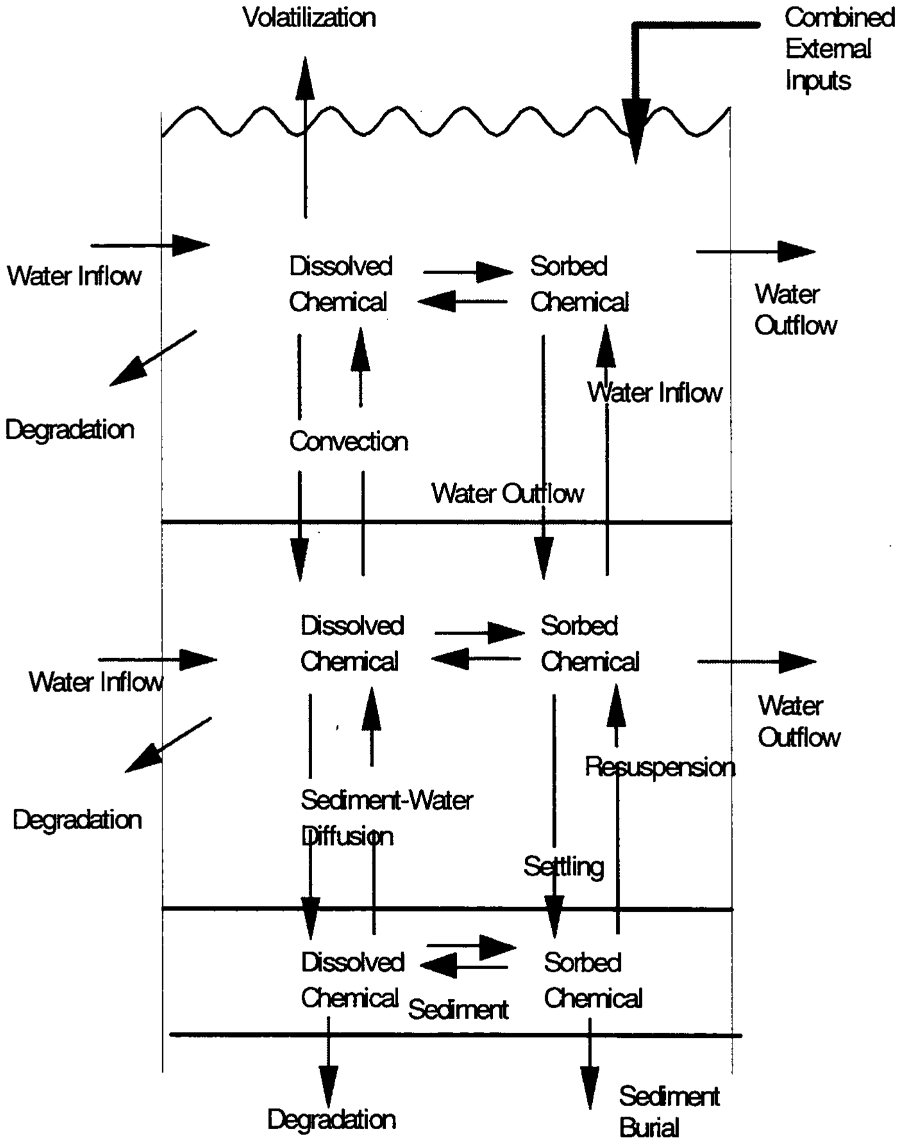


Figure 7-4 Conceptual diagram of feeding interactions in the Saanich Inlet food-chain.

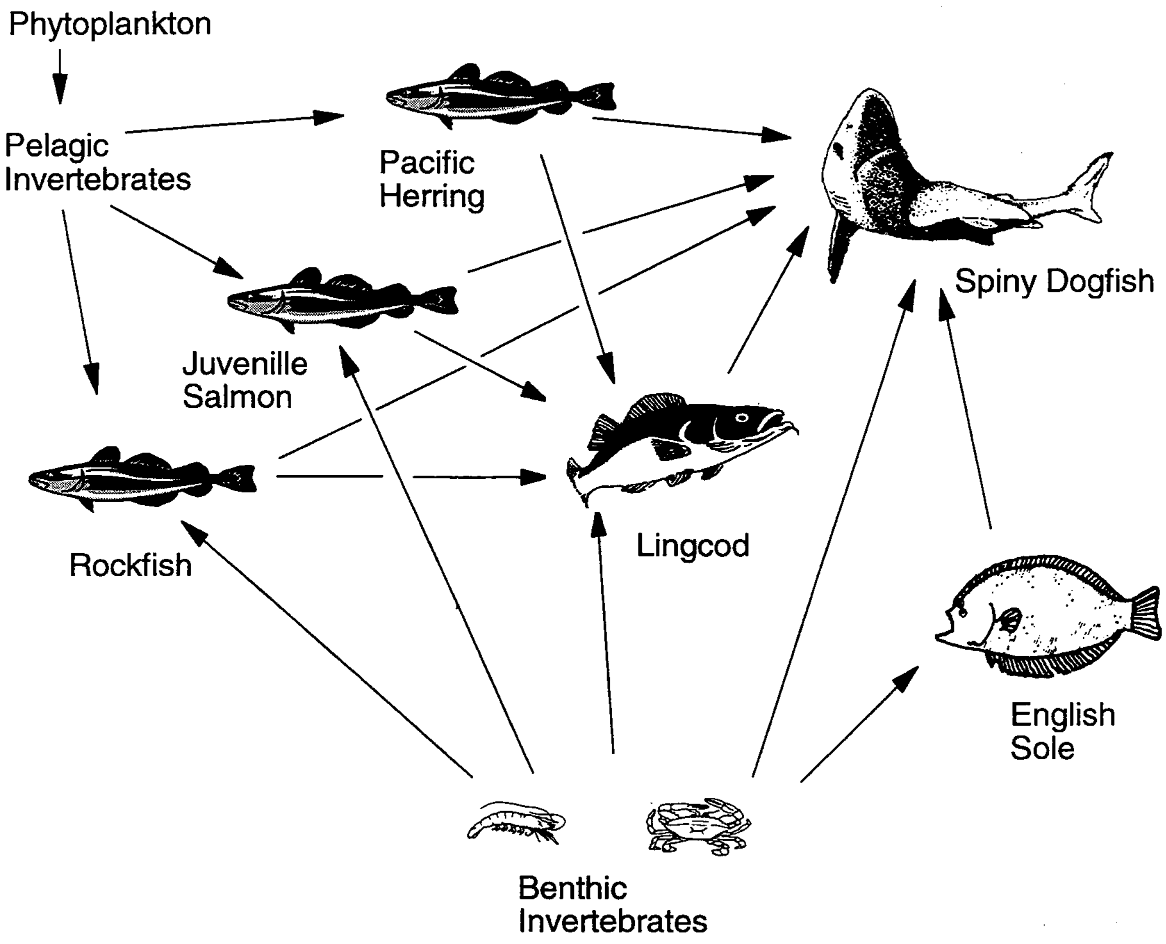


Figure 7-5 Schematic diagram of chemical uptake and elimination processes in fish.

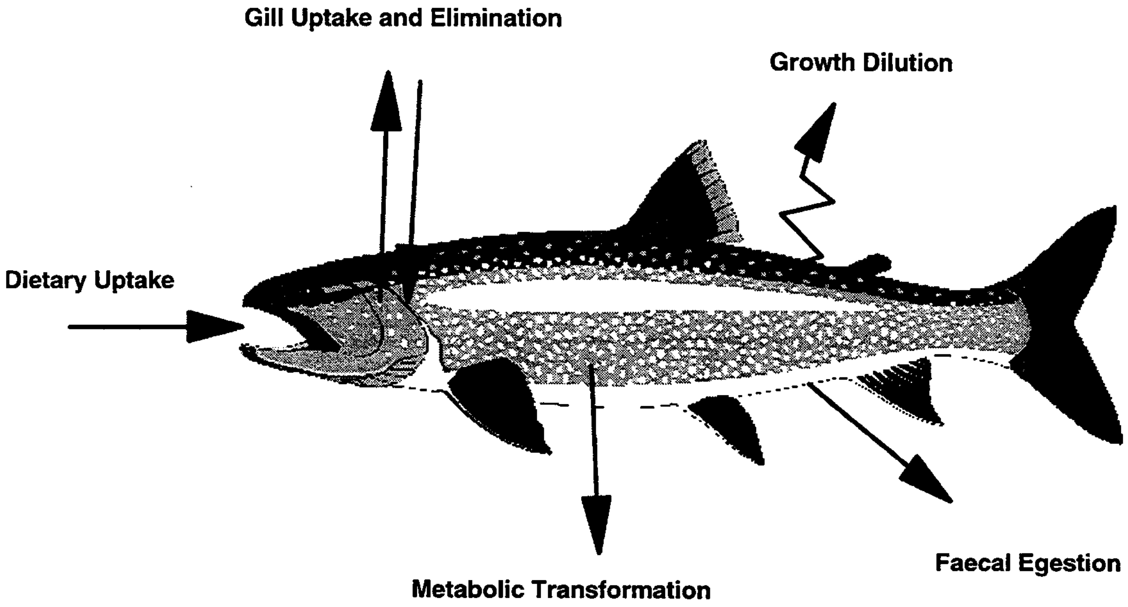


Figure 7-6 Chemical fluxes of benzo(a)pyrene in Finlayson Arm (Summer).

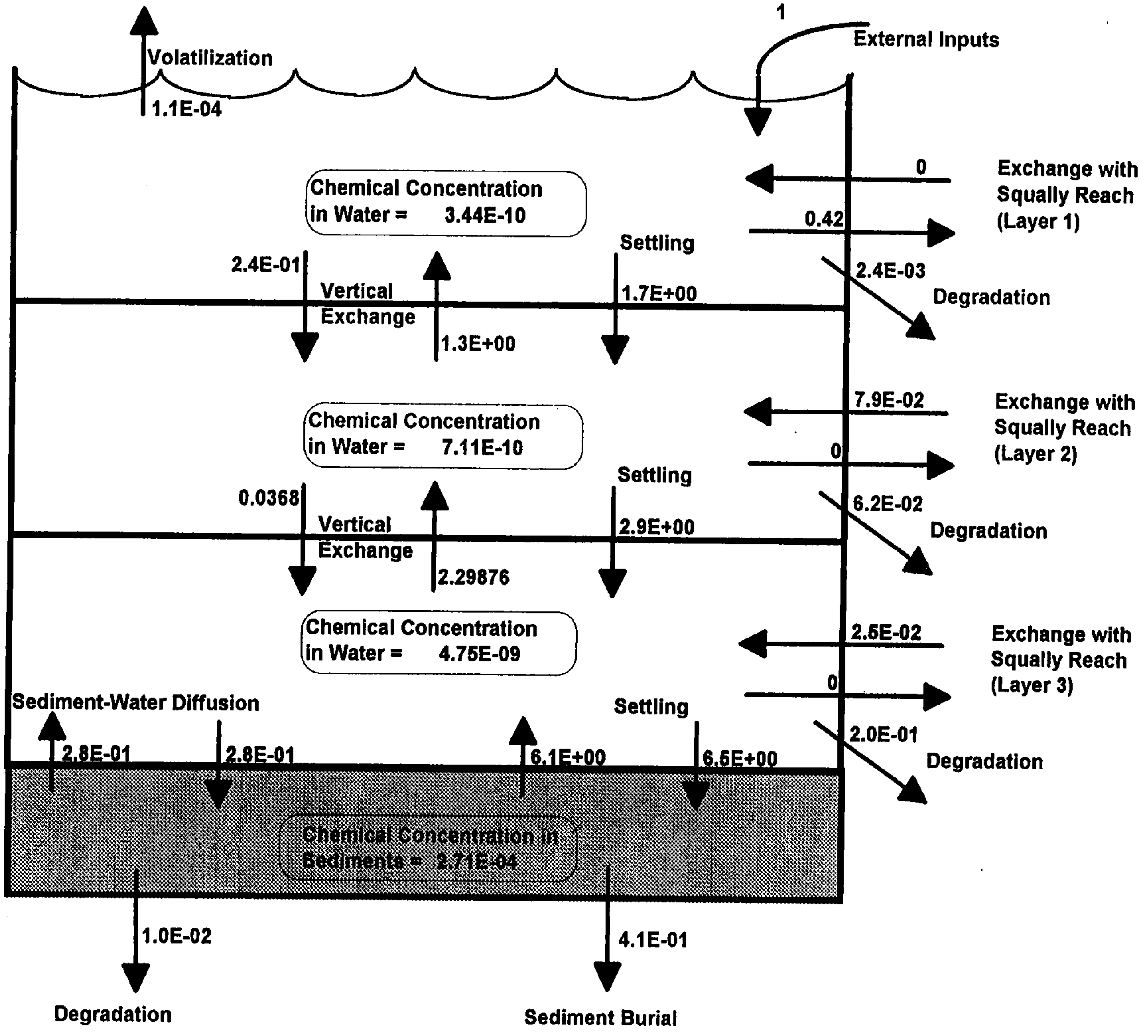


Figure 7-7 Maximum chemical input levels of mercury in Brentwood Bay that will meet the MELP sediment quality criteria, the "maximum" and "30 day average" MELP water quality criteria and the MELP fish tissue guideline for "high" and "low" fish consumption rates.

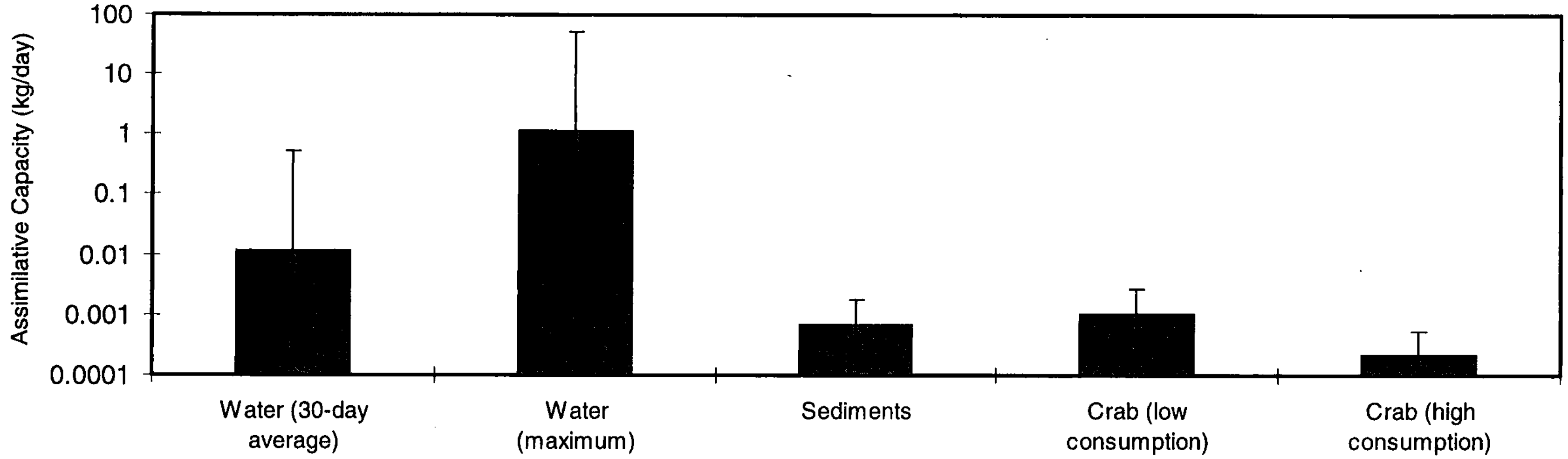


Figure 7-8 Graphical representation of the estimates of the historic input levels (kg/day) of four chemical substances in Brentwood Bay in relation to Brentwood Bay's assimilative capacity (kg/day). The assimilative capacity is defined as the maximum chemical input level that will meet the MELP sediment quality criteria.

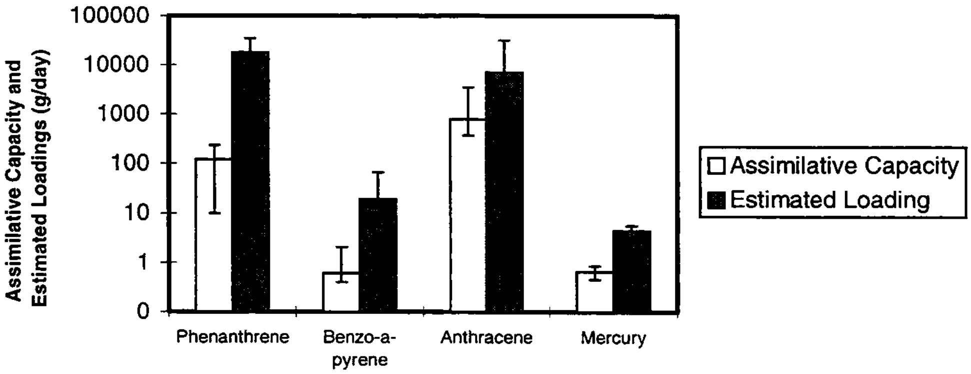
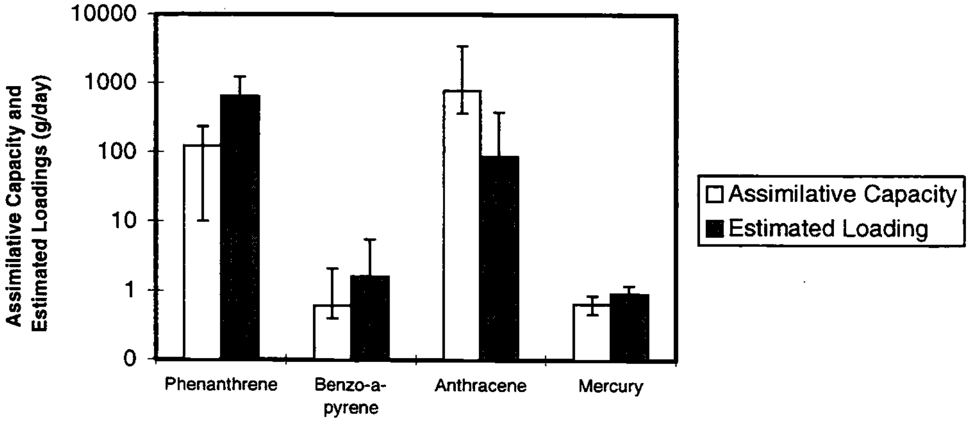


Figure 7-9 Graphical representation of the estimates of the historic input levels (kg/day) of four chemical substances in Tod Inlet in relation to the assimilative capacity (kg/day). The assimilative capacity is defined as the maximum chemical input level that will meet the MELP sediment quality criteria.



8. BACTERIAL CONTAMINANTS

8.1 Background

This section discusses bacterial contamination in context with other issues related to wastewater. In the absence of industrial development, wastewater generated by populated areas has two main components: domestic sewage and stormwater runoff. It enters marine waters through a variety of pathways: concentrated point sources such as marine outfalls and boat discharges; and more dispersed sources such as small streams and creeks, surface runoff and groundwater seepage.

Domestic sewage is generally more than 99% water, but it has several constitutents with the potential to harm the marine environment, including: organic materials; nutrients; suspended solids; pathogens such as bacteria, viruses and parasites; and inorganic and organic chemical contaminants. The exact composition depends on a variety of factors such as the health and diet of the contributing households, the watershed uses, the chemical composition of the water supply and the level of treatment prior to discharge.

Stormwater runoff may enter the marine environment either directly through natural seepage and watercourses, or through a storm-drain system. Constituents of concern are site-specific and can include heavy metals and oils associated with runoff from streets and parking lots, combustion by-products such as polycyclic aromatic hydrocarbons (PAHs) and suspended solids. In agricultural areas, stormwater may also include significant levels of nutrients and various pathogens.

The nature of potential environmental impacts associated with wastewater entering the marine environment depends on its composition. Organic materials decay, potentially leading to depleted levels of dissolved oxygen. Sedimentation of particulate matter can smother benthic organisms and affect sensitive species. Nutrient additions may impact planktonic communities and lead to eutrophic conditions. Bacteria, viruses and parasites have potentially significant health effects for humans, whether through direct recreational contact or through the consumption of contaminated shellfish. Chemicals may also cause a variety of adverse impacts depending on their type and concentration.

Many of these issues are discussed elsewhere in this report. For instance, chemical contamination is discussed in Section 7. The impacts of nutrient and organic additions to Saanich Inlet for a variety of loading scenarios are examined in Section 9. This section examines the impacts to Saanich Inlet of pathogenic materials contained within wastewater.

Human pathogens do not generally pose a threat to marine organisms. Instead, it is the organic material (e.g., nutrients, chemical contaminants) associated with wastewater discharges that may lead to changes in the receiving waters. Since many of these human pathogens pose little or no direct risk to marine organisms, this section primarily focuses on issues related to human health.

Biological contaminants associated with wastewater discharges (i.e., point and non-point sources) include viruses, bacteria and parasites. The degree and nature of contamination is highly variable, both over time and spatially within the inlet. Since it would be impractical to monitor both wastewater discharges and the receiving environment for individual pathogens, specific indicator organisms, such as fecal coliforms, are measured as a surrogate. Fecal coliforms are associated with fecal material originating from warm-blooded mammals (including humans) and birds. Although they may be present in the water column in the absence of wastewater contamination, elevated fecal coliform levels are generally due to anthropogenic inputs.

While fecal coliforms themselves are not usually a direct threat to human health or to the marine environment, they indicate the potential presence of pathogens (e.g., viruses, parasites, other harmful bacteria). Instead of monitoring for a wide range of possible biological contaminants, fecal coliforms are used as an indicator of the presence of wastewater, with the level of coliform contamination considered representative of the associated level of risk to human health posed by pathogens (although this will also depend on the health of the discharging population). Fecal coliforms themselves are rarely pathogenic.

Fecal coliform measurements do not differentiate between fecal materials originating from humans, other mammals and birds. Each of these sources is associated with a different level of risk to human health. However, fecal coliform concentrations do serve as a general indication of the level of contamination by fecal materials, and are relatively easily measured. As such, concentration levels of fecal coliforms in the water column are widely used as a water quality standard designed to protect humans from illness arising from exposure to water-borne pathogens.

There are two primary human-health related concerns: consumption of contaminated shellfish; and, direct exposure through water-contact activities. Bivalves such as oysters, clams and mussels are filter feeders, and can concentrate water-borne pathogens within their tissues. Therefore, consumption of contaminated shellfish increases the risk of illness in humans. Also, direct exposure to wastewater-contaminated waters through activities such as swimming, water-skiing, windsurfing and SCUBA diving increases the risk of illness in humans.

8.2 Existing Levels of Fecal Contamination

As discussed, wastewater generated by populated areas has two main components: domestic sewage and stormwater runoff. Wastewater enters the marine environment through a variety of pathways which generally include both point and non-point sources.

Fecal coliforms are generally found in stormwater as well as in domestic sewage, although the source of the fecal material and the associated health risk to humans is less clear. In areas of agricultural development, fecal coliforms in stormwater and natural watercourses generally reflect the presence of fecal material from cattle, horses, sheep or pigs, depending on the nature of the agricultural activities. In residential areas, fecal inputs to stormwater may be linked to household pets or to inadequate sanitary sewers (e.g., leakages, cross-connections) and septic fields.

Fecal coliform bacteria in the waters of Saanich Inlet have been measured through several previous studies, the majority of which are described in Drinnan et al. (1995). These studies are summarized here, along with the results of several recent monitoring programs.

8.2.1 Shellfish Water Quality Monitoring Program

Shoreline areas in Saanich Inlet have been monitored for fecal coliform bacteria since 1979 through the federal Shellfish Water Quality Protection Program (SWQPP). Its primary purpose is to protect public health from the consumption of contaminated shellfish by controlling recreational and commercial harvesting of shellfish within Canada (Calder and Mann, 1995). As part of this program, shellfish beds in Saanich Inlet have been identified and point and non-point sources of pollution evaluated. Shoreline surveys focusing on the sources of pollution and bacteriological assessment of the waters overlying the shellfish beds form the basis of the sanitary survey program.

Saanich Inlet has been sub-divided into six shellfish sectors; these are shown in Figure 8-1 along with the harvesting closures as of January 1995. Many of the shellfish closures in Saanich Inlet were initiated in 1987, with re-evaluation surveys conducted annually since 1990 (Drinnan et al., 1995).

For an area to be considered safe for shellfish harvesting, the fecal coliform median value must not exceed 14/100 mL, with not more than 10% of the samples exceeding a level of 43/100 mL when sampled under adverse pollution conditions (DFO, 1995). These criteria are based on a minimum of 5 samples collected within a 30 day period. In this document, the convention used for describing fecal coliform values is *x* fecal coliforms/100 mL water. Harvesting of bivalve shellfish is prohibited within 125 m of any wharf, dock, platform or other structure used for vessel moorage; any permanently anchored floating structures, including float homes, barges, platforms and vessels; or any marine outfall (Drinnan et al., 1995; Calder and Mann, 1995).

The Saanich Inlet fecal coliform data presented by Calder and Mann (1995) show that, while many of the stations had median values below 14/100 mL, the 90th percentile values often exceeded the criteria of 43/100 mL. The resulting shellfish closures reflect the strong influence of the 1990 survey results when unusually high fecal coliform levels were measured. The elevated levels are thought to be a result of the extremely heavy rainfall during the 1990 survey period (Calder and Mann, 1995). Elevated levels of fecal coliform bacteria and associated pathogens may also be present in the inlet during other extreme rainfall events, particularly if the rainfall occurs after an extended dry period.

The SWQPP data have been reassessed by Drinnan et al. (1995) to more closely examine spatial variability within Saanich Inlet. Figure 8-2 shows the geometric mean values for eleven areas: Deep Cove, Pat Bay, Coles Bay, Brentwood Bay, Tod Inlet, McKenzie Bight, Finlayson Arm, Squally Reach, Bamberton Park, Mill Bay and Hatch Point. The highest levels of contamination by fecal materials are seen in Tod Inlet, Deep Cove and Mill Bay.

Drinnan et al. (1995) also examined temporal variations in fecal coliform concentrations by combining data from Deep Cove, Pat Bay and Coles Bay. These data are plotted in Figure 8-3 for the 1979, 1990, 1992 and 1994 surveys. No significant long-term trend is apparent, although the impact of the extremely heavy rainfall during the 1990 sampling period is evident.

8.2.2 Additional Monitoring

In addition to the regular sampling conducted through the shellfish monitoring program, a survey of fecal coliform and Enterococci bacteria was conducted on two separate days during March of 1995 (Drinnan et al., 1995). Enterococci bacteria also reside in gastrointestinal tract of warm-blooded animals and, as such, are also considered to be valuable indicators of fecal contamination (APHA, 1995). Sample locations are shown in Figure 8-4, with concentration values plotted in Figure 8-5 for the eleven sub-areas described above. The highest levels of coliform bacteria were seen in Deep Cove, Pat Bay and Coles Bay. Enterococci bacteria show a similar pattern, with highest levels found in Deep Cove and Pat Bay.

Many of the stations used during the March 1995 sampling program were visited on two separate days. Differences were evident between the two sampling dates, with samples collected during a heavy rain showing higher coliform concentrations than those collected during a dry period. For example, the data from Deep Cove, Pat Bay and Coles Bay show a mean for the wet period of 46/100 mL (N=20), with a value of 1/100 mL (N=21) for the same sites during the dry period (Drinnan et al., 1995).

Drinnan and Hull (1996) measured fecal coliform concentrations in Deep Cove, Patricia Bay and Coles Bay during October and November, 1995. The objectives of this study were to determine the degree of contamination in the receiving waters and to what degree stormwater discharges contributed to the problem. The sampling strategy involved the collection of water samples at eight set distances from the shoreline, along several parallel, equally-spaced transects perpendicular to the shoreline at 5 m, 10 m, 20 m, 50 m, 100 m, 200 m 300 m, 400 m and 500 m. All sampling was conducted after several days of rainfall, during an ebbing tide to maximize potential offshore levels.

Overall, fecal coliform levels in Deep Cove and Coles Bay were relatively low during the October survey. Little or no stormwater flow (<1 L/min) was entering these bays in spite of several days of previous rainfall (total precipitation of 17 mm for the six days prior to sampling). Fecal coliform levels beyond 50 metres distance from the waterline were all ≤4/100 mL. In both Deep Cove and Coles Bay, generally higher concentrations of fecal coliforms were present within 50 metres of the waterline, ranging from 1 - 100/100 mL.

Stormwater flows were much higher on the November 8/9, 1995 survey (i.e., 15 - 7500 L/min), which was expected as a result of the preceeding the heavy rainfall (59 mm in the 6 days prior to sampling). This survey sampled the stormwater discharges and receiving waters of Deep Cove and Pat Bay. Fecal coliform concentrations were higher in the discharges sampled during the November 8/9 survey, ranging from 2,000 to 19,000/100 mL in Deep Cove and 1,500 to 6,200/100 mL in Pat Bay. The higher coliform levels in the discharges were reflected in higher coliform levels in the receiving waters. As a relative comparison, in Deep Cove the geometric mean of samples between 50 and 500 metres was 1/100 mL in October compared to 37/100 mL in November.

A final sampling trip was conducted on November 16, 1995, which surveyed Pat Bay and Cove Bay. During the six days prior to sampling the total precipitation was 39 mm. Stormwater flows ranged from 1->500 L/min. In Pat Bay all samples were ≤10/100 mL. In Coles Bay all samples but two were ≤30/100 mL.

The guideline for fecal coliforms for primary contact (i.e., swimming) is a geometric mean of <200/100 mL, from a minimum of five samples taken within a 30-day period (CCME, 1995). Very few individual samples exceeded this geometric mean limit (five in Deep Cove on November 8/9 and six in Pat Bay on November 9). While the sampling protocol for this study was not designed to monitor whether recreational water quality guidelines were met, the geometric mean of samples collected at the 5 m and 10 m stations were 61/100 mL (N=22) for Deep Cove, 6/100 mL for Pat Bay (N=18), and 24/100 mL for Coles Bay (N=12), well below the guideline of 200/100 mL.

8.2.3 Potential Sources of Fecal Contamination in Saanich Inlet

The sources of fecal contamination entering marine waters are varied, and generally include both point and non-point sources as discussed in Section 8.1. The sewage treatment plant discharging into Mill Bay represents the only point source of sewage entering Saanich Inlet. However, it has very low discharge volumes and a recent upgrade to this plant is expected to reduce fecal loadings. Potential non-point sources of fecal materials to the waters of Saanich Inlet include the many small streams and creeks entering the inlet, surface runoff (particularly from agricultural lands with livestock operations), marine mammals, seabird colonies, leaky septic fields or sewer lines along the shoreline, and discharge from boats within the inlet.

The potential sources of pollution to Saanich Inlet have been evaluated as part of the sanitary shellfish surveys conducted by Environment Canada (Calder and Mann, 1995). Sampling locations included ditches as well as storm drains and natural tributaries discharging into the inlet. Results from these surveys found the highest fecal coliform concentrations in the source waters entering at Deep Cove, Pat Bay, Brentwood Bay and Mill Bay (Figure 8-6).

Fecal coliform concentrations were also measured in major storm drains and most tributaries entering Saanich Inlet during the March 1995 survey. Sampling locations for this survey are shown in Figure 8-7. Again, the highest levels of fecal coliforms were found in sources entering at Deep Cove, Pat Bay, Brentwood Bay and Mill Bay (Figure 8-8). The sampling program described by Drinnan and Hull (1996) also found the highest levels of fecal coliforms in the storm drains and ditches discharging to Deep Cove, Pat Bay and Coles Bay, particularly during periods of high rainfall.

Assessment of the patterns of water movement in Saanich Inlet (Section 5) has shown that relatively large exchanges occur between Saanich Inlet and the waters of Satellite Channel. Thus, the waters of Satellite Channel must also be considered as a potential source for pathogenic materials entering Saanich Inlet.

The waters of Satellite Channel are themselves strongly influenced by the outflow from the Cowichan and Koksilah Rivers. As such, fecal coliform concentrations were measured in the

Cowichan and Koksilah Rivers, along the north and south shores of Cowichan Bay, and along the shoreline between Cowichan Bay and Saanich Inlet during the period from February 2 to March 20, 1995 (Kangasniemi, pers. comm. 1996). Shoreline measurements were generally collected from 200 to 400 m offshore from the beach.

This sampling program showed relatively low levels of fecal coliforms at the most downstream site in the Cowichan River (<1 - 100/100 mL), with higher values further upstream in the watershed. Shoreline measurements along the southern shore of Cowichan Bay and between Cowichan Bay and Saanich Inlet were generally higher than those in the river waters, ranging from 2 to 350/100 mL. These elevated levels suggest that localized sources of fecal material to the marine waters of Cowichan Bay and Satellite Channel are present.

8.2.4 Current Status of Fecal Contamination in Saanich Inlet

Previous components of the Saanich Inlet Study (Howie, 1995; Drinnan et al., 1995; Calder and Mann, 1995) have concluded that closures of shellfish beds in Saanich Inlet are unacceptable to most users of the inlet. As such, the assimilative capacity for wastewater discharges, as indicated by fecal coliform concentrations, has already been exceeded throughout much of the nearshore zone in Saanich Inlet. The long-term objective identified during the public consultation process is to restore the bivalve shellfish beds to approved status, requiring median fecal coliform concentration values to be less than 14/100 mL and the 90th percentile value to be less than 43/100 mL. The source of coliforms to Saanich Inlet are likely from nearshore inputs such as leaky septic or sewer systems and agricultural runoff; however, the relative contributions of each source are unclear.

The studies described above show that the highest concentrations of coliform bacteria occur in the coastal embayments bordering Saanich Inlet (i.e., Deep Cove, Pat Bay, Coles Bay, Brentwood Bay, Tod Inlet and Mill Bay). These areas are generally associated with the highest population densities and include the unsewered areas of Deep Cove, Pat Bay and Coles Bay. Deep Cove, Pat Bay and Brentwood Bay show the highest coliform concentrations in the ditches, storm drains and tributaries entering the inlet. Note that IOS sewage is treated at the Sidney sewage treatment facility.

Coliform data are available primarily for shoreline areas, with few measurements available for areas further offshore. Offshore measurements are limited to samples taken within 500 m of the shoreline (Drinnan and Hull, 1996; Kangasniemi, pers. comm. 1996). In the absence of offshore outfalls and significant inputs from marine mammals and birds, the major sources of fecal material are considered to be at the shoreline. Problems are known to exist with septic systems in both Deep Cove and Coles Bay, with malfunctioning septic fields in the Coles Bay area leading to contamination of drinking water. Agricultural runoff is also a concern. However, the relative contributions of leaky septic or sewer systems and agricultural runoff to the high loadings of fecal coliforms to the coastal embayments are unknown at the present time.

8.3 Potential for Fecal Contamination from a Point Source Discharge of Wastewater

Potential residential developments bordering Saanich Inlet will need to consider options for sewage treatment and disposal, one of which would be a deep outfall into the waters of the inlet. This option may also be considered as a remediation measure for the communities in Deep Cove and Pat Bay. The intent of the work described in this section is to briefly examine several scenarios, with respect to bacterial contamination, for deep water wastewater outfalls in Saanich Inlet. At present, there is only one point-source sewage discharge to Saanich Inlet.The regulatory background affecting point source discharges into the waters of Saanich Inlet is discussed in Section 1.6.

During the Saanich Inlet Study, considerable information on Saanich Inlet was compiled. Development and remediation pressures have required MELP to examine the potential for wastewater discharge to Saanich Inlet. A new deep water outfall (point-source discharge) into the waters of Saanich Inlet may also be proposed as a wastewater disposal option for future residential developments bordering the inlet. In recognition of these factors, the Province included a point-source modelling exercise in the Saanich Inlet Synthesis Study.

Water quality in the immediate vicinity of a point source discharge (i.e., within a few hundred metres of the discharge point) is essentially a near-field problem that is not amenable to the box model approach (Section 4). The appropriate analysis technique is to apply plume theory to the initial dilution problem. However, it should be realized that, as a near-field problem, the results of these analyses may be *highly* site-specific. In addition, the actual dilutions achieved will be highly dependent on the outfall configuration. The following modelling scenarios do not reflect the level of engineering effort that would go into the optimization of a site-specific outfall design; thus, the results should be considered highly qualitative rather than quantitative. The following model results do, however, serve to illustrate the probable behaviour of a deep outfall at various locations within the inlet.

These modelling scenarios also allow exploration of the sensitivity and assimilative capacity of the inlet to point source discharges, from the perspective of pathogens. However, decisions regarding the suitability of any proposed outfall must also consider factors such as chemical contaminants, nutrients and dissolved oxygen levels (Sections 7 and 9). It should be recognized that other treatment options are available for both remediation of existing problems and future wastewater disposal needs, but only conventional deep discharge of treated sewage is explored here. This is reflected in the recommendations of the Saanich Inlet Study.

8.3.1 Assumptions

The modelling scenarios described in the remainder of this section are subject to several limitations and assumptions. These include:

- Model runs have been performed for summer and winter stratification conditions in the inlet, as described by the December 1994 and July 1995 IOS data sets (Cross and Chandler, 1996). These data, although providing the most comprehensive spatial coverage of Saanich Inlet, may not represent worst-case conditions for plume dilution. A worst-case assessment would require a detailed assessment of available data sets and is beyond the scope of the simplified approach presented herein.
- Background levels of fecal coliforms in the receiving waters are assumed to be ≤1/100 mL.
- Dilution of the effluent plume is considered in the near-field only. A near-field approach is often adequate to determine if receiving water criteria for fecal coliforms are met at the boundary of the initial dilution zone. However, it does not consider the possibility of long-term build-up of coliforms throughout the receiving environment. This possibility exists in water bodies with limited flushing such as the coastal embayments of Saanich Inlet. To assess the likelihood of a long-term build up of coliforms occurring in the receiving waters, a far-field analysis would be required.
- Decay of coliforms is assumed to be insignificant for the near-field modelling described in this section, due to the short-time frames associated with initial dilution processes. Coliform decay should be included in any far-field assessment of effluent build-up in the receiving environment.
- Currents are assumed to be negligible in the receiving waters which is usually a conservative assumption. Currents generally act to increase the rate of plume dilution; however a shoreward current may cause the effluent plume to impinge on the shoreline.
- Point source discharges will only be considered below a water depth of 50 m., based on findings in Section 9.

- A simplified diffuser configuration will be used for all model runs which is a conservative assumption. This diffuser configuration has not been optimized for each effluent flow rate under consideration. Actual rates of dilution may be higher than those given here.
- The model's default values will be used for any adjustable parameters in the plume dilution model (e.g., entrainment coefficient).

8.3.2 Modelling Scenarios

Several simple scenarios were used to examine the potential impacts of a deep wastewater discharge on water quality as reflected by fecal coliform concentrations in the receiving waters of Saanich Inlet. It is recognized that wastewater discharge can have other effects (Section 8.1).

First, potential water depths and locations for such discharge must be assessed. The nutrient modelling described in Section 9 of this report indicates that an outfall discharging 5000 m^3/day of sewage effluent must be located below a water depth of 50 m in order to avoid significant disruption of the plankton communities in the surface waters. An additional constraint to discharge depths is the requirement that an outfall must be located such that oxygen depletion in the water column above the outfall does not occur. Oxygen depletion may occur if anoxic or low oxygen waters present at depth in Saanich Inlet are entrained into the buoyant plume and carried upwards into shallow water depths; this process is often referred to as effluent pumping.

Data presented by Drinnan et al. (1995) indicate that dissolved oxygen levels decrease rapidly with increasing depth below the surface in Saanich Inlet, with the anoxic interface at its shallowest near the head of the inlet and deepening towards the sill. The depth of the interface varies over the year, and is at its shallowest during the fall months. At a water depth of 50 m, dissolved oxygen levels may be as low as 2.0 mg/L at the head of the inlet during the late summer and fall months. This level is substantially lower than those at the water surface, where dissolved oxygen concentrations range between 6 and 8 mg/L.

Thus, any outfall must be deep enough to avoid disruption of the plankton communities in the surface waters, but at the same time be placed such that anoxic or unacceptably low oxygen conditions are not created in the upper waters. An outfall placed below the surface waters in Saanich Inlet has the potential to move low oxygen waters upwards in the water column; the impacts associated with effluent pumping should be considered in the detailed assessment of any outfall proposal. For the purpose of this brief assessment, outfall depths of 50, 70 and 200 m will be considered.

The possible locations for a mid-depth outfall (defined here as discharging between 50 and 70 m) are limited by the locations of shellfish beds and by the steepness of the shoreline surrounding the inlet. To avoid shellfish beds, outfalls should be located away from the nearshore zones of the coastal embayments and other shoreline areas where shellfish beds are found (Figure 8-1).

The steepness of the coastline surrounding Saanich Inlet limits the distance from shore that an outfall can be placed while maintaining a discharge depth between 50 and 70 m. If the outfall is located too close to shore, the discharge plume will impinge on the shoreline, possibly leading to high shoreline bacterial concentrations. Onshore currents may exacerbate this condition. While this assessment will not focus on specific locations for a mid-depth outfall in Saanich Inlet, the steepness of the coastline suggests that a mid-depth outfall may be more suited to locations near the entrances to the coastal embayments bordering the inlet. Conversely, possible locations for a deep outfall are limited geographically by the available water depth. To assess the suitability of a particular site in the inlet, whether at the entrance to a coastal embayment or along a steep coastline, detailed site-specific assessments would be required.

The assessment presented here has been designed to illustrate some qualitative aspects of discharge plume behaviour in several areas of the inlet, rather than to provide a detailed design investigation of a specific site. For these purposes, the differences between outfalls located near the mouth of Saanich Inlet in the vicinity of Deep Cove, in the central regions of the inlet near Coles Bay, and in Squally Reach will be considered. The possible water depths for outfalls near Deep Cove and Coles Bay are limited by bathymetry; outfalls at 50 and 70 m will be considered near Deep Cove, and at 50 m near Coles Bay.

Three levels of sewage discharge will be modelled: 5000, 7000 and 9000 m^3/day, corresponding to the scenarios examined in the nutrient modelling described in Section 9. For the initial dilution analyses, no decay will be assumed for coliforms due to the short time scales associated with initial mixing. Although coliform die-off does occur in the marine environment, the rate of die-off is variable and highly dependent on exposure to light. As well, the modelling will assume negligible currents, representing worst-case conditions in the inlet when onshore currents are not of concern.

The initial dilution achieved by an outfall at a given location is a strong function of the outfall design and diffuser configuration. Design parameters such as pipe size, port size and spacing, etc. are determined based on detailed analyses of each individual site and the range in effluent discharge rates and characteristics. For this analysis, a simple diffuser consisting of 10 ports, each 8 cm in diameter and spaced 5 m apart will be used for all model runs.

Model runs were performed for summer and winter conditions based on IOS data sets (Cross and Chandler, 1996). Since the analysis is limited to two seasons, it may not represent worst-case conditions for plume detection.

Conditions at the mouth of Saanich Inlet have been characterized by the CTD profiles obtained at IOS Station S6, those near Coles Bay are based on the profiles at Station S4D, while the stratification in Squally Reach is based on measurements at Station S2. Station locations are shown in Figure 5-3 and Figure 5-17 in the Physical Oceanography section (Section 5).

8.3.3 Initial Dilution Results

The initial dilution of the wastewater plume has been modelled using the UM model and the PLUMES interface developed by the U.S. Environmental Protection Agency (Baumgartner et al., 1994). A complete description of the model system and theoretical basis is contained in Baumgartner et al. (1994) and other references listed in that document.

The results of the modelling exercise are summarized in terms of initial dilution, with the implications for fecal coliform concentrations and water quality standards discussed in Section 8.3.4. For the purposes of this project, dilution can be considered as the ratio of the volume of ambient dilution water (seawater) to the volume of effluent. Initial dilution is defined as that dilution occurring due to the combined effects of momentum and buoyancy in the discharge plume.

The rate of dilution is relatively rapid in the first few minutes after discharge, but decreases quickly as the momentum and buoyancy of the discharge plume are dissipated through mixing with the ambient seawater. As the wastewater plume mixes with the surrounding seawater, it rises through the water column. Depending on the relative densities of the wastewater effluent and the ambient seawater, the plume may rise to the water surface or become trapped at some intermediate water depth. Trapping generally occurs when the receiving waters are strongly stratified, and is often associated with the lowest dilutions for a given outfall configuration and location. The zone of initial dilution is usually considered to end when the wastewater plume reaches either the water surface or the trapping depth.

Model results for a wastewater discharge rate of 5000 m^3/day are presented in Table 8-1 for all three CTD stations (S6, S4D and S2), representing conditions near the entrance to the inlet, near the mouth of Coles Bay and in Squally Reach. For a discharge located at 50 m water depth, the differences between the three locations are relatively minor, and are significantly less than the differences between winter and summer conditions at a single station.

The wastewater plume remained trapped at depth for all of the discharge scenarios considered in this assessment. During the winter months, density stratification in Saanich Inlet is primarily a result of the high fresh water content in the surface waters. During the summer months, density stratification is mainly driven by vertical gradients in water temperature rather than in salinity. The thermocline is significantly thicker during the summer months than is the halocline during the winter months; thus, the effluent plume becomes trapped lower in the water column during summer than during winter conditions. Since the rate of dilution decreases rapidly once the plume becomes trapped, initial dilutions are less in the summer months than in winter.

Table 8-1 shows the effects of discharge depth on initial dilutions at two locations in the inlet: Station S6, near Deep Cove at the mouth of the inlet, and Station S2 in Squally Reach. Near the mouth of the inlet, an increase in discharge depth from 50 to 70 m leads to a decrease in initial dilution for the two cases examined. Conversely, the 70 m discharge in Squally Reach has a slightly higher initial dilution during winter than does the same outfall at 50 m water depth. The highest dilutions are associated with the deep discharge at 200 m. The optimal discharge depth can be seen to be site-specific, requiring detailed investigation during the design process and including the complete range of stratification conditions at the site of interest.

The initial dilutions for effluent discharge rates of 7000 and 9000 m^3/day are given in Table 8-2 and Table 8-3 for the three locations discussed above. These tables show that initial dilutions decrease slightly as the discharge rate increases, given the same diffuser configuration for all three discharge rates. As the discharge rate increases, the initial velocity of the discharge jet also increases. This increase leads to enhanced momentum-driven mixing in the immediate vicinity of the diffuser, reducing the density difference between the effluent plume and the ambient seawater. The reduced density difference leads to lower buoyancy-driven mixing, with a lower overall dilution for the effluent plume as a whole.

8.3.4 Fecal Coliform Concentrations

The preceding model results illustrate the initial dilutions that could be achieved for a specific outfall configuration at different locations in Saanich Inlet, based on two measured cases of water column stratification. Predicted effluent dilutions for this limited analysis range from roughly 100 to 1000 (volume ratio of seawater to effluent).

The main purpose of this modelling work is to assess the impacts of a wastewater discharge on fecal coliform concentrations in Saanich Inlet, as one aspect of water quality (Section 8.1). Although fecal coliforms generally do not pose a direct threat to human health or to marine organisms, they are used to indicate the level of contamination of the receiving waters by fecal materials and to assess the associated risk to human health. The initial dilution estimates presented in Table 8-1 through to Table 8-3 can be used to estimate the resulting near-field coliform concentrations if the coliform concentrations in the discharged effluent are known.

The level of sewage treatment has a considerable impact on the concentrations of fecal coliforms in the discharged effluent. MELP requires that secondary treatment be used as a minimum level of treatment. For this assessment, secondary and tertiary treatment, with and without disinfection, will be considered. The associated effluent concentrations of fecal coliforms are given in Table 8-4 (Kangasniemi, pers. comm. 1995). These effluent concentrations reflect typical order-of-magnitude values, and that actual loadings can vary significantly depending on performance of the particular sewage treatment plant and processes under consideration. Table 8-1 shows that tertiary-treated effluent with disinfection has a typical fecal coliform concentration of 2/100 mL. At this level, the effluent itself is predicted to meet the shellfish criteria of 14/100 mL and no further dilution would be required. However, areas of the inlet with limited flushing should still be avoided to reduce the possibility for re-entrainment of previously discharged effluent into the discharge plume. The potential for effluent re-entrainment should be assessed in a detailed evaluation of any proposed outfall. For tertiary-treated effluent with disinfection, other potential impacts related to a point source wastewater discharge should be considered, such as: nutrient additions to the receiving water, the effects of chemical contaminants, sedimentation, and effluent pumping. These may be the limiting factors in assessing the suitability of a given discharge scenario. The environmental effects of the proposed disinfectant would also need to be evaluated, as well as the reliability of the sewage treatment process in terms of pathogen removal and plant failure.

Similarly, secondary-treated effluent with disinfection has a typical coliform concentration of 200/100 mL. This effluent meets the recreational contact standard of 200/100 mL without further dilution and will meet the shellfish criteria with an initial dilution of roughly 14. This level of dilution should be easily obtained with a discharge depth of 50 m or deeper. Again, effluent re-entrainment, chemical contaminants, sedimentation, nutrient or dissolved oxygen concerns are likely to be the limiting factors in assessing the suitability of a given outfall location. The options for effluent disinfection and plant reliability would also need to be thoroughly assessed to evaluate a proposal.

For a typical secondary-treated effluent without disinfection, fecal coliform concentrations are on the order of 500,000/100 mL. To achieve the recreational contact criteria of 200/100 mL, an initial dilution of 2500 would be required. This is an extremely high dilution ratio and is unlikely to be achieved within an acceptable mixing zone (typically 50 to 100 m from the discharge point) for a mid-depth outfall. However, the feasibility of a deep outfall (discharge depth on the order of 200 m), where the effluent remains trapped within the bottom anoxic layer, cannot be discounted here. If effluent could be kept within the bottom anoxic layer, fecal coliform concentrations would not necessarily have to meet recreational standards. Further detailed analyses would be required to determine the feasibility of such an outfall; far-field analyses would likely be necessary.

Finally, tertiary-treated effluent without disinfection has a typical fecal coliform concentration of 100,000/100 mL, thus requiring an initial dilution of 500 to meet the recreational use standard in surface waters. The initial dilution values presented in Table 8-2 through Table 8-4 suggest that a mid-depth outfall in Saanich Inlet could be designed to meet this criterion; however, detailed site-specific analyses would be required in order to assess worst-case conditions. In particular, the range of stratification conditions in the receiving waters would have to be carefully assessed, along with the potential for plume surfacing, shoreline impact, effluent pumping, and re-entrainment and potential impacts of sewage treatment plant failure. Again, a deep outfall into the anoxic layer may provide a viable discharge option for tertiary-treated effluent without disinfection; however, full assessment of this option would require further detailed studies.

The possibility of the plume impinging on the shoreline during times of shoreward surface currents, and thereby bringing effluent to the surface, was not considered in this report. Such should be investigated in site-specific studies for any discharge proposal.

8.4 Discussion

Previous work has clearly shown that the assimilative capacity for pathogens contained in wastewater discharges, as indicated by fecal coliform bacteria, has already been exceeded in the nearshore waters of Saanich Inlet (Section 8.2.4), particularly in the coastal embayments. The main sources of wastewater and the associated coliforms are considered to be at the shoreline.

The modelling work described above has been designed to illustrate some aspects of the behaviour of a deep outfall at various locations within Saanich Inlet, and thus to give some qualitative indications of the assimilative capacity of the deep waters in the inlet for fecal contamination. This assessment has shown that the assimilative capacity of the deep waters in the inlet cannot be determined in the form of a simple, generalized wastewater or fecal coliform loading rate. The initial dilution of a wastewater plume, and thus the waste loading rate, is highly dependent on the design of the outfall and diffuser configuration, the specific location within the inlet, the type of effluent and the characteristics of the receiving water (density stratification). Also and importantly, other potential impacts associated with sewage outfalls (e.g., oxygen levels, chemical contaminants, sedimentation, nutrients, effluent pumping), rather than pathogenic considerations, may be the factors governing the environmental acceptability of a given outfall scenario.

The modelling work has shown that, under the receiving water conditions described previously, an effluent plume discharged below 50 m water depth in Saanich Inlet tends to remain trapped below the surface waters in the inlet. While plume trapping tends to decrease the initial dilution, it also keeps the effluent out of the surface waters and away from human contact. However, the plume may surface during conditions other than those examined herein. In particular, the potential for plume surfacing should be assessed using the conditions with the least stratification in the water column.

In summary, location of a potential wastewater discharge in Saanich Inlet is severely restricted by:

- Impacts related to nutrient discharge (Section 9) which restrict discharge to >50 m of water.
- Avoidance of entrainment of anoxic deep Saanich Inlet water to depths above its present range.
- The steepness of Saanich Inlet's floor, which prohibits placement of an outfall in steep areas, nearshore.
- Avoidance of shellfish beds and areas of sensitive marine species such as subtidal sponges.

Any new point-source discharge into Saanich Inlet would require detailed, site-specific analyses to determine whether or not fecal coliform criteria in the receiving waters could be met. The impacts on human health of sewage treatment plant interruptions or failures should be included in any detailed assessment. However, these findings must not be used in isolation of other potential impacts of wastewater discharge (Section 8.1).

8.5 Model Certainty

The numerical models used for the predictions of plume dilution presented in this section have been developed and tested by the U.S. Environmental Protection Agency (U.S. EPA). The UM model and the PLUMES interface represent the most current version of a long series of plume dilution models developed, tested and supported by the U.S. EPA. These models are widely used throughout North America for the modelling of wastewater plumes and are certainly the most widely accepted models for this purpose. Additionally, these models are fully independent from the other models used in the Saanich Inlet Synthesis Study; thus, the results are not affected by propagated errors from other numerical models.

The initial dilution results presented in this report are likely somewhat conservative, in that it has been assumed that coliforms do not decay in the receiving waters, currents are not present, and the diffuser configuration has not been optimized for the range of flow conditions under consideration. The overall confidence in the modelling process is relatively high, although uncertainties in contaminant loading rates will be propagated forward to any model predictions of receiving water concentration levels.

Table 8-1 Initial dilution estimates for a buoyant plume at three locations in Saanich Inlet with wastewater discharge rate of 5000 m^3/day.

Station	Discharge Rate (m^3/day)	Season	Discharge Depth (m)	Initial Dilution	Trapping Depth (m)
S6	5000	winter	50	535	26
S6	5000	summer	50	255	37
S6	5000	winter	70	415	53
S6	5000	summer	70	130	62
S4D	5000	winter	50	560	25
S4D	5000	summer	50	250	37
S2	5000	winter	50	455	29
S2	5000	summer	50	200	39
S2	5000	winter	70	495	47
S2	5000	summer	70	200	59
S2	5000	winter	200	1080	149
S2	5000	summer	200	735	167

Table 8-2 Initial dilution estimates for a buoyant plume at three locations in Saanich Inlet with wastewater discharge rate of 7000 m^3/day.

Station	Discharge Rate (m^3/day)	Season	Discharge Depth (m)	Initial Dilution	Trapping Depth (m)
S6	7000	winter	50	470	24
S6	7000	summer	50	230	36
S6	7000	winter	70	375	49
S6	7000	summer	70	120	62
S4D	7000	winter	50	480	24
S4D	7000	summer	50	225	36
S2	7000	winter	50	410	27
S2	7000	summer	50	180	39
S2	7000	winter	70	435	46
S2	7000	summer	70	180	59
S2	7000	winter	200	930	147
S2	7000	summer	200	655	164

Table 8-3 Initial dilution estimates for a buoyant plume at three locations in Saanich Inlet with wastewater discharge rate of 9000 m^3/day.

Station	Discharge Rate (m^3/day)	Season	Discharge Depth (m)	Initial Dilution	Trapping Depth (m)
S6	9000	winter	50	425	23
S6	9000	summer	50	210	36
S6	9000	winter	70	350	48
S6	9000	summer	70	115	62
S4D	9000	winter	50	435	23
S4D	9000	summer	50	210	36
S2	9000	winter	50	375	26
S2	9000	summer	50	170	38
S2	9000	winter	70	395	45
S2	9000	summer	70	170	59
S2	9000	winter	200	835	146
S2	9000	summer	200	600	162

Table 8-4 Typical effluent fecal coliform concentrations for different levels of sewage treatment.

Treatment Level	Fecal coliforms per 100 mL
Secondary	500,000
Secondary with disinfection	200
Tertiary	100,000
Tertiary with disinfection	2

Figure 8-1 DFO shellfish sectors and bivalve shellfish closure areas in Saanich Inlet.

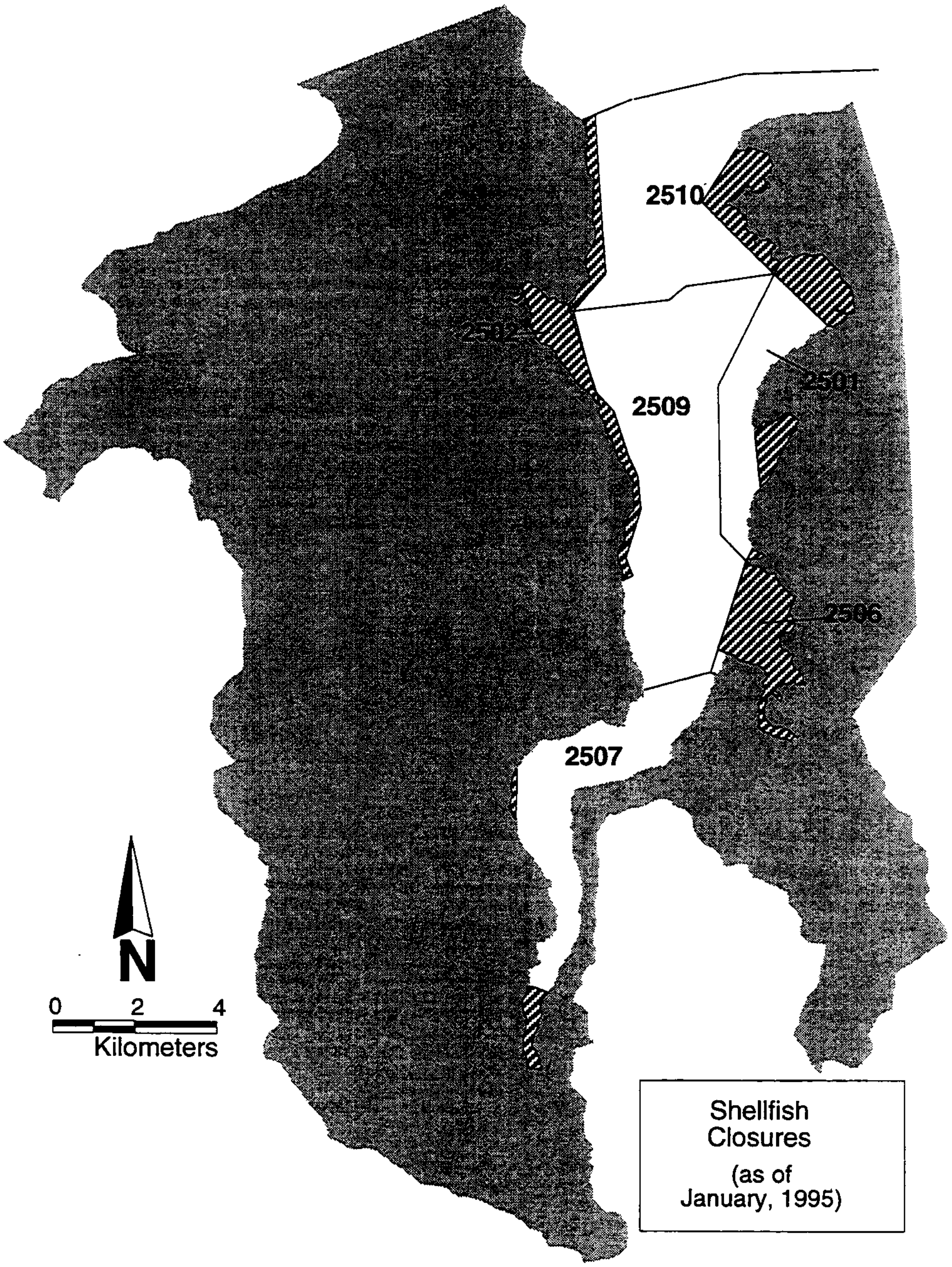


Figure 8-2 Fecal coliform levels in marine waters, by sub-area (Environment Canada data).

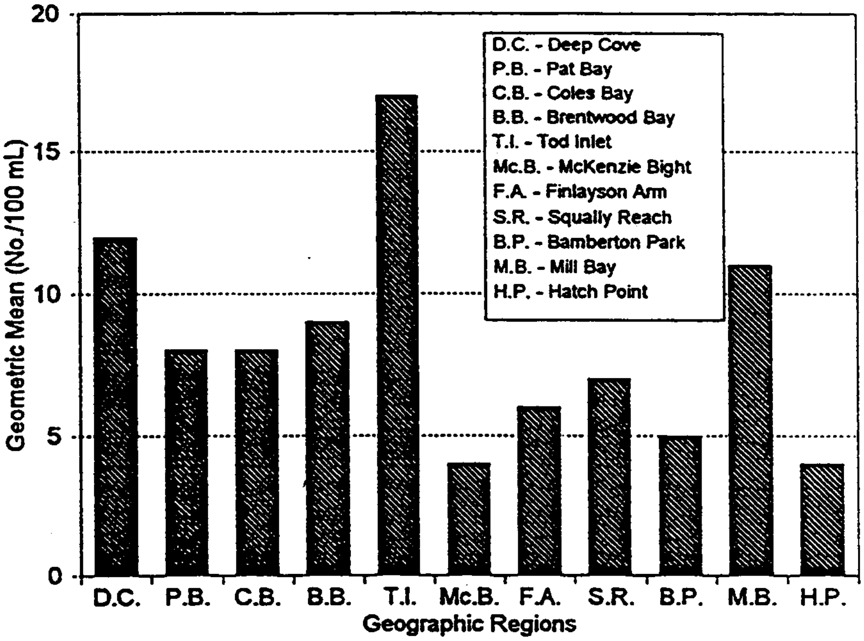


Figure 8-3 **Fecal coliform levels in marine waters for selected years, sub-areas 1,2 and 3 combined (Environment Canada data).**

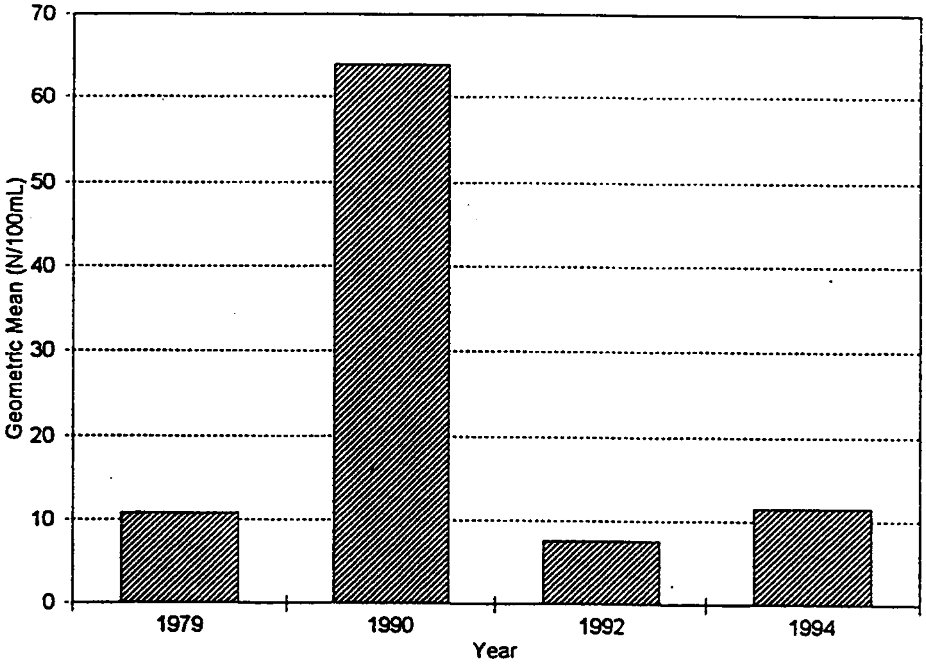


Figure 8-4 Marine bacteriological sampling sites (March 1995 survey).

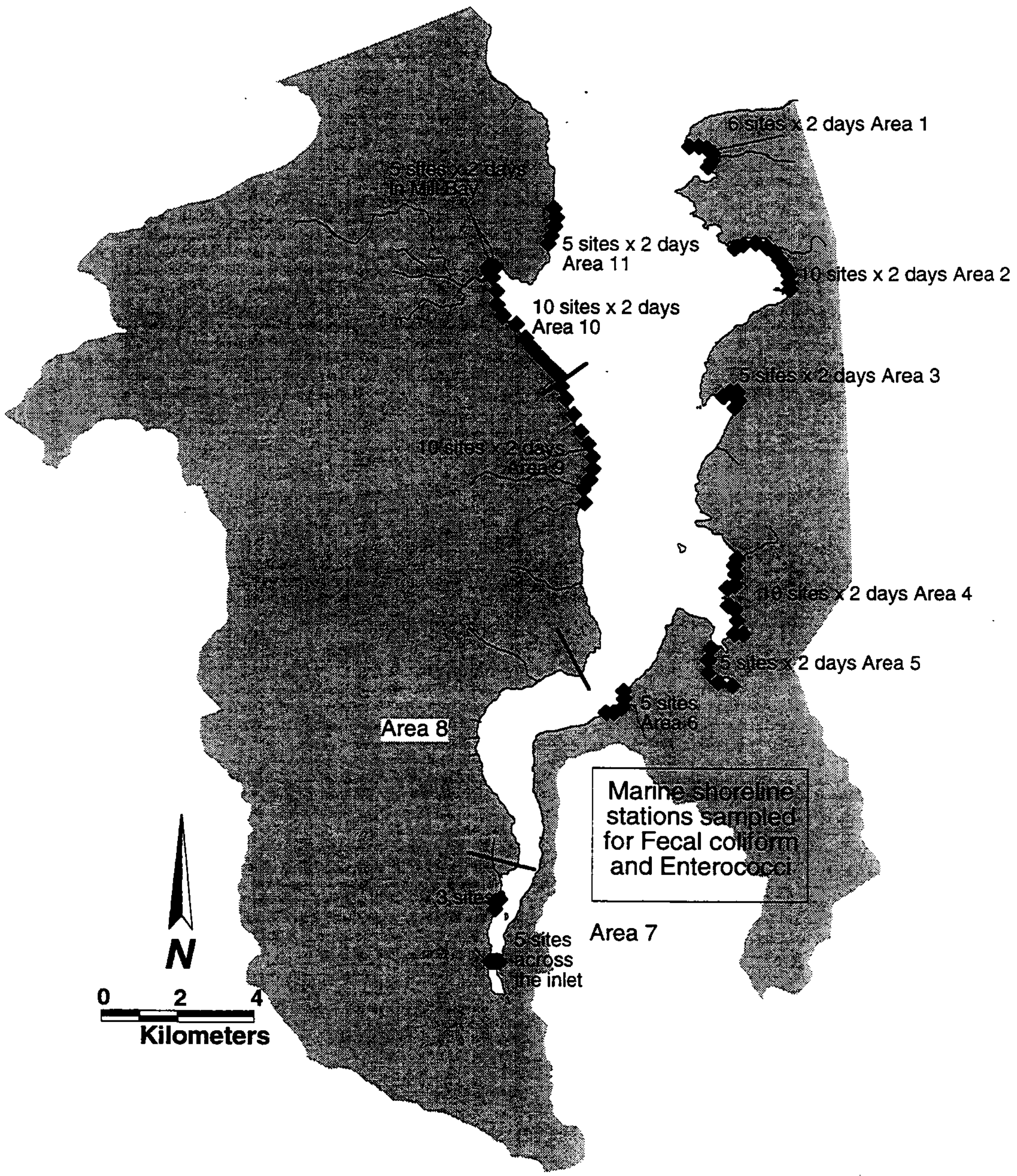


Figure 8-5 Fecal coliform and enterococci levels in marine waters, by sub-area (March 1995 survey).

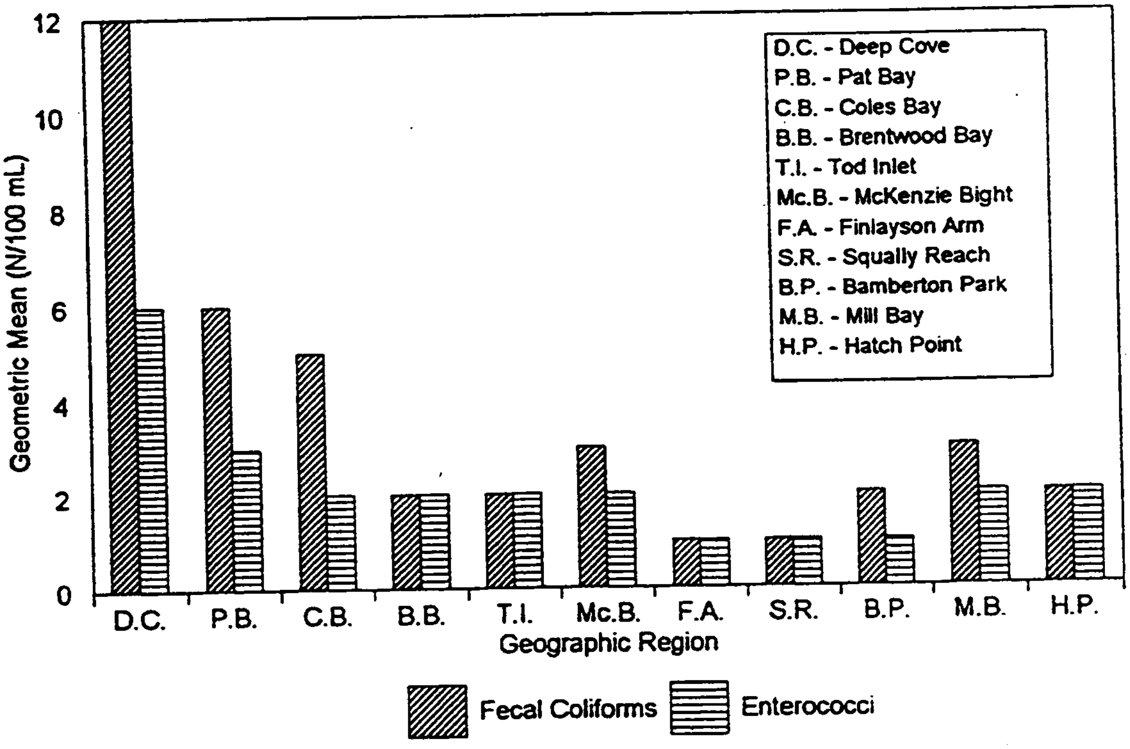


Figure 8-6 Sources of fecal coliform bacteria, by sub-area (Environment Canada data 1995).

