Fate and Effects of Pulp Mill Effluents in the Fraser River Ecosystem

Identification of Research and Monitoring Priorities

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Fate and Effects of Pulp Mill Effluents in the Fraser River Ecosystem

Identification of Research and Monitoring Priorities

Prepared for

Environment Canada
Conservation and Protection
Pacific and Yukon Region

by

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Table of Contents

List of Figures

Figure

List of Tables

Table

1.0 Introduction

1.1 This Report in the Context of the Fraser River Action Plan

The Fraser River Action Plan is a six-year $100 million effort under the Federal Government's Green Plan, intended to:

1. *Build partnerships* through the development of a cooperative Management Program with the Provincial and local governments as well as other concerned groups and individuals;

2. *Clean up pollution [improve environmental quality]* in order to arrest and reverse the existing environmental contamination and degradation of the Fraser River ecosystem and to virtually eliminate the discharge of persistent toxic substances into the river; and

3. *Renew the productivity of the natural environment* through the restoration and enhancement of the environmental quality and the natural productive capacity of the Fraser River ecosystem and through the restoration and maintenance of salmon populations to historic levels of abundance. (Environment Canada 1992)

The program will be implemented by the federal Departments of Fisheries and Oceans and Environment, with relative spending priorities as shown in Figure 1.1. To deal with their responsibilities under the "Improving Environment Quality" objective, both government departments have formed Environment Quality Technical Committees. The Environment Canada committee has three objectives:

1. *Assessment:* identification of current levels of contamination and monitoring the effects of pollution abatement measures over time;

2. *Criteria:* development and negotiation of environmental quality criteria and objectives (EQOs); and

3. *Research:* funding research on environmental quality in the basin.

Each of these objectives are briefly summarized below.

The Assessment objective seeks to:

- determine the current condition;
- measure changes over time;
- develop information to anticipate and avoid problems;
- produce data to support EQOs; and
- advise the research component of research required to more effectively conduct monitoring surveys and interpret the results.

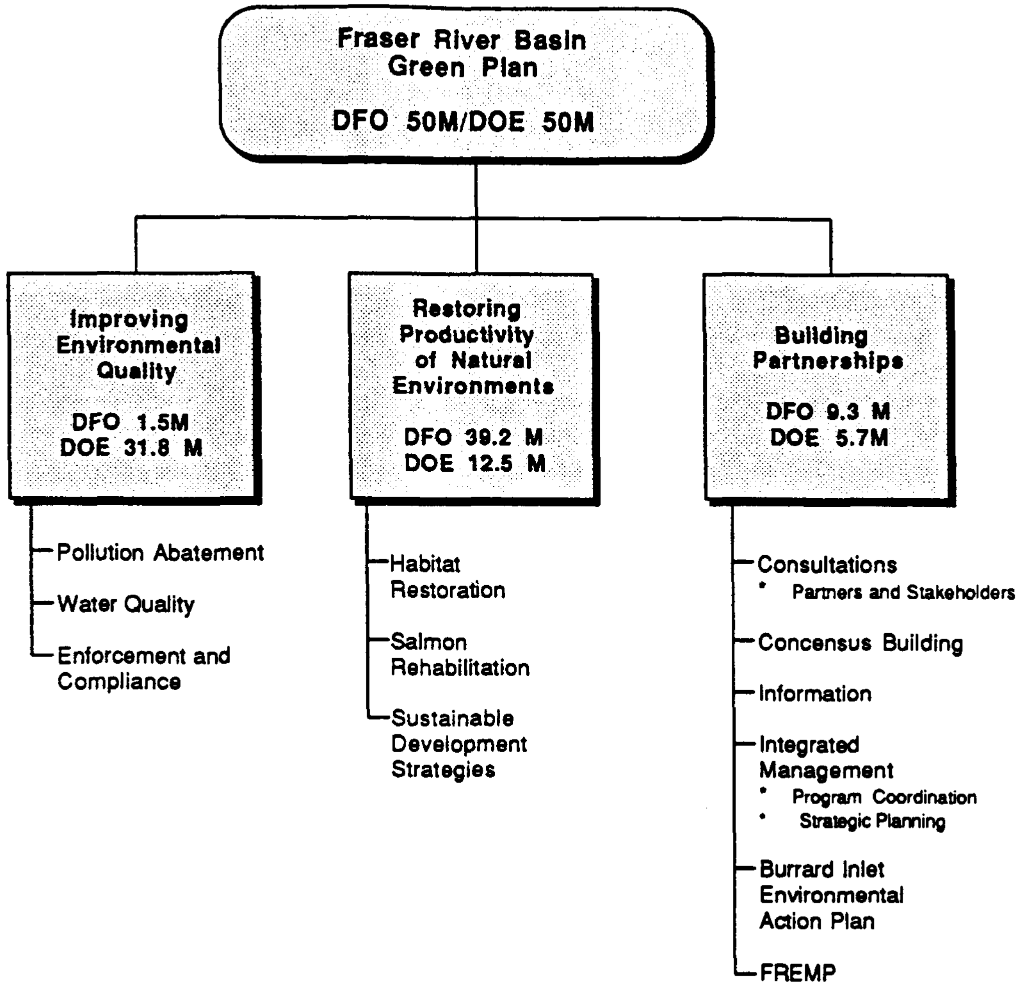


Figure 1.1: Structure of the Fraser River Basin Green Plan initiative.

Proposed elements under consideration include contaminant levels in various media (water, suspended sediments, bed sediments and biota), biological/ecosystem status indicators (fish, invertebrates, plants/algae and higher tropic levels), and use of bioassay testing methods. The Assessment component intends to collaborate with Environmental Effects Monitoring programs being carried out by industry.

Environmental quality criteria are defined as scientific data evaluated to derive recommended limits for water uses. Objectives are defined as numerical concentrations or narrative statements to support designated uses. These criteria and objectives are to be developed in cooperation with the Assessment component, with research supplying important dose-response relationships.

The Research component is intended to:

- improve the ecosystem context of Assessment work;
- identify cause/effect linkages;
- contribute to data bases; and
- enhance predictive ability.

It will be planned and implemented collaboratively, through government, university and industry research.

The Environment Quality Technical Committee (and other parts of the FRAP) intend to use a public participation process to identify priority concerns for each of the plan's major areas of activity. While this process is getting started, however, the six-year clock on completing research and monitoring is ticking. Since the fate and effects of pulp mill effluent were certain to be an important issue in the Fraser River system, Environment Canada's Committee decided to conduct a pilot project on this topic to initiate research planning. The overall objectives of this project are to produce:

1. a priorized list of key research items required to assess the fate and effects of pulp mill effluent in the Fraser River, identified through the development of a prototype simulation model;

2. increased awareness of the exact implications of available industrial and environmental management options;

3. increased mutual understanding between environmental managers and researchers; and

4. short- and long-term savings on and effectiveness of research efforts supported by the Fraser River Action Plan.

The ultimate objective of the FRAP research is to develop methods to assess the present status of the Fraser River ecosystem (including water quality, fish, and other ecosystem components) and to detect changes in ecosystem status as pulp mill loadings change. The prototype model and research plan is being developed through an interactive process involving scientists and managers from a variety of disciplines, whose ideas and data are being integrated together by a team from ESSA Environmental and Social Systems Analysts Ltd. The first major step of this process was an initial model development workshop, held April 13th-16th at the Robson Square Media Centre in Vancouver. Over 35 participants attended, from a variety of federal and provincial government agencies, and university departments (see Appendix 1). The second step was a technical meeting (June 9-10th) to further refine the priorities and design of research and monitoring activities. This report is a synthesis of the results of both meetings. We welcome all comments, and apologize for any errors.

1.2 Background Information on Pulp Mills in the Fraser River

In 1987, the six pulp mills in the Fraser River Basin discharged over 500,000 m^3 of effluent per day (Table 1.1), which represented 22% of the pulp effluent discharged to receiving waters in British Columbia (Schreier et al. 1991). These pulp mills are the primary contributors to the 38-fold increase in total wastewater discharges to the Upper Fraser over the period from 1965-1985, and the 12-fold increase in the Thompson River during the same period (Servizi 1989). As indicated in Table 1.1, these effluents receive secondary treatment, but the treated effluent still represents a number of possible threats to ecosystems, as indicated by the following observations (summarized from Schreier et al. 1991):

- *Acute toxicity.* Based on 96-hour bioassays performed in 1987, only the Northwood mills have not shown acute toxicity to fish[1]; the Prince George and Intercontinental mills' effluent failed this test 20% of the time; the Cariboo and Quesnel mills' effluent failed 56% and 65% of the time (respectively). Fortunately, the Upper Fraser River has considerable dilution capacity: about 25:1 at Prince George (Derksen 1981) and about 60:1 at Marguerite, 60 km south of Quesnel. Nevertheless, there is concern for possible sublethal effects on overwintering juvenile chinook, which may be attracted into the warmer temperatures of dilution zones (Servizi 1989).

- *Chlorinated Phenolic Compounds.* Treated kraft mill effluent and downstream waters contain a large number of these compounds, including chlorophenols, chloroguaiacols, and chlorocatechols (Voss and Yunker 1983, Kringstad and Lindstrom 1984, McLeay et al. 1987). Though small in volume, (e.g. total chlorophenol discharges from four plants amounted to only 56 kg/d in 1981) these compounds are persistent, can bioconcentrate in fish tissue and taint it, and may have sublethal to lethal effects, depending on concentrations. Rogers et al. (1988) found chlorinated guaiacols in eulachon collected from the Lower Fraser, which may indicate that these contaminants can persist several hundred kilometres downstream from their pulp mill sources.

- *Chlorinated Dioxins and Furans.* Though these compounds occur in very low concentrations in pulp mill effluent, they are very insoluble, and can bioconcentrate by 3-6 orders of magnitude in the lipid tissue of biota (Esposito et al. 1980). One member of the dioxin group, 2,3,7,8-TCDD has been associated with human health effects at higher concentrations (e.g. the 1976 chemical plant accident in Seveso, Italy, and application of Agent Orange in Viet Nam). In the Fraser River, there appears to be primarily a concern both for sub-lethal effects on biota, and for long-term human health effects from consuming contaminated fish. An indicator of the concern for dioxins is EPA's water quality criterion - 0.013 pg/L (i.e. 10^{-12} g/l). Mah et al. (1989) found that downstream of pulp mills there were elevated levels of chlorinated furans in sediments, and elevated levels of both chlorinated dioxins and furans in fish. The concentrations of the dioxin 2,3,7,8-T4CDD in fish tissue exceeded the 20 pg/g level considered safe for human consumption. Other studies

[1] Northwood tests are for 75% effluent, while the other mills expose fish to 100% effluent.

have found elevated dioxins and furans in great blue heron eggs collected from colonies in the Fraser Estuary, which are thought to be responsible for poor hatching success and juvenile survival (Whitehead 1988).

Table 1.1: Characteristics of pulp mills located in the Fraser River Basin[1].

Pulp Mill and Location	Type of Mill & Year	Wastewater Treatment Aerated Lagoon	Effluent Volume[2] (m^3/day)	Pulp Production (ADT/day)
Northwood Pulp and Paper Ltd., Prince George	Bleached Kraft 1966	8 day retention	143,082	1337
Prince George Pulp and Paper Ltd., Prince George	Bleached Kraft 1966	4.5 day retention	146,346	1821
Intercontinental Pulp and Paper Co. Ltd., Prince George	Bleached Kraft 1968	4.5 day retention		
Cariboo Pulp and Paper Ltd., Quesnel	Bleached Kraft 1972	aerated	93,800	784
Quesnel River Pulp Co. Ltd., Quesnel	Thermo-chemical 1981 Chemi-thermomech 1983	aerated	10,823	784
Weyerhaeuser Canada Ltd., Kamloops	Bleached Kraft 1965, exp. 1972	5 day retention	142,811	1224

[1] Data from Servizi (1989), summarized in Schreier et al. 1991
[2] Effluent and production values for 1987 (EPS 1987)

In spite of the major increases in wasteloads over the last 25 years, stocks of Fraser River sockeye and pink salmon have increased, indicating that the wastewaters did not impede migration or spawning (Servizi 1989). There is, nevertheless, still considerable concern for various ecological impacts, including wastewater impacts on overwintering juvenile salmon near dilution zones, effects on fish during low flow periods, effects on bird reproduction, and the cumulative long term impacts on various biota including humans (Servizi 1989; Valiela, pers.

comm.). The ecological significance of sub-lethal responses to dilute effluent (e.g. induction of oxidase enzymes in chinook fry (Dwernychuk 1990)) is of interest and importance.

At present the primary regulatory control on toxic organics discharged by pulp mills is the criterion that adsorbable organic halides (AOX) should be reduced to 2.5 kg AOX/ADT (air-dried tonne) by 1993. There is some concern over not only this criterion level (1.5 kg AOX/ADT was originally proposed) but perhaps more importantly whether this is the appropriate indicator of pulp mill effluent's risk to ecosystems. The concerns include:

- whether a concentration criterion is appropriate (the total loading could increase while the concentration declines);
- the very variable dioxin and furan concentrations per kg AOX; and
- poor (sometimes inverse) correlations between with AOX concentrations and effluent toxicity to *Ceriodaphnia* (Dwernychuk 1990).

Changes in chemical use (e.g. substituting chlorine dioxide for chlorine) as well as major industrial process changes are expected to reduce concentrations of chlorinated organic compounds over the next several years. There is a need to know which control options are likely to be most effective in protecting ecosystems, and which approaches to ecological monitoring are likely to be most effective in detecting the effects of changes in loading. This requires improved knowledge of the fate and effects of organic contaminants discharged in pulp mill effluent.

1.3 Using the Model Development Process to Determine Research Priorities

In summarizing the recent Environmental Effects Monitoring study of Dwernychuk (1990), Schreier et al. (1991, pp. 105) concluded:

> With [supplementary] information and additional studies of similar detail during the different seasons an attempt could be made to construct a simulation model for toxic substances from pulp mills. Such a model would aid in identifying information gaps in our understanding of the behaviour and ecological impacts of the pulp mill pollutants.

The workshop used the Adaptive Environmental Assessment and Management (AEAM) process (Holling 1978). One of the key precepts of this process is that research groups should start building a simulation model of a problem long before they fully understand it. The structured model-building process used in AEAM forces an interdisciplinary group of scientists *and managers* to think very clearly about their ultimate objectives, the key linkages and processes operating in the system and the exact nature and extent of current conceptual and data gaps. The model building process forces a level of communication, integration and consensus not possible through other means. By building the linkages between regulatory actions and system response right from the start, the process builds consensus both among scientists and between scientists, regulatory agencies and stakeholders. AEAM is ideally suited to the problem of developing research priorities for understanding the fate and effects of pulp mill effluents in the Fraser River.

Pulp mills, however, are only one of many stressors affecting the status of the Fraser River ecosystem (Figure 1.2). By identifying indicators and system connections important to the fate and effect of pulp mill effluents, we are only examining part of the overall problem (Figure 1.3). This exercise nevertheless provides a template for the analysis of other stressors affecting the river. After reading this report, it is important to step back and consider how the indicators, submodels and research/monitoring strategies developed herein accommodate other stressors, such as agriculture, forestry, mining and urbanization. In attempting to avoid the "confounding effects" of other stressors, we may have avoided certain integrative indicators or sampling locations which would assess cumulative impacts or overall ecosystem status.

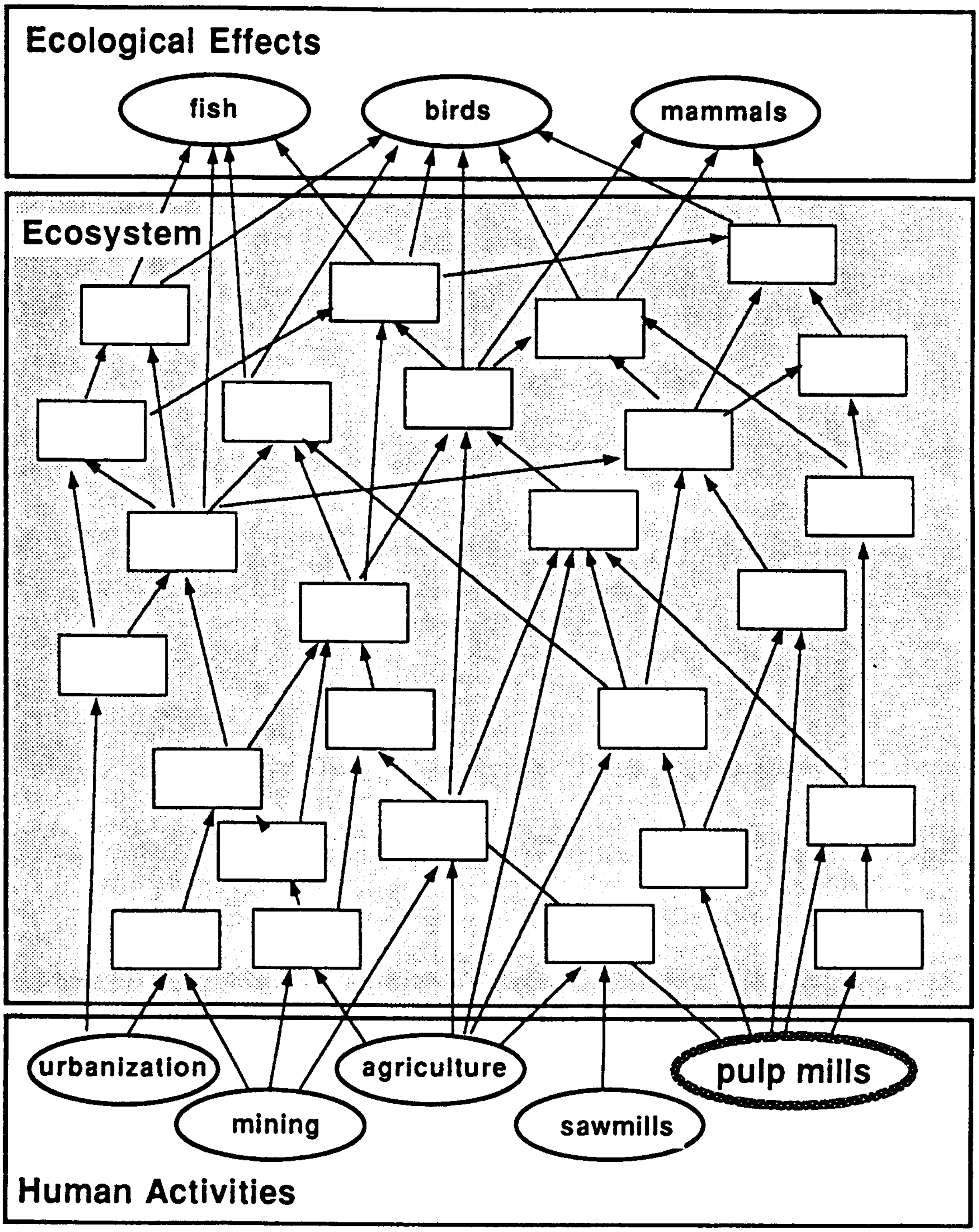


Figure 1.2: Illustration of the interaction of human activities in affecting the status of the Fraser River ecosystem.

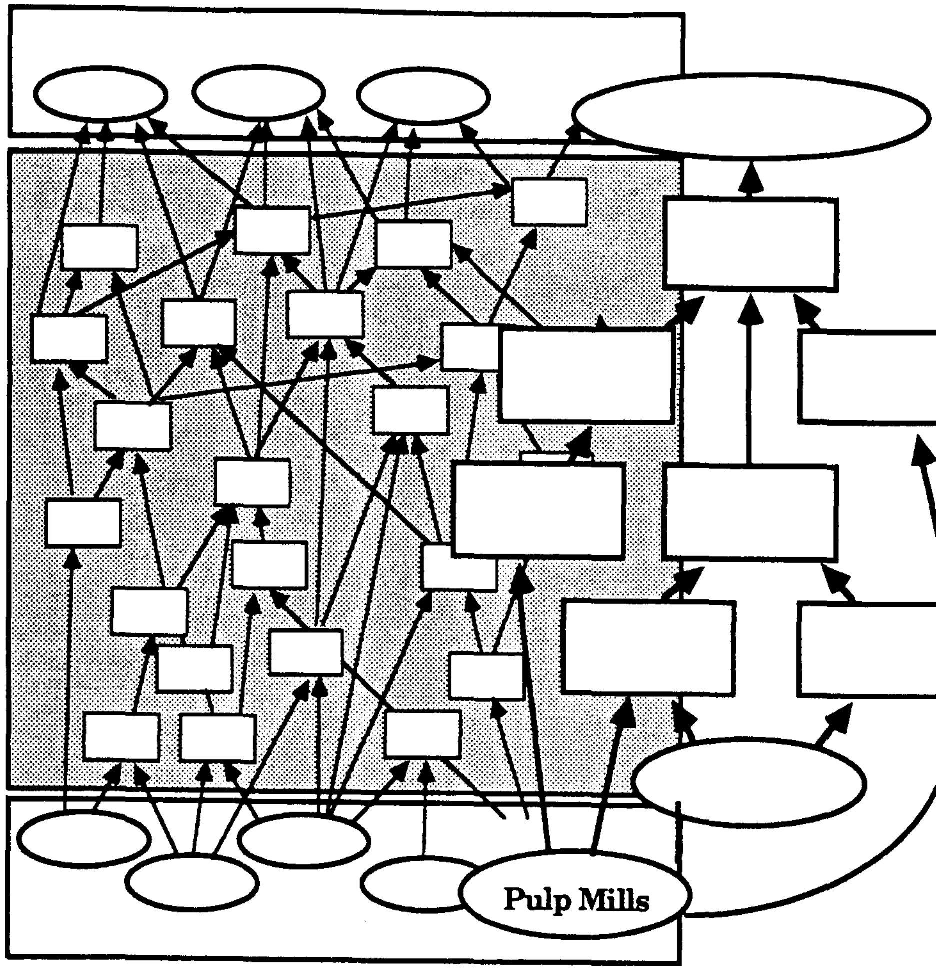


Figure 1.3: Extraction of the pulp mill effluent problem from the complete set of ecosystem stresses (see Figure 1.2).