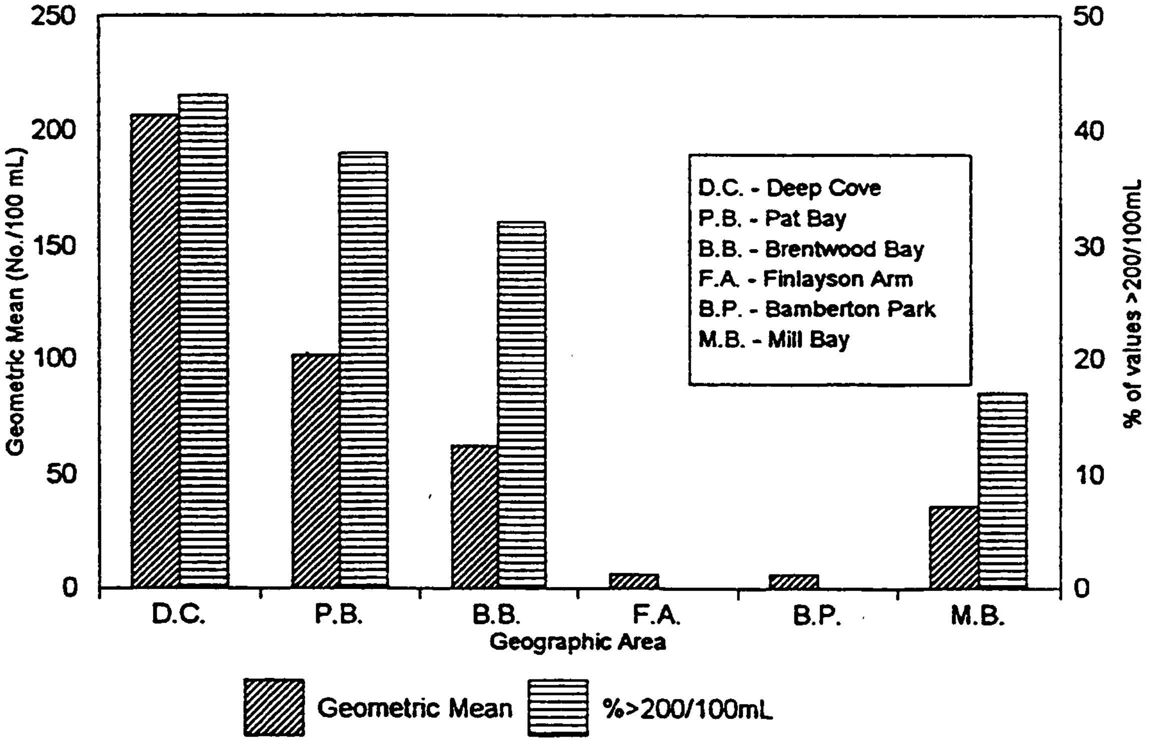


Figure 8-7 Major discharges sampled for fecal coliform bacteria (March 1995 survey).

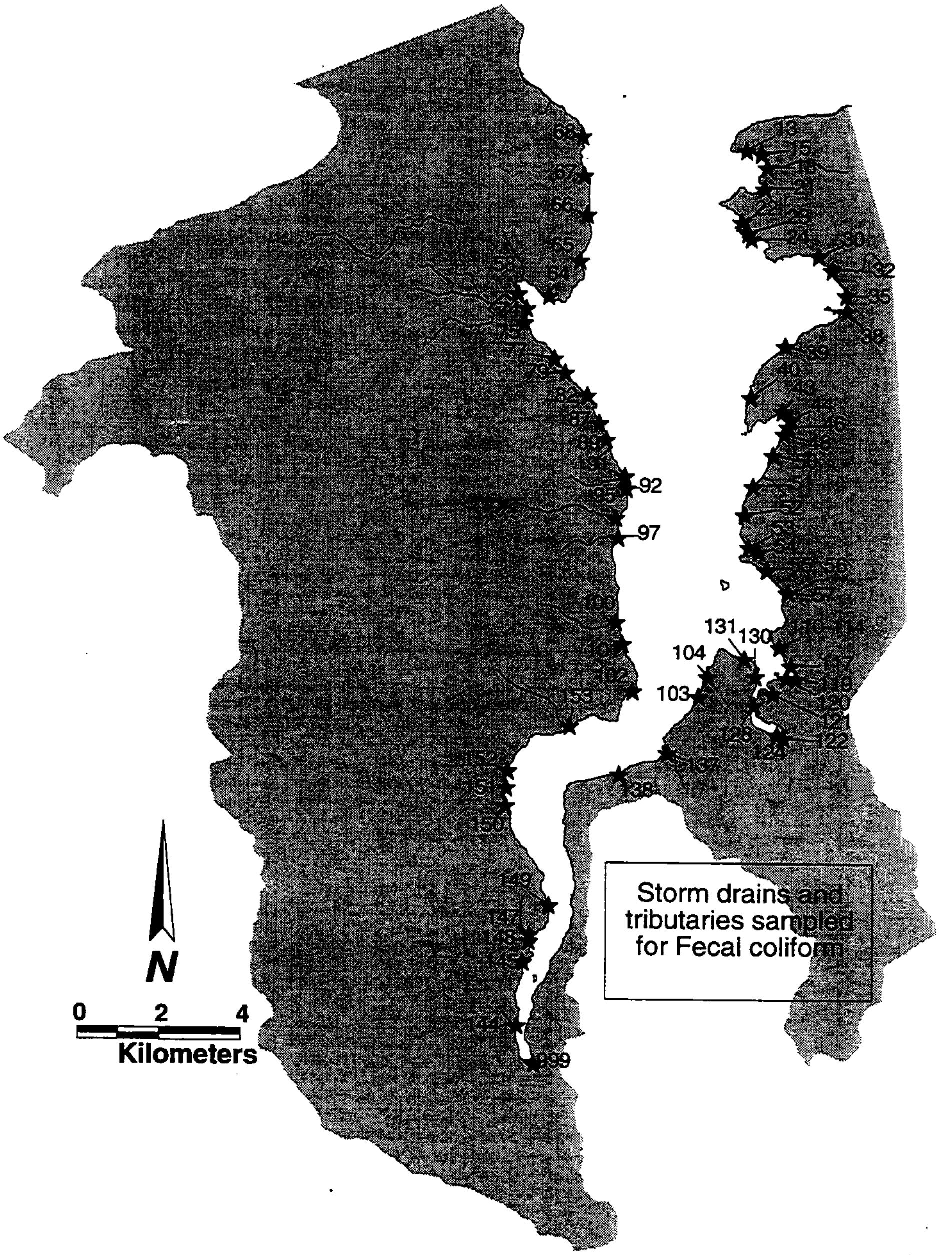
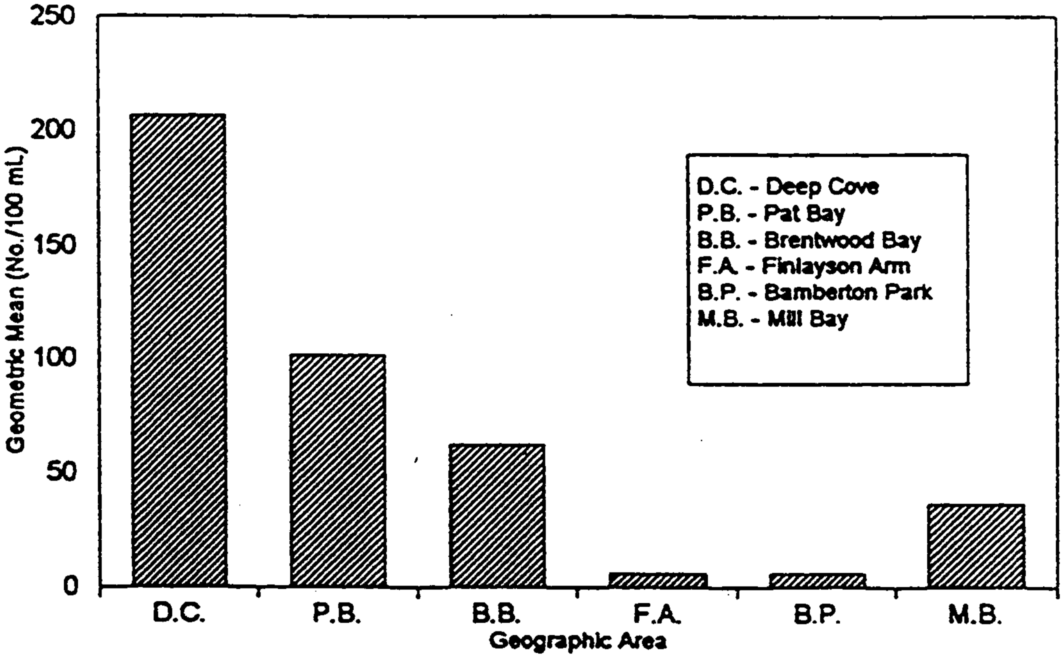


Figure 8-8 Sources of fecal coliform bacteria, by sub-area (March 1995 survey).



9. NUTRIENTS, OXYGEN AND PHYTOPLANKTON

9.1 Background

This section discusses nutrient contamination in context with other issues related to wastewater. In the absence of industrial development, wastewater generated by populated areas has two main components: domestic sewage and stormwater runoff. It enters marine waters through a variety of pathways: concentrated point sources such as marine outfalls; and more dispersed sources such as small streams and creeks, surface runoff, boat discharge and groundwater seepage.

The nature of potential environmental impacts associated with wastewater entering the marine environment depends on its composition. Organic materials decay, potentially leading to depleted levels of dissolved oxygen. Sedimentation of particulate matter can smother benthic organisms and affect sensitive species. Nutrient additions may impact planktonic communities and lead to eutrophic conditions. Bacteria, viruses and parasites have potentially significant health effects for humans, whether through direct recreational contact or through the consumption of contaminated shellfish. Chemicals may also cause a variety of adverse impacts depending on their type and concentration. Chemicals can travel with fat globules which may rise to the surface, even if the plume is trapped.

Many of these issues are discussed elsewhere in this report. For instance, chemical contamination is discussed in Section 7. Bacterial contamination is examined in Section 8. Sedimentation is discussed in Sections 6 and 10. The current section will focus on predicting the impacts of a point-source wastewater discharge to Saanich Inlet, with respect to nutrients, oxygen and phytoplankton. This is a specific requirement of the scope of work, stemming back to MacKay (1994; see also Section 1 for background).

Nutrient levels in Saanich Inlet have not been identified by previous studies as reaching levels of concern. There have been observations about heavy algal growth in intertidal areas, which has been attributed anecdotally to nutrient discharges from leaky septic fields. Models to predict the potential impact of such non-point sources of nutrients are not nearly as well developed as those which exist for point sources. A brief look at the additive effects of surface nutrients and a deeper nutrient discharge is discussed in Section 9.3.8.

This section focuses on predicting the impacts related to nutrient release of hypothetical wastewater discharge; however, it is important to recognize that further development which leads to greater use of septic fields does not avoid the issue of nutrient discharge to Saanich Inlet. Whether the wastewater is collected and discharged, or treated on-site with some loss to aquatic systems, the issue of waste treatment and its impacts on Saanich Inlet remains.

Increased nutrient and/or organic loadings to an aquatic system may result in increased biological production, and possibly changes in the composition of the plankton community. Potential sources of increased nutrient loadings can be natural (e.g., introduction of nutrient rich water through oceanographic processes) or anthropogenic (e.g., inputs from municipal, industrial or agricultural activities).

Most coastal waters are considered to be nitrogen limited (i.e., biological production is limited by the amount of nitrogen in the water), which is in contrast to fresh water systems which are more often phosphorus limited (Harrison et al., 1994). Saanich Inlet is considered nitrogen limited, so the nutrient modelling exercise focused on predicting impacts related to the addition of nitrogen to the inlet. Nutrient concentrations can undergo dramatic natural fluctuations in most systems; accordingly, the relative impacts of anthropogenic nutrient loadings will depend heavily on the state of the system receiving the inputs. Under some conditions, additional nutrients can enhance biological productivity without resulting in negative impacts such as nuisance algal blooms. However, the addition of nutrients under other conditions can lead to eutrophic conditions, which are characterized by abnormally high biological productivity and gross changes in the community composition of plankton. Prolonged nutrient enrichment may result in extensive adverse ecosystem-level effects (e.g., Rosenberg, 1985).

The *Water Use Report* (Drinnan et al., 1995) states that annual anthropogenic nutrient loading to Saanich Inlet contributes an insignificant amount (< 1%) to the inlets net nutrient flux considered on an inlet-wide basis. As mentioned previously, the effects of nutrient inputs are dependent on the conditions of the system. Some characteristics affecting the system condition include, but are not limited to, physical oceanographic processes (e.g., flushing rates, mixing rates), biochemical processes (e.g., existing nutrient regime) and season. For example, it has historically been shown that what may be true of large water bodies may not be true for small inlets and bays within the system. Waldichuck (1969) documented severe eutrophication in Portage Inlet (a small inlet adjoining the Strait of Juan de Fuca), while in general the adjacent waters of the Strait were not considered to be affected.

A carbon/nutrient model was developed to predict the effect of enhanced nutrient loading, ostensibly from urban or agricultural development, on the waters of Saanich Inlet. The model was used to predict the effect of nitrogen discharged from a (hypothetical) small community sewage discharge on the production of chlorophyll by plankton at different times of the year. These predictions allowed estimates to be made regarding the assimilative capacity or sensitivity of Saanich Inlet to inputs of nitrogen delivered by a point source. Although phosphorus was also modeled, it was assumed to have no effect on biological production because Saanich Inlet is nitrogen limited. Unless there is an unlikely change in the N/P ratio of effluent, the most important element to consider is inorganic nitrogen.

The modelling approach addresses changes in the plankton production of the inlet, but does not address potential changes in species composition. Based on recent information provided by Dr. Lou Hobson (University of Victoria), the plankton community of Saanich Inlet has remained fairly similar over the past century, with minor shifts occurring in Patricia and Coles Bay (Appendix C). The changes in species composition of the embayments may be due to organic inputs, and the recent appearance of certain phytoplankton species (i.e., *Pterosperma cristatum*) throughout the inlet may be caused by short term changes in oceanographic patterns.

Community shifts can occur if effluent from a near surface outfall cause changes in the ratio of different nutrients in surface waters. In general, this is less serious than if the total quantity of nutrients drives a system to species dominance. Unfortunately, the relationship between species diversity and nutrient ratios is poorly understood and therefore impossible to model with any certainty. For these reasons, the modelling approach has focused on predicting the effects of nutrient enrichment on biological productivity.

9.2 Approach

9.2.1 Description

The carbon/nutrient model characterized the hydrodynamics and biological fate of hypothetical nutrients discharged to embayments in Saanich Inlet. The hydrodynamics were represented by a time-dependent, one dimensional (vertical) turbulent mixing model. A time-dependent food web model was super-imposed that tracked the flows of carbon, dissolved oxygen and macro nutrients (Figure 9-1; a more detailed description is provided in Appendix D).

In order to perform model calculations, geographical surface areas relevant to Saanich Inlet were required. Geographical surface areas for the seven embayments (Deep Cove, Patricia Bay, Coles Bay, Brentwood Bay, Finlayson Arm, Bamberton, and Mill Bay) were estimated to range from 0.89 to 4.4 km^2. For the purposes of the model calculations, a surface area of 1.0 km^2 was selected to allow the conversion of the prescribed effluent constituent mass fluxes to equivalent water-column loadings. Therefore, the model runs explore the impacts of loadings on hypothetical areas with a surface area of 1 km^2.

To assess impacts in the model, effects were defined by the presence or absence of abnormal phytoplankton and bacterial blooms (i.e., standing stocks outside the range of normal seasonal variability) resulting from a prescribed nitrogen loading in the context of a local mixing regime. Since the effects of increased nitrogen loadings to these embayments would likely depend on the rate, depth and time of year of the prescribed effluent loading, assessments were performed for a range of loading rates (worst-case and best-case scenarios), depths of discharge, and times of year. Furthermore, the effects of geographical surface area, wind, and available surface nutrients on phytoplankton and bacterial blooms were also characterized.

A time-dependent analysis was undertaken because if localized eutrophication occurred during the summer, it could be expected to manifest as episodic departures from the (nutrient-limited) steady-state. The model was run for a time period of 20 days because the increase and decrease in plankton blooms and oxygen changes generally have time scales of approximately this length. During this time period, the daily flux of nutrients from natural and anthropogenic sources was added to any residual nutrient for a particular time of year (e.g., high winter nitrates, low in summer). A significant event was interpreted as one that fell outside the general range of chlorophyll *a* (1 - 30 mg/m^3) or oxygen (5 - 15 mg/l) values provided in the Water Use Report (Drinnan et al., 1995).

The model estimated average concentrations of chlorophyll, dissolved organic carbon, silicon, nitrate, ammonia, phosphate, oxygen, and detritus, in the upper 10 meters of water. This depth interval was chosen because it represented the most visually observable region of change. The biological parameters for phytoplankton and bacteria are similar to those used in the MULES model which has been the subject of several publications (e.g., Parsons and Kessler, 1987).

Consistent with the precautionary principle, this is a worst-case scenario approach used to test for effects of increased nutrient inputs; such cases would exist if nutrients were released into small embayments with no physical flushing. Any physical flushing that did occur, as described in other parts of this report, would ameliorate the condition of eutrophication described here. Consequently the following model experiments assumed an embayment that remains effectively isolated from

Saanich Inlet for at least a 20 day period, a fresh water plume of effluent that rose from a discharge pipe to form a layer of brackish water which spread horizontally and uniformly over the entire area of the embayment (usually 1 km^2).

This nutrient model does not address the possibility of the effluent surfacing due to conditions of upwelling, winds or unusual oceanographic conditions. These aspects would need to be examined to fully evaluate any discharge permit.

9.2.2 Model Assumptions

The following assumptions were used for the nutrient model:

- Water exchange did not occur between the embayments and the rest of Saanich Inlet (worst case).
- The embayments were horizontally well-mixed.
- The embayments were assumed to have a surface area of 1 km^2.
- Effluent characteristics were modelled for untreated sewage (worst case).
- The ratio of nutrients in surface waters was not altered by the surface outfall.
- Species composition of primary producers was not altered by increased nitrogen loadings.
- The model did not consider episodic storm events lasting a few days, but it did include changes in wind strength over 20 days.

Modelling the embayments as isolated water masses, and horizontally well-mixed, was necessitated by the needs of computational economy. This major simplification of the actual system represents a worst-case scenario, because the loss of ambient and particle bound nutrients to adjacent waters was ignored.

The embayments were assumed to have a surface area of 1 km^2 to simplify model calculations. This assumption allowed the effluent constituent mass fluxes to be easily converted to water-column loadings.

The calculations of the assimilative capacity were highly dependent on the effluent characteristics of the outfall. The effluent characteristics modelled and shown in Appendix B are for untreated sewage. Sewage treatment performance in terms of nitrogen removal can range from 2 to 97% depending on the technology implemented (USNRC, 1993). Using untreated sewage for this model results in worst case nitrogen loading.

While the model considered the total quantity of nutrients (in terms of inorganic nitrogen) added to embayments, it did not consider the ratio of different nutrients which could be altered by a near surface outfall. The ratio of nutrients would determine the different types of species which would occur during a seasonal succession of phytoplankton. The effects of nutrient additions on species composition was not considered in this modelling study for two reasons. First, the relationship between the ratio of nutrients in surface waters and species composition is not well enough understood to model correctly. Second, based on preliminary estimates of the nutrient budget described in Section 9.3.1, it appears that additions of nutrients from anthropogenic sources would remain within the seasonal range of nutrient supply for the year. Therefore, anthropogenic additions could be expected to increase the amount of primary and secondary producers but not to change the species composition of the plankton. There is no evidence at present in the historical plankton data that Saanich Inlet develops abnormal plankton blooms outside of the seasonal succession of diatoms and flagellates (Drinnan et al., 1995; Appendix C). In general, a spring bloom of diatoms occurs in April or May, and the species composition shifts to primarily nano-flagellates and dinoflagellates during the summer months. Some short-lived diatom blooms may also occur during the summer and fall, but by late fall and throughout the winter, the most prevalent species are nano-flagellates. The fossil record indicates that the seasonal trends in plankton succession have remained fairly similar over the past several decades.

The model did not analyze episodic storm events lasting a few days. Since such events in summer months would be infrequent, it was assumed that they were unimportant to the general assimilative capacity. In fact, such events would be associated with upwelling of the natural supply of nutrients which would dominate in the productivity of the surface layers.

9.2.3 Scenarios

A number of scenarios were used to describe the effects of increased nitrogen loadings from a hypothetical small scale residential outfall on biological production. First, preliminary calculations were performed to assess the validity of the assumption that anthropogenic nitrogen inputs do not alter the species composition of the plankton. Subsequently, various simulations were performed using the carbon/nutrient model to predict the effects of outfall and receiving environment conditions (nitrogen loading, depth of discharge pipe, time of year, etc.) on eutrophication. In general, the simulations assumed a discharge between 0 and 9000 m^3/day discharging to a 1 km^2 embayment, at a depth ranging from 5 to 70 m. These conditions are representative of a small community outfall discharging to an embayment approximately equal in size to Deep Cove or Coles Bay. The following model simulations were run:

- The model was run for several months of the year assuming natural conditions (i.e., no additional inputs of nitrogen).This provided background or natural conditions of the inlet which could be compared with subsequent scenarios to assess impacts.
- The model was used to predict the effects of a discharge at different depths.
- The model was used to assess the effect of discharging at different times of the year.
- The model was used to predict the effects of different wind conditions.
- The model was used to assess the effects of different discharge rates.
- The model was used to assess the effects of altering naturally occurring nutrient levels.
- The model was used to assess the effects of discharges on near surface properties below 10 m, the extinction coefficient of the waters, and oxygen content of the water.

9.3 Findings

The results of the predictive nutrient evaluations have been summarized in the following sections. For complete printouts of the results of the carbon/nutrient model, please refer to Appendix D.

9.3.1 Preliminary Estimation of Nutrient Budgets

The present average amount of anthropogenic nutrient loading rate to Saanich Inlet is estimated as 979.5 kg nitrogen/day from all sources (septic fields, outfalls, atmosphere, golf courses and agricultural lands) (Drinnan et al., l995). On an annual basis this is less that 1% of the natural flux of inorganic nitrogen into the inlet. However, during the summer months when the potential nutrient flux into the euphotic water column is low, a daily input of the above amount per square metre could represent a more significant fraction of the natural input.

Estimates of the flux of nutrients (inorganic nitrogen) over two ten day periods, one in May and another in July were made. These estimates were based on the available standing stock of inorganic nitrogen in the water column at the two time periods, the amount of nutrient excreted by zooplankton in the first 30 m and the flux of inorganic nitrogen from vertical diffusion. The results of these approximations showed that in May the near surface available nitrogen was about 21 μmols/L and in July it was 1.3 μmols/L during a ten day period. The current anthropogenic supply of nitrogen averaged over the surface of Saanich Inlet to a depth of 10 m for a period of 10 days represents only 5% of the flux in May but nearly 80% of the natural flux in July. Adding an outfall from approximately 2000 persons (assuming a per capita nitrogen excretion of 5 kg/year scaled to 10 days and a 10 m water column) would represent a 10% addition to the natural flux in May, but a 175% addition in July.

If the additions of nutrients from anthropogenic sources at any time of the year remain within the seasonal range of nutrient supply for the year, then we might expect to increase the amount of primary and secondary producers but not to change the species composition of the plankton. If, as has been the case in some lakes and estuaries, the amount of anthropogenic nutrient vastly exceeds the natural seasonal range of nutrients, then a change in plankton species might be realized leading to the dominance of one or two species. This would result in a very different form of eutrophication than in the first case of low nutrient additions.

The purpose of the above approximate calculations was to assure us that we are much more concerned with the former case than the latter. In fact there is no evidence at present in the historical plankton data that Saanich Inlet develops abnormal plankton blooms outside of the seasonal succession of diatoms and flagellates (Drinnan et al., 1995; Hobson in Calder and Mann, 1995). Our modelling of the effect of nutrient additions has therefore been concerned with low level enrichment, such as might come from a small community outfall into an embayment having an area of about l km^2.

9.3.2 Natural Conditions

In an initial series of predictions, the model was run for six different months of the year to examine the background effect of seasonal changes in parameters with no anthropogenic nutrient additions. Figure 9-2 provides a summary of the model results for the months of January, March, April, June, September and December. In all cases model forcing and starting conditions used were representative of the ambient nutrient, light and physical conditions for each month. In January, Chlorophyll *a* did not exceed about 1 mg/m^3 and that the macrozooplankton remained virtually constant. In March, there was a diatom bloom of about 5 mg/m^3 Chlorophyll *a* and a phytoflagellate bloom of about 2 mg Chlorophyll *a*/m^3 which was still increasing after 20 days; as silicate decreased the diatom growth slowed and was gradually replaced by phytoflagellates. Macrozooplankton increased steadily during this period in response to the phytoplankton growth. In April, there was a more rapid growth of both diatoms and then phytoflagellates and the total maximum Chlorophyll *a* value is about 10 mg/m^3. In June, Chlorophyll *a* values were generally less than about 2 mg/m^3; there was little macrozooplankton growth but some bacterial and microzooplankton growth. In September, a second phytoplankton bloom occurred and there was significant growth of macrozooplankton but less than in March. The results for December were similar to those of January.

Comparing the above results with those summarized in the Water Use Report (Drinnan et al., 1995) and with results from field experiments in the 1970s (Takahashi et al., 1982), the following observations can be made:

- The seasonal trend from high spring to low summer and a second fall peak in phytoplankton and zooplankton were consistent with the Water Use Report and maximum and minimum values of chlorophyll a (<1 to 10 mg/m^3) fell within the seasonal range provided in the historical data report.
- The growth of phytoplankton over 4 to 5 days in the spring (April) was consistent with the effect of nutrient additions to enclosures (Takahashi et al., 1982).
- In spite of these general observations, the model did not include tidal intrusions of nutrient and phytoplankton rich water and for this reason the model results were more typical of areas in the centre and southern parts of the inlet and less typical of areas such as Deep Cove.
- In spite of the more rapid growth of diatoms, the model did not strongly reproduce the observed persistent dominance of diatoms in the phytoplankton throughout the spring.

One reason for this latter observation is that the observed diatom dominance may be an artifact of their generally large size, giving rise to a perceived dominance. A possible reason is that the emergence of diatom dominance is strongly dependent on the Carbon:Silicon ratio; this is held constant in the model. This ratio has been poorly studied *in situ* and so there are few guidelines on how it might be changed. In any event, the total production of phytoplankton appears to be a lot more important in this analysis than the ratio of diatoms to flagellates.

9.3.3 Discharge at Different Depths

In order to predict the effects of a discharge at different depths, a discharge of 5000 m^3/day was added during the month of June (lowest nutrients). The depth of the pipe was varied from 5, 15, 30 to 50 m and all other model parameters were not altered. It was assumed that the vertically distributed outfall plume became uniformly distributed over an area of 1 km^2, representative of one of the smaller embayments (e.g. Coles Bay).

The results of the model simulation have been summarized in Figure 9-3. The results indicate that a strong response of phytoplankton blooms and heterotrophic activity (bacteria and microzooplankton) occurs when the pipe was located at 5 m and that this was also reflected in an increase in zooplankton. When the pipe was lowered to 15 m, there was a similar response. At 30 m the algal and macrozooplankton did not increase as much but the heterotrophic activity was still very strong. At 50 m depth discharge, the results indicated that the first 10 m of water were very similar to events shown for June with no discharge.

The results indicate that in a hypothetical case of a 5000 m^3/day discharge, an embayment of about 1 km^2 could receive this discharge of nitrogen without causing any significant disruption of the near surface pelagic ecology, based only on the plankton community, if the outfall was located at 50 m. It is important that this finding be put in context with other potential impacts of wastewater discharge (Section 9.1).

In the above simulations, the effluent temperature was maintained at 10 °C. In additional simulations the temperature of the effluent was increased to 15 and 20 °C. This did not produce any effect on the results. This result would be different if discharge was being made into fresh water where temperature controls stratification. In the sea, however, salinity controls stratification in coastal areas (e.g. it takes approximately a 7 °C change in temperature to cause a density change equivalent to one part per thousand of salinity).

9.3.4 Changing the Month in Which Nutrient is Discharged

In the previous simulations, the month of June was chosen to illustrate the maximum effect of nutrient additions because it is generally the month of lowest natural nutrients. July and August are also months when nutrients are lower than normal. Simulations were run for these months and while the natural productivity of the water column differs in June, July and August, there was very little or no added effect of discharge at 50 m of 5000 m^3/day. In the winter month of January when primary productivity is severely light limited, an added discharge of this size and depth also had little effect.

9.3.5 The Effect of Wind

Simulations were performed to predict the effects of increasing the wind speed from 0 to 10 m/sec during January (for a discharge of 5000 m^3/day at 50 m). Wind speed is important because increased speed gives greater diffusity to the water column. The model results indicate that an increase in wind velocity from 0 to 3 m/sec has little effect on standing stocks. However, an increase in wind speed to 10 m/sec caused an small increase in the standing stocks of phytoflagellates in the second half of the 20 day period and this is accompanied by a small increase in microzooplankton.

These simulations assumed that cloud cover existed. A single simulation was also performed (assuming a wind speed of 3 m/sec) to determine if removing the cloud cover would significantly affect the results. Removing the cloud cover had little effect on the system response.

9.3.6 The Effect of Decreasing Nutrient Discharge Area

Decreasing the discharge area from 1 km^2 (10^6 m^2) to 10^5 m^2 (for a 5000 m^3/day discharge in June) had little effect on phytoplankton standing stocks.

9.3.7 The Effect of Increasing the Nutrient Discharge

Simulations were performed to predict the effects of increasing the effluent discharge at a depth of 50 m from 7000 to 9000 m^3/day for the month of June. The results of these simulations are summarized in Figure 9-4. The results predict that a 1 km^2 area will tolerate a 5000 m^3/day discharge but that the plankton ecology responds rapidly to quantities above this level.

If the 9000 m^3/day discharge was located at 75 m instead of 50 m, the effects of the higher discharge rate were removed. Since the maximum depth at which an outfall pipe can be located without entraining anoxic water is not known precisely, the above simulation was also run with an outfall pipe at 65 m; this predicted the same result as locating the pipe at 75 m.

9.3.8 The Effect of Surface Nutrients

In the previous simulations it was assumed that nutrients entered the embayment in a pipe as part of an outfall system. In this simulation, consideration was given to a surface runoff of nutrients in June. For the purpose of this simulation, the quantity of nutrients available in the water column during April were added to the water column in June. The results show that this causes large blooms of phytoplankton in the first 10 m as well as changes in other parameters compared with the natural sequence of events in June.

Another way to simulate this effect was to add small volumes of effluent to the euphotic zone during June. Simulations were performed to determine the effect of adding 2000, 500 and 100 m^3/day of effluent at 10 m. An effluent discharge of 2000 m^3/day predicted a phytoplankton bloom and large changes in the zooplankton and bacterial communities; 500 and 100 m^3 both cause changes but these are largely by increasing the bacteria, microzooplankton and macrozooplankton. The heterotrophic cycle in the presence of sufficient organic carbon can dominate in warm waters over the autotrophic cycle of phytoplankton and this appears to be happening when small quantities of effluent are released into the surface layers during June.

9.3.9 Changes in Near Surface Properties Below 10 m

All of the previous simulations reported changes in the near surface (average for 10 m) properties of the plankton community. Below this depth there can be changes caused by the release of effluent that does not reach the surface. In order to examine this effect, changes in the water column were averaged for the 15 to 20 m depth interval (instead of 0 to 10 m). The results indicate that a small amount of photosynthesis in this light restricted, but nutrient rich, domain causes a continual increase in the macrozooplankton. When effluent released at 50 m comes up to 18 m (i.e., below the depth monitored in earlier simulations), there were substantial changes in the bacterial, microzooplankton and detritus communities that were not apparent at shallower depths.

The system can tolerate these changes provided there is some flushing rate associated with these layers. Minimum summer flushing rates that are quoted elsewhere in this report are in the region of 2 to 3 m^3/sec for small bays such as Mill Bay and Brentwood Bay. This rate of flushing is about 50 times greater than the rate at which effluent is being released (i.e., 5000 m^3/day) and are expected to be sufficient to prevent any build up in heterotrophic activity. This would require site-specific verification.

9.3.10 Changes in the Extinction Coefficient of the Waters

The extinction coefficient measures the clarity of seawater and it may be altered by natural events (e.g., sediment from rivers) or from unnatural events (e.g., dredging or shoreline construction). The effect of such activities are seen best during a period of the year when nutrients are plentiful but the system is limited by light. To examine this effect, the extinction coefficient was increased from k=0.2 to k=0.4 for the month of April (assuming no discharge).

Under conditions of no cloud cover, the natural results in April were to produce large blooms of phytoplankton. However, by altering the transparency of the water (e.g., with a load of silt) the phytoplankton blooms were greatly suppressed.

9.3.11 Changes in the Near Surface Ecology with Nutrient Discharge at Depth During the Spring Months

Discharge of surface effluent has its greatest effect during the summer months because nutrients are limiting in this period. During the spring months, nutrients are not limiting and productivity is controlled more by the availability of light. On the other hand, the water column is less stable which will allow a discharge at 50 m to penetrate further into the near surface waters, than in the summer months.

To address this issue, simulations were performed whereby 5000 m^3/day of effluent was discharged at 50 and 65 m in March, and at 65 m in April. Discharge of effluent at 50 m (in March) caused no change in the phytoplankton bloom but there was much higher bacterial activity in the first 10 m of the water column. This was accompanied by an increase in microzooplankton. These two effects were largely removed by releasing the same amount of effluent at 65 m instead of 50 m. Release of effluent at 65 m during April did not change the general pattern of phytoplankton production but there was a noticeable increase in the near surface bacterial populations and microzooplankton. From an ecological point of view this change would not seem to be highly significant and may even help the spring productivity of the inlet. However, it says nothing about the pathological properties of the plume reaching the near surface layers of the inlet (Section 8).

9.3.12 Changes in Oxygen

In earlier simulations, changes in the level of oxygen in the first 10 m have been recorded. Oxygen in the inlet has a seasonal cycle being highest in May (ca. 14 g/m^3) and lowest in November (ca. 8 g/m^3). This seasonal cycle was large compared to the fluctuations resulting from the different perturbations. This is because oxygen is present in a large excess (g/m^3) relative to the nutrient changes examined in this text (mg/m^3). Thus changes in surface oxygen values are not seen as a problem from this analysis.

9.4 Discussion

With regard to the total assimilative capacity of Saanich Inlet for nutrients (as opposed to the problem of embayments as discussed above) a very approximate estimate was made based on the prediction that 1 km^2 could tolerate the nutrients from a 5000 m^3/day outfall (assuming no sewage treatment), if the outfall pipe is located below 50 m. The estimate would differ depending on the characteristics of the effluent (i.e., nutrient levels) which could differ from what was assumed in this study. Discharge characteristics are dependent on the population size, level and type of industrial activity, water use patterns, and the type of wastewater treatment used. This nutrient model does not address the possibility of (1) effluent surfacing due to conditions of upwelling, winds or unusual oceanographic conditions and (2) the possibility of a plume impinging on the shoreline during times of shoreward surface currents, and thereby bringing effluent to the surface. These aspects would need to be examined to fully evaluate any discharge permit.

The total area of Saanich Inlet waters is 70 km^2; however the area of water which is suitable for effluent discharges is topographically limited to much less. The area falls between 50 m and about 65 m, since below the latter depth a wastewater plume may upwell naturally anoxic water from the inlet. The area of inlet that falls between these two depths is less than 10% of the total area. Taking a maximum value of 10% and a minimum value of 5%, the approximate nutrient assimilative capacity of the inlet for outfall discharges might range from (70 km^2 x {0.10 or 0.05} x 5000 m^3/day per km^2) equals 17,500 to 35,000 m^3/day. This calculation does not account for the flushing rate of the inlet which is estimated in Chapter 6, consequently this assimilative capacity estimate is a worst-case estimate. This estimate only addresses nutrients (i.e., nitrogen) and it is important that these results be viewed in the context of all the potential impacts of wastewater discharge (Section 9.1).

9.5 Model Certainty

This section is largely a predictive exercise, to evaluate scenarios that do not presently occur in Saanich Inlet. Therefore, it was not possible to verify by direct measurement whether the model accurately predicts the effects of low level enrichment on phytoplankton productivity in the inlet. However considering that data used in development of the nutrient model applied in the Saanich Inlet Study is well developed, it is reasonable to assume that confidence in model predictions is moderately high. Field-scale experiments were conducted in Saanich Inlet in the 1970s under the CEPEX program (summarized in Parsons, 1990). Nutrient additions were made to large enclosures to look at the impact to aquatic communities in the water column. Similar calculations have also been used successfully in fresh water environments, providing the basis for the sockeye salmon enhancement program of Department of Fisheries and Oceans, where lakes are fertilized to enhance productivity (LeBrasseur et al., 1979). The biological parameters for phytoplankton and bacteria are similar to those used in the MULES model, which has been the subject of many publications (e.g., Parsons and Kessler, 1987).

Consistent with the precautionary priniciple, generally worst-case assumptions (Section 9.3.2) have been used. The model assumes that horizontal exchange does not occur between the embayment and the rest of the inlet. Horizontal exchange of nutrients out of the embayment would tend to reduce concentrations of nutrients in embayment waters. Thus, the "flushing" effect would reduce the impact of discharges. Although, water exchange in some of the embayments is low, it is nevertheless significant. Estimated residence times of water in various portions of the inlet are provided in Table 5-4. The assumption that untreated sewage is discharged into the inlet is also worst case. Untreated sewage generally has much higher nitrogen levels than secondary or tertiary treated sewage since the treatment process removes a large proportion of the nutrients associated with the effluent.

The model calculations are also independent of any other models developed as part of this study. Therefore, any uncertainty in other models is not added to the uncertainty associated with this model.

Figure 9-1 A model of Saanich Inlet water column.

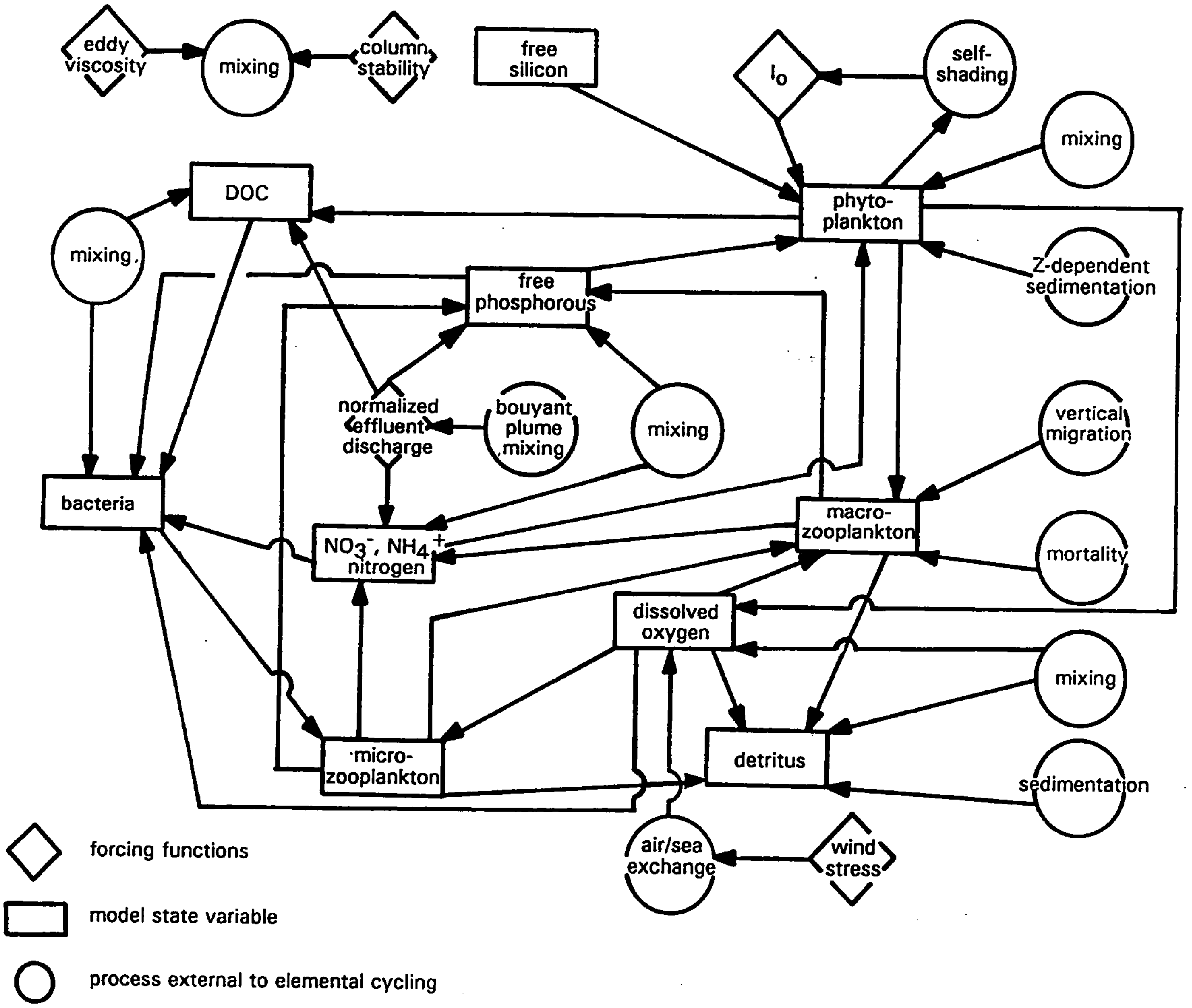


Figure 9-2 Summary of seasonal cycle of phytoplankton and zooplankton biomass and primary productivity.

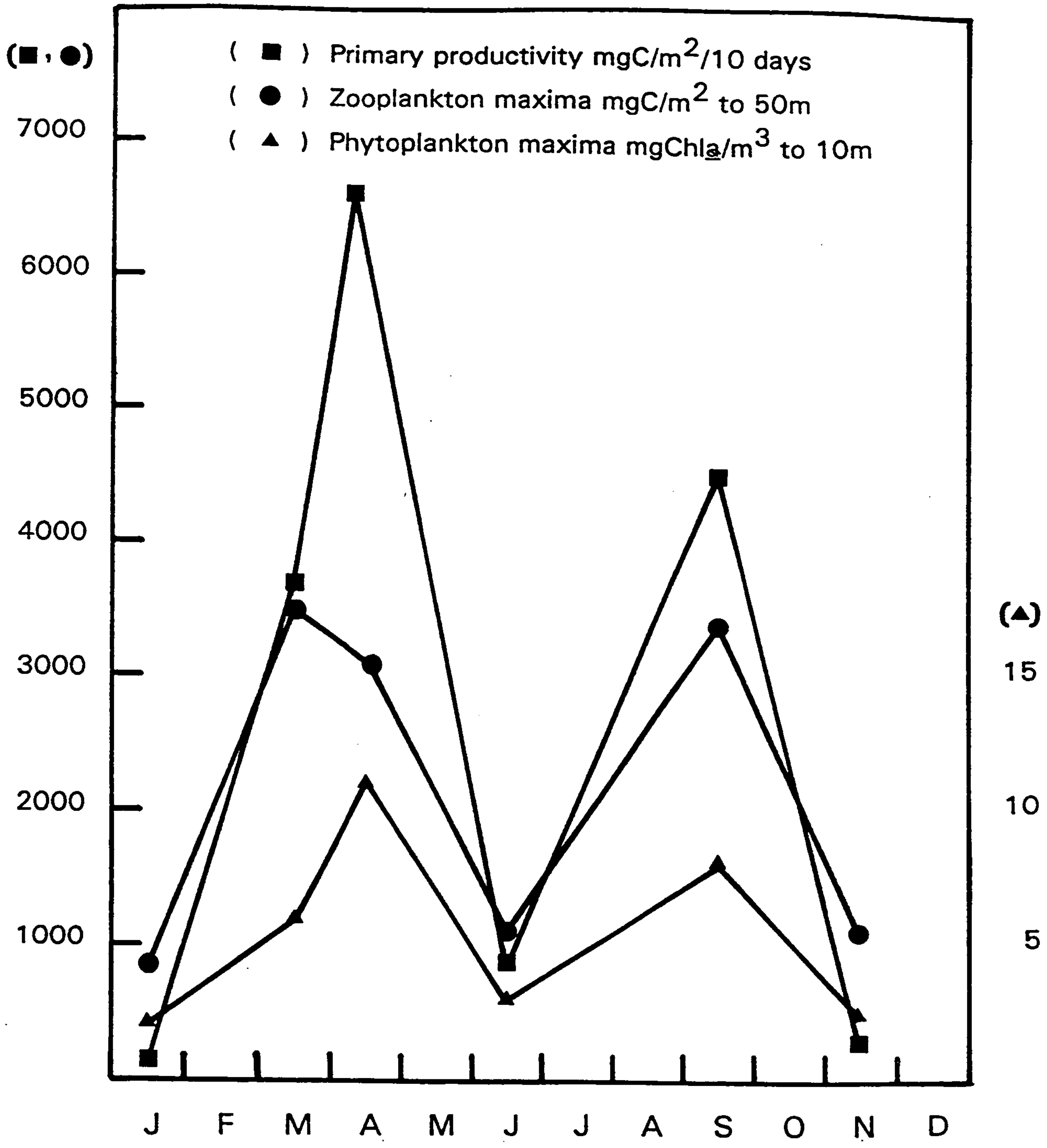


Figure 9-3 **Summary of primary productivity and maximum zooplankton standing stock for different depths of discharge.**

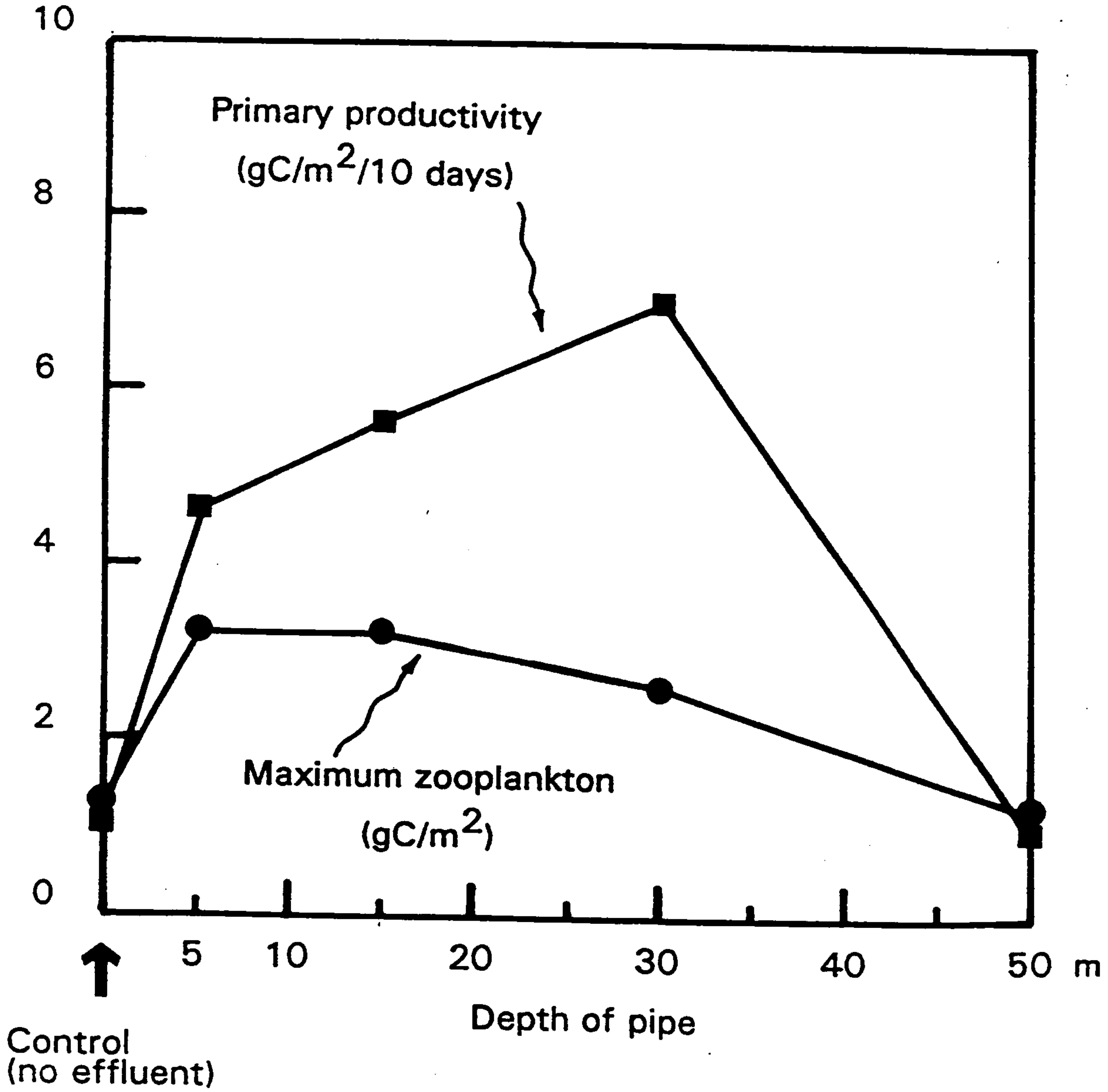
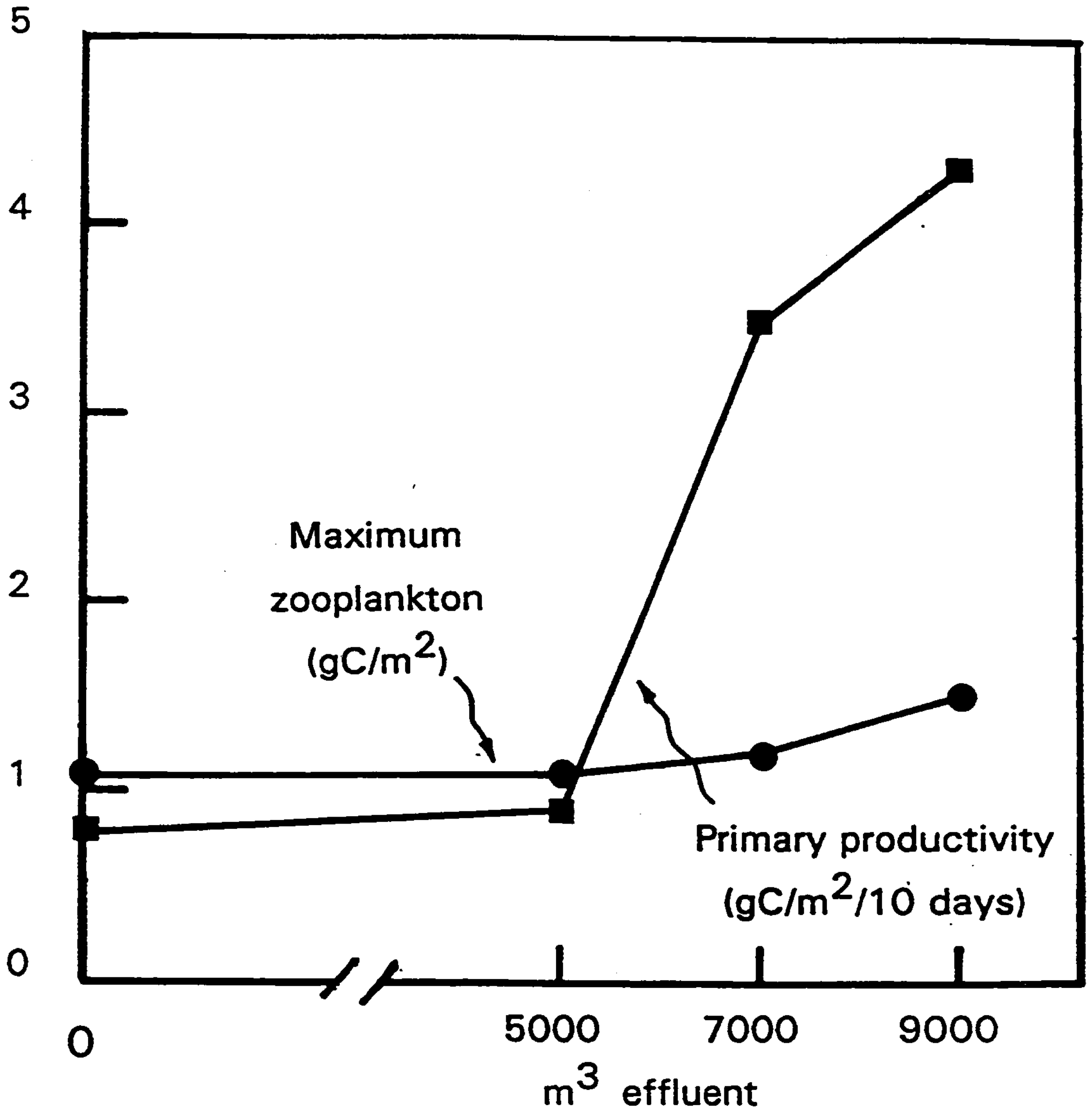


Figure 9-4 Summary of increasing the volume of effluent from 0 to 9000 m^3 showing changes in primary production, and zooplankton.



10. MARINE LIFE

10.1 Introduction

There is perhaps no better indicator of the ability of Saanich Inlet to assimilate contaminants and marine habitat disturbances than the health of its marine life. This point has not been missed by the general public, as demonstrated by respondents cited in the *Saanich Inlet Study: Open House Report* (Howie, 1995) listing marine life as one of the inlet's characteristics most sensitive to the effects of urbanization. A valued ecosystem component (VEC) approach was used in this section to determine the sensitivities of key marine ecosystem components to anthropogenic stressors. The selection of organisms or habitats as valued ecosystem components (VECs) was based on their ecological, economic or social importance to Saanich Inlet. There is much concern regarding the potential impacts of urbanization on marine life used directly as "resources" in Saanich Inlet, and consequently, many of the VECs are fishery related (e.g., salmon, prawns, clams). Recognizing the importance of other organisms and habitats to the marine ecosystem in the inlet, several non-fishery VECs were also included in this assessment (e.g., glass sponges, eelgrass habitat, marine birds). While certain rare or unique species may have been excluded for consideration due to lack of information, the biota addressed in this section cover a wide ecological range. Details of this approach are presented in Section 10.2.

Humans have relied on the inlet's marine life for millennia. First Nations usage of the inlet's fishery resources extends back approximately 5000 to 6000 years (Simonsen et al., 1995). The Straits Salish and Halkomelem generally occupied the Saanich Peninsula area during the winter months and pursued subsistence fishery activities. The arrival of Europeans, creation of boundaries between Canada and the U.S., and the establishment of Indian Reserves drastically altered traditional First Nations fishery resource usage in Saanich Inlet.

In 1912, the inlet was declared a recreational fishing reserve by the British Columbia government and the Federal Department of Fisheries (Victoria Daily Colonist, June 11, 1912, as cited in Drinnan et al., 1995). In the 1930s this declaration was amended to permit the commercial harvest of shellfish, primarily clams, as this was a major source of income for local native communities (Gilbert, pers. comm. 1995). The declaration was further amended in the 1940s to allow commercial long-line fishing of dogfish. Today, the inlet's geoduck/horseclam, crab, prawn, goose barnacle, sea cucumber, sea urchin, octopus, dogfish, and halibut resources are open to commercial harvest (Drinnan et al., 1995); however, actual harvesting is generally limited to prawns, crab, clams, octopus, and dogfish. Recreational harvesting of the inlet's resources presently focus on salmon, ground fish, crab, prawns, and clams (Howie, 1995).

10.2 Approach

The Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop (Calder and Mann, 1995) described a common vision of the inlet, with the following principles:

- No further degradation to marine life; no further loss of habitat.
- The inlet's natural systems should be rehabilitated.
- Utilize marine resources in a sustainable manner; where this in not currently possible, resource use should be stopped altogether until resource levels rise to sustainable levels.
- Humans within the inlet must co-exist.
- Employ the precautionary principle (i.e., err towards conservatism in the face of uncertainty).

These guiding principles have been adopted for this assessment of marine life in Saanich Inlet. Accordingly, assimilative capacity is defined as the point beyond which population decline or habitat degradation occurs.

The VEC (or biota) approach consisted of the following:

- Assessment of the current status and historical trends of VEC.
- Identification of stressors to which VECs are most sensitive.
- Recommendation of protective or remedial measures where appropriate.

The VEC assessments were based primarily on information provided in the component reports of the Saanich Inlet Study (Drinnan et al., 1995; Simonsen et al., 1995; Howie, 1995; Calder and Mann, 1995; Austin et al., 1996).

When interpreting the status and trends of marine life within Saanich Inlet it is important to consider the present and historical health of these resources throughout the Strait of Georgia, as the former and the latter are linked in many cases. Thorough assessment of the status of marine life in the Strait of Georgia was beyond the scope of the Saanich Inlet Study, however, where possible this information was included from other sources. Depressed resource abundance within Saanich Inlet may be related to factors affecting that resource throughout the Strait of Georgia, and not due to any problems specific to the inlet. However, the occurrence of broad-scale resource reductions in the Strait of Georgia does not necessarily mean that remedial actions taken within the inlet will not be of some benefit. It is important, therefore, to determine the factors likely responsible for inlet-scale and broader-scale reductions in fisheries resources, and develop remedial strategies for those within-inlet factors that are likely to significantly affect resource health.

For those VECs directly harvested by humans, the very nature of being a "fishery resource" implies that the resource must not only be able to naturally sustain itself, but also be resilient enough to support the added drain on the population caused by harvesting. A population may be defined as sustainable when it does not show a consistent tendency to decrease (under harvesting if applicable to VEC). The objective of this study was to predict the degree of contaminant loading and habitat disturbances that Saanich Inlet could withstand without incurring environmental degradation (i.e., reductions in abundance in the case of fisheries). For fisheries resources, harvesting itself is an anthropogenic disturbance and must also be considered when examining "How much is too much?"

The major stressors considered in this assessment were:

- Chemical contamination.
- Habitat disturbance.
- Harvesting pressure.
- Sedimentation.
- Enhancement interactions (where appropriate).
- Nutrient enrichment.

While this assessment focuses primarily on the direct effects of these stressors, it is important to recognize that indirect effects may also occur. Of particular significance would be stressor-related reductions in food supply. In addition, addressing the potential effects of global environmental phenomena (e.g., climate change and ozone depletion) was not included in the objectives of the Saanich Inlet Study. These phenomena, however, could result in significant direct impacts to marine life and exacerbate the impacts of the stressors considered herein.

In natural ecosystems, specific shifts often occur in response to changing conditions (e.g., temperature, food supply, predation). It is difficult to assess why certain species are no longer observed in the inlet (or are observed less frequently). Gilbert (pers. comm. 1995) has noted that the following species are presently rare or no longer occur in Saanich Inlet:

- Petrale sole
- Anchovy
- Pilchard (Pacific sardine)
- Salmon shark
- Basking shark
- Yellow-fin seabass
- Pacific hake

While this listing is not intended as an exhaustive accounting of all such species, it does demonstrate the changing nature of the inlet. While the causes of these species shifts may be related to human activity or global processes, they could also be due to complex natural cycles in the marine environment of which we know little.

10.3 Uncertainty and Limitations

The intent of the Marine Life section is to synthesize available information (quantitative and qualitative) regarding the status of each type of biota and their sensitivity to anthropogenic stressors in Saanich Inlet. The utility of this evaluation is not only to find out what VECs may need immediate attention, but also to identify what stressors are likely to have the strongest influence on the biota. This information can then be used to set priorities for protective or remedial actions.

While Saanich Inlet is one of the most-studied marine systems in British Columbia, it was not possible to complete the assessment of biota without relying on anecdotal evidence and scientific judgement. This should not be considered a drawback, however, since quantitative data are only one piece of the puzzle. Much of the so-called anecdotal evidence has been provided by people who, though not classically trained as scientists, are first-rate naturalists with decades of experience in the inlet. Where uncertainty regarding VEC status or sensitivity to stressors is high, this has been accounted for by the provision of conservative recommendations for their protection and/or remediation.

10.4 Salmon

10.4.1 Status

Salmon are perhaps the most important fishery resource in Saanich Inlet. Simonsen et al. (1995) report that salmon are associated with 12 Saanich Inlet place names and that salmon is one of the culturally and nutritionally significant foods amongst the inlet Nations (Simonsen et al., 1995). Furthermore, Open House results indicate that salmon were the most sought-after of the inlet's recreational fisheries resources (approximately 2300 fishing days/year) (Howie, 1995).

There are currently two primary components to the Saanich Inlet salmon fishery:

- A chinook and coho year-round hook and line recreational fishery based largely on non-local stocks.
- A First Nations chum net fishery at Goldstream River (i.e., based on local stocks).

Temporal trends in salmon abundance in Saanich Inlet were assessed by Drinnan et al. (1995) using recreational fishery catch data (coho and chinook; available since 1969) and escapement rates for Goldstream River and Shawnigan Creek (available since 1953). The results of their investigation are summarized below.

Chinook/coho recreational fishery: Recreational catch trends over the past 25 years clearly indicate a decreasing trend in both coho and chinook salmon in Saanich Inlet. Once the primary component of the recreation fishery in the inlet, coho catches (absolute and catch per unit effort [CPUE]) dropped markedly in the early 1970s and have continued to decline into the 1990s (Figure 10-1 and Figure 10-2). Chinook catch (absolute and CPUE) increased in the 1970s then decreased sharply through the 1980s and 1990s. Notwithstanding this latter downturn in catch, chinook have surpassed coho in importance in the Saanich Inlet recreational salmon fishery. Regardless of their relative importance, it is evident that both coho and chinook abundance in the inlet have decreased over the past few decades.

The Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop reported that Saanich Inlet is home to fish from Sacramento to Alaska (Calder and Mann, 1995). This appears to be generally true for salmon, as tagged fish indicate that the majority of salmon caught in the recreational fishery are not from Saanich Inlet stocks and come from as near as the Cowichan River and as far away as the west coast of Vancouver Island, Oregon, and Johnstone Strait (Kadowaki, pers. comm. 1996). Drinnan et al. (1995) report that chinook and coho originating from many British Columbia and Washington/Oregon stocks used Saanich Inlet historically, and that these fish supported the sport fishery in the 1970s and early 1980s. These fish likely used the inlet to take advantage of the local food supply (e.g., herring and euphausiids). Reductions in the available food supply may be a contributing factor.

Although recreational catch data do not show a major decrease in coho salmon catch in the Strait of Georgia (Figure 10-1 and Figure 10-2), a recent assessment of these stocks indicates that spawning escapement, juvenile densities and marine survival rates are low and exploitation rates too high to sustain the resource (PSARC, 1994). Remedial management actions were taken in 1995 to reduce fishery exploitation.

Recreational catch data for chinook salmon in the Strait of Georgia show decreases similar to those found in Saanich Inlet. Both absolute catch and CPUE have steadily decreased since the early 1980s. Based on the recreational catch data, chinook populations do not appear to be sustainable in the Strait of Georgia.

Chinook and coho abundance in Saanich Inlet has been decreasing over the last few decades. Chinook and coho abundance in the Strait of Georgia also appear to be decreasing. The exact cause of these declines in Saanich Inlet is not clear, the status of these fish in the Strait of Georgia suggests that it may be a broad-scale phenomenon (e.g., oceanographic changes). Another possibility could be the reduction of food supply within Saanich Inlet.

Local spawning stocks: There is little direct information on the status of local anadromous salmonid populations and spawning habitats for the majority of tributaries within Saanich Inlet. This section uses information reported in Drinnan et al. (1995), Calder and Mann (1995), Simonsen et al. (1995) and DFO (1988) to piece together the present state of knowledge on a stream by stream basis. The objective of this section was not to conduct a comprehensive watershed management plan or fisheries assessment for each creek, but rather to make a first attempt at compiling available information to identify data gaps and make some recommendations on remedial or protective measures for each tributary. Note that human intervention has affected all runs of local anadromous salmonids. Not all interventions have been negative, but the end result is that some runs have been created, while others have disappeared.

Due to the generally steep terrain surrounding the inlet, anadromous spawning habitat is limited. Falls or steep slopes near the mouths of many tributaries greatly restrict anadromous salmon spawning potential. Consequently, the condition of these limited habitats is critical to the survival of natural runs.

The present status of salmonid populations in each tributary was determined qualitatively from available data (Table 10-1). The only run in Saanich Inlet that is presently considered "healthy" (i.e., high enough returns to naturally sustain the stock) is Goldstream chum; this run has responded positively to habitat enhancement efforts in Goldstream. The river's existing spawning redds can accommodate approximately 15,000 to 20,000 spawning chum salmon. Since 1978, the number of returning spawners has been generally increasing, and concern about the adverse effects of overspawning existing redds led to the initiation of a First Nations' seine fishery for surplus chum. Since 1990, this fishery has operated under the Aboriginal Fishing Strategy, and has landed 140,000 (1995) to 70,000 fish annually.

The coho runs in Goldstream and Shawnigan Creek are presently listed as good, but not self-sustaining due to insufficient rearing habitat (Kadowaki, pers. comm. 1996). The change from fry release to smolt release for hatchery-bred coho in Goldstream in 1991 appears to have had a positive effect on returns (approximately 3000 coho in 1994; 1995 results estimated at approximately 2000; Peers, pers. comm. as cited in Drinnan et al., 1995). However, it is still too early to tell whether recent returns are solely attributable to the change in coho rearing at the hatchery. The status of all other runs in the inlet is either poor, unknown, or believed extinct (Table 10-1).

A stream by stream breakdown of spawning habitat is provided in DFO (1988) for most salmonid tributaries.

10.4.2 Sensitivity to Stressors

Identifying the potential factors contributing to the decline of anadromous salmonid populations is the first step in trying to determine whether remedial activities within Saanich Inlet will help populations recover. A summary of the relative sensitivity of salmonids to anthropogenic stressors is presented in Table 10-2.

Chemical Contamination

The extent and magnitude of chemical contamination within Saanich Inlet are described in Section 7. Studies in Puget Sound have linked exposure to toxic substances to deleterious biological affects in juvenile salmonids (Casillas et al., 1993; Varanasi et al., 1993); therefore, possible exposure of salmon to contaminants cannot be overlooked. Although the majority of Saanich Inlet does not contain contaminants at levels of concern, the limited data available indicate that a few areas exist where concentrations might be of concern to salmonids. The sediment contaminant data were generated in a survey that focused on the estuaries of streams (Drinnan et al., 1995). While these habitats only take up a small portion of the inlet, they are vital to salmon rearing.

At present, there is no information that indicates that the limited chemical habitat degradation in Saanich Inlet is impacting salmonids. As salmon are water column fish (as opposed to bottom dwellers) and migratory, the potential for their exposure to sediment-bound contaminants is relatively low. The vulnerability of spawning and marine rearing habitats to contaminant-related degradation, however, warrants careful monitoring of contaminant inputs to these areas. For example, sediment contamination could possibly be a contributing factor to the apparent loss of eelgrass beds in Tod Inlet.

Habitat Disturbance

Schmitt et al. (1994) state that habitat loss is the most significant factor affecting the health of salmonid populations in the Georgia Basin. For salmonids in Saanich Inlet, physical habitat degradation can be broadly categorized into fresh water/estuarine and marine, with each type of degradation affecting different life history stages.

Degradation of fresh water/estuarine habitats can affect salmonid spawning and early life history. There have been many reviews of the effects of poor land use practices on salmonids and their habitats (e.g., Meehan and Bjornn, 1991; Bisson et al., 1992). These practices (e.g., clearing of riparian canopy, deforestation, fresh water diversions, road building) may cause any of the following effects:

- Stress to salmon embryos and fish through increased variation in seasonal and diurnal water temperature
- Loss of spawning habitat (i.e., redds) and smothering of salmon embryos through increased sedimentation

- Stress to spawning adults and embryos through extreme flow alterations (e.g., reduced flows due to diversions and flooding due to reduced cover)

The relative success of habitat restoration efforts in Goldstream River (i.e., improved chum run) indirectly indicates the importance of fresh water/estuarine habitat for salmonids spawning in Saanich Inlet. The habitat quality of salmonid-bearing streams/estuaries within the Saanich Inlet watershed is not well documented. Simonsen et al. reported on Tseycum village's efforts in the late 1970s to rehabilitate spawning habitat in local creeks, however, "...fisheries said that there was no use to do this since these streams were also polluted..." (Simonsen et al., 1995, Appendix B, Area 8). Table 10-2 presents available spawning habitat information: habitat is at least partially degraded in many of the creeks in the Saanich Inlet watershed.