Maintaining and restoring ecosystem health is a dominant thrust of the Fraser River Action Plan. Ecosystem health is a very broad concept; to be useful in directing research planning it must be defined in more operational terms. Rapport (1989) lists three approaches or criteria commonly used to assess ecosystem health: 1) identification of systematic indicators of ecosystem functional and structural integrity; 2) measurement of ecological sustainability or resiliency (i.e. the ability of the system to handle stress loadings, either natural or anthropogenic); and 3) an absence of detectable symptoms of ecosystem disease or stress. Thus, ecological health is defined as both the occurrence of certain attributes deemed to be present in a healthy sustainable resource and the absence of conditions that result from known stressors or problems affecting the resource. The first approach can be thought of as a top-down approach which begins with integrative response indicators and works through exposure/habitat indicators to possible stressors. The third approach is a bottom-up approach that begins with stressors and tracks the cause-effect pathway to response indicators. The two approaches are complimentary, and mutually supportive.

Whether one is using a top-down or bottom-up approach to grapple with the concept of ecosystem health, the construction of an explicit *conceptual model* is essential, to explicitly link stressors and response indicators. Conceptual models serve as reference points, both for identifying needed indicators for assessing ecological resource condition, and for guiding data analyses of possible causes/correlations. The workshop process, therefore, invested considerable effort in the development of conceptual models.

The workshop was divided into four distinct phases: model bounding, looking outward, submodel development, and synthesis (see workshop agenda in Appendix 4). Each of these phases involved a set of structured discussions by which the participants determined the structure and components of the model. The bounding process at the start of the workshop identified the indicator and stressor (action) ends of an overall conceptual model, and the subgroup discussions were used to fill out all the boxes and arrows that lie between these two ends of the problem. A simple steady-state model of contaminant fate in the Fraser River, developed by Dr. Frank Gobas of Simon Fraser University's School of Resource and Environmental Management, was presented at the end of the model bounding session to clarify submodel connections and stimulate discussion.

The workshop process applied to this problem is illustrated in Figure 1.4. Model building involves a synthesis of existing models, existing data, and the intuitive understanding of the system contained in participants' heads. The latter is by far the most important source of knowledge. The process of model building generates functional understanding as each component is seen in relation to all others, and helps to identify knowledge gaps, both conceptual gaps concerning important processes, and more straightforward data gaps. These knowledge gaps, and the proposed functional representation of the system, generate research hypotheses and data gaps to be tested or filled in the field. All models are gross simplifications of nature. Much of the habitat and ecosystem complexity cannot be represented in a model, yet an understanding of that complexity is essential to designing successful models, and to successful research and monitoring activities. This understanding of habitat and ecosystem complexity, therefore, forms a critical filter (through sampling/monitoring constraints) in deciding which research hypotheses and data needs are actually incorporated in the program. Implementation of a well-designed program explicitly feeds back to revise models, data bases and system understanding.

Quantitative models can serve many purposes. They have been used to:

1. increase understanding of the system, and make mental models explicit;

2. improve communication among scientists and between scientists, managers and policy advisors;

3. identify knowledge gaps and priorize research planning;

4. explore the consequences of different hypotheses about system behaviour;

5. design management experiments, simulating the range of system responses;

6. assess or refine experimental designs, to maximize learning and statistical power;

7. teach managers or policy makers the effects of system feedbacks and indirect effects on policy interventions; and/or

8. show the range of possible futures of a system under different management policies.

At the initial workshop, we focused on uses 1-3. As the model becomes more developed, both conceptually and quantitatively, it can serve some of the other functions as well.

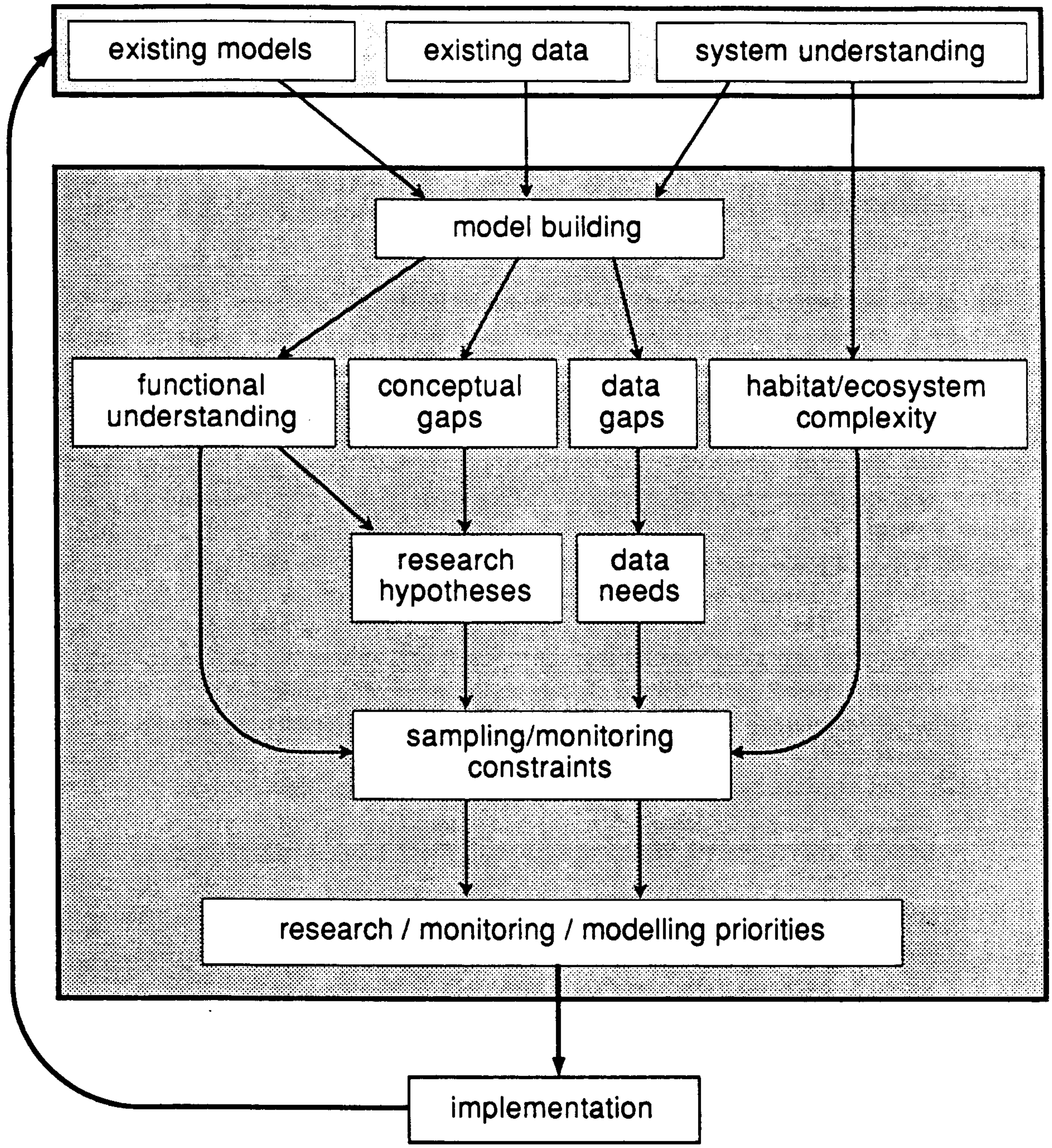


Figure 1.4: Using the model building process to determine research priorities.

1.4 Ecological Response and Human Health Endpoints

The objectives of FRAP (Section 1.1) indicate that both human health risk and ecological responses are concerns. Each of these concerns can lead to different paradigms, or conceptual frameworks of the pulp mill effluent problem. Toxic contaminants are the greatest human health concern. A contaminant-centric view of the problem (e.g. Figure 1.5) presents bioaccumulating contaminants as the only stressor. This perspective was seen as far too narrow by many of the ecologists at the workshop, who recognize that the ecological effects of pulp mill effluent are the result of many different factors and processes other than bioaccumulation (e.g. Figure 1.6). These two figures were provided as examples at the start of the workshop; the conceptual models developed at the workshop are presented in Sections 3 - 5.

Some tension between these two paradigms was evident at the first workshop. This is healthy since different objectives require different research priorities, and both perspectives are clearly necessary. Even if some persistent organic compounds accumulating in animals can be shown to have no significant effects on the animals themselves, they may still be of some concern for human health. Conversely, assessing ecological response must consider the integrative responses of individual animals, populations and ecological communities to the complete suite of physical and chemical stresses produced, not merely those potentially harmful to human health.

1.5 Structure of this Report

The report is structured as follows:

- Section 2 presents the results of the Bounding Exercise;
- Section 3 summarizes the Ecological Response subgroup's discussions;
- Section 4 summarizes the Biotic Fate subgroup's discussions;
- Section 5 summarizes the Physical and Chemical subgroup's discussions;
- Section 6 provides a synthesis and proposal for future directions; and
- Section 7 priorizes the recommended research and monitoring activities.

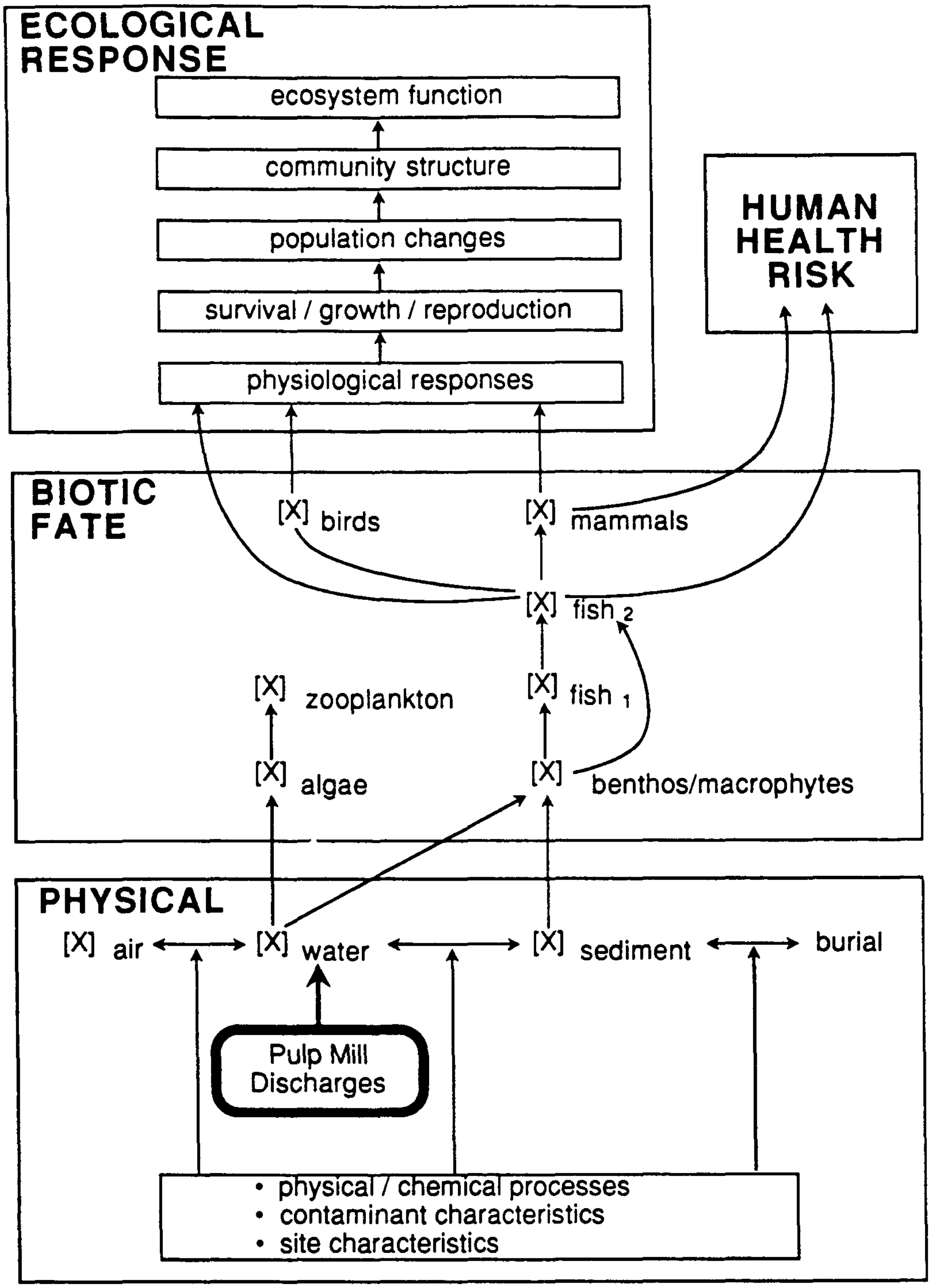


Figure 1.5: An example of a "contaminant-centric" view of the problem of pulp mill effluents.

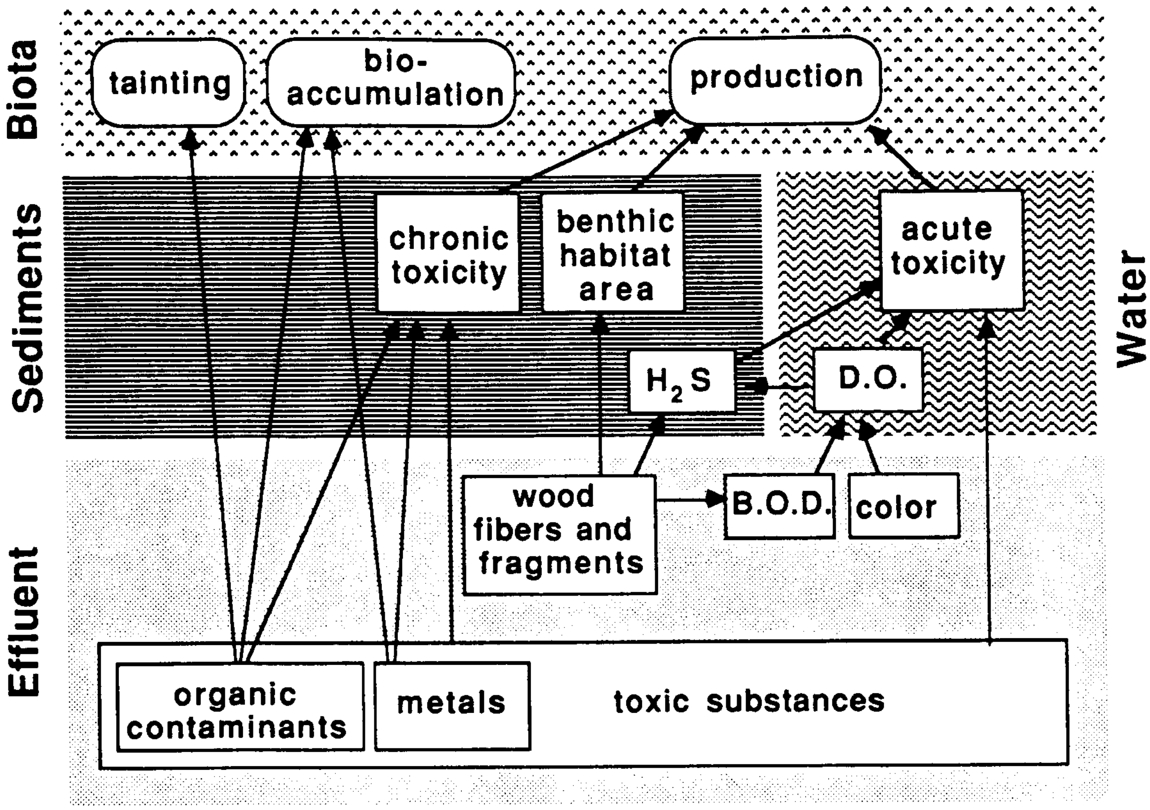


Figure 1.6: An example of an ecological response view of the problem of pulp mill effluents. (Source: Bernard et al. 1987)

2.0 Bounding

Perhaps the most important decisions that are made in any modelling exercise are the basic level of concern and the choice of components to be explicitly considered in addressing this level of concern. These choices are initiated by what is known as a bounding exercise. The bounding exercise forces the workshop to define a finite and realistic set of model actions and indicators and place them in an appropriate spatial and temporal framework. The results of the bounding exercise completed during the first day of the April workshop and related issues discussed during the June technical meeting are summarized below.

2.1 Indicators

We define indicators as those quantities which allow one to observe and evaluate the performance of a system in response to changes in key model parameters and management actions. They are generally variables which have economic, political, or social importance, or at least direct relevance to environmental decisions. Different people use the term "indicator" in different ways. Biologists use "indicator species" as early warning signals of change. Most State of Environment programs have adopted the following definition (Hunsaker and Carpenter 1990):

1. **Response indicators** represent characteristics of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, ecosystem, or landscape level of organization (e.g. numbers, productivity, or mortality rates of fish populations).

2. **Exposure indicators** provide evidence of the occurrence or magnitude of contact of an ecological resource with a physical, chemical, or biological stressor (e.g. concentrations or accumulations of toxic substances).

3. **Habitat indicators** are physical, chemical, or biological attributes measured to characterize conditions necessary to support an organism, population, community, or ecosystem (e.g. availability of snags; substrate of stream bottom; vegetation type, extent, and spatial pattern).

4. **Stressor indicators** are natural processes, environmental hazards, or management actions that effect changes in exposure and habitat (e.g. climate fluctuations, pollutant releases, species introductions).

The "actions" defined in the workshop overlap with the terms included under "stressor indicators". We consider actions as those activities that management can consider in their attempts to manipulate a system to meet goals and objectives. Actions can therefore be positive (e.g. mitigative, remedial) as well as stressful to ecosystems. Actions are considered in more detail in Section 2.2.

Indicators for assessing the ecological response, biological and chemical fate of persistent chemicals in pulp mill effluent discussed during the first day of the workshop are listed below.

Ecological Response and Biological Fate Indicators

The following species were suggested as being useful indicators of the ecological fate and effects of organizational groups pulp mill effluent in the Fraser River.

Periphyton

Benthos

Fish
- Pacific Salmon
- Rocky Mountain Whitefish
- Sturgeon
- Keystone species (e.g. Longnose Dace in Thompson River)
- Lamprey larvae

Birds
- Great Blue Herons
- Ospreys
- Grebes

Mammals
- Minks
- River Otters
- Seals

For these organisms, one or more of the following measures were suggested:

- abundance
- reproductive success (e.g. egg survival, fecundity)
- productivity
- susceptibility to disease
- physiological and behavioral responses (e.g. liver MFO, swimming speed)
- survival

Response indicators specific to pacific salmon include the successful migration of both adults to spawning grounds and smolts to the estuary. In some instances, indicators will be location-specific. For example, attempting to measure the response of primary productivity to changes in pulp mill loadings may be an appropriate choice in the Thompson River whose food chain is based on autotrophic production, but not useful in the Fraser estuary which has a predominantly detrital-based food chain.

There was a wide range of criteria used to select indicator species including:

- high commercial/social value (Pacific salmon, sturgeon);

- life history characteristics making the species a good indictor for persistent chemicals (e.g. Rocky Mountain Whitefish are a species which may spend its entire life history in the Fraser River mainstem);
- previous evidence showing the species is a useful indicator of persistent chemicals (e.g. Great Blue Herons); and/or
- high ecological importance (e.g. Longnose dace as a keystone species in the Thompson River).

Some species are poor indicators for monitoring ecosystem response to changes in pulp mill effluent (e.g. adult salmon) but were included because of their high economic/social importance. Ultimately, the selection of ecological response and biological fate indicators will be driven by specific research and monitoring questions; different questions within the research program may demand different indicators.

Chemical Fate Indicators

The set of contaminants found in pulp mill effluent may be important either in terms of human health effects, or in terms of ecosystem status. Some evidence from one or both of these perspectives is necessary to focus research efforts. During the bounding session, the participants identified three representative contaminants:

- 2,3,7,8 TCDF (tetrachlorodibenzofuran), an hydrophobic substances;
- 3,4,5 TCG (trichloroguaiacol), a pulp mill-specific chemical; and
- organic sulphur compounds which are found in pulp mill effluent generated from both chlorinated and non-chlorinated pulping techniques.

During discussions in the biological fate subgroup, it was felt that in view of the recent changes in treatment processes to reduce chlorination it was appropriate to add two other representative compounds: 2,4 DCP (dichlorophenol); and 5,6 DCV (dichlorovanillin). Lower chlorination may eventually reduce the levels of furans to below detectable levels. It was also agreed during the biological fate subgroup discussions that in view of the "moving target" of effluent changes and the uncertainty in identifying the chemical(s) responsible for ecological responses, the modelling method adopted should be based on physical-chemical properties. Models can then be easily adapted to deal with substances other than the five examples considered here.

It was pointed out during the June technical meeting that there is not much additional expense in analysing a suite of chemicals rather than just a few. A number of new compounds were suggested including:

- dichlorosteric acid, a toxic chemical which behaves differently relative to other pulp mill contaminants (e.g. it does not bioaccumulate); and

- resin acids, which, although usually eliminated in secondary treatment and shown to have no direct effect on chronic or acute toxicity in PAPRICAN investigations, require further study (in terms of toxicity and concentration in the receiving environment).

The actual choice of compounds to monitor will depend on the technology of each mill and the objective of the monitoring program. If, for example, the objective is to determine the extent and effects of historical (i.e. existing) contamination, chloroguaiacols might be the indicator of choice. Due to increasing chlorine substitution in pulp mill processes, substances such as dichlorphenols and divanillans would be better indicators for monitoring future trends. Each mill will have to be contacted to gather information concerning current and future processes to provide a better idea of which compounds to monitor in the near field of each mill. The recent work by Nadene Henderson of BC MELP in grouping compounds on the basis of their physical/chemical properties and toxicities (summarized in Appendix 5) is a useful approach to priorization.

Total suspended solid and dissolved oxygen concentrations were considered to be important physical indicators of pulp mill effluent. Changes in these parameters in the river can have direct impacts on ecosystem status but can also affect the biological and chemical fate of persistent chemicals.

2.2 Actions

Actions are simply those activities that management can consider in their attempts to manipulate a system to meet goals and objectives. From the standpoint of a model, they are quantities (e.g. pollutant loading rates) which have some influence on the model but which are not predicted by the model. Instead, their levels are specified outside of the model, usually as part of an overall policy or management strategy (e.g. effluent abatement, changes in either waste treatment or industrial processes).

The majority of actions identified during the bounding exercise focused on changes in the quantity and quality of pulp mill effluent resulting from:

- ClO_2 substitution lowering chlorine levels in the effluent;
- activated sludge treatment reducing the BOD and increasing the effluent nutrient;
- introduction of other bleaching technologies (e.g. UV, oxygen) reducing chlorine levels;
- altered filtration methods reducing the concentration of suspended solids;
- changes in the frequency and quantity of accidental spills; and/or
- changes in the number and/or location of mills.

Other changes occurring in the Fraser River basin altering the hydrology, water temperature or ambient water quality were also considered because of their influence on the fate of contaminants and ecological responses. These included:

- changes in flow or water temperature resulting from climate change, hydroelectric development, and/or water withdrawal;
- increases in inorganic nutrient levels (nitrogen and phosphorous) resulting from increased agricultural activity, timber harvesting, and urban development;
- changes in the ambient levels of suspended sediments resulting from different forest harvesting techniques and/or harvesting rates.

2.3 Spatial Horizon and Resolution

Any model of a physical system is necessarily confined within some sort of spatial horizon. The terms of reference for the study have defined this as the Fraser River, which refers to the entire Fraser River Basin (Figure 2.1). During the bounding discussions at the workshop, it was agreed that the entire Fraser Basin (including the Thompson River) should be considered with the downstream boundary being constrained to the limits of the estuary as defined by the Fraser River Estuary Management and Protection boundary (the area between Sturgeon Banks and Boundary Bay).

Within the overall spatial horizon, the spatial structure may be resolved into greater detail in a number of ways. Typically, pollution problems in rivers are handled by dividing the system into a "train" of river reaches, with each unit having a specific relationship to other units. Within each reach, various compartments are represented (e.g. atmosphere, water, active sediment, inactive sediment, biota). Heterogeneity within each reach (e.g. dilution zones, backwater areas) can often be represented implicitly, in which distinct subunits are only represented by the amount of area they occupy within each reach, regardless of their position within the system. During the bounding exercise, it was recognized that the spatial resolution depends on the processes being considered. For this reason the definition of reach boundaries was considered in each subgroup and is presented in the summaries of subgroup discussions (Sections 3-5).

The ecological response, biological and physical/chemical fate subgroups all discussed the importance of distinguishing between near field and far field zones at the April workshop. In reaches containing a point source, both near and far field zones would exist in the reach. Reaches in the lower sections of the river (e.g. downstream of Hope) would each be comprised of a far field zone.

During the June technical meeting, the rules or criteria defining the near field boundary were discussed in detail and a number of definitions were developed. Multiple criteria are required to define the near field area as it will vary depending on physical processes, river morphology, and season. From a dilution perspective, the near field zone is defined as the distance downstream from a point source at which the effluent is completely mixed across the entire width and depth of the channel. The Environmental Effects Monitoring (EEM) program define the zone of effluent mixing based on:

- 1.0% (100:1 dilution) effluent concentration, or
- one-tenth of the lowest IC25 (level causing chronic response in 25% of the population) or NOEC (No Observable Effect Concentration) obtained in effluent sublethal toxicity tests relevant to current mill operations,

whichever is the least spatially extensive (Anon. 1992).

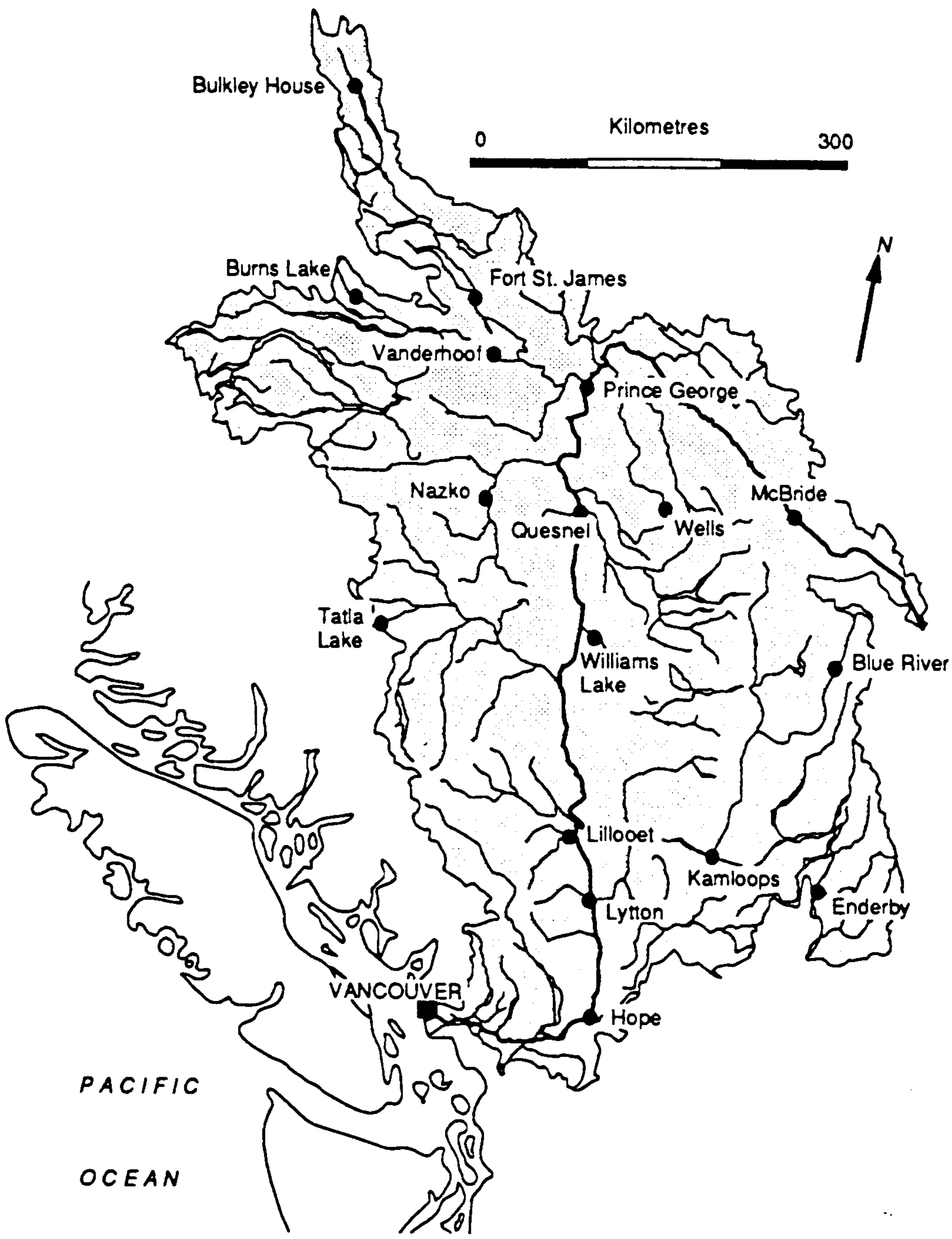


Figure 2.1: Study area. (Source: Dorcey 1991)

In the Fraser River, the length of the near field is variable and is dependent on flow characteristics and channel morphology downstream of each point source. Downstream of Quesnel the near field zone will extend from 3-10 km while the near field downstream of Prince George is considerably longer (downstream to Stoner). The near field zone downstream of the

The definition of the near field zone is also dependent on the processes being examined. Research/monitoring of biological fate/effects of pulp mill contaminants occurs in a more restricted zone closer to the outfall relative to the physical definition of the near field described above. EEM studies examining the effects of effluent on fish (Anon. 1992) define the near field as the predicted zone of any sublethal effects or in the immediate vicinity of the effluent discharge. Sediment transport studies/monitoring will use another definition of the near field based on the location of major deposition and erosion downstream of the outfalls.

2.4 Temporal Horizon and Resolution

Bounding the model temporally poses similar questions as were addressed for spatial bounding. Both the temporal horizon (for how long should the model run?) and resolution (what is the time step - years, months, days?) must be addressed. The temporal horizon should be determined by the length of time required to see responses in model indicators to different effluent loading scenarios. The temporal resolution is determined by both the rate at which important processes occur in nature, and the data available to reasonably describe these processes.

Two distinct time horizons were discussed during the first day of the workshop. The first time horizon is defined by the length of time required to observe indicator responses to changes in pulp mill effluent loadings. In terms of detecting changes in tissue concentrations, the horizon must be at least as long as the lifespan of the indicator to detect the response. In the case of a long-lived species such as sturgeon, this horizon could be on the order of two to three decades. A potentially confounding factor in detecting long term responses to pulp mill effluents discharged in the Fraser is that changes in the type and quantity of persistent chemicals in the effluent have been occurring (and are projected to occur) quite rapidly. The suite of chemicals discharged five years ago was very different from that of today, and the projected change in the make-up and quantity of effluent over the next five years is even greater. These changes, and the time lags in some animals' contaminant concentrations and ecological responses, limit our ability to determine the causes of observed indicator responses. This highlights the need to target monitoring activities towards chemicals which are likely to be present in future pulp mill effluents.

The objectives of the Fraser River Action Plan define the second set of time horizons. A 30% reduction in toxicity is targeted for the year 1997 leading to a 100% toxicity reduction by 2000. Specifically, FRAP wants to:

1. reduce by 30% the total discharge of environmentally disruptive industrial effluents entering the waters of the Fraser Basin within the first five years; and

2. affect the virtual elimination of the release of persistent toxic substances (as determined under the Canadian Environmental Protection Act) entering the waters of the Basin by 2000.

There are only five remaining years of funding under the current FRAP framework. To detect change in a statistical sense, reasonably long time series are required both before and after loading changes due to the high variability inherent in most of the indicators discussed in

Section 2.1. Because of the limited amount of baseline data available, the likelihood of detecting "before-after" statistical changes in response indicators within the current FRAP time horizon is low. The best that could be hoped for over this period would be the observation of trends in rapidly responding indicators. The monitoring data being collected within the five-year FRAP time horizon will provide very useful baseline data for detecting long term changes in ecosystem status in response to future changes in effluent loading or other stressors.

The temporal resolution required for research/monitoring and modelling activities was not discussed during the bounding exercise. The temporal resolution is dependent on the processes being modelled or the type of response being monitored. For example, a water chemistry and sediment submodel might have a very short time step to account for fast processes such as resuspension of adsorbed contaminants during high flow periods, while a biotic submodel could have a longer time step. Temporal resolution issues are therefore discussed within the summaries of the subgroup sessions (Sections 3-5).

2.5 Submodel Definition and Looking Outward

Having specified actions and indicators, as well as the spatial and temporal bounds of the system, it is necessary to divide the problem into a number of subsystems. This division is required primarily to facilitate more efficient model development than would be possible if all participants worked together on the entire model. It was agreed in the opening plenary session that the pulp mill effluent problem could be logically split into three submodels:

1. a physical/chemical fate submodel which would implement regulatory policies and pollution control scenarios as pollution loadings over space and time (considering the somewhat episodic nature of these loadings) and represent flow, sediment dynamics, chemical partitioning and reaction for each spatial unit;

2. a biological fate and distribution submodel which would consider various processes affecting contaminant uptake, and bioaccumulation; and

3. an ecological responses and effects submodel, which would consider physiological, population level and community structure dose response.

It is important that the connections between submodels be made as explicit as possible before participants divide into subgroups. In other words, the responsibilities (and level of detail) of each submodel should be defined in terms of the information it is required to provide to other submodels. This explicit definition of submodel responsibilities is called the Looking Outward exercise. In this exercise only information exchanges between submodels are considered, as opposed to the internal details of individual submodels. Following a strategy of "beginning at the end and working backwards", the opening plenary discussions produced a looking outward matrix (Table 2.1). The linkages between submodels are discussed in more detail at the beginning of each subgroup summary (see Sections 3-5). In an actual integrated model of the system, each of the items listed in Table 2.1 would be passed between submodels every time step, for each spatial unit. At a more conceptual level, the Looking Outward exercise helps to keep specialists focused on the overall system, rather than only the subsystem with which they are best acquainted.

Table 2.1: The looking outward matrix developed at the April workshop. The symbol [X] denotes the concentration of a persistent single chemical or group of chemicals.

To From	Physical/Chemical Fate	Biological Fate	Ecological Response
Physical/Chemical Fate		$[X]_{\text{dissolved, suspended sediment, bedload}}$ $[\text{organic carbon}]_{\text{sediment}}$ pH Temperature Total suspend solids particle size dist'n.	$[X]_{\text{dissolved}}$: (biologically available concentration) Area of spawning habitat Dissolved oxygen $[\text{Phosphorous}]_{\text{dissolved}}$ Temperature ice cover
Biological Fate	Bioturbation/ biodegradation rates Biofilm activity Zooplankton pelletization rates biological activity on suspended sediments (e.g. flocculation of particles into larger aggregates through enzymes excreted by organisms)		$[X]_{\text{fish}}$ $[X]_{\text{birds}}$ $[X]_{\text{benthos}}$ residence time (1/2 life)
Ecological Response	Benthic algal growth Spatial distributions of Phytoplankton/zooplankton abundance	Major changes in food web Location of fish	

3.0 Ecological Response Subgroup

Figure 3.1 summarizes the subgroup's responsibilities, as delineated in the Bounding Exercise. These responsibilities were very broad. The goal was to integrate the various stressors released by pulp mills (bottom left of Figure 3.1) and other management actions (top left of Figure 3.1) into predictions of the ecological responses of a diverse set of indicators (top right of Figure 3.1). In addition, the subgroup was to generate an approach towards predicting some of the ecological responses to pulp mill effluent which could influence either physical/chemical or contaminant uptake processes (bottom right of Figure 3.1). By focusing on ecological responses, the subgroup specifically did not discuss human health as an endpoint. Nevertheless, aspects of the group's discussions (i.e. contaminant bioaccumulation by fish) are directly relevant to the human health issue.

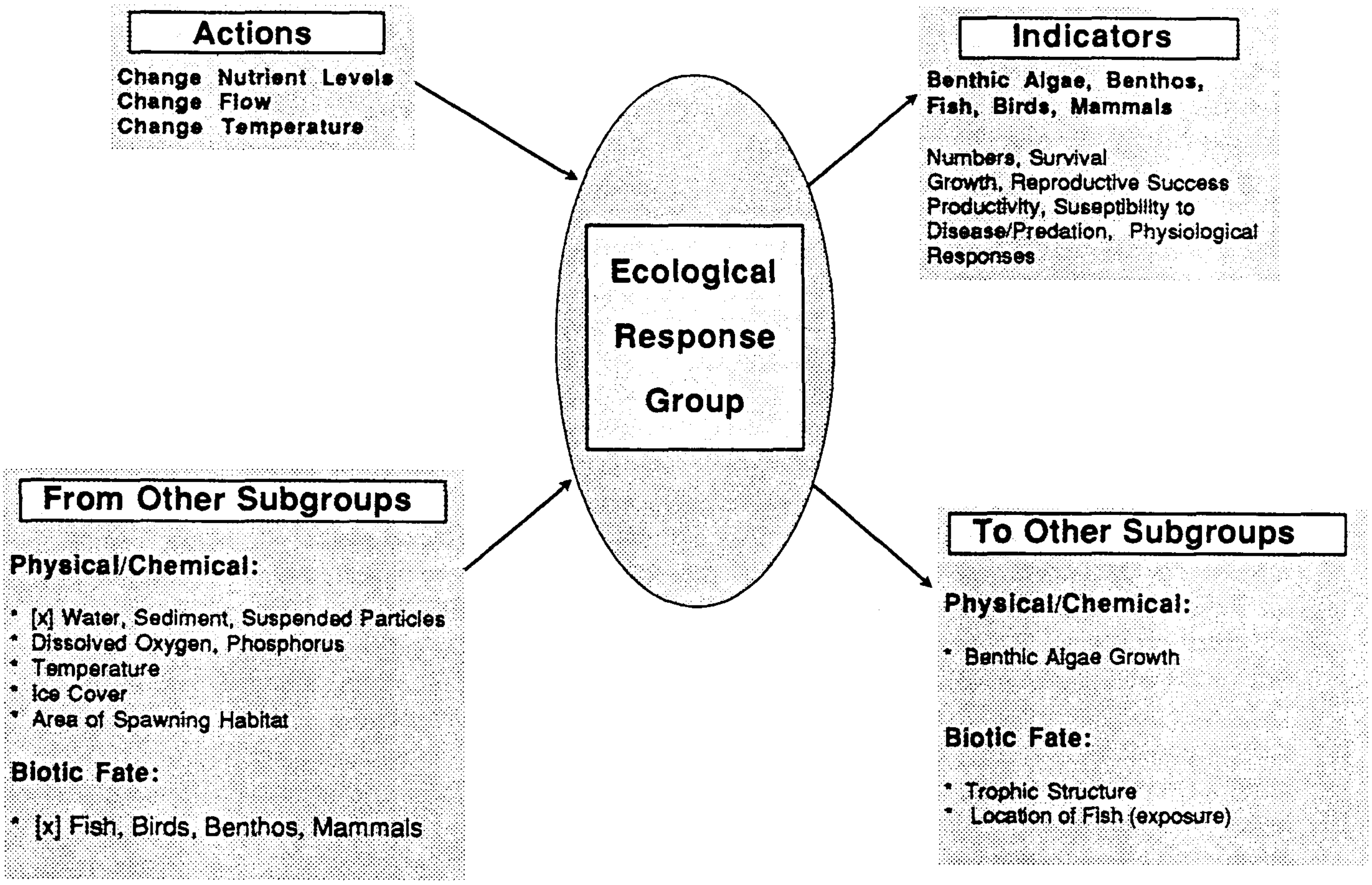


Figure 3.1: Responsibilities of ecological response group. [X] refers to concentration of any contaminant.

Given this very broad mandate, it was considered more appropriate to develop detailed conceptual models of the overall problem, rather than to develop a quantitative modelling approach for the few problem components that are sufficiently well understood to support quantification. Once the problem had been attacked at a qualitative level, the subgroup could address the question of how to turn this conceptual understanding into tools which could aid decision making. The basic approach was therefore to:

1. divide the Fraser River watershed into special interest zones;

2. identify key issues and observations for each zone;

3. develop generic impact hypotheses to serve as a template;

4. identify for each zone the key data gaps, research needs and monitoring requirements; and

5. develop a list of overall research priorities, and a strategy for implementing this research.

In reporting the results of this discussion, we present the spatial resolution and generic conceptual model first (items 1 and 3), then all the results pertinent to each zone (items 2 and 4), and finally the overall research strategy.

The subgroup saw their charge in the overall context of understanding ecosystem status and developing regulations appropriate to maintaining or restoring it. Both the amelioration of the known, current impacts of mills, and the detection of unknown effects is required. An approach for meeting these goals is presented in Figure 3.2. Monitoring of ecosystem health (status) is used to determine the status and extent of "sick" systems, and to identify the most effective response measures from candidate indicators (presented later in this section). There was no consensus at the workshop on an explicit definition of ecosystem health; working towards a definition was seen as one of the goals of the research program. This is an iterative process of hypothesis formulation and testing. Monitoring triggers diagnostic studies of possible causes, and productivity measurements to assess whether the effects are manifested at the population level. Once the general causes have been identified, mesocosm or laboratory experiments are conducted to: 1) determine more precisely which specific chemical combinations are responsible for the observed problems; 2) quantify the concentrations or doses of these substances below which no effects are observed; and 3) refine field monitoring programs and definitions of ecosystem health (feedback loop in upper right part of Figure 3.2). These levels, or broader remedial measures determined directly from diagnostic studies, can then be embodied in legislative regulations. The effectiveness of these regulations is evaluated through continued monitoring (feedback loop in lower right part of Figure 3.2). This model is particularly appropriate given the "moving target" of changing technologies and loadings in the Fraser River system, and evolving definitions of ecosystem health. The technologies introduced to deal with previously identified problems (e.g. ClO_2 substitution, increased use of recycled fibre) may generate other compounds with ecological effects.

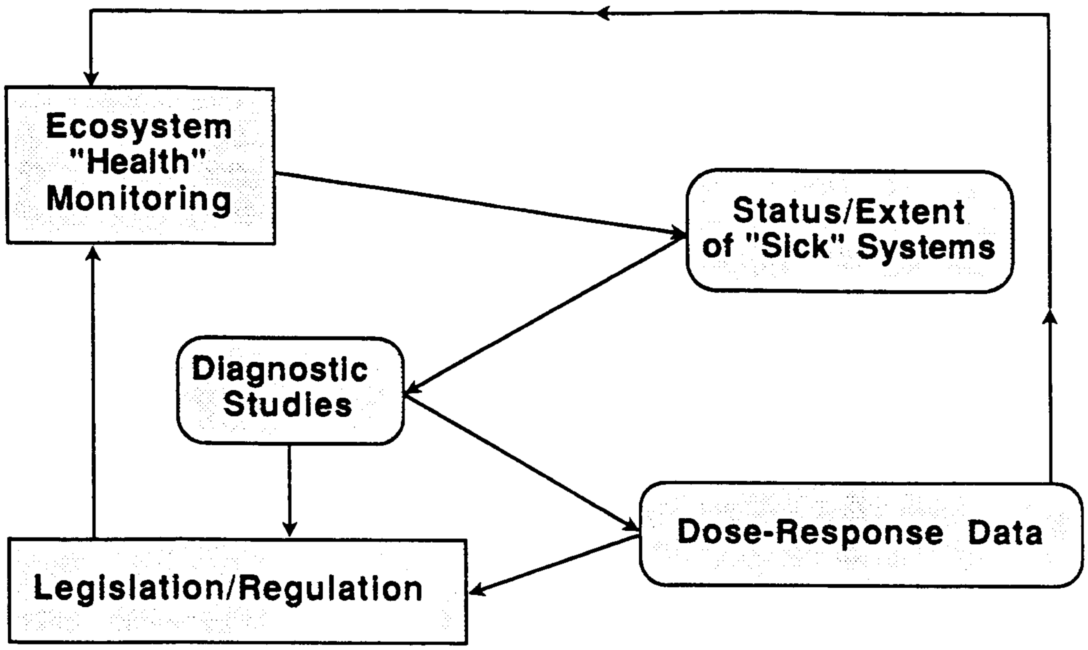


Figure 3.2: Relationship of ecological response monitoring and research activities to legislation and regulation.