While no studies have addressed marine habitat use by salmonids in Saanich Inlet, the quality of non-local marine habitat and food supply are likely reasons that Saanich Inlet has been a rearing ground for grilse and post-smolt salmonids. These habitats generally support important food webs in which salmonids play an integral part. Habitat disturbances that affect any part of these food webs can reduce the abundance of salmonid prey organisms (e.g., herring). Although no studies have addressed temporal changes in marine habitat quality in Saanich Inlet, there is concern that the virtual cessation of herring spawnings in the inlet is habitat related and has resulted in decreased food supply for salmonids (Section 10.6). Nearshore habitat is probably of particular importance for Goldstream chum salmon fry for rearing before leaving the inlet (Levings, pers. comm. 1996).

Harvesting Pressure

Schmitt et al. (1994) listed three major reasons why overfishing of salmonid populations generally occurs:

- General mixed-stock fisheries
- Overfishing wild populations to take full advantage of hatchery populations
- Interception fisheries

The ability of salmonids to sustain fishing pressure can vary among different salmonid stocks. Tagging data indicate that coho and chinook caught in the Saanich Inlet recreational fishery are from a number of different stocks, and therefore would constitute a mixed-stock fishery. Fishing mixed-stocks applies equal fishing pressure to each stock, which may result in the overfishing of stocks that cannot sustain that level of fishing pressure. The degree to which mixed-stock fishing in Saanich Inlet affects individual stocks is not known, however, the Strait of Georgia mixed-stock fishery would likely have a much larger impact.

Simonsen et al. (1995) suggest that changes in the semi-nomadic lifestyle of First Nations around Saanich Inlet may have affected salmon fisheries. Prior to the 1800s, Saanich, Malahat, and Cowichan people would travel to the mainland, where salmon was harvested from the bountiful Fraser River. However, year-round harvesting for subsistence and commercial usage in contemporary times has increased pressure on available resources (Simonsen et al., 1995).

On a related note, another source of fishing pressure to salmonids are marine mammals. Two pinneped species, harbour seals and California sea lions, have increased tremendously in the Strait of Georgia over the last two decades. Prior to 1970 there was a bounty on harbour seals, as they were perceived to be a competitor to the fishing industry. A recent study (Olesiuk, 1993) investigated prey consumption by harbour seals. The study concluded that seals are opportunistic feeders and will take advantage of a wide variety of local food resources. Salmon averaged only four percent of the overall seal diet, however, they comprised up to 20 percent for seals inhabiting estuaries. This has led to some concerns with specific salmon runs, particularly chinook runs in Comox Harbour and Cowichan Bay, and the introduced coho run in Shawnigan Creek. The overall annual consumption of salmon by seals in the Strait of Georgia was estimated to be about 400 metric tonnes, or about 10 to 30 percent of the recreational fishery catch of coho and chinook (Drinnan et al., 1995). With salmonid consumption by sea lions approximately 10-fold less than harbour seals (Schmitt et al., 1994), it is not likely that these two species appear to have a significant impact on the abundance of salmonids in the Strait of Georgia.

Sedimentation

Suspended and deposited fine sediment can adversely affect salmonid spawning and rearing habitat if present in excessive amounts. Affects of suspended sediments on salmonids range from complete avoidance of an area to clogged gills and reduced feeding. Indirect effects (e.g., degradation of spawning redds) of sedimentation are likely to affect salmonid populations long before adults are harmed directly. Reduced food supply, lowered egg and alevin survival, and loss of appropriate spawning habitat are possible effects of deposited sediments. While primary inputs of sediment to Saanich Inlet are from external sources (i.e., sediment comes in over sill), erosional events affecting streams due to heavy rainfall or land use activities may affect spawning habitat on a site-specific basis.

Enhancement Interactions

Hybridization between local and hatchery stocks are thought to reduce local adaptations and may adversely affect the fitness of wild fish stocks. Increased competition and predation related to the release of hatchery-reared salmonids can also impact wild fish stocks. The impacts of these factors on wild stocks within Saanich Inlet are not known.

Nutrient Enrichment

Nutrient enrichment is not generally considered a major stressor to salmonids in marine systems. Species composition changes in response to increased nutrient loadings may ultimately affect salmonids by altering the food-chain, however, information on this issue is lacking. Gross inputs of nutrients could reduce water quality (e.g., dissolved oxygen) to the point where acute effects to salmonids occur, however, present nutrient levels in the inlet are relatively low, making such inputs to the system unlikely.

10.4.3 Recommended Protective or Remedial Measures

The guiding principles put forth by the Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop (Calder and Mann, 1995) stated that no further degradation should occur and that society should work towards returning the inlet to its "natural" state (i.e., the state it was in before human influences). While the latter objective may be difficult to ultimately achieve, it certainly provides clear goal-posts to aim for. This section will provide recommendations for remedial or protective measures which serve as a starting point on the pathway back to a more natural state within Saanich Inlet. The priority should be placed on protective measures to ensure that no further degradation occurs. Once these measures are in place, remedial activities could be conducted to rehabilitate degraded areas. Because both local and non-local salmonids use the inlet, and because their usage of the inlet is quite distinct, specific recommendations will be provided for each group separately.

Non-local Salmonids

The reason for the decline in the coho and chinook recreational fishery (based primarily on non-local stocks) in Saanich Inlet is unclear; therefore, specific recommendations to remedy the situation are not provided. Some of the more plausible explanations, such as the habitat loss in their home streams or fishing pressure outside the inlet, would require solutions that are beyond the scope and mandate of the Saanich Inlet Study. Given the uncertainty of the reasons for the decline, and the possibility that the causes lie outside the inlet, what are the options available to ensure that the inlet offers a healthy ecosystem for those salmonids that do utilize its resources?

The guiding principles offered by the Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop (Calder and Mann, 1995) provide clear direction. The major stressors to salmonids in the inlet are likely habitat disturbance, sedimentation and harvesting pressure. The following specific recommendations afford protection to salmonids from these stressors:

- Land-based activities are the primary cause of habitat disturbance and sedimentation. The Land Development Guidelines for the Protection of Aquatic Habitat (Chilibeck et al., 1992) recommend incorporating undisturbed "leave strips" adjacent to fish habitat. The sensitivity of nearshore habitats should be recognized by the establishment of a Sensitive Habitat Buffer Zone extending a minimum of 100 m (wider if necessary) from the high tide mark and covering areas of the inlet watershed with steep upland slopes. Any development within this area should be required to show that no adverse environmental impacts will occur.
- Current recreational fishing policy for Saanich Inlet should be reevaluated to prevent further decline in non-local stocks using the inlet.
- All marine habitat in Saanich Inlet should be considered sensitive and afforded a high level of protection.

Local Salmonids

Salmonids spawning in the Saanich Inlet watershed are listed in Table 10-1. The most sensitive part of the life cycle of anadromous salmonids centres around reproduction and early development, a period which unfortunately coincides with their closest association to human influence. Specific recommendations of protective or remedial measures for local salmonid stocks must be based on their ecological requirements, particularly during sensitive life history stages (i.e., time spent in fresh water). The general habitat requirements of anadromous salmonids in fresh water are listed below (DFO, 1981):

- **Access** - Spawning and nursery areas of streams must be accessible to adult and juvenile salmonids, respectively. Debris barriers resulting from upland and riparian habitat alterations can delay or prevent access to key instream habitats.

- **Streamflow** - Streams with relatively stable flows (i.e., without extreme freshets or droughts) make the best salmonid streams. Freshet conditions can result in increased turbidity and redd disturbance. Low flow conditions associated with droughts can cause extreme temperatures, expose redds, and reduce habitat availability.

- **Substrate** - Successful spawning requires the presence of stable, clean gravel beds (i.e., redds). Conservative estimates of redd spatial requirements per mating pairs range from 10 to 20 m^2 depending on the species. The optimal size of the gravel ranges from 1 cm to 15 cm in diameter depending on the species. This type of substrate is also the most productive for aquatic insects, a major food source for salmonids in fresh water. Provincial water quality criteria state that no significant induced benthic sediment deposition (particles < 3 mm) is allowed in salmonid spawning areas.

- **Cover** - Stream salmonids require cover in the form of undercut banks, logs, rubble substrate, turbulence, overhanging riparian vegetation and deep pools. Such cover is used by juveniles for feeding stations, food sources, and refuges for escape and over-wintering. Adults use the cover for resting and escape from predators.

- **Temperature** - Young salmon generally prefer water temperatures ranging from 12 to 14 °C. Temperatures above this range are strongly avoided, with lethality occurring at about 24 °C. The higher metabolic rates associated with increased water temperatures require more oxygen, however, warmer water holds less oxygen (see below). The Province currently has several water quality criteria for temperature depending on site-specific conditions (MELP, 1995b).

- **Oxygen** - Salmonids require relatively high dissolved oxygen concentrations in both intragravel and surface waters. Reductions in dissolved oxygen can result in impaired development, swimming and feeding. The provincial water quality criteria for dissolved oxygen for full protection of embryo and larval stages is 11 mg/L in surface water. When less-sensitive life stages are present, the criteria is 8 mg/L for no production impairment (MELP, 1995b).

- **Clarity** - Increased turbidity can reduce primary production resulting in lower abundances of benthic invertebrates, impair juvenile feeding, and physically abrade sensitive gill tissue. Indirect effects of sedimentation include loss of spawning habitat. Provincial water quality criteria state that induced turbidity must be less than 5 NTU for streams with background NTU of 50 or less (MELP, 1995b).

- **Water Quality** - Exposure to water-borne contaminants can lead to adverse effects such as reproductive impairment or even death. The province has water quality criteria for many contaminants (MELP, 1995b).

There is a strong link between the quality of streams and local water and land use practices. Ensuring the ecological requirements of salmonids are met means that the status of each tributary has to be known. Available information was compiled in Section 10.4.1 to summarize the present state of knowledge for each tributary, however, more detailed information is needed to make sound management decisions. For example, the natural hydrology and morphology of some streams may make them poor salmon streams, so efforts to improve salmon productivity may be wasted. Also, there is no sense in expending resources to improve the quality of a tributary if existing land use activities within its watershed will damage the system again.

The following recommendations provide a starting point for the process to improve local salmonid stocks:

- Land-based activities are the primary cause of habitat disturbance and sedimentation. The Land Development Guidelines for the Protection of Aquatic Habitat (Chilibeck et al., 1992) recommend incorporating undisturbed "leave strips" adjacent to fish habitat. The sensitivity of stream/riparian habitats should be recognized by establishing a Sensitive Habitat Buffer Zone extending from the high water mark (e.g., minimum of 50 m) and covering areas of the watershed with steep upland slopes. Any development within this zone should be required to show that no adverse environmental impacts will occur in the stream.

- For regulated streams, streamflows should be stabilized during spawning periods and sensitive developmental stages; every effort should be made to ensure that foreign water (i.e., water from a different watershed) is not used.

- Stream assessments should be conducted to document the current status of each tributary. An evaluation of salmon production potential should be made with an emphasis on the costs and benefits of habitat and stock enhancement activities.

- For streams where enhancement efforts would benefit local stocks, the establishment of Stream Stewardship programs should be encouraged. Public education is an important component of improving salmon instream habitat.

- Any stock enhancement activities should strive to maintain the genetic diversity of the inlet's native stocks.

A short summary of recommendations on a creek by creek basis and for the entire inlet is provided in Table 10-3. Specific recommendations for remedial measures were only possible for the Tod Creek/Tod Inlet area because of data availability.

10.5 Rockfish and Lingcod

10.5.1 Status

The Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop concluded that rockfish and lingcod populations are on the decline in Saanich Inlet (Calder and Mann, 1995). Next to salmon, these fish are the most popular recreational fishery catch (Howie, 1995) and are also been targeted in First Nations fisheries (Simonsen et al., 1995). Recreational fishery catch data since 1983 were the primary source of information for this assessment of rockfish and lingcod resources in Saanich Inlet.

Recreational catch trends over the past 12 years suggest that rockfish populations in Saanich Inlet have been relatively stable (Figure 10-3). It is difficult to make inferences about these data as fishing effort has not been taken into account (i.e., no CPUE data). Due to concerns about declining rockfish stocks in the Strait of Georgia, the daily sportfish possession limit was reduced from 8 fish to 5 fish in 1993. In that year rockfish landings in Saanich Inlet fell to less than 2,000 fish. In 1994 over 8,000 rockfish were landed, possibly due to redirected fishing effort, as very few salmon were caught in Saanich Inlet in 1994. This redirected effort could have serious impacts on quillback and copper rockfish.

Schmitt et al. (1994) state that the condition of inshore rockfish stocks in the Strait of Georgia is poor. Catches increased from a low of 60 tonnes in 1974 to a peak of 688 tonnes in 1986 before stabilizing around 600 tonnes in the late 1980s. Increasingly concern regarding stocks led to progressively restrictive regulations which had limited harvesting to 300 tonnes by 1993. These trends suggest that rockfish stocks may have reached a harvesting pressure threshold in the Strait of Georgia. The situation in the Strait of Georgia should serve as a warning to adopt a conservative management strategy for rockfish in Saanich Inlet.

Rockfish abundance within Saanich Inlet has been relatively stable over the last decade. Rockfish catch in the Strait of Georgia increased throughout the 1980s, however, inshore stock abundances are not considered healthy and annual catch has dropped off since 1990. This serves as a warning that Saanich Inlet rockfish may have reached a threshold in their capacity to assimilate further stress.

In British Columbia the recreational fishery for lingcod has historically been closed from mid-November to mid-March to protect spawning stocks. In the 1980s fisheries managers realized that lingcod stocks in the Strait of Georgia were declining to extremely low levels of abundance (Murie et al. 1994). In 1990 the commercial lingcod fishery in the Strait of Georgia was closed and, in 1991, the sportfish regulations were amended; reducing the daily catch limit from 3 to 1 fish, instituting a minimum size of 65 cm, and reducing the fishing season to four months (June to September). Schmitt et al. (1994) report that annual lingcod catches have decreased from approximately 900 tonnes to less than 50 tonnes in the Strait of Georgia since 1970. Saanich Inlet lingcod catch data also show a continual decreasing trend between 1983 and 1994 (Figure 10-3).

Lingcod abundance in Saanich Inlet appears to have steadily declined over the last decade. This trend follows that found in the Strait of Georgia. The ability of lingcod in Saanich Inlet to assimilate stressors has been surpassed.

10.5.2 Sensitivity to Stressors

The relative sensitivity of rockfish and lingcod to anthropogenic stressors in Saanich Inlet is summarized in Table 10-4. Sensitivities were predicted based on the ecology and biology of these fish.

Rockfish and lingcod inhabit rocky reefs in water depths ranging from a few metres to more than 350 metres (Williams, 1989). In Saanich Inlet, the depth of the anoxic layer would limit the lower end of the depth range (Gilbert, pers. comm. 1995). Prey species for both fish range from large zooplankton to herring and sandlance. Both species share some common life history and ecological features that make them particularly sensitive to harvesting pressure and habitat loss: they are relatively long-lived (up to 90 years for yelloweye rockfish [Williams, 1989]; up to 20 years for lingcod [Williams, 1989]) compared to other harvested species, and they rely heavily on nearshore habitat for sensitive stages (e.g., juvenile rearing) of their lifecycle.

Rockfish and lingcod are voracious predators, which makes them particularly susceptible to fishing pressure. Avoided in the past when salmon were more easily caught, they are now considered popular sportfish. In addition, these fish are likely an important component of by-catch in the long-line dogfish commercial fishery.

Rockfish are also ovoviviparous (i.e., bear live young), a life-history strategy geared towards increasing larval survival. The trade-off of the increased investment of energy spent carrying the eggs until hatching is that fewer offspring are produced. This makes rockfish susceptible to any factors which might decrease larval survival. Degradation of rearing habitat could have significant implications to rockfish populations. While lingcod are not ovoviviparous, they do rely on rocky reef habitat to lay their adhesive eggs. Lingcod nests are likely to be sensitive to stressors such as sedimentation.

10.5.3 Recommended Remedial or Protective Measures

There is little doubt that lingcod have exceeded their ability to assimilate anthropogenic stressors in Saanich Inlet. For rockfish, recent trends in the Strait of Georgia indicate that Saanich Inlet stocks may be at the threshold of their assimilative capacity. Two stressors standout as likely having the most significant influences on these fish: fishing pressure and habitat loss/degradation (Table 10-5). While the relative impacts of these two stressors is not known, fishing pressure is likely to have a greater overall effect. The relative impacts of recreational fishing and commercial catch need to be determined. Available evidence suggests that habitat degradation is limited to certain areas of the inlet; habitat degradation may have significant adverse effects in these areas.

10.6 Herring

10.6.1 Status

Pacific herring (*Clupea harengus pallasi*) spawn in shallow water, depositing their adhesive eggs on marine vegetation and rocky substrates. The Fisheries Workgroup at the Saanich Inlet Study Synthesis Workshop concluded that herring are an important component of the marine ecosystem of Saanich Inlet, serving as the primary food source for salmonids in the inlet when present in large numbers. The First Nations peoples have traditionally relied on herring as a food source, collecting roe and raking fish during mass spawning events (First Nations). Major changes in herring abundance would have profound ecological and cultural effects on Saanich Inlet.

Herring have historically used Saanich Inlet for two purposes: spawning and pre-spawning aggregation. The former involved only Saanich Inlet resident stocks, while the latter involved stocks from all over the southern Strait of Georgia.

Observational herring spawn records in Saanich Inlet span 63 years (1931 to 1994). (Hay et al. 1989, as cited in Drinnan et al., 1995). Herring have historically spawned in three general locations (Figure 10-4):

- Deep Cove and Pat Bay
- Coles Bay, Thompson Cove and Tod Inlet
- Goldstream estuary

Herring are also reported to have spawned historically in Mill Bay (Gilbert, pers. comm. 1995). Spawning has been documented along 35 km of the inlet shoreline, with a cumulative spawn area of 123 ha. The mean spawning date is March 28. Spawning is most frequent and intense in the Goldstream estuary. Eelgrass is the preferred spawning substrate in Saanich Inlet.

Herring spawning events in Saanich Inlet have decreased dramatically in the last quarter-century. There has been only one herring spawn recorded in Saanich Inlet since 1972. From 1931 to 1972, spawning occurred in pulses of six to ten years with, at most, eight years separating pulses. No one can remember a gap between spawning pulses comparable to the 20-year gap observed between 1973 and 1993. Furthermore, only minimal spawning was observed in 1993 and the pulse failed to continue to 1994. A concomitant decline in the abundance of juvenile herring, which serve as a food source for rearing salmonids, has also been observed within the inlet (Gilbert, pers. comm. 1995). Saanich Inlet herring production is not currently sustainable.

There is no evidence to evaluate whether the use of Saanich Inlet as a pre-spawning aggregation area has changed temporally. In January 1991 large numbers of dead herring were reported near Bamberton. Hydroacoustic surveys of the area estimated 1,500 to 2,000 tonnes of herring were in the area at the time, and some 230 tonnes of dead herring were observed by divers. These mortalities were attributed to anoxia or hydrogen sulphide associated with the anoxic layer. A similar episode resulted in large-scale pilchard mortalities in 1941. These events do no appear to be linked to anthropogenic reductions in water quality. The use of Saanich Inlet as a pre-spawning aggregation area appears to be sustainable, although more detailed information is needed to make a proper assessment.

Schmitt et al. (1994) list the current status of the herring population in the Strait of Georgia as "high" (the highest listing among marine fish). From a commercial marine (i.e., non-salmonid) fishery perspective, herring are far and away the mainstay of the industry. Annual herring catch in the strait, while quite variable due to herring's relatively short life span, average approximately ten thousand metric tonnes per year. Recruitment to the Strait of Georgia stocks is less variable than other areas of British Columbia due to the buffering from predation and environmental variation found in the open ocean. Drinnan et al., (1995) report that spawning events have decreased in frequency in the southern Gulf Islands stocks, particularly in the main stock in Ganges Harbour on Salt Spring Island. The causes of the general decline in southern Gulf Island herring stocks have not been identified. In summary, while herring stocks in the Strait of Georgia are considered healthy, the southern Gulf Island stocks have suffered a general decline in the past decade.

Herring have virtually stopped spawning in Saanich Inlet for the last two decades. While herring stocks in the Straight of Georgia are healthy, there has been a general decline in the southern Gulf Islands over the last decade.

10.6.2 Sensitivity to Stressors

There are a variety of anthropogenic stressors that are likely to cause adverse effects to herring. Estimated sensitivity of herring to various anthropogenic stressors is presented in Table 10-6. Its dependence on nearshore vegetation as a spawning substrate make herring particularly vulnerable to degradation or loss of that habitat. Historical trends in British Columbia show that herring are also sensitive to overharvesting; abundance bottomed-out in the late 1960s when high fishing pressure was accompanied by several years of suboptimal oceanographic conditions (Schmitt et al., 1994).

10.6.3 Recommended Remedial or Protective Measures

The cause of the virtual collapse of local Saanich Inlet herring stocks is unclear, therefore it is difficult to suggest remedial or protective measures. While the decline may be linked to more wide-scale population reductions in the southern Gulf Islands, the timing of the events does not appear to support the relationship. There has only been one recorded spawning event of local Saanich Inlet herring stocks since the early 1970s, while spawning continued normally in Ganges Harbour (a major southern Gulf Island spawning site) until the early 1980s. What happened in the late 1960s or early 1970s that could have affected spawning stocks in Saanich

Inlet? Herring stocks in British Columbia have been monitored consistently since about 1950 (Schmitt et al., 1994), and Strait of Georgia stocks were at historically low levels in the late 1960s due to intense fishing pressure and poor recruitment due to adverse climatic conditions. Most stocks recovered in the 1970s as the roe fishery began, but it is possible that Saanich stocks were lost. The spawning event of 1993 in Deep Cove and in Pat Bay does provide some hope that herring spawning will return to Saanich Inlet.

The Fisheries Workgroup from the Saanich Inlet Study Workshop suggested that herring should be designated as a primary management focus due to its importance as an indicator species. It is not clear whether local herrings stocks could ever recover regardless of the state of the inlet, however, there are some ways their chances can be increased if they do (Table 10-7). The dependence of herring on nearshore habitats as spawning grounds warrants providing these habitats the highest level of protection to ensure that no further degradation or loss occurs. This will ensure that adequate spawning habitat is available if herring spawners return to Saanich Inlet.

10.7 Other Fish

10.7.1 Status

Flatfish

Flatfish, primarily rock sole (*Lepidopsetta bileneata*) and English sole (*Parophrys vetulus*), generally inhabit the larger, flat bottomed bays (e.g., Patricia Bay) in Saanich Inlet. There is currently a daily possession limit of eight flatfish (excepting halibut) for the recreational fishery. The creel census data does not summarize the catch of flatfish separately from species such as perch, herring, greenling and hake, therefore the status of flatfish abundance in Saanich Inlet is not known.

Rock sole and English sole are the two primary flatfish caught recreationally in Saanich Inlet. English sole catches in the Strait of Georgia have decreased since the late 1970s and are now relatively stable at 50 tonnes per year. English sole abundance in the strait is listed as average (Schmitt et al., 1994).

The status of flatfish in Saanich Inlet is unknown. Flatfish abundance in the Strait of Georgia is considered average.

Dogfish

Dogfish (*Squalus acanthias*) are commercially fished by longline, an array of baited hooks attached to a length of groundline resting on or near the bottom. In Saanich Inlet this fishery generally takes place at 20 m to 40 m depth (Gilbert, pers. comm. 1995). The fishing effort is limited, only one or two boats set a few longlines each year (Beckman, pers. comm. as cited in Drinnan et al., 1995). The catch statistics complied by DFO do not distinguish landings in Saanich Inlet (Area 19A) from other subareas within Area 19, thus the quantity of dogfish landed from the inlet is unknown. While the fishery targets dogfish, other demersal fish may also be caught. There are no data quantifying by-catch mortality for other fish in Saanich Inlet. This issue needs to be addressed.

The spiny dogfish population is at average to high levels in the Georgia Basin (Schmitt et al., 1994). Estimated biomass was 60,000 tonnes in 1988, while annual harvests average approximately 2500 tonnes. The life-history characteristics (slow growth, long life and low reproduction) warrant careful management of this resource. Based on the above estimates of biomass and annual harvest rates, dogfish abundance in the Georgia Basin is expected to increase over the next decade (Thomson, 1994, as cited in Schmitt et al., 1994). Historical variation in harvest rates (e.g., up to 8000 tonnes in 1979) have resulted from changes in market demand and restrictions imposed on fisheries for other species.

The status of dogfish in Saanich Inlet is unknown. Dogfish abundance in the Strait of Georgia is expected to increase over the next decade. The impacts of commercial long-line fishing on other fish (e.g., lingcod, rockfish and flatfish) is not known.

10.7.2 Sensitivity to Stressors

The estimated sensitivities of flatfish and dogfish to anthropogenic stressors is presented in Table 10-8. Flatfish typically inhabit soft-bottom substrates and feed on benthic invertebrates. This lifestyle makes them particularly vulnerable to chemical contamination; uptake through direct contact and dietary ingestion would be the primary routes of exposure. Dogfish are slow growing, late to mature, have a long gestation period (up to two years) and produce very few young; these characteristics should make it unresilient to fishing pressure.

10.7.3 Recommended Remedial or Protective Measures

Due to the relative scarcity of fisheries data for these fish, it is difficult to make specific recommendations for remedial or protective measures. Remedial measures do not appear warranted at this time. Protective measures should include general habitat protection (from chemical and physical degradation) and closer monitoring of recreational catch for these species (Table 10-9).

10.8 Prawn and Euphausiids

10.8.1 Status

Prawns

The commercial prawn fishery in Saanich Inlet has been in existence since the late 1970s. The fishery was closed in 1985, however, annual commercial catch has ranged from 2500 to 15,000 kg since that time. The management strategy of employing a catch-per-unit-effort-based criteria for closing the fishery on an annual basis appears to have been relatively successful in ensuring that enough mature females escape the fishery. Significant mortality can result from sudden changes in the depth of the anoxic layer (Jamieson, pers. comm. 1996). Based on the fishery results since 1985, the population of prawn in Saanich Inlet appears to be relatively healthy.

Prawn larvae and juveniles may be an important component of the food-chain for fish rearing in the inlet (Gilbert, pers. comm. 1995). Losses of mature females to the fishery may, therefore, result in reductions in food supply for rearing fish. No studies have been conducted to date addressing this possibility.

Prawn abundance in Saanich Inlet is apparently healthy enough to support a fishery, however, the impact of this fishery on the food-chain is not known.

Euphausiids

Euphausiids are small, shrimp-like crustaceans and are an important food source for many fish species (particularly coho salmon). Drinnan et al. (1995) report that euphausiid biomass in Saanich Inlet is approximately 2500 tonnes. With no historical data against which to compare this estimate, no assessment of temporal changes in euphausiid biomass can be made.

Consequently, no conclusions can be made on the relative health of the population. There was an experimental trawl fishery in the late 1970s and early 1980s. Post-spawning adults were harvested (between 2 - 5% of biomass/year); while long-term impacts of the fishery to euphausiid populations were unlikely, the fishery was closed in the early 1980s in recognition of both the historic net fishery closure and concerns regarding reducing the food supply for salmon and other fish (Drinnan et al., 1995). The importance of euphausiids as a food source of many fish species may warrant their inclusion in future monitoring programs.

The status of euphausiids in Saanich Inlet is unknown.

10.8.2 Sensitivity to Stressors

The estimated sensitivity of prawns and euphausiids to anthropogenic stressors is presented in Table 10-10. Prawn spend the first year of their lives in shallow habitat, feeding heavily on amphipods and mysids which are in turn supported by detritus from summer algal blooms. Habitat degradation, sedimentation and chemical contamination would likely be most prevalent during this time. After their first winter, prawn move to considerably deeper water.

Stressors affecting primary and secondary productivity are going to have the greatest impact on euphausiids. Large scale sedimentation may reduce the penetration of light and reduce productivity of euphausiid food supply. Nutrient enrichment may have varying effects depending on the degree of eutrophication. Minor inputs of nutrients may result in increased productivity of euphausiid food supply, however, as nutrient inputs increase, key prey species can be displaced by unpalatable nuisance species. Section 9 discusses the effects of nutrient enrichment on phytoplankton.

10.8.3 Recommended Remedial or Protective Measures

The current status of both prawn and euphausiids populations in Saanich Inlet appears to be healthy. These invertebrates play an important part in the inlet food-chain, therefore ensuring their health should be an integral part of the overall management plan for Saanich Inlet. Prawn populations are "monitored" during the fishery, however, euphausiids have been virtually ignored since the close of the fishery in 1980. Not only should their habitats be protected, but the health of these populations should be directly monitored to ensure their continued health (Table 10-11).

10.9 Crab

10.9.1 Status

Two species of crab are harvested recreationally in Saanich Inlet, the Dungeness crab (*Cancer magister*) and the red rock crab *(Cancer productus)*. Dungeness crab are usually most abundant in sandy habitat, but also occur on mud and gravel bottoms. The recreational crab fishery is open year round, with peak activity during the summer. Gilbert (pers. comm. 1995) reports that some 50 to 60 traps may be fished monthly in the Goldstream area. Red rock crab is more abundant than the more popular Dungeness crab (Gilbert, pers. comm. 1995). The latter, therefore, would likely be more susceptible to population reductions due to fishing pressure. Crab are also an important First Nation resource, particularly near adjacent reserve lands in Pat Bay, Coles Bay and Brentwood Bay.

Crab populations in Saanich Inlet appear to be relatively healthy, although Dungeness crab are generally less abundant.

10.9.2 Sensitivity to Stressors

The estimated sensitivity of crab to anthropogenic stressors is presented in Table 10-12. There does not appear to be a single stressor to which either Dungeness or red rock crab are most sensitive. The adult stage is benthic and opportunistic, while the larval stages are planktonic predators. Stressors may impact each life stage differently; for example, moderate nutrient enrichment may benefit adult crab by increasing their food supply, however, shifts in phytoplankton to nuisance species may adversely affect larval food supply.

Actual crab sensitivity to chemical contamination is estimated as moderate, however, that estimation is from an ecological perspective. While direct exposure to contaminants in the inlet at present concentrations is not likely to result in acute (i.e., lethal) effects, tissue concentrations of bioaccumulative chemicals may be an issue from a human health perspective (note that this may only be likely in localized areas with sediment contamination). No crab tissue chemistry data are available from these areas to address this potential issue.

10.9.3 Recommended Remedial or Protective Measures

The results of the Saanich Inlet Study Open House questionnaires (Howie, 1995) indicate that crab are the most popular non-finfish recreational fishery item in Saanich Inlet. Over 500 person-days are spent fishing for crab each year. Simonsen et al. (1995) documents the cultural importance of crab fishing to the inlet's First Nations. While crab populations appear to be fine, some general protective measures are presented in Table 10-13.

10.10 Clams and Oysters

10.10.1 Status

Manila (*Venerupis japonica*), littleneck (*Protothacea staminea*) and butter (*Saxidomus giganteus*) clams are found on most of the intertidal sand and sand/gravel beaches in Saanich Inlet. These three species, as well as horse clams (*Tresus sp.*) and cockles (*Clinocardium nuttallii*), have traditionally been harvested by the First Nations of Saanich Inlet, and remain an important resource to the native community (Drinnan et al., 1995; Simonsen et al., 1995).

All clam beaches except MacKenzie Bight, Spectacle Creek and Senanus Island (off limits to recreational harvesting as it is located on a reserve) are currently closed to harvest due to fecal coliform contamination (Figure 10-5), although limited harvesting continues at many of the closed beaches (Drinnan et al., 1995).

There is a commercial clam fishery for manila and littleneck clams in Saanich Inlet. Clams are harvested and held in a depuration facility (Coopers Cove Oysters Ltd.) in Sooke prior to distribution. Coopers Cove Oysters has held permits to harvest from beaches at Goldstream, Bamberton and Mill Bay since 1989 (Helgeson, pers. comm. as cited in Drinnan et al., 1995). The permits specify a maximum annual harvest from each beach, based on surveys carried out by Coopers Cove Oysters under direction from the Department of Fisheries and Oceans. There is no available harvest data for recreational or First Nations clam harvest in Saanich Inlet. There is a daily limit of 75 littleneck or manila clams and 25 butter clams in effect for the recreational fishery (DFO 1995 Sportfish Regulations, as cited in Drinnan et al., 1995).

In general Manila, littleneck and butter clam stocks in Saanich Inlet are relatively healthy but utilization of these stocks is severely restricted by fecal coliform closures. Future improvement of water quality and lifting of shellfish closures may put significant stress on stocks. In addition access to smaller beach areas in the inlet is more difficult as a result of residential foreshore development (Sampson pers. comm. as cited in Drinnan et al., 1995). Some residents attempt to restrict public access to foreshore adjacent their properties not realizing that their property rights do not extend beyond the high water mark.

The introduced Pacific oyster (*Crassostrea gigas*) also occurs on many of the intertidal beaches. Towner Bay, just north of Pat Bay, is recognized as an oyster seed area (CRF 1981, Sampson, pers. comm. as cited in Drinnan et al., 1995). There is a relatively small First Nation and recreational harvest of oysters, but there are no oyster leases or commercially productive beds in Saanich Inlet. The native Olympic oyster is no longer found in abundance in the inlet.

Clams and oyster populations in Saanich Inlet appear to be relatively healthy, primarily due to the closure of the majority of harvesting areas due to fecal coliform contamination. The coliforms are not harmful to the shellfish, but are general indicators of sewage-related human pathogens. Introduced species have changed the inlet's shellfish communities; the impacts of this change on other marine life is not known.

10.10.2 Sensitivity to Stressors

The estimated sensitivity of bivalves to anthropogenic stressors is presented in Table 10-14. Clams and oysters are suspension feeding (i.e., filter plankton and detritus from the water) organisms that live in either on or in the bottom substrate. The feeding habits of these animals make them particularly susceptible to chemical contamination. Large volumes of water are filtered daily to obtain sufficient food intake, so clams and oysters are exposed to water-borne contaminants much more than non-suspension feeders. In addition, they often live in the sediment, which means that they are directly exposed to contaminated sediments and pore water. Contaminant concentration in Saanich Inlet, however, are not generally found at levels where adverse effects would be expected to occur (Section 9).

Bacteria (i.e., fecal coliforms) concentrations in Saanich Inlet would also not be expected to cause adverse affects to clams and oysters, however, the potential association of human pathogens with fecal coliforms makes coliform contamination a serious human health issue. At which time the water quality issues are resolved and the beds are reopened to harvesting, stress from habitat disturbance and harvesting pressure will be much more of an issue.

10.10.3 Recommended Remedial or Protective Measures

The Saanich Inlet Study Synthesis Workshop Fisheries Workgroup listed edible (i.e., from a human health perspective) as one of the criteria for nearshore fisheries. The closure of shellfish beds due to high fecal coliform concentrations clearly shows that this criteria is not being met in Saanich Inlet. While not directly damaging to shellfish, fecal coliforms are considered possible indicators of the presence of human pathogens. It was clear at the Saanich Inlet Study Synthesis Workshop that remedial efforts should be directed towards reopening closed shellfish harvesting areas. The source of fecal coliforms to Saanich Inlet is most likely seepage from poorly operating septic fields, or agricultural inputs. Remediation of these fields should receive top priority to prevent further degradation of nearshore water quality and improve shellfish habitat (Table 10-15).

10.11 Intertidal Benthic Communities

10.11.1 Status

Due to the relative scarcity of data on benthic communities in Saanich Inlet, MELP commissioned a survey under the Saanich Inlet Study to identify potentially sensitive benthic species and habitats within the inlet. The intent of the survey was to conduct a reconnaissance-level investigation (i.e., semi-quantitative) broadly covering most areas of the inlet. The survey was divided into three parts:

- Intertidal Communities
- Subtidal Boot and Cloud Sponge Habitats
- Eelgrass Habitat

The intertidal benthic community assessment (described in Section 10.11) was conducted by Dr. Bill Austin from Khoyatan Marine Laboratory. Detailed information on the entire survey is reported in Austin et al. (1996) (Intertidal Benthos - Section 10.11; Subtidal Sponge Habitats - Section 10.12; Eelgrass Habitat - Section 10.13).

The overall status of intertidal benthic communities is that the species diversity in Saanich Inlet is somewhat less than that in more open waters with comparable substrate in more southerly Gulf Islands and significantly less than in more oceanic waters toward Victoria. While quantitative documentation cannot be provided, other researchers concur with this assessment (e.g., Yousef Ebrahim, Univ. Victoria; Jim Cosgrove, Royal B.C. Museum).

Intertidal Rocky Shores

Seventeen rocky shore stations were surveyed. Low species diversity on intertidal rocky shores is generally typical in B.C. fjords such as Howe Sound, Indian Arm and Jervis Inlet (Austin, pers. observation). This may be related, in part, to either increased surface temperature and/or decreased salinity in surface waters associated with limited mixing of surface waters and proximity to large land masses. Druehl (1967) refers to these factors as possible causes of submergence of algal species populations toward the head of Indian Arm. Increased species diversity and population biomass in areas of mixing such as at First and Second Narrows in Burrard Inlet and Skookumchuk Narrows in Sechelt Inlet is in part related to increase food supplies for suspension feeders. It is likely also related to lowered temperatures and/or increased salinities better tolerated by species populations adapted to more oceanic waters.

The results of the survey (Figure 10-7) are briefly summarized below by diversity groups:

High (relative) Diversity

The Bamberton site had the highest species diversity (76 species) among those sites assessed in Saanich Inlet. Also, it visually had the highest biomass of macroalgae in the lower intertidal. Sites both north (Tanner Rock, Verdier Pt., Whisky Pt. Hatch Pt.) and south (McCurdy Pt., Willis Pt., Christmas Pt.) were less diverse.

The next highest species diversity was at Wain Rock (52 species). The location of Wain Rock at the entrance to the fjord and its reef configuration, largely submerged at high tide, would suggest a potentially high diversity based on minimal impacts from temperature stress at a fjord entrance and localized currents around and over rock platforms. Fresh water influence and sedimentation from the Cowichan and Koksilah Rivers might account for the reduced diversity relative to Bamberton.

Moderate Diversity

Sites with intermediate levels of species diversity ranged from Whisky Point, north of Mill Bay to Christmas Point, approximately 2 km from Goldstream Estuary. There is no clear pattern of change in species diversity along the east or west side of Saanich Inlet. This is most likely a reflection of the minimal fresh water input from Goldstream coupled with significant low salinity water intrusions at the entrance to the inlet.

Low Diversity

The lowest species biodiversity was recorded at Coal Point (Station 8) and Tozier Rock (Station 11). However, these figures may not be realistic as these stations were only sampled briefly (10-15 min.) while enroute to other stations and the exposed portion of Tozier Rock is little more than a small flat reef topped by a concrete marker.

Stations 19 and 35 at the elbow point where Tod Inlet turns from N-S to E-W contains the only evident bedrock/boulder area in the inlet. Most of the inlet shoreline is cobble/gravel. It is somewhat more wave protected than Sawluctus Island although the biota may be influenced by small waves from the many boats using the inlet. The diversity here was slightly lower than elsewhere. Notably absent or scarce intertidally were seaweed, sponges, sea anemones, snails, limpets, mussels, tube worms, crab, sea cucumbers, and sea squirts. The absence of seaweed may be due to lack of nutrients related to restricted circulation, and that reduced number of animals may be influenced by desiccation related to a south facing slope. If the apparent impoverished biota is related to anthropogenic impacts, these might also be limited to the surface layer contacting the intertidal region such as concentrated oil. The intertidal sessile species which were moderately abundant (barnacles, orange bryzoan) are those which occur in highly impacted areas such as marinas.

The station on Sawluctus Island (Station 21) is broadly comparable to Tod Inlet in terms of proximity to a fresh water stream. It is somewhat more exposed to wind generated waves than the elbow point station in Tod Inlet. The species diversity at Sawluctus [26] is not significantly greater than in Tod Inlet, however, species abundances were generally higher at the former station.

The other sites sampled which have relatively low numbers of species were Verdier Pt. (Station 13) and nearby Tanner Rock (Station 12). Verdier Pt. is the only station sampled which is regularly visited by beach walkers and collectors. Dr. Austin has repeatedly observed people here turning rocks and removing animals. Tanner Rock is offshore and is likely visited little, if at all, by people. However, it is a significant seal haul out area (30 during our visit) and one might speculate that high levels of fecal material and urea could impact on the biota. The nutrient tolerant sea lettuce (*Ulva* species) was present in the intertidal zone.

Soft Sediment Shore Biodiversity

The highest diversity was at Boatswain Bank which is just north of Saanich Inlet. Deep Cove and Patricia Bay had a somewhat lower diversity. All stations had a predominantly muddy sand substrate. All are exposed to moderate wave action. Boatswain Bank is subjected to more wave action based on fetch to the east and, in addition, is likely to have stronger tidal currents.

The lowest diversity was at the head of Tod Inlet. This location was the most wave protected of those stations surveyed. The mud here was like quicksand. The only macrophytes were a thin bladed Enteromorpha, a species typically associated with fresh water runoff, and glasswort or pickleweed in the high intertidal. Most macroscopic animal species were represented by few individuals.

Mill Bay also had moderately low diversity, however, most of the species occurring there were abundant. The substrate was sandy mud (varying with locality), but was considerably firmer than in Tod Inlet. Many additional species occurred on rocky areas in the estuary, but were not included in the species diversity count for sand/mud biota.

Goldstream Estuary had a surprisingly high diversity. The lower portions of the estuary were muddy sand and included sand dollars, a species not normally associated with estuaries. The polychaete *Hediste limnicola*, noted by Drinnan et al. (1995) as a rare species, was abundant. It may, in fact, be a new species (MacDonald, pers. comm. as cited in Drinnan et al., 1995). The introduced varnish clam (*Nuttallia obscurata*) was also found here.

10.11.2 Sensitivity to Stressors

Potentially Sensitive Species and Habitats

There is little documentation on the sensitivity of species and habitats in Saanich Inlet, therefore much of the information provided in this section is based on the experience of Dr. Austin. It is quite possible that species populations once present in the inlet have already disappeared unnoticed. Sensitivity is considered in terms of species or suites of species which are, or might be expected to be, sensitive to specific anthropogenic impacts.

The rate at which populations might be re-established after the reduction or elimination of some impact also needs consideration. Most of the species found in the present intertidal survey are relatively short lived, on the order of less than one to four or five years and with correspondingly frequent recruitment. Populations could potentially recover over a short period after some short term or single event impact. Alternatively, species populations with slow recruitment would take correspondingly longer to recover. Also, the pre-impact age class structure of a population may take decades to become re-established in a slow growing species.

Some species might then be considered sensitive from the standpoint of a potentially long life and at least often slow recruitment and/or slow growth rate. Those intertidal species in this category which can be identified from Saanich Inlet are as follows (Feder, 1980b; Haderlie et al., 1980; Littler and Littler, 1980; Harbo, pers. comm. as cited in Drinnan et al., 1995):

- Purple seastar, *Pisaster ochraceous*, 20+ years, common
- Geoduck, *Panope abrupta*, 140 years, rare intertidally
- Butter clam, *Saxidomus giganteus*, 20+ years, common
- Pacific cockle, *Clinocardium nuttalli*, 12-16 years, common
- Horse clam, *Tresus capax*, 12-15 years, few to common
- Mottled anemone, *Urticina crassicornis*, 20+ years?, rare
- Tarspot alga, *Petrocelis middendorffii*, 25-90 years, common

The Japanese or Pacific oyster, *Crassostrea gigas*, is, perhaps, a special case. While it grows relatively fast, recruitment is slow in Saanich Inlet. Spawning only occurs when water temperatures reach about 20°C., a temperature regularly reached in the oyster's native habitat but of infrequent occurrence in most B.C. waters.

Commercial/Native/Recreational Harvesting

Species populations may be at risk directly from harvesting or indirectly from disturbance or burial during harvesting. At present harvested species requiring a commercial or recreational license include clams, mussels, prawns, oysters and crab. Although most beaches are closed for bivalve harvesting, 30-70 tons of Manila and littleneck clams are harvested annually from three moderately polluted areas under special permit (Drinnan et al., 1995).

There are no current regulations for a number of species which are potentially harvestable such as snails, limpets, chitons, bait worms, seaweeds or eelgrass, although any substantial commercial or recreational harvest would quickly be reviewed by DFO, with appropriate management actions taken if needed.

Other Habitat Disruption

Habitat disruption by visitors at Verdier Point was noted earlier by Dr. Austin. Most of the sites he visited were only accessible by water; however, most of the sites surveyed by the University of Victoria biology class were accessible by road. Class students commented that they considered a number of habitats at these sites at risk from trampling, other disruption and removal. Species most sensitive to this type of impact might be those with the slowest recruitment such as the purple seastar or those living where disruption was frequent such as under rocks regularly overturned.

Sediment

Increased sediment input would be expected to decrease overall species diversity and/or the abundance of certain species. It might impact directly through:

a) Covering organisms.

b) Covering hard substrate during initial settlement phases.

c) Decreasing assimilative efficiencies for some suspension feeders.

d) Decreasing light intensity for photosynthesis.

a) Covering Organisms

Moore (1977) provides an extensive review of effects of suspended particles on individual marine species. In addition, the effects of sedimentation on subtidal organisms has been discussed by Evans et al. (1980) in a Norwegian Fjord and by Farrow et al. (1983) in a British Columbia fjord. Norse (1993) cites reports that logging of the Olympic Peninsula has resulted in sediment coating rocky reefs and eliminating many kilometres of kelp forest. There are reports of intertidal impacts of sedimentation from logging during a study in Clayoquot Sound (Radcliffe, 1991). However, direct evidence for broad habitat impacts based on controlled studies in the NE Pacific Intertidal is lacking.

In temperate waters rocky shore species with thin encrusting growth forms might be expected to be most susceptible to sedimentation (e.g., Jackson, 1977). In Saanich Inlet intertidal encrusting species of sponges, bryozoans, and social sea squirts are largely limited to the undersides of boulders and overhangs where they would be less likely to be directly affected by sedimentation than if on sloping or horizontal surfaces. Representatives of these species become rapidly fouled when oriented on horizontal surfaces during sedimentation events in aquaria at the Marine Ecology Station in Cowichan Bay. Existing levels of sedimentation in Saanich Inlet may therefore limit the survival of such species on surfaces subject to sediment accumulation.

Under boulder and under overhang refugia are largely unavailable to algae which require sufficient light for growth and reproduction. Bellamy et al. (1968; cited by Dawes, 1981) suggested that key macroscopic algae might act as phytometers (i.e., indicator species of polluted conditions). He noted that sediments on kelp forest plants acted as light filters preventing high rates of photosynthesis. Burrows and Pybus (1971) found that silt was the most likely factor affecting growth rates of *L. saccharina* under experimental and field conditions. A silt layer was observed on *Laminaria saccharina* (sugar kelp) fronds at Hatch Point. *Laminaria saccharina* is suggested as a potentially useful indicator species. This was likely due to sediment input from the Cowichan River.

b) Covering hard substrate during initial settlement phases

High sedimentation levels at critical periods of settlement and early growth stages could also limit distribution of both animals (e.g., Lilly et al., 1953) and macroalgae (e.g., Devinny and Volse, 1978). Most intertidal species with seasonal recruitment produce settling stages in spring and early summer. Species most likely to be affected are those where settlement on horizontal and moderately sloping surfaces is obligatory, such as macroalgae on surfaces where there is sufficient light. Devinny and Volse (1978) found small amounts of sediment inhibited successful settlement of the giant kelp *Macrocystis pyrifera*. They noted that increased sedimentation associated with urbanization in southern California might be a contributory factor to the loss of kelp beds. Recruitment of the sugar kelp, *Laminaria saccharina*, might be a useful indicator species.

Some animals species which occur on sedimented surfaces and which we tend to consider as sedentary could initially settle on vertical surfaces then subsequently move to sloping or horizontal surfaces. Dr. Austin has observed blue mussels (*Mytilus trossulus*) and plumose anemones (*Metridium senile*) plowing through sediment on rocks. However, he did not find any increased ratio of mobile to sedentary suspension feeders in areas of apparent or likely increased sedimentation.

c) Decreasing assimilative efficiencies for some suspension feeders

Increasing admixture of non-nutritive sediment with plankton and detritus would be expected to decrease the assimilation efficiencies of most suspension feeders. Presumably, species in areas of high turbidity are adapted to such conditions or conditions causing relatively slow growth rates are not a disadvantage. Species which have efficient particle rejection systems, such as mussels and most clams, and species using external appendages which largely capture only coarser material, such as barnacles and porcelain crab, may be able to tolerate higher levels of suspended sediment. In general there is an overall shift from colonial to solitary species correlated with decreasing currents and increasing distance from oceanic waters such as toward the head of typical fjords in B.C. (Austin, pers. observ.). Greene et al. (1983) found a succession from colonial to solitary forms on settling plates in the fjord-like habitats of southern Puget Sound over a one year period. One of several possibilities is that, on balance, small colonial species are less able to survive winter periods of limited food supply and/or decreasing assimilation efficiencies with increased admixture of suspended sediment.

On Saanich Inlet rocky shores with small colonial species, Dr. Austin found no hydroids, rarely sponges, no colonial polychaete worms, only one bryozoan species and only one colonial species of seasquirt. The colonial sea anemone *Metridium senile* was common in some areas. It differs from most colonial species in its mobility and the relatively large size of individuals. It may be comparable to other motile passive suspension feeders such as some sea cucumbers in expending relatively little energy in feeding.

The lightbulb sea squirt *Clavelina huntsmani* may be a candidate for an indicator species on rocky shores of suspended sediment load during the spring/summer. It is a colonial suspension feeder which occurs abundantly in Squally Reach and along the middle portion of the inlet along the east side (Dyer Rocks, Henderson Point). It was absent north of Patricia Bay on the east side and from Bamberton north on the west side. It was also absent within Tod Inlet and near the head of Finlayson Arm during the sampling period in August. This distribution pattern fits what is likely the areas with minimum summer suspended silt load. Colonies die back in the fall to small overwintering bodies which start budding in the spring (Abbott and Newberry, 1980).

d) Decreasing light intensity for photosynthesis

The absence or decreased vertical distribution range of macrophytes such as eel grass and large seaweeds has been ascribed to modified light regimes due to turbidity (e.g., Phillips and Menez, review by Moore, 1977). Such impacts are comparable to direct covering of photosynthetic surfaces from sedimentation as discussed above for sugar kelp. Any decrease in *macrophytes* may also be expected to affect associated species which live on or in macrophyte communities.

While it is most likely that increases in sediment input into Saanich Inlet would have significant impacts on a range of species, the nature, targets, and degree of impacts would depend on several factors which are not easily assessed such as sediment composition, duration, seasonality, resuspension, and co-occurrence with other variables such as salinity, substrate slope, and currents.

Eutrophication

Increase in nitrogen tends to result in increase in growth rates of opportunistic algal species (Littler and Littler, 1980) such as sea lettuce (*Ulva* spp.) and *Enteromorpha* and other forms with a high surface to volume ratio (thin blades or finely branched). Increases in such species associated with sewage outfalls and/or fertilizers has resulted in anoxia under algal mats with loss of sensitive species, and also in other species disappearing due to competition for space and settlement sites (e.g., Rosenberg, 1985; review by Lobban and Harrison, 1994). Mats of *Ulva* sp. have been observed to cover large areas of the intertidal area south of Cherry Point during the summer. These mats appear to be much more extensive in recent years but no quantitative studies have been made to document these observations. The macroalgal species assemblage along the west side of the inlet, south to Bamberton differs dramatically from that on the east side and Squally Reach. Differences in nutrient levels are a likely contributory cause. It is of interest that the stick-like coralline alga *Lithothrix aspergillum* is a dominant species at many sites on the east and south portion of the inlet. It is not recorded as a common species elsewhere in British Columbia (Hawkes, pers. comm. as cited in Drinnan et al., 1995). Ninety percent of the algal biomass downstream of a sewage outfall in southern California were coralline algae (*Bossiella* and *Corallina*) and some corallines have been shown to be highly tolerant to high concentrations of sewage (Dawson, 1959; reviewed by Lobban and Harrison, 1994). It would, perhaps, be instructive to assess what species changes occurred in other comparable habitats which have been studied such as Oslo Fjord where the algal distribution has been monitored over the past 40 years relative to sewage loading and in the Baltic and Kattegat where low oxygen concentrations have resulted in die offs of fish and clams (Rueness, 1973; Rosenberg, 1985).

Populations of the sugar kelp *Laminaria saccharina* vary considerably both along Saanich Inlet and between the east and west sides of the inlet. This species has been used as an indicator of sewage pollution in England (Bellamy et al., 1968; Burrows and Pybus, 1971). This species might be considered a good candidate for monitoring this feature in the inlet with the appropriate recognition of potential physiological adaptation of local populations (e.g., Kindig and Littler, 1980; Burrows, 1971). It might also be considered a rocky shore counterpart to eelgrass in soft substrate areas in the sense of providing a three dimensional habitat for many species both in the blade canopy (blades to 3.5 m long) and in and under the holdfasts. However, where studied in B.C., it appears to be an annual, dying back in the winter unlike the perennial populations in Europe (Druehl, pers. comm. as cited in Drinnan et al., 1995).

Fertilizers can have a more immediate, short-term effect. For example, liquid fertilizer used on a farm was carried into the sea near Cherry Point just outside Saanich Inlet during a storm event in February 1996. The fertilizer caused a discoloured foamy water which was toxic to fish based on bioassays (Broadland, pers. comm. 1996).

Temperature/Dessication

The periodic warm surface water temperatures during the summer are atypical for the southern British Columbia coast as a whole, excluding the Strait of Georgia and many other inlets, and correspond to other inlets and fjords with minimal currents, low summer fresh water input, and high insulation such as inner Ladysmith Harbour and Pendrell Sound (e.g., Thomson, 1981).

Periodically ocean-going ships anchor in Saanich Inlet while awaiting a berth elsewhere. Release of ballast water into the warmer summer waters of Saanich might favour the survival of introduced warmer water species. Many of the species introduced into British Columbia and occurring in Saanich Inlet (listed in Calder and Mann, 1995) are of Japanese origin such as the Pacific oyster, Japanese weed (*Sargasssum*), Manila clam, Japanese varnish shell, Japanese little mussel (*Musculista senhousia*), and, perhaps, the orange encrusting bryozoan *Schizoporella unicornis.* The introduction of exotic species may have a profound impact on marine communities in Saanich Inlet.

Alternatively warm water may exclude or limit the distribution of some cold water species. Dr. Austin has not found evidence for such exclusion in the present survey. However, as noted earlier several species of macroalgae were partially bleached during the August survey. Discolouration may result from high temperatures either while submerged or from drying out during low tides (e.g., Lobban and Harrison, 1994); however, some other factor cannot be excluded. Observations on several of the Gulf Islands indicate that there may be major die offs of macroalgae in late winter when the lowest tides switch from night to mid-day which occurs concomitantly with increased insulation (Austin et al., 1996). These die-offs are species specific; some species being much more resistant to desiccation than others (e.g., Dawson, 1966; Waaland, 1977). The correlation between shading and distribution of intertidal biota was clearly demonstrated in the classic study by Stephenson and Stephenson (1972) on the north and south facing slopes of Brandon Island in Departure Bay. Removal of trees along some shorelines in the inlet would be expected to modify intertidal biota distribution patterns.

Tributyl Tin

The levels of Tributyl tin (TBT) at a series of stations in southwestern British Columbia were recently assessed by Stewart and Thompson (1994) for sediment and some invertebrates. One station, Coal Bay, was in Saanich Inlet. Mussels here had a level of 52 ng/g Sn dry weight. The highest level recorded in their study was 314 ng/g Sn dry weight for mussels off the mouth of the Fraser River. They note that TBT contamination is widespread in the survey area despite restrictions on the use of organotin-based marine antifouling paints since 1989. There is limited qualitative data showing that TBT is present in Deep Cove and Patricia Bay (Thompson, pers. comm. as cited in Drinnan et al., 1995). While the Canadian Navy has reportedly discontinued use of TBT, it is not unlikely that it is used on at least some of the numerous foreign ships which anchor in Saanich Inlet while waiting for space elsewhere.

TBT has deleterious affects on many species and reduction in populations of the certain snails resulting from "imposex" has been the subject of numerous studies. The NE Pacific frilled dogwinkle *Nucella lamellosa* is particularly susceptible to TBT (for a closely related species at levels of less than 1 part per trillion, Gibbs [1993]) and significantly sterility and population declines for this species and possible association with vessel traffic has been recorded in southern B.C. (Bright and Ellis, 1990; Saavedra Alvarez and Ellis, 1990).

Oil and Oil Products

Given the complexity of oil mixtures and differences in amounts of highly toxic compounds (e.g., aromatics), no attempt will be made here to assess specific species sensitivities. In terms of physical effects, oils are more likely to adhere to hydrophobic, oleophilic surfaces such as on eelgrass and marsh plants than on the mucous surfaces of most macrophytes and shell-less invertebrates. Oil coated rock surfaces may result in removal of mobile species which depend on suction for attachment, such as sea stars, limpets, snails, and chitons (Austin, pers. observ. of Van Lene Spill in 1972).

The residence time of oil on Saanich Inlet shores is likely to be greatest on gravel beaches (Saunders et al., 1980; pers. observ. after Exxon Spill). These beaches constitute a major portion of the shoreline (Drinnan et al., 1995). It is likely that most impacts from petroleum in Saanich Inlet will be from shore runoff and outboards (Geyer, 1980; Mele, 1993). Such effects are likely to be subtle, but over time could be considerable.

Surface Film Contaminants

Many anthropogenic materials in addition to oil and oil products may become concentrated in sea surface films. Under appropriate conditions these may include pesticides, PCBs, organic metals (including organotins) and inorganic metals, and a variety of floatables after secondary sewage treatment (e.g., review by Gardiner, 1992). Intertidal organisms in Saanich Inlet are exposed to surface films up to four times daily. To the degree a material which is enriched in a surface film is toxic, it is more likely to negatively impact intertidal populations than subtidal and midwater populations. It may also impact adults and life history stages floating or adhering to the surface layer (neuston).

10.11.3 Summary and Recommendations for Sensitive Species Candidates

The focus of the intertidal benthic community survey was to document species and habitats present in Saanich Inlet and to provide some indications as to which species and habitats might be particularly sensitive to anthropogenic stressors. The following points summarize the results:

- Given the multiplicity and potential synergism of potential impacting factors and the lack of historical data, direct evidence for sensitivity of various species to present or potential impacts in Saanich Inlet could not be found.

- Species distribution of rocky shore biota supports the characterization of Saanich Inlet as having fresh water and sediment input largely at the mouth rather than at the head, as in most British Columbia fjords.

- Rocky shore species diversity was greatest at a station at Bamberton midway along the length of the inlet.

- Both species diversity and composition differed markedly between the east and west sides of rocky shores in the inlet north of Squally Reach.

- The relatively high species diversity for soft sediments at Boatswain Bank is likely, at least, in part, related to moderate currents and wave fetch. These would provide more food for suspension feeders per unit time. However, the location of the bank outside the inlet may also be a contributing factor if there are negative impacts limited to the inlet.

- The moderately high species diversity and species composition at Goldstream Estuary suggests that, at present, there is relatively low sediment input from this source.

- Low species diversity and overall impoverished soft sediment biota at the head of Tod Inlet suggests impact over and above both the stresses of low water flow and a periodic fresh water lens on the surface.

- Based on qualitative distribution and abundance data together with literature reports for other areas, Dr. Austin suggested that the following species might be sensitive and/or indicators for the conditions specified:

  Eel grass (*Zostera marina*) depth range: suspended sediment

  Pickleweed (*Salicornia virginica*) abundance: sediment deposition

  Sugar kelp (*Laminaria saccharina*) abundance, depth: sediment

  Lightbulb sea squirt (*Clavelina huntsmani*): suspended sediment

  Sand dollar (*Dendraster excentricus*): fine sediment

  Opportunistic algae (*Ulva* spp., *Enteromorpha* spp., fine reds): Eutrophication

  Stick coralline (*Lithothrix aspergillum*): Eutrophication?

  Frilled dogwinkle (*Nucella lamellosa*): Tributyl tin

- Slow growing and/or slow recruiting species may be considered sensitive to the degree that re-establishment of existing age class structure would take longer than for other species after an impact causing substantial mortality (Section 10.10.2).

10.12 Subtidal Sponge Communities

10.12.1 Status

The second component of the benthic survey commissioned by BCE was a study identifying boot and cloud sponge (hexactinellids) habitat within Saanich Inlet. This work was conducted by Dr. Bill Austin, Jim Cosgrove and Sally Leys; detailed results are proved in Austin et al. (1996). Hexactinellids are relatively common in deep waters throughout the world. Their unusual occurrence in shallow waters in British Columbia may be a result of: (a) regional upwelling, (b) low light levels in the shallow waters of fjords, (c) cold waters (<13°C), (d) high silicate levels in shallow waters (Austin, 1984), or a combination of the above factors.

A distinctive feature of Saanich Inlet is a sill rising to 70 m at the entrance, which traps an anoxic layer of water at 100-200 m depth in the inlet. This layer is reported to rise and fall seasonally, and has been recorded as shallow as 60 m (Tunnicliffe, 1981). Hence, in the inlet, hexactinellids are restricted to a narrow zone from 20 to 100 m in depth, limiting available options for recruitment and survival.

The occurrence of hexactinellids in Saanich Inlet is correlated with slope of the rock substrate, depth, and degree of siltation (Figure 10-8). Boot sponges were more common on vertical rock surfaces, while cloud sponges were found attached to both vertical and shelving rock substrates. If the wall was nearly vertical, boot sponges were found as shallow as 25 m (e.g., Willis Pt.). Both species were absent where there was heavy silt covering the rock.

McCurdy Pt. had the highest density of both boot and cloud sponges. Other invertebrate life was abundant and diverse there too, and unlike most other sites, there was little silt. McCurdy Pt. may experience relatively more water exchange and is probably less subject to fresh water runoff.

10.12.2 Sensitivity to Stressors

Primary anthropogenic stressors to hexactinellids in Saanich Inlet are likely sedimentation and physical disturbance from divers, anchors and fishing tackle. Both stressors may affect sponge feeding, which occurs by filtration of water through their tissues. Rates of pumping in boot sponges range between 0.5 and 1.2 cm/s for different sized sponges (Leys, 1995). Preliminary laboratory experiments show that sufficient mechanical jolting or increased sediment load in the water column causes cessation of pumping (Leys, unpublished). Instantaneous increase in sediment load causes immediate cessation of pumping, while a gradual increase in sediment load results in a reduced pumping rate. These figures suggest that despite their patchy occurrence along fjord walls, hexactinellids may play an important role in filtering water along the walls of Saanich Inlet.

10.12.3 Recommended Remedial or Protective Measures

While some damage to cloud and boot sponge populations has been noted in popular diving and fishing locations, no widespread degradation of these sensitive organisms has been documented. This may be due to their relatively low profile (i.e., limited to deep water habitats where few people venture) compared to other species in the inlet, or indicative that the influence of anthropogenic stressors is low (i.e., assimilative capacity may not have been reached). There was a general consensus at the Saanich Inlet Study Synthesis Workshop that these organisms are likely highly sensitive to sedimentation and that their habitats should be fully protected. It is important to note that they are most often found on steep sloped walls within the inlet. These marine habitats are also generally associated with steep upland areas where poor development practices could lead to major sediment inputs due to slope instability. Any development in upland areas adjacent to boot and cloud sponge habitats (Figure 10-8) should be given thorough review prior to approval.

10.13 Eelgrass Habitat

10.13.1 Status

A baseline study to assess the distribution and size of eelgrass beds in Saanich Inlet was completed (Austin et al., 1996). The study investigated both the native *Zostera marina* and the introduced *Z. japonica*. The study revealed that the inlet currently has 40.9 ha. of healthy eelgrass (Table 10-16). The distribution of eelgrass in Saanich Inlet was basically restricted to the three areas of the inlet that have soft-bottom substrate at intertidal and shallow subtidal elevations (Figure 10-8). The only area which appears to provide suitable eelgrass habitat, and yet was devoid of either species, was Tod Inlet.

There was discussion as to whether eelgrass ever existed in Tod Inlet. Many people recollect seeing fairly large eelgrass beds in the vicinity of Tod Creek and closer to the mouth of Tod Inlet. Furthermore, DFO reports that a fishery officer observed eelgrass in Tod Inlet in 1971. Thus, available information supports the past existence of eelgrass in Tod Inlet.

10.13.2 Sensitivity to Stressors

Eelgrass beds are severely impacted by high rates of sedimentation (burial), currents (erosion), turbidity (light reduction) and thermal pollution, which may lead to disease. The local species of eelgrass can tolerate sedimentation as long as the rate does not exceed that of leaf elongation. The leaves of eelgrass are buoyant which maximizes the photosynthetic potential of the plant, however, this trait also increases the likelihood that shoots become uprooted and are swept away with moderate to strong currents. The maximum depth of eelgrass colonization on suitable substrate is determined by light penetration. Therefore, an increase in water turbidity may result in a reduction of the depth to which a bed may extend. It has been speculated for decades that thermal pollution may be causing 'wasting disease'. Entire populations of eelgrass have been decimated by this disease in both Europe and North America. Riggs (1995) reports that eelgrass may be negatively impacted from conditions of eutrophication which result in hypoxia.

Eelgrass is relatively resistant to many substances in concentrations that would be lethal to other forms of marine life (McRoy and Helfferich, 1980). Seagrasses have been shown to concentrate cobalt, manganese, iron (Parker et al., 1963), zinc (Parker, 1962), and copper (Barsdate and Nebert, 1971). The plants store these elements without apparent damage. However, they may make these metals available for transfer up the food-chain, resulting in biomagnification of the toxic substances. Eelgrass beds function as natural filters, causing settling of sediment and organic material. McConnaughey (1974) recorded an instance where the efficiency of a *Zostera* meadow to filter raw sewage was established when the removal of the plants lead to poisoning of the benthos. Oil spills cause temporary damage to eelgrass leaf blades if oil contacts the blade in air (Dalby, 1968). Leaves which were covered with water during an oil spill sustained no apparent damage. Rhizomes and roots do not appear to be damaged by oil (Phillips, 1984). Dalby (1968) reported that leaves damaged by oil spills were shed and that new leaves regenerated from the rhizomes.

The most likely impact on eelgrass resulting from increased development in Saanich Inlet would be an increase in turbidity. An increase in turbidity could reduce the size of subtidal eelgrass beds significantly. Dredging operations often result in high sedimentation rates in surrounding habitats which could negatively impact eelgrass. Eelgrass beds can tolerate considerable amounts of metals and sewage without apparent damage. However, these toxins may be biomagnified up the food-chain.

10.13.3 Recommended Remedial or Protective Measures

Recommendations to Minimize Impacts

- Dredging operations near eelgrass beds should be avoided. If dredging can not be avoided, then the operation should be conducted during the spring/summer season when the eelgrass is rapidly growing. Eelgrass should be monitored during and after dredging for possible impacts. Reductions in bed area should be compensated for by a transplanting and monitoring program.

- Activities that could lead to an increase in currents, water temperature, or turbidity in adjacent eelgrass beds should be avoided.

Recommendations to Protect or Remediate Eelgrass Habitat

Based on current eelgrass coverage estimates, *Zostera japonica* may make up some 25-50% of the eelgrass beds in Saanich Inlet. The potential long-term implications of a shift from the endemic *Z. marina* to *Z. japonica* needs to be evaluated. A central point in this evaluation should be determining whether *Z. marina* is being displaced or whether *Z. japonica* is inhabiting new areas. The occurrence of mixed beds and *Z. japonica*'s strong presence suggests the former.

Restoration of historical eelgrass beds in Tod Inlet should be explored. This should be conducted in coordination with other remedial activities in Tod Inlet to ensure that existing contaminant sources are controlled prior to expending resources on eelgrass habitat restoration. Caution should be applied, however, to ensure that restoration is limited to endemic species.

10.14 Marine Birds

10.14.1 Status

The status of marine bird population in Saanich Inlet is largely unknown because historic data is lacking, bird populations are naturally highly variable, and populations breeding elsewhere may be negatively affected by influences outside Saanich Inlet. The most comprehensive survey of marine birds in Saanich Inlet was conducted between March and December, 1986 (Morgan, 1989). A total of 48 bird species were recorded in Saanich Inlet during this time frame. Abundances and the total number of species were highest during the spring and fall migration periods, and lowest during the summer. Birds were also most abundant in shallow embayments such as Pat Bay, Coles Bay, and Mill Bay, and least abundant on rocky shorelines.

Based on the results of this survey, common year-round residents include the glaucous-winged gull, pelagic- and double-crested cormorant, marbled murrelet, and pigeon guillemont. waterfowl including the American wigeon, white-winged scoter, surf scoter, Barrow's goldeneye, bufflehead, and red-breasted merganser are most abundant in spring and fall. Gulls were the most abundant group during the summer months. Grebes are abundant during spring and fall, and Saanich Inlet has a very large population of western grebes. All four species of loons winter in Saanich Inlet (i.e., common loon, pacific loon, red-throated loon, and yellow-billed loon), and alcids (i.e., common murre and marbled murrelet) are most common in late summer and fall. Of the commonly occurring species found in Saanich Inlet, the pelagic and Brant's cormorant, western grebe and common murre are red listed as candidate species for legal listing as threatened or endangered by the provincial government.

Some limited information is available regarding population trends in the Strait of Georgia. It appears that populations of glaucous-winged gulls, pelagic and double-crested cormorants, Canada geese, and bald eagles have increased since the 1970s and are probably stable at the current time. Little is known about the population status of the fork-tailed storm-petrel, Leach's storm-petrel, common murre, pigeon guillemot, marbled murrelet, and many species of shoreline birds that breed in the Strait of Georgia (Mahaffy et al., 1994; Noble, 1990).

Based on the limited information available, Saanich Inlet is an important habitat on Vancouver Island for many species of marine birds. It is reasonable to assume that population trends occurring in the Georgia Basin Region are likely reflected in trends occurring in Saanich Inlet, but data are unavailable to confirm this (Morgan, pers. comm. 1996).