3.1 Conceptual Model

In developing a conceptual model of the problem, the subgroup was confronted with several problems:

- the bioaccumulating contaminants which have been tested to date do not appear to have biological impacts on fish though they may be important higher in the food chain;
- it is not known which non-bioaccumulating compounds may be responsible for observed impacts on fish (the "*Factor X*" problem);
- the industrial process changes and future loading scenarios have not been explicitly defined ("For what processes or actions are we trying to detect effects?");
- there are numerous knowledge gaps concerning the basic structure, population biology (e.g. life history) and dynamics of the ecosystem;
- in the lower part of the Fraser, pulp mill effluent is only one of several ecosystem stresses;
- lags in the system, and changes in other stressors (e.g. land use, sediment loads) may lead to impacts from pulp mill effluent which are not currently observable; and

- the resilience of populations and communities may be changing with no observable effects.

The conceptual model of the problem developed by the subgroup therefore includes all effluent components which could potentially affect habitat quantity and quality (bottom of Figure 3.3): biochemical oxygen demand (B.O.D.); nutrients; metals, temperature, toxic organics; and particulate organic carbon. The subgroup stressed that toxic organics are only one of the important effluent constituents (dashed line in Figure 3.3). In addition, participants were concerned that the representative organic chemicals considered in the bounding session and other submodel development exercises were probably not the ones causing problems in fish, even though they may be of concern for birds, mammals, and human health. The overall set of pollutants interact with the natural levels of oxygen, light and food/nutrients in the system to produce changes in the quantity and quality of habitat for any given trophic level (bottom of Figure 3.3). These habitat changes may affect behaviour, adult survival, energetics, juvenile survival and contaminant bioaccumulation (pathways 1-5 in Figure 3.3). Changes in pathways 1-3 potentially cause a decrease in reproduction through a reduction in the number of females and/or the eggs per female. Decreased reproduction and/or juvenile survival result in reduced recruitment and therefore production (top of Figure 3.3).

Decreased production and increased contaminant bioaccumulation at one trophic level may cause effects at the next tropic level (top of Figure 3.3). The conceptual model is therefore best visualized as a box with several connected layers or shelves, where each layer represents a different trophic level (as in Figure 3.3), with effluent spilling onto each. Since this is hard to draw, we have just represented one layer (fish) in Figure 3.3, and added higher trophic levels to the top. Space and time represent added dimensions to the problem: some pathways are quite localized and cause short-term responses; others have a greater spatial extent and temporal duration.

The "behaviour" and "energetics" pathways represent a considerable simplification of a host of chronic effects observed on fish exposed to pulp mill effluent in various locations around the world. These include:

- changes in the immune system, # of white and red blood cells
- liver tumours
- delayed onset of maturity
- decrease egg size
- changes in secondary sexual characteristics - decreased gonad size
- increased liver size
- changes in lipid metabolism - fatter but stored differently
- changes in steroid regulation
- decreased stress response
- liver enzyme induction

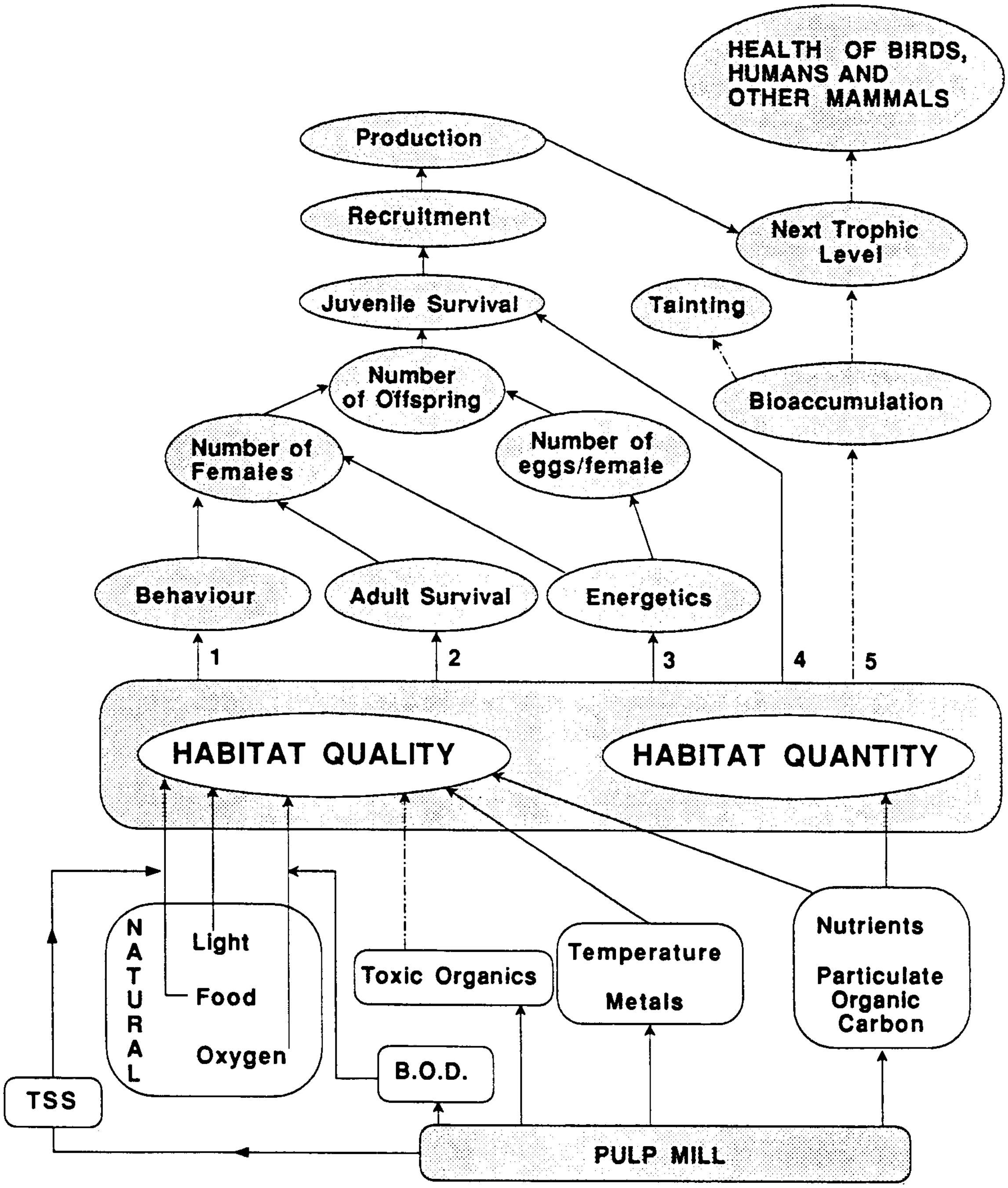


Figure 3.3: Conceptual model of the ecological response of any trophic level to the release of pulp mill effluents into the Fraser River system. Through the addition of birds, humans and mammals to the top of this figure, we implicitly assume it refers to fish.

The conceptual model in Figure 3.3 could potentially be converted into or linked with a simulation model once the triggers activating behavioural, energetics or survival pathways have been determined. These triggers might be concentration thresholds for various chemicals in sediment, water or biota; the quantity of available habitat; or levels of production at a lower trophic level. These triggers are almost certainly dependent on ambient conditions (e.g. natural levels of light, food and oxygen) at a give site, as well as the quantity and quality of effluent. Any detectable concentrations of bioaccumulating toxic substances would activate pathway 5 (the biotic fate submodel). These ecological triggers could be used, together with fish consumption guidelines for human health, in a linked physical/chemical/biotic fate model to assess what loadings would maintain the system in a condition which does not cause negative ecological impacts.

3.2 Spatial Resolution

The subgroup initially discussed four major regions of concern (see "near field impact zones" in Figure 6.1:

Region A: Prince George and Quesnel

Region B: Thompson River

Region C: Hope to Fraser Estuary, divided into
- Region C_1: Hope to Rosedale Bridge, and
- Region C_2: Rosedale Bridge to Port Mann Bridge.

Region D: Port Mann Bridge to Sturgeon Banks

Regions A and B would also include reference or control sites, since a critical part of the recommended monitoring and research approach is upstream<->downstream comparisons. After some discussion it was agreed to focus on region C_1, since in region C_2 the signal from pulp mill activities may be swamped by local impacts (i.e. agriculture, sawmills, urbanization); subsequently we consider area C as the portion of the river from Hope to Rosedale Bridge. The interacting set of stresses in C_2 may, however, make it a future candidate site for assessing the resilience of individuals and populations. All parts of the conceptual model apply to regions A and B, whereas contaminants become of predominant importance in regions C and D. These regions match those discussed by both the Biological Fate subgroup (Section 4) and the Physical/Chemical subgroup (Section 5).

3.3 Temporal Resolution

The temporal resolution of research and monitoring studies depends on both the organism and the response indicator. Though this topic was not discussed in detail, it was noted that for fish it was important to sample over a six-month period during the non-spawning season. This ensures that captured fish are indeed resident, yet still permits an evaluation of fecundity. More work is required on this topic, so that there is the maximum possible congruence in the sampling periods for physical, chemical, bioaccumulation and ecological response indicators. For initial studies at near field impact zones, the fall season is most important.

3.4 Details of Conceptual Model

As described in the introduction to this section, the subgroup began by cataloguing the observed environmental effects within each of the four spatial zones, using the conceptual model as a guide. These effects are described in more detail below, and summarized in Table 3.1. As one would expect there is a much greater range of observed effects (Table 3.1) in the near field impact zones (A: Prince George/Quesnel and B: Kamloops), than in the far field bioaccumulation zones (C & D), where toxic organic accumulation and fish tainting are the primary concerns. Once the current situation was characterized, the subgroup identified for each zone the key data gaps, research needs and monitoring requirements (Table 3.2). The research and monitoring needs (Table 3.2) naturally reflect the pattern shown in Table 3.1; there are more phenomena to be understood in zones A and B, and the cause-effect relationships are most easily deduced in these locations. An understanding of the basic biology of fish (life history, distribution, diet) is the most fundamental, ubiquitous knowledge gap.

Table 3.1: Summary, by area of environmental effects apparent from existing information. A = Prince George and Quesnel; B = Thompson River; C = Hope to Rosedale Bridge, and D = Port Mann Bridge to Sturgeon Banks.

Issue	Spatial Zone			
	A	B	C	D
Toxic Organic Accumulation				
birds	T	T	T	T
mammals	T	?	?	T
fish	T	T	T	T
Chronic/Sublethal Effects				
birds	T	T	?	T
resident fish	T	T	?	T
Behavioural Induced Toxicity				
fish	T	T		
Benthic Community Changes	T	T		
Nutrient Enrichment	T	T T		
Particulate C Loading	T	T		

Benthic Biofilm		T		
Fish Tainting	T	T	T	
Reduced Resilience			T	

Table 3.2: Summary, by area, of major research and monitoring needs. A = Prince George and Quesnel; B = Thompson River; C = Hope to Rosedale Bridge, and D = Port Mann Bridge to Sturgeon Banks.

Need	Spatial Zone			
	A	B	C	D
Synoptic Survey				
mammals, birds		T	T	T
Basic Biology				
fish	T	T	T	T
Reproduction Measurements				
birds	T	T		T
fish	T	T		T
Growth Measurements				
fish	T	T		
Biofilm				
biology, toxics	?	T		
Benthos				
community composition	T	T		
Genetic Diversity				
fish	?	?	?	?
Trophic Dynamics	T	T		

The following sections summarize the analysis of the conceptual model for each zone, and particular organismal groups within each zone. The group tackled the Thompson River first, and then compared other areas to it. The observations of current impacts (i.e. links in the conceptual model for which there is some evidence) are generally listed first, followed by the data and conceptual gaps in current knowledge, and the consequent needs for monitoring and research.

3.4.1 Thompson River (Area B)

The Thompson River system has some unique features relative to the other near field impact zones in the main stem. First, its sensitivity to nutrient loading may swamp or interact with other effects. For example, nutrients may be increasing the system's productivity while contaminants are decreasing it; this has potential management implications. Second, the presence of Kamloops Lake may result in some filtering (i.e. sedimentation) of pollutants, such as particulate carbon. Third, there are major salmon spawning grounds below the mill, with overwintering eggs. No problem has been observed with respect to salmon spawning, but this may be because to date scientists have not looked in the right places. Though not an ecological problem, aesthetic issues (colour, odour) are of concern.

Birds and Mammals

Accumulation of toxic organics has been observed in mink, otter, and birds (particularly osprey) (P. Whitehead, pers. comm.). Osprey are migratory, however, and there is a need for seasonal measurements (including eggs) to separate out the sources of these contaminants. At this point, the main evidence of impacts on osprey is survey data and a limited amount of dose-response studies of eggs, looking at subcutaneous edemas, hatchling size and organ weights. There's a need for *laboratory dose-response experiments* to determine the mechanisms of action of toxicants, and assess the potential for higher level effects in the conceptual model (i.e. reproduction, population changes). *Synoptic surveys* of contaminant levels and *baseline data on the population age structure, year-to-year variation in recruitment and survival* would be valuable (for both downstream sites and upstream reference areas) to help set the stage for long term monitoring studies. There is generally much less information available for mammals (mink, otter, martin, bears) than for osprey. Synoptic surveys are required to identify both what mammals are there and what they contain.

Fish

There is some reference data on the species present in the system, but there are major gaps in understanding of their general biology. There is also a need to know more about what these fish are eating, the interspecific interactions between resident fish and salmonids.

Contaminant accumulation and possible sublethal effects are an important issue. Chlorinated organics have been found in Rocky Mountain whitefish and longnose dace, but have not yet been examined in juvenile salmonids. A difficulty with Rocky Mountain whitefish is that it is not known where they spawn, and this knowledge is likely to be difficult to acquire; despite their large body burdens they may not be the best species to monitor. Though chronic sublethal impacts (pathways 1 and 3 in Figure 3.3) have not been studied in the Thompson, various such effects have been observed downstream of pulp mills in Ontario which have similar levels of dilution. It is possible that such effects are also occurring to salmon and steelhead, though it is notable that the spawning success of Thompson River pink salmon has to date not been affected. Indicators such as decreased healing rates and elevated white blood cell counts may be useful for revealing stress even though the fish has been able to eliminate the toxicant.

In addition to monitoring contaminant levels in juvenile salmon and steelhead (which has declining escapements), the following research priorities are indicated for the selected species (best candidates to date are longnose dace and rainbow trout):

1. *field and lab studies to assess the effects of elevated contaminants, through upstream/downstream studies of reproductive success, growth, survival, physiology and behaviour*. Behaviour studies could include attraction to or avoidance of the plume, disease resistance, swimming performance, and temperature preferences.

2. *field and lab studies to assess the relative importance of food web transmission to direct contaminant uptake.* The distribution of contaminants in biofilm, algae, and plankton would be assessed.

3. *studies, perhaps in mesocosms, of the interaction between nutrient levels and contaminant bioaccumulation.*

There may be some acute toxicity (i.e. reduced survival, pathways 2 and 4 in Figure 3.3) for fish exposed directly to the effluent plume, but it is not known what proportion of the population is so affected.

Benthos

Direct and indirect impacts of pulp mill effluent have been observed on the benthic community (i.e. productivity and species composition), though there has also recently been some recovery (M. Bothwell, pers. comm.). Sewage additions in the early 1970's complicate the analysis of this issue. Some baseline data on *seasonal community changes* and *genetic diversity* could be valuable in the context of long term monitoring, though there is a need first to *evaluate the statistical issues surrounding various potential benthic monitoring indicators*. The interactions between nutrient enrichment, benthic algae production, dissolved oxygen concentrations, biofilm stimulation, and benthic community changes need to be better understood. In addition to providing food, biofilm may affect the fate of organochlorines through transformation and translocation. *Upstream/downstream comparisons, probably in mesocosms*, would be valuable to help sort out these issues.

3.4.2 Prince George and Quesnel (Area A)

In this zone the interactions between nutrients and biofilm are thought to be of much less importance than in the Thompson River, though it's possible that nutrients may exacerbate naturally low oxygen levels during the ice-covered season (data are not available to confirm or reject this hypothesis). Ice cover also serves to prevent volatilization, creating an elongated exposure zone. The seasonality of effects may have important implications for management and regulation. There is also a very different food web here compared to the Thompson River, as there is less in-river primary production.

Birds and Mammals

Bioaccumulation has been observed in mink, otter and birds. It is suspected that the routes of these toxicants may be both aquatic and atmospheric.

Fish

Bioaccumulation of contaminants has been observed in various fish species in this area. Concentrations of 2,3,4 TCG in Rocky Mountain whitefish are four times higher here than in the Thompson River. This may be because considerable densities of fish overwinter near the outfalls where, probably because the water is warmer and there is more food. If attraction to the outfalls can be shown to occur (e.g. through *Y-maze studies*) then different effluent management strategies (e.g. effluent cooling) may be indicated. Fish tainting has reportedly occurred in this zone (no reference). Though obviously important to humans, it is not known whether this has any ecological impacts (e.g. changes in predation).

All mills have failed to comply with LC_{50} regulations at some time. Lab studies of *fish attraction* to different temperatures and consequent effluent exposures, together with *field studies of fish distribution*, may help to indicate what proportion of the population are killed by acute toxicity. Underwater videos of these effects could be released under the title *Fatal Attraction*.

Benthos

Some changes to the standing crop of benthos have been documented, but there are no data on changes in production. Loadings of particulate organic carbon are more important in this area than in the Thompson. They not only have an impact on benthic populations, but may also cause contaminants to become biologically entrained as microbial flocs and therefore available for biological uptake.

3.4.3 Hope to Rosedale Bridge (Area C)

This area is relatively free of agricultural impacts, and represents the last chance to monitor the system before large confounding factors (e.g. agriculture) swamp the signals from pulp mills. It could therefore be used to determine the farthest extent of distinct mill effects on resident fish. In addition, looking at the broader mandate of the Fraser River Action Plan, this zone could serve as a control for the effects of agriculture. Due to changes in river flow this is a major deposition zone for many substances. From the perspective of ecological responses, however, it is definitely a lower priority for study than regions A and B. There may be considerable confounding of "controls" in this zone.

Birds and Mammals

There is the potential for accumulation of chlorinated organics in bear, heron and eagles, but there have been no such studies to date.

Fish

Bioaccumulation has been observed in resident fish in this zone. Key questions are:

- Are contaminants reaching this zone through contaminated biota that are carried or migrate downstream, or via physical/chemical pathways?

- How much has contaminant bioaccumulation reduced the resilience or resistance of the fish community to other stresses (e.g. predation, disease, other contaminants)?

Possible fish species worth monitoring include sculpins, shiners (very abundant), suckers, chub, sticklebacks, starry flounders (perhaps a poor choice since it is a marine species), Rocky Mountain whitefish, salmonids and squawfish. There is a lack of detailed information on what species are present; *basic life history information* is required to develop appropriate stress indicators.

Benthos

Assessing the impacts on the benthic community is very difficult in this zone because the habitat is so dynamic; selection of study sites could be very tricky. It is worth assessing contaminant levels in detritivores, amphipods (epibenthic fauna), and *Neomysis*.

3.4.4 Estuary: Port Mann Bridge to Steveston (Area D)

This is a an area of enormous biological productivity, with many different stressors affecting the system.

Birds and Mammals

Elevated levels of contaminants have been observed in heron and cormorants. The actual effects of many substances have not been determined however, and more dose-response experiments are required.

Fish

The Scott pulp and paper mill, while not thermochemical, may still be releasing "factor X" which causes non-lethal effects in fish. It is possible that there are residual effects of pulp mill effluents on salmonid migration from fresh to salt water due to lowered resilience and stamina, though none have been observed in recent studies (J. Servizi and T. Farrell, pers. comm.). As for Area C, a key question is the transport media for contaminants into this zone (water, sediment or biota); this has important implications for designing control strategies.

Benthos

Possible biomonitoring organisms include chironomids, amphipods and crabs.

3.5 Research Strategy for Near Field Impact Areas

For fish in areas A and B (Prince George/Quesnel, Thompson River near Kamloops), a hierarchical strategy was considered ideal (Table 3.3). **Tier 1** of this strategy is to *identify problems, and select indicators*. This would involve sampling 1-2 sites below the outfall, and several reference sites, during the fall season. Twenty fish of each sex would be sampled and measured for mean age, length, weight, condition, proximate analysis and fecundity. If effects are detected, then one would move to a **Tier 2** analysis to *determine the population status*. Selected indicators would be measured more intensively (more sites, more individuals) to confirm that the effect observed in the first pass is indeed real. If it is, one would go to a **Tier 3** study to *assess the extent of the problem*. This would involve examination along an exposure gradient, which would have the added benefit of establishing *empirical dose-response relationships*, or discriminant functions to use as indices of environmental quality. **Tier 4** would involve repeated Tier 3 studies to establish trends. Bottom-up studies (e.g. MFO studies to document exposure) should also be considered, in addition to this top-down approach.

Table 3.3: Hierarchical approach to assessing ecological responses in near field impact zones.