10.14.2 Sensitivity to Stressors

Bird populations can be negatively impacted by a number of human activities which can result in both direct and indirect impacts. Direct impacts can occur through oil spills, disturbances by humans and domestic animals, hunting, and entanglement in debris and fishing gear. Indirect impacts can occur from: contamination of the prey with persistent chemicals which may biomagnify in the food-chain, reduction of food supply, and loss of critical habitat (Mahaffy et al., 1994; Noble 1990). The threat of hunting to bird populations is probably of minor consequence because little or no hunting presently occurs in the inlet (Vermeer, pers. comm. 1996). Although indirect effects on the abundance and type of food available can occur through sedimentation, enhancement interactions, and nutrient enrichment, these effects are probably of lesser concern. The estimated sensitivities of marine birds to anthropogenic stressors is presented in Table 10-17.

Oil Spills

Although large freighters carrying oil do not frequent the waters of Saanich Inlet, a large oil spill occurring of the coast of Vancouver Island could affect seabirds there, resulting in lower use of Saanich Inlet. Oil released in the environment can cause drowning, hypothermia, toxic effects from ingestion of oil and contaminated food, and susceptibility to disease and predation. Birds most likely to be affected by oil spills include common murres, grebes, loons, breeding populations of alcids, and wintering diving ducks (Mahaffy et al., 1994). Because western grebes congregate in large flocks, and rarely fly (especially during the molting season), they are particularly susceptible to oil spills (Clowater, pers. comm. as cited in Drinnan et al, 1995). Ducks, geese, and shorebirds may also be negatively impacted through degradation of their feeding habitat (Vermeer and Vermeer, 1975).

Entanglement

Birds can become entangled in the gillnets and purse seines used to catch seafood. Gillnets pose the greatest hazard, and the gillnet fishing season often overlaps with the arrival of bird populations that overwinter in the Strait of Georgia region. The main species at risk include diving birds such as: common murres, western grebes, marbled murrelets, rhinoceros auklets, and cormorants (Troutman et al., 1991). It is not anticipated that large numbers of birds are affected by fishing equipment in Saanich Inlet because the commercial fishery there is limited, and the salmon and herring gillnet fishery is currently closed (Drinnan et al., 1995).

Chemical Contaminants

Bird populations are sensitive to chemical contamination of the environment, primarily through contamination of food sources by halogenated organic chemicals and methlymercury which biomagnify in food webs. High levels of these substances in bird tissues can cause weight loss, nervous disorders, death, and reproductive effects such as eggshell thinning, embryo mortality and deformities. Also of concern, are trace metals such as cadmium, copper and lead which may cause lethal and sublethal effects. Unfortunately, monitoring of contaminant levels in seabird eggs has not occurred for birds nesting in Saanich Inlet so it is not possible to assess temporal trends and overall magnitude of concentrations. Although, certain bird species in B.C. may have suffered contaminant induced declines in the past, monitoring data from the Strait of Georgia suggest that concentrations of most contaminants of concern have declined over the past 20-30 years, and that current levels are not sufficiently high to adversely affect bird populations (Noble, 1990).

Habitat Disturbance

Probably of greatest concern to bird populations in Saanich Inlet is habitat disturbance resulting from increased urbanization. Developments encroach upon, degrade, and destroy important habitats such as wetlands. For instance, the development of marinas and docks could destroy important habitat and result in increased pollution (Vermeer, pers. comm. 1996). The most important habitats threatened by shoreline development are shallow areas with brackish water such as found in Mill Bay and Patricia Bay (Vermeer, pers. comm. 1996). Also associated with the population growth is increased disturbance by humans and dogs through increased shoreline and water based activities such as boating, fishing, diving, and beachcombing

(Mahaffy et al., 1994). Of particular concern are disturbances to foraging, roosting and nesting habitat. For instance, increases in boating traffic could disturb the large population of western grebes that is found between Mill Bay and Pat Bay in the spring and late fall (Morgan, pers. comm. 1996).

Prey Availability

Certain fish-eating species may be at risk due to declines in their prey species in Saanich Inlet. For instance, the decline in herring stocks and other feed fish could affect populations of cormorants, gulls, herons, and raptors in the inlet. Unfortunately, cause-effect relationships between prey availability and the health of bird populations is difficult to establish because the ecology of the inlet is complex, and limited data regarding temporal trends of forage species and feeding preferences of birds are available.

10.14.3 Recommendation for Protection and Remediation

The following general recommendations are intended to support marine bird populations in Saanich Inlet:

- Local wildlife groups could establish a census program to track marine bird populations over time. Comparisons to other coastal areas may be used to determine if bird populations in Saanich Inlet are in decline.
- Identify marine areas that are important habitat for various bird species (e.g., nesting and feeding areas). These areas may require protection from human development and other human activities such as boating and fishing. Some of these areas may also be candidates for restoration.

A summary of recommended remedial or protective measures is provided in Table 10-18.

Table 10-1 Status of spawning anadromous salmonid stocks, spawning habitat, and enhancement efforts in Saanich Inlet.

Tributaries Cabable of Supporting Anadromous Salmonid Spawning[1]	Status of Populations[2]	Status of Spawning Habitat[3]	Natural Spawning Potential[4]	Enhancement[5]	
				Habitat	Stock
Goldstream	Coho ★ **E** Chinook ★ **E** Chum ★★★ Steelhead ★ Cutthroat ★	healthy	good	★★★	★★★
Tod	Coho ★ Chum ? Cutthroat ⊗	poor	good ?	?	?
Shawnigan	Coho ★ **E**	barrier at mouth	0	?	★★
Hagan	Coho ? Chinook ? Chum ?	barrier at mouth	0	?	0
Tseycum	Chum ?	poor	good?	0	?
Pease	Coho ? Chum ?	?	fair ?	?	?
Spectacle	Chum ?	fair	fair ?	?	?
Johns	Cutthroat ? ⊗ Chum ? ⊗	poor	fair ?	?	?
Malahat	Cutthroat ? ⊗	poor	?	?	?
Coles Bay Creek	?	?	?	0	0

[1] Compiled from Drinnan et al. (1995) and Calder and Mann (1995).

[2] Relative importance of run in tributary (★★★ = major; ★★= moderate; ★= minimal; ? = unknown; ⊗ = extinct; **E** = enhanced).

[3] Present status of spawning habitat for all species (healthy; fair; poor; 0 = none; ? = unknown) based on an overall assessment (i.e., quality may vary among species).

[4] Natural spawning habitat potential (i.e., historical or potential future) (good; fair; poor; 0 = none; ? = unknown).

[5] Enhancement efforts (★★★ = good; ★★ = tried at least once; 0 = none; ? = unknown).

Table 10-2 Salmonid sensitivity to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	★	Limited direct contact with sediments, but possible food-chain exposure for bioaccumulative contaminants
Habitat Disturbance	★★★	Spawning, rearing and feeding areas
Harvesting Pressure	★★	Relative impacts of commercial (outside inlet) and recreational fishing (within inlet) uncertain
Sedimentation	★★★	Spawning, rearing and feeding areas
Enhancement Interactions	★	Impact unknown
Nutrient Enrichment	★	Potentially toxic at high levels, no reason to suspect any problems at current levels

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★).

Table 10-3 Summary of general and specific recommended remedial or protective measures for salmonids in Saanich Inlet.

Areas	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
	General Recommendations	
ALL SAANICH INLET	·Establish Sensitive Habitat Buffer Zone ·Protect marine habitats ·Evaluate recreation fishing policy	★★★
ALL TRIBUTARIES	·Establish Sensitive Habitat Buffer Zone ·Conduct fishery assessment ·Prevent further habitat degradation	★★★
Tributaries	Specific Recommendations	Priority
Goldstream	·Maintain current habitat protection ·Stabilize streamflow during spawning periods ·Continue enhancement efforts ·Maintain genetic diversity of wild stocks	★★★
Tod	·Delineate extent of contaminated sediments ·Delineate impact area	★★★
Shawnigan	·Evaluate, installing fish ladder to bypass falls	★★
Hagan	·Evaluate installing fish ladder to bypass falls	★★
Tseycum	·Investigate potential	★★★
Pease	·Investigate potential	★
Spectacle	·Investigate potential	★
John's	·Investigate potential	★
Malahat	·Investigate potential	★
Deep Cove Creek	·Investigate potential	★

[1] Priority (★★★= high; ★★= medium; ★= low).

Table 10-4 Rockfish and Lingcod sensitivity to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	★★	Close contact with hard bottom substrate
Habitat Disturbance	★★★	Strong reliance on habitat
Harvesting Pressure	★★★	Rockfish grows slowly and is long-lived; lingcod popular recreational catch; both species may suffer significant mortality as by-catch in commercial dogfish fishery.
Sedimentation	★★	Lingcod may be sensitive to sedimentation as egg masses are laid onto rocky reefs
Enhancement Interactions	NA	NA
Nutrient Enrichment	★	

[1] Sensitivity qualitatively estimated as low (★), medium (★★). high (★★★)
NA = Not applicable.

Table 10-5 Summary of general and specific recommended remedial or protective measures for rockfish and lingcod in Saanich Inlet.

Fish Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Lingcod	·Establish Sensitive Habitat Buffer Zone ·Protect habitats ·Reduce fishing pressure	★★★
Rockfish	·Establish Sensitive Habitat Buffer Zone ·Prevent further habitat degradation ·Reduce fishing pressure	★★★

[1] Priority (★★★ = high; ★★= medium; ★= low).

Table 10-6 Herring sensitivity to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	★★	Adults pelagic; juveniles school nearshore; eggs laid on intertidal and subtidal vegetation
Habitat Disturbance	★★★	High reliance on habitat during spawning, especially eelgrass
Harvesting Pressure	★★★	Commercial fishing
Sedimentation	★★	May affect eggs directly; adults affected indirectly
Enhancement Interactions	NA	NA
Nutrient Enrichment	★	

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★)
NA = not applicable.

Table 10-7 Summary of general and specific recommended remedial or protective measures for herring in Saanich Inlet.

Fish Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Herring	·Establish Sensitive Habitat Buffer Zone ·Protect habitats	★★

[1]Priority (★★★ = high; ★★= medium; ★= low).

Table 10-8 Flatfish and dogfish sensitivities to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	Flatfish★★★ Dogfish★★	Flatfish and dogfish live in close contact with sediment
Habitat Disturbance	Flatfish★★ Dogfish★★	
Harvesting Pressure	Flatfish★★ Dogfish★★★	Dogfish are long-lived and produce few offspring
Sedimentation	Flatfish★ Dogfish★	
Enhancement Interactions	NA	NA
Nutrient Enrichment	Flatfish★ Dogfish★	

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★)
NA = not applicable.

Table 10-9 Summary of recommended remedial or protective measures for flatfish and dogfish in Saanich Inlet.

Fish Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Flatfish	·Establish Sensitive Habitat Buffer Zone ·Monitor resource more closely	★★
Dogfish	·Establish Sensitive Habitat Buffer Zone ·Monitor resource more closely	★★

[1] Priority (★★★ = high; ★★= medium; ★= low).

Table 10-10 Prawn and euphausiid sensitivities to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	Prawn ★★ Euphausiids ★	Prawns exposed via dietary intake of benthic invertebrates
Habitat Disturbance	Prawn ★★ Euphausiids ★	Prawns dependent on nearshore habitat for first year; euphausiids are pelagic
Harvesting Pressure	Prawn ★ Euphausiids ★	Prawns exposed to relatively low fishing intensity; no current euphausiid fishery
Sedimentation	Prawn ★★ Euphausiids ★★	
Enhancement Interactions	NA	NA
Nutrient Enrichment	Prawn ★ Euphausiids ★	

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★)
NA = not applicable.

Table 10-11 Summary of recommended remedial or protective measures for prawn and euphausiids in Saanich Inlet.

Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Prawns	·Establish Sensitive Habitat Buffer Zone ·Monitor resource more closely	★
Euphausiids	·Establish Sensitive Habitat Buffer Zone ·Monitor resource more closely	★★

[1] Priority (★★★ = high; ★★= medium; ★= low).

Table 10-12 Crab sensitivity to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	Dungeness ★★ Red rock ★	Crab exposed via dietary intake; Dungeness at greater risk due to increased exposure to sediments
Habitat Disturbance	Dungeness ★★ Red rock ★★	Both species live in close contact with benthic habitat
Harvesting Pressure	Dungeness ★★ Red rock ★★	Small commercial harvest for Dungeness; recreation fishery targets both
Sedimentation	Dungeness ★ Red rock ★★	Dungeness lives in sandy habitat; Red rock lives in more rocky areas
Enhancement Interactions	NA	NA
Nutrient Enrichment	Dungeness ★★ Red rock ★★	Possible impacts to larvae and adults, will depend on degree of enrichment

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★)
NA = not applicable.

Table 10-13 Summary of recommended remedial or protective measures for crab in Saanich Inlet.

Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Crab	·Establish Sensitive Habitat Buffer Zone ·Measure tissue concentrations in areas with sediment contamination	★

[1] Priority (★★★ = high; ★★= medium; ★= low).

Table 10-14 Clam and oyster sensitivities to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	★★★	Intimate contact with bottom substrate, suspension feeder; chemical concentrations are generally low, but bacteriological concentrations are high from a human health perspective
Habitat Disturbance	★★	Both species live in close contact with benthic habitat
Harvesting Pressure	★	Small commercial depuration harvest; currently low recreational fishing pressure
Sedimentation	★★	Heavy siltation likely to reduce filtering efficiency, change substrate characteristics, smother
Enhancement Interactions	NA	NA
Nutrient Enrichment	★★	Possible impacts to larvae and adults, will depend on degree of enrichment

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★)
NA = not applicable.

Table 10-15 Summary of recommended remedial or protective measures for clams and oysters in Saanich Inlet.

Fish Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
Clams & Oysters	·Establish Sensitive Habitat Buffer Zone ·Improve water quality - fecal coliforms	★★★

[1] Priority (★★★ = high; ★★= medium; ★= low).

Table 10-16 Summary of intertidal and high subtidal coverage by eelgrass in Saanich Inlet (Source: Austin et al., 1996).

LOCATION	SPECIES (number of polygons)			RELATIVE ELEVATION (number of polygons)			AREA (HA)			
	Z.m	both	Z.j	sub	sub/ inter	inter	Z.m	both	Z.j	total
EAST COAST										
Deep Cove	3	1	5	1	3	0	2.8	<0.1	1.3	4.1
Deep Cove to Pat Bay	2	11	0	2	9	0	0.2	0.8	0.0	1.0
Pat Bay	8	9	3	8	8	1	5.6	1.9	6.6	14.1
Pat Bay to Coles Bay	0	1	0	0	1	0	0.0	0.2	0.0	0.2
Coles Bay	4	0	0	1	2	1	<0.1	5.2	1.3	6.5
Brentwood Bay	4	0	0	4	0	0	1.2	0	0.0	1.2
total	**21**	**22**	**8**	**16**	**23**	**2**	**9.8**	**8.1**	**9.2**	**27.1**
WEST COAST										
near Bamberton	1	0	0	0	1	0	0.0	0.3	0.0	0.3
Mill Bay	3	1	0	2	2	0	2.4	5.0	0.0	7.4
Hatch Point to Mill Bay	4	0	2	4	0	0	0.7	0.0	2.7	3.4
total	**8**	**1**	**2**	**6**	**3**	**0**	**3.1**	**2.3**	**2.7**	**11.1**
SOUTH END										
Goldstream Estuary	2	0	0	0	2	0	0.0	1.9	0.0	1.9
SAANICH INLET	**31**	**23**	**10**	**24**	**28**	**2**	**12.9**	**15.3**	**11.9**	**40.9***

Z.m - Z. marina Z.j - Z. japonica both - Z.m & Z.j sub - subtidal inter - intertidal
*value includes polygon areas of <0.1 ha that were not included in the table (0.8 ha)

Table 10-17 Marine bird sensitivity to anthropogenic stressors.

Stressor	Sensitivity[1]	Notes
Chemical Contamination	★★★	Sensitive to oil spills and contaminants in aquatic food sources
Habitat Disturbance	★★★	Developments may degrade feeding, roosting, and nesting areas. Birds may be disturbed by humans and domestic animals
Harvesting (hunting) Pressure	★	Little or no bird hunting in the inlet
Sedimentation	★	Impact unknown, may affect food sources
Enhancement Interactions	★	Impact unknown, may affect food sources
Nutrient Enrichment	★	Impact unknown, may affect food sources

[1] Sensitivity qualitatively estimated as low (★), medium (★★), high (★★★).

Table 10-18 Summary of general and specific recommended remedial and protective measures for marine birds in Saanich Inlet.

Bird Type	Recommended Protection & Remediation	Priority[1] for Protection & Remediation
All Marine Birds	• Protect habitats	★★
	• Census conducted by local birders to track bird populations over time	★★

[1]Priority (★★★ = high; ★★= medium; ★= low).

Figure 10-1 Recreational catch (absolute) of chinook and coho salmon in Saanich Inlet and the Strait of Georgia (Source: Drinnan et al., 1995). Notes: 1 = minimum size 30 cm, daily limit 4 fish; 2 = minimum size 45 cm, daily limit 4 fish; 3 = minimum size 45 cm, daily limit 2 fish; 4 = minimum size 62 cm, daily limit 2 fish.

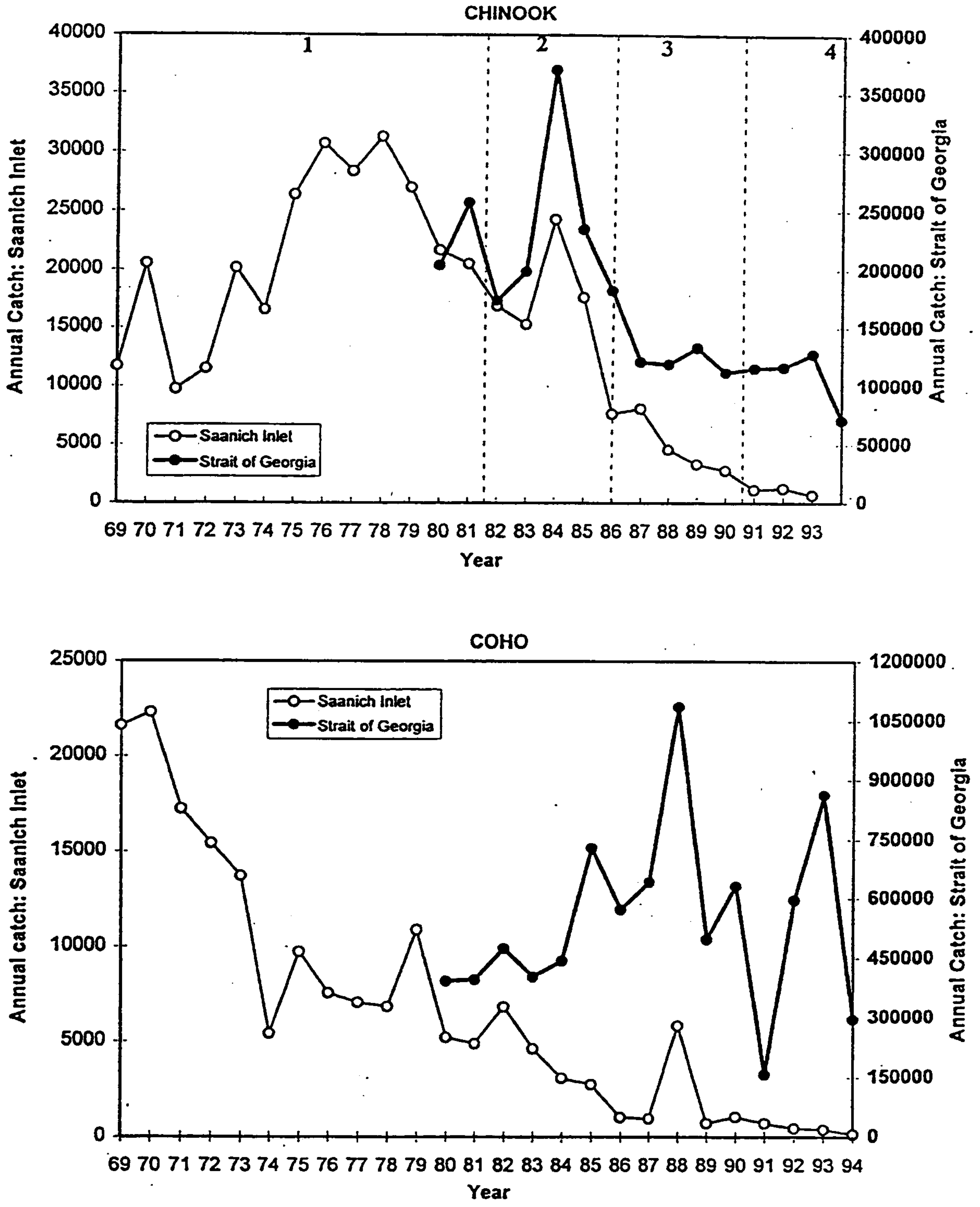


Figure 10-2 Recreational catch (catch per unit effort) of chinook and coho salmon in Saanich Inlet and the Strait of Georgia (Source: Drinnan et al., 1995). Notes: 1 = minimum size 30 cm, daily limit 4 fish; 2 = minimum size 45 cm, daily limit 4 fish; 3 = minimum size 45 cm, daily limit 2 fish; 4 = minimum size 62 cm, daily limit 2 fish.

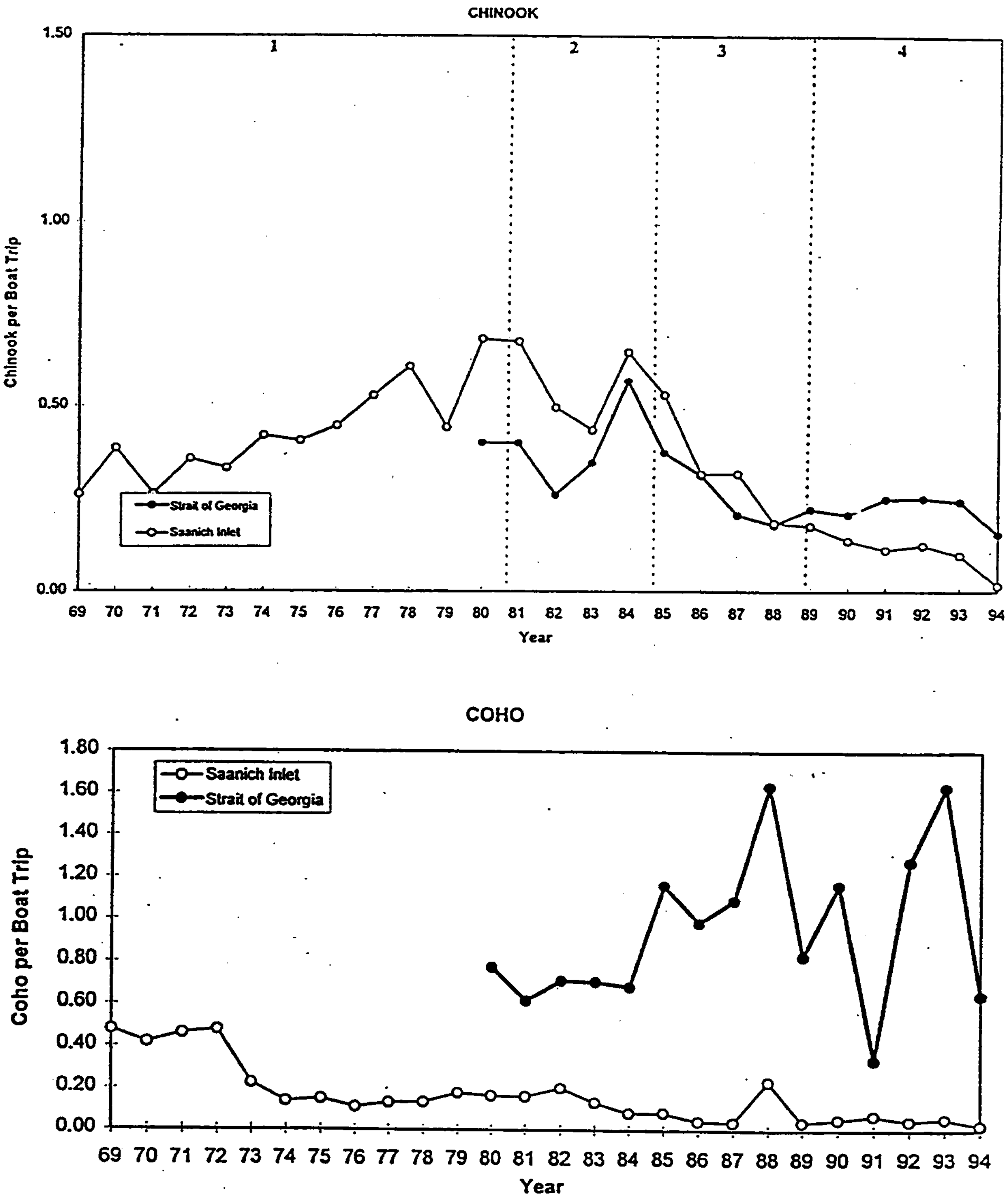
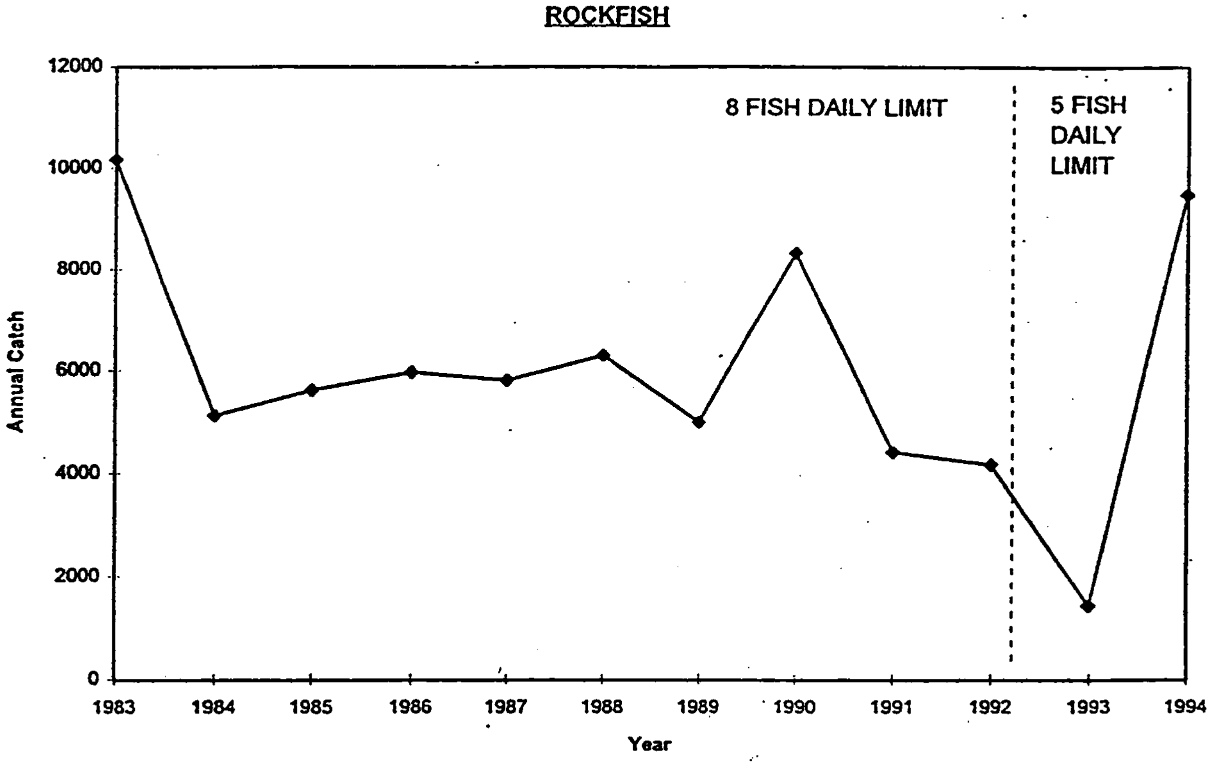


Figure 10-3 Annual recreational catch of rockfish and lingcod in Saanich Inlet (Source: Drinnan et al., 1995).



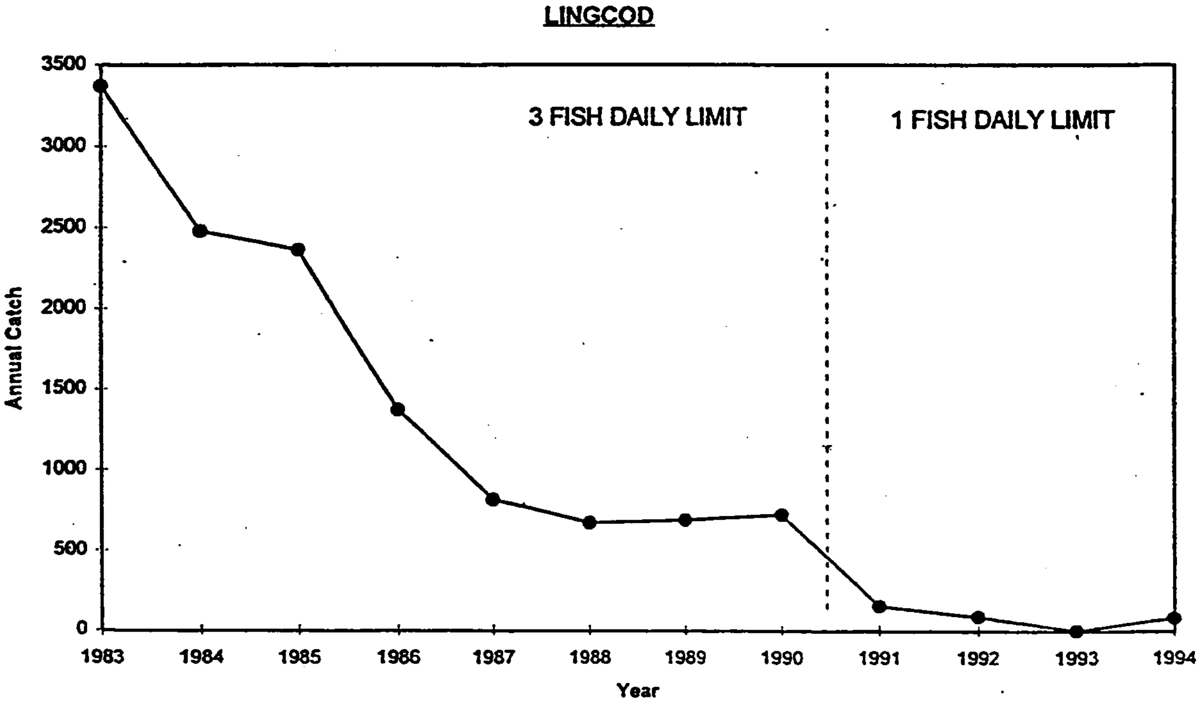


Figure 10-4 Historical herring spawn areas and adult winter holding areas (Source: Drinnan et al., 1995).

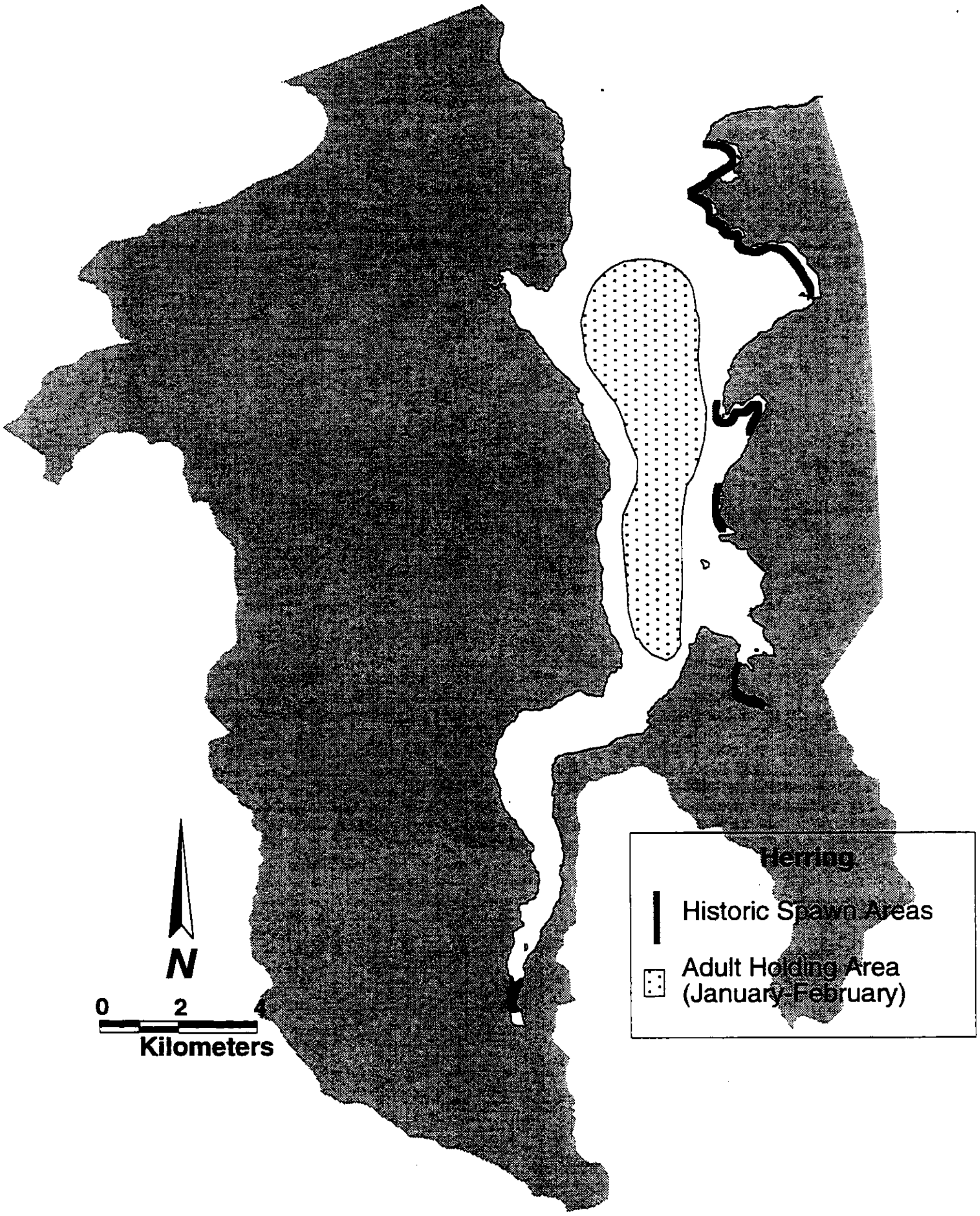


Figure 10-5 Location and current status of intertidal shellfish harvesting areas of Saanich Inlet (Source: Drinnan et al., 1995).

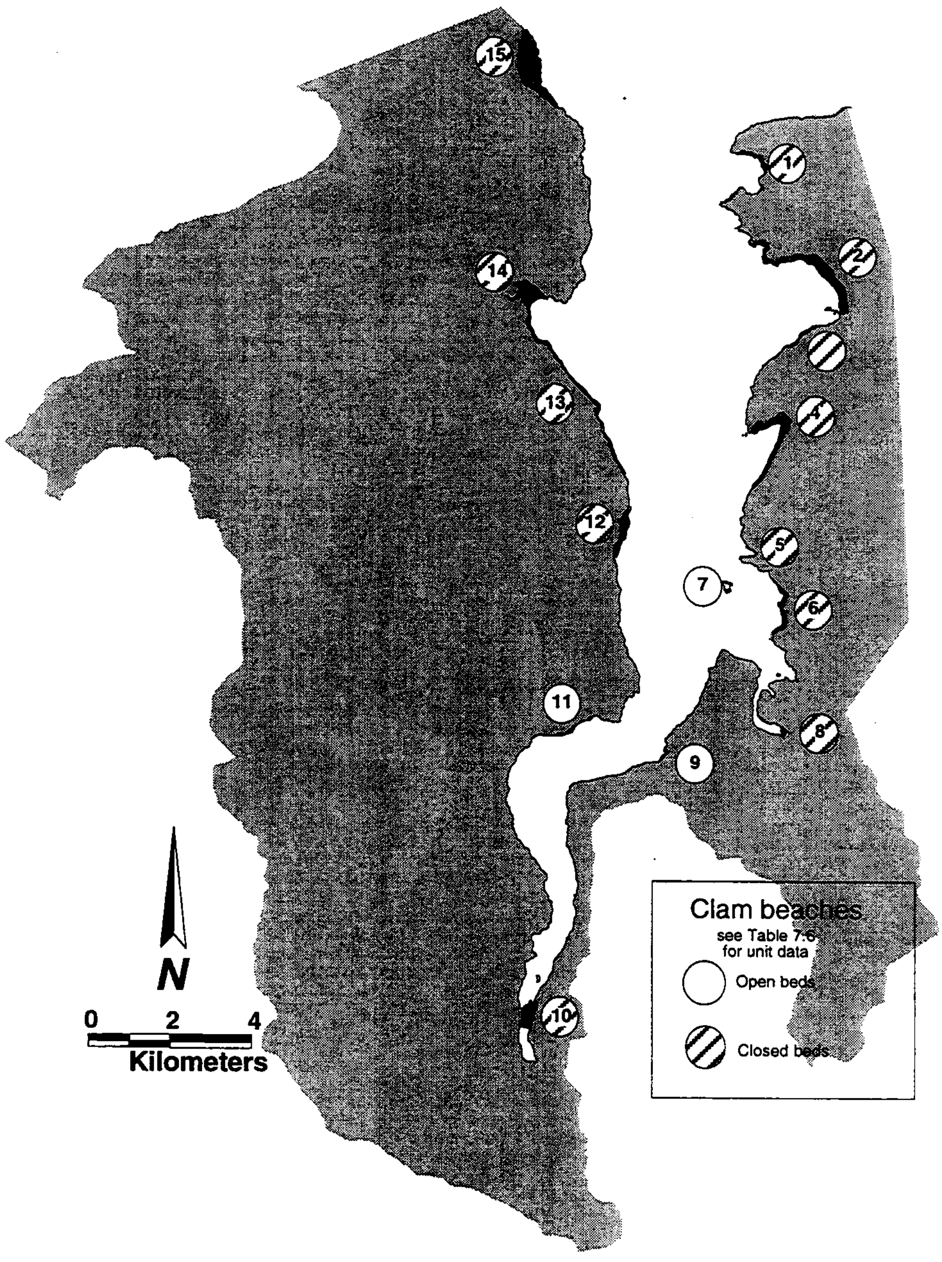


Figure 10-6 Rocky shores species diversity in Saanich Inlet (Source: Austin et al., 1996).

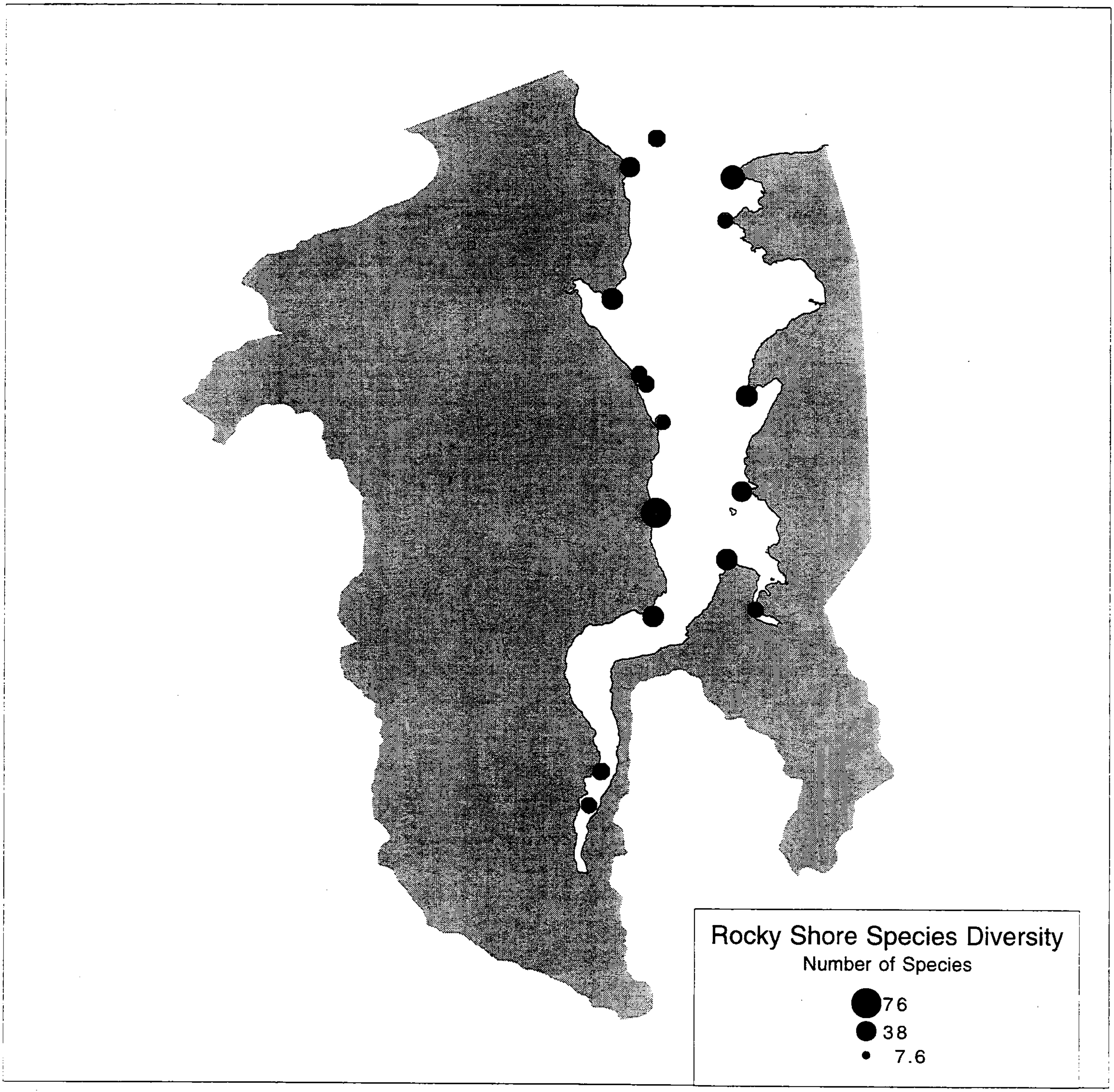


Figure 10-7 Glass and boot sponge habitat in Saanich Inlet (Source: Austin et al., 1996).

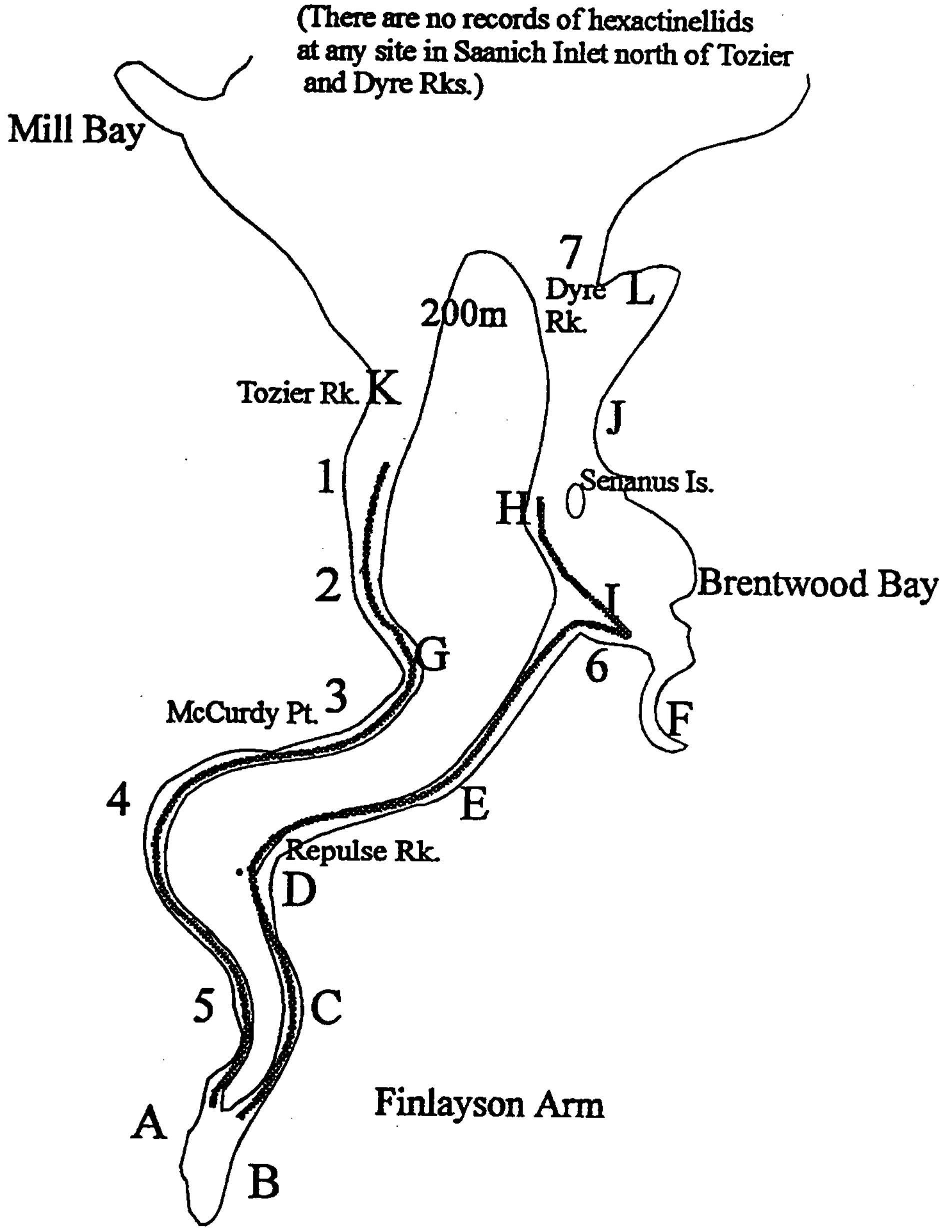
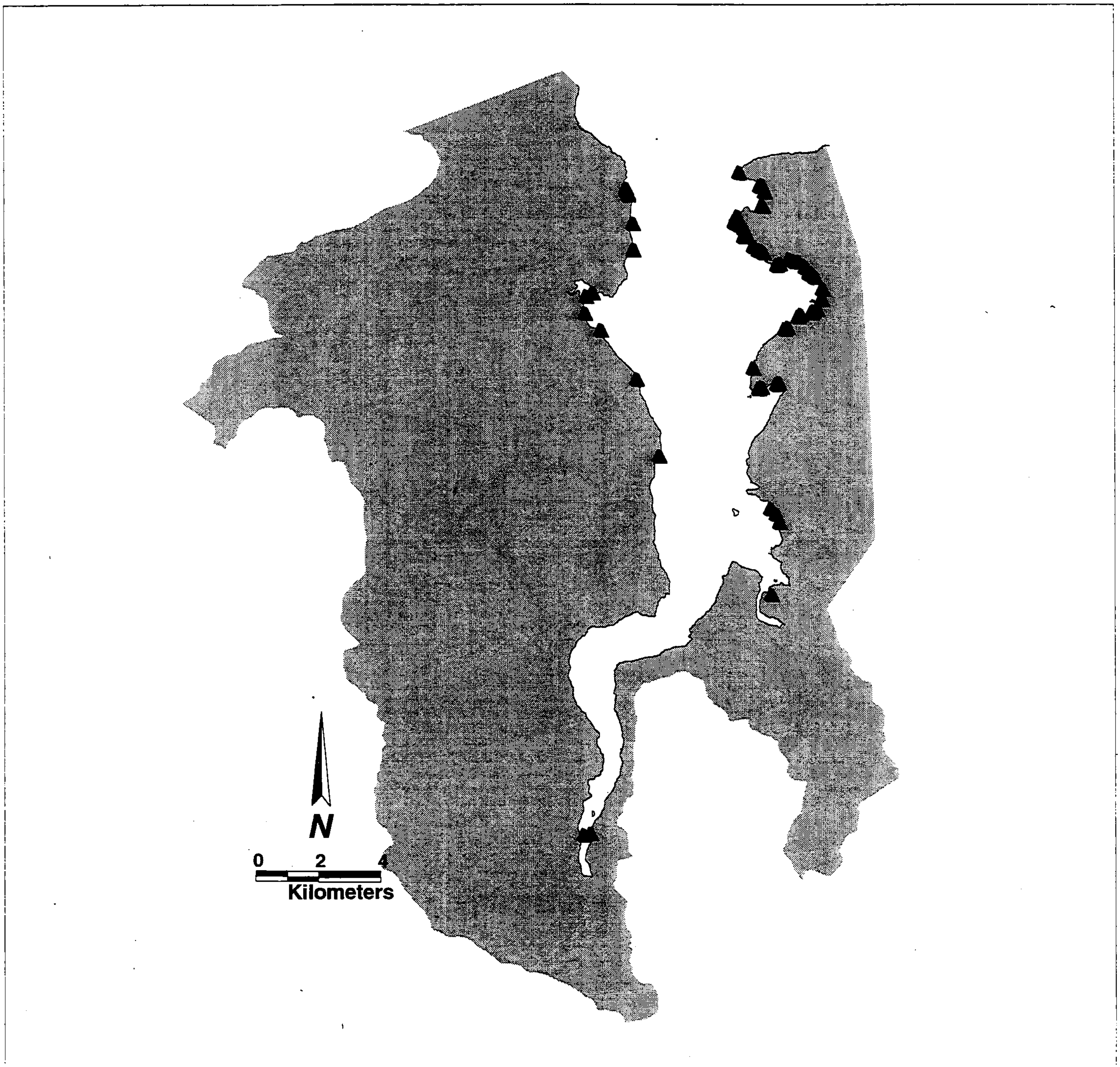


Figure 10-8 Eelgrass habitat in Saanich Inlet (Source: Austin et al., 1996).

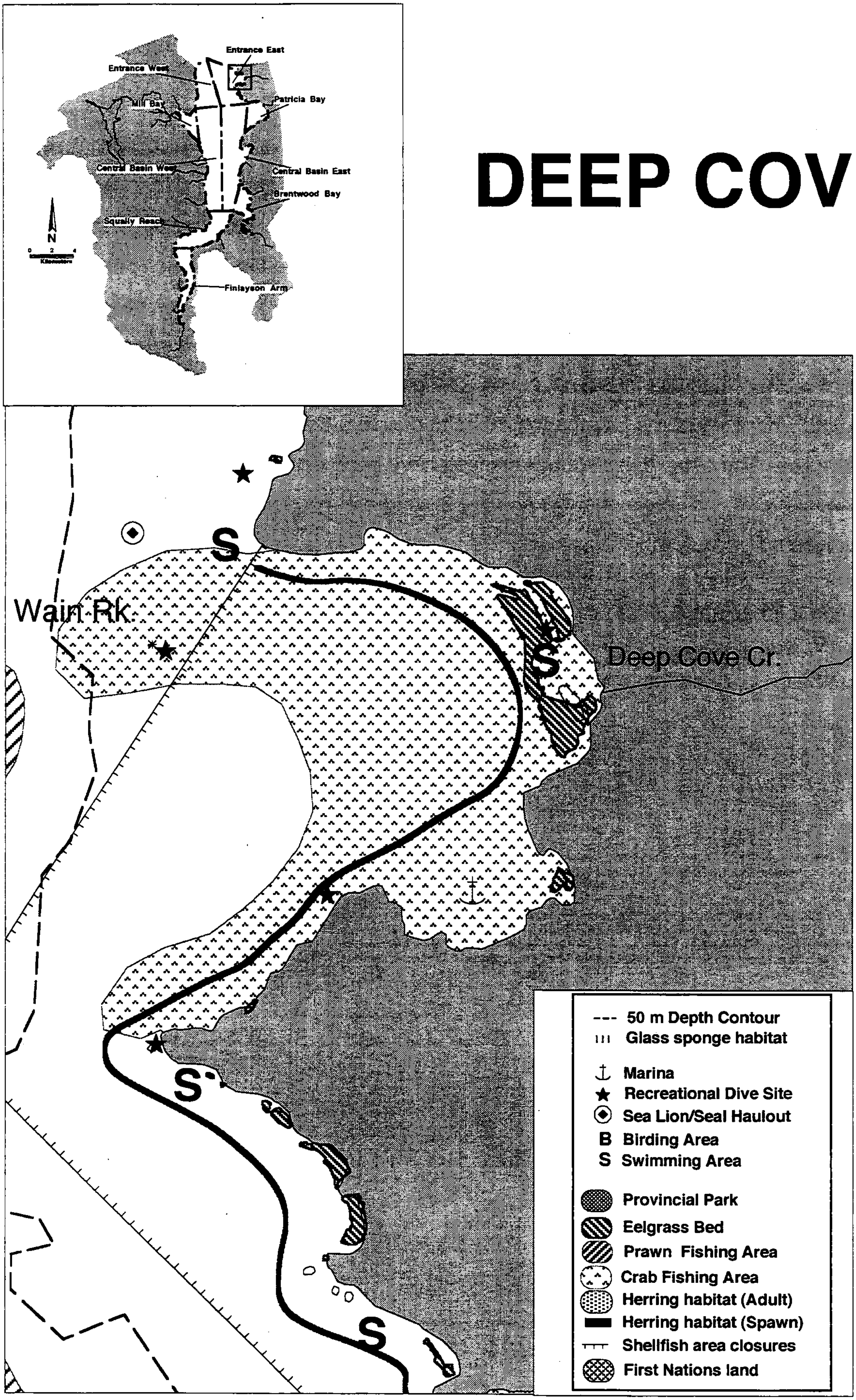


11. GEOGRAPHICAL SUMMARY OF SAANICH INLET

The following summary presents an overview of key uses and sensitive resources drawn from the technical component reports. The environmental status, sensitivity, uses, habitats and other characteristics of Saanich Inlet are presented for each geographic area in text and as maps. These include parks, recreational fishing areas and dive sites, glass sponge habitat, eelgrass beds, birding areas, marinas and First Nations' lands. The degree of water movement is also presented; descriptions are based on computer model results and are relative to the range of water movement in Saanich Inlet. Geographic areas were selected to represent key use areas where adequate information exists to describe environmental conditions for a variety of measures. The geographic summary maps have been constructed from source information of various scales and levels of detail and are therefore only approximate representations of the resources and attributes.

Common themes appear repeatedly in the more sensitive and urbanized areas of Saanich Inlet, indicating that certain human influences consistently lead to environmental impacts. These themes have provided the basis for many of the study conclusions and recommendations.

DEEP COVE


Entrance East
Entrance West
Mill Bay
Patricia Bay
Central Basin West
Central Basin East
Brentwood Bay
Squally Reach
Finlayson Arm
N
0 2 4
Kilometers
S
Wain Rk.
Deep Cove Cr.
S
S
S
--- 50 m Depth Contour
ııı Glass sponge habitat
⚓ Marina
★ Recreational Dive Site
◈ Sea Lion/Seal Haulout
B Birding Area
S Swimming Area
Provincial Park
Eelgrass Bed
Prawn Fishing Area
Crab Fishing Area
Herring habitat (Adult)
Herring habitat (Spawn)
Shellfish area closures
First Nations land

DEEP COVE

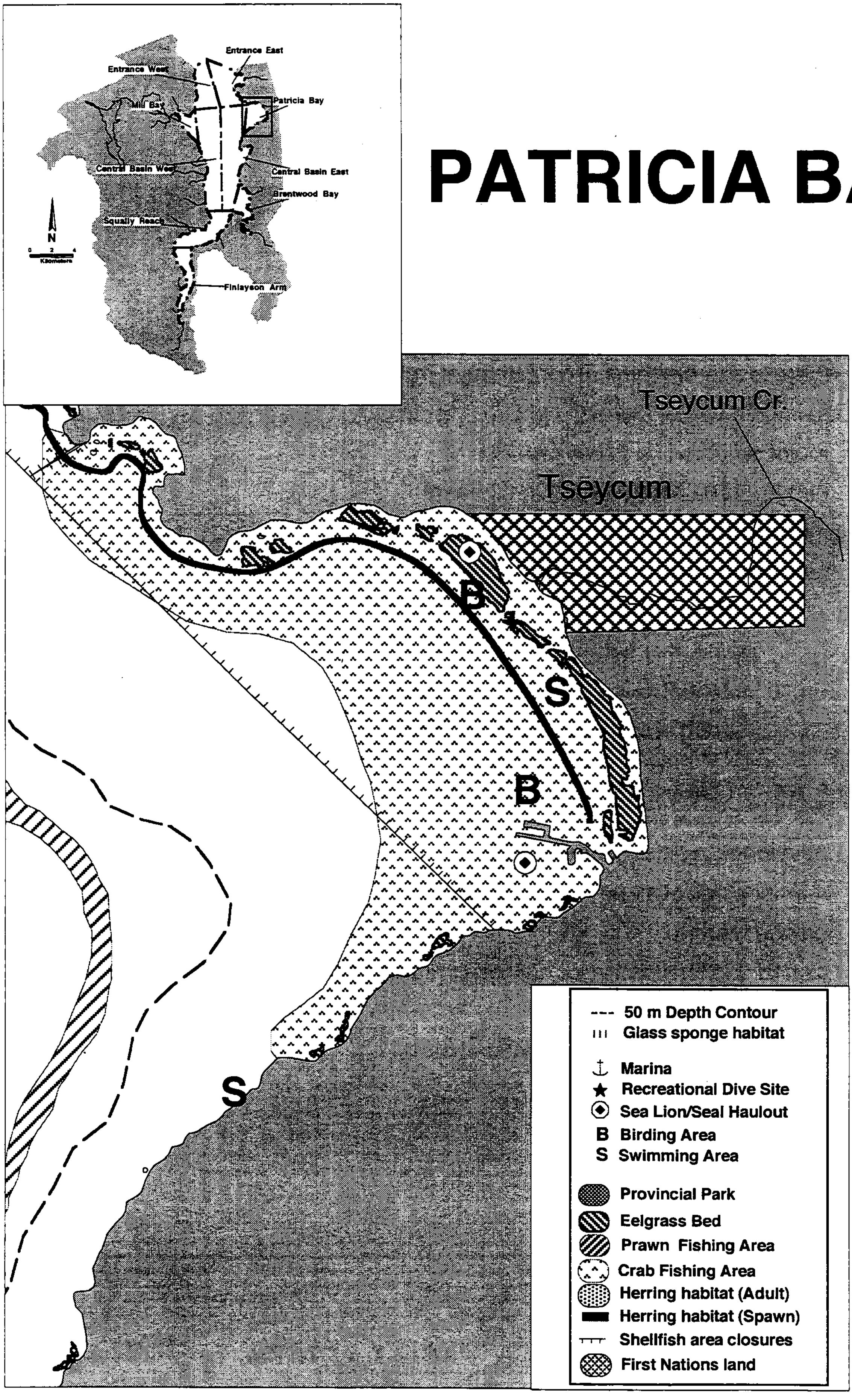
ENVIRONMENTAL STATUS

- water circulation is moderate
- coliform bacteria exceed shellfish criteria (highest levels in the inlet)
- there is some chemical contaminant input from Deep Cove Creek
- salmonid use of Deep Cove Creek is unknown
- major eelgrass beds are present
- herring have not spawned in 23 years
- harbour seal haulouts exist
- sensitive environments include:
  - eelgrass beds (major beds present)
  - productive soft-bottom invertebrate community
  - potential salmonid spawning habitat in Deep Cove Creek
  - rearing area for chinook and coho smolt (summer/fall)

USES AND CHARACTERISTICS

- developed residential foreshore
- 4 archeological sites
- private marina
- closed shellfish beds (for harvest) resulting from fecal contamination
- recreational fishing areas
- significant swimming and diving spots

PATRICIA BAY



PATRICIA BAY

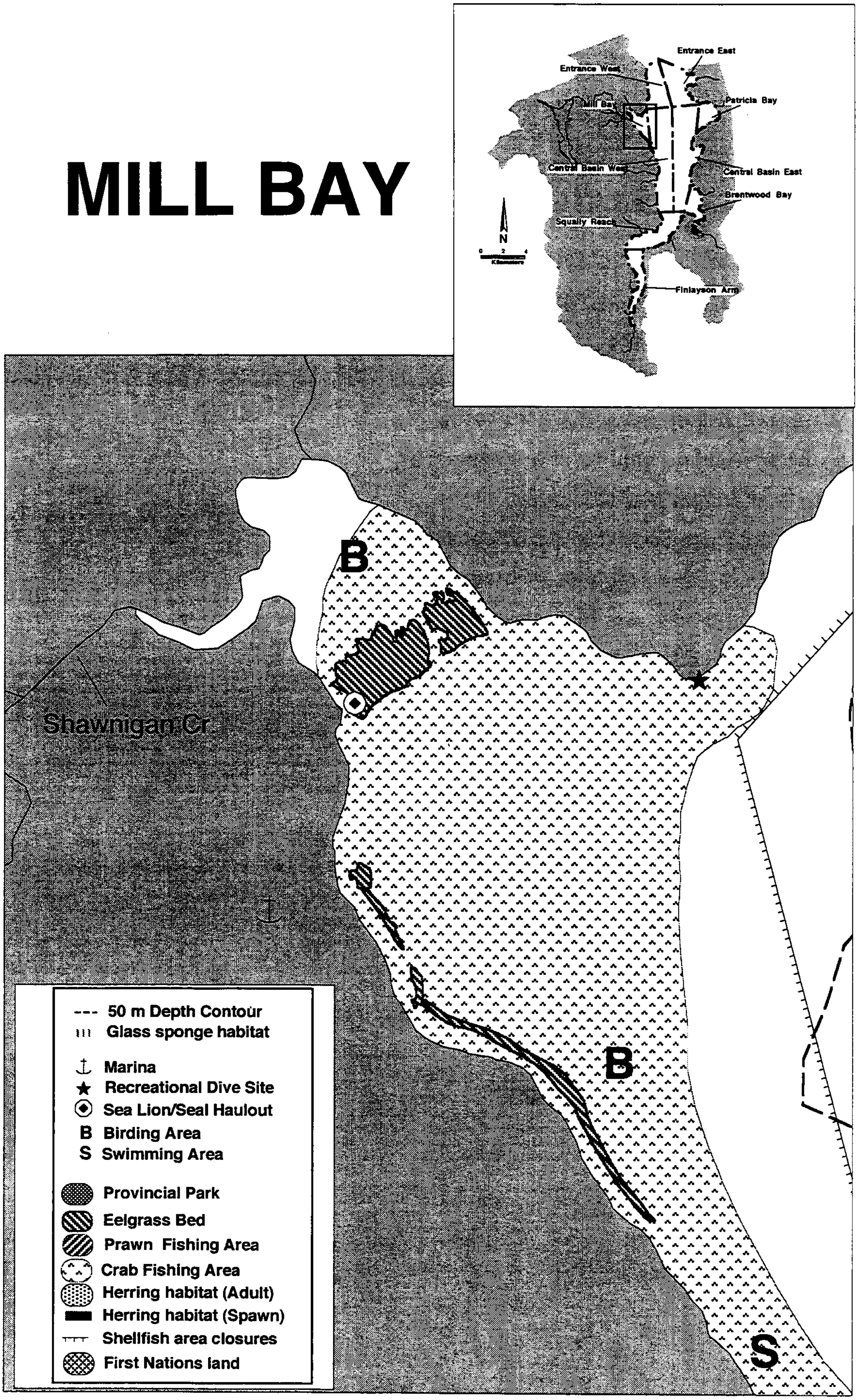
ENVIRONMENTAL STATUS

- water circulation is moderate
- coliform bacteria exceed shellfish criteria
- chemical contaminant concentrations are elevated in Airport Creek
- there is historical salmonid use of Tseycum Creek; habitat is presently degraded
- herring have not spawned in 23 years
- harbour seal and seal lion haulouts exist
- sensitive environments include:
    - eelgrass beds (large beds present)
    - productive soft-bottom invertebrate community
    - salmonid spawning habitat in Tseycum Creek
    - salmonid smolt rearing area

USES AND CHARACTERISTICS

- urbanized and industrialized foreshore; Institute of Ocean Sciences facility and float plane operation
- Tseycum Village on waterfront
- 8 archeological sites
- closed shellfish beds (for harvest) resulting from fecal contamination
- recreational fishing areas
- some swimming and diving spots
- birding areas
- Patricia Bay Park

MILL BAY


Entrance East
Entrance West
Patricia Bay
Mill Bay
Central Basin West
Central Basin East
Brentwood Bay
Squally Reach
Finlayson Arm
N
0 2 4
Kilometers
B
Shawnigan Cr.
B
S
--- 50 m Depth Contour
ııı Glass sponge habitat
⚓ Marina
★ Recreational Dive Site
◉ Sea Lion/Seal Haulout
B Birding Area
S Swimming Area
Provincial Park
Eelgrass Bed
Prawn Fishing Area
Crab Fishing Area
Herring habitat (Adult)
Herring habitat (Spawn)
Shellfish area closures
First Nations land

MILL BAY

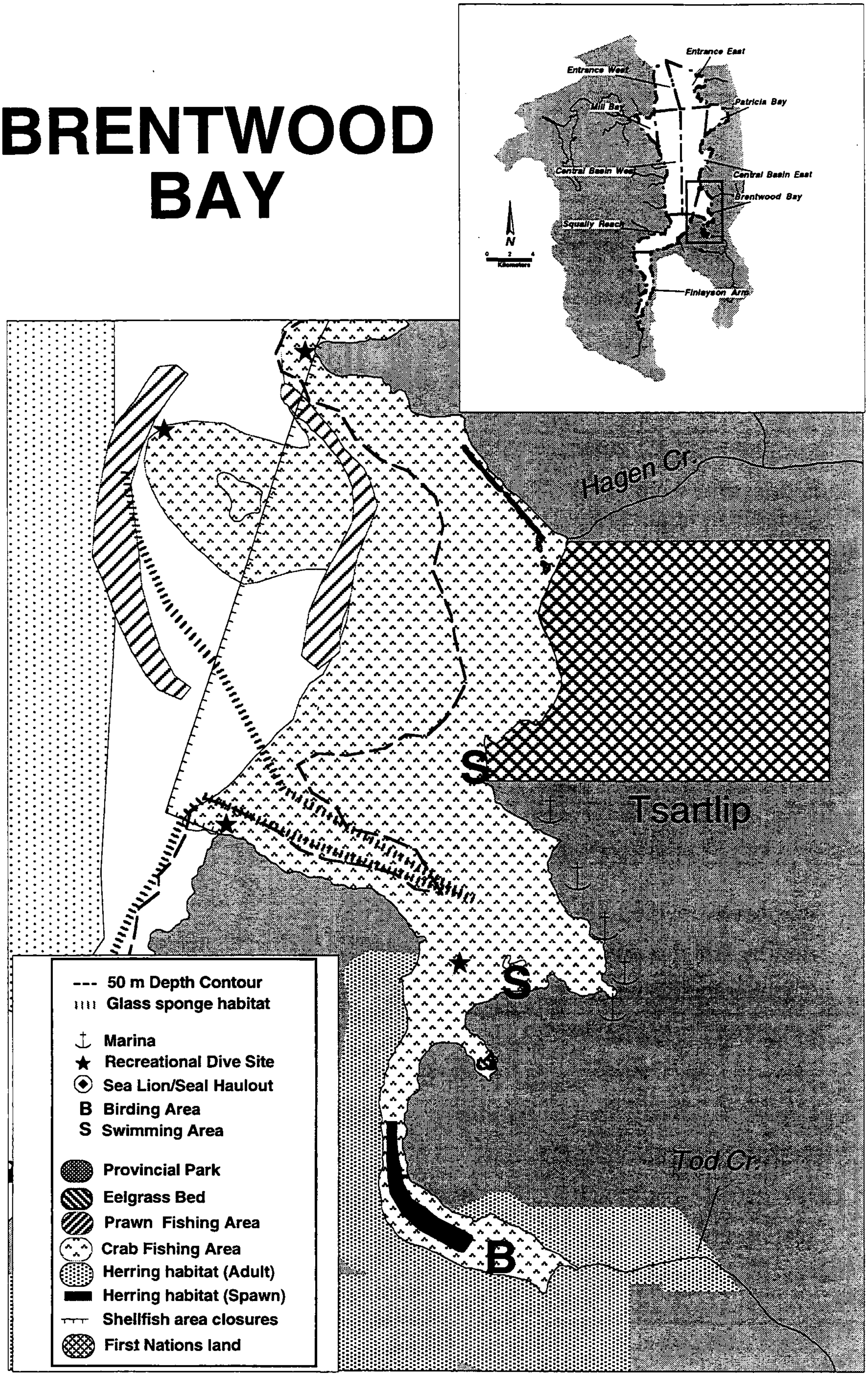
ENVIRONMENTAL STATUS

- water circulation is moderate
- coliform bacteria exceed shellfish criteria
- there is a small sewage discharge which is the only point-source discharge in the inlet
- low chemical contaminant concentrations occur in lower Shawnigan Creek
- impassable waterfall is close to mouth of Shawnigan Creek, but coho have been introduced upstream
- there is a seal haulout in marina
- sensitive environments include:
    - eelgrass beds
    - productive soft-bottom invertebrate community
    - rocky shores with high biodiversity south of Bay

USES AND CHARACTERISTICS

- moderate development of foreshore
- nearby Malahat Village
- 7 archeological sites
- small ferry terminal nearby
- boating use; 1 marina with fuel dock
- closed shellfish beds (for harvest) resulting from fecal contamination
- recreational fishing areas
- limited swimming; some diving spots
- birding areas
- Mill Bay Nature Park