Tier	Sampling	Measurement	Product
1	1-2 sites below several sites above ref. 20 females, 20 males fall season	mean age, length weight, condition proximate analysis fecundity	Problem ID Indicator selection
2	more sites larger number individuals	selected indicators	population status
3	wider geographic area gradient	selected indicators	problem extent environmental quality indices
4	over time	selected indicators	trends

3.6 Summary of Research Needs

The major areas of research identified include:

1. compiling a *reference data base* for each area, which includes:
   - ! trophic dynamics for resident fish,
   - ! identification of keystone species, sentinel species
   - ! basic life history information (especially for Rocky Mountain whitefish);

2. *field studies to identify physiological and population-level changes* resulting from exposure, via comparisons with reference sites;

3. *estimates of the geographic extent of ecological responses*, through both intensive studies near mills and synoptic monitoring downstream;

4. *dose response experiments* to establish mechanisms and threshold dose levels/concentrations;

5. *determine significance of altered trophic fluxes of carbon and nutrients on productivity (1^o to 3^o), and biotic fate of toxic organics*; and

6. *examine slow variables (ecosystem resilience, genetic diversity)*.

The group identified a long list of potential candidate biomonitoring species (Table 3.4). This list needs to be systematically evaluated against a set of criteria for indicator selection. Ideally, some widespread species could be used for interzonal comparisons. In general, it is desired to focus on higher trophic levels to establish the ecological significance of impacts, though lower trophic levels are sometimes more tractable for trend detection.

For the research program to succeed, the ecological response research activities need to have substantial influence on the direction of the physical/chemical and biotic fate modelling work. There are at least four ways in which this should occur:

- ! better information on the basic life histories and near field distributions of fish will improve the estimates of exposures for contaminant modelling;

- ! better understanding of trophic dynamics will improve the representation of food webs in contaminant fate models;

- ! isolation of factor X (or factors X,Y and Z!) should lead to adaptation or expansion of field calibration and laboratory work that is done in support of contaminant modelling; and

- ! thresholds determined from field and dose-response experiments should serve as endpoints for using contaminant accumulation models in a policy context to determine desired regulations.

It is neither feasible nor advisable to attempt to build a complete ecosystem simulation model. The development of quantitative dose-response modules for particular ecological responses can be quite valuable however. When linked to the other submodels, this can provide useful guidance towards the evaluation of proposed policies and regulations, as well as refining the designs of long term monitoring plans.

Finally, the ecological response research has obvious links to the main FRAP program objectives, as outlined in Section 1:

- the synoptic monitoring and associated dose-response work will help to determine environmental quality criteria;
- the upstream/downstream work at near field impact sites, and the synoptic monitoring at far field bioaccumulation sites, will help in the identification of current levels of contamination and monitoring the effects of pollution abatement measures over time.

Table 3.4: Candidate biomonitoring species, by spatial unit.

Candidate Biomonitoring Species	Spatial Zone			
	A	B	C	D
Mammals				
mink	?	?	?	
otter	?	?		
seals			✓	
Birds				
osprey	?	✓		
great blue heron				✓
cormorant				✓
eagle			✓	✓
Fish				
sticklebacks			✓	✓
rocky mountain whitefish	✓		✓	
shiners			✓	
longnose dace		✓		
rainbow trout		✓		
eulachons				✓
salmon	?	?		
suckers	✓	✓	✓	
Invertebrates				
neomysis			✓	
crayfish			✓	
insects	✓	✓		✓
amphipods				✓
crabs				✓
Algae				
diatoms		✓		

4.0 Biotic Fate Subgroup

The primary charge to the Biotic Fate group was to develop a method of estimating the concentrations of various contaminants in a set of valued ecosystem components. The set of contaminants may be important either in terms of human health effects, or in terms of ecosystem health. Some evidence from one or both of these perspectives is necessary to focus research efforts. During the bounding session, the participants identified three representative contaminants: 2,3,7,8 TCDF (tetrachlorodibenzofuran); 3,4,5 TCG (trichloroguaiacol); and organic S compounds (Section 2). The subgroup felt that in view of the recent changes in treatment processes to reduce chlorination it was appropriate to add two other representative compounds: 2,4 DCP (dichlorophenol); and 5,6 DCV (dichlorovanillin). Lower chlorination may reduce the levels of furans to below detectable levels. It was agreed that in view of the "moving target" of effluent changes the modelling method adopted should be based on physical-chemical properties, so that it could be easily adapted to deal with substances other than the five example substances considered here. This is particularly important since the "smoking gun" causing physiological responses in fish populations has not yet been identified (Section 3).

The bounding exercise identified the following set of valued ecosystem components (VECs): benthos, fish (salmon, longnose dace, rocky mountain whitefish, sturgeon); birds (herons, osprey, grebes), and mammals (mink, river otter, seals). This initial set of VECs was reviewed and revised by the subgroup. The participants then grappled with possible modelling and monitoring approaches towards estimating contaminant concentrations for each of the revised list of VECs.

The subgroup first organized the problem by building a conceptual model of contaminant pathways through a simplified food chain. The participants then examined each of the linkages within this conceptual model to determine what methods are available for quantifying the process. In considering each organismal group, the subgroup assessed:

- possible breakdowns of the ecosystem component (i.e. functional classes or representative species which are likely to show different magnitudes of contaminant accumulation);
- the relative risk of contamination of each of these classes or species, and possible confounding effects from pollution sources outside the Fraser River (e.g. Georgia Strait pulp mills, industries within the migratory range of birds);
- the spatial distribution of the organism relative to pollution sources;
- sampling issues (for monitoring or model calibration/validation);
- the spatial and seasonal variation in diet, which affects contaminant pathways;
- the possible modelling approaches to predict contaminant concentrations;

- knowledge gaps (both conceptual gaps requiring advanced understanding and more straightforward data gaps); and

- the work required to fill those knowledge gaps (literature reviews, laboratory studies and experiments, field monitoring and experiments, and modelling).

In addition to predicting contaminant concentrations in the VECs, the Looking Outward exercise generated a number of other desired outputs from the Biotic Fate subgroup to the other two subgroups (bottom right of Figure 4.1). There was insufficient time at the workshop to deal with all of these, but the most important linkages were discussed. The key physical/chemical information needs of the subgroup (bottom left of Figure 4.1) were contaminant concentrations in the water, sediment, and suspended particles; and water conditions which influence the rate of contaminant uptake (i.e. pH, temperature, TSS and particle size distributions). The subgroup discussed an appropriate level of spatial and temporal resolution for this physical/chemical information. From the ecological response group it was important to know possible changes in the food web (trophic structure), and fish life history (location, exposure), since these factors can affect the amount of contaminant bioaccumulation. [2]

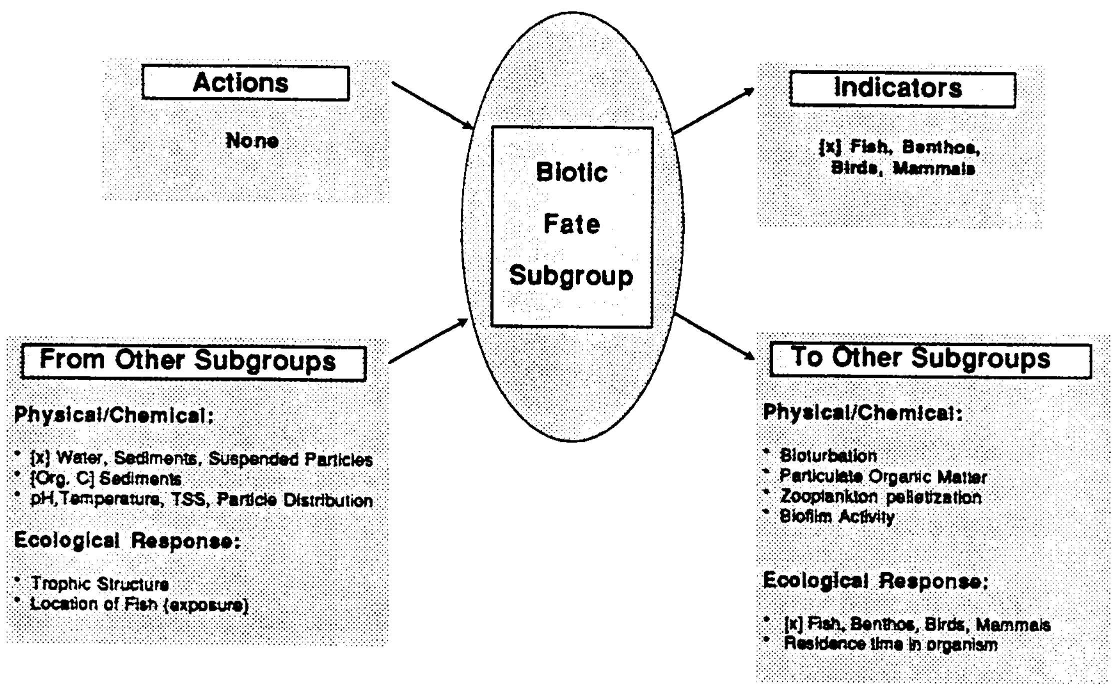
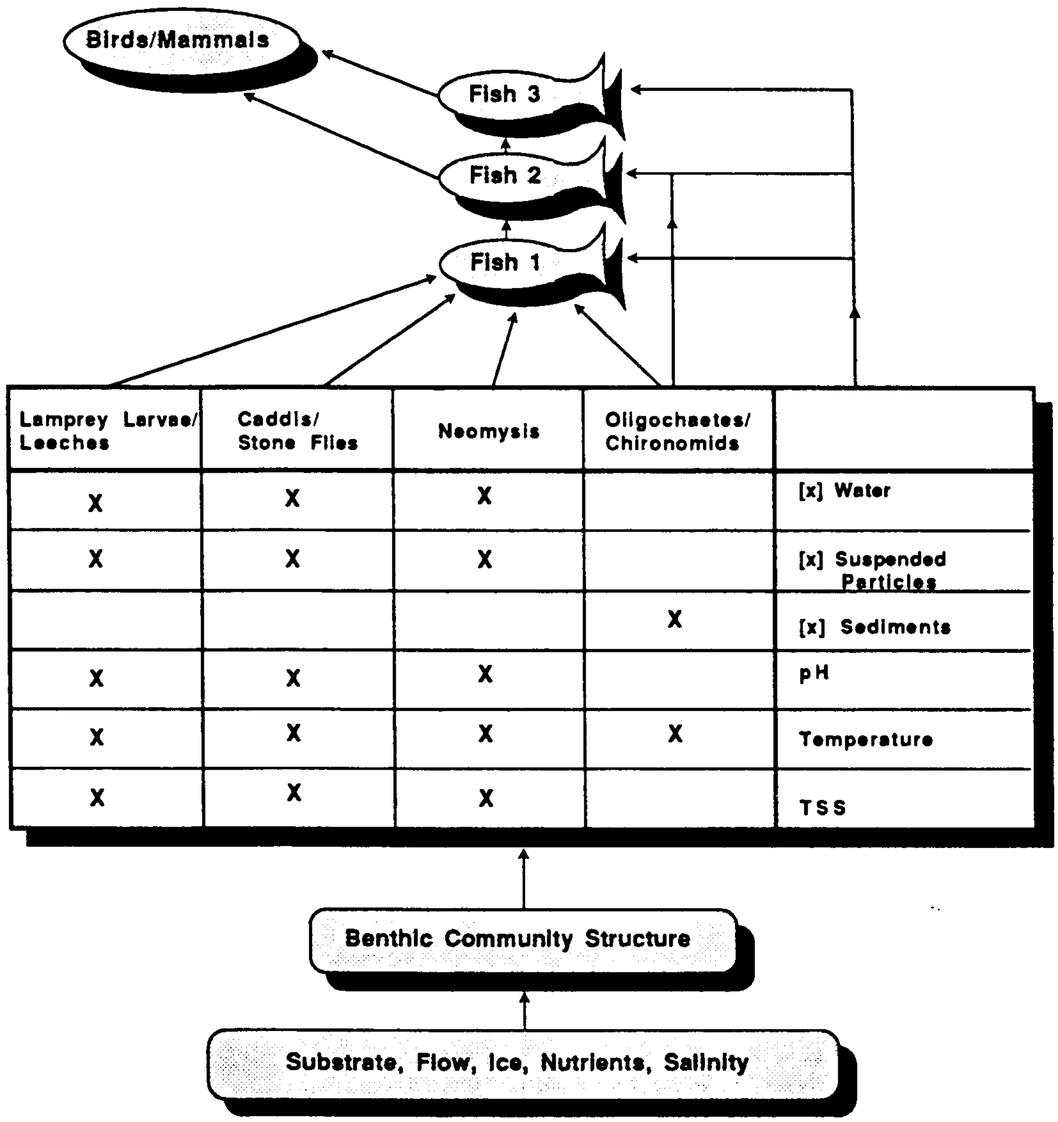


Figure 4.1: Responsibilities of Biological Fate subgroup. Items marked with an "*" were not considered at the workshop.

[2]Different definitions are used by different authors. Here we refer to *biomagnification* refers to the uptake of contaminants through food, and the increase in contaminant concentrations at successive trophic levels (i.e. food chain effects). *Bioconcentration* is an organism's uptake and concentration of contaminants directly from water. *Bioaccumulation* is the sum of these two processes (e.g. bioaccumulation factors represent $[X]_{organism}/[X]_{water}$, which combine both bioconcentration and biomagnification processes.

4.1 Conceptual Model

The subgroup developed a simple conceptual model of the problem of estimating contaminant uptake in the Fraser River system (Figure 4.2). Within each reach, the benthic community structure is determined by a number of physical and chemical factors (substrate, flow, ice, nutrients, salinity). From the perspective of contaminant uptake, the spatial stratification of the Fraser River should be driven by these factors. Fortunately, these same factors drive the stratification from the perspectives of ecological response (Section 3) and physical/chemical modelling (Section 5).



Lamprey Larvae/ Leeches	Caddis/ Stone Flies	Neomysis	Oligochaetes/ Chironomids	
X	X	X		[x] Water
X	X	X		[x] Suspended Particles
			X	[x] Sediments
X	X	X		pH
X	X	X	X	Temperature
X	X	X		TSS

Figure 4.2: Conceptual model of contaminant fate within biota.

The box in Figure 4.2 illustrates the interaction between physical/chemical conditions and contaminant bioaccumulation within representative components of the benthic community. The bioavailability of the contaminant is affected by adsorption onto suspended solids (assessed by *TSS*) and the level of dissociation of the compound (determined by *pH* and the compound's pK, or dissociation constant). *Temperature* affects both uptake rates and metabolic rates. Five very simplified groups of benthic organisms were chosen to reflect different contaminant uptake processes and habitats:

- mostly bioconcentration from the water (lamprey larvae, which are important to sturgeon, and leeches);
- freshwater filter feeders and shredders taking up contaminants from water, suspended particles, and detritus (e.g. caddis flies and stoneflies);
- estuarine filter feeders (e.g. *Neomysis*);
- epifaunal detritivores (e.g. chironomids); and
- infaunal feeders taking up contaminants directly from the sediment (e.g. oligochaetes).

The particular taxa chosen (e.g. caddis flies) are meant to be representative of an entire functional group (i.e. freshwater filter feeders).

Assuming that the contaminant concentrations in these benthic groups can be estimated (proposed methods are described below), the next step in the group's overall conceptual model is to estimate the average dietary composition of each fish species of interest. This involves specifying the proportions of each benthic group in fish diets, by season if necessary. The spatial distribution of each fish species across major river reaches must also be known, a major knowledge gap for several fish species. The diets of fish obviously include a much greater diversity of organisms than the benthic organisms shown; for estimating biotic fate, however, what matters is different *modes* of contaminant uptake, not taxonomic differences. A considerable body of theory and empirical evidence is available for predicting contaminant bioaccumulation in fish, using pharmacokinetic models (discussed below). The physical/chemical factors discussed above for benthos are equally important for fish. Once fish contaminant concentrations are estimated, the process is repeated for piscivorous birds and mammals. Though the theory and models of contaminant uptake are not so well developed for these groups, the problem is somewhat simpler in that only biomagnification, and not bioconcentration, needs to be considered.

4.2 Spatial Resolution

As discussed above, a number of physical/chemical factors determine the appropriate spatial resolution for modelling contaminant uptake. A rough description of these zones, together with the kinds of activities foreseen in each, is provided in Table 4.1. The rationale for the recommended activities is provided below.

Table 4.1: General description of spatial stratification for contaminant bioaccumulation submodel: substrate, types of benthic organisms, and proposed research and monitoring activities.

River Reach	Substrate	Types of Benthic Organisms	Proposed Activities
FRASER MAINSTEM			
Nechako to Confluence with Fraser	rock/gravel	filter feeders/grazers	control site
Above Prince George	cobble/sand/gravel bars	filter & detrital feeders/ grazers	control site
Prince George to Quesnel			bioaccumulation tests
Quesnel to Lytton			
Lytton to Hope	high energy	?	
Hope to Mission	braided/sand	filter feeders?	bioaccumulation tests
Mission to Kanata Creek	sand	filter feeders/ oligochaetes/ Neomysis	
Estuary	mud/sand/silt	oligochaetes/ Neomysis	bioaccumulation tests
THOMPSON RIVER			
Upstream of Mill	?	?	control site
Kamloops Lake	lake sediments	grazers?	bioaccumulation tests
Savona to Lytton	?	grazers?	

To predict the bioaccumulation of contaminants within organisms, it is necessary to know the average contaminant concentrations (i.e. $[X]_{water}$, $[X]_{sediment}$, and $[X]_{susp.\ part.}$ within each of the above spatial units. For spatial units with effluent sources, there may be a very large difference in concentrations between the near field and far field zone (Section 5). The subgroup, therefore, felt that an estimate of the average contaminant concentrations within both zones was appropriate. A more detailed spatial stratification was considered unnecessary, since there is insufficient knowledge of fish distribution to make use of such information.

4.3 Temporal Resolution

Animal diets, animal distributions and contaminant concentrations change seasonally within the Fraser River. A seasonal time step (for modelling and monitoring) is therefore necessary to understand and predict the biotic fate of contaminants. There are, however, substantial knowledge gaps in the defining the seasonal variation of animal diets and distributions.

4.4 Details of Conceptual Model

4.4.1 Benthos

Composition of Benthos

We need to better understand the basic composition of the benthos in each of the above identified zones, particularly those in which field experiments are recommended. A synthesis of existing literature is therefore the first step, with targeted field monitoring to fill identified gaps.

Modelling and Monitoring Benthic Contaminant Uptake

For modelling contaminant bioaccumulation, the subgroup considered infauna (animals such as oligochaetes and chironomids living within the sediment) separately from epifauna (filter feeders and grazers which live at or on the sediment surface). For infauna, two approaches were considered acceptable:

1. the theoretical approach of Shea (1988), Gobas et al. (1989), and Gobas (in press), in which the accumulation of hydrophobic contaminants is treated as equilibrium partitioning of the chemical between the lipids of the organism, the organic carbon fraction of the sediment, and the interstitial water; and

2. an empirical calculation of bioaccumulation factors (BAF) for oligochaetes, where $BAF = [X]_{org}/[X]_{sed}$.

For epifauna relying on suspended particles, analogous approaches were recommended:

1. a theoretical approach (development of simple pharmacokinetic models for caddis flies which consider the organism's rates of contaminant uptake from water and suspended particles, and aggregate loss rates); and

2. empirical estimates of BAFs, where here $BAF = [X]_{org}/[X]_{susp.\ part.}$.

The pharmacokinetic approach has been well developed for fish (described in the next section), but is in a much earlier level of understanding for benthic organisms. Participants guessed that it might take six years before a fully validated pharmacokinetic model was available for filter-feeders. One of the difficulties is that though average "k" values (uptake and elimination rates) could be determined in the laboratory, there are some major hurdles to be cleared before the seasonal variation in these parameters is both understood and quantified. Field validation of laboratory-derived rates, or at least their net effect, is essential. While model development proceeds, empirically derived BAFs offer a useful first cut approach to estimating bioaccumulation.

Field monitoring studies were proposed to both estimate BAFs empirically, and test the predictions of the theoretical approaches. This approach has been conducted using leeches, with BAFs for chloroguaiacols measured in the 400-800 range (Ken Hall, unpub. data). Actually, these data are more indicative of bioconcentration factors (BCFs) since the leeches were not eating. Separating out the effects of bioconcentration and biomagnification (using either leeches or lipid bags) would be of value in calibrating/validating models. The proposed monitoring studies would be conducted seasonally at the four sites downstream of effluent sources and the two control sites listed in Table 4.1. Ideally, BAFs for benthic organisms would be measured at both the near-field mixing zone and the far-field zone in spatial units downstream from effluent sources. A pilot study at two sites (one control) would be worthwhile to refine the methodology, since the full design could involve a large number of samples (i.e. 10 sites (4 downstream sites*2 locations + 2 controls) * 4 seasons * 6 benthic organisms = 240 experimental chambers, without any replication). The contrast in the data collected could provide empirical evidence of the variation in BAFs with temperature (due to changes in uptake/metabolism), pH (due to dissociation), TSS (changes in bioavailability) and salinity. Ideally, BAF's would not vary with contaminant concentrations in sediment and suspended particles, so that empirical relationships could be used with some confidence under different loading scenarios. Field validation at sites other than those were the BAFs were derived is essential to boost the level of confidence in this approach.

One significant uncertainty is the correct particle size range to use in estimating $[X]_{susp.\ part.}$. The ideal size range is the one which generates consistent estimates of BAF for filter-feeders with low variance across a range of $[X]_{susp.\ part.}$. The subgroup proposed that pilot tests be performed with concentrations calculated for a number of different particle size ranges, so that the optimal size range could be selected for filtering samples.

Participants were concerned about the amount of error propagation though a set of models/equations linked together to represent a food chain. Integrated uncertainty analyses, and field validation at each step in the food chain, were considered essential to assess and control this problem.

Biofilm

The microbial community on the sediment/rock surface was raised during the bounding session as a potentially important ecosystem component. The subgroup did not discuss biofilm in detail. Degradation of contaminants by biofilm was, however, considered to be a potentially important process for the more water-soluble contaminants. Laboratory and field studies to assess their significance were recommended.

4.4.2 Fish

Preferred Species

The species considered for monitoring and modelling are listed in Table 4.2, together with the subgroup's judgement of the utility of including each species (yes or no), and the rationale for that decision. The criteria used to evaluate candidate species are listed in at the start of this chapter.

Table 4.2: Fish species considered for monitoring and modelling of contaminant bioaccumulation. Y=yes; N=no; "res." = residence time.

Species	Model/Monitor	Rationale
Adult salmon	N	low [x], low res, not eating
Overwintering juvenile chinook	Y	eating?, near outfalls?
Rocky mountain whitefish	Y	high [x], good data
Large Scale Sucker	Y	low [x], compare to whitefish
Longnose dace	Y	keystone spp. diet?
Sturgeon	Y N	native use, benthic feeder long-lived, low #
Dolly varden Squawfish	Y	high-level predators
Eulachon	N	high lipid but low res. time
Rainbow trout	?	good P-K data; [x]?

- *Adult salmon* returning to spawn are obviously a very valued ecosystem component, but their low observed concentrations of contaminants, short residence time and lack of food intake during spawning migration all indicated a low level of contamination risk.

- *Overwintering juvenile chinook*, on the other hand, have been shown to accumulate chloroguaiacols, dioxins and furans at Quesnel and Prince George (Rogers et al. 1989). Though no pathological symptoms were observed in fish tissue, there were observed physiological responses (mixed function oxidase induction). The proportion of juvenile chinook overwintering near outfalls, their dietary uptake of contaminants, and the biological significance of physiological responses are key uncertainties.

- *Rocky mountain whitefish* downstream of pulp mills have been found to have significant concentrations of chlorinated guaiacols and phenols, furans and dioxins (Voss and Yunker 1983; unpublished data). Though there is considerable uncertainty concerning their distribution, this fish appears to be a useful response indicator of both contaminant accumulation and general ecological responses. It is a resident species present in large numbers, has a similar diet to shiners, and is important for recreational fishing.

- *Large scale suckers* have been found to have lower concentrations of dioxins and furans than rocky mountain whitefish, though they still accumulate contaminants (e.g. chlorinated phenolics increase significantly in fish tissue below the pulp mill outfalls of Prince George and Quesnel (Dwernychuk 1990, cited in Schreier et al. 1991)). Though suckers were considered of a lower priority for assessing contaminant fate and effects than rocky mountain whitefish, it was felt that examination of the reasons for the difference in contaminant bioaccumulation between these two species might be instructive in terms of contaminant pathways. Are these differences due to physiology, metabolism, diet, distribution or some combination?

- *Longnose dace* were identified in the bounding session as a keystone species in the Thompson River system; they feed mostly on aquatic insect larvae (e.g. chironomids), and during spawning their own eggs (Scott and Crossman 1973).

- *Sturgeon* were favoured because of their importance to native people, and as a representative benthic feeder. Its long lifespan, however, means that measured concentrations of persistent compounds may reflect the river's pollution history rather than current conditions. Also, its low numbers raise a concern regarding the environmental impact of destructive sampling for contaminants. A voluntary sampling program (contributions of tissue from guides) is now in effect but has not generated many samples. Non-destructive methods (analogous to fistulated cows for assessing foraging) do not yet exist for fish. On balance, the subgroup was opposed to including this fish in a modelling and monitoring program.

- *Dolly varden and squawfish* were selected as representative high-level predators that are principally piscivorous. In studies near Prince George and Quesnel squawfish showed comparable levels of chlorophenol and chloroguaiacol bioaccumulation to suckers (Dwernychuk 1990, cited in Schreier et al. 1991). The log K_{OW} of chlorophenols ranges from <2 (o-chlorophenol) to 5.4 (tetrachlorophenol), while chloroguaiacols have a log K_{OW} in the 2-4 range (data provided at workshop by N. Henderson). Based on the theoretical calculations and field data analyses of Thomann (1989), one might expect more contaminant bioaccumulation in these predators (relative to suckers) for contaminants with a log K_{OW} in the 5-7 range, where food chain biomagnification is greater (e.g. dioxins).

- *Eulachon* have high lipid concentrations, and quickly bioconcentrate hydrophobic compounds during their six week (non-feeding) spawning run in the lower Fraser River (Rogers et al. 1990). Eulachons are abundant during their migration, and serve as important food for marine mammals, birds and resident fish. The subgroup felt, however, they were not appropriate for modelling/monitoring the fate of pulp mill effluents because of the brief duration of their spring migration to the Lower Fraser.

- *Rainbow trout* occur naturally in the Fraser River system. Because of their frequent use as a laboratory fish, there are a considerable amount of data on rates of contaminant uptake and loss (pharmacokinetic models). If it is judged to be important for other reasons (i.e. ecological response), then its relative ease (or lack of difficulty) in modelling would make it a good choice.

Modelling and Monitoring Approach

The subgroup reviewed in detail the pharmacokinetic modelling approach of Gobas (in press). In this model, the change in the fish's contaminant concentration over time is represented by:

$$\frac{dC_F}{dt} = k_1 C_{WD} - k_2 C_D + k_D C_D - k_E C_F - k_G C_F - k_M C_F \qquad [4.1]$$

where:

- k_1 is the rate of water uptake through the gill (L/kg/day);
- k_2 is the rate of elimination via the gills to the water (1/day);
- k_D is the rate of food consumption ((kg food/kg fish/day);
- k_E is the rate of elimination (1/day);
- k_G is the growth rate (/day);
- k_M is the rate of metabolic breakdown of the contaminant, which is set to zero for persistent contaminants (1/day);
- C_{WD} is the biologically available contaminant concentration in the water (µg/L);
- C_F is the contaminant concentration in the fish (µg/kg fish); and
- C_D is the average contaminant concentration in the fish's diet (µg/kg), calculated from a food-fraction-weighted average of the contaminant concentrations in diet organisms.

At steady state this simplifies to:

$$C_F = \frac{(k_1 C_{WD} + k_D C_D)}{(k_2 + k_E + k_G + k_M)} \qquad [4.2]$$

or:

$$C_F = BCF \times C_{WD} + BMF \times C_D \qquad [4.3]$$

where BCF and BMF are the bioconcentration factor [$k_1/(k_2+k_E+k_M+k_G)$] and biomagnification factor [$k_D/(k_2+k_E+k_M+k_G)$], respectively. Each of the rate parameters in Equations 4.1 and 4.2 are derived from empirical equations which hold for many different species, and are related only to a few simple inputs: the mass of the fish, its growth rate and diet preferences, water temperature, and the K_{OW} (octanol-water partition coefficient) of the contaminant (Gobas in press). This makes these relationships generally applicable.

The subgroup endorsed this approach, since it is simple and appears to work reasonably well for persistent compounds. To apply it to the problem of pulp mill effluents in the Fraser River, participants felt three improvements were necessary:

- estimating k_M (rates of chemical metabolism) for less persistent substances, using values from the literature, laboratory experiments and field validation;
- using a simple dynamic form of the model to account for seasonal changes in fish distribution and diet; and
- accounting for the transfer of persistent compounds from female spawners to eggs.

Fish distribution, both among and within spatial units, and across seasons, is a major knowledge gap. Perhaps the most important issue is whether fish are randomly or preferentially distributed with respect to the near-field and far-field zones downstream of effluent sources. A synthesis of existing literature, followed by field tagging studies to fill important gaps, are required to better understand this problem.

The last improvement is particularly important for tracking persistent compounds which are likely to be gradually decreasing over the next few years (e.g. dioxins and furans). Modelling (or monitoring) the changes in these contaminants over time involves a consideration of the change in concentration that occurs from adult to egg (e.g. a 2/3 reduction has been observed for some species). Fish contaminant concentrations of chlorinated phenols and guaiacols are likely to reach equilibrium relatively quickly, and could be modelled by running the steady state version of the model every four months. By contrast, concentrations of more persistent compounds need to be carried forward from the previous modelling time step. This discussion highlighted the need for deciding on a standardized age or length for monitoring each species' contaminant concentrations, so that trends over time can be properly evaluated.

It was agreed that the model should be calibrated and validated with resident species (e.g. rocky mountain whitefish). This will require pre-specifying the dietary proportions of the modelled benthic organisms for each season. A first guess was that the diet of rocky mountain whitefish would be made up roughly 50:50 of filter feeding organisms (represented in the model by caddis flies) and infauna/detritivores (represented by oligochaetes and chironomids). A proper synthesis of the existing literature, stomach analyses of preserved fish, and perhaps stable isotope analyses were the recommended sequence of activities to fill these knowledge gaps. In terms of modelling food uptake, it may be worth considering modelling approaches to represent the combined effects of spatial/temporal variations in the abundance of prey and predator preferences. This could be important where the prey items differ significantly in their concentration of contaminants.

4.4.3 Mammals and Birds

These groups were not considered in as much detail as fish. Table 4.3 presents the classes of piscivorous mammals and birds considered for inclusion in a contaminant modelling and monitoring program. Each of these groups are discussed separately.

- *Sea lions and seals* were considered inappropriate as representative mammals. They have a short residence time in the Fraser River (overlapping the spring eulachon migration), they are subject to the influences of pulp mills in the Strait of Georgia, and their contaminant concentrations are unknown.

Table 4.3: Mammals and birds considered for monitoring and modelling of contaminant bioaccumulation. Y=yes; N=no; "res." = residence time.

Species	Model/Monitor	Rationale
Sea Lions/Seals	N	[x]?, low res., marine influence
Mink/Otter	Y?	probably sensitive, getting data now from trappers, home range unknown
Heron (estuary)	Y	good data [TCDD] decreasing, but very wide diet
Grebes	Y?	less data available, more useful for interior
Osprey (upstream)	Y	[2,3,7,8 TCDD] increasing below mills, other TCDD's high *everywhere* (C. & S. America?)
Cormorant	N	piscivorous but diet unknown; hard to sample
Bald Eagles	?	

- *Mink and otter* are potentially useful biomonitors and modelling endpoints. Mink have been shown to be very sensitive to PCB's, and are suspected of being sensitive to dioxins as well. Some data are available for the U.S. part of the Columbia River system (relatively high contaminant concentrations), the Kootenay region (low concentrations), but there are so far no data for the Fraser. CWS has set up a program to obtain tissues for analysis from trappers. Two potential difficulties with this type of program were discussed: 1) the home range of collected animals is unknown; and 2) if mink are very sensitive to toxics, it is possible that the most contaminated animals have already died.

- *Great blue herons* are considered to be a good contaminant biomonitoring organism in the Fraser estuary. Elevated concentrations of dioxins and furans have been found in eggs collected from colonies the estuary, and are implicated in poor hatching success and juvenile survival (Whitehead 1988). Recent data show a decline in 2,3,7,8 TCDD dioxin, consistent with the programs of ClO_2 substitution in pulp mills. One potential drawback of these birds is that they have a very wide diet which includes both aquatic and terrestrial organisms (sculpin, juvenile salmon, stickleback; voles, amphibians). This may result in confounding influences from urban area pollutant sources (e.g. municipal incinerators, open garbage burning, industrial boilers).

- *Grebes* are less well studied than herons for contaminant levels. They have the advantage of overwintering in the upstream areas of the Fraser River (provided there is not too much ice on the river). They could be a useful biomonitor for the interior region, though their exact home range (i.e. contaminant sampling region) is not well understood.

- *Osprey* are another possible contaminant monitoring/modelling organism for the upstream interior regions. Elevated concentrations of 2,3,7,8 TCDD dioxin have been found downstream of pulp mills (P. Whitehead, pers. comm.), though other TCDDs are elevated both upstream **and** downstream of pulp mills. This is suspected of being due to exposures in their overwintering range in Central and South America.

- *Cormorants* are primarily piscivorous but their exact diet is unknown and they are hard to sample. This led the group to conclude they were a less practical choice for biomonitoring and modelling.

- In the final plenary session, *bald eagles* were also recommended as a potential biomonitor. There was insufficient time at the workshop to fully discuss the merits of this proposal.

Modelling Strategy

As mentioned in Section 4.1 (Conceptual Model), models of contaminant uptake are not so well developed for birds and mammals as they are for fish. However, the problem is somewhat simpler in that only biomagnification, and not bioconcentration, needs to be considered. The bioenergetics/fugacity modelling approach of Norstrom et al. (1986) and Clark et al. (1987) was recommended as a possible route to follow. This would require adapting a model originally developed for herring gulls in Lake Ontario to the birds and food chains of the Fraser River. The model estimates seasonal changes in contaminant concentrations within blood plasma, lipids and eggs. Rates of contaminant movement between blood plasma and lipids are determined by temperature and chemical properties (e.g. log K_{OW}).

4.5 Summary of Research Needs

This summary of the biotic fate subgroup discussions has identified a number of research and monitoring activities. These activities are summarized in Table 4.4, for each of the organismal groups (benthos, fish, birds and mammals). It was agreed that the activities should proceed concurrently, beginning with literature syntheses, and moving through a series of modelling/monitoring/calibration/validation activities. The sequence within each category in Table 4.4 reflects a logical order to pursue the identified activities. The principal to be followed is to use existing models to refine the experimental design of field monitoring activities, and to move from simple to more complex models only as required by the evidence from field studies.

Table 4.4: Summary of research/monitoring needs identified by the contaminant fate subgroup for benthos, fish, birds and mammals. Lit = literature review or synthesis of existing data, Lab = laboratory experiments/analyses, Fld = field sampling and monitoring.

Knowledge Gap/Activities	**Data/Conceptual Gap**	**How to Fill?**
Benthos:		
! determine general composition of benthos by spatial unit and by near field / far field zones within each spatial unit	data	lit., field
! modelling to refine experimental design of monitoring program	conceptual	lit. estimates of spatial/temporal F^2
! collect data on BAFs and BCFs for various benthic organisms, and $[X]_{water, sediment, susp. part.}$	data	lit, field (organisms, leeches, lipid bags), lab
! calibrate existing theoretical models for inbenthos	data	modelling
! develop empirical models for BAF, BCF prediction	data	data analysis, lab
! develop pharmacokinetic approach for filter-feeders	conceptual/data	literature, lab, field
! validate, revise above models	conceptual/data	field
Fish:	conceptual/data	
! determine general diet for key species by spatial unit, near field / far field, and season	data	lit., analyze stomachs of preserved fish, stable isotope analysis
! estimate general distribution of key species by spatial unit, near field/far field zones, and season	conceptual	lit.?, field tagging
! validate existing model for persistent substances	data	field
! determine parameters for low K_{OW} substances, other representative contaminants	conceptual/data	literature, lab, field validation
! validate fish model for non-persistent substances	data	field
! determine standardized length and age for different species and contaminants	data	field, data analysis
Birds and Mammals:		
! Assess feasibility of monitoring candidate birds	logistics/data	field
! Adapt herring gull bioenergetics model to selected bird species	conceptual/data	lit., lab, field, modelling
! Calibrate bird model to historical data, use to evaluate monitoring design, and validate with current monitoring data	data	lit., field

! Review mammal data and assess feasibility of building mammal model	conceptual/data	field
Overall:		
! link models to other submodels to assess ecological implications of changes in loadings	conceptual	modelling
! assess uncertainty, error propagation in linked models	conceptual	modelling

5.0 Physical/Chemical Subgroup

The physical/chemical subgroup developed a conceptual model which considers the processes influencing the dispersion, partitioning and reactivity of persistent chemicals of pulp mill effluent. The activity of building a conceptual model provided a structure in which participants could:

- agree upon which physical/chemical processes must be considered;
- identify existing models which could be applied to modelling the dispersion and chemical fate of pulp mill effluent in the Fraser River;
- identify critical conceptual gaps in process understanding; and
- outline monitoring programmes to provide data both for model parameterization/validation and to better understand the physical fate of persistent chemicals.

Based on the plenary discussions during the first day of the workshop, the charge of the physical/chemical subgroup was to develop a model which would predict the concentration of chemicals in the water column (both dissolved and suspended) and sediment on a seasonal timestep for the reaches defined by the biotic fate subgroup. A schematic diagram of the output requirements, input from other submodels, and actions considered by the physical/chemical submodel is given in Figure 5.1.

The following three classes of organic chemicals were considered:

- Tetrachloro-dibenzo-Furans to provide an example of extremely lipophilic substances;
- Trichloro-guaiacols to provide an example of a pulp mill-specific class of chemicals with lower hydrophobicity then dioxins; and
- organic sulphur compounds to provide an example of a class of chemicals which are unaffected by changes in bleaching techniques.

Although the modelling and field sampling strategies developed during the subgroup discussion were based on these three chemical classes, the methodologies could be applied to any other persistent single chemical or group of chemicals found in pulp mill effluent (e.g. 2,4 DCP (dichlorophenol) and 5,6 DCV (dichlorovanillin)).

The physical/chemical subgroup, in addition to treating organic chemicals, was also charged with predicting the following water quality parameters downstream of pulp mill discharges:

- pH;
- temperature;
- dissolved phosphorous;
- total suspended solids; and
- odour/taste.

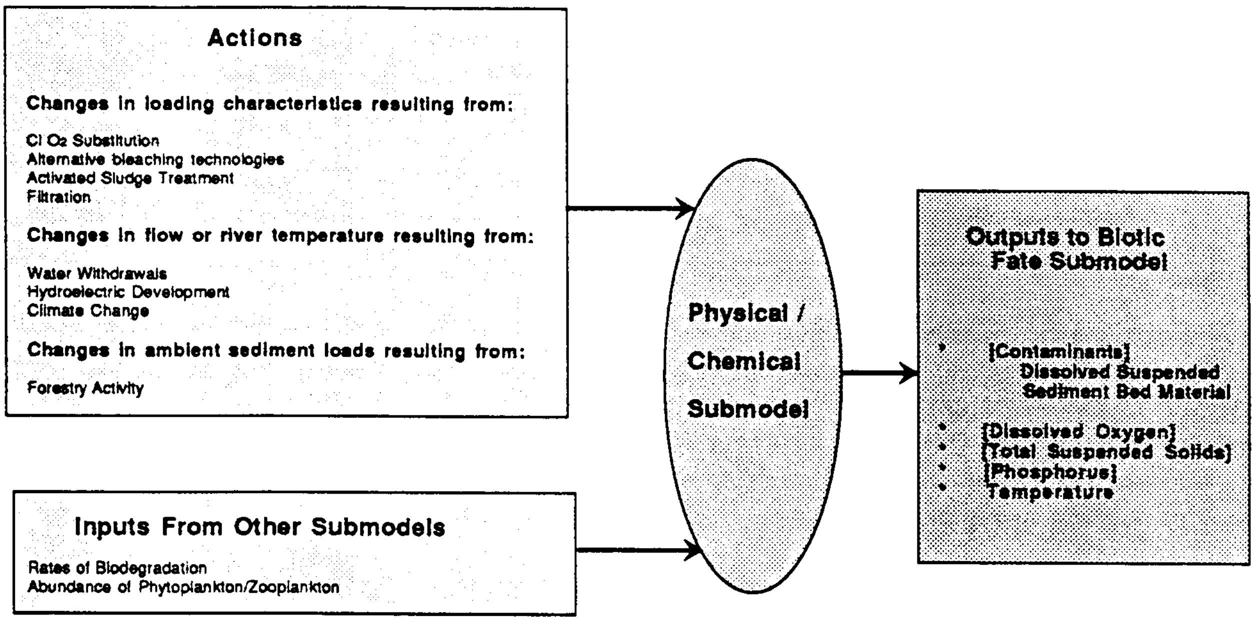


Figure 5.1: Responsibilities of physical/chemical subgroup. Items marked with an "*" were not considered.

These physical parameters were considered for three reasons. First, many of the most obvious and immediate impacts of pulp mill effluent affect temperature, water clarity, odour/taste, and nutrient and oxygen levels. Second, parameters such as pH and temperature can potentially have significant effects on the toxicity, bioavailability, and bioaccumulation of contaminants. Finally temperature, suspended solid concentrations, and pH can influence the dispersion and physical/chemical fate of organochlorines and other potentially toxic chemicals found in effluent of pulp mills.

5.1 Conceptual Structure

The processes considered in the physical/chemical subgroup can logically be divided into hydrodynamic, sediment transport and chemical fate components as depicted in Figure 5.2.