BRENTWOOD BAY



BRENTWOOD BAY

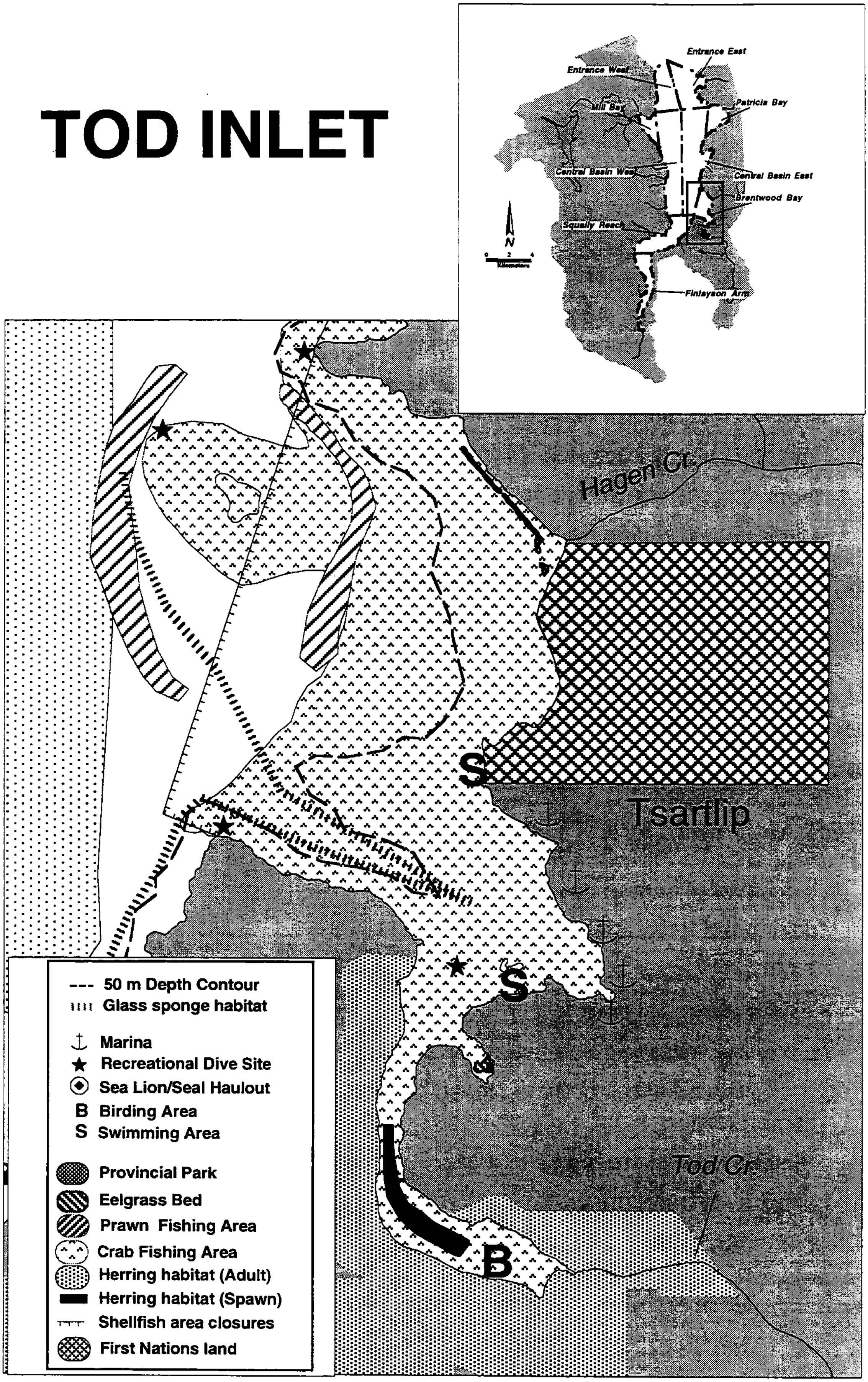
ENVIRONMENTAL STATUS

- water circulation is low
- coliform bacteria exceed shellfish criteria; there are numerous sources of coliform input, including Hagan Creek
- there are high chemical contaminant concentrations in marine sediments (based on limited sampling, extent unknown)
- Hagan Creek is impassable for salmonids close to mouth
- there is some tidewater use of Hagan Creek by salmon
- sensitive environments include:
  - rocky shores with high biodiversity
  - glass sponge habitat on seaward edge of Brentwood Bay (sensitive to sedimentation and physical disturbance)
  - some eelgrass beds

USES AND CHARACTERISTICS

- high level of human use
- developed foreshore
- Tsartlip Village
- 13 archeological sites
- 5 marinas including boat haul-out facilities
- 2 shellfish beds out of 3 are closed (for harvest) as a result of fecal contamination
- recreational fishing areas
- some swimming areas
- numerous small parks (e.g., Verdier, Brooks, Ravine Parks)

TOD INLET


Entrance East
Entrance West
Mill Bay
Patricia Bay
Central Basin West
Central Basin East
Brentwood Bay
Squally Reach
Finlayson Arm
N
0 2 4
Kilometers
Hagen Cr.
S
Tsartlip
S
B
Tod Cr.
--- 50 m Depth Contour
IIII Glass sponge habitat
⚓ Marina
★ Recreational Dive Site
◈ Sea Lion/Seal Haulout
B Birding Area
S Swimming Area
Provincial Park
Eelgrass Bed
Prawn Fishing Area
Crab Fishing Area
Herring habitat (Adult)
Herring habitat (Spawn)
Shellfish area closures
First Nations land

TOD INLET

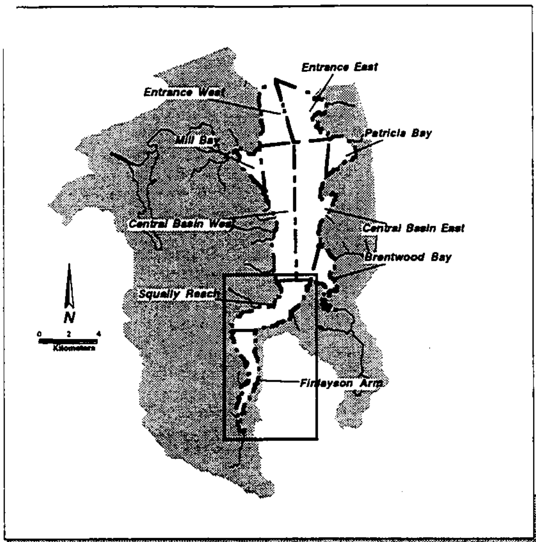
ENVIRONMENTAL STATUS

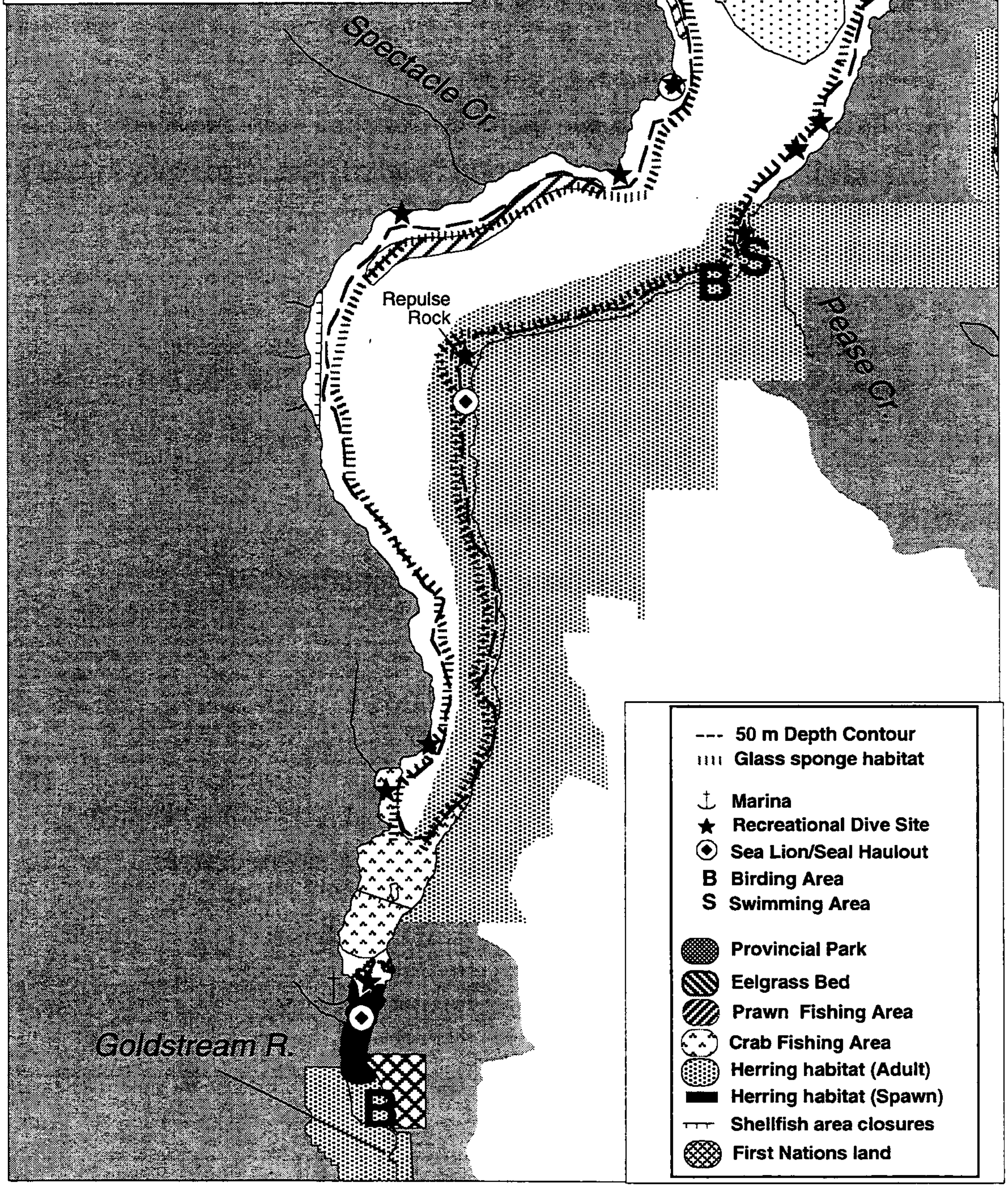
- coliform bacteria exceed shellfish criteria
- there are high chemical contaminant concentrations in Tod Creek and inlet sediments (based on limited sampling; extent unknown)
- limited salmon spawning habitat in Tod Creek is in poor condition; coho are extinct
- herring have not spawned in 23 years
- historical eelgrass beds have apparently disappeared or declined
- has lowest soft sediment biodiversity in Saanich Inlet, which may indicate impact of chemical contaminants or fine sediments
- sensitive environments include:
  - salmon spawning habitat in lower Tod Creek
  - soft-bottom invertebrate community
  - eelgrass beds

USES AND CHARACTERISTICS

- moderate level of human recreational use; not urbanized
- largely parkland foreshore
- 3 archeological sites
- Boat Club
- historically used as quarry
- closed shellfish beds (for harvest) as a result of fecal contamination
- recreational fishing areas for numerous fish and invertebrates
- high self-powered small boat use
- waterskiing
- birding area
- Gowlland-Tod Provincial Park

SQUALLY REACH
FINLAYSON ARM





SQUALLY REACH/FINLAYSON ARM

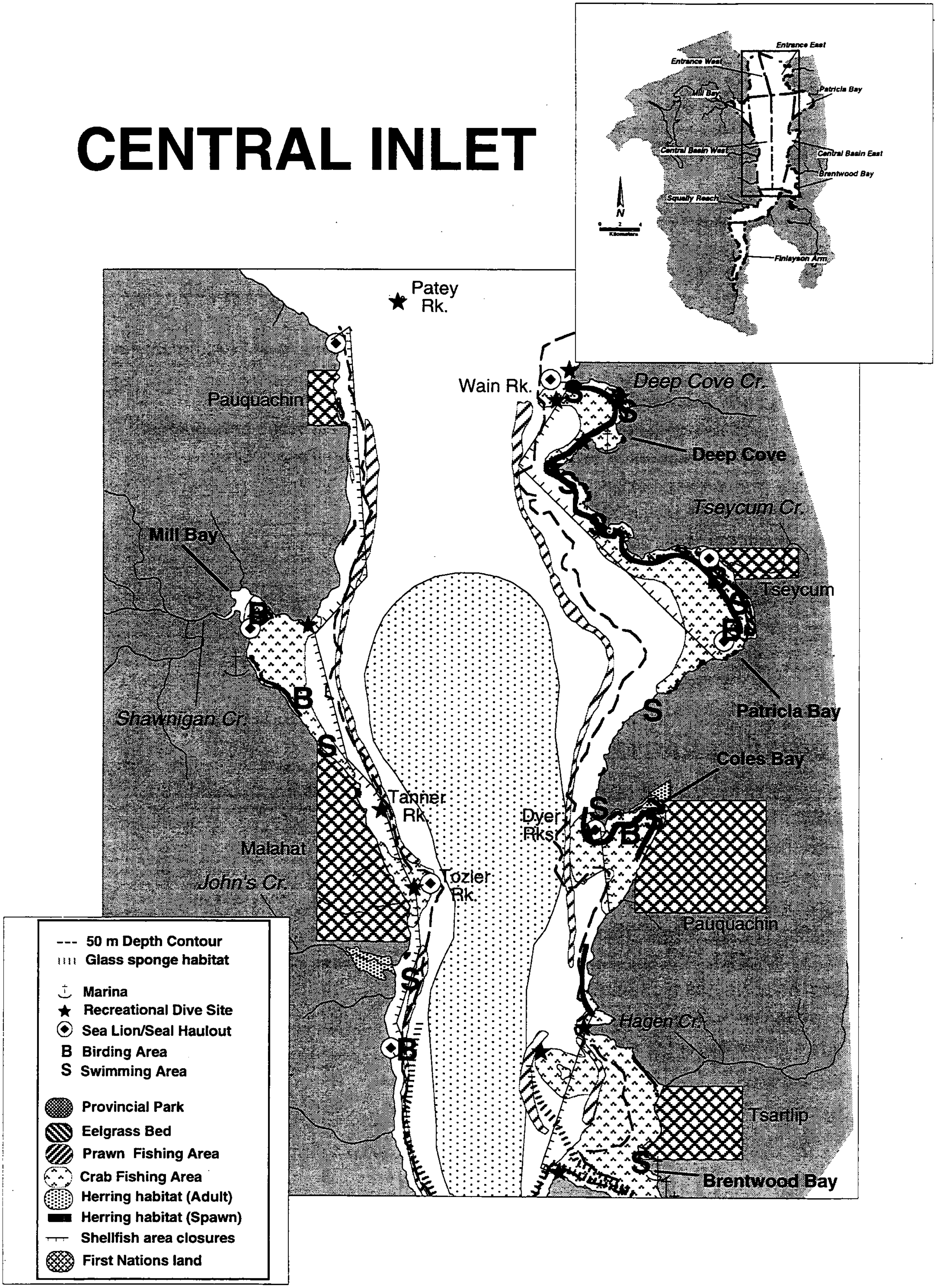
ENVIRONMENTAL STATUS

- water circulation is moderate in surface waters, low in intermediate waters, with poorly flushed deep waters
- deep waters below approximately 75 metres have little or no oxygen and have unusual marine life (natural condition)
- observation that episodes of increased turbidity (i.e., sedimentation) in water may be related to slope failures
- there are low chemical contaminant concentrations in sediments of Goldstream River and Estuary
- eelgrass beds are present in Goldstream Estuary
- there is good salmon spawning habitat in Goldstream; active stock enhancement
- there is little information on salmonid use of Spectacle and Pearse Creeks
- harbour seal haulouts exist
- herring have not spawned in 23 years
- there is a commercial crab fishery off Goldstream Estuary
- sensitive environments include:
  - salmon spawning habitat in Goldstream River
  - productive soft-bottom community near estuary
  - rocky shores with high biodiversity
  - significant glass sponge habitat
  - eelgrass beds

USES AND CHARACTERISTICS

- low level of human use (except for the estuary at Goldstream Park); upland and estuarine areas are parkland on east shore
- western shore subject to low density development
- First Nations land at Goldstream
- 20 archeological sites
- boating activity, 1 small marina
- two of three shellfish beds are open for recreational harvest; closed bed used for commercial depuration (purifying) harvest
- recreational fishing areas
- some swimming spots and diving sites
- birding area
- Gowlland-Tod Provincial Park
- Goldstream Provincial Park

CENTRAL INLET



CENTRAL INLET

ENVIRONMENTAL STATUS

- surface waters and intermediate layer waters are moderately flushed, with poorly flushed bottom waters
- deep waters below approximately 75 metres have little or no oxygen, and unusual marine life (natural condition)
- Johns Creek is a source of fecal contamination
- productive salmonid and shellfish areas exist
- this area is an historic adult herring holding area
- harbour seal and sea lion haulouts exist
- sensitive environments include:
    - productive soft-bottom invertebrate community
    - glass sponge habitat
    - diverse intertidal/subtidal communities
    - eelgrass in Coles Bay

USES AND CHARACTERISTICS

- historic use of Bamberton by a cement plant
- numerous archeological sites
- Pauquachin Village at Coles Bay
- Malahat Village near Mills Bay
- closed shellfish beds (for harvest) resulting from fecal contamination
- recreational fishing areas
- some swimming and diving sites
- birding areas
- Bamberton Provincial Park
- Coles Bay Regional Park

12. MAJOR FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Saanich Inlet, British Columbia has several attributes that make it an important and sensitive ecosystem - physically, ecologically and culturally. The inlet is a fjord, with unusual features related to water circulation and the presence of a natural deep layer of poorly-oxygenated water. Saanich Inlet has a number of special and sensitive species which are supported by the unusual physical characteristics of the inlet. Together, the inlet's relatively low flushing rate and coastal ecology make it sensitive to human influence. In addition, Saanich Inlet has high human value and supports important cultural and recreational uses. The area is world-renowned for its beauty. It is ironic that the values and uses of Saanich Inlet that attract humans can suffer degradation due to the influx of people and related pressures.

The concept of assimilative capacity applied in the Saanich Inlet Study is intended for use as a management tool to effectively direct protection and remediation efforts, as opposed to "a pollute-up-to-level". Contaminants include fecal contamination (as indicated by measurement of fecal coliform bacteria), nutrients associated with human and domestic animal wastes, chemicals (e.g., hydrocarbons from fuels and oils, chemicals associated with fertilizers and pesticides, heavy metals from street runoff) and suspended sediments.

It is important that the various indices of assimilative capacity (i.e., measurements or criteria indicative of "health" for each component in the Synthesis Report) be integrated so that decisions are made in the context of the whole system. In addition, the geographical and technical boundaries of the study need to be clearly delineated to ensure that the conclusions and recommendations are reviewed in context.

Geographical Boundaries: The study focused on the waters of Saanich Inlet and, to some extent, the fresh water tributaries. However, there are a number of factors outside Saanich Inlet which influence its physical, chemical and biological nature. For example, water from the Straits of Georgia enters Saanich Inlet carrying nutrients, sediments and phytoplankton. Also, the Fraser River and Cowichan River contribute to sediment loading in Saanich Inlet. For biota such as salmon, herring and marine birds influences outside of Saanich Inlet affect their abundance in Saanich Inlet.

Technical Boundaries: Catastrophic events such as landslides, underwater turbidity currents and inversion of the anoxic layer were not included in this evaluation. In addition, global processes such as ozone depletion, associated increases in ultraviolet radiation, and potential global warming could have profound impacts on ecosystem function and, hence, human activities. These potential global processes cannot be accounted for in this baseline study. However, such significant threats underlie the urgency of ensuring ecosystems are managed to maintain maximum biodiversity in order that they may withstand these stresses, as well as the more localized stresses addressed in this study. Therefore, the Precautionary Principle was applied so that protective assumptions were made, with greater caution applied when uncertainty was high.

During the course of this study, a great deal of information was compiled to form the basis for making predictions and drawing conclusions. Saanich Inlet is one of the best studied aquatic systems in B.C.; however, data gaps and uncertainties remain. Throughout the Synthesis Report, the assumptions and certainty for each component are clearly stated, to place the findings in context. Overall, the level of certainty in the findings is reasonable, particularly given the extensive studies that have been conducted. However, model results must be viewed as illustrations of trends and relative comparisons, rather than absolute answers.

This section summarizes the major findings and recommendations of the Saanich Inlet Study. The authors want the readers to recognize that this summary report and the conclusions and recommendations presented here contain only select highlights from the baseline study. This report does not fully describe the depth of information in some areas and the lack of detail in other areas. The Saanich Inlet Study was a collaborative effort involving hundreds of residents, local First Nations, scientists and non-government organizations. Broad input was provided by a public Advisory Committee and a Technical Committee.

The Saanich Inlet Study has covered a range of topics and developed a number of tools which have the potential for future application:

- Public consultation on human water uses, values and concerns
- Consultation with First Nations regarding their concerns, values, cultural history and compilation of existing archaeological records
- Surveys of oceanographic properties
- Surface current surveys during winter and summer conditions
- Review of existing water quality information and environmental criteria
- Review of historical fisheries and marine life information

- Surveys of sensitive intertidal biota, boot and cloud sponge distribution and eelgrass habitat
- Surveys of sources of fecal contamination and computer modeling of fecal coliform dispersion
- Assessment of sediment chemical contamination and computer modeling of sediment transport
- Computer modeling of impact of nutrient enrichment on phytoplankton growth
- Computer modeling of rates of water exchange between various parts of the Inlet
- Computer modeling of fate for chemical contaminants in tissues and marine sediments, with prediction of assimilative capacity

The reader is urged to use the component documents listed in Appendix A for complete information for detailed evaluation and decision-making. These tools can be used to explore specific questions and assist our understanding of processes in Saanich Inlet.

12.1 SAANICH INLET STUDY CONCLUSIONS

1. Saanich Inlet is a highly valued place.

Overwhelming participation rates at public open houses confirmed the high level of interest in Saanich Inlet (Howie, 1995). Public response at the open houses indicated that the characteristics most highly valued were the natural beauty and scenery, plant and animal life, recreational opportunities, cultural/spiritual qualities, peace and solitude.

The high value placed on these characteristics is reflected in the resolutions of many surrounding municipal councils and Official Community Plans. These documents spell out the need to protect various qualities of the area such as natural and scenic features, water quality, open space, wildlife resources, rural character, and outdoor recreational areas (see also Section 2). Communities have also called for designation of the area as a marine park or some form of "protected area". This suggestion was strongly supported by open house participants.

Another indication of the high value placed on the area is the strong public resistance to siting an outfall in the inlet. Regulatory agencies have approved only one point source discharge and have maintained a practice of not approving further discharges in the absence of detailed studies.

Saanich Inlet is valued by First Nations as an inextricable link to their culture (Simonsen et al., 1995). The area has special significance related to the numerous remains of aboriginal camps, villages, processing areas, sacred grave sites and other features which make up the archaeological record of the inlet people. Past and present traditional activities such as hunting, fishing, shellfish gathering, food and medicinal plant gathering, spiritual practices and a host of other traditions are focused on the land and the sea of Saanich Inlet.

In addition, the aesthetic and recreational value of Saanich Inlet is a major factor in attracting tourism to Southern Vancouver Island, one of the most important economic generators in the region.

2. Highly valued characteristics of Saanich Inlet, including aesthetic, cultural, spiritual and environmental attributes, have been degraded or diminished.

The very characteristics that make Saanich Inlet such a highly valued place attract the human use and development that threaten the maintenance of its aesthetic appeal, cultural and spiritual significance, and environmental quality.

Open house participants expressed the belief that their enjoyment of the inlet has reduced over time (Howie, 1995). They were particularly distressed over reductions in the scenic beauty of the area resulting from increased development. Also noted was a reduction in the peace and solitude of the area related to increased noise (often linked to power boats and "seadoos") and increased use of the area. Other changes perceived by participants were loss of fishing opportunities, loss of plant and animal life, and a decrease in water quality.

Characteristics valued highly within First Nations communities have been lost and degraded (Section 2). Among these are privacy and solitude, access to important cultural sites, integrity of sacred grave sites, and the opportunity for sustenance and cultural use of natural resources. First Nations consulted during the study expressed a feeling that their traditional culture has been lost as a result of land alienation and disappearing natural resources (Simonsen et al, 1995; Calder and Mann, 1995). Further losses to the First Nations culture are not acceptable.

3. *Human Uses of Saanich Inlet have been degraded or diminished.*

The most apparent loss of use in Saanich Inlet is related to shellfish collection: 12 out of 15 shellfish beds are presently closed due to bacterial contamination (Sections 3, 8 and 10). This represents a significant loss for First Nations. Cumulative impacts have also resulted in dramatic reductions to the abundance and quality of many marine species such as salmon, herring, lingcod and rockfish. Again, this results in heavy loss for First Nations whose traditional fishing and hunting rights are guaranteed under the Douglas Treaties. It is clear that further loss of marine species in the inlet is not acceptable to First Nations.

Recreational fishing effort, as well as the catch of coho and chinook, has declined consistently since the 1980s (Drinnan et al., 1995; Section 10). The number of chinook taken annually by the Saanich Inlet recreational fishery declined from 15,000 - 25,000 fish in the early 1980s to less than 200 fish in 1994.

Open house participants expressed a decrease in their use of the inlet for swimming (Howie, 1995). This was related to a perception of reduced water quality. Information collected on recreational uses of Saanich Inlet pointed to a shift away from fishing and swimming towards more land-based activities such as hiking, walking, beachcombing and picnicking.

4. *Water circulation in Saanich Inlet is generally sluggish compared to adjacent waters.*

Water circulation in Saanich Inlet was examined using a number of approaches including review of existing data, collection of new data, and development of a mass balance model of physical oceanography. Saanich Inlet has been relatively well-studied from an oceanographic perspective so there was a significant amount of data available, summarized in Drinnan et al (1995) and Section 5. However, more data were needed to determine water circulation patterns in the inlet, so the Saanich Inlet Study conducted two drogue studies (Cross and Chandler, 1996; Cross, 1995). The oceanographic module of the mass balance model for Saanich Inlet (Section 5) was developed to represent mean circulation patterns. The oceanographic model is data-driven and essentially divides Saanich Inlet up into a series of boxes, representing water masses of similar characteristics.

Model assumptions, limitations and uncertainty are detailed in Section 5, but overall our confidence in the model for the purposes of the Saanich Inlet Study is reasonable, particularly given the conservative assumptions made. Therefore, the model results can satisfactorily be used to examine trends and compare relative differences in water circulation between different areas of Saanich Inlet. It should be noted that the oceanographic model was used as the basis for modelling sediment transport and chemical contaminant fate in Saanich Inlet, so any inherent uncertainties would also be carried into the results of those models.

A number of oceanographic processes in Saanich Inlet were examined such as surface and deep water circulation, salinity gradients, fresh water inflows from creeks and streams and deep water renewal patterns. The annual cycles of water circulation in the inlet were divided into five periods or seasons to represent conditions over time. In this way, "worst case" conditions for flushing and water circulation could be identified.

Based on the work reviewed and conducted by the Saanich Inlet Study, the inlet has the following oceanographic characteristics:

a) Tidal currents are generally weak and the vigorous tidal mixing, typical of adjacent straits and channels, does not occur.

b) The presence of a 70 m sill at the mouth traps the inlet's deep water creating a low oxygen water mass below a depth of approximately 100 m.

c) Estuarine circulation is weak or non-existent at times due to the absence of major rivers at the head and along the shores of the inlet; external influences, primarily from the Cowichan and Fraser Rivers, are at times the main source of fresh water entering the inlet.

d) Water residence times for many embayments are in the order of a few weeks, rather than hours to days as is the case for well flushed coastal areas. These physical attributes limit the capacity of the inlet to assimilate contaminants.

5. For fecal contamination and, in some areas, chemical contamination, the assimilative capacity of Saanich Inlet has been exceeded. Fish populations have declined dramatically and eelgrass and other aquatic habitats have been degraded. The inlet is sensitive to nutrient enrichment, specifically nitrogen, in surface waters.

A number of measures or indicators of environmental quality were used to determine the assimilative capacity and sensitivity of Saanich Inlet to the effects of contamination and marine habitat disturbance. For each measure, key findings are summarized below; note that in making a final determination of assimilative capacity, one should take into account the cumulative effects of all stressors.

Chemical Contamination

Chemical contamination was initially assessed by reviewing existing data. However, little information was available for Saanich Inlet. As part of the Saanich Inlet Study, Drinnan et al. (1995) collected new sediment quality data. The chemical fate model (Section 7) is based on a generic model developed by Dr. Gobas of Simon Fraser University that was modified for Saanich Inlet. As there are relatively few data, predictions of assimilative capacity were largely back-calculated based on criteria values. However, the combination of available data and modelling provides enough information to identify chemical contaminants as a stress to Saanich Inlet, as summarized below.

- A number of metals and polycyclic aromatic hydrocarbons exceed environmental criteria in marine sediments, specifically in Brentwood Bay and Tod Inlet; however, this finding is based on limited sampling and there is insufficient information available to evaluate the extent of chemical contamination.

- For fresh water tributaries, Tod Creek sediments were noted to exceed MELP criteria, particularly for the pesticide pp-DDT. Airport Creek and Hagan Creek have intermittent exceedances of water quality criteria. Data were largely non-existent for other tributaries.

- Based on computer model results, relatively low chemical loadings into the embayments are predicted to result in elevated chemical concentrations in sediment and tissue, particularly in Brentwood Bay and Tod Inlet. Squally Reach and Finlayson Arm are also vulnerable to chemical contamination due to their water circulation patterns.

Fecal Contamination

To assess fecal contamination, a number of approaches were used including review of existing information (Drinnan et al., 1995; Section 8), collection of new data (Section 8) and near-field modelling (Section 8). The modelling exercise was intended to illustrate some of the aspects of discharge plume behaviour, given various levels of wastewater treatment. Major findings are summarized below:

- The assimilative capacity of Saanich Inlet shellfish growing areas in nearshore waters is exceeded for coliform bacteria, which are indicative of fecal contamination. This is evidenced by the fact that 12 of 15 shellfish beaches are closed for harvesting due to fecal contamination.
- Coliform bacteria concentrations in deeper waters do not appear to be of concern.
- Fecal coliform bacteria are present in surface runoff to Saanich Inlet in high concentrations during and after rainfall events.
- Based on model results, for discharge at greater than 50 m below surface, the plume was predicted to become trapped and not rise to the surface for the limited range of conditions examined. Disinfection will greatly reduce the possibility of bacteria reaching surface waters, but oily particles will likely rise, carrying some bacteria. This model does not address the possibility of (1) effluent surfacing due to conditions of upwelling, winds or unusual oceanographic conditions and (2) the possibility of a plume impinging on the shoreline during times of shoreward surface currents, and thereby bringing effluent to the surface. These aspects would need to be examined to fully evaluate any discharge permit.

Nutrients

To predict the effects of nutrient additions to Saanich Inlet, a plume model developed by Drs. Tom Kessler and Tim Parsons was modified for Saanich Inlet (Section 9). A carbon/nutrient model characterized the hydrodynamics and biological fate of various scenarios of nutrient discharge to waters with the volume of a typical embayment. The nutrient of primary interest in marine systems is nitrogen. As such, the modelling exercise focused on predicting impacts related to the addition of nitrogen to the inlet. The model defines impacts (and hence assimilative capacity) as the presence or absence of abnormal phytoplankton and bacterial blooms (i.e., standing stocks outside of the normal seasonal variability) in surface waters of Saanich Inlet. The level of confidence in this model and its findings is reasonable as extensive data were used to develop the model and its accuracy has been demonstrated elsewhere (Section 9).

The model was applied to a range of scenarios including various loadings, times of year, and depths of discharge. It should be noted that shifts in species composition may result when changes in the ratios of different nutrients in surface waters occur. Changes in the species composition in the embayments have been documented for a single sampling episode (Appendix C). This kind of impact cannot be modelled, but should be included in any evaluation of a wastewater discharge.

A summary of findings is provided below:

- The annual anthropogenic nutrient loading to Saanich Inlet contributes an insignificant amount (less than 1%) to the inlet's net nutrient flux, when considered on an inlet-wide basis. There is no evidence of general nutrient enrichment of the inlet, although there have been observations of green algal mats in intertidal areas.
- The nutrient of primary interest in Saanich Inlet is nitrogen; phosphorus inputs are not considered critical.
- Based on model results, nutrient addition to waters less than 50 m deep is predicted to cause blooms of phytoplankton, which is indicative of negative effects.
- Based on model results, it is predicted that nutrient addition (small community scenarios for untreated wastewater, as a conservative assumption) to waters greater than 50 m deep will not cause negative effects.

Fisheries Populations

There is a significant amount of information on the status of fisheries of Saanich Inlet, as reviewed by Drinnan et al. (1995) and Section 10. In addition, there is a wealth of anecdotal information about historic fish status and the changes in fisheries. As there is great interest in restoring fish populations, Section 10 makes specific remedial recommendations. Major findings with respect to fishery populations are summarized below:

- There have been significant reductions in recreational fisheries, including chinook, coho and ling cod. The causes are not clear, but likely include broad-scale effects (e.g., oceanographic changes, harvesting).

- Herring are considered to be an important component of the marine ecosystem of Saanich Inlet, serving as a primary food source for salmon. Herring have not spawned in significant numbers in Saanich Inlet since 1972 and there has been a general decline of stocks in the southern Gulf Islands over the last decade. However, herring stocks in the Straight of Georgia are relatively healthy.

- The status of dogfish and flatfish is poorly documented.

- Declines in fish populations are due to effects both within and outside of Saanich Inlet. Potential effects within the inlet include: habitat damage, reduced food supply, harvesting and chemical contamination. Potential effects outside of the inlet include: climate change, oceanographic changes, harvesting, habitat damage and food supply.

- Prawn abundance appears healthy, based on fishery results since 1985; however, the impacts of the commercial fishery are unknown. The status of euphausiids is unknown.

- Crab populations appear healthy, although Dungeness crab tend to be less abundant.

Eelgrass Beds

Eelgrass beds are considered to be an important component of a healthy ecosystem, due to their productivity and provision of valuable habitat for other organisms. In cooperation with the Department of Fisheries and Oceans, the Saanich Inlet Study conducted an investigation into eelgrass distribution and health in Saanich Inlet (Austin et al., 1996). Currently 40.9 ha of healthy eelgrass beds exist in Saanich Inlet.

- Eelgrass beds occur where expected with the significant exception of Tod Inlet, where none were found.

- A significant portion of eelgrass beds are composed of an introduced exotic species of eelgrass.

Aquatic Habitat

Aquatic habitats were described by the Saanich Inlet Study by Drinnan et al. (1995) and Austin et al. (1996). New information was collected under the auspices of the Saanich Inlet Study in surveys of intertidal habitat, boot sponge habitat and eelgrass distribution.

- Stream habitat in Tod Creek and Tseycum Creek is in poor condition, and the status of many other streams is not well documented.

- Some intertidal and foreshore areas are prone to disturbance from beach use.
- Boot and cloud sponges are found in deep waters of Saanich Inlet.

6. Several marine species are sensitive to disturbance and contamination.

Marine species such as glass (cloud and boot) sponges and other invertebrates, appear to have healthy populations but are considered at risk due to their sensitivity to direct physical disturbance, habitat loss, and sedimentation. Such species are vulnerable to any activity that resuspends aquatic sediments or causes terrestrial sediments to enter Saanich Inlet. Many marine invertebrate species are long-lived (60-100 years for sponges); therefore, if they are damaged, recovery could take decades. Sedimentation is also an issue in fresh water tributaries to Saanich Inlet, since salmon spawning beds are sensitive to clogging by fine sediments.

7. Declines in fish populations are due to causes both outside of and within Saanich Inlet.

Larger scale factors (e.g., El Niño, potential global warming, fisheries management practices) affecting fisheries production for the Georgia Basin and the Pacific Coast are considered the primary cause of reductions of herring, and coho and chinook salmon which previously frequented Saanich Inlet (Section 10). For example, herring spawning habitat is available in Saanich Inlet, so it is possible that their absence is related to factors outside Saanich Inlet. Local stresses to fish populations include harvesting, changes in predator populations, and degradation of foreshore and stream habitat. On the positive side, the stream clean-up and hatchery activities have enhanced salmon returns to Saanich Inlet. This is a good example of what can be achieved with restoration efforts.

8. Non-point sources are at present the primary source of contaminants to Saanich Inlet.

Non-point sources (NPS) to Saanich Inlet include: storm water; ineffective septic systems; runoff from residential, agricultural and residential lands; atmospheric deposition; and spills and leaks from boats and marinas. These are likely the primary sources of contaminants to Saanich Inlet. A treated sewage discharge in Mill Bay is the only point-source discharge in Saanich Inlet.

Very little information about non-point source pollution has been collected in coastal British Columbia, including Saanich Inlet.

9. ***Saanich Inlet has been subject to cumulative impacts which can result from individually minor - but collectively significant - damage over time.***

If the trend of incremental degradation continues, the environmental quality of Saanich Inlet will worsen. In particular, if non-point pollution sources continue to increase it is expected that further environmental degradation of the inlet will occur. Therefore, it is important that impacts of specific stresses to Saanich Inlet be viewed in the context of all stresses.

10. ***Fecal contamination in storm water and runoff flowing over beach areas during and following heavy rainfall raises potential health concerns for beach users during these periods.***

Fecal coliforms indicate the presence of microorganisms that may be harmful to human health. Fecal coliform contamination of nearshore areas of Saanich Inlet is well-documented (Drinnan et al., 1995; Section 8) and responsible for closures of shellfish beaches; the assimilative capacity has been exceeded. To identify the sources of fecal contamination, the Saanich Inlet Study conducted an investigation of storm water and runoff entering Saanich Inlet (Section 8). During dry periods, fecal coliform levels in fresh water runoff and nearshore areas of Saanich Inlet were relatively low, but during and following heavy rainfall, coliform levels increased significantly. While coliform criteria for primary contact were rarely exceeded in marine waters, the flows of fresh water over beaches contained coliform levels that raise potential health concerns for beach users during and after heavy rainfall periods. Recreational bathing closures have not been posted in the past due to the timing of sampling and the seasonality of beach use.

11. ***Embayments and isolated reaches such as Mill Bay, Finlayson Arm, Tod Inlet, Brentwood Bay, Coles Bay, Patricia Bay and Deep Cove are most vulnerable to environmental degradation.***

There are localized environmental problems in several areas in Saanich Inlet. Embayments are most vulnerable to environmental degradation due to their proximity to stresses, lower water circulation and sensitive ecology. For example, most embayed areas are closed for shellfish harvest due to fecal coliform contamination. In a limited survey of marine sediment quality (Drinnan et al., 1995), chemical contamination was found in Brentwood Bay and Tod Inlet. Some creeks discharging to embayments exceed water quality criteria (e.g., Airport Creek and Hagan Creek) and sediment quality criteria (e.g., Tod Creek). Embayments and isolated reaches also tend to have the lowest water circulation, so flushing of bacterial and chemical contaminants is relatively low. The shallower waters of embayments tend to provide habitat for important species such as eelgrass, juvenile fish, and shellfish (Section 10). Finally, human habitation and activity is often concentrated around embayments and isolated reaches, which places potential stresses in close proximity to sensitive marine resources.

12. Saanich Inlet is a threatened but still largely viable ecological system.

Despite the present levels of degradation which have affected human uses and values, ecological processes are still functioning. The uses and values of Saanich Inlet can be maintained and/or improved by implementing the recommendations of the Saanich Inlet Study. Saanich Inlet would likely not return to pristine conditions, due to irreversible influences such as introduced exotic species introductions, species loss, influences from outside the inlet, alteration of fresh water flows, habitat loss and the non-point source effects of land use. However, there is an opportunity here to halt the degradation and restore the environmental quality of Saanich Inlet.

12.2 SAANICH INLET STUDY RECOMMENDATIONS

1. The level of protection afforded to Saanich Inlet must be based on the most sensitive human or ecological use and must be consistent with human values. The Precautionary Principle must apply where there is uncertainty or missing information. The concept of assimilative capacity must not be viewed as a “pollute-up-to-level”, but rather as a tool to effectively direct protection and remediation efforts.

2. Within the Saanich Inlet watershed, all levels of government must coordinate and clarify their environmental responsibilities with a view to protecting and enhancing the health of Saanich Inlet. Ecosystems are not bounded by jurisdictional lines. Points of reference must focus on the inlet, not jurisdictional compartments. All levels of government and jurisdictions need to work together in the interests of the ecosystem, perhaps by forming a body to aid in implementing study recommendations.

3. The environmental issues identified in Saanich Inlet must be ranked from a watershed perspective, relative to the risk they pose, and solutions should be applied in order of priority.

4. The theme of Conservation, Protection and Restoration must be applied when considering remedial action.

5. Management of Saanich Inlet must be directed towards maintaining and improving biodiversity and preventing further environmental degradation.

6. Source control actions for non-point sources must be implemented using an integrated approach to address chemical contaminants, bacterial contaminants as well as sediment loading.

7. Comprehensive legislative, policy and technological tools are needed to assist all levels of governments to adequately manage non-point source contaminant issues related to land and water use. Regulations, policies and technologies to control non-point source contaminants are not well developed.

8. Education programs and community stewardship initiatives should be supported to ensure local residents are involved in source control of contaminants, habitat enhancement and monitoring programs. Education programs should reach residents, farmers and developers. Source control cannot be effective without public participation.

9. To effectively address environmental issues in Saanich Inlet, the Cowichan Valley Regional District's Regional Growth Strategy and the Capital Regional District's Regional Growth Strategy to be prepared under the *Growth Strategies Statutes Amendment Act* need to be linked. These initiatives must utilize the findings of the study and guidance from these initiatives should be applied to land and water use decisions made by all jurisdictions bordering on Saanich Inlet. The link between the land and the water cannot be broken.

10. The relative merits and disadvantages of various technologies (e.g., on-site treatment/disposal, community treatment plants, regional treatment plants) need rational examination in the context of the study findings, local liquid waste management plans and the planned regional growth management initiatives. Present practices with respect to conventional septic disposal system design, siting, monitoring, enforcement and operation are not sufficient.

11. More emphasis must be placed on habitat protection and restoration for aquatic ecosystems. Biodiversity is particularly sensitive to habitat degradation and loss.

12. Habitat buffer zone guidelines for stream and foreshore environments need to be implemented to protect aquatic systems.

13. Land development practices must minimize sedimentation and runoff; for example, avoidance of steep areas, use of retention ponds and constructed wetlands, appropriate surface drainage systems and post-development planting.

14. First Nations values and uses must be considered in context of their long term historical presence in the Saanich Inlet area. Land use and development decisions that affect First Nations must involve consultations to determine whether or not there will be infringement of existing aboriginal rights or Douglas Treaty rights.

15. For harvested marine species, including species traditionally used by First Nations, fishing policies for commercial, First Nations and recreational groups should be reexamined, with a renewed emphasis on conservation, protection and restoration.

16. Further investigation of chemical concentrations in sediments is needed in areas where the limited sampling has indicated a problem. Sediment sampling identified areas that exceed provincial criteria, but the extent and sources of contamination is unknown.

17. Development proposals in the vicinity of Saanich Inlet must be assessed in terms of their impact on the environment, and the following should apply:

    a) All environmental impacts related to a given proposal should be considered, and not be confined only to those required by regulation or permit. Attention to non-point source contaminants is a high priority, given the sensitivity of the nearshore where assimilative capacity is exceeded in many areas of Saanich Inlet.

    b) For any proposed point-source discharge to Saanich Inlet, the suitability of discharge locations or treatment technologies cannot be based on the findings of the Saanich Inlet Study alone. Site-specific studies are required to tailor the impact assessment and reduce uncertainty, so good decisions can be made.

    c) A cumulative effects approach, in which Saanich Inlet is considered in its entirety, should guide the evaluation of developments, land use and water use. Several small developments may have cumulative effects equal to or greater than a single large one, particularly with respect to non-point sources.

d) The inlet should also be viewed as an important part of a larger system, encompassing the Georgia Basin, particularly with respect to fisheries issues.

13. REFERENCES

Abbott, D.P. and A.T. Newberry. 1980. Urochordata: the tunicates pp. 177-226. In: Morris, R.H., D.P. Abbott and E.C. Haderlie (eds). Intertidal invertebrates of California. Stanford Univ. Press, Stanford.

Anderson, J.J. and A.H. Devol. 1973. Deep water renewal in Saanich Inlet, an intermittently anoxic basin. Estuar. Coast. Mar. Sci. 1:1-10.

Anonymous. 1995. British Columbia Greenhouse Gas Action Plan. November 1995. Ministry of Energy, Mines and Petroleum Resources and Ministry of Environment, Lands and Parks. 49 pp.

APHA (American Public Health Association). 1995. Standard Methods for the Examination of Water and Wastewater. 19th edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

ASA Consulting Ltd. 1986. The Halifax Inlet water quality study: phase 2. Final report. Prepared for Metropolitan Area Planning Commission, Halifax, Nova Scotia.

Austin, W.C., S.P. Leys and C. Durance.1996. Saanich Inlet Study: Sensitive habitats and biota. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by Khoyatan Marine Laboratory, University of Victoria Department of Biology, and Precision Biological Consultants. In 3 parts: Part 1 - Assessment of Intertidal Sensitive Species & Habitats; Part 2 - Hexactinellid Sponge Habitats in Saanich Inlet; and Part 3 - Eelgrass Habitat Assessment.

Austin, W.C. 1984. Underwater birdwatching. Proceedings of a multidisciplinary symposium on Saanich Inlet. Juniper, S.K. and P.O. Brinkhurst (eds). Can. Tech. Rep. Hydrol. Ocean Sci. 38:83-89.

Baker, P.D. 1992. Low frequency residual circulation in Knight Inlet, a fjord of coastal British Columbia. M.Sc. Thesis, Department of Oceanography, University of British Columbia.

Barsdate, R.J. and N. Nebert. 1971. Copper and lead in the Southeast Berring Sea and adjacent areas. Proc. Alaska Sci. Conf. 22:113

Baumgartner, D.J., W.E. Frick and P.J. Roberts. 1994. Dilution models for effluent discharges (3rd edition). U.S. Environmental Protection Agency. Report EPA/600/R-94/086.

Bellamy, D.J., D.M. John and A. Whittick. 1968. The "kelp forest ecosystem" as a "phytometer" in the study of pollution of the inshore environment. In: Underwater Assoc. Rep. 1968. London. pp. 79-82.

Biodiversity Working Group. 1994. Canadian biodiversity strategy - Canada's response to the Convention on Biological Diversity. November 1994.

Bisson, P.A., T.P. Quinn, G.H. Reeves and S.V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. In: R.J. Naiman (ed) Watershed management - balancing sustainability and environmental change. Springer-Verlag, New York. pp. 189-232.

Black, E.A. 1984. The stomach content of Pacific cod, sablefish, and lingcod in the Queen Charlotte Straits 1978-1981. Fisheries Data Report no. 7. Fisheries Branch, Ministry of Environment, Province of British Columbia.

Blais, A. 1992. Holocene sediments from Saanich Inlet, British Columbia and their neotectonic implications; In: Current Research, Part A, Geological Survey of Canada, Paper 92-1A, pp. 195-198.

Blaxter J.H.S., F.S. Russell and M. Yonge 1980. Advances in Marine Biology. Volume 18. Part I. Academic Press. London.

Blecik, B. 1995. Personal communication (fax to S. Davidson, Sea Science). B.C. Ministry of Environment, Lands and Parks. 4 August.

Bobrowsky, P.T. and J.J. Clague. 1990. Holocene sediments from Saanich Inlet, British Columbia, and their neotectonic implications; In Current Research, Part E, Geological Survey of Canada, Paper 90-1E, pp. 251-256.

Bright, D.A. and D.V. Ellis. 1990. A comparative survey of imposex in northeast Pacific neogastropods (Prosobranchia) related to tributyltin contamination, and choice of a suitable bioindicator. Can. J. Zool. 68:1915-1924.

MELP (British Columbia Ministry of Environment, Lands and Parks). 1995a. Draft Guidelines and Standards Policy, 29 September.

MELP. 1995b. Approved and working criteria for water quality. ISBN 0-7726-2522-0.

British Columbia/Washington Marine Science Panel. 1994. The shared marine waters of British Columbia and Washington. A report to the British Columbia/Washington Environmental Cooperation Council. 109 pp. + appendices.

Broadland, K. 1996. Personal communication (telephone conversation with Dr. Bill Austin), B.C. Ministry of Environment, Lands and Parks, Conservation Officer, Duncan, B.C.

Buddemeier, R.W. 1969. A radiocarbon study of the varved marine sediments of Saanich Inlet, British Columbia: unpublished Ph.D. Thesis. University of Washington. Seattle.

Burrows, E.M. 1971. Assessment of pollution effects by the use of algae. Proc. R. Calder, A., Saanich Inlet Study Coordinator, Ministry of Environment, Lands and Parks. E-mail communication to EVS. September 8, 1995.

Burrows, E.M. and C.Pybus. 1971. *Laminaria saccharina* and marine pollution in Northeast England. Mar. Poll. Bull. 2:53-56.

Calder, A.M. and G.S. Mann. 1995. Saanich Inlet Study: Synthesis workshop summary, April 25/26, 1995. Compiled by EVS Consultants and Sea Science. Prepared for Water Quality Branch, Environmental Protection Department, B.C. Ministry of Environment, Lands and Parks.

Carmack. E. 1995. Personal communication (telephone communication with S. Davidson, Sea Science). Department of Fisheries and Oceans, B.C. July.

Casillas, E., J.E. Stein, M.R. Arkoosh, D.W. Brown, D.A. Misitano, S.L. Chan and U. Varanasi. 1993. Effects of estuarine habitat quality on juvenile salmon: I. Chemical contaminant exposure and II. Altered growth and immune function. In: Coastal Zone '93 Proceedings, The Eighth Symposium on Coastal and Ocean Management, New Orleans, LA. pp. 548-562.

CCME (Canadian Council of Ministers of the Environment). 1987. (Updated December 1995). Canadian water quality guidelines. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Ministers of the Environment. Ottawa, ON.

Chilibeck, B., G. Chislett and G. Norris. 1992. Land Development Guidelines for the Protection of Aquatic Habitat. Department of Fisheries and Oceans and B.C. Ministry of Environment, Lands and Parks. 128 pp.

Clark, B. 1995. Personal communication (letter to Michael Z'Graggen, Simon Fraser University, Burnaby, B.C. regarding feeding preferences of juvenile salmonids). Department of Fisheries and Oceans. Habitat Management Unit. June 1995.

Claxton, E., Sr. and J. Elliott, Sr. 1994. Reef Net Technology of the Saltwater People. Saanich Indian School Board, Brentwood Bay.

Coastal Zone Oceanography Section. 1980. Salinity/temperature profiles in Saanich Inlet, British Columbia. Pacific Marine Report. 80-5.

Cross, S.F. and P.C.P. Chandler. 1996. Saanich Inlet Study: Surface Circulation Patterns. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC by Aquametrix Research Ltd. 52 pp. + appendices.

Cross, J.N., Fresh, K.L., Miller, B.S., Simenstad, C.A., Steinfort, S.N. and J.C. Fegley. 1978. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of the common nearshore fish. NOAA Technical Memorandum ERL MESA-32.

Dalby, D.H. 1968. Some factors controlling plant growth in the intertidal environment. In The biological effects of oil pollution on littoral communities. Carthy, J.D. and Arthur, D.R. (eds) Field Studies 2, (Suppl.): 21-37.

Dawes, C.J. 1981. Marine Botany. Wiley, New York. 628 pp.

Dawson, E.Y. 1966 Marine Botany, an introduction. Holt, Rinehart, Winston, New York, 371 pp.

DFO (Department of Fisheries and Oceans). 1981. A handbook for fish protection on forest lands in British Columbia. Land Use Unit, Habitat Protection Division, Field Services Branch, Department of Fisheries and Oceans. 165 pp.

DFO. 1988. Stream Catalogue, Subdistrict #19, Victoria., BC. July 1988.

DFO. 1995. Canadian Shellfish Program Manual. Department of Fisheries and Oceans.

Devinny, J.S. and L.A. Volse. 1978. Effects of sediments on the development *of Macrocystis pyrifera* gametophytes. Mar. Biol. 48:343-348.

Diamond, M.L., D. MacKay, D.J. Poulton and F.A. Stride. 1994. Development of a mass balance model of the fate of 17 chemicals in the Bay of Quinte. J. Great Lakes Res. 20:643-666.

DiToro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomass and P.R. Paquin. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals by using equilibrium partitioning. Environ. Toxicol. Chem. 10:1541-1587.

Drinnan, R.W. and D. Hull. 1996. Fecal coliform surveys in Saanich Inlet. Report to Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks. Victoria, B.C. Prepared by Aquatic Science Consultants Ltd., Victoria, B.C.

Drinnan, R.W., B. Emmett, B. Humphrey, B. Austin, D.J. Hull. 1995. Saanich Inlet Study: Water Use Inventory and Water Quality Assessment. Prepared for the Water Quality Branch, Environmental Protection Department, B.C. Ministry of Environment, Lands and Parks. June 1995.

Druehl, L.D. 1967. Vertical distribution of some benthic marine algae in a British Columbia Inlet, as related to some environmental factors. J. Fish. Res. Bd. Can. 24(1):33-46.

Environment Canada. 1994a. Proceedings of the Workshop on "Incorporating societal values in ecosystem health objectives: addressing the challenge, held in Ottawa, Ontario, Canada. Sponsored by Environment Canada, Department of Indian Affairs and Northern Development, and the International Development Research Centre. June 19, 1994. 28 pp. + appendices.

Environment Canada. 1994b. Interim Sediment Quality Assessment Values: Soil and Sediment Quality Guidelines Division. Ecosystem Conservation Directorate, Evaluation and Interpretation Branch, Ottawa, Ontario. September 1994.

Evans, M.S. and P.F. Landrum. 1989. Toxicokinetics of DDE, benzo(a)pyrene and 2,4,5,2',4',5'-hexachlorobiphenyl in *Pontoporeia hoyi* and *Mysis relicta*. J. Great Lakes Res. 15(4):589-600.

Evans, R.A., B. Gulliksen and O.K. Sandnes. 1980. The effect of sedimentation on rocky bottom organisms in Balsfjord, Northern Norway. pp. 603-607 In: Freeland, H.J.,D.M. Farmer and C.D.Levings (eds). Fjord oceanography. NATO Conference Ser. Vol. 4.

EVS (EVS Environment Consultants), Sea Science and Frank Gobas Environmental Consulting. 1995. Modelling the fate of contaminant discharges in Burrard Inlet. Prepared for the Burrard Inlet Environmental Action Program, North Vancouver, British Columbia, October 1995.

Farrow, G.E., J.P.M. Syvitski and V. Tunnicliffe. 1983. Suspended particulate loading on the macrobenthos in a highly turbid fjord: Knight Inlet, British Columbia. Can. J. Fish. Aquat. Sci. 40(1):273-388.

Feder, H.M. 1980a. Distribution, abundance, community structure and trophic relationships of benthos of the northeastern Gulf of Alaska from Yakutat Bay to Cross Sound. In: Environmental Assessment of the Alaska Continental Shelf, Annual Reports 1:597-648. U.S. Dep. Commer., Natl. Oceanic. Atmos. Admin., Off. Mar. Pollut. Assess., Juneau, Alaska.

Feder, H.M. 1980b. Asteroidea: The sea stars. pp. 117-135 In: Morris, R.H., D.P. Abbott and E.C. Haderlie (eds). Intertidal invertebrates of California. Stanford Univ. Press, Stanford.

Finnie, J. 1995. Personal communication (fax to Lloyd Erickson, CVRD regarding policy on point source wastes to Saanich Inlet). Ministry of Environment, Lands and Parks, Vancouver Island Regional Office. 10 August.

Francois, B. 1988. A study on the regulation of the concentrations of some trace metals (Rb, Sr, Zn, Pb, Cu, V, Cr, Ni, Mn and Mo) in Saanich Inlet sediments, British Columbia, Canada. Mar. Geol. 83:285-308.

Gardiner, W.W. 1992. Sea surface films: deposition and toxicity in intertidal habitats. M.S. Thesis. Western Washington University, Bellingham, Washington. 72 pp. ALSO IN: Padilla Bay National Estuarine Research Reserve Reprint Series No. 16 (reprinted 1992).

Garrett, C. 1995. Personal communication (letter to Michael Z'Graggen, EVS Consultants regarding lipid content data for invertebrates and fish). Environment Canada. August.

Geyer, R.A. 1980. Marine environmental pollution. Vol. 1: Hydrocarbons. Elsevier, Amsterdam.

Gibbs, P.E. 1993. A male genital defect in the dog-whelk *Nucella lapillus* (Neogatropoda), favouring survival in a TBT-polluted area. J. Mar. Biol. Ass. UK 73:667-678.

Giese, A.C. 1966. Lipids in the economy of marine invertebrates. Physiol. Rev. 46:245-298.

Gilbert, J. 1995. Personal communication (telephone conversation with Gary Mann, EVS Consultants, regarding marine life in Saanich Inlet). Recreational Fisheries Consultant, Vancouver Island, B.C. 20 December.

Gobas, F.A.P.C. 1993. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. Ecol. Model. 69:1-17.

Gobas, F.A.P.C., D.C. Bedard, J.J.H. Ciborowski and G.D. Haffner. 1989. Bioaccumulation of chlorinated hydrocarbons by the Mayfly *Hexagenia limbata* in Lake St. Clair. J. Great Lakes Res. 15:581-588.

Gobas, F.A.P.C., E.J. McNeil, L. Lovett-Doust and G.D. Haffner. 1991. Bioconcentration of chlorinated aromatic hydrocarbons in aquatic macrophytes (*Myriophyllum spicatum*). Environ. Sci. Technol. 25:924-929.

Gobas, F.A.P.C., M.N. Z'Graggen and X. Zhang 1995. Time response of the Lake Ontario ecosystem to virtual elimination of PCBs. Environ. Sci. Technol. 29(8):2038-2046.

Greene, C.H., A. Schoener and E. Corets. 1983. Succession on marine hard substsrata: the adaptive significance of solitary and colonial strategies in temperate fouling communities. Mar. Ecol. Prog. Ser. 13:121-129.

Gross, M.G., S.M. Guchluer, J.S. Creager and W.A. Dawson. 1963. Varved marine sediments in a stagnant fjord. Science. 141:918-919.

Gucluer, S.M. and M.G. Gross. 1964. Recent marine sediments in Saanich Inlet, a stagnant marine basin. Limnol. Oceanogr. 9(2):359-376.

Haderlie, E.C., C. Hand and W.B. Gladfelter. 1980. Cnidaria (Coelenterata): the sea anemones and allies. pp. 40-75. In: Morris, R.H., D.P. Abbott and E.C. Haderlie (eds). Intertidal invertebrates of California. Stanford Univ. Press, Stanford.

Hagan, M. 1995. Personal communication (letter to Michael Z'Graggen, EVS Consultants regarding lipid content data of invertebrates and fish from coastal regions of B.C.). Environment Canada. Environmental Protection. Industrial Programs Section. Pollution Abatement Division. June.

Halifax Harbour Task Force. 1990. Final report. Prepared for the Honourable John Leeje, Minister of Environment, Nova Scotia. 84 pp. + appendices.

Harrison, P.J., D.L. Mackas, B.W. Frost, R.W. MacDonald and E.A. Crecelius. 1994. An assessment of nutrient, plankton and some pollutants in the water column of Juan de Fuca Strait, Strait of Georgia and Puget Sound, and their transboundary transport. In: Wilson, R.C.H, R.J Beamish, F. Aitkens and J. Bell. 1994. Review of the marine environment and biota of the Georgia, Puget Sound and Juan de Fuca Strait. Can. Tech. Rep. Fish. Aquat. Sci. no. 1948.

Hart, J.C. 1973. Pacific fishes of Canada. Fish. Res. Bd. Can. Bull. no. 180.

Hay, D.E., P.B. McCarter, R. Kronlund and C. Roy. 1989. Spawning areas of British Columbia herring: a review, geographical analysis and classification, volume V: Strait of Georgia Can. Man. Rep. Fish. Aquat. Sci. no. 2019. 268 pp.

Herbes, S.E. and C.P. Allen 1983. Lipid quantification of freshwater invertebrates: method modification for microquantitation. Can. J. Fish. Aquat. Sci. 40:1315-1317.

Herlinveaux, R.H. 1962. Oceanography of Saanich Inlet in Vancouver Island, British Columbia. Fish. Res. Bd. Can. 19(1):1-37.

Howard Paish and Associates 1975. An ecological assessment of the Seymour - Maplewood foreshore area.

Howard. 1991. Chemfate. Lewis Publishers, Chelsea, MI.

Howie, P. 1995. Saanich Inlet Study - Open House Report. Prepared by Woodward Environmental Management for Water Quality Branch, Environmental Protection Department, B.C. Ministry of Environment, Lands and Parks. 30 pp. + appendices.

Hull, J. 1995. Personal communication (discussion at physical oceanography meeting). Greater Victoria Water District, B.C. 25 July.

Humphrey, B. 1995. Personal communication (e-mail to S. Davidson, Sea Science). EnviroEd Consulting Ltd. 7 August.

IPCC (Intergovernmental Panel on Climate Change). 1995. Summary for policymakers: impacts, adaptions and mitigation options. Working Group II Second Assessment Report. Tuesday, October 24, 1995 (Draft).

Jackson, J.B.C. 1977. Competition on marine hard substrata: the adaptive significance of solitary and colonial strategies. Am. Natur. 111:743-767.

Jamieson, G. 1996. Personal communication (comments on Saanich Inlet Study report sent to Ben Kangasniemi, B.C. Ministry of Environment). Department of Fisheries and Oceans, Pacific Biological Station. 11 January.

Johnson, R. 1995. Personal communication (letter to A. Calder, B.C. Environment, Saanich Inlet Study Administrative Coordinator). Cowichan Valley Regional District, Engineering Services Department. 29 September.

Jones, B.C. and G.H. Geen. 1977. Food and feeding of spiny dogfish (*Squalus acanthias*) in British Columbia waters. J. Fish. Res. Bd. Can. 34:2067-2078.

Kadowaki, R. 1996. Personal communication (memorandum to Frank Whitney, DFO - Institute of Ocean Sciences, regarding Saanich Inlet Study) DFO, South Coast Salmon/Stock Assessment. 9 January.

Kangasniemi, B. 1995. Personal communication (e-mail message to S. Davidson, Sea Science - Data provided by D. Wetter, MELP). Ministry of Environment, Lands and Parks, Victoria, B.C. 27 October.

Kangasniemi, B. 1996. Personal communication (fax to S. Davidson, Sea Science - original data from L. Erickson, MELP). Ministry of Environment, Lands and Parks, Victoria, B.C. 12 January.

Kindig, A.C. and M.M. Littler. 1980. Growth and primary productivity of marine macrophytes exposed to domestic sewage effluents. Mar. Environ. Res. 3:81-100.

Kravitz, M.J., W.G. Pearcy and M.P. Guin. 1976. Food of five species of flatfishes on Oregon's continental shelf. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 74: 984-990.

LeBrasseur, R.J., C.D. McAllister and T.R. Parsons. 1979. Addition of nutrients to a lake leads to greatly increased catch of salmon. Environ. Conserv., 6:187-190.

Lee, R.F., Nevenzel, J.C. and G.A Paffenhofer. 1971a. Importance of wax esters and other lipids in marine food-chains: phytoplankton and copepods. Mar. Biol. 9:98-108.

Lee, R.F., Hirota, J and A.M. Barnett 1971b. Distribution and importance of wax esters in marine copepods and other zooplankton. Deep Sea Res. 18:1147-1165.

Levings, C. 1996. Personal communication (memo to Ben Kangasniemi, B.C. Ministry of Environment, regarding comments on Saanich Inlet Study report) DFO, West Vancouver Laboratory. 10 January.

Leys, S.P. 1995. Cytoskeletal architecture and organelle transport in giant syncytia formed by fusion of hexactinellid sponge tissues. Biol. Bull. 188:241-254.

Lilly, S.J., J.F. Sloane, R. Bassindale, F.J. Ebling and J.A. Kitching. 1953. The ecology of the Lough Ine rapids with species reference to water currents. IV. The sedentary fauna of sublittoral boulders. J. Anim. Ecol. 22:87-122.

Littler, M.M. and D.S. Littler. 1980. The evolution of thallus form and survival strategies in benthic macroalgae: field and laboratory test of a functional form model. Am. Nat. 116:25-44.

Livingston, P.A. and B.J. Goiney, Jr. 1983. Food habitats literature of North Pacific marine fishes: a review and selected bibliography. U.S. Department of Commerce. National Oceanic and Atmospheric Administration and National Marine Fisheries Service. NOAA Technical Memorandum NMFS F/NWC-54. 81pp.

Lobban, C.S. and P.J. Harrison. 1994. Seawed ecology and physiology. Cambridge Univ. Press, New York. 366 pp.

Lymann, W.J., W.F. Reehl and D.H. Rosenblatt. 1990. Handbook of chemical property estimation methods, American Chemical Society.

MacKay, D.L. 1994. Preliminary report on Cowichan Valley Regional District Bylaws 1500 and 1501: Bamberton development proposals. Prepared for Ministry of Municipal Affairs, Province of British Columbia. 27 pp.

MacKay, D.L., W.Y. Shiu and K.C. Ma. 1992-1994. Illustrated handbook of Environmental Properties, Lewis Publishers. Chelsea, MI.

Mahaffy, M.S., D.R. Nysewander, K. Vermeer, T.R. Wahl and P.E. Whitehead. 1994. In: Wilson, R.C.H., R.J. Beamish, F. Aitkens and J. Bell (eds). Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Proceedings of the B.C./Washington Symposium on the Marine Environment, January 13-14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. no. 1948.

McConnaughey, B.H. 1974. Introduction to Marine Biology. C.V. Mosby, St. Louis. 544 pp.

McRoy, C.P. and C. Helfferich. 1980. Applied aspects of seagrasses. In Handbook of seagrass biology: an ecosystem perspective. Phillips, R.C. and C.P. McRoy (eds). Garland STPM Press, New York.

Meehan, W.R. and T.C. Bjornn. 1991. Salmonid distributions and life histories. In: W.R. Meehan (ed) Influences of forest and rangeland management on salmonid fishes and their habitats. Amer. Fish. Soc. Sp. Publ. 19. pp. 47-82.

Mele, A. 1993. Polluting for pleasure. W.W. 224 pp. Norton, New York.

Moore, P.G. 1977. Inorganic particulate suspension in the sea and their effect on marine animals. Oceanogr. Mar. Biol. Ann. Rev. 15:225-363.

Morgan, K.H. 1989. Marine birds of Saanich Inlet, a Vancouver Island fjord entering the Strait of Georgia. pp. 158-165 In: K. Vermeer and R.W. Butler (eds). The ecology and status of marine and shoreline birds.

Morgan, K.H. 1996. Personal communication (telephone conversation with M. Z'Graggen, EVS Environment Consultants). Institute of Ocean Sciences, B.C. 26 January.

Morrison, H. 1995. Bioaccumulation of organochlorines in the Lake Erie food-chain. Ph.D. Thesis. University of Windsor. In preparation.

Murie, D.J., L.J. Richards and K.L. Yamanaka. 1994. Inshore lingcod. pp. 22-32 In: M. Stocker (ed). Groundfish stock assessments for the west coast of Canada in 1993 and recommended yield options for 1994. Can. Tech. Rep. Fish. Aquat. Sci. 352 pp.

Nijman, R. 1995. Personal communication (letter to S. Davidson, Sea Science). Ministry of Environment, Lands and Parks. August.

Noble, D. 1990. Contaminants in Canadian seabirds. State of the Environment Report no. 90-2. Prepared for State of the Environment Reporting, Environment Canada; and Canadian Wildlife Service, Conservation and Protection, Environment Canada. 75 pp.

Norse, E.A. 1993. Global marine biological diversity. A strategy for building conservation into decision making. Island Press, Washington, D.C. 383 pp.

Olesiuk, P.F. 1993. Annual prey consumption by harbor seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia. Fish. Bull. 91:491-515.

Pacific Salmon Assessment Review Committee (PSARC). 1994. Annual Report for 1994. Can. Manusc. Rep. Fish. Aquat. Sci. 2227.

Parker, P.L. 1962. Zinc in a Texas Bay. Publ. Inst. Mar. Sci. Univ. Tex. 8:75-79

Parker, P.L., A. Gibbs and R. Lawler. 1963. Cobalt, iron and magnesium in a Texas Bay. Publ. Inst. Mar. Sci. Univ. Tex. 1: 28-32

Parsons, T.R. 1990. The use of mathematical models in conjunction with mesocosm ecosystem research. In: C.M. Lalli (ed). Enclosed experimental ecosystems: a review of recommendations. Springer-Verlag, New York. pp. 196-210.

Parsons, T.R. and T.A. Kessler. 1987. An ecosystem model for the assessment of plankton production in relation to the survival of young fish. J. Plank. Res. 9:125-137.

Parsons, T.R., R.I. Perry, E.D. Nutbrown, W. Hseih and C.M. Lalli. 1983. Frontal zone analysis at the mouth of Saanich Inlet, British Columbia, Canada. Mar. Biol. 73:1-5.

Petrie, B. and D. Yeats. 1990. Simple models of the circulation, dissolved metals, suspended solids and nutrients in Halifax Harbour. Water Poll. Res. J. Can. 25(3):325-349.

Phillips, R.C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/24. 85 pp.

Pickard, G. 1975. Annual and longer term variations in deep water properties in the coastal waters of British Columbia. J. Fish. Res. Bd. Can. 32(9):1561-1587.

Poth, J. 1983. Saltwater People as told by Dave Elliott, Sr. A resource book for the Saanich Native Studies Program. Native Education, School District 63. 84 pp.

Radcliffe, G. 1991. Clayoquot Sound: life support services and natural diversity. Strategy for sustainable development in Clayoquot Sound. Madrone Consultants Ltd., Duncan, B.C. 165 pp.

Ratnayake, M.N. and R.G. Ackman 1979. Fatty alcohols in Capelin, Herring and Mackerel oils and muscle lipids: I. Fatty alcohol details linking dietary copepod fat with certain fish depot fats. Lipids. 14:795-803.

Riggs, S.R. 1995. The effect of exposure to environmental normoxia and hypoxia on photosynthetic rate and chlorophyll concentration in intertidal *Zostera marina* leaves. Master's Thesis, Western Washington University, Bellingham, Washington. 74 pp. ALSO: Padilla Bay National Estuarine Research Reserve Reprint No. 22 (reprinted 1995).

Rosenberg, R. 1985. Eutrophication - the future marine coastal nuisance? Mar. Poll. Bull., 16:227-231.

Rosenthal, R.J. 1980. Shallow water fish assemblages in the northeastern Gulf of Alaska: habitat evaluation, species composition, abundance, spatial distribution and trophic interaction. Unpublished manuscript, 84 pp. Alaska Coastal Research, P.O. Box 937, Homer, AK. 99603.

Rueness, J. 1973. Pollution effects on littoral algal communites in the inner Oslofjord, with special reference to *Ascophyllum nodosum.* Helgol. Meeresunters. 24:446-454.

Saavedra Alvarez, M.M. and D.V. Ellis. 1990. Widespread neogastropod imposex in the northeast Pacific: implications for TBT contamination surveys. Mar. Poll. Bull. 21:244-247.

Sancetta, C. and S.E. Calvert. 1988. The annual cycle of sedimentation in Saanich Inlet, British Columbia: implications for the interpretation of diatom fossil assemblages. Deep-Sea Res. 35:71-90.

Sargent, J.R. 1976. The structure, metabolism and function of lipids in marine organism. In: D.C. Malanus (ed). Biochemical and biophysical perspectives in marine biology. vol. 3. Academic Press.

Sargent, J.R. and R.J. Henderson 1986. Lipids. In: E.D.S. Corner and S.C.M. O'Hara (eds). The Biological Chemistry of Marine Copepods. Clarendon Press. Oxford.

Saunders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. J. Mar. Res. 38:265-380.

Schmitt, C, Schweigert, J and T.P. Quinn. 1994. Anthropogenic influences on fish populations of the Georgia Basin. In: review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Tech. Rep. Fish. Aquat. Sci. no. 1948.

Simonsen. B.O., A. Davis and J. Haggarty. 1995. Saanich Inlet Study - Report on First Nations Consultation. Prepared by Bastion Group Heritage Consultants and Shoreline Archaeological Consultants for Water Quality Branch, Environmental Protection Department, B.C. Ministry of Environment, Lands and Parks. 26 pp. + appendices + map.

Stephenson, T.A. and A. Stephenson. 1972. LIfe between tidemarks on rocky shores. W.H. Freeman, San Francisco. 425 pp.

Stewart, C. and J.A.J. Thompson. 1994. Extensive butyltin contamination in southwestern coastal British Columbia, Canada. Mar. Poll. Bull. 28:601-606.

Stucchi, D. 1996a. Personal communication (data presented at technical committee meeting). Institute of Ocean Sciences, Department of Fisheries and Oceans, B.C. 10 January.

Stucchi, D. 1996b. Personal communication (telephone conversation with S. Davidson). Institute of Ocean Sciences, Department of Fisheries and Oceans, B.C. 2 February.

Stucchi, D. and L.F. Giovando. 1983. Deep water renewal in Saanich Inlet, B.C. In: Juniper and Brinkhurst (eds). Proceedings of a multidisciplinary symposium on Saanich Inlet, 2nd February, 1983.

Takahashi, M., I. Koike, K. Iseki, P.K. Bienfang and A. Hattori. 1982. Phytoplankton species responses to nutrient changes in experimental enclosures and coastal waters. In: G.D. Grice and M.R. Reeve (eds). Marine Mesocosms. Springer Verlag, N.Y. pp. 333-430.

Taylor, L. 1995. Personal communication (telephone conversation with Ben Kangasniemi, MELP regarding CRD position on discharge of sewage to Saanich Inlet). Capital Regional District, B.C. 9 June.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56, 291 pp.

Tinis, S.W. 1995. The circulation and energetic of the Sechelt Inlet system, British Columbia. Ph.D. dissertation, Department of Oceanography, University of British Columbia.

Troutman, B.L., S.L. Jefferies and T.A. Young. 1991. Identification of areas for potential seabird mortality in the commercial gillnet and purse seine fisheries of Juan de Fuca Strait and Northern Puget Sound. Wash. Dep. Wildl., Olympia, WA, 26 pp.

Tunnicliffe, V. 1981. High species diversity and abundance of the epibenthic community in an oxygen-deficient basin. Nature. 294:354-357.

U.S. EPA (U.S. Environmental Protection Agency). 1993. Risk assessment and modelling overview document. EPA 905-R93-007. United States Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL.

U.S. EPA. 1994. Great Lakes Water Quality Initiative Technical Support Document to determine Bioaccumulation Factors. EPA-822-R-94-002.

USNRC (U.S. National Research Council). 1993. Managing coastal wastewater in coastal urban areas. U.S. National Research Council. National Academy Press. 447 pp.

Varanasi, U., E. Casillas, M.R. Arkoosh, T. Hom, D.A. Mitsitano, D.W. Brown, S.L. Chan, T.K. Collier, B.B. McCain and J.E. Stein. 1993. Contaminant exposure and associated biological effects in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from urban and nonurban estuaries of Puget Sound. NOAA Tech. Memo. NMFS-NWFSC-8.

Vermeer, K and R. Vermeer. 1975. Oil threats to birds on the Canadian coast. Can. Field. Nat. 89:278-298.

Vermeer, K. 1996. Personal communication (telephone conversation with M. Z'Graggen, EVS Environment Consultants). Institute of Ocean Sciences, B.C. 26 January.

Waaland, J.R. 1977. Common seaweeds of the Pacific coast. J.J. Douglas, Vancouver, 120 pp.

Waldichuck, M. 1969. Eutrophication studies in a shallow inlet on Vancouver Island. J. Water Poll. Control Fed. May Part 1, pp. 745-764.

Walker, S. 1996. Water Quality Guidelines: are they safe? M.Sc. Thesis. School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C.

Whitney, F. 1995a. Personal communication (e-mail to S. Davidson, Sea Science). Institute of Ocean Sciences. 16 October.

Whitney, F. 1995b. Personal communication (telephone conversation with S. Davidson, Sea Science). Institute of Ocean Sciences. October.

Whitney, F. 1995c. Personal communication (review comments on Saanich Inlet Report). Institute of Ocean Sciences. 20 December.

Whitney, F.A. and C.S. Wong. 1984. In: S.K. Juniper and R.O. Brinkhurst (eds). Proceedings of a multidisciplinary symposium on Saanich Inlet, 2nd February, 1983. Can. Tech. Rep. Hyd. and Oc. Sci. no. 38.

Williams, G.L. 1989. Coastal/estuarine fish habitat description and assessment manual. Part I. Species/habitat outlines. Prepared for Supply and Services Canada. September. 107 pp. + illustrations.

York, D. 1995. Personal communication (memorandum to Ben Kangasniemi, Head Marine Programs, Water Quality Branch, Ministry of Environment, Lands and Parks). Engineering Services, Cowichan Valley Regional District. 15 August.

14. GLOSSARY

a posteriori	After the fact; with prior knowledge.
Acenaphthylene	A polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Advection	The horizontal movement of a mass of air that causes changes in temperature or in other physical properties of the air.
Aesthetic	Dealing with those aspects of water that are perceivable to the senses.
Alevin	A newly hatched salmon still attached to the yolk sac; a non-feeding young fish.
Algal Bloom	Large proliferations of algae (microscopic plant blooms) within water than can absorb nutrients and make the water look cloudy or coloured. When large numbers of the algae in the bloom die, decomposition by bacteria can use much of the dissolved oxygen in the water and sometimes cause the deaths of other organisms such as fish.
Ambient	Refers to present environmental conditions surrounding an organism. The current qualities of the environment, especially with respect to physical factors such as temperature.
Ameliorate	To improve, or make tolerable.
Amplification	To make larger or greater.
Anadromous	Fish (e.g., certain salmonid species) which spend their early life stages in fresh water, enter the sea for a period of active feeding and growth, and return to fresh water to spawn.
Anoxic	Having little or no oxygen.
Anthropogenic	Referring to changes in the environment resulting from the presence or activities of humans.

Assimilation	Processes which include dilution, inactivation, metabolism and breakdown. These may be chemical, biological or physical processes.
Assimilative Capacity	Assimilation refers to processes which include dilution, inactivation, metabolism, and breakdown. These may be physical, chemical or biological processes. Assimilation is used here in a very broad sense and is intended to apply to the resilience of natural systems as well. Assimilative capacity is not a pollute-up-to level; it is the threshold beyond which natural processes cannot accept wastes and disturbances without environmental degradation.
Assumptions	The supposition that a certain fact is true, or factor applicable to a particular situation.
Autotrophic	Organisms which are able to synthesize the organic materials they require from inorganic sources. All green plants are autotrophic and use light as a source of energy for the synthesis.
Ballast	A heavy substance used to improve the stability and control the draft of a ship.
Baseline	Background conditions or status quo. Baseline studies are often conducted pre-development.
Benchmark Concentration	Specific concentrations at which some level of biological effects are expected (e.g., LC25, MATC). These concentrations are derived from hazard assessment.
Benthic	Referring to organisms living in or on the sediments of aquatic/marine habitats.
Benzo(a)anthracene	A polycyclic aromatic hydrocarbon compound (PAH). See polycyclic aromatic hydrocarbon.

Bioaccumulation	A general term, meaning that an organism stores within its body a higher concentration of a substance than is found in its environment. Includes uptake of substances from water (= bioconcentration), sediment and from food. This phenomenon is not necessarily harmful. For example, fresh water fish must bioaccumulate common salt if they are to live because the water in which they swim dissolves the salts out of their bodies. Many toxicants, such as arsenic, can be excreted by aquatic organisms, and are not included among the bioaccumulative substances (e.g., certain chemicals in food eaten by a fish tend to accumulate in its liver or other tissues).
Biodiversity	A reflection of habitat or community complexity measured in terms of the number of species.
Biogenic	Oceanic sediment produced by living organisms.
Biota	The sum total of the living organisms (plants and animals) of any designated area.
Brackish	Describes water having a low salinity, within the range of 0.5 to 17 o/oo (parts per thousand). Somewhere between salt and fresh water.
Bryozoan	A phylum of marine invertebrates which live in colonies attached to rocks, seaweed or shells.
Buffer Zone	A neutral area separating two conflicting land uses, a protective strip which acts to protect sensitive areas from potential environmental degradation.
Calibration	The systematic standardization of either the response of instruments used for measurements or the chemical separation achieved by a laboratory cleanup procedure.
Carcinogen	A chemical substance or physical aspect which induces cancer in living organisms.

Chemical Contaminants	Concentrations of chemicals found in the environment which exceed background concentrations.
Chemical Loadings	The quantity of chemical released into the environment during a specific time period (e.g., day).
Chiton	An order of marine molluscs with a dorsal shell of calcareous plates.
Chlorophyll	Principal green plant pigment, essential for photosynthesis, which allows plants to grow using only sunlight, water, and some nutrients.
Chrysene	A polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Coefficient	Any of the factors of a product considered in relation to a specific factor.
Coliform Bacteria	A group of bacteria which includes many species. Fecal coliform bacteria are those coliform bacteria which are found in the intestinal tract of warm-blooded animals. The presence of high numbers of fecal coliform bacteria in water can indicate the contamination by untreated wastewater and/or the presence of animals. This may indicate the presence of pathogens.
Contaminants	Contaminants include all foreign substances usually associated with urban, rural and agricultural discharges whether they originate from point or non-point sources and include nutrients, pesticides, metals, organic matter, suspended sediments, hydrocarbons, pathogens and other potentially polluting substances.
Convergence	The act of moving together toward union or uniformity.
Creel	Assessment of fisher's catch.
Criteria (Water Quality)	An estimate of the concentration of a chemical or other constituent in water which, if not exceeded, will protect an organism, a community of organisms, or a prescribed water use or quality with an adequate degree of safety.

Crustacean	Of the Class Arthropoda which are mostly aquatic organisms having an outer skeleton ("exoskeleton") composed of chitin (nitrogenous polysaccharide) and often segmented. It includes crab, lobster, shrimp and barnacles.
Cumulative Impacts	The combined environmental effects that accrue over time and space from a series of similar or related individual actions, contaminants, or projects.
Current Meters	A device to measure the rate of flow of a river or stream.
Cyclonic	Moving in a circular motion.
Deposition	The accumulation of sediments on the bottom by either physical processes or chemical reactions.
Depuration	A process that results in elimination of material (impurities) from the digestive tract of an aquatic organism.
Detritus	Non-living particles of disintegrating biological material (inorganic and dead and decaying organic material) that can be suspended in the water column or settled on the bottom of lakes, streams, oceans, etc.
Diatoms	A group of microscopic unicellular phytoplankton (algae). Their cell walls are impregnated with silicon compounds. Colonial diatoms form long hair-like filaments of cells that have a slippery texture. Some diatoms are pollution-tolerant.
Dibenzo(a,h)anthracene	Polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Diffusion	The random movement and scattering of water-soluble contaminants in water, and the interstitial waters of sediments and into the overlying water column.
Dispersion	To spread or distribute from a fixed or constant source.
Diurnal	Daily; during the day.

Dredging	Any physical digging into the bottom of a water body. Dredging can be done with mechanical or hydraulic machines and is performed in many waters of the world for the maintenance of navigation channels that would otherwise fill with sediment and block ship passage.
Drifter/Drogue	An oceanographic instrument designed to move passively with prevailing currents; a submerged sail or sock-like structure ensures that currents, not winds, are responsible for any observed movement.
Ecological Sustainability	The concept of steady-state management of natural resources, where consumption is matched by production, and ecological integrity is retained.
Ecosystem	An interacting system of all living organisms in a defined region of similar characteristics, including the non-living substrate, nutrients, energy, and other environmental components, the biotic community and its abiotic environment. The ocean is an example of a large ecosystem.
Ecotoxicology	The science that deals with toxins and their effects in natural ecosystems and on living organisms.
Embayment	A bay or a conformation resembling a bay.
Environmental Degradation	Environmental degradation occurs when a water use, such as swimming or shellfish harvesting, is impaired. Water uses include human activities such as recreation and fishing but also include human values such as aesthetic and spiritual values. Water uses also include aquatic life whether or not they are of direct economic value; consequently harm to non-commercial species such as most algae and benthic degradation. Broadly accepted criteria to protect water uses are available for many contaminants.
Environmental Health	The relative health of an organism or ecosystem as defined by specific benchmark values relating to that system.

Epibenthic	Referring to organisms that live at the surface of (on, and not in) the sediments of aquatic habitats.
Equilibrium	A state in which opposing processes or reactions take place at a rate such that no net change is observed.
Estuarine	Residing or situated in a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage.
Euphasiid	An order of crustacean that resemble shrimp and are usually luminescent.
Euphotic Zone	Zone near the surface of a body of water into which sufficient light penetrates for active photosynthesis (i.e., productivity of plants).
Fecal Coliform	see Coliform Bacteria
Fjord	A long, narrow, steep-sided marine inlet, carved by a glacier, usually with a sill at the mouth.
Flagella	A fine long thread having lashing of undulating movement, projecting from a cell. Responsible for movement of unicellular organisms and reproductive cells which bear them, and are responsible for movement of water through sponges.
Flagellate	A class of protozoa characterized by possession of one or more flagella.
Flushing Rate	The rate at which water passes through a waterbody (a mechanism that removes dissolved/suspended nutrients from the system).
Flux	A continuous moving on or passing by of fluid.
Foreshore	A strip of land margining a body of water.
Freshet	The period in late spring/early summer when the flow of a river or stream is greatly increased by the melting of snow and ice.

Gammarid	An organism in the order crustacea, commonly known as amphipods.
Geostrophic	Relating to deflective force due to the rotation of the earth.
Global Warming	The phenomenon of temperature increase occurring worldwide at a faster rate than previously experienced on earth. This phenomenon is closely correlated to an increase in atmospheric carbon dioxide concentrations, which have increased steadily for the last century. The warming trend is less pronounced at the equator, and most pronounced at the polar regions where ecosystems are particularly sensitive to such changes.
Gyre	To move in a circle or spiral.
Habitat	The place in which an organism lives, which is characterized by its physical features or by the dominant plant types.
Habitat Management	Decisions made with regard to the place in which an organism lives, which is characterized by its physical features or by the dominant plant types.
Heterotrophic	Plants and animals that are dependent on organic matter for food; derive nutrition and carbon from organic substances.
Homogeneous	Evenly distributed.
Human Water Use	Human requirements of a water resource.
Hydroacoustic	Relating to the production, control, transmission and reception of sound in water.
Hydrocarbon	An organic compound composed primarily of carbon and hydrogen, either straight-chain, or cyclic. They are constituents of our pollution (as a result of the burning of fossil fuels) or water pollution (contributed to by crude oil). Petroleum and its derived compounds are primarily hydrocarbons. Environmentally important hydrocarbons include PAHs.

Hydrodynamics	A branch of science dealing with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.
Hydroxyl	The univalent group or radical OH consisting of one hydrogen and one oxygen.
Imposex	Sexual deformities (e.g., development of female characteristics by male whelks) resulting from exposure to toxins (e.g., tribulyltin)
in situ	On site. Usually used to distinguish work conducted "in the field" from work done in the laboratory.
Inlet	A bay or recess in the shore of a lake, sea or river.
Intertidal Area	The area between high and low tide levels.
Introduced Exotic Species	The species which inhabit an area where they are not naturally found. For example, the Manila clam was accidentally introduced to British Columbia with the importation of Pacific oysters from Japan in 1938.
Invertebrates	Animals lacking a dorsal column of vertebrae or a notochord.
Laminae	The leaflike part or blade of the thallus of certain algae, notably kelps.
Land Use	The way land is developed and used in terms of the types of activities allowed (agriculture, residences, industries, etc.) and the size of buildings and structures permitted.
Leaching	The downward movement of a material in solution through soil.
Lipid	A fat or oil molecule.
Longitudinal	Relating to length or the lengthwise dimension.

Marine Habitat Disturbances	Habitat disturbances in the marine system refers to disturbances associated with human activity which can cause environmental degradation, and includes alteration and reduction of fresh water flows and destruction and alteration of shoreline and estuarine habitat.
Matrix (Matrices)	The sample material in which the chemicals of interest are found (e.g., water, sediment, tissue).
Metals	Elements such as mercury, lead, nickel, zinc, copper and cadmium that can be of environmental concern because they do not degrade over time. Although many are necessary nutrients, they are sometimes magnified in the food chain, and they can be toxic to life in high concentrations.
Migratory	To pass, usually predictably (based on aquatic species), from one region or climate to another for purposes of feeding, breeding, etc.
Model	Usually, a (computer) simulation of a series of events used to predict the outcome of something that cannot be directly observed, such as the mixing of an exhaust plume in the atmosphere, an effluent plume in a receiving water body, or the movement of water through the soil.
Morphology	The study of form and structure of organisms, especially their external form.
Naphthalene	A polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Neap Tide	A tide of minimum range occurring at the first and the third quarters of the moon.

Non-point Source Pollution (NPS)	Source of pollution in which pollutants are discharged over a widespread area or from a number of small inputs rather than from distinct identifiable sources (e.g., storm runoff, aerial deposition). NPS pollution is of particular concern in nearshore areas and ultimately comes from specific human products and activities, such as: poorly maintained septic fields, vehicle and boat maintenance, gardening products, wood preservatives, crop management, livestock handling, and road construction and maintenance.
Nutrients	Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to degradation of water quality and the growth of excessive numbers of algae. Some nutrients can be toxic at high concentrations. In aquatic systems, nitrogen and phosphorus are the nutrients that control the amount of plant growth. In marine systems, nitrogen is generally more important in controlling plant growth.
Omnivore	An animal that eats both plants and animals.
Organic	Pertaining to or derived from organisms; a natural or man-made chemical containing a carbon complex (chains or rings).
Ozone Depletion	The destruction of the protective layer of atmospheric ozone gases in the stratosphere which act to shield the earth from ultraviolet (UV) radiation. This destruction is commonly attributed to synthetically produced chemicals such as Chlorofluorocarbons (CFCs). The resulting "ozone hole" permits harmful UV radiation to penetrate the atmosphere.
Parameter	A characteristic substance or factor that is measured in order to describe a system. A quantifiable or measurable characteristic of something (e.g., height, weight, sex and hair colour are all parameters that can be determined for humans). Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.
Pathogen	A specific causative agent (i.e., a bacterium or virus) of a disease.
Paucity	Smallness of number, few.

Pelagic	Organisms inhabiting the water column and subject to the current; usually inhabit open water of a sea or lake.
Perturbation	Disturbance.
Pesticide	A general term used to describe any substance, usually chemical, used to destroy or control organisms including herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.
Phenanthrene	A polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Photosynthesis	The process by which plants (and some bacteria) make sugar (complex carbohydrates) as stored chemical energy, and release oxygen from carbon dioxide and water using the energy of the sun's light.
Phytoplankton	Plant life, mostly microscopic, found floating or drifting in the oceans or large bodies of fresh water; forms the basis of most aquatic food-chains as the main primary producer.
Pinneped	An aquatic mammal of the Pinnipedia, a suborder of the Carnivora (e.g., seals, sea lions, walruses) with limbs modified as flippers.
Plume	The main pathway for dispersal of effluent within the receiving waters, prior to its complete mixing (also refers to smoke, gases, etc.).
Point Source	A source of pollution that is distinct and identifiable, such as an outfall pipe from an industrial plant. Generally, any discharge pipe is considered to be a point source.

Polycyclic (or Polyaromatic or Polynuclear) Aromatic Hydrocarbon PAHs	Chemical substances characterized by the presence of more than one benzene ring; a class of complex organic compounds, some of which are persistent and carcinogenic. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAHs are found in fossil fuels such as coal and oil and are formed by incomplete combustion of organic fuels like gasoline, wood, and oil. They are commonly formed by forest fires, wood stoves, and internal combustion engines. They often reach the aquatic environment through atmospheric fallout, highway runoff and oil discharge.
Point-source	A source of pollution that is distinct and identifiable, such as an outfall pipe from an industrial plant.
Pollution Prevention	To avoid, eliminate or reduce the creation, the use or the release of polluting substances.
Porosity	The quality of possessing pores, permeable to water.
Precautionary Principle	Where there are threats of serious or irreversible damage, the lack of full scientific certainty shall not be used as a measure for postponing measures to prevent environmental degradation (MELP, 1995a).
Pyrene	A polycyclic aromatic hydrocarbon compound. See polycyclic aromatic hydrocarbon.
Qualitative	Relating to, or involving quality, kind or essential character.
Quantitative	Relating to, or involving the measurement of quantity or amount.
Quaternary	The geological time period from the end of the Tertiary to the present time, the corresponding system of rocks.

Recovery	The amount of a chemical detected in a sample extract at the end of a procedure relative to the total amount present in a sample before the procedure was begun. Also, the amount of a chemical detected in a sample relative to the amount added (i.e., spike) or known to be present (i.e., in a naturally derived standard reference material). Recovery is usually expressed as a percentage.
Remediation	Activities undertaken to correct an existing condition (e.g., improve fish spawning habitat that was previously degraded).
Renewal	Used here in context of oceanography; replacement of deep fjord waters by transport of water over the sill from outside the fjord.
Residence Time	Average time spent by a parcel of water in a basin before being flushed out to sea.
Resilience	The ability of a system to recover from perturbations.
Risk Assessment	A set of formal scientific methods for estimating the probabilities and magnitudes of undesired effects resulting from the release of chemicals, other human actions or natural phenomena.
Salinity	A measure of the quantity of dissolved salts in seawater. Formally defined as the total amount of dissolved solids in seawater - in parts per thousand by weight - when all the carbonate has been converted to oxide, the bromide and iodide replaced by chloride, and all organic matter is completely oxidized.
Salinity Gradient	The rise and fall in salinity over a horizontal or vertical stretch of water.
Sediment	Material, such as sand or mud, suspended in or settling to the bottom of a liquid. Sediment input to a body of water comes from natural sources, such as erosion of soils and weathering of rock, or as the result of anthropogenic (human) activities, such as forest or agricultural practices, or construction activities. Certain contaminants tend to collect on/adhere to sediment particles.
Seine Fishery	To catch fish using a large net with sinkers on one edge and floats on the other, that hangs vertically in the water and is used to enclose fish when its ends are drawn together or drawn ashore.

Sill	Shallow submerged pile of rock debris left across a basin by a retreating glacier; called a moraine on land.
Siltation	The process by which a river, lake, or other water body becomes clogged with sediment. Silt can clog gravel beds and prevent successful salmon spawning.
Site-Specific	Pertaining to a particular region or spatial area.
Soft-Bottom Community	A group of organisms which live in soft-bottom materials (i.e., mud, sand) as opposed to hard-bottom materials (i.e., rock). These organisms include benthic animals (bottom-living) such as worms, clams, amphipods, etc.
Sorption	The process whereby dissolved substances (i.e., contaminants) physically or chemically bind to the surface of particles. Can include adsorption (to the surface of a solid body) and absorption (into a body).
Source Control	To control the discharge of a contaminant as its point of origin.
Spatial	Relating to, or having the character of space.
Speciation	The chemical form of any chemical constituent/element; refers to the bonds or substances a particular element makes (e.g., copper can form copper sulphate, copper carbonate, etc.).
Spring Tide	A tide of maximum range occurring at the second and fourth quarters of the moon.
Standing Stock	The amount of a type of organism, usually measured in biomass, at a given point in time.
Steady-State	The state at which competing rates of uptake and elimination of a chemical within an organism, tissue or system are equal. An apparent steady state is reached when the concentration of a chemical in tissue remains essentially constant during a continuous exposure.

Stewardship	The individual's responsibility to manage its life, property and environment with proper regards of others.
Stormwater	Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.
Stratification	A term given to the process/period whereby a lake develops two or more distinct water layers (strata) of different densities/temperature.
Subtidal	Area below the intertidal zone, usually delineated by the mean lower low tide level.
Synergism	A phenomenon in which the toxicity of a mixture of chemicals is greater than that which would be expected from a simple summation of the toxicities of the individual chemicals present in the mixture.
Terrigenous	Oceanic sediment derived directly from the destruction of rocks on the earth's surface.
Tertiary Treatment	This is a final process of effluent treatment after primary and secondary treatment steps. It includes a broad range of processes used to remove items such as colour, odour, taste, and toxicity. It is often used for removing nutrients, especially phosphorus, from municipal effluents.
Threshold Concentration	The lowest concentration demonstrated or estimated to cause a detectable effect or response.
Topography	The configuration of a surface including its relief and the position of its natural and man-made features.
Transect	A straight line across an expanse of ground along which ecological measurements are taken, continuously, or at regular intervals.
Treated Sewage	Sewage which has been treated by physical (screening, settling), chemical (precipitation), biological (degradation), or other means to reduce the levels of potentially harmful pollutants.
Tributary	Usually a smaller stream or river flowing into a larger one.

Turbidity	A measure of the amount of material suspended in the water as the result of stirred-up sediment from the bottom; from floating debris, plants, and animals; and/or from solids falling through the water (e.g., discharged dredged material). Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life.
Upwelling	The upward movement of deeper, colder and often nutrient-rich waters to the surface.
Volatilization	The evaporation of substances, especially those with low boiling points. For example, cleaning fluids discharged into the sewer system may evaporate into the atmosphere in the pipes and in the sewage treatment plant. Another example is the loss of a chemical substance from dredged material by evaporation, typically after the dredged material has been dried out at an upland or nearshore disposal site.
Water Use	see Human Water Use.
Water Value	In context of this study, human affinity for water and its environs.
Watershed	Either the total area drained by a river and its tributaries, or the total area of land contributing runoff above a given point on a stream.
Zoning	To designate, by ordinances, areas of land reserved and regulated for specific land uses.
Zooplanktivorous	Feeding primarily on zooplankton.
Zooplankton	Animal life, usually microscopic, found floating or drifting in the water column of oceans or bodies of fresh water; form the bulk of the primary consumer link in the aquatic food-chain. Zooplankton form the link between primary producers (phytoplankton) and the higher trophic levels (e.g., fish, humans).

APPENDIX A

SAANICH INLET STUDY COMPONENT REPORTS

SAANICH INLET STUDY COMPONENT REPORTS

The following series of complementary projects have been prepared under the Saanich Inlet Study.

- Simonsen, B.O., A. Davis and J. Haggarty. 1995. *Report On First Nations Consultation*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by The Bastion Group Heritage Consultants (first two authors) and Shoreline Archaeological Consultants Ltd. (third author). 26 pp. + appendices.

  A documentation of water uses, values and concerns of local First Nations people.

- Howie, P. 1995. *Open House Report*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by Woodward Environmental Management. 30 pp. + appendices.

  A documentation of input ,received at public open houses through short questionnaires, written comment forms, and discussions with Ministry staff and members of the Saanich Inlet Study Advisory and Technical Committees.

- Drinnan, R.W., B. Emmett, B. Humphrey, B. Austin and D.J. Hull. 1995. *Water Use Inventory & Water Quality Assessment*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by Aquatic Science Consultants Ltd., Archipelago Marine Research Ltd., EnviroEd Consultants Ltd. and Khoyatan Marine Laboratory. 242 pp. + appendices.

  Comprehensive documentation of the current environmental status of the inlet. This component report also includes results from a field survey of non-point contaminant sources conducted in March 1995.

- Calder, A.M. and G.S. Mann (eds.). 1995. *Synthesis Workshop Summary April 25/26, 1995*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by EVS Environment Consultants Ltd. and Sea Science, Vancouver, BC. 130 pp. + appendices.

  The proceedings of a workshop of marine environmental experts who presented and discussed early Saanich Inlet Study findings.

- Cross, S.F. and P.C.P. Chandler. 1996. *Saanich Inlet Study: Surface Circulation Patterns*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by Aquametrix Research Ltd. 52 pp. + appendices.

  An investigation of nearshore and mid-channel surface currents in Saanich Inlet during the winter and summer by the B.C. Ministry of Environment, Lands & Parks, and the Department of Fisheries and Oceans.

- Austin, B., S. Leys and C. Durance. 1996. *Saanich Inlet Study: Sensitive Habitats & Biota*. Prepared for Water Quality Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, BC, by Khoyatan Marine Laboratory, Precision Biological Consultants, and the University of Victoria Department of Biology. In 3 parts: Part 1- Intertidal Sensitive Species & Habitats Assessment; Part 2- Eelgrass Habitat Assessment; and Part 3- Hexactinellid Sponge Assessment.

  Documentation of field surveys of potentially sensitive marine habitats and resources. The intertidal survey involved identification and assessment of the relative abundance of invertebrate and algal species at 38 sites. The eelgrass field survey also included the interpretation of aerial photographs. The Hexactinellid sponge survey was based on SCUBA surveys.

Saanich Inlet Study reports and newsletters are available from:

Ministry of Environment, Lands and Parks
Environmental Protection Department
Water Quality Branch
Third Floor, 765 Broughton Street
Victoria, BC V8V 1X4

Tel.: (604) 387-9500
Fax.: (604) 356-8298

Reports, newsletters and additional information regarding the Saanich Inlet Study is also available online at http://www.env.gov.bc.ca/epd/epdpa/wq/saanich/sis.html

APPENDIX B

MODEL PARAMETERS OF THE ENVIRONMENTAL FATE AND FOOD-CHAIN BIOACCUMULATION MODELS

Mass balance equations and methods for the assessment of rate constants of organic contaminants in the Saanich Inlet environmental fate model.

Mass-balance equations & concentrations

Total mass of contaminant in water M_w (g): single layer	$dM_W/dt = L + (\Sigma F_{ji}.C_{W,j}) + k_{SW}.M_S - (k_V + k_O + k_{WR} + k_{WS}).M_W$
Total mass of contaminant in water M_w (g): surface layer	$dM_W/dt = L + (\Sigma F_{ji}.C_{W,j}) - (k_V + k_O + k_{WR} + k_{WS}).M_W$
Total mass of contaminant in water M_w (g): middle layer	$dM_W/dt = L + (\Sigma F_{ji}.C_{W,j}) - (k_O + k_{WR} + k_{WS}).M_W$
Total mass of contaminant in water M_w (g): bottom layer	$dM_W/dt = L + (\Sigma F_{ji}.C_{W,j}) + k_{SW}.M_S - (k_O + k_{WR} + k_{WS}).M_W$
Total mass of contaminant in sediments M_S (g)	$dM_S/dt = k_{WS}.M_W - (k_{SW} + k_B + k_{SR}).M_S$
Concentration of contaminant in water (g/L)	$C_W = X_W/V_W$
Concentration of contaminant in sediments (g/kg dry)	$C_S = X_S/V_S$
Freely dissolved concentration of contaminant in the water (g/L)	$C_{WD} = \phi_{DW}.C_W$

Rate Constants

Outflow (1/day)	$k_O = \Sigma F_{ij} / (1000.V_W)$
Volatilization (1/day)	$k_V = S_{AW}.\phi_{DW}.v_E / V_W$
Overall water-to-sediment transport (1/day)	$k_{WS} = k_{WS1} + k_{WS2}$
Overall sediment-to-water transport (1/day)	$k_{SW} = k_{SW1} + k_{SW2}$
Solids settling (1/day)	$k_{WS1} = S_{AW}.v_S.(1 - \phi_{DW}) / V_W$
Water-to-sediment diffusion (1/day)	$k_{WS2} = S_{AS}.v_D.\phi_{DW} / V_W$
Solids resuspension (1/day)	$k_{SW1} = (ResFlux/C_{SS}).(1 - \phi_{DS}) / (1000.V_S)$

Sediment-to-water diffusion (1/day)	$k_{SW2} = S_{AS} \cdot v_D \cdot \phi_{DS} / V_S$
Burial (1/day)	$k_B = S_{AS} \cdot v_B \cdot (1 - \phi_{DS}) / V_S$
Degradation in water (1/day)	$k_{WR} = 0.693/t_{1/2,W}$
Degradation in sediment (1/day)	$k_{WR} = 0.693/t_{1/2,S}$

Other Equations

Volatilization mass transfer coefficient (m/d)	$v_E = 1 / (1 / v_{EW} + 1 / (K_{AW} \cdot v_{EA}))$
Air-water partition coefficient (unitless)	$K_{AW} = H / (8.314 . (273 + T_W))$
Temperature dependence of H	$\ln H(T_W) = \ln H(298) + 20.18 - 6013.6/T_W$
Fraction of freely dissolved contaminant in water (unitless)	$\phi_{DW} = 1 / (1+(C_{PW} . OC_{PW} \cdot K_{OW} / d_{PW})$
Fraction of freely dissolved contaminant in sediments (unitless)	$\phi_{DS} = 1 / (1 + (C_{SS} \cdot OC_{SS} \cdot K_{OW} / d_{SS})$
Settling of sediment solids flux (kg/d)	$SetFlux = 1000 . C_{PW} \cdot v_S \cdot S_{AW}$
Burial Flux of sediment solids (kg/d)	$BurFlux = 1000 . C_{SS} \cdot v_B \cdot S_{AS}$

Compartment and chemical specific properties

Compartment surface area (m^2)	S_{AW}
Sediment surface area (m^2)	S_{AS}
Average water depth (m)	D_W
Depth of active sediment layer (m)	D_S
Water volume of Compartment (m^3)	V_W
Sediment volume (m^3)	V_S
Water temperature (C)	T_W
Water in- and out-flow (L/d)	F

Concentration of particles in water (kg/L)	C_{PW}
Concentration of solids in sediment (kg/L)	C_{SS}
Density of suspended solids (kg/L)	d_{PW}
Density of sediment solids (kg/L)	d_{SS}
Organic carbon content of suspended solids (unitless)	OC_{PW}
Organic carbon content of bottom sediment (unitless)	OC_{SS}
Density of organic carbon (kg/L)	d_{OC}
Water-side evaporation mass transfer coefficient (m/d)	v_{EW}
Air-side evaporation mass transfer coefficient (m/d)	v_{EA}
Solids settling rate (m/d)	v_S
Water-to-sediment diffusion mass transfer coefficient (m/d)	v_D
Sediment burial mass transfer coefficient (m/d)	v_B
Degradation half-life time in water	$t_{1/2,W}$
Degradation half-life time in sediment	$t_{1/2,S}$
Total external loading (g/d)	L
pH of water	pH

Mass balance equations and methods for the assessment of rate constants of mercury (Hg) in the Saanich Inlet environmental fate model.

Mass-balance equations & concentrations

Total mass of Hg in water M_w (g): single layer	$dM_W/dt = L + (\Sigma F_{ji} \cdot C_{W,j}) + k_{SW} \cdot M_S - (k_V + k_O + k_{WR} + k_{WS}) \cdot M_W$
Total mass of Hg in water M_w (g): surface layer	$dM_W/dt = L + (\Sigma F_{ji} \cdot C_{W,j}) - (k_V + k_O + k_{WR} + k_{WS}) \cdot M_W$
Total mass of Hg in water M_w (g): middle layer	$dM_W/dt = L + (\Sigma F_{ji} \cdot C_{W,j}) - (k_O + k_{WR} + k_{WS}) \cdot M_W$
Total mass of Hg in water M_w (g): bottom layer	$dM_W/dt = L + (\Sigma F_{ji} \cdot C_{W,j}) + k_{SW} \cdot M_S - (k_O + k_{WR} + k_{WS}) \cdot M_W$
Total mass of Hg in sediments M_S (g)	$dM_S/dt = k_{WS} \cdot M_W - (k_{SW} + k_B + k_{SR}) \cdot M_S$
Concentration of Hg in water (g/L)	$C_W = X_W/V_W$
Concentration of Hg in sediments (g/kg dry)	$C_S = X_S/V_S$
Freely dissolved concentration of Hg in the water (g/L)	$C_{WD} = \phi_{DW} \cdot C_W$

Rate Constants

Outflow (1/d)	$k_O = \Sigma F_{ij} / (1000 . V_W)$
Volatilization (1/day)	$k_V = S_{AW} \cdot F_{HgW} \cdot \phi_{DIW} \cdot v_E / V_W$
Overall water-to-sediment transport (1/day)	$k_{WS} = k_{WS1} + k_{WS2}$
Overall sediment-to-water transport (1/day)	$k_{SW} = k_{SW1} + k_{SW2}$
Solids settling (1/day)	$k_{WS1} = S_{AW} \cdot v_S \cdot (F_{MeW} \cdot (1 - \phi_{DOW}) + (1 - F_{Mew}) \cdot (1 - \phi_{DIW})) / V_W$

Water-to-sediment diffusion (1/day)	$k_{WS2} = S_{AS} \cdot v_D \cdot (F_{MeW} \cdot \phi_{DOW} + (1 - F_{MeW}) \cdot \phi_{DIW}) / V_W$
Solids resuspension (1/day)	$k_{SW1} = (\mathrm{ResFlux}/C_{SS}).(1 - \phi_{DS}) / (1000.V_S)$
Sediment-to-water diffusion (1/day)	$k_{SW2} = S_{AS} \cdot v_D \cdot F_{MeS} \cdot \phi_{DOS} / V_S$
Burial (1/day)	$k_B = S_{AS} \cdot v_B \cdot (F_{MeS} \cdot (1 - \phi_{DOS}) + 1 - F_{MeS}) / V_S$
Degradation in water (1/day)	$k_{WR} = 0.693/t_{1/2,W}$
Degradation in sediment (1/day)	$k_{WR} = 0.693/t_{1/2,S}$

Other Equations

Volatilization mass transfer coefficient (m/d)	$v_E = 1 / (1 / v_{EW} + 1 / (K_{AW} \cdot v_{EA}))$
Air-water partition coefficient (unitless)	$K_{AW} = H / (8.314.(273 + T_W))$
Temperature dependence of H	$\ln H(T_W) = \ln H(298) + 20.18 - 6013.6/T_W$
Fraction of freely dissolved organic mercury (CH_3Hg^+) in water (unitless)	$\phi_{DOW} = 1 / (1+(C_{PW}.OC_{PW}.K_{OW} / d_{PW})$
Fraction of inorganic mercury in freely dissolved forms (Hg^{2+}) in water (unitless)	$\phi_{DIW} = 1/(1 + C_{PW}.K_{PW})$
Suspended particles-water partition coefficient of inorganic mercury (Hg^{2+}) (unitless)	$K_{PW} = 7.69 \times 10^5$
Fraction of freely disolved Hg in water (unitless)	$\phi_{DW} = F_{MeW} \cdot \phi_{DOW} \cdot + (1 - F_{MeW}) \cdot \phi_{DIW}$
Fraction of organic mercury (CH_3Hg^+) in freely dissolved form in sediments (unitless)	$\phi_{DOS} = 1 / (1 + (C_{SS}.OC_{SS}.K_{OW} / d_{SS})$
Fraction of methylmercury in water (unitless)	$F_{MeW} = 0.30$
Fraction of methylmercury in sediments (unitless)	$F_{MeS} = 0.01$

Fraction of metallic mercury & dimethylmercury in water (unitless)	$F_{HgW} = 0.10$
Settling of sediment solids flux (kg/d)	$SetFlux = 1000.C_{PW}.v_S.S_{AW}$
Burial Flux of sediment solids (kg/d)	$BurFlux = 1000.C_{SS}.v_B.S_{AS}$

Compartment and chemical specific properties

Comartment surface area (m^2)	S_{AW}
Sediment surface area (m^2)	S_{AS}
Average water depth (m)	D_W
Depth of active sediment layer (m)	D_S
Water volume of Compartment (m^3)	V_W
Sediment volume (m^3)	V_S
Water temperature (°C)	T_W
Water in- and out-flow (L/d)	F
Concentration of particles in water (kg/L)	C_{PW}
Concentration of solids in sediment (kg/L)	C_{SS}
Density of suspended solids (kg/L)	d_{PW}
Density of sediment solids (kg/L)	d_{SS}
Organic carbon content of suspended solids (unitless)	OC_{PW}
Organic carbon content of bottom sediment (unitless)	OC_{SS}
Density of organic carbon (kg/L)	d_{OC}
Water-side evaporation mass transfer coefficient (m/d)	v_{EW}

Air-side evaporation mass transfer coefficient (m/d)	v_{EA}
Solids settling rate (m/d)	v_S
Water-to-sediment diffusion mass transfer coefficient (m/d)	v_D
Sediment burial mass transfer coefficient (m/d)	v_B
Degradation half-life time in water	$t_{1/2,W}$
Degradation half-life time in sediment	$t_{1/2,S}$
Total external loading (g/d)	L
pH of water	pH
Octanol-water partition coefficient of methylmercuric chloride (CH_3HgCl) (unitless)	K_{OW} (Cl) =1.7
Octanol-water partition coeffcient of methylmercuric hydroxide (CH_3HgOH) (unitless)	K_{OW} (OH) = 0.07
Average octanol-water partition coefficient of methylmercury (CH_3Hg^+) (unitless)	$K_{OW} = K_{OW}(OH)\,\phi_{OH} + K_{OW}(Cl)\,(1-\phi_{OH})$
Fraction of methylmercury in hydroxide form (CH_3HgOH) unitless	$\phi OH = 10^{(-9.95 + pH)} / ([Cl^-] + 10^{(-9.95 + pH)})$
Average chloride concentration in water (mol/L)	$[Cl^-] = 0.0079$

Summary of the chemical properties of selected contaminants in Saanich Inlet.

Chemical Name	Molecular Weight (g/mol)	Log(Octanol / Water Partition Coefficient)	Henry Law Constant (Pa.m3/mol)	Transformation Half Life Time - in water (days)	Transformation Half Life Time - in sediment (days)
Benzo-a-pyrene	252.32	6.04	0.81	365	2000
Phenanthrene	178.24	4.46	4	180	1185
Mercury	250	0.23	743	1000	1825
Anthracene	178.24	4.63	6	100	141

Lipid contents of biological organisms represented in the Saanich Inlet model.

Species	Lipid Content (% wet weight)	Sources
Phytoplankton (diatoms)	1.0[a,c]	Lee et al. (1971a)
Copepod (*Calanus spp.*)	7.6[a,c]	Sargent and Henderson (1986)
Euphausiid (*Euphausia* spp.)	2.5[c]	Blaxter et al. (1980)
Shrimp (*Pandalus spp.*)	2.5[b]	Mike Hagan (pers. comm.)
Dungeness Crab (*Cancer magister*)	8.8[c]	Giese (1966)
Mussel (*Mytilus edulus*)	0.8[d]	Chris Garrett (pers. comm.)
Amphipod (*Gammaridae spp.*)	11.4[a,c]	Lee et al. (1971b)
Annelid (Polychaeta and Oligochaeta)	11.0[a,c]	Lee et al. (1971b)
Pacific Herring (*Clupea harengus pallasi*)	15.2[e]	Ratnayake and Ackman (1979)
English Sole (*Parophrys vetulus*)	4.0[c]	Chris Garrett (pers. comm.)
Lingcod (*Ophiodon elongatus*)	9.4[f]	Mike Hagan (pers. comm.)
Juvenile Salmonid (*Oncorhynchus spp.*)	4.7[c]	Mike Hagan (pers. comm.)
Quillback Rockfish (*Sebastes maliger*)	19.0[f]	Mike Hagan (pers. comm.)
Dogfish (*Squalus acanthias*)	15.0	

[a] Lipid contents for these species were reported on a dry weight basis. The lipid contents on a dry weight basis were converted to lipid contents on a wet weight values by assuming that the dry weight of invertebrates is 20% of the organism's wet weight wet and that the dry weight of phytoplankton is 10% of the wet weight (Evans and Landrum, 1983; Herbes and Allen, 1983).

[b] Lipid content of muscle tissue

[c] Lipid content of whole organism

[d] Lipid content of soft tissue

[e] Lipid content of muscle and skin tissue

[f] Lipid content of liver tissue

Organism body weights and prey composition of fish species from Saanich Inlet used in the food-chain bioaccumulation model.

Fish Species	Weight	Copepod	Euphausiid	Prawn	Crab	Mussel	Amphipod	Annelid	Herring	Sole	Lingcod	Juv. Salmon	Rockfish
Herring	10 g	96%	3%				1%						
Sole	200 g		2%	26%		2%	38%	32%					
Lingcod	1000 g						10%	10%	50%			10%	20%
Juv. Salmon	5 g	77%	12%	3%		5%	3%						
Rockfish	200 g	10%	30%	20%			30%	10%					
Dogfish	3000 g	12%	17%	10%	9%		1%	1%	28%	3%	3%	10%	6%

APPENDIX C

PHYTOPLANKTON COMPOSITION OF SAANICH INLET

To: Beth
EVS Consultants
Vancouver, B.C.

From: Lou Hobson
Department of Biology
University of Victoria
Victoria, B.C.

11 January 1996

Re: Phytoplankton Composition - Saanich Inlet

Almost all studies of the seasonality of the compositions of phytoplankton assemblages in Saanich Inlet during the past 20 years have been carried out in the vicinity of Station E, located on a line half way between Patricia and Mill Bays. Based on this work, we know that a well-developed spring diatom bloom occurs in April or May (Hobson 1981, 1983) usually composed of the genera *Minidiscus* sp. (Sancetta 1989) and *Thalassiosira*, including the species, *pacifica, eccentrica, gravida, nordenskiöldii* and *rotula* (Hobson 1981, Huntley and Hobson 1978, Sancetta 1989, Sancetta and Calvert 1988, Takahashi *et al.* 1978) and in some cases, a small form of *Skeletonema costatum* (Sancetta 1989), during the early phase of the bloom. Later in the bloom, the early assemblage is replaced by a number of *Chaetoceros* species, including *compressus, radicans* and perhaps *socialis*, and a large form of *S. costatum* (Hobson 1981, 1983, Sancetta 1989, Sancetta and Calvert 1988, Takahashi *et al.* 1977). The end of the bloom is usually considered to be due to decreasing nutrient fluxes as stratification builds and the large diatom assemblage disappears. The taxonomic composition shifts from diatoms to a diverse group of nano-flagellates (Smith and Hobson, 1994) and dinoflagellates (Hobson 1981, 1983) in June, July and August, although *S. costatum* may continue to be present (Sancetta, 1989). Nutrient fluxes may occasionally increase during summer months due either to increased mixing by short-lived storms (Takahashi *et al.* 1977) or to tidal advection of nutrient-rich water (Parsons *et al.* 1983), after which short-lived diatom blooms of *Corethron criophilium, Ditylum brightwellii, Detonula pumila, Eucampia zoodiacus, Leptocylindrus danicus, Nitzschia pungens* and *S. costatum* occur (Sancetta, 1989). Mixing and advection become more intense in fall and stratification may weaken, resulting in blooms of several *Chaetoceros* species, including *compressus, concavicornis, debilis, diadema, didymus, lorenzianus* and *vanheurkii, C. criophilium, Rhizosolenia setigera, S. costatum* and *Thalassionema nitzschioides* (Sancetta 1989). *D. brightwellii* may also persist into the fall months (Sancetta 1989, Sancetta and Calvert 1989, Takahashi *et al.* 1977). Most diatoms tend to disappear during October or early November as irradiation declines, leaving nano-flagellates (Takahashi *et al.* 1978) many of which are heterotrophic (Smith and Hobson, 1994) to make up the phytoplankton for the remainder of the year. However, *Paralia marina* (often confused with the species *sulcata*) and other benthic diatom species as well as *Minidiscus* sp. are present in small numbers during winter (Sancetta 1989).

This record was extended back in time an additional 71 years for some of the diatoms when fossil frustules and resting stages were examined in sediment cores taken at Station E (McQuoid, 1995). Although variations occur, in general a seasonal record similar to that outlined above was observed for those diatoms whose frustules preserve in sediments. Some exceptions were recorded; for example, *Rhizosolenia*, probably the species *setigera* only appeared after 1942. In addition, one apparent correlation was between low abundances of *Skeletonema costatum* and El Niño events.

The above results were generated from samples taken in mid-inlet, and to extend these observations to the perimeter, I examined assemblages in Deep Cove, Patricia Bay, Coles Bay, Mill Bay Brentwood Bay and off Elbow Point for comparison to Station E on 11 and 18 July, 1995, during spring and neap tidal cycles, respectively. To date, only samples for 11 July have been analyzed, when I found that cell concentrations were similar, 247,965±38,123 cells L^{-1}, throughout the inlet, except in Brentwood Bay where the concentration was 828,920 cells L^{-1}. This was caused by a large concentration of *Skeletonema* sp. (580,060 cells L^{-1}), which was found in smaller concentrations elsewhere (48,293±28,649 cells L^{-1}). Its morphology is closest to the species *potamos,* a fresh- to brackish-water form; thus, it is an unlikely species to be found in the inlet. The number of species observed in 16.5 mL of seawater only slightly varied (45±2), while diversity decreased with distance away from Deep Cove, reaching a minimum value of 1.89 bits $(\text{individual})^{-1}$ in Brentwood Bay. I selected a number of species to use as indicators of oceanographic and anthropogenic properties of the inlet. For example, *Ditylum brightwellii*, is an indicator of turbulence and its associated nutrient flux and concentrations of this diatom were maximal in Deep Cove and Patricia Bay (12,510±721 cells L^{-1}) and minimal at Elbow Point (180 cells L^{-1}), exactly as predicted by tidal flows in the inlet. Also, the euglenophyte, *Eutreptiella marina*, probably is an indicator of organic loading (Hobson, 1985) and it occurred in large concentrations (116,870±14,345 cells L^{-1}) in Patricia and Coles Bays, while only 60 cells L^{-1} were found at Station E. Large concentrations of protozoa (18,647±6,281 cells L^{-1}), which consume bacterial and small flagellated algal cells (Laybourn-Parry, 1992), were found in Mill and Brentwood Bays and at Elbow Point, while reduced levels (1,630±523 cells L^{-1}) were recorded in Patricia and Coles Bays. Finally, as an indicator of change in the inlet as a whole, a small flagellated chlorophyte, *Pterosperma cristatum*, and its resting stage were found in large numbers (46,448±10,046 cells l^{-1}) throughout the inlet, although its numbers were somewhat reduced in Patricia and Coles Bays (19,900±2,404 cells L^{-1}). This organism has only recently been found in Japanese waters and the Adriatic

Sea (Inouye, 1990) and in Saanich Inlet during June, July and August, 1990 (Smith and Hobson, 1994). Prior to 1990, it was never, to the best of my knowledge, found in the inlet.

In conclusion, the phytoplankton composition in the open region of Saanich Inlet has remained similar for the past 100 years, except for the appearance of *Rhizosolenia setigera* in 1942. However, the recent appearance of *Pterosperma cristatum* throughout the Inlet may signal, at least short term, oceanographic changes. Changes in assemblages in the perimeter waters are apparent, probably due to organic loadings and *Eutreptiella marina* in Patricia and Coles Bays. Furthermore, Brentwood Bay appears to be unique because of the presence of large concentrations of *Skeletonema* sp., but the cause(s) of this is(are) unknown.

APPENDIX D

CARBON/NUTRIENT MODEL DESCRIPTION AND RESULTS

General Description

The model used in the simulation analysis consists of a wind-driven water-column mixing (1-d vertical) and atmosphere/ocean oxygen exchange submodel super-imposed onto a local elemental carbon, oxygen and the macro-nutrients flow submodel (while both components are time-dependent, vertical exchange of pertinent constituents is modeled by the mixing submodel against a frozen vertical density structure). The combined models are intended to represent non-steady state dynamics up to a time-scale of several weeks, characteristic of plankton blooms; though in principle steady state scenarios can also be investigated through appropriate extension of simulation run times.

One of the main goals of the analysis is to characterize the system response to perturbation brought on by domestic waste-water discharge. Accordingly, the model also contains a module that estimates the required near-field mixing characteristics (i.e. terminal plume rise and waste-field thickness) as a function of the effluent temperature, flow rate and discharge depth.

Basic Assumptions

The main basic assumptions underlying the model are:

1) The receiving waters are horizontally well-mixed.

2) Vertical steady flow has minimal effect on transport.

3) Turbulent exchange can be described by an eddy viscosity-eddy diffusivity model.

4) Eddy viscosity above the pycnocline can be characterized by a wind driven constant stress boundary layer.

5) The change in water-column temperature and static stability over simulation time-scales is minimal within the range of wind-stress and surface buoyancy (heat) flux evaluated.

6) Effluent discharge can be adequately represented by a buoyant simple plume within a non-stagnant ambient fluid.

7) The re-mineralization of silicon is minimal over simulation time-scales.

8) Neither phytoplankton nor bacterial growth rates are potentially limited by ambient free phosphorus concentration.

9) Autotrophy and heterotrophy both obey a switching function growth limitation law.

10) Super-saturating ambient light levels do not inhibit phytoplankton growth rates.

11) The sinking rate of phytoplankton is depth-dependent.

12) The vertical distribution of macro-zooplankton omnivores is instantaneously proportional to prey distribution.

Basic Equations

The model tracks 11 state-variables: The standing stock of diatoms, (autotrophic) phytoflagellates, heterotrophic bacteria, zooplankton omnivores, zooplankton bacteriovores; the ambient concentrations of nitrite+nitrate, ammonia, available silicon and phosphorus, zooplankton fecal detritus, autotrophic DOC leakage, and dissolved oxygen.
The governing equation used to describe the z, t distribution for each is of the form

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(K_V \frac{\partial C}{\partial z}\right) + \text{Sources} - \text{Sinks} - \Big[E\Big] - \Big[w_S \frac{\partial C}{\partial z}\Big]. \tag{1}$$

The right side terms represent respectively turbulent exchange, local growth, local losses, local excess resulting from a change in prey redistribution, and sedimentation; where K_V is the vertical eddy diffusivity and w_S is sinking velocity. The first term in brackets applies only to the macro-zooplankton while the second term in brackets does not apply to DOC, nutrients, dissolved oxygen and the macro-zooplankton.
The terminal rise h for the (buoyant) effluent discharge is calculated on the basis of the initial buoyancy flux

$$B = \mathrm{g}(\Delta\rho/\rho_a)Q, \quad \text{from which}$$

$$h = 2.9\rho_a B^{1/4}/\mathrm{g}\dot{\rho}_a$$

in which $\Delta\rho$ is the initial difference in density between the receiving fluid and the effluent discharge and $\dot{\rho}_a$ is the ambient density gradient. The associated waste-field thickness is calculated on the basis of the empirical relationship $d = 0.7h$ (Chu 1979).
Eddy diffusivity is effectively defined by a depth-independent eddy viscosity A_V and density distribution above and within the pycnocline and solely by the density distribution below the pycnocline:

$$K_V = \begin{cases} A_V(1 + R_i)^{-1.5} \\ 1.2 \cdot 10^{-8} N^{-0.6}, \end{cases}$$

where the local density distribution is described by the bulk Richardson number R_i and the buoyancy frequency N respectively.

Normalizing Effluent Discharge

The (specified) absolute effluent loading rate is converted in the model to the required water-column loading rate by also specifying a surface area for the affected receiving waters. Broadly speaking the latter parameter was made geographically representative of the area of interest. However, adjustment was made to meet two limiting conditions: The receiving basin surface area was made large enough to prevent unrealistic accumulation of ambient nutrient given the existing model dynamics (as defined by the parameter set) and the associated characteristic diffusion time-scale $t \propto L^{2/3}$ was kept below the phytoplankton intrinsic doubling time.

Model Forcing

Model forcing terms are the clear-sky surface irradiance and, climatic month-averaged cloud cover and water-column temperature/density distribution. Calculation of the time-of-year specific clear-sky irradiance follows Davies and Hay (1978), while climatic cloud cover was inferred from the AES Victoria Airport 30-year bright sunshine time-series, again according to procedures outlined in Davies and Hay (1978). The 30-year month-averaged profiles for Saanich Inlet as presented in Herlinveau (1962) for Stn J were used to represent the climatic water-column temperature and density profiles.

It should be noted that while seasonal water-column stability/temperature structure is relatively well defined by Herlinveau's long-term averages, the average seasonal surface wind power is not since the arithmetic mean wind speed underlying the available climatological data gives a biased estimator (i.e. underestimate). Thus a useful exercise, not included in this report, is wind speed manipulation that evaluates sensitivity to uncertainty in average wind power. On the other hand, wind speed manipulation cannot properly evaluate wind storm effects *per se* since the water-column density structure remains fixed. Though it would be a simple matter to unfreeze density distribution, correct modeling of the evolving distribution requires explicit evaluation of the water column buoyancy fluxes against which the wind must work. Evaluation of this balance is implied in the analysis presented in this report by forcing the (frozen-density) modeling with corresponding seasonal averages of temperature distribution and wind stress.

Starting Conditions

Starting conditions, other than those associated with model free parameters, are the initial profiles of dissolved oxygen, nitrite+nitrate, free silicon and phosphorus. As in the case of the forcing profiles, climatic oxygen profiles for each month were taken from Herlinveau (1962), while monthly nitrite+nitrate profiles were inferred from profiles for Saanich Inlet obtained between February 9, 1983 and June 8, 1983 (Frank Whitney, IOS, person. commun.). Mid-month interpolation of nitrite+nitrate profiles for unrepresented months as well as general extrapolation to the other macro-nutrients was aided using the 1965-1968 month-averaged surface Georgia Strait macro-nutrient data presented in Table 1 of Parsons *et al.* (1970).

Boundary Conditions

Water surface boundary conditions are:

eddy viscosity defined by the specified climatic wind speed

$$A_V = \begin{cases} 1x10^{-4}W^3, & \text{if } W < 6 \text{ m}\cdot \text{s}^{-1} \\ 4x10^{-4}W^2, & \text{otherwise} \end{cases}$$

zero flux for all state-variables except oxygen

$$K_V \frac{\partial C}{\partial z} - \left[w_S C \right] + \left[F \right] = 0,$$

where the first term in brackets applies only to the phytoplankton and fecal detritus and the second term in brackets applies only to dissolved oxygen.

oxygen exchange $F = K_P \Delta O_2$ (positive water-column efflux sign convention) where the piston velocity K_P is defined by wind speed W and surface temperature T

$$K_P = \begin{cases} 0.0017W/S_C^{2/3}, & \text{if } W \leq 3.6\text{m}\cdot\text{ s}^{-1} \\ (0.029W - 0.10)/S_C^2, & \text{if } 3.6 < W \leq 13\text{m}\cdot\text{s}^{-1} \\ (0.059W - 0.49)/S_C^2, & \text{otherwise} \end{cases}$$

where $Sc(T)$ is the ratio of the kinematic to molecular viscosity for oxygen gas.

Bottom boundary conditions are:

zero diffusive flux for all state-variables

$$K_V \frac{\partial C}{\partial z} = 0.$$

Numerical Solution

Equations (1) along with the boundary conditions were solved using a time-splitting finite difference scheme. The advective term was solved explicitly by up-wind differencing combined with weighted interpolation correction, while the diffusive term was solved semi-implicitly using Crank-Nicholson. The local terms were solved using a truncation error-controlling Runge-Kutta scheme.

FIGURES

The following figures illustrate various perturbations to the natural plankton ecology of Saanich Inlet. As a guide to these figures, the following should be noted:

On the computer print-outs:

All abscissa scales are for twenty days

The units for all ordinate scales are the same as given in Table 2 (although the absolute length of the scale may have been shortened or extended to accommodate higher and lower values in different figures)

All effluent discharge volumes are per day

All units are mg/m^3 except for oxygen which is in gm/m^3

All results plotted on the graphs represent the average value 0 to 10 m, except as discussed in Fig.28 and 29 where the depth averaged values shown are 15 to 20 m.

Figure 1 January plankton and nutrients without effluent discharge.

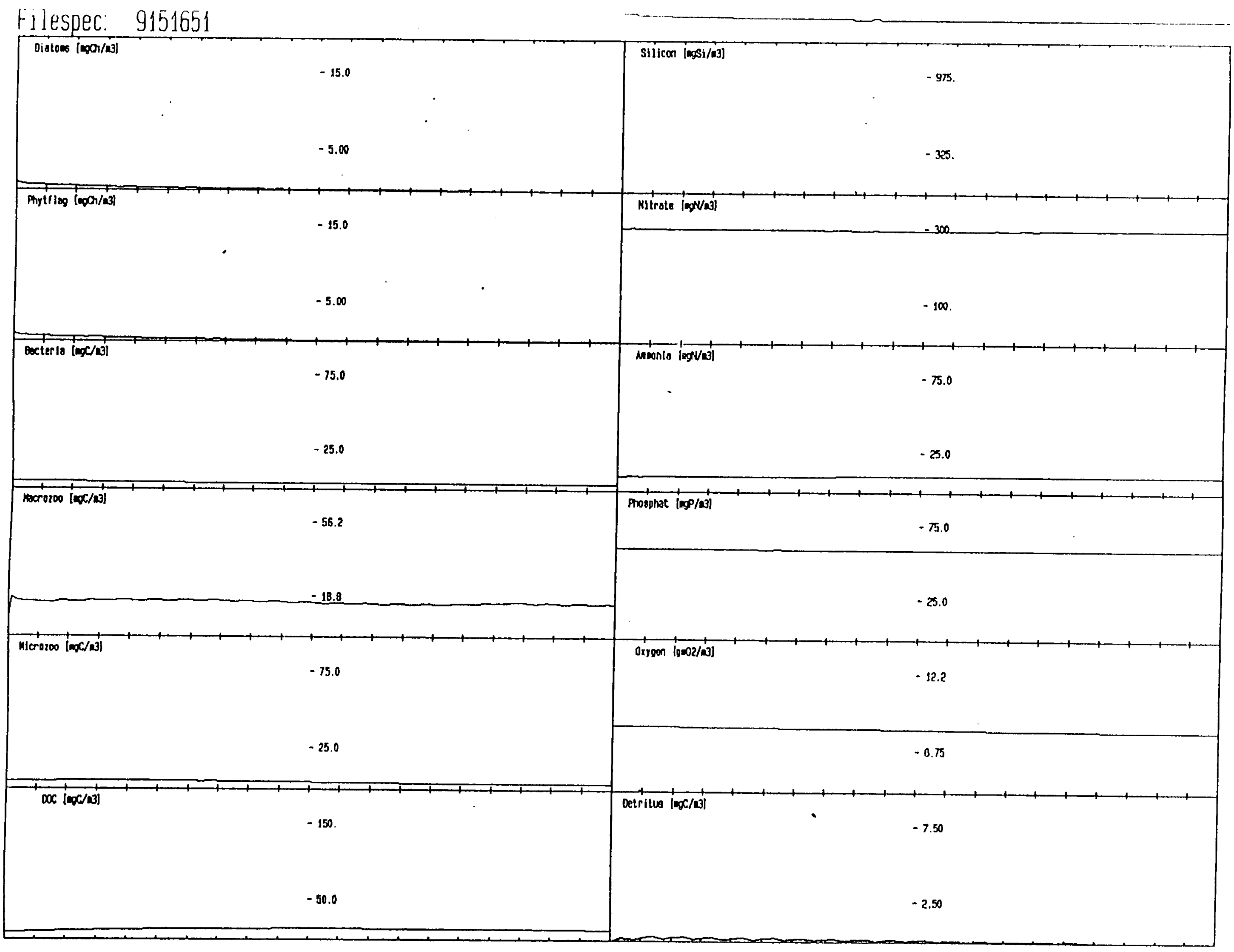


Figure 2 March plankton and nutrients without effluent discharge.

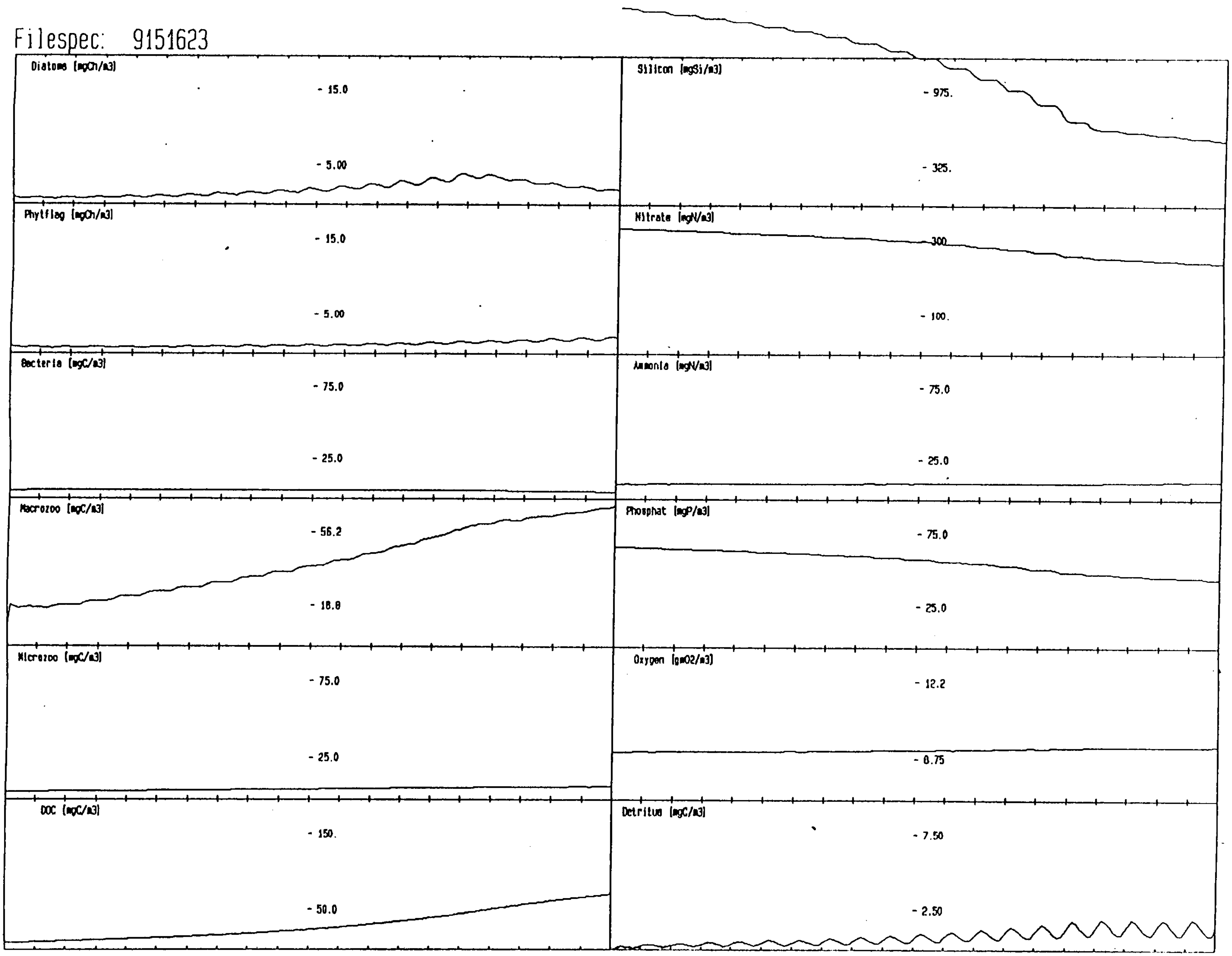


Figure 3 April plankton and nutrients without effluent discharge.