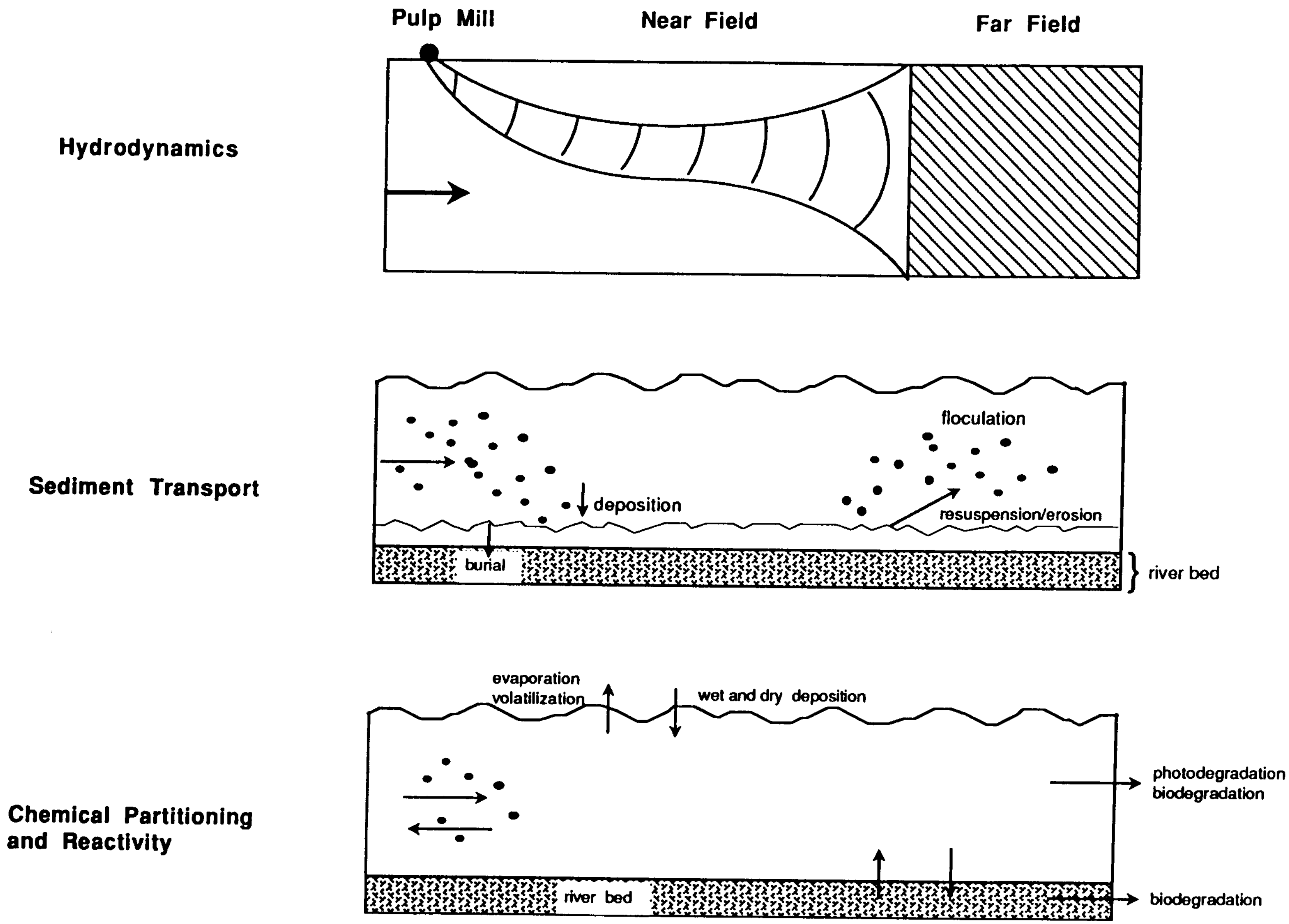


Figure 5.2: Conceptual structure of hydrodynamic sediment transport and chemical components of the Physical/Chemical submodel.

The hydrodynamic submodel would simulate the dispersion and advection of suspended and dissolved chemicals in the water column. An existing hydraulic model could be used to predict flow and velocity. The information can be used in conjunction with effluent loading characteristics (volume discharged and concentration of chemical) to estimate downstream concentrations using existing near and far field dispersion models.

The sediment transport submodel encompasses processes such as suspended sediment deposition, erosion, burial of bed material and flocculation. Sediment loads in the Fraser, as in other rivers, can be divided into wash load and bed material load. Wash load is fine material that is transported entirely in suspension and is generally not found in appreciable quantities on the bed. The coarser bed material load consists of bed sediment that is transported episodically in suspension or along the bottom as bed load. Thus, the suspended load may consist of both wash load and suspended bed material load (Kostaschuk et al. 1989a). The location and timing of deposition/resuspension is dependent on the predicted velocity/flow conditions (provided by the hydrodynamic submodel), the volume and characteristics of the wash load, as well as physical channel characteristics (e.g. particle size distribution of bed load, channel morphology).

Following the workshop, B.G. Krishnappan reviewed existing flow and sediment transport models which could be applied to the Fraser River. The results of his review are presented in Appendix 2.

The chemical submodel considers the fate of dissolved and particulate chemicals in air, water (dissolved and suspended sediment), and bed sediment. The concentration of a given substance in any medium (e.g. dissolved in water) is dependent on the loading, partitioning between media (e.g. water-to-air, suspended sediment-water, and bed load sediment-water), as well as the reactivity of the chemical in that media (e.g. biodegradation, photodegradation, volatilization).

5.2 Spatial Resolution

For the purposes of hydrodynamic and sediment transport modelling, the Fraser and Thompson rivers were subdivided into 8 and 2 zones, respectively (see Figure 2.1). A description of these reaches is given in Table 5.1. The division into reaches or zones is based principally on the location of effluent loadings as well as hydrological characteristics. For example, the upstream boundary of reach 4 in the Fraser River mainstem is defined by the location of two pulp mills at Quesnel while the lower boundary occurs at the confluence with the Thompson River. This spatial stratification is consistent with that developed by the Biotic Fate subgroup (Table 4.1), though the latter is a bit more detailed.

The Thompson River spatial structure was not discussed in the physical subgroup session. Following the same principles applied to the Fraser River, the Thompson would be divided into two reaches. This would include a source zone (reach 5) upstream of the Kamloops pulp mill discharge, and a mixing/dilution zone (reach 6) downstream of the discharge extending to the confluence with the Fraser River. Kamloops Lake located within the mixing and dilution zone would have to be considered separately in the hydrodynamic and sediment transport modelling for reach 6 as its characteristics are quite different from river reaches.

Table 5.1: Description of spatial structure defined by the physical/chemical subgroup.

Reach/Zone #	Reach Type	Description
1	upstream source	Nechako River to confluence with Fraser River
2	upstream source	Fraser River downstream to pulp mills at Prince George
3	mixing/dilution	pulp mills at Prince George to pulp mills at Quesnel
4	mixing/dilution	pulp mills at Quesnel to confluence of Thompson River
5	upstream source	Thompson River downstream to pulp mill at Kamloops
6	mixing/dilution	pulp mill at Kamloops downstream to confluence with Fraser River, including Kamloops Lake
7	dilution	confluence of Fraser and Thompson rivers downstream to Hope
8	dilution	Hope to Mission
9	estuarine	Mission to river mouth
10	intertidal	river mouth to FREMP estuary boundaries

There are five reach types defined in Table 5.1. Upstream source zones (i.e. upstream of effluent sources) need to be characterized to determine the inputs to mixing/dilution zones, which are areas where pulp mill effluent is introduced to the system and mixed with water from upstream source zones. Dilution zones are distinguished from mixing/dilution zones by their lack of effluent inputs. The estuarine zone is subject to tidal influences and salt wedge effects. The intertidal zone was defined by the physical/chemical subgroup but its hydrological/sediment transport characteristics were considered too complex for subgroup discussion.

Once the spatial structure of the Fraser and Thompson rivers were defined, the physical/chemical subgroup discussed what information would be required from upstream source, mixing/dilution, and estuarine zones. Dilution zones were not discussed but presumably the information required to model them would be a subset of the information needed for mixing/dilution zones. The requirements for modelling the intertidal zone were not discussed due to both its complexity and the confounding influences of contaminants introduced from pulp mills in the Strait of Georgia.

The amount of spatial resolution required to model the physical fate of contaminants within a reach is dependent on the zone type and the modelling approach within each zone. Detailed spatial considerations will be discussed within the context of the modelling descriptions for each type of zone.

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5.3 Upstream Source Zone

There is no need to model the hydrodynamics, sediment transport or chemical fate of material in upstream source zones. Information from these zones will be required as input data to model the mixing and dilution of pulp mill effluents in reaches where loading is occurring. Data requirements for all upstream source zones will be identical, though data to be collected will of course vary based on the availability of information. For the purposes of simplifying the discussion, the physical/chemical subgroup only considered the availability of information for the Fraser River mainstem source zone upstream of the pulp mills at Prince George. Table 5.2 summarizes the information requirements and data needs for this upstream zone and provides an example of data requirements for other upstream source zones.

Flow information combined with upstream concentrations of a particular substance (e.g. suspended solids or dissolved [X]) required in the upstream source zones are needed to estimate the load of suspended sediments and persistent chemicals moving into a mixing dilution zone. Because of the high variability in flow within a year, relatively continuous measurements (i.e. daily or weekly) need to be obtained to estimate upstream loadings accurately over the coarse of a year. The existing flow information collected at the Hansard and Shelley stations provide a baseline annual flow regime (or set of annual flow regimes) to drive upstream loading estimates. This flow data are critical to modelling the hydraulic conditions (flow and velocity) within the mixing dilution zone.

Suspended sediment concentrations in upstream source zones are required to estimate background loads within the mixing/dilution zones. The particle size distribution of bed material in upstream source zones need to be determined since some of this material is resuspended and becomes part of the wash load. The organic content of the suspended sediment in upstream source zones affects the sorption of dissolved pulp mill contaminants to upstream sources of suspended sediment.

Upstream concentrations of dissolved contaminants and physical parameters affected by pulp mill effluent are required to define background levels. In terms of organochlorines, there have been miscellaneous data collected for specific chemicals. In many cases concentrations were below the detection limits of the analytical procedure being applied. Thus for initial modelling activities, it may be possible to assume that upstream source concentrations of persistent chemicals found in pulp mill effluents are negligible.

Of all the physical parameters (e.g. D.O., temperature, pH) listed in Table 5.2, only the temperature of upstream source waters needs to be characterized in order to determine the buoyancy of the effluent. If dissolved oxygen, phosphorous, pH, or dissolved organic carbon are to be modelled in the mixing dilution zone, then upstream concentrations need to be determined. Alternatively, these parameters could be measured at various distances downstream of the discharge point. Concentrations of conservative elements such as sodium or chloride from upstream source reaches are useful when calibrating the plume models in mixing/dilution zones.

Table 5.2: Data Requirements for upstream source zones. The "data available" and "data to be collected" columns are based on the availability of information for reach 2 (Fraser River downstream to the pulp mills at Prince George). [ ]: concentration, SS: suspended sediment, D.O.: dissolved oxygen, P: phosphorous, DOC: dissolved organic carbon.

Data Requirements	Data Available	Data to be Collected
continuous flow data (daily or weekly)	Hansard and Shelley hydrological stations	
suspended sediment []	historical data avail. 1970-1986	
particle size distribution of bed material	1989 Water Survey of Canada	representative bed material survey
organic content of suspended sediment	?	quantity of organic matter in suspended sediment
upstream [] of contaminant (SS and dissolved) and conservative elements (Na, Cl)	Hansard-AOX/phenols TCG for specific periods	daily --> weekly monitoring of bed & SS [] to get background levels

upstream D.O., colour, temp., pH, [DOC], [P], odour/taste	short term bi-annual information for some parameters	daily --> weekly measurements to capture variability in background levels

5.4 Mixing/Dilution Zone

Within any of the Fraser or Thompson River mixing/dilution zones, the five following components must be defined or modelled:

1. effluent loading;
2. hydraulic conditions;
3. near field dispersion and far field dilution;
4. near and far field sediment transport; and
5. chemical partitioning and reactivity.

The physical/chemical subgroup agreed that near field modelling in the vicinity of effluent discharges is critical to provide accurate estimates of downstream concentrations of any parameter. The near field area can be defined as the zone downstream of the discharge where the effluent plume is not fully mixed with ambient waters. A near field dispersion model would determine the rate of vertical and horizontal mixing of the effluent plume and establish the distance downstream of the discharge where complete mixing has occurred. It is important to model the concentrations of pollutants in the near field for three reasons (L. Gomm, pers. comm.):

1. The elevated concentrations in the near field may lead to increased reaction kinetics. In many of the reactions, concentration is the driving force. This is of particular importance in higher order chemical reactions. Thus, averaging the concentration or load from a discharge across an entire reach/zone would provide substantially different downstream predicted concentrations in comparison to the downstream fully mixed concentration estimated using near field plume and sediment transport models.

2. Within this mixing zone, aquatic species are directly exposed to higher contaminant levels. This is a concern where there is a tendency of the biota to be attracted to the warmer, nutrient rich plume.

3. Near field dispersion and sediment transport models provide better spatial resolution of contaminant concentrations (sediment and water column) within the immediate area of the discharge. This information is useful for near field monitoring design.

The subgroup agreed that existing hydraulic and near/far field plume and sediment transport models could be applied to the mixing/dilution zones in the Fraser and Thompson rivers (see Appendices 2 and 3). There is a large range in the temporal and spatial resolution of these models and in many cases the same model can used at different levels of resolution. Finer resolution models provide more accurate projections but require considerably more input data and computational power. The biotic submodel requires projections at a very coarse spatial scale (11 reaches for the entire Fraser and Thompson rivers) on a seasonal basis. The physical subgroup emphasized that to provide reasonable projections at this coarse resolution, it would be necessary to use finer spatial and temporal timesteps in the physical modelling, and then average the results to generate projections at the scale required by the biotic fate model.

5.4.1 Effluent Loading

Both the volume and composition of pulp mill effluent must be known to model the dispersion and dilution of a substance. Effluent volumes are currently reported and are available at an adequate temporal level of resolution. In terms of effluent composition, concentrations of some organochlorines are monitored, but the relative proportion in suspended sediment and solution is not measured. This information will be critical to model the physical fate of a contaminant once introduced to the mixing/dilution zone and must be monitored.

The temperature of effluent is monitored and is needed to establish the buoyancy of the effluent in river water. pH is also routinely measured and will be needed by the chemical submodel to determine the fraction of any ionic chemical which is in a disassociated form. If the effects of carbon input on benthic/detrital-based ecosystems are to be considered, then dissolved organic carbon concentrations in the effluent need to be monitored. Finally, the size distribution of suspended sediments in the effluent is not routinely monitored but will be required as input for the sediment transport submodel. Subgroup participants indicated that rare measurements have been recorded for some pulp mills on the Fraser River but more detailed monitoring will be required.

If the model is to be used to predict future conditions, then all of the above will need to be specified for any future loading scenario. Subgroup participants did not have sufficient understanding of the most probable loading scenarios.

5.4.2 Hydraulic Modelling

An existing hydraulic model (e.g. MOBED; see Appendix 2) could be used to estimate flow and water velocity within the mixing/dilution zones. Knowing the flow in upstream source zones and the cross sectional areas, gradients and alluvial bed roughness in the mixing/dilution reach, velocity, flow, and stage height can be estimated. For a first cut at a coarse spatial resolution, the subgroup felt that much of the required information for hydraulic modelling in the Prince George and Quesnel mixing/dilution zones already exists with the exception of alluvial bed roughness. This parameter will have to be measured by collecting echosounding information and bed material samples. Cross sectional velocity measurements are required to calibrate the model.

5.4.3 Dispersion/Dilution Modelling

Once the hydraulic conditions throughout the mixing zone have been established and the effluent discharge characterized, the dispersion of the effluent can be modelled using an existing near field plume model (e.g. RIVMIX; see Appendix 2). The two most obvious features of pulp mill effluent plumes are their buoyancy and their rate of transverse spreading. The mixing zone may extend for many kilometres downstream of the discharge. Buoyancy inhibits the vertical mixing of the plume but may enhance lateral mixing. The model coefficients used to determine lateral spreading and vertical mixing could be initially defined based on existing values from the literature for buoyant fluids. Effluent temperature will affect the plume's buoyancy and can be incorporated in the plume model. More details on the primary physical process influencing mixing are given in Appendix 3.

To calibrate the near field models, conservative element tracers can be measured at a variety of locations downstream of the discharge. If one knows the concentration of the element in the ambient water (based on upstream source zone monitoring), the effluent and at various stations downstream of the discharge, it is possible to refine the dispersion coefficients used in the near field model.

A far field dispersion model (e.g. FETRA; see Appendix 2) could be used to predict the concentration of introduced chemicals in the fully mixed zone downstream of the discharge. Although not discussed in detail by the subgroup, the far field dispersion model would dilute the fully mixed concentration downstream of the near field zone based on flow inputs from other tributaries. For example, a tributary input within a far field zone would result in two predicted concentrations in the far field, a higher value upstream of the tributary input, and a diluted concentration downstream of the input. In the case where the inflowing tributary contained appreciable levels of the same contaminant being modelled, it would be necessary to use a near field dispersion model to simulate the mixing of inflow water within the mixing/dilution zone in the reach being processed.

5.4.4 Sediment Transport Modelling

Existing near and far field sediment transport models could be used to simulate the deposition of suspended material from the water column and the resuspension/erosion and burial of bed material. Like the dispersion model, a near field, more detailed model is required to simulate deposition/resuspension at a finer spatial scale immediately downstream of the discharge where sediment contaminant concentrations are highest (e.g. MOBED; see Appendix 2).

Three components to the sediment transport model dominate the predictions of the rates and locations of deposition and resuspension:

1. the bed material characteristics;

2. the incoming wash load characteristics (volume of suspended sediments and size distribution of particles); and

3. the bed shear stress coefficients, influencing erosion/deposition rates.

The transport of water and sediment in river channels is intimately linked to channel morphology and both the flow and sediment transport modelling and field sampling programs will require a comprehensive description of variations in channel morphology. Morphologic requirements of the flow and sediment transport models include cross-sectional profiles of channels, bed slope, boundary roughness and sediment grain size. Of particular importance to contaminant transport are depositional zones where sediment and toxins can be temporarily stored and resuspended. Depositional zones may consist of point bars on the inside of bends, flood channels, surfaces of braid bars, floodplains and distributary channels on the delta. Much of the necessary data on channel morphology could be obtained from published and unpublished reports, maps and air photos. Extensive morphologic data are available in the lower Main Arm of the estuary (e.g. Kostaschuk and Atwood 1990; Kostaschuk et al. 1989a), but additional field surveys would be needed for other distributary channels (R. Kostaschuk, pers. comm.).

There is a considerable amount of overlap in the data requirements of the sediment transport and hydrodynamic models. Flow and velocity influence deposition and resuspension rates. The alluvial bed roughness observations needed in the hydrodynamic model are also required to characterize the bed load for the sediment transport model.

To calculate the bed shear stress coefficients, bed material samples have to be collected at various locations downstream of the discharge. In the laboratory, stress coefficients can be measured using these samples under a range of flow conditions. Areas of high deposition and erosion are the most critical.

Of particular importance to contaminant transport in the Fraser is the movement of the fine-grained wash load in the spring (George Derksen, pers. comm.). This material passes though the river system as a "pulse", produced by a declining supply of fines over the freshet season (e.g. Kostaschuk et al. 1989b). The magnitude of the wash load peaks is influenced by both flow and the wash load supply, the latter factor being controlled by bank erosion, mass wasting events, and other discontinuous (and unpredictable) physical processes. Samples of water and suspended sediment would be needed from all reaches of the river, especially during the early freshet, to establish contaminant levels in the wash load.

A detailed experimental study of the behaviour of the wash load and associated contaminants is possible using B.G. Krishnappan's "rotating flume" (Krishnappan and Ongley 1988). This requires analysis of *in situ* particle sizes of suspended sediment in the river using Krishnappan's laser diffraction instrument and the transport of 1000 l of Fraser water and sediment mixture to the laboratory. Various field characteristics, such as salinity and shear stress, could be replicated in the flume, thus reducing field sampling requirements.

As discussed in Section 5.3, the fraction of organic carbon in the bed sediment and suspended sediment must be known to determine the rate at which dissolved substances sorb to particulate matter. The organic carbon content of sediments in the Fraser River is largely unknown and needs to be measured in the suspended and bed material as part of the sediment sampling program outlined here.

Flocculation can affect the physical fate of contaminants. There has been little work to date on the mechanism and importance of this process in the Fraser River basin and the subgroup highlighted the need for research in this area.

Contaminants moving with sediment can be deposited and resuspended with particles. Samples of sediment are therefore required from the active bed and depositional zones in all reaches of the river. Particular attention should be paid to sites of fine sediment deposition. Some data on contaminant concentration in bed sediments are available (e.g. Swain and Walton 1988) but these are limited spatially to the Main and North Arms. Additional samples would be needed from other channels in the estuary, especially where fines are deposited (R. Kostaschuk, pers. comm.).

5.4.5 Chemical Modelling

The chemical submodel considers the partitioning of substances between physical compartments (air, water, sediment) and their reactivity within the sediment and water. The temporal and spatial resolution of the chemical model will be driven by the scales required by the dispersion and sediment transport models.

The structure of the model is described in detail by Mackay et al. (1992) where it was used to model the concentration of PCB's in Lake Ontario. This model has been adapted by Dr. Frank Gobas and applied to the Fraser River. Prior to the elaboration of the physical modelling approach described here, there was considerable discomfort from most participants with regards to the way physical processes (flow and sediment transport) were represented by Dr. Gobas' model. The structure of the chemical component of Dr. Gobas' model was regarded as adequate, however, and forms the conceptual structure for the model described here.

The movement of a substance from one compartment to another (e.g. water to air) is controlled by a mass transfer coefficient. The rate of chemical partitioning is calculated as the product of the amount present in the water or the sediment and a rate constant (with units of time). Mass transfer coefficients are used to determine the exchange between:

- air and water (dissolved);
- water (dissolved) and bed sediment; and
- water (dissolved) and suspended sediment.

The chemical submodel would be applied in every river reach except for the upstream source zones.

To estimate the rate of exchange between air and water for each substance, Henry's constant (H) must be estimated to calculate the volatilization rate constant. The volatilization constant varies as a function of depth, pressure, and temperature. To determine the proportion of a substance which is truly dissolved the octanol-water partition coefficient (K_{ow}) must be known. For ionic substances, the dissociation constant (pK_a) is required to determine the fraction in the ionized form. The reactivity of ionic substances is greatly influenced by the extent of dissociation. To estimate the sorption of a dissolved substance to suspended and bed sediment, the organic carbon-water partition coefficient (K_{oc}) and the fraction of organic carbon in the sediment must be determined. For the majority of chemicals found in pulp mill effluent, these chemical characteristics (H, K_{ow}, pK_a, K_{oc}) have not been measured, and thus their chemical fate cannot be modelled. The subgroup highlighted the need for laboratory analyses to measure these critical chemical behaviour characteristics of pulp mill contaminants.

Laboratory estimates of the physical behaviour of chemicals found in pulp mill effluent can be used to estimate the mass transfer coefficients to refine the partitioning projections. Although mass transfer estimates can be made using laboratory experiments, these projections should be confirmed with field studies which actually measure these values under a variety of ambient conditions.