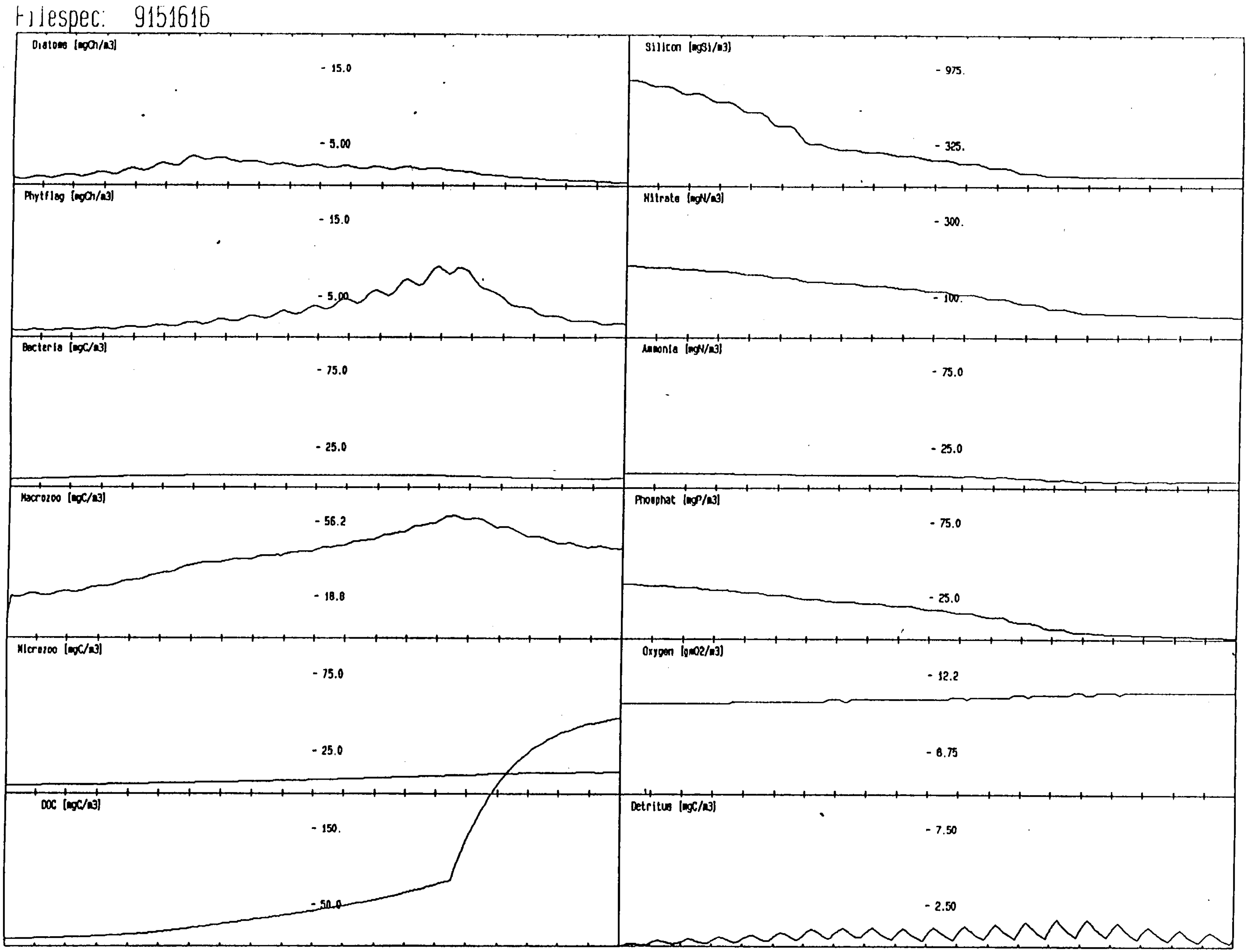


Figure 4 June plankton and nutrients without effluent discharge.

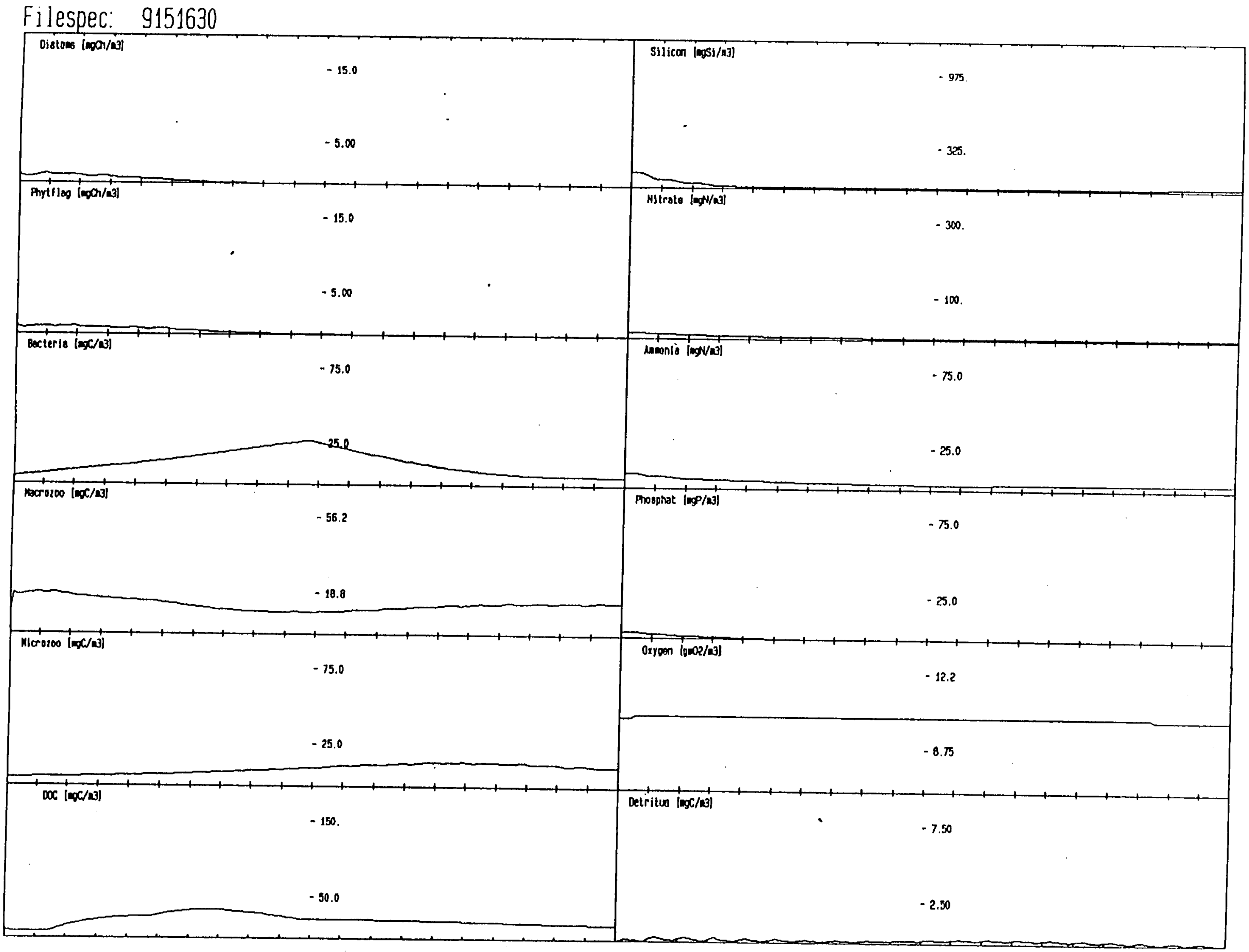


Figure 5 September plankton and nutrients without effluent discharge.

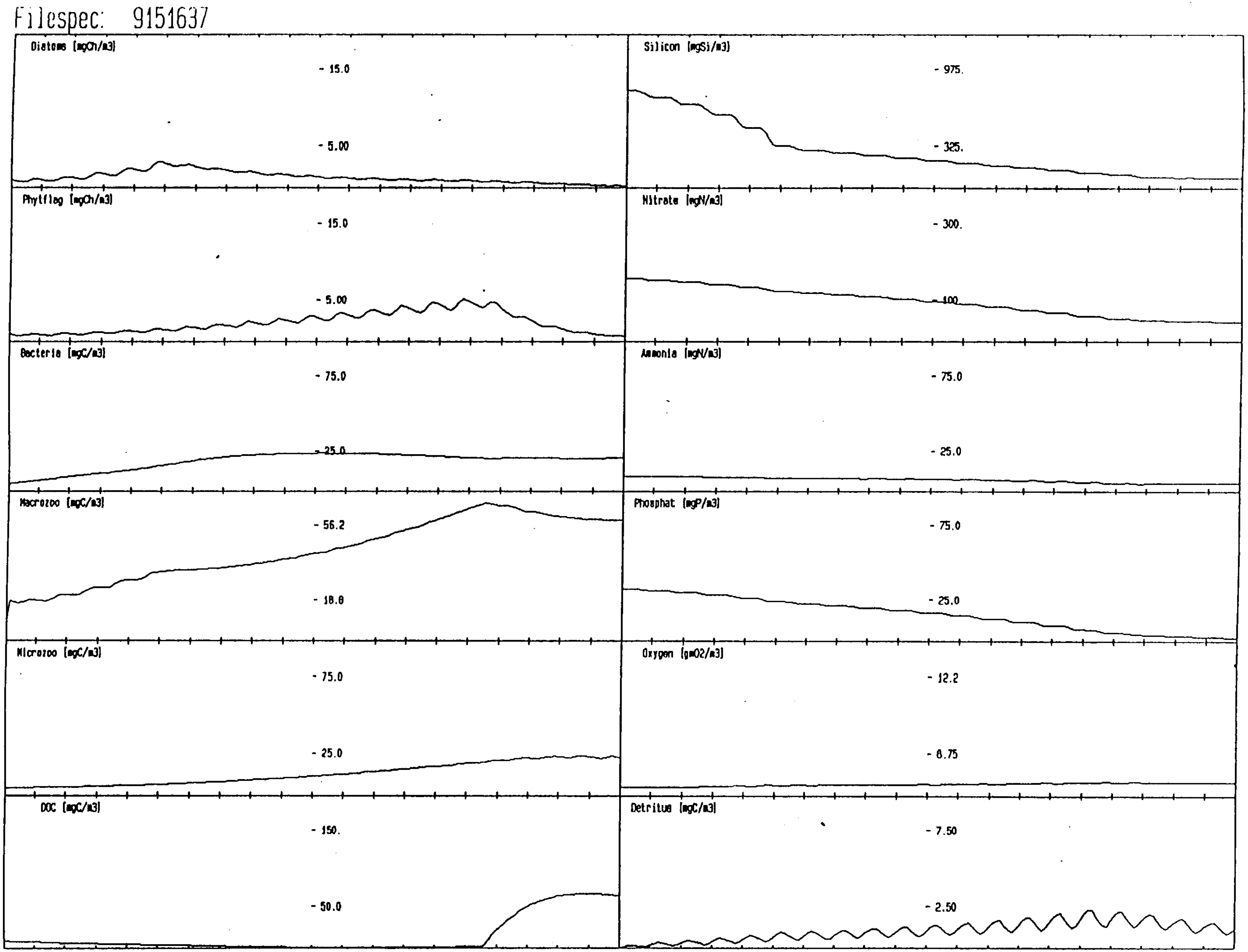


Figure 6 December plankton and nutrients without effluent discharge.

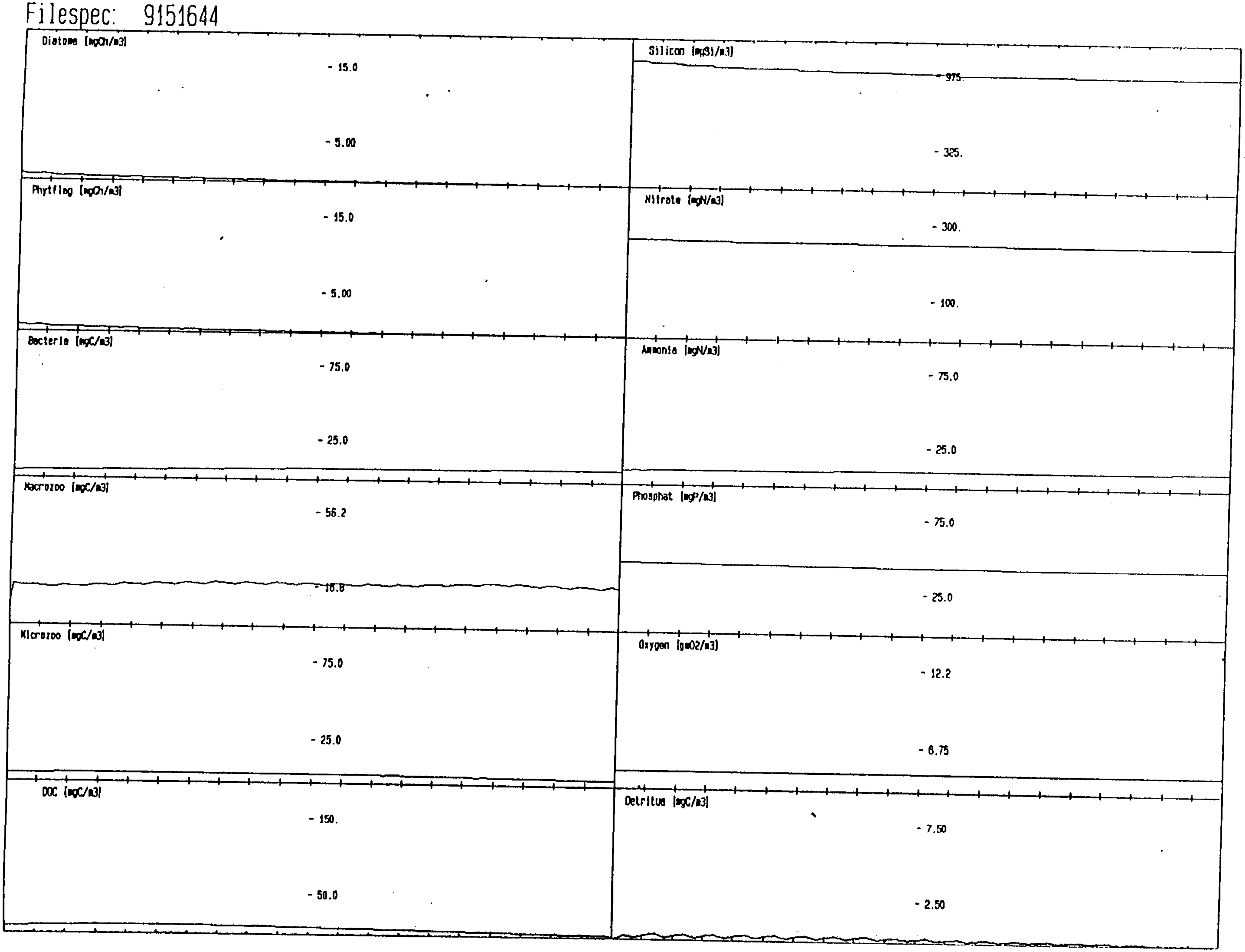


Figure 7 June parameters (Fig.4) but adding 5000m^3 of effluent at discharge 5m depth to an area of 10^6 m^2.

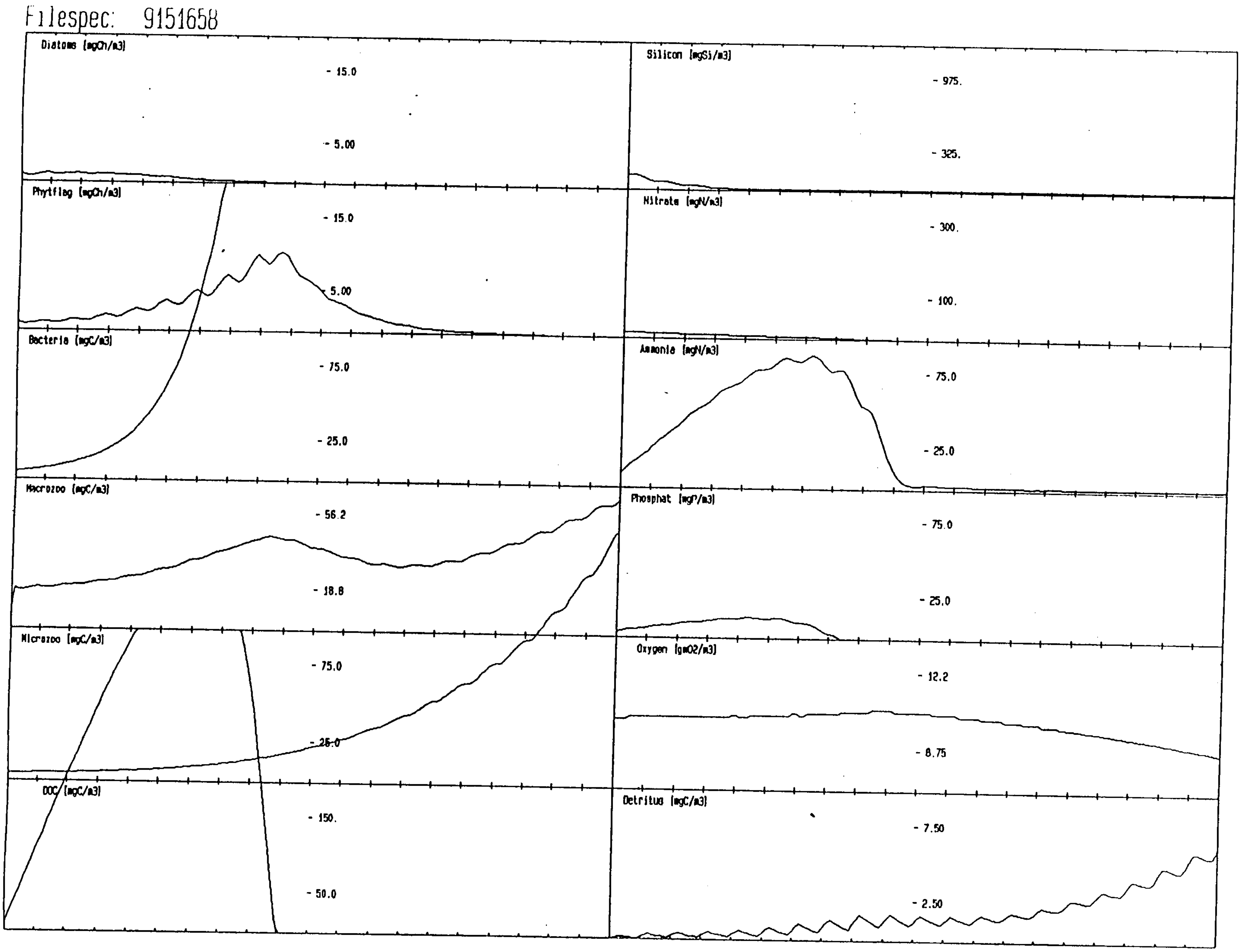


Figure 8 June parameters (Fig.4) and effluent as in Fig.7 but discharge at 15m depth.

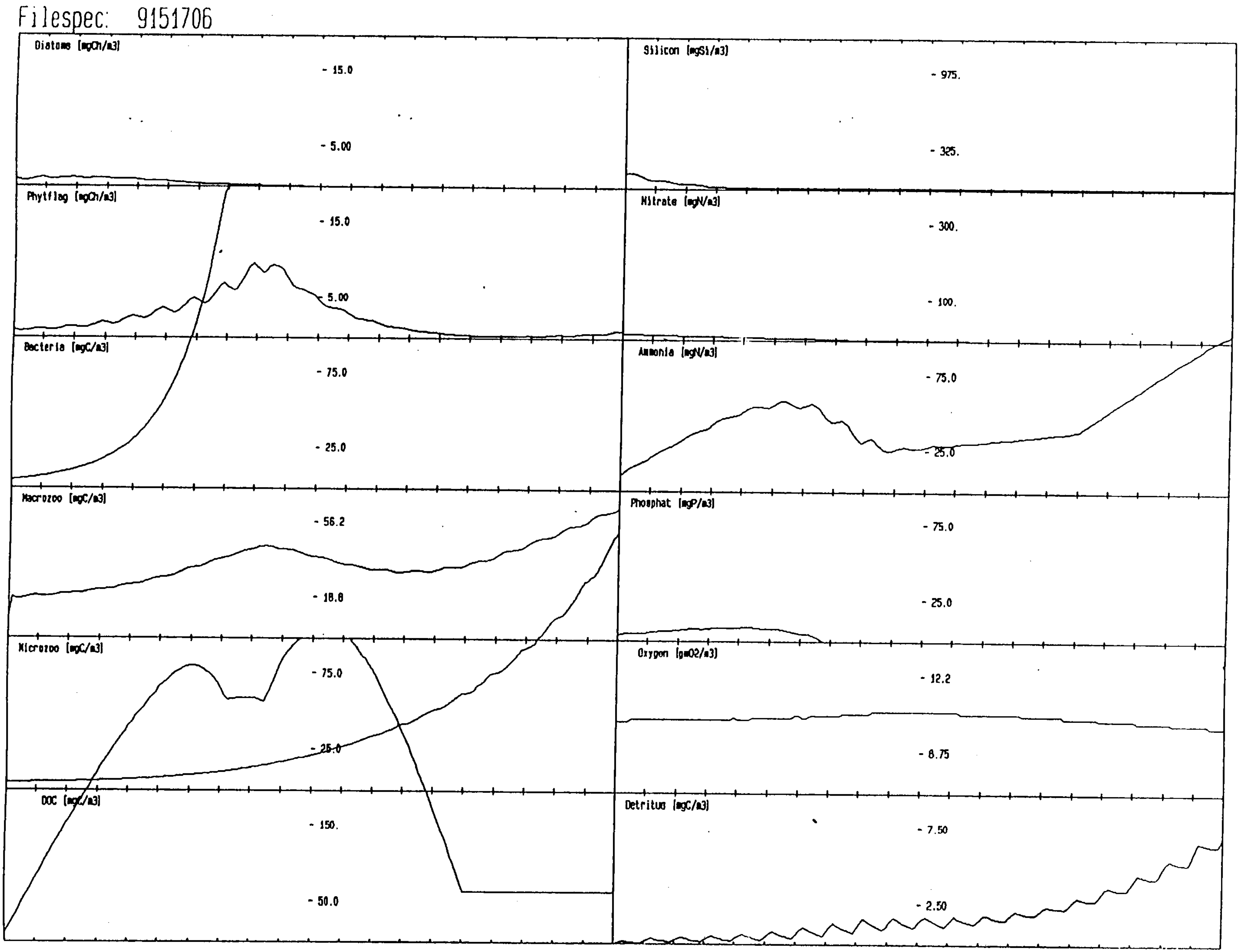


Figure 9 June parameters (Fig.4) and effluent as in Fig.7 but discharge at 30m depth.

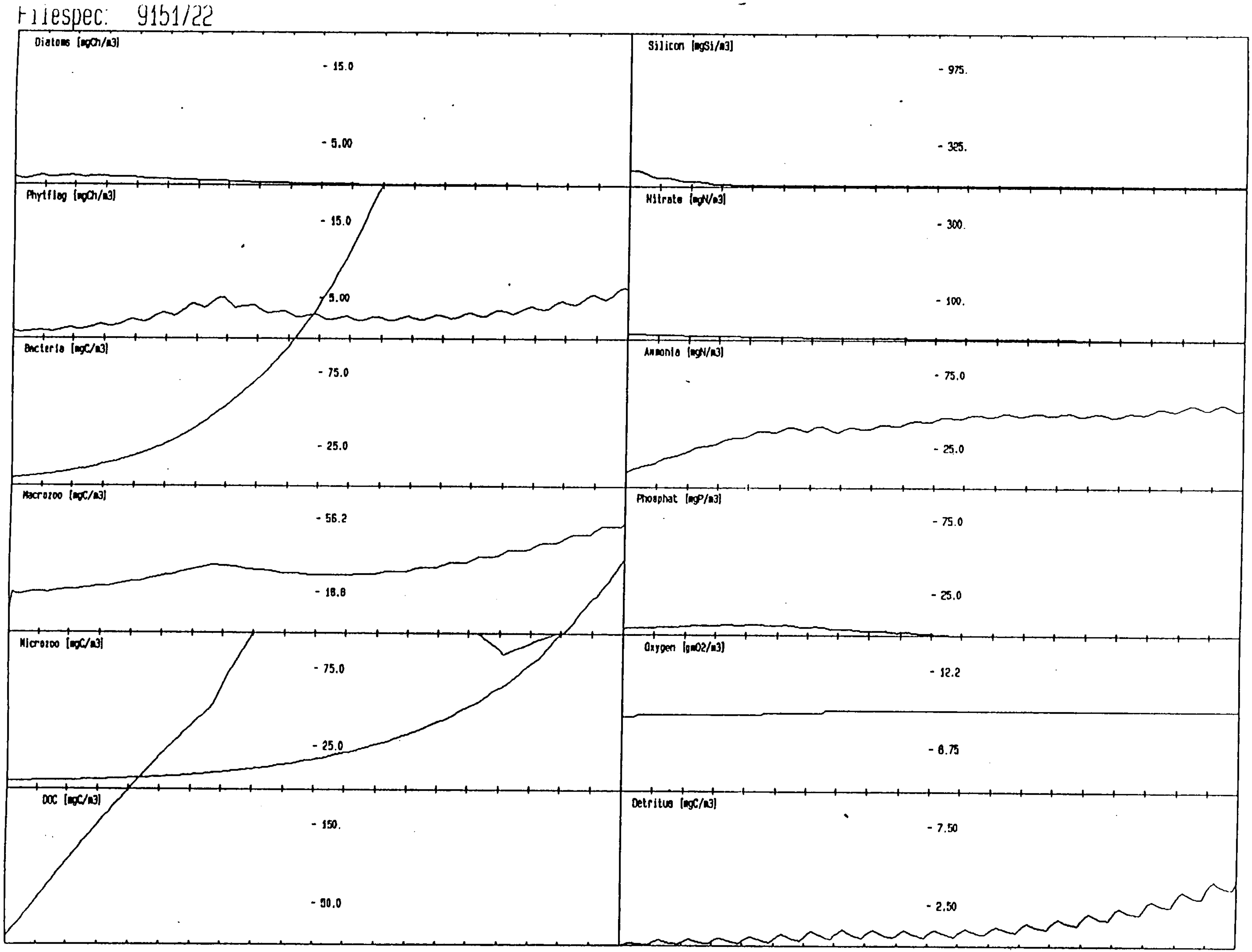


Figure 10 June parameters (Fig.4) and effluent as in Fig.7 but discharge at 50m depth.

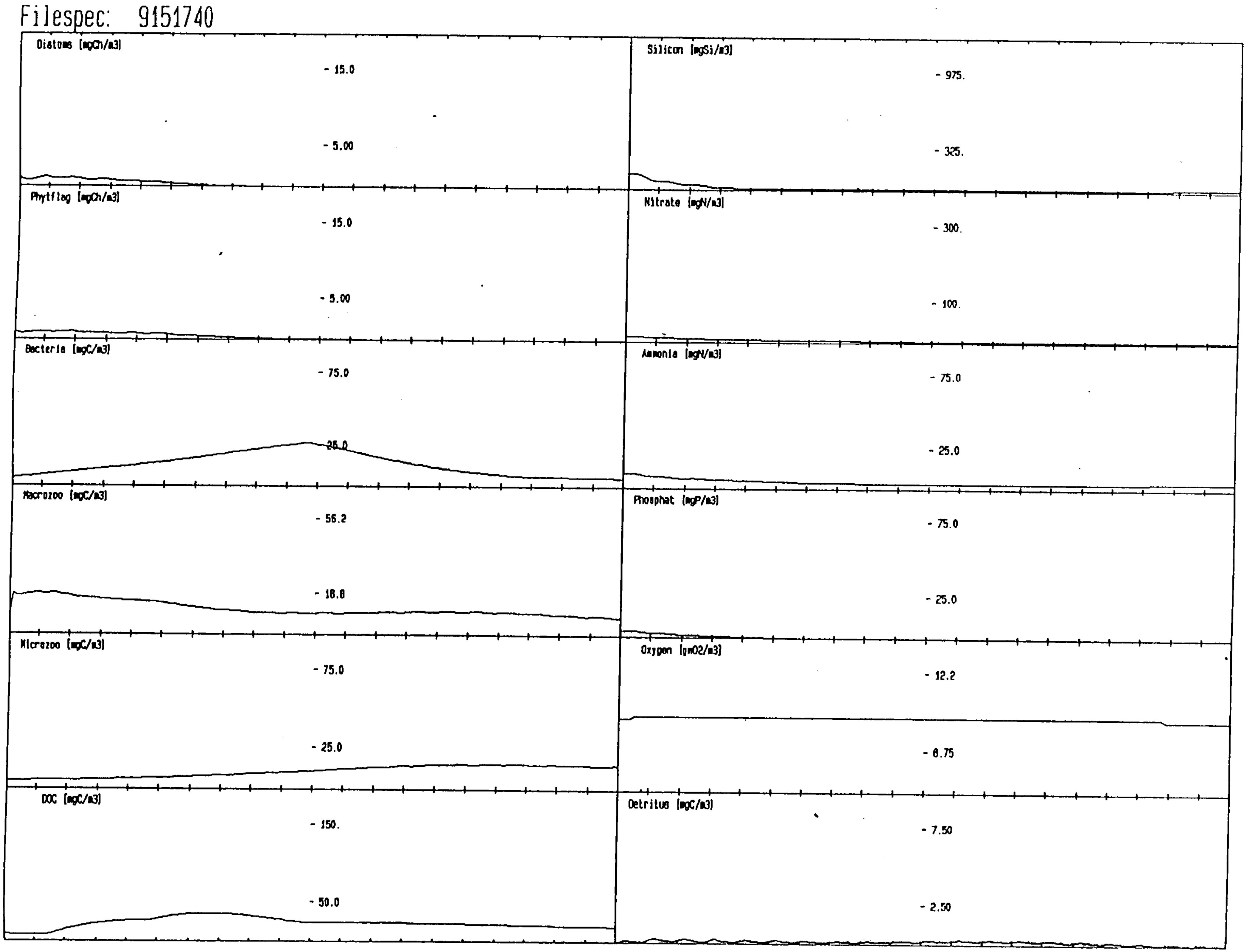


Table 1 Model parameters showing some initial conditions

CARBON/NUTRIENT BUDGET MODELING
INTEGRATION & MODEL PARAMETERS, STARTING & FORCING CONDITIONS

	Value	Description	Units
1	1.0	time-step	[hrs]
2	0.1	mixing stepsize relative to initial time-step	[N.D.]
3	999.	semi-implicit to implicit intregration ratio	[N.D.]
4	20.	integration interval	[days]
5	4	mid-month start of simulation [1-12]	
6	0	specify nitrate profile [0=based on simulation start time	
7	1.E-2	maximum relative local (rk) integration error	[N.D.]
8	5.0	vertical grid spacing	[m]
9	50.	simulated bottom depth	[m]
0	1.	starting diatom concentration	[mgCHLA/m^3]
1	1.	starting phytoflagellate concentration	[mgCHLA/m^3]
2	5.	starting bacteria concentration	[mgC/m^3]
3	5.	starting microzooplankton concentration	[mgC/m^3]
4	10.	starting macrozooplankton concentration	[mgC/m^3]
5	10.	starting DOC concentration	[mgC/m^3]
	10.	starting ammonia concentration	[mgN/m^3]
7	5.	phytoplankton carbon:nitrogen ratio	[N.D.]
	17.	phytoplankton carbon:phosphorus ratio	[N.D.]
	25.	phytoplankton c:chla ratio	[N.D.]
	0.25	diatom carbon:silicon ratio	[N.D.]
	10.	bacteria carbon:nitrogen ratio	[N.D.]
	17.	bacteria carbon:phosphorus ratio	[N.D.]
	5.	microzooplankton carbon:nitrogen ratio	[N.D.]
	17.	microzooplankton carbon:phosphorus ratio	[N.D.]
	0.	phytoplankton ammonia NO3-uptake inhib. coef.	[m^3/mgN]
	0.	bacterial ammonia NO3-uptake inhib. coef.	[m^3/mgN]
	0.035	diatom growth rate log10 temp. dependence	[days^-1'C^-1]

```
                      --
28    -0.07      diatom growth rate log10 constant                        [days^-1]
                      --
29    0.0275     phytoflagellate grwth rate log10 dependence              [days^-1'C^-1]
                      --
30    -0.14      phytoflagellate growth rate log10 constant               [days^-1]
                      --
31    0.1        phytoplankton respiration (fraction of Gmax)             [N.D.]
                      --
32    0.10       bacteria growth rate log10 temp. dependence              [days/'C]
                      --
33    -1.0       bacteria growth rate log10 constant                      [days^-1]
                      --
34    0.1        bacteria respiration (fraction of Gmax)                  [N.D.]
                      --
35    15.        diatom N-limitation saturation constant                  [mgN/m^3]
                      --
36    50.        diatom Si-limitation saturation constant                 [mgSi/m^3]
                      --
37    20.        diatom light-limitation saturation constant              [watts PAR/m^2]
                      --
38    15.0       phytoflagellate N-limitation sat. constant               [mgN/m^3]
                      --
39    20.        phytoflagellate light-limitation sat. constant           [watts PAR/m^2]
                      --
40    5.0        bacteria N-limitation saturation constant                [mgN/m^3]
                      --
41    3.0        bacteria DOC-limitation saturation constant              [mgC/m^3]
                      --
42    0.5        nutrient-limited phyto. DOC release rate                 [day^-1]
                      --
43    1.         phytoplankton/detritus maximum sinking rate              [m/day]
                      --
44    0.6        microzooplankton max. specific grazing rate              [day^-1]
                      --
45    20.        microzooplankton grazing saturation constant             [mgC/m^3]
                      --
46    0.1        microzooplankton ration excretion fraction               [N.D.]
                      --
47    0.5        microzooplankton growth efficiency                       [N.D.]
                      --
48    0.5        macrozooplankton max. specific grazing rate              [day^-1]
                      --
49    20.        macrozooplankton grazing saturation constant             [mgC/m^3]
                      --
50    0.2        macrozooplankton ration excretion fraction               [N.D.]
                      --
51    0.6        macrozooplankton growth efficiency                       [N.D.]
                      --
52    0.01       macrozooplankton export rate                             [days^-1]
                      --
3     0.         wind speed                                               [m/s]
                      --
4     0.2        background light attenuation                             [m^-1]
                      --
5     1          climate cloud cover correction [0=no; 1=yes]
                      --
6     000.       freshwater effluent/run-off discharge rate               [m^3/day]
                      --
7     10.        effluent temperature                                     ['C]
```

58	10.	outfall depth	[m]
59	0.0	effluent nitrate concentration	[gmN/m^3]
60	40.	effluent ammonia concentration	[gmN/m^3]
61	8.	effluent available phosphorus concentration	[gmP/m^3]
62	0.0	effluent available silicon concentration	[gmSi/m^3]
63	200.	effluent DOC concentration	[gm/m^3]
64	1.E+6	surface area of receiving water body	[m^2]

Table 2 Plotting and reporting parameters for the model

CARBON/NUTRIENT BUDGET MODELING
PLOTTING & REPORTING PARAMETERS

Value	Description	Units
0.	report averaging depth range (top)	[m]
10.	report averaging depth range (bottom)	[m]
0.1	reporting/plotting interval	[days]
1	screen plot [0=no; 1=yes]	
1.	first plotting/reporting depth	[m]
5.	second plotting/reporting depth	[m]
20.	third plotting/reporting depth	[m]
0	print model output report [1=yes; 0=no]	
2	plot hard copy [0=no; 1=to printer ; 2=to HPGL plotfile]	
0.0	panel #1 y-axis minimum	
20.0	panel #1 y-axis maximum	
0.0	panel #2 y-axis minimum	
20.0	panel #2 y-axis maximum	
0.0	panel #3 y-axis minimum	
100.0	panel #3 y-axis maximum	
0.0	panel #4 y-axis minimum	
75.	panel #4 y-axis maximum	
0.0	panel #5 y-axis minimum	
50.	panel #5 y-axis maximum	
0.0	panel #6 y-axis minimum	
200.	panel #6 y-axis maximum	
0.0	panel #7 y-axis minimum	
1500.	panel #7 y-axis maximum	
0.0	panel #8 y-axis minimum	
400.0	panel #8 y-axis maximum	
0.0	panel #9 y-axis minimum	
100.0	panel #9 y-axis maximum	
0.0	panel #10 y-axis minimum	
100.0	panel #10 y-axis maximum	
7.0	panel #11 y-axis minimum	
14.0	panel #11 y-axis maximum	
0.0	panel #12 y-axis minimum	
10.0	panel #12 y-axis maximum	

State-variable key

1:diatoms	[mgChla/m^3]
2:phytoflagellates	[mgChla/m^3]
3:bacteria	[mgC/m^3]
4:macro-zooplankton	[mgC/m^3]
5:micro-zooplankton	[mgC/m^3]
6:DOC	[mgC/m^3]
7:available silicon	[mgSi/m^3]
8:nitrate	[mgN/m^3]
9:ammonia	[mgN/m^3]
10:available phosphorus	[mgP/m^3]
11:dissolved oxygen	[mgO2/m^3]
12:detritus	[mgC/m^3]

Figure 11 January parameters (Fig.1) but adding 5000m^3 of effluent at discharge 50m depth to an area of 10^6 m^2.

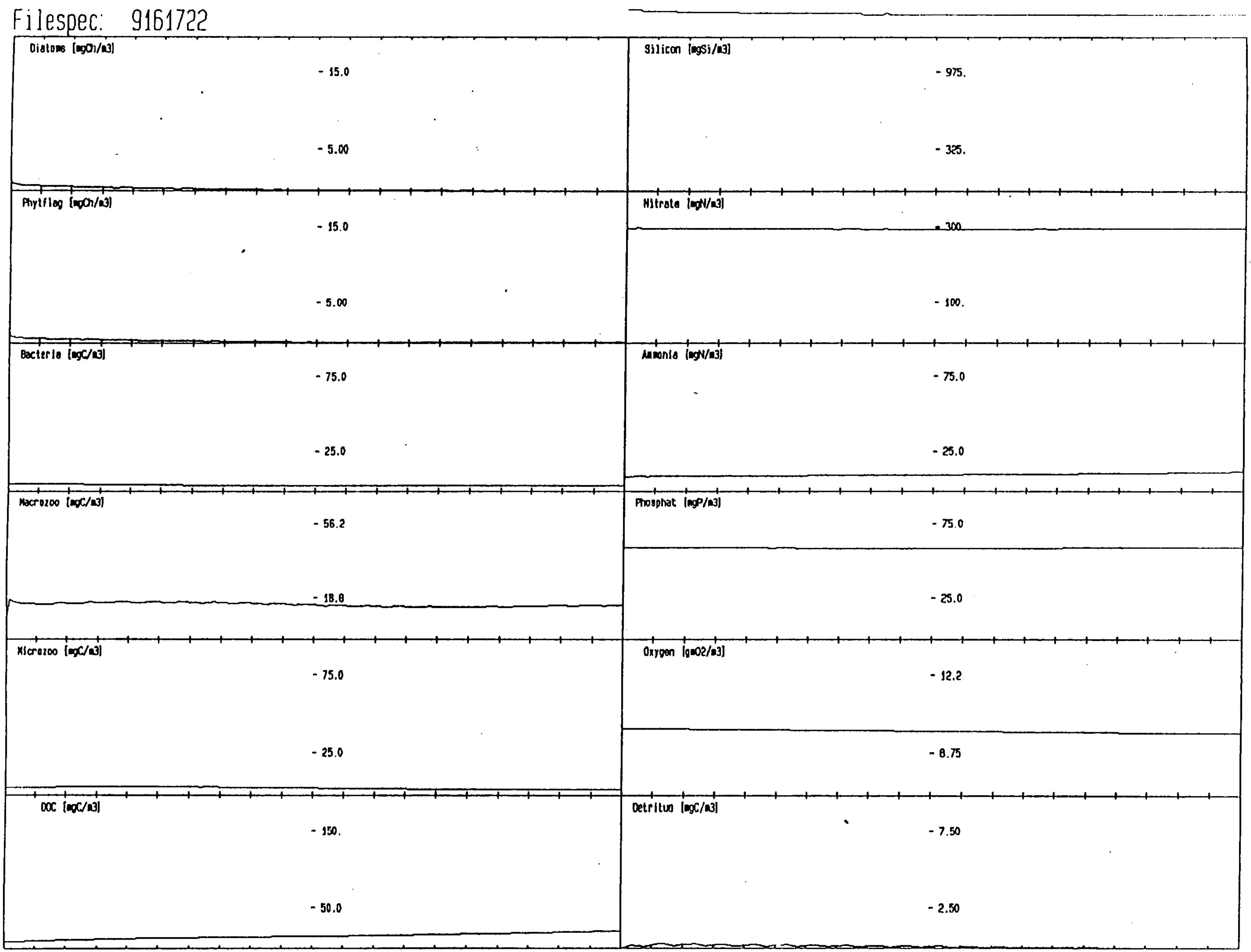


Figure 12 June parameters (Fig.4) but adding a wind speed of 1m/sec and discharge as in Fig.10.

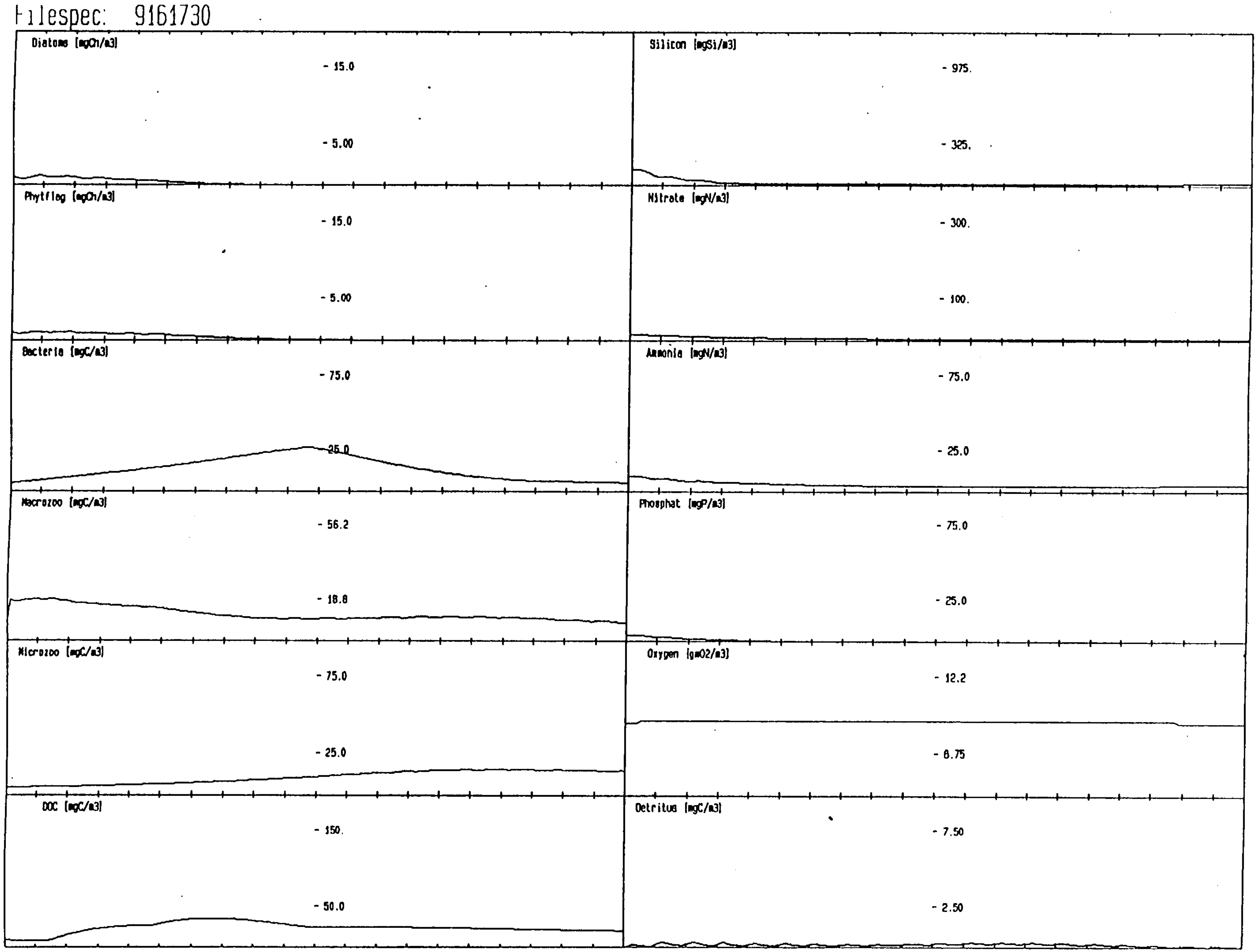


Figure 13 June parameters (Fig.4) but adding a wind speed of 3m/sec and discharge as in Fig.10.

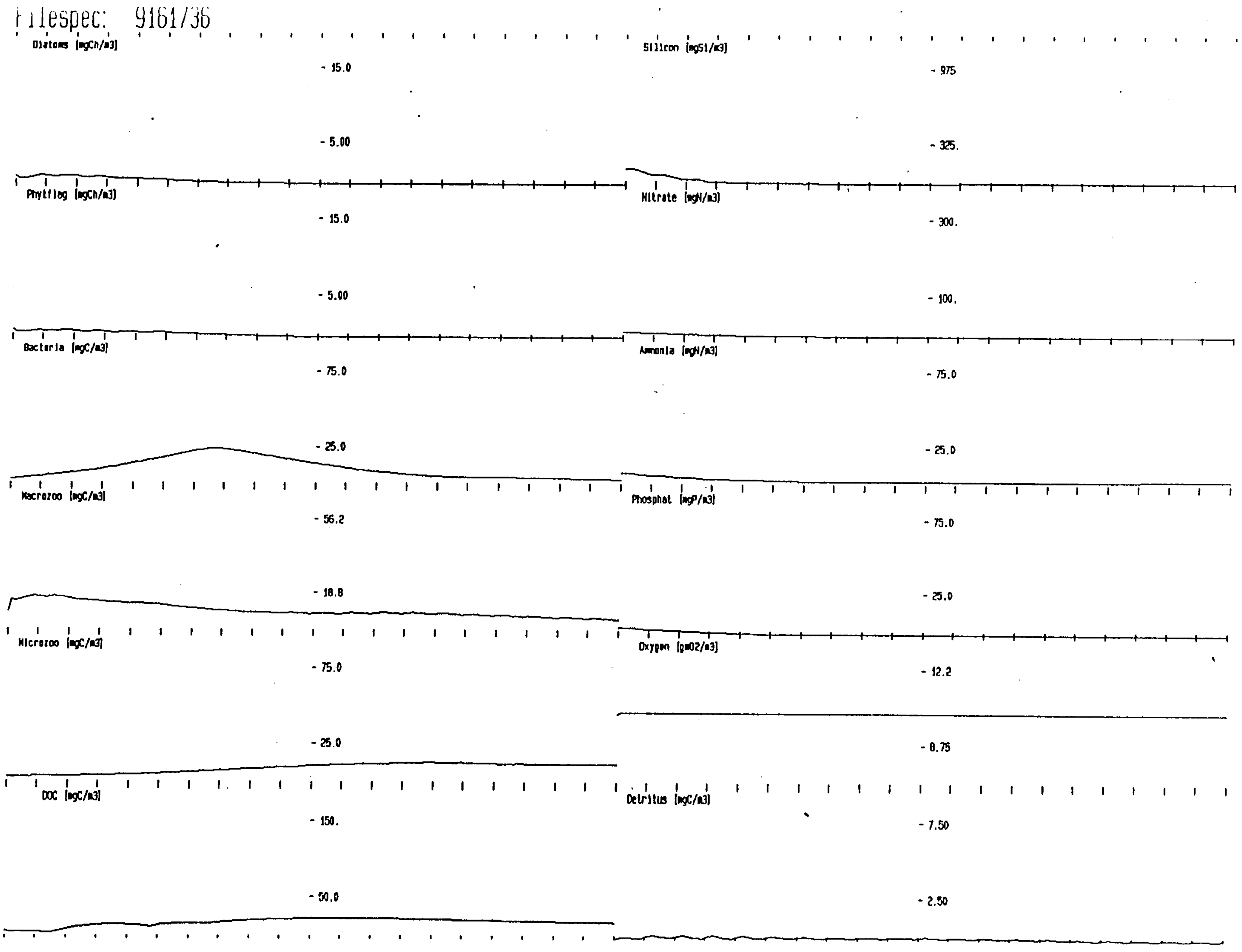


Figure 14 June parameters (Fig.4) but adding a wind speed of 10m/sec and discharge as in Fig.10.

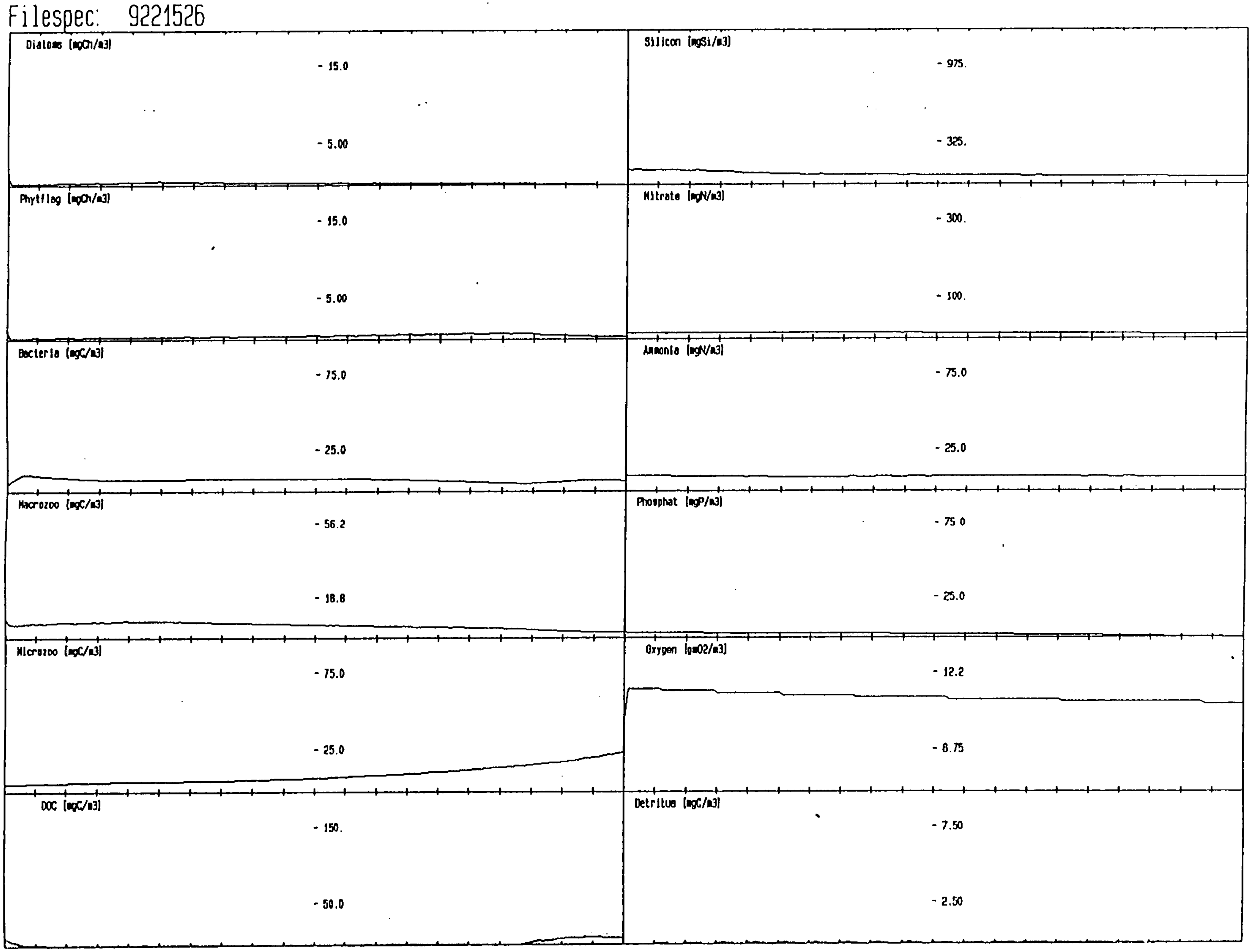


Figure 15 June parameters with wind of 3m/sec (Fig.13) but removing cloud cover.

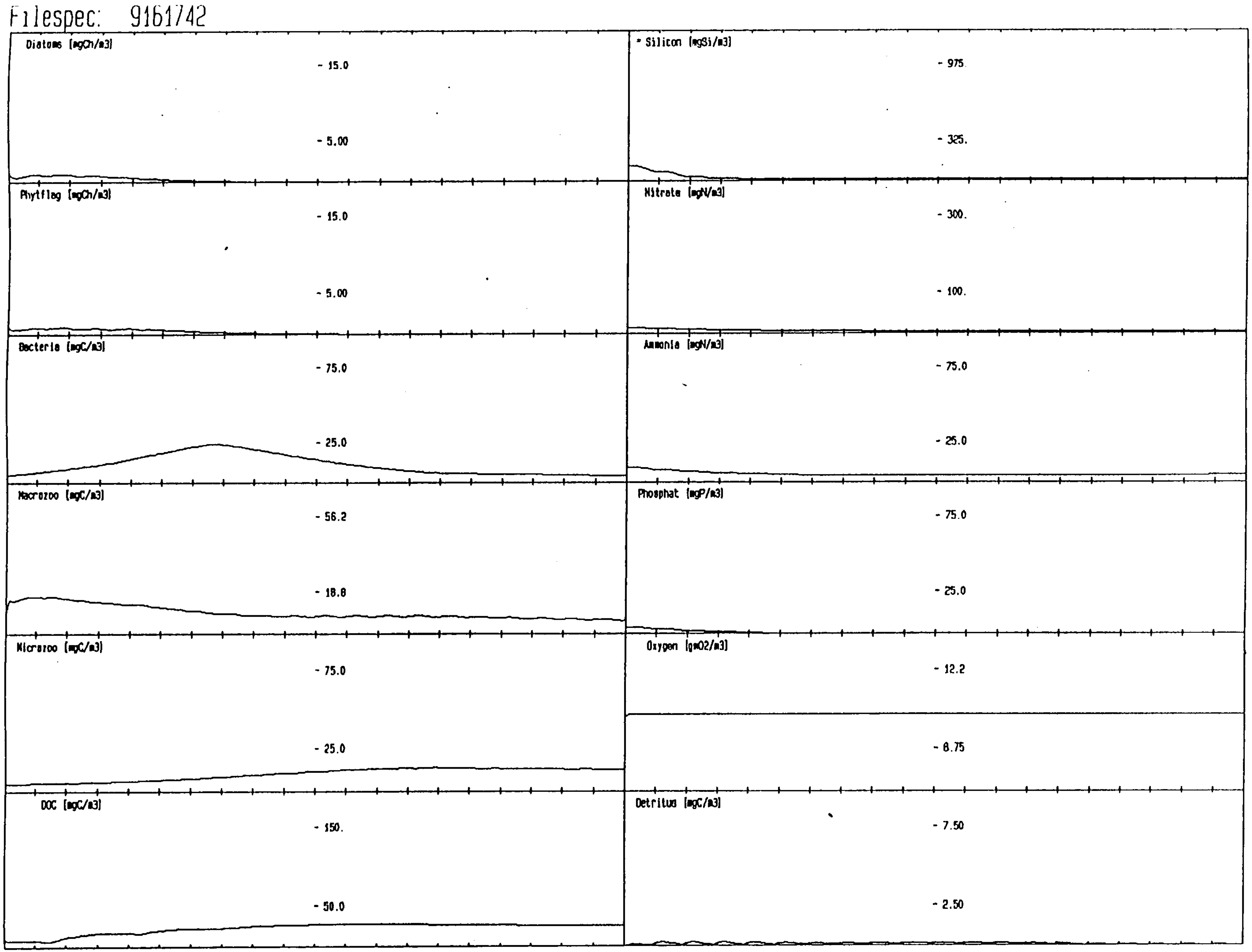


Figure 16 June parameters, wind 3m/sec, no cloud cover and a discharge of 7000 m³/day at 50m.

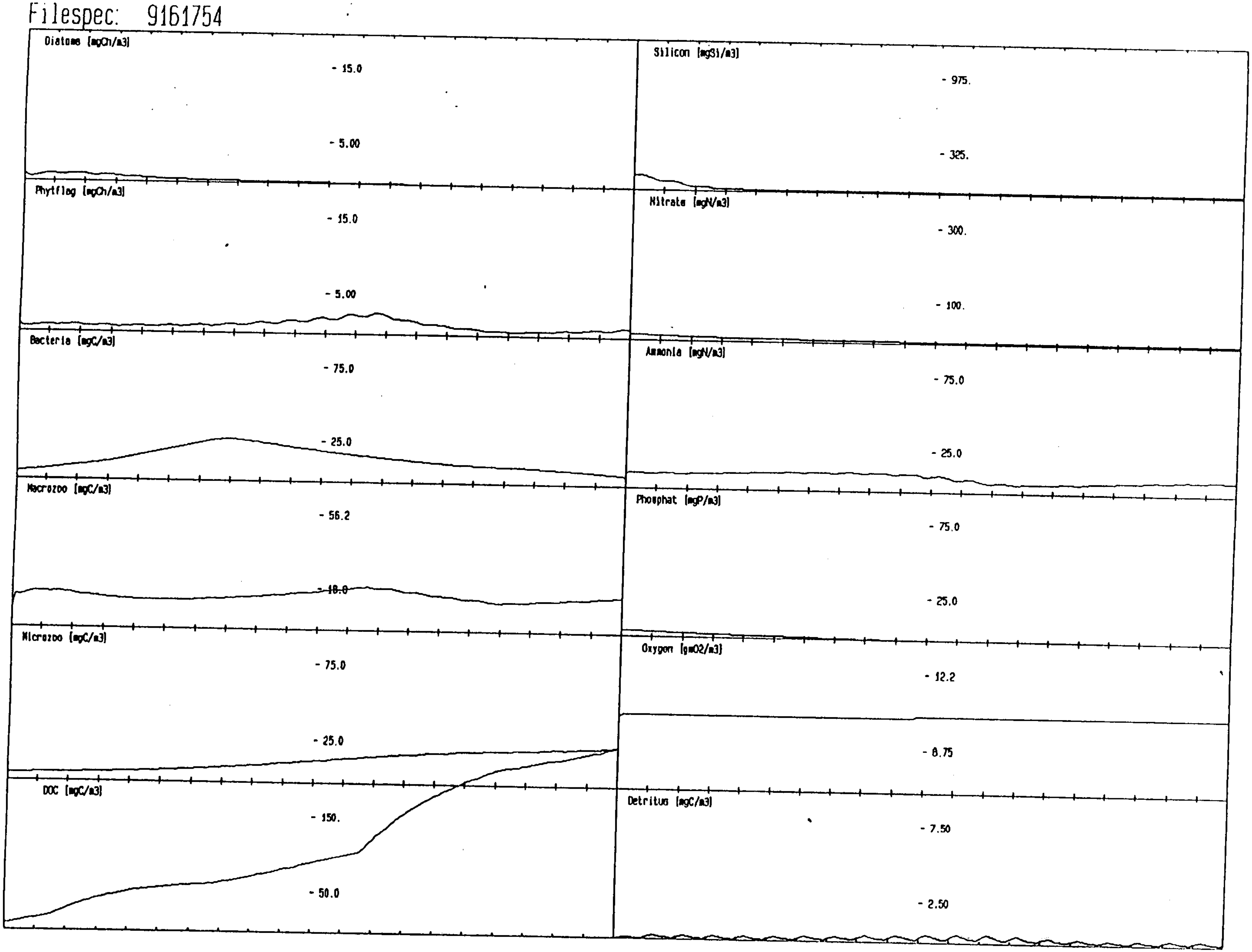


Figure 17 June parameters, wind 3m/sec, no cloud cover and a discharge of 9000 m³/day at 50m.

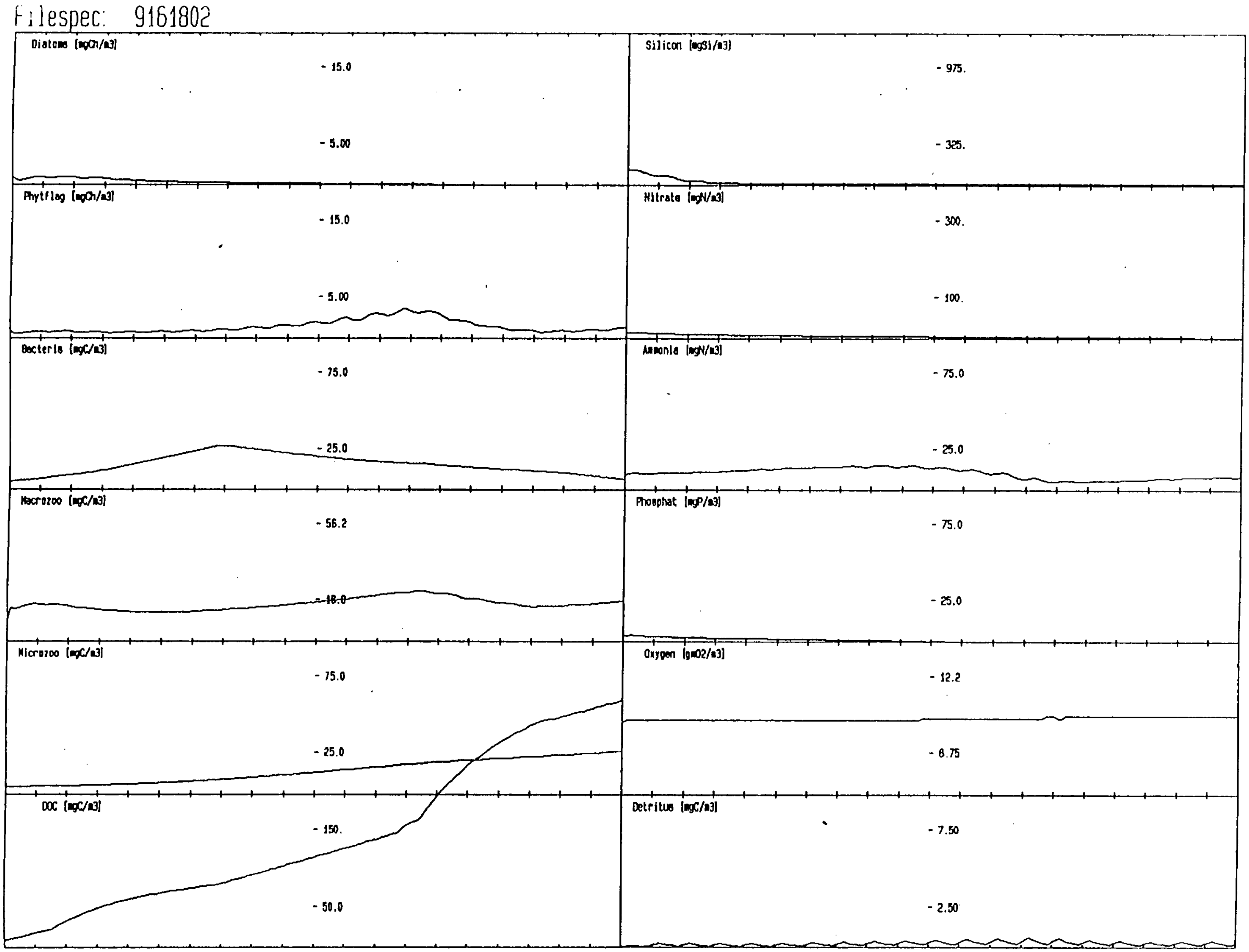


Figure 18 June parameters, discharge 5000 m^3 (Fig.10) but decreasing the discharge area to 10^5 m^2.

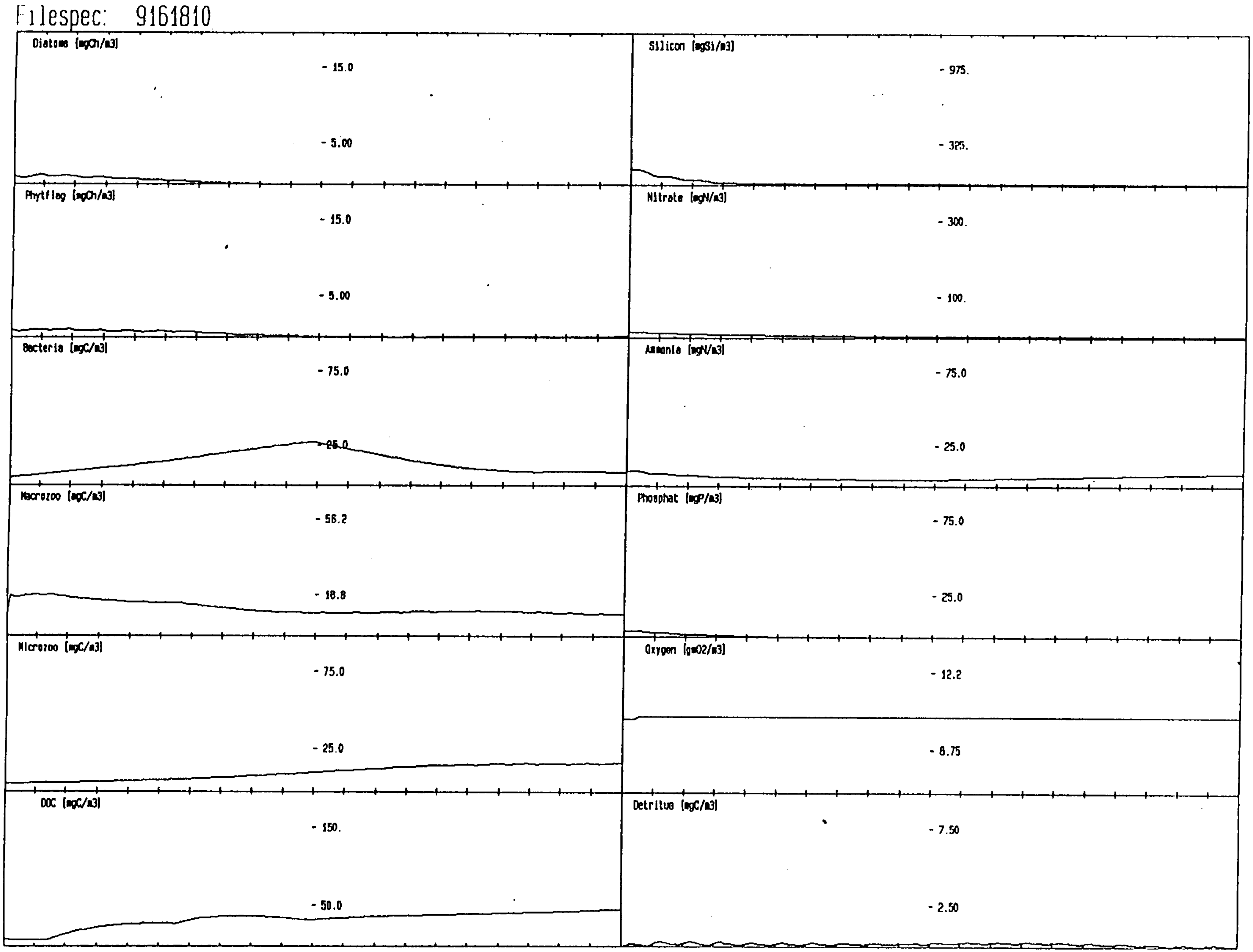


Figure 19 June parameters, discharge 9000 m^3 (Fig. 17) but increasing the depth to 75m for a discharge area of 10^6 m^2.

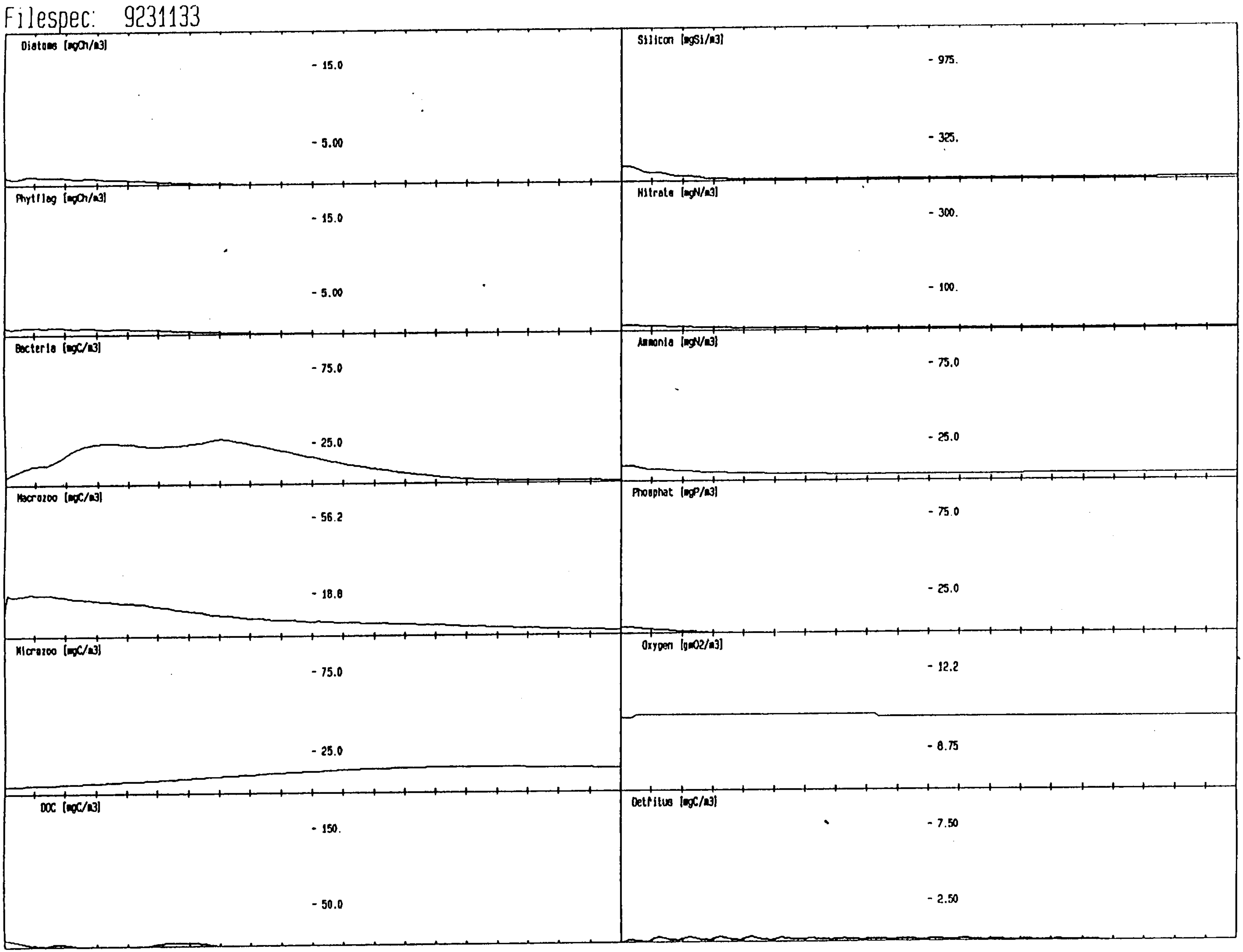


Figure 20 June parameters (Fig.4) but adding surface nutrients equivalent to spring (April) values.

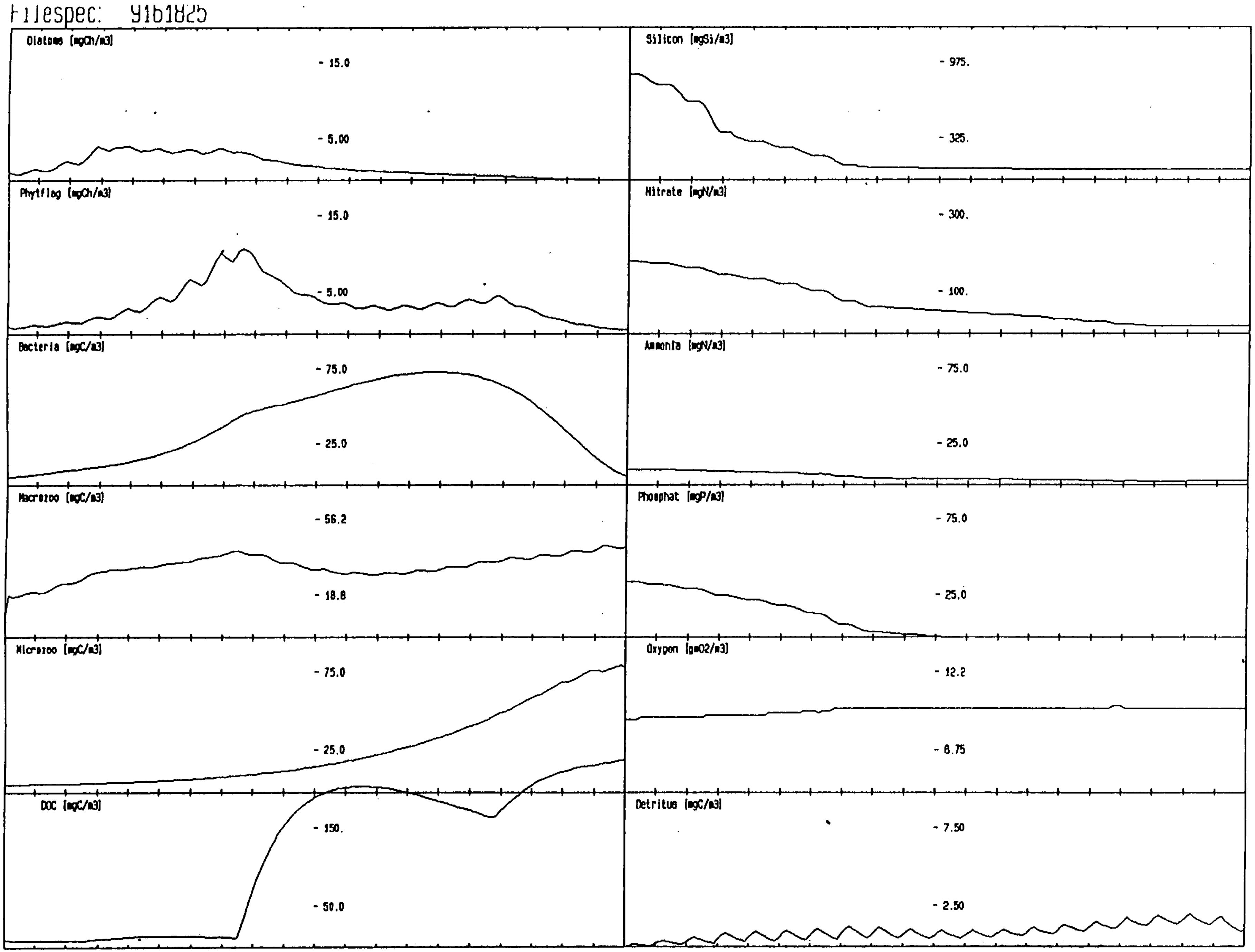


Figure 21 June parameters (Fig.4) but adding 2000 m^3 of effluent discharge at a depth of 10m (1km^2).

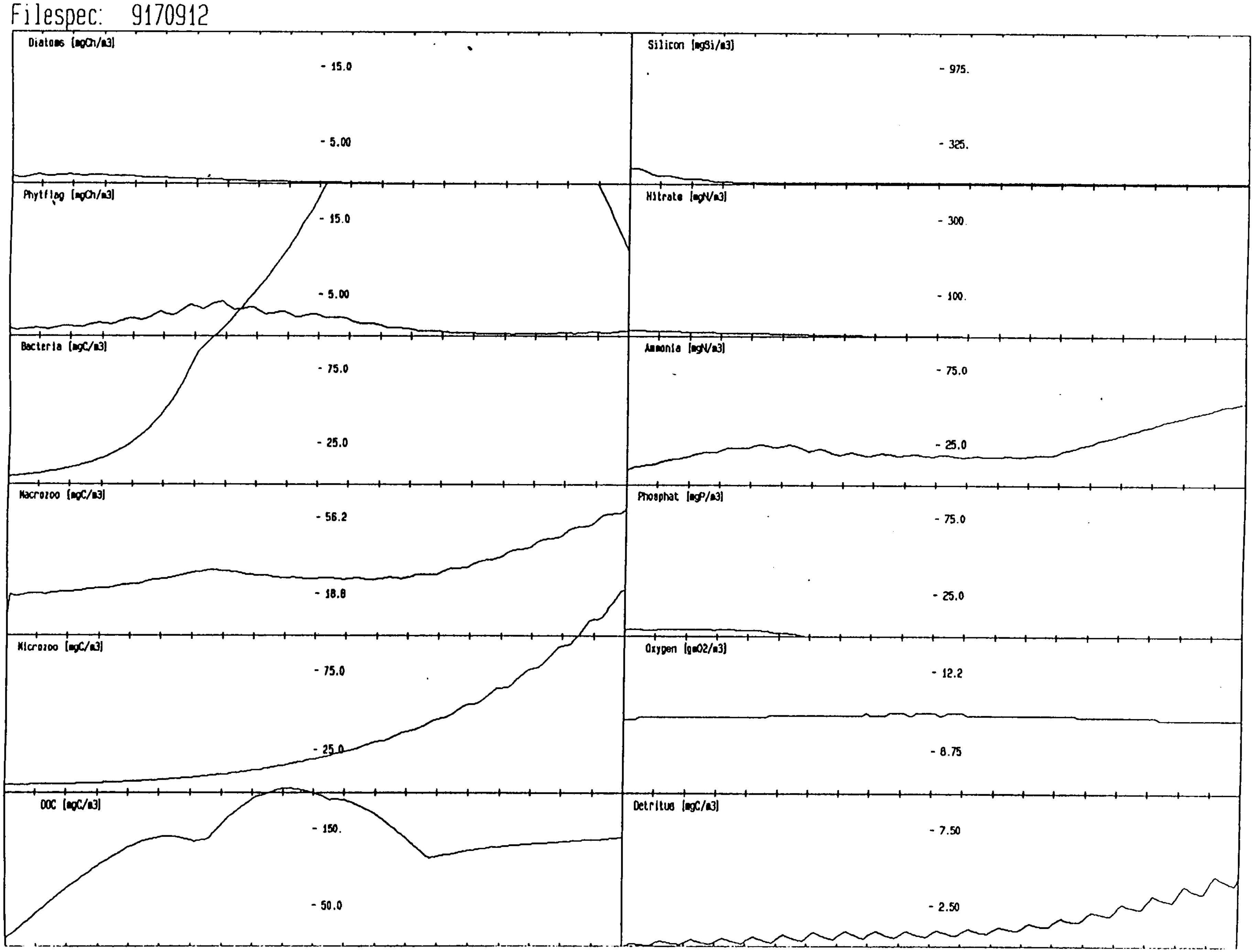


Figure 22 June parameters (Fig.4) but adding 500m^3 of effluent discharge at a depth of 10 m (1km^2).

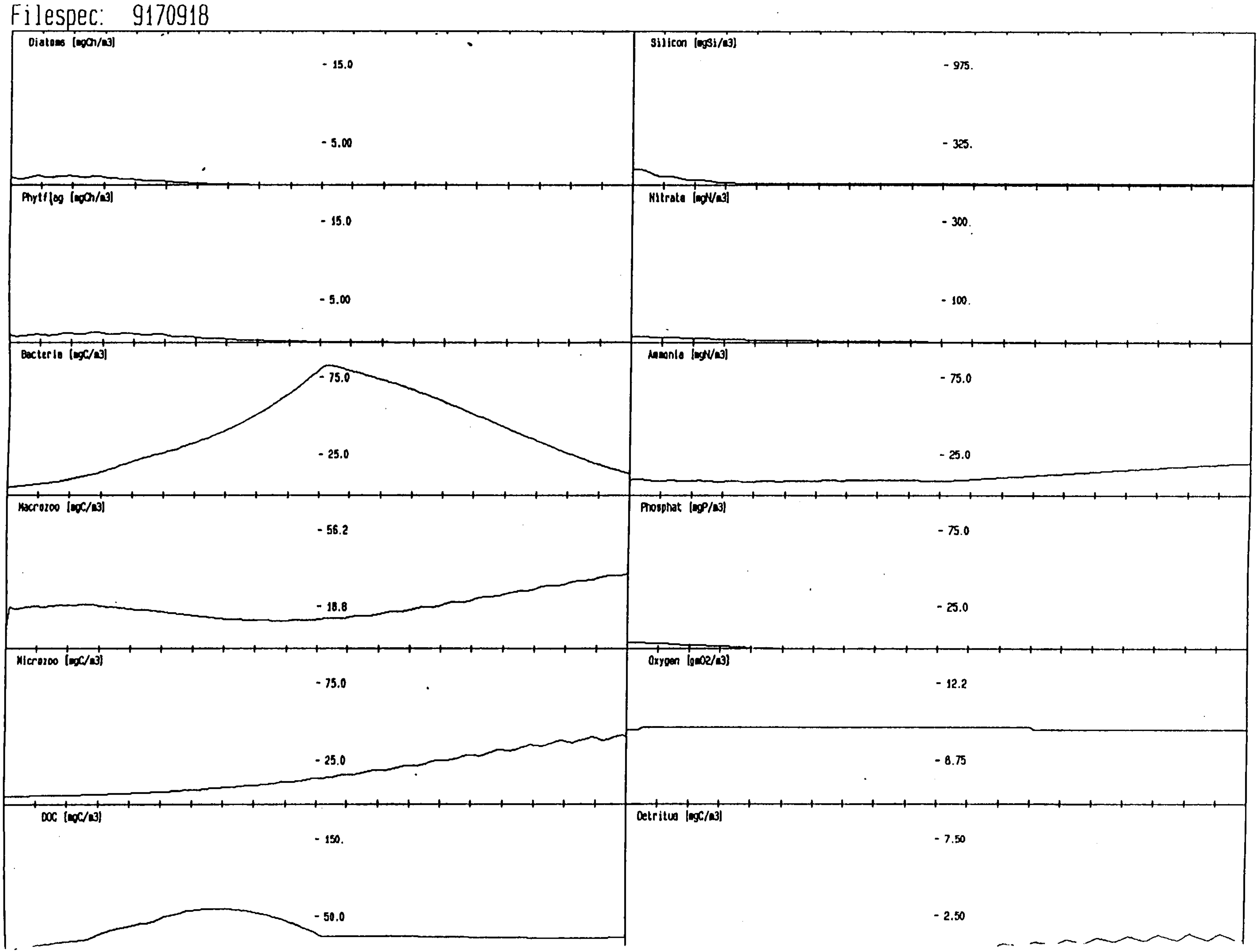


Figure 23 June parameters (Fig.4) but adding 100 m^3 of effluent discharge at a depth of 10m (1km^2).

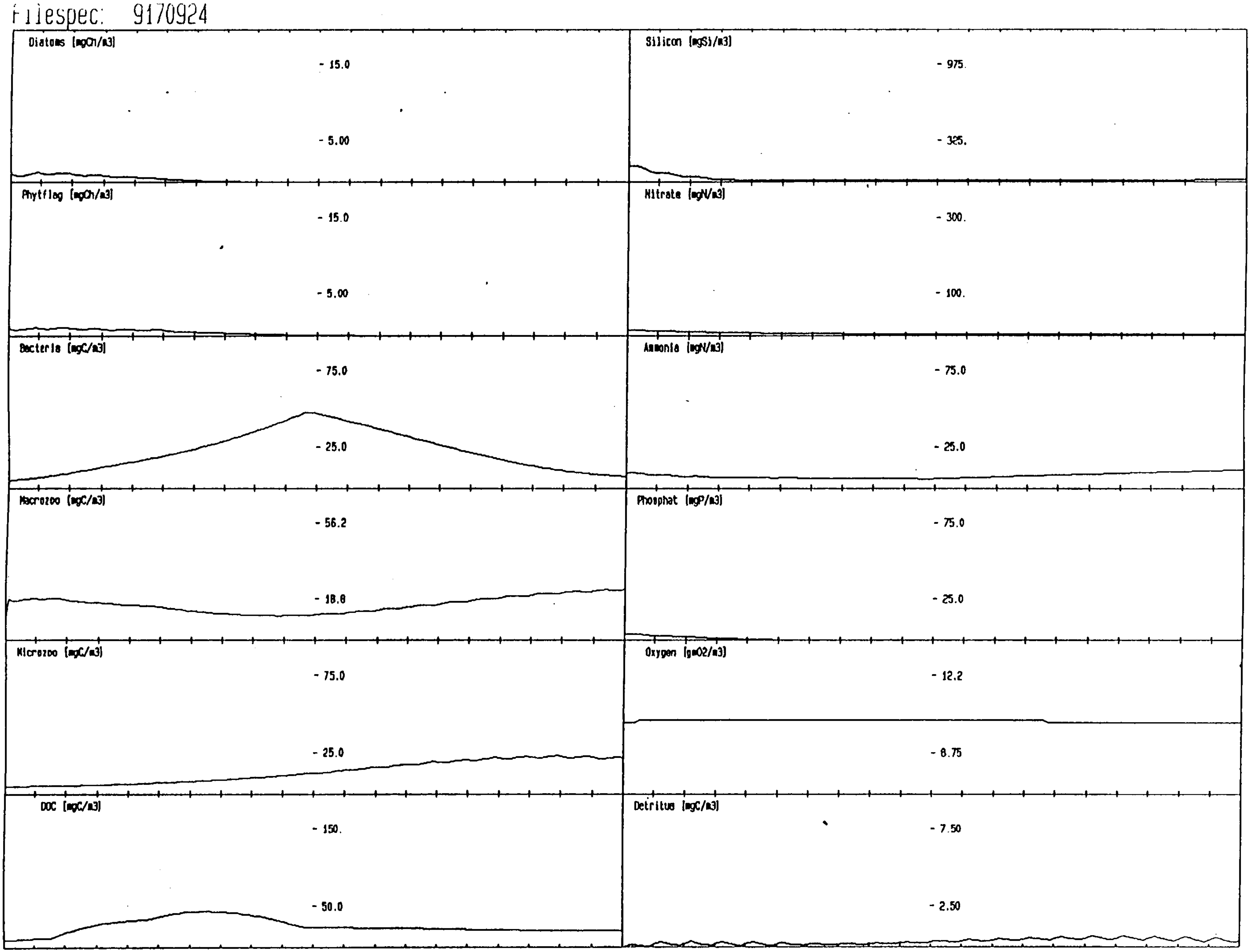


Figure 24 June parameters (Fig.4) but averaged for 20m depth instead of 10m.

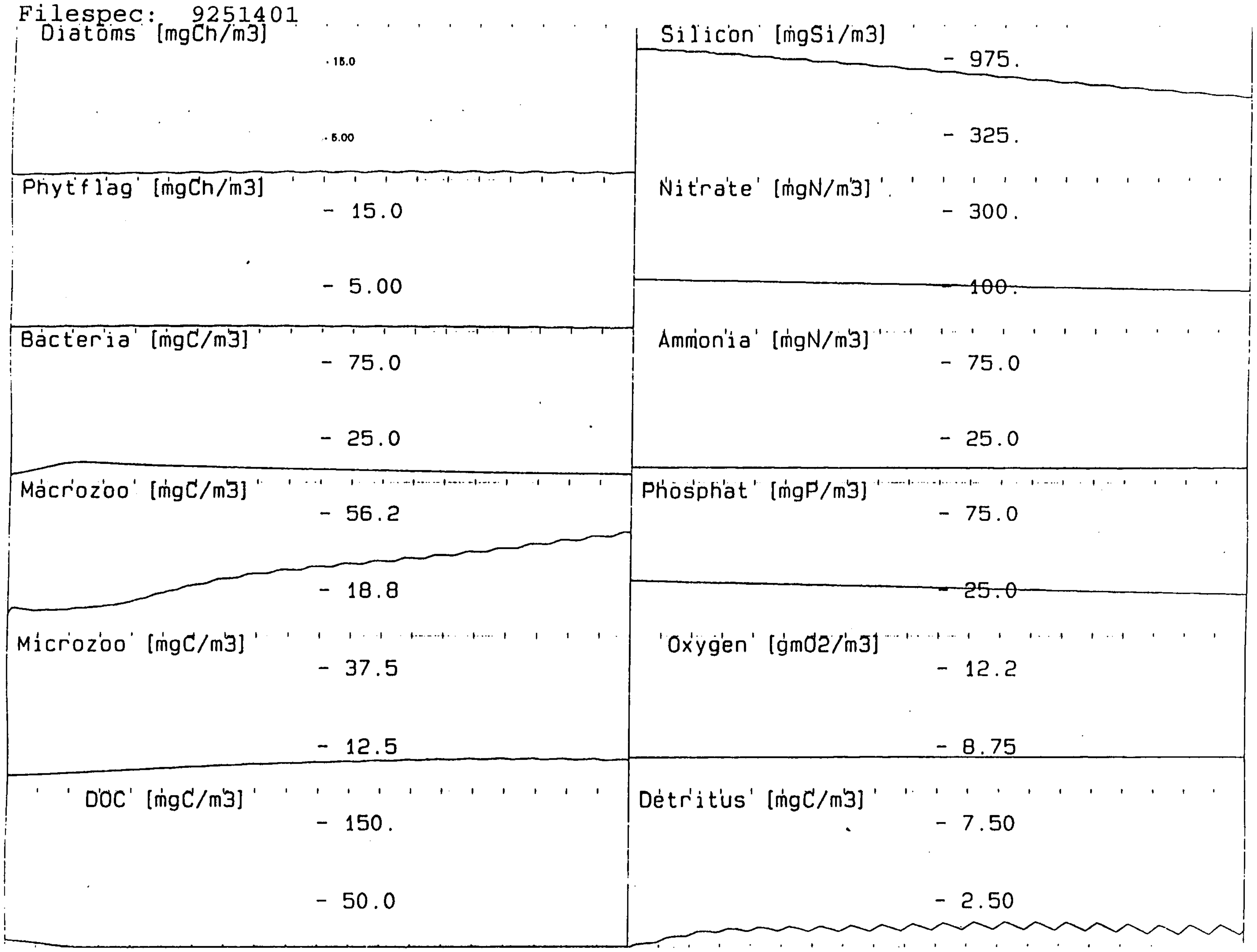


Figure 25 June parameters with 5000 m³ effluent (Fig.10) but averaged for 20m depth instead of 10m.

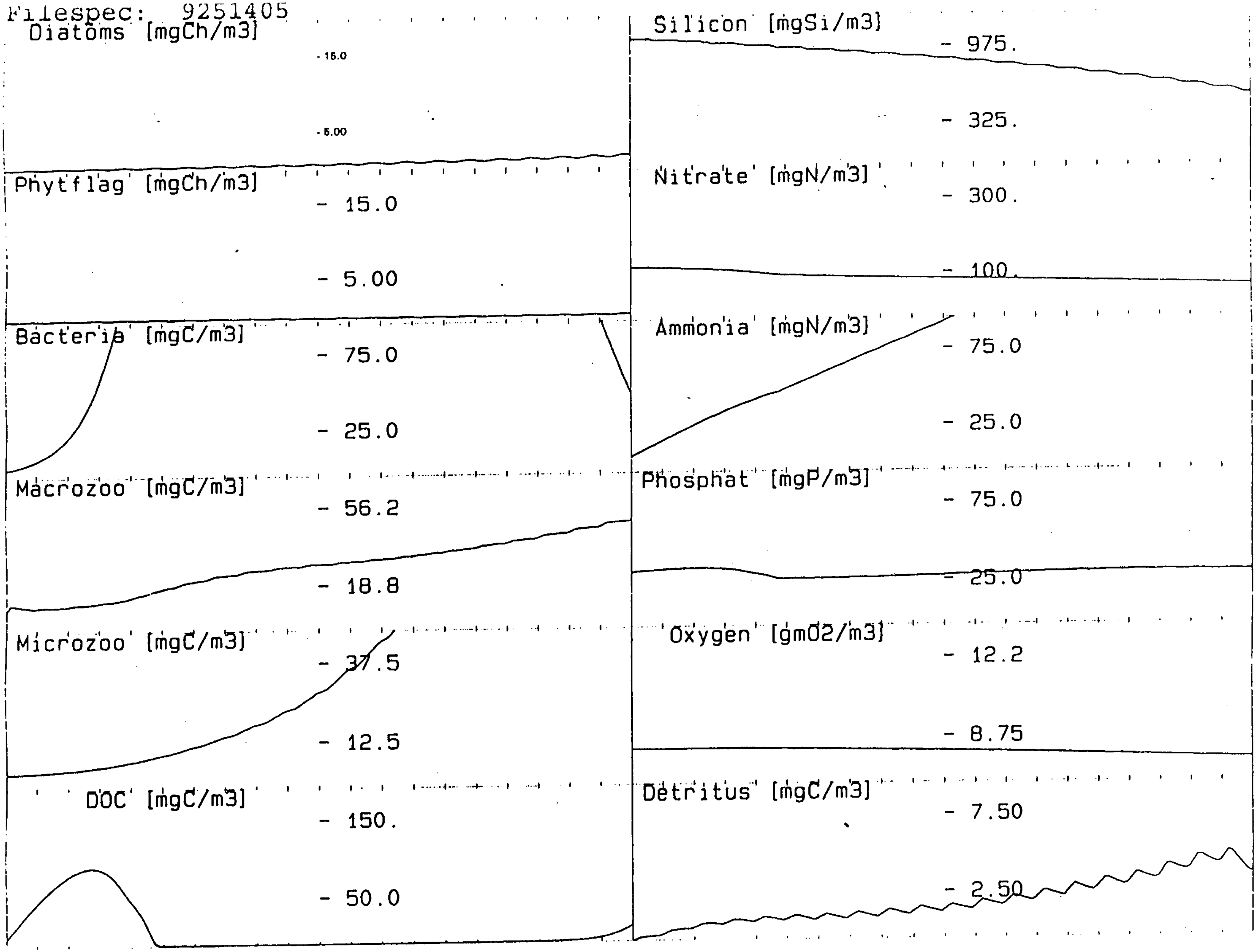


Figure 26 April parameters with no cloud cover and no discharge; extinction coefficient k= 0.2.

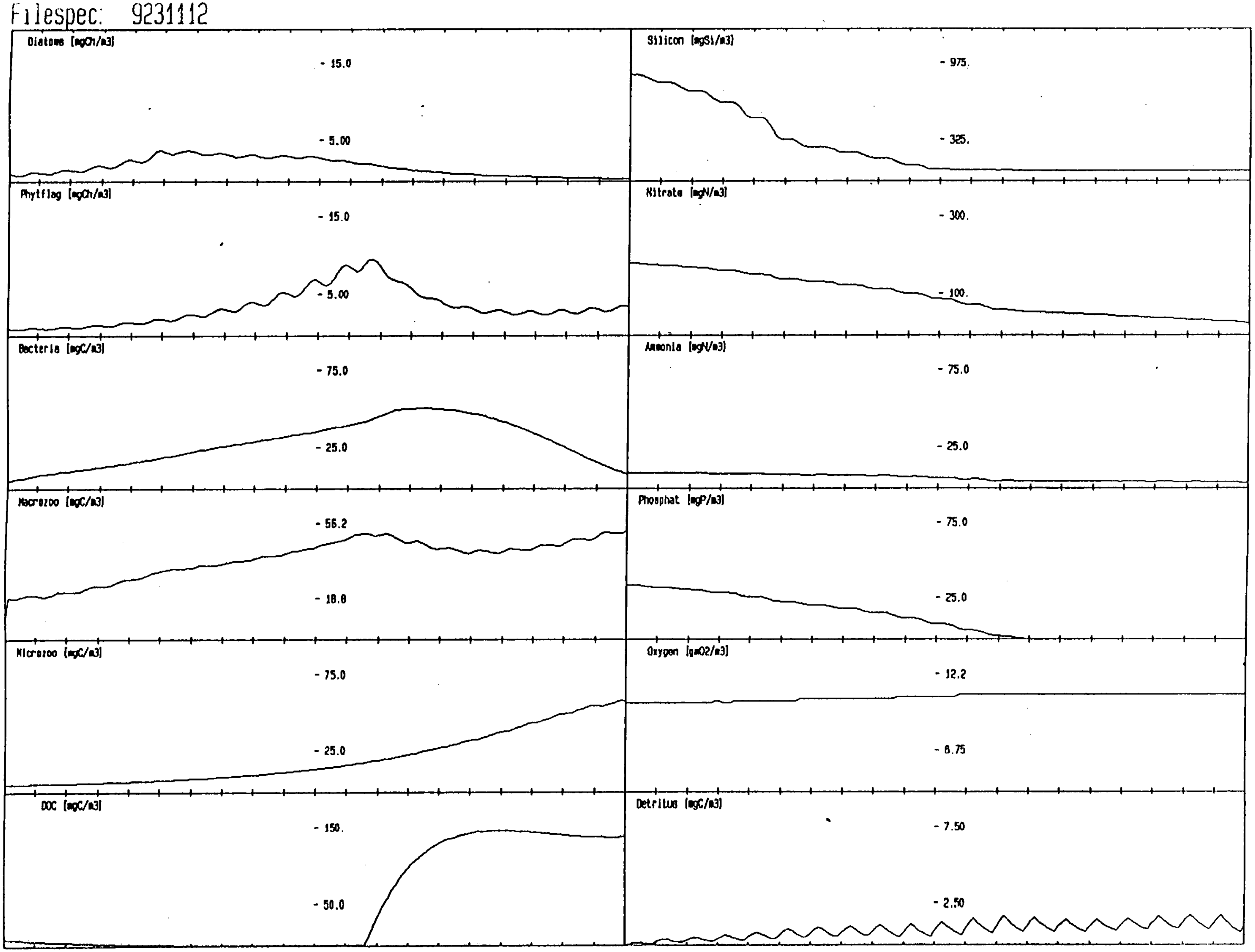


Figure 27 April parameters with no cloud cover and no discharge; extinction coefficient k= 0.4.

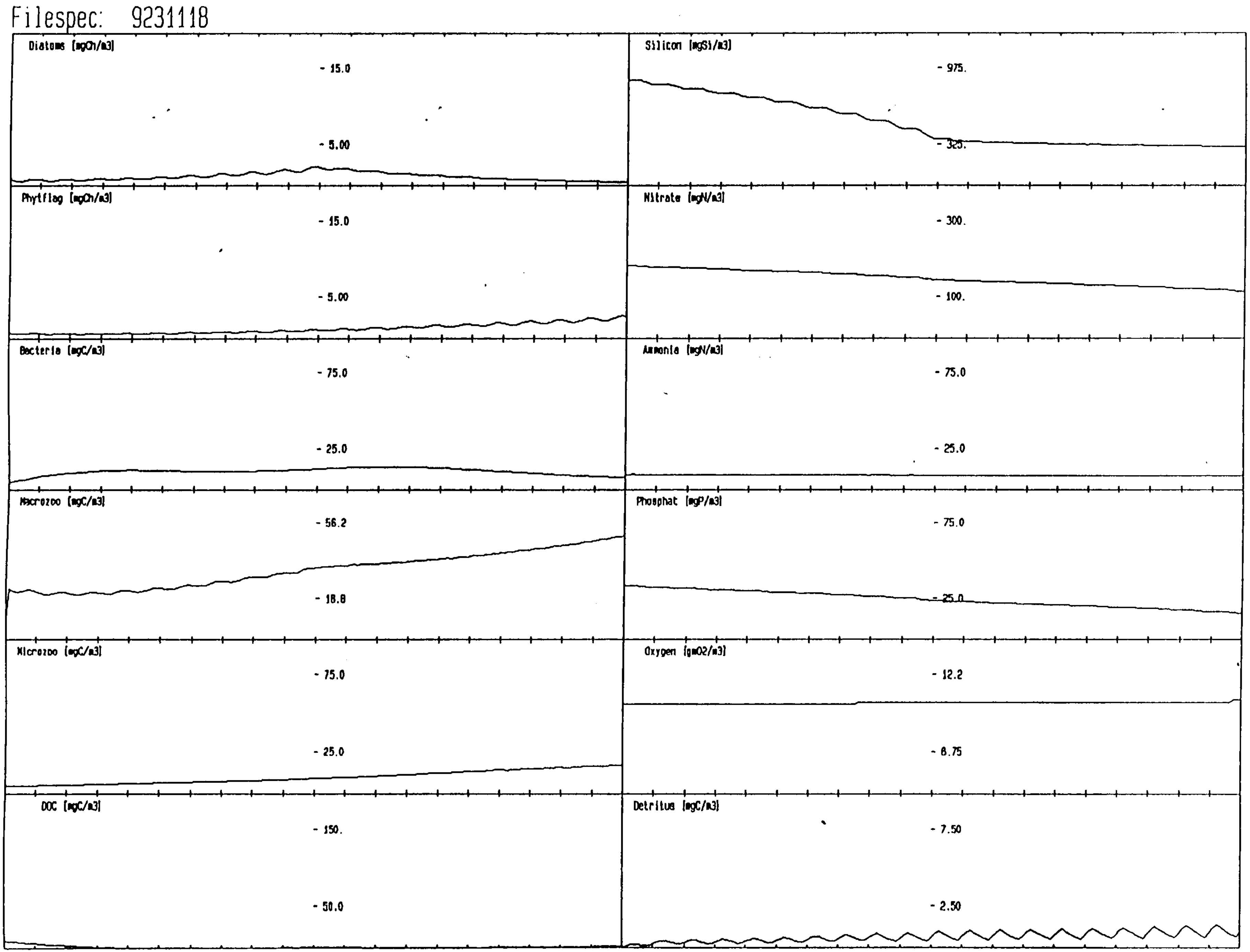


Figure 28 March parameters with an effluent discharge of 5000m³/day at 50m.

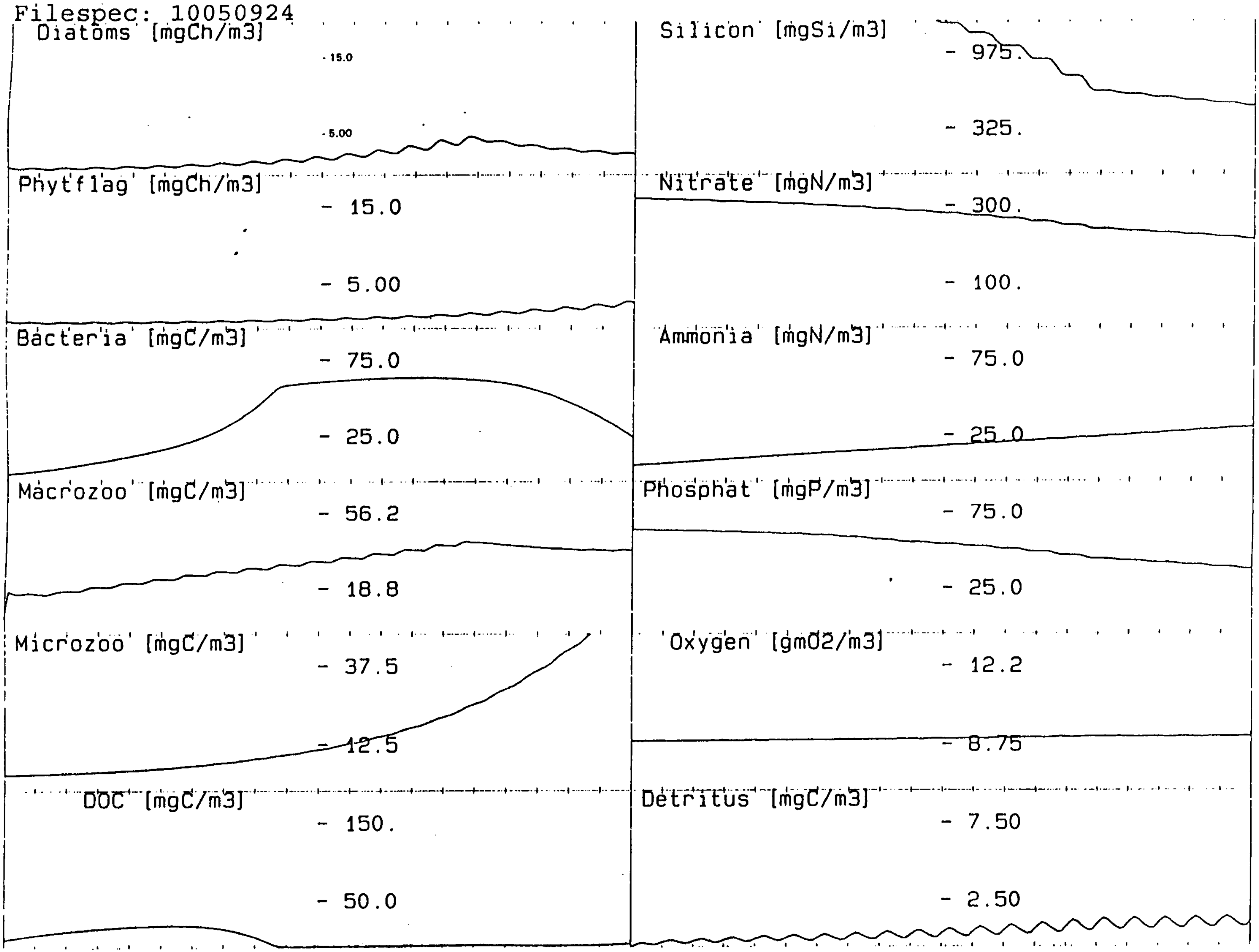


Figure 29 March parameters with an effluent discharge of 5000m³/day at 65m.

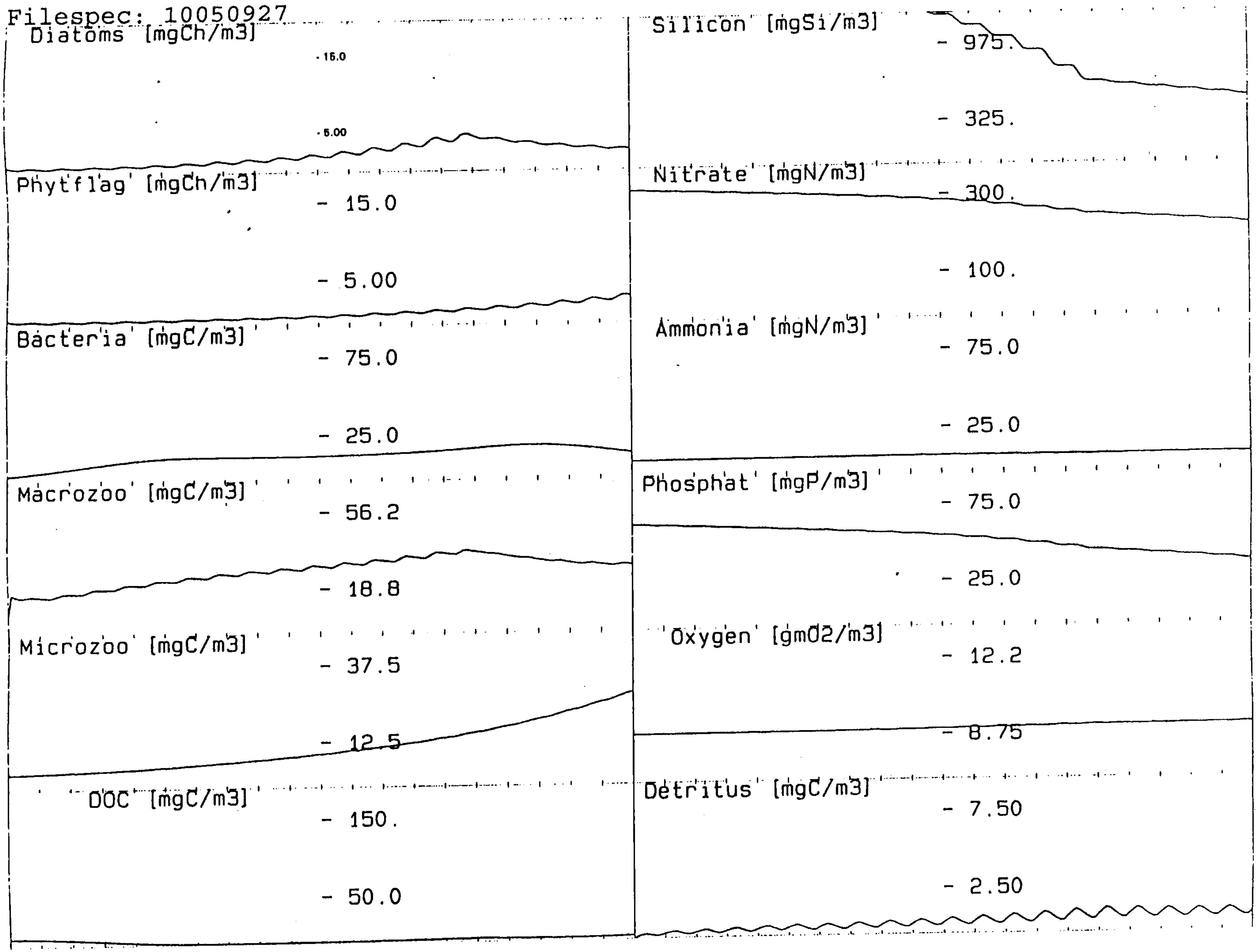
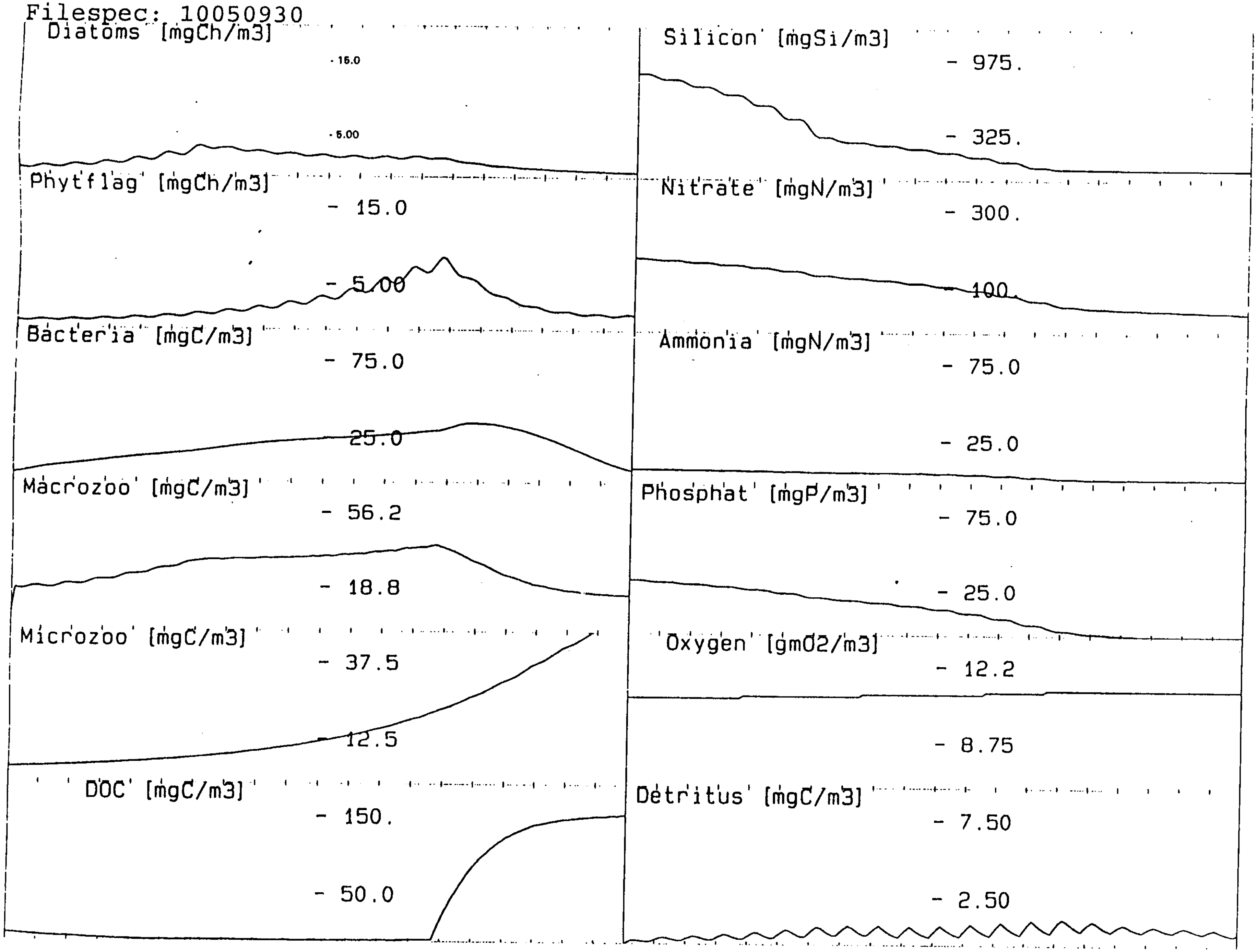


Figure 30 April parameters with an effluent discharge of 5000m³/day at 65m.



Victoria, 1996

Figure 24 June parameters (Fig.4) but averaged for 20m depth instead of 10m.

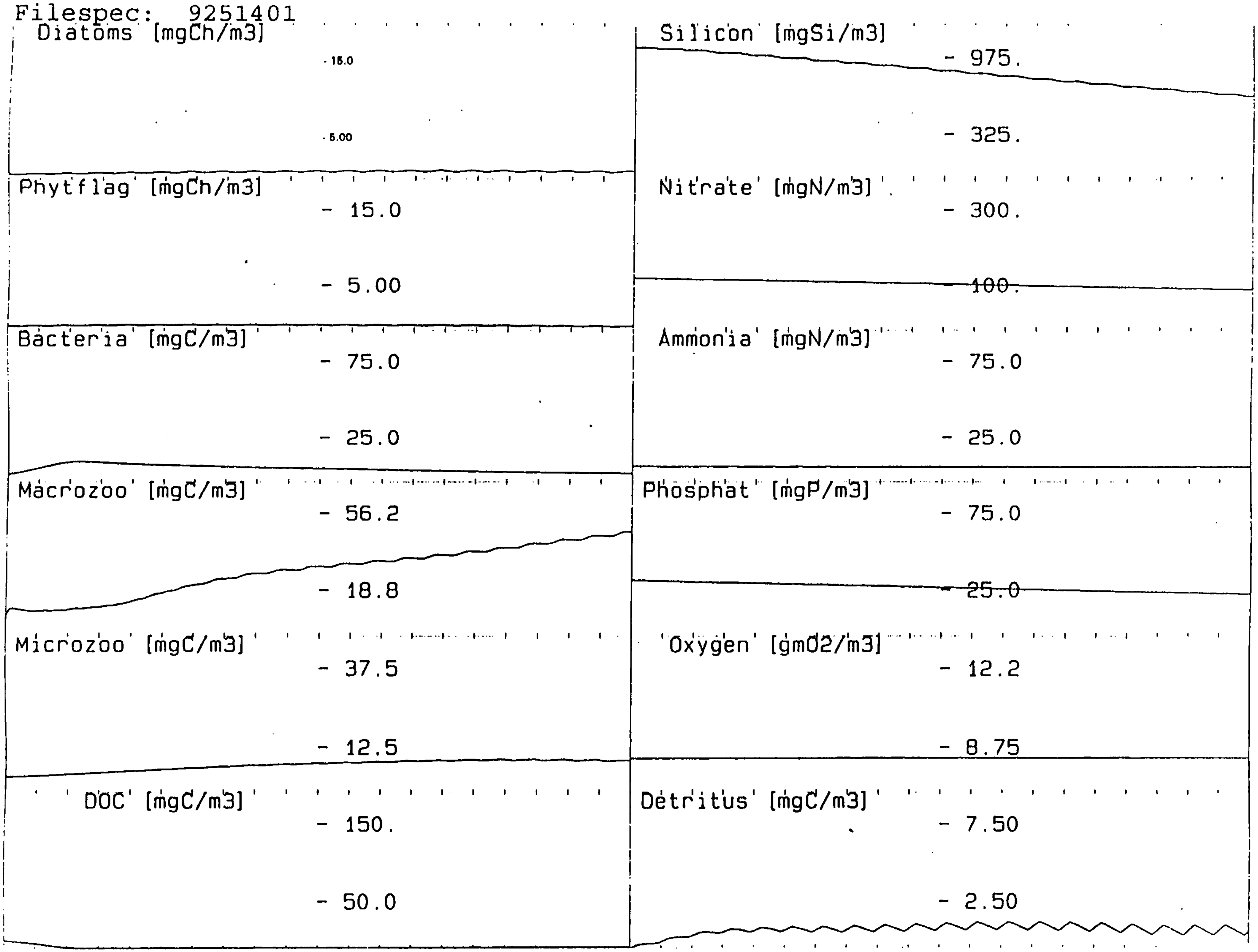


Figure 25 June parameters with 5000 m³ effluent (Fig.10) but averaged for 20m depth instead of 10m.

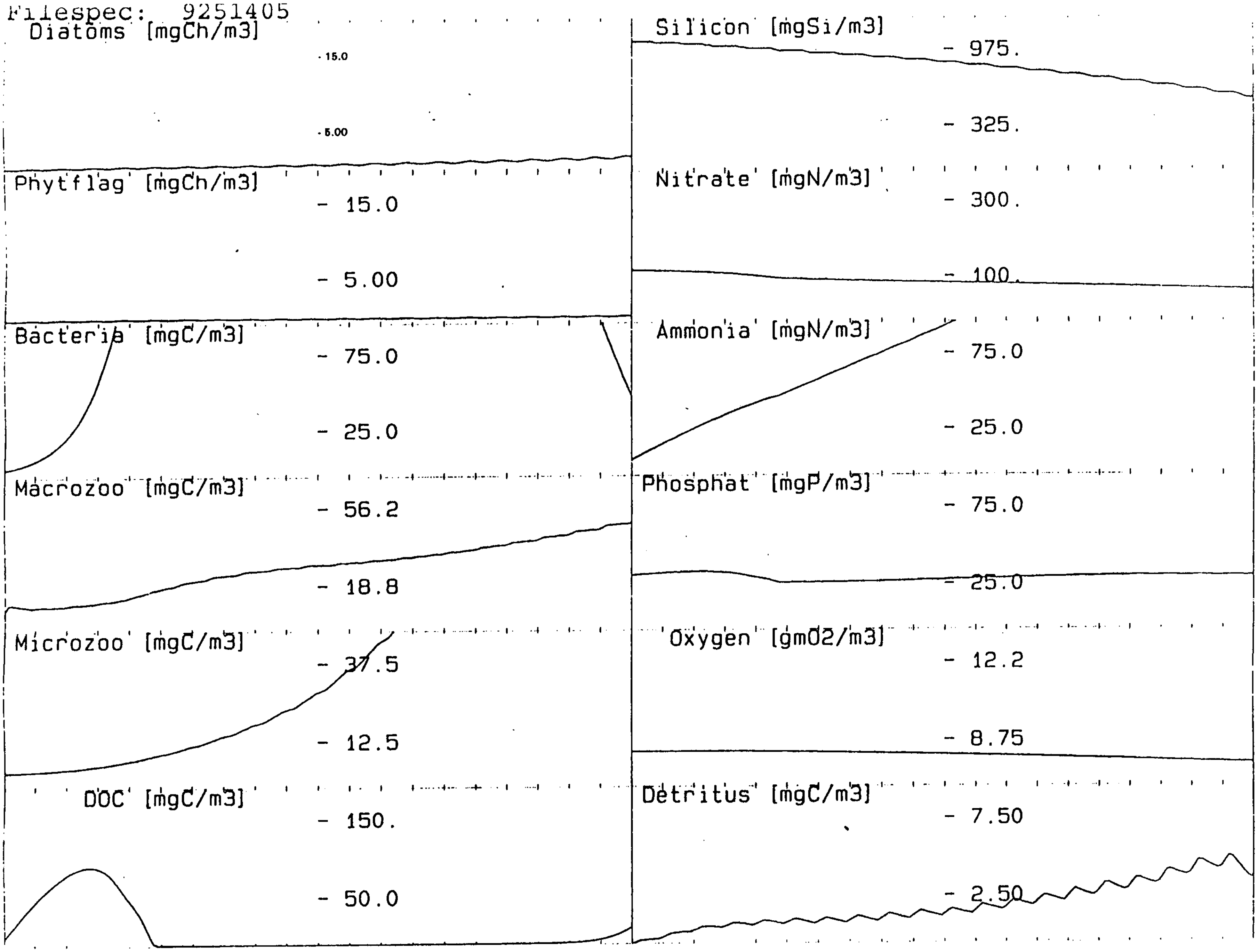


Figure 26 April parameters with no cloud cover and no discharge; extinction coefficient k= 0.2.

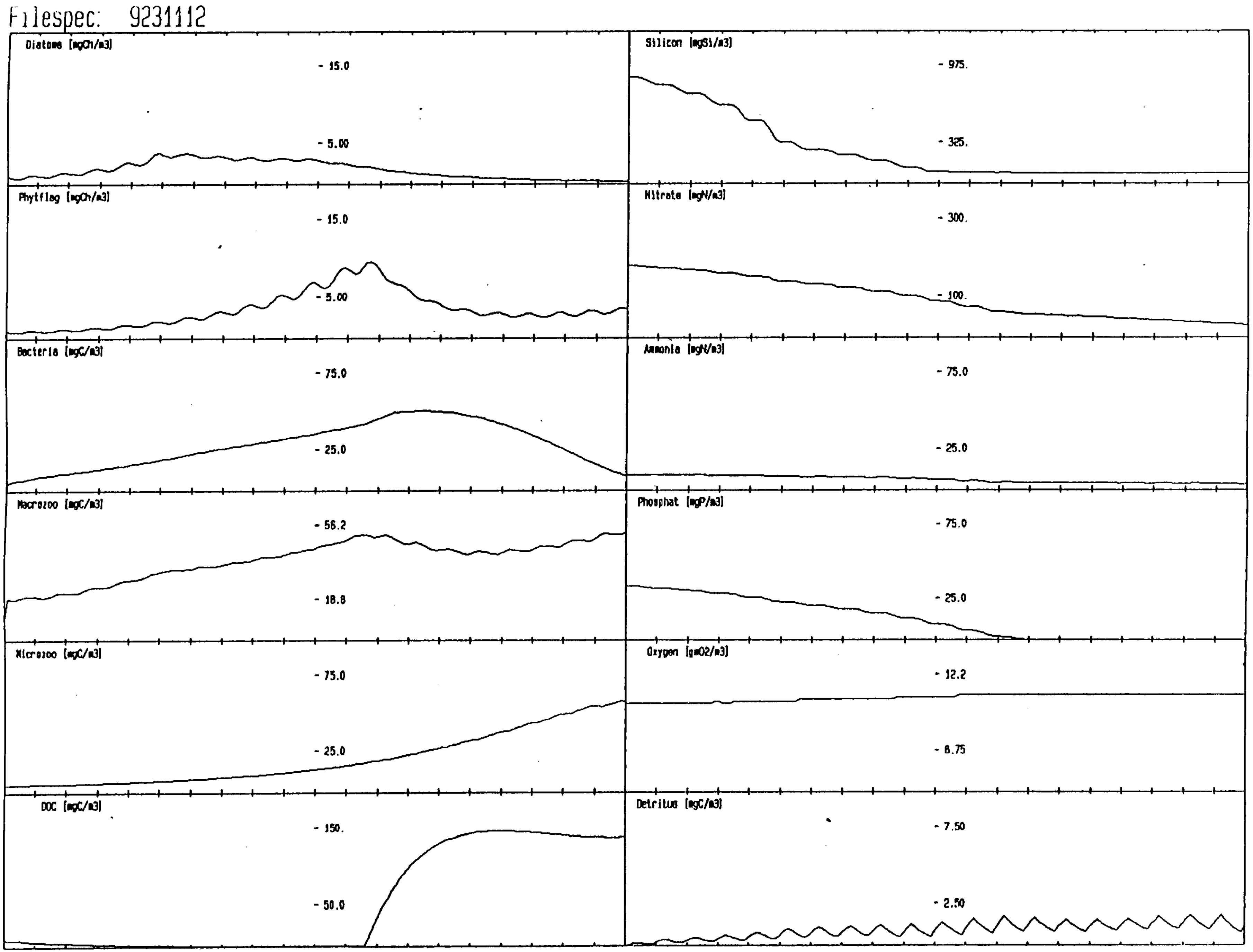


Figure 27 April parameters with no cloud cover and no discharge; extinction coefficient k= 0.4.

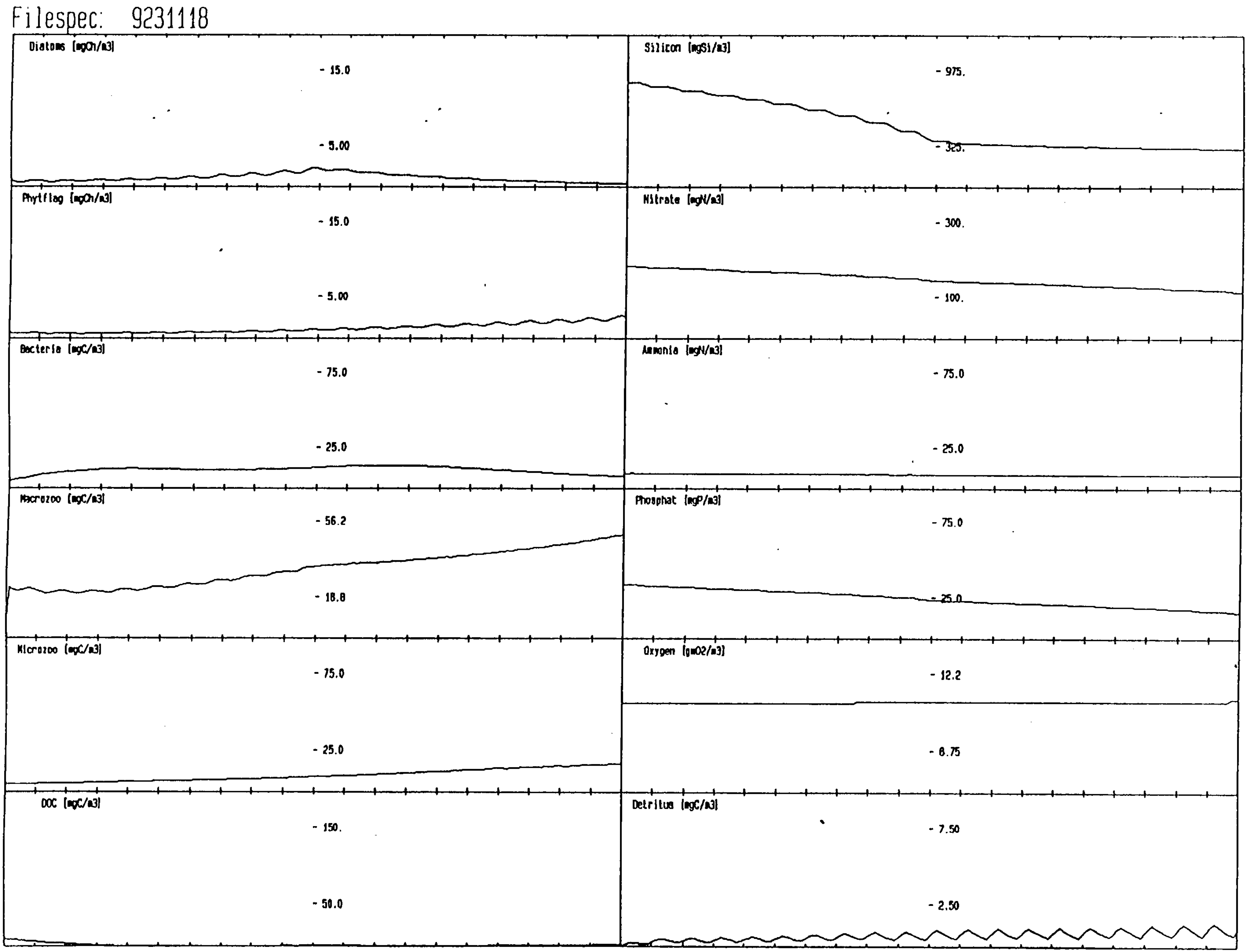


Figure 28 March parameters with an effluent discharge of 5000m³/day at 50m.

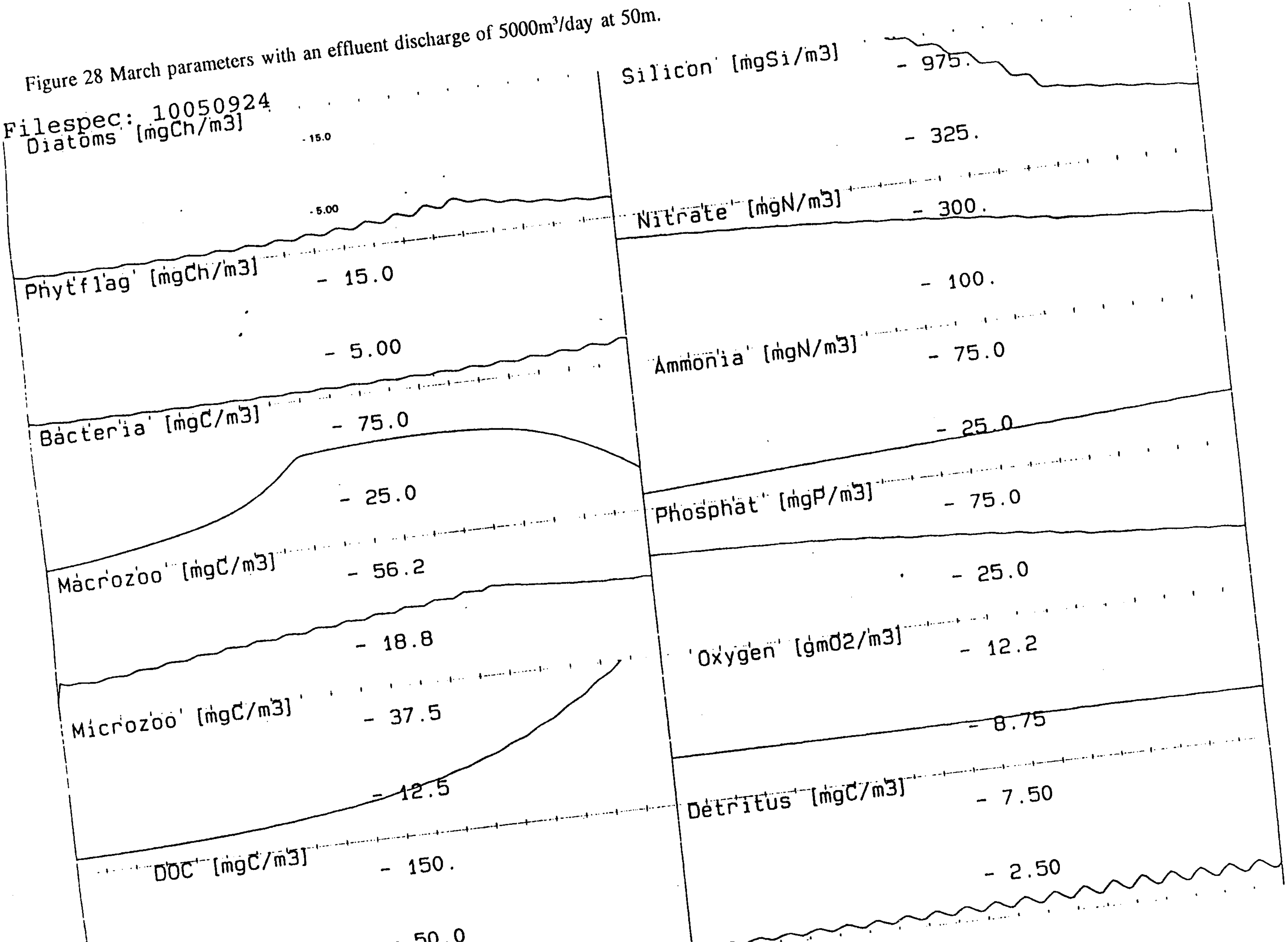


Figure 29 March parameters with an effluent discharge of 5000m³/day at 65m.

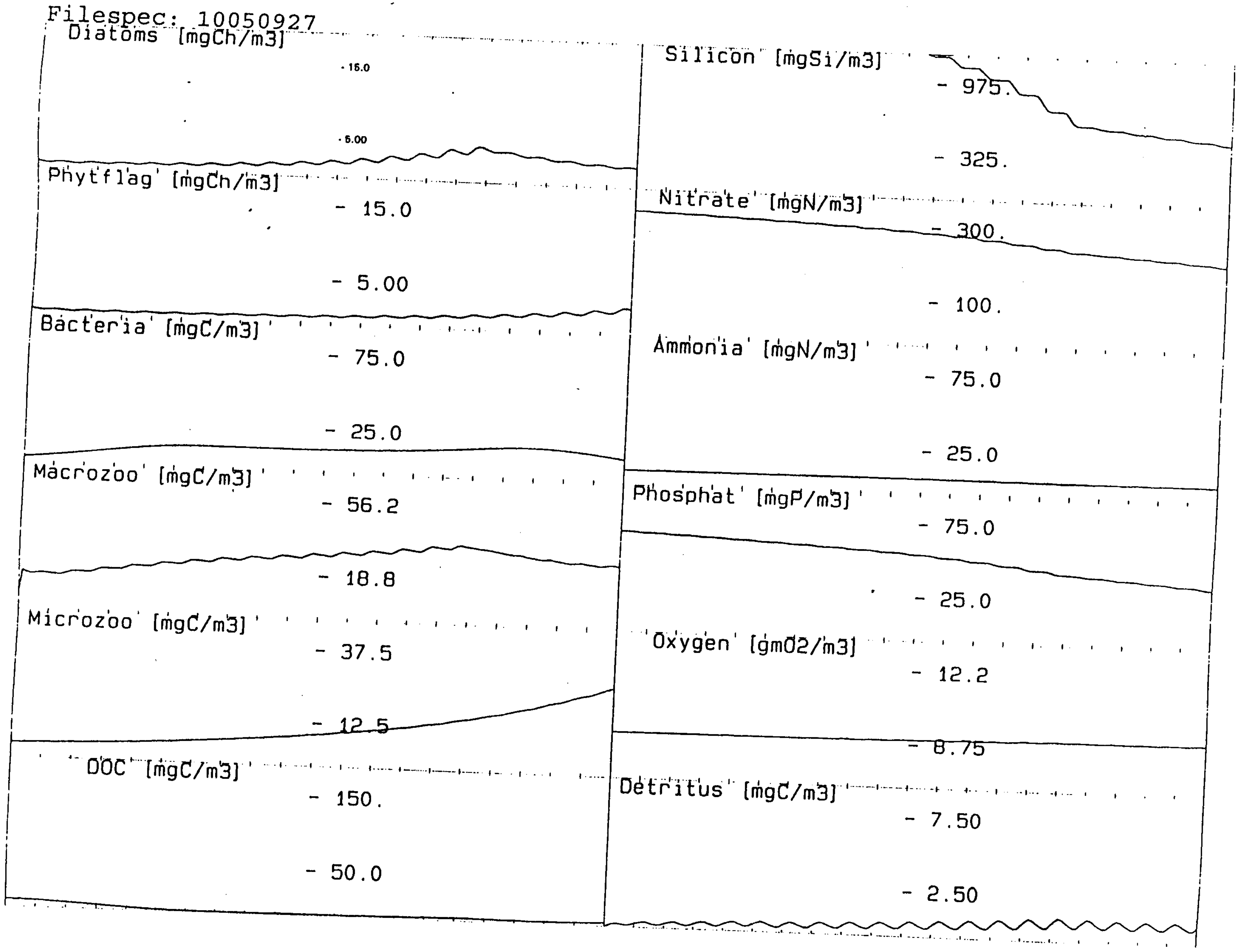
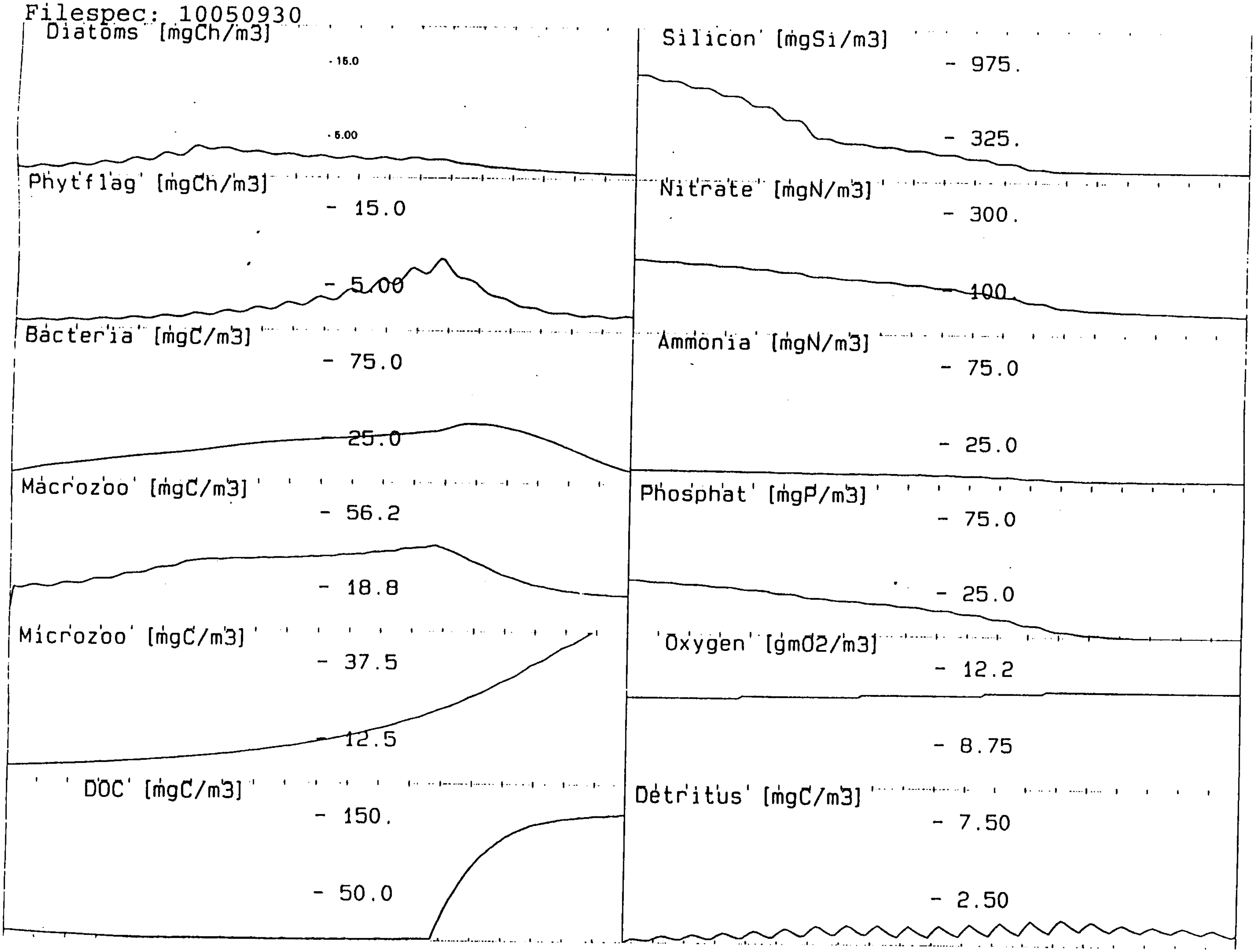


Figure 30 April parameters with an effluent discharge of 5000m³/day at 65m.



Queen's Printer for British Columbia ©
Victoria, 1996