Chemical transformation rates are used to simulate photodegradation and biodegradation process in the water and sediment. These transformation rates are generally low for organochlorines but the actual rate is specific to the physical/chemical properties of each substance. If biodegradation rates are to be explicitly modelled based on the abundance and metabolic transformation rates of organisms which degrade a particular contaminant, the chemical submodel will require biodegradation projections generated by the biotic fate submodel. Alternatively, annual or seasonal biodegradation rates could be manually set for each reach. The former approach is preferred, since biodegradation rates are required to estimate time concentrations of less persistent substances.

There are very few laboratory studies which have estimated the half lives (a measure of reactivity) of chemicals found in pulp mill effluents. The subgroup identified the need for laboratory determination of the reactivity of these chemicals. *In situ* bottle experiments could be used to confirm degradation rates in the field for those chemicals with high reactivity rates. Given the current lack of information on reactivity of pulp mill effluent contaminants, the subgroup agreed that for preliminary models it is necessary to assume negligible reactivity rates. This provides worst-case estimates of the persistence of these substances.

5.5 Estuarine Zone

Though the principal physical processes in the Fraser River estuary (Mission-river mouth) are well understood qualitatively, modelling these processes and capturing their spatial variability would require considerable effort. The estuary provides critical habitat for birds, fish and aquatic mammals. In addition, it is believed that a large proportion of persistent contaminants bound to suspended sediment ultimately get deposited in the estuarine zone. The ecological importance of the estuary and the probable high loadings of contaminants it receives reinforces the need for pursuing modelling and field work activities in this zone; not withstanding the complexities.

To model the deposition of sediments in the estuarine zone, the sediment transport model used in the mixing/dilution zones could be modified to account for salt wedge effects and tidal interactions. Another alternative is to adapt the LAEM model described in Appendix 2. Modelling estuarine processes to predict the fate of chemicals in this portion of the river will require considerably more effort than for the mixing/dilution zones. To capture the spatial variability in deposition throughout the estuary it will be necessary to characterize the flow splits as water moves towards the river mouth to determine the fate of the wash load.

In the lower Main Arm of the estuary, considerable data are available on flow and suspended sediment transport (e.g. Stephan 1990; Ilersich 1992; Kostaschuk et al. 1989b). Some data are available on contaminants in water in the Main and North Arms (e.g. Carey and Hart 1988), but little is known on contaminant levels in suspended sediment. A sampling program is required to establish relations between contaminant concentrations and water and sediment movement in the estuary, emphasizing the wash load pulse during different tidal conditions. The "turbidity maximum" in the estuary (Kostaschuk et al. 1992) is an important sampling locale, because this may represent a zone where suspended sediment and toxins are concentrated (R. Kostaschuk, pers. comm). Since sediment contaminant concentrations in the lower estuary are influenced by other industries, characterization of the effect of pulp mill effluent on sediment concentrations in the estuary requires monitoring/modelling pulp mill specific compounds.

5.6 Empirical Analyses

A series of empirical analyses of existing flow and sediment data were discussed by the physical/chemical subgroup. The following tasks were suggested:

1. gather information on mean daily discharge, elevation, cross-sectional area, average velocity, and cross-sectional velocities collected at Hansard, Shelley, Texas Creek, Lytton, Hope, Mission, Agassiz, and Marguerite;

2. synthesize this data to provide seasonal estimates of flow at all these stations;

3. develop rating curves from this data to estimate flow from area and velocity measurements in other parts of the river;

4. gather information on daily and annual sediment loads for Hansard, Marguerite, Mission, and Agassiz;

5. categorize these loads by broad size fraction categories (e.g. silt/clay, sands/gravels);

6. gather available information of organochlorine concentrations in water and sediment.

From the data listed above it would be possible to estimate preliminary loadings along the river for particular contaminants. The loadings would provide a rough indication of the variability in loadings of a substance across seasons, as well as the expected proportion of the chemical in different size classes of the sediment.

5.7 Research/Monitoring Priorities

Throughout this summary of the physical/chemical subgroup discussions, a number of research and monitoring activities have been identified. These activities have been summarized in Table 5.3 and are split into effluent loading, hydrodynamic, dispersion/dilution, sediment transport and chemical fate categories. The subgroup agreed that the activities defined for each of these categories should proceed concurrently. The order within each category in Table 5.3 reflects a logical order to pursue the identified actions.

The research/monitoring activities defined by the physical/chemical subgroup are unique from those of the ecological and biotic fate subgroups in that many of the items identified will provide data/coefficients to be used by existing models. As seen in Table 5.3, there are fewer conceptual gaps in our understanding of the key physical and chemical processes governing the fate of persistent chemicals compared to the those identified in the ecological response and biotic fate subgroup discussions. There is, however, a great need to measure certain aspects of the physical conditions within the Fraser River to provide reasonable inputs for existing physical models. In addition, the chemical characteristics of persistent substances of concern must be quantified if their chemical fate is to be understood.

The physical/chemical subgroup considered the feasibility of developing a physical/chemical model for the Fraser and Thompson rivers to be quite high. The details of the modelling activity and the supporting data and monitoring needs will need to be worked out by the appropriate individuals within the subgroup. To provide a useable management tool, these activities will have to be coordinated and synthesized into a single computer program which can be linked to the biotic fate and ecological response submodels.

The research and monitoring needs identified by the physical/chemical subgroup are extensive and lead one to pose the following two questions:

1. How long will the physical/chemical tasks take to complete?

2. What fraction of available FRAP resources will be required to complete these tasks?

Table 5.3: Summary of research/monitoring needs identified by the physical/chemical subgroup. Lit = literature review or synthesis of existing data, Lab = laboratory experiments/analyses, Fld = field sampling and monitoring.

Action	Data/Conceptual Gap	Research/ Monitoring
Effluent Loading		
• synthesize total loading information and available data on size fractions of suspended sediments in effluent	data	Lit
• monitor [] in dissolved and suspended sediment and size fractions of suspended sediment	data	Fld
Hydrodynamic		
• assemble existing info. for hydraulic modelling (flow, width, depth,..)	data	Lit
• collect additional data for calibration	data	Fld
Dispersion/Dilution		
• estimate dispersion coefficients	data	Lit
• calibrate plume model using conservative element concentrations	data	Fld
• improve dispersion coefficient estimates	data	Lab/Fld
Sediment Transport		
• synthesize wash load and bed material information	data	Lit
• locate major deposition/erosion sites	data	Fld
• characterize suspended sediment	data	Fld
• measure shear stress coefficients	data	Fld/Lab
• study flocculation	conceptual	Fld/Lab
Chemistry		
• gather info. on phys/chem properties	data	Lit
• measure physical characteristics	data	Lab/Fld
• measure reactivity	data	Lab/Fld

There could be a wide range in the costs and time required to implement the research and monitoring program summarized in this section. It depends on the required spatial and temporal resolution. It is important, therefore, to examine the range of possible physical/chemical models and their data requirements in light of the uncertainties identified by the biotic and ecological effects subgroups. A high resolution or "Cadillac" model will provide the most accurate projections but will require considerable resources in terms of calibration and data input. By contrast, a simpler or "bicycle" model will deliver less accurate projections but will also have less intensive data requirements. There is little point in building a "Cadillac" physical/chemical submodel to tow "bicycle" biological fate or "tricycle" ecological response submodels!! The next task in the research priorization process is to select the appropriate level of effort required for physical/chemical modelling, research and monitoring.

6.0 Synthesis of Research and Monitoring Needs

Each of the previous three sections concluded with quite specific but nevertheless extensive lists of research, monitoring and modelling activities (Tables 3.2, 4.4 and 5.3). There is a need to now step back from the individual submodels, and attempt to formulate a well-integrated broad strategy. Once such a strategy is established, we can begin the process of narrowing down its focus to what is achievable within available resources and best meets FRAP's objectives. Examining the lists of research needs raises several questions:

- how well do these activities link together?
- what is the interaction between modelling, monitoring and research?
- how can the best suite of biomonitoring indicators be selected?
- what is the logical sequencing and interweaving of activities?
- how should activities be priorized?

Each of these questions is discussed below.

6.1 Congruence in Research Plans Among Submodels

Congruence is a state of agreement or consistency; in geometry it is the exact coincidence of superimposed figures. There are at least four different forms of congruence which must be explicitly established if the interdisciplinary research strategy proposed herein is to be successful:

- *spatial congruency:* Will data that needs to be integrated together be collected at the same field sites?
- *sampling frequency congruency:* Will data that needs to be integrated together be collected during the same time periods (i.e. seasons, years)?
- *organismal group congruency:* Will different classes of indicators (e.g. bioaccumulation, physiological responses) be collected for the same species or functional groups?
- *submodel linkages:* Will the information expected by subgroup A from subgroup B actually be collected by subgroup B (and vice versa)? How will the submodels be integrated?

There appears to be a good consensus on the broad spatial stratification of research and monitoring studies. Figure 6.1 shows a consistent set of study sites for all of the research proposed by the three subgroups. There are altogether eleven zones: three upstream control sites, three near field impact sites, three mixing/dilution zones, and two far field bioaccumulation sites.

The logical approach would be for all three groups to agree on one near field and one far field zone for pilot studies. Within each zone, however, finer scale spatial resolution still need to be resolved. For example, will resuspension and deposition zones form another stratum of stratification within each zone?

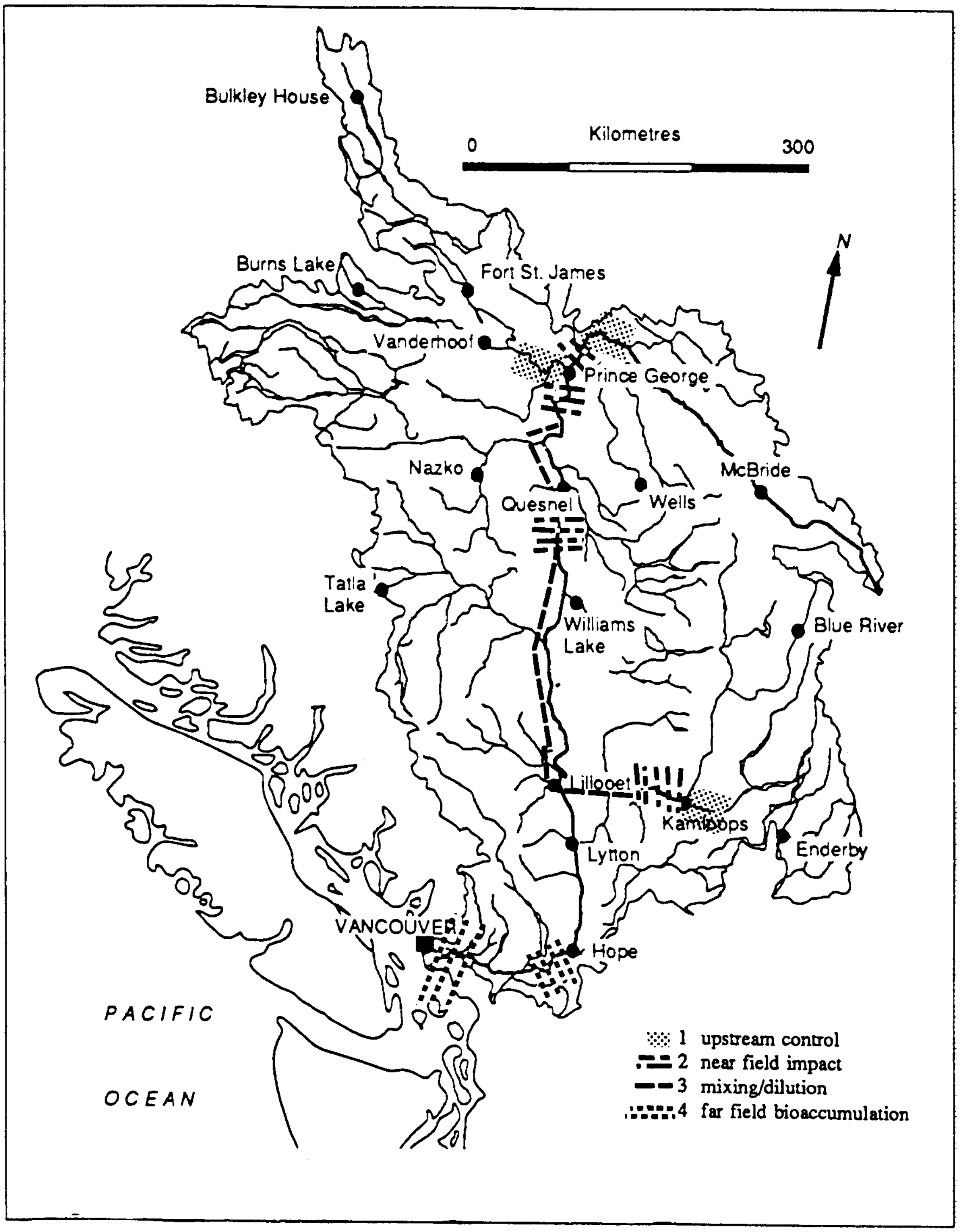

Figure 6.1: Key research and monitoring locations. (Adapted from: Dorcey 1991)

There is to date much less coherence on sampling frequency. While there certainly does not need to be a uniform sampling period within each year for all indicators, this is essential for some variables. For example, the calculation of bioaccumulation factors requires that contaminant concentrations in water, sediments and suspended particles are measured during the same season as tissue concentrations in biota. For long term monitoring, trend detection, and correlation analyses, it is important that the same sampling pattern be applied to related variables (e.g. all sampled in odd years). A frequently updated data base of the spatial and temporal resolution of all monitoring variables can save much pain later.

The biotic fate and ecological response group should maximize the overlap and classification consistency in the organismal groups studied. This will permit a far greater range of empirical and modelling analyses of the collected data. A list of evaluation criteria for choosing biomonitoring organisms needs to be developed to shorten the long list of potential animals in Table 3.4.

The submodel linkages are still quite loose at this point. The Looking Outward matrix (Table 2.1) needs to be iteratively revised, and adhered to, as the conceptual models and research/monitoring plans of different groups evolve. Unless this is done, there is a tendency to mistakenly assume that the other group is collecting or will collect the data you need, when in fact this is not the case. Integrated mock analyses (trial assessments before the data are actually collected) are very useful for detecting potential problems.

On the technical side, there is the question of how to integrate quantitative models developed at different spatial and temporal scales. Figure 6.2 presents a preliminary attempt to conceptualize an integrated regional model of the Fraser system. The suite of physical and chemical models would be driven by a data base of alternative future scenarios which represent a range of different technologies and regulations, resulting in a particular magnitude and quality of effluent loadings. The physical and chemical modules would calculate the required variables (which might include such constituents as nutrients or dissolved oxygen, as well as chlorinated organics) for both the near field and far field zones. These physical/chemical modules would be linked to both a biotic fate model and a set of ecological "dose-response" modules. Depending on the significance of the feedbacks from these latter two models, they could operate on the same spatial and temporal resolution of the physical/chemical modules, or on a much coarser resolution with a looser coupling. Iterative evaluation of changes in contaminant bioaccumulation and ecological responses could be performed to assess the effects of different scenarios.

Such an integrated model could also be used to simulate the kinds of data that would be collected by different types of monitoring program designs. This analysis would need to incorporate the uncertainty in collected data due to measurement error, natural variability within the spatial sampling unit and temporal sampling window, and natural year-to-year variation.

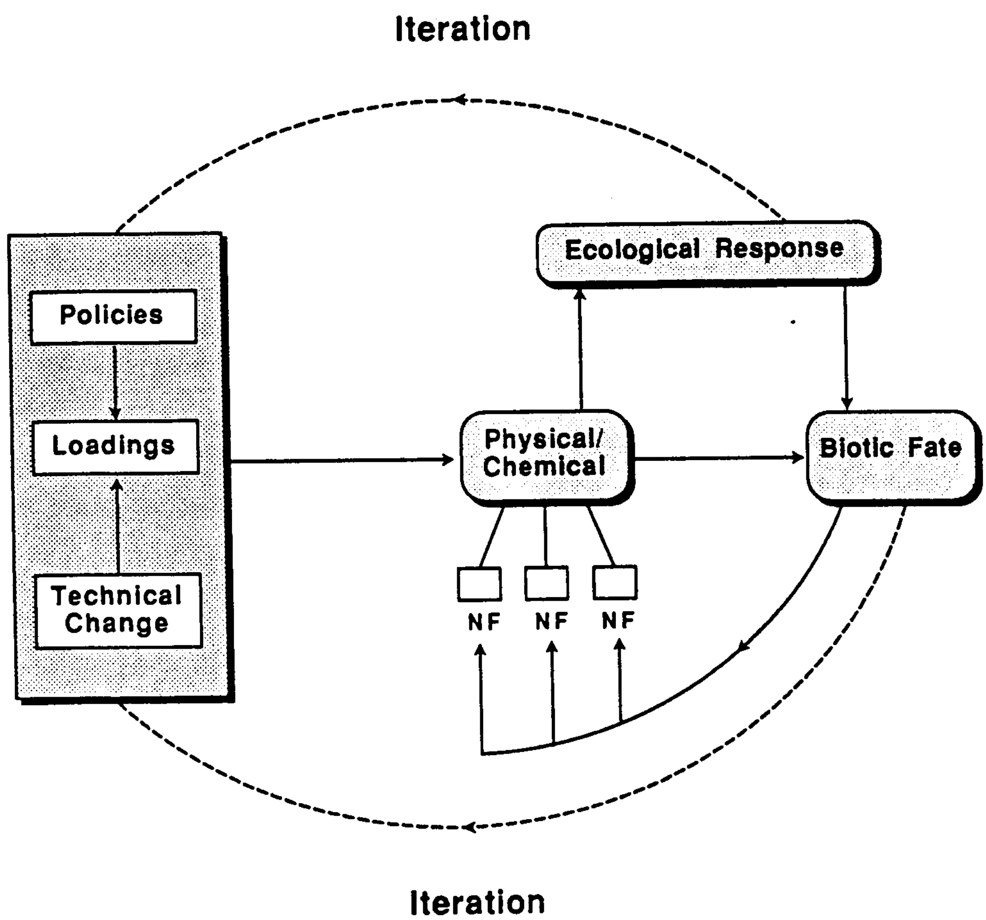

Figure 6.2: Modelling strategy.

6.2 Linkage of Modelling, Monitoring and Research

A number of research programs have discovered that the greatest advances in understanding are made through an iterative sequence of modelling and field studies. This is simply an application of the scientific method, where the model represents an integrated hypothesis that is tested and refined. The simplest quantitative modelling approaches (our best guesses) can first to be used to refine monitoring plans (e.g. avoiding taking water samples of contaminants that will be undetectable). The results of this initial monitoring serves to test and refine the simple models into tools that are probably more complicated, but work better. Upstream-downstream ecological response studies and dose-response experiments can redirect the focus of modelling towards particular contaminants. Conversely, models can be used to explore management experiments (e.g. cooling the Prince George effluent during winter to avoid attracting fish), which can be tested in subsequent field seasons.

6.3 Selection of Monitoring Indicators

A key monitoring decision is the selection of indicators. One should approach this task with the understanding that not all indicators serve the same functions, and that there are many different possible evaluation criteria (Knapp et al. 1991). Harwell et al. (n.d.) distinguish between *early warning indicators* and *reliable indicators*:

> An early warning indicator responds rapidly to a stress...[is] exposed to the stress early in its introduction into the ecosystem,... and responds rapidly once exposed. The early warning indicator is a red flag hoisted to signal the need for closer examination of a potential problem. Consequently, the discrimination of the indicator can be rather low, that is, it need not provide all the information needed to evaluate effects on the ecological endpoints of concern, and tight, causal relationships between the stress and the triggering of the early warning indicator are not required. Hence, this functions as a screening tool, where false positives are acceptable at a relatively high rate (i.e. having the flag go up even though further evaluation demonstrates no ecological effects of concern). Conversely, early warning indicators need to minimize false negatives; thus, they need to avoid missing a warning for a problem which is real.

By contrast, Harwell et al. (1991) define a *reliable indicator* as one:

> ... with high fidelity in characterizing an adverse effect on an ecological endpoint of concern... is focused on *actual* ecological effects rather than on *potential* ecological effects. Thus the key issue is not the rapidity of response, but the reliability for characterizing changes in ecological endpoints. This type of indicator does require strong evidence of causal relationships with the stress, and the response should be relevant to the state of the ecosystem... A criterion for this category of indicators is to minimize false positives, since incorrectly predicting unacceptable adverse impacts could lead to uneconomical over-regulation.

To move from the general research strategy to a concrete implementation plan, there are a host of design and statistical issues to be addressed:

- development of an experimental design with sufficient power to detect effects of changes in loadings;
- assessing the tradeoffs between ecological relevance and statistical power for different indicators;
- development of multiple controls for different stressors;

It should be recognized from the outset that for many indicators we may be unable to do comparisons before and after chlorine substitution due to the fact that we have little data from the "before" period. We can, however, still assess trends; the power of different indicators and experimental designs to detect trends is a key issue. Determining the power to detect trends in particular indicators requires a knowledge of the level of natural temporal variation (both within-year and between year), natural spatial variation within the sampling unit, and the level of measurement error. These four sources of variation are generally poorly quantified. A particularly valuable part of the first year of the program would be a synthesis of existing literature to quantify this variation, and targeted monitoring to fill data gaps.

A start towards addressing these issues is to ask the following questions for each proposed long term monitoring indicator or index:

- What level of change in this indicator (or index) could you detect statistically over a six-year period, given the various natural sources of variation? Over a ten-year period?
- What biological/ecological significance would this level of change have?
- What would you need to know to improve this indicator's (or index's) power to detect changes?

6.4 Logical Sequencing

Figure 6.3 is a first attempt to develop a logical sequence for the general categories of research proposed at the workshop. No attempt was made at priorization. Some explanatory comments on this figure may help clarify its rationale and assumptions (beginning at the top and working down):

- the identification of chemical characteristics is done iteratively, to account for both potential changes in loading and advances in the understanding of the contaminants causing biological effects;
- the bedload contaminant concentrations listed under the Physical/Chemical submodel should be monitored both in the near-field and in major deposition/erosion zones identified in the synoptic physical survey;
- contaminant concentrations in water, suspended sediment and bedload should be sampled most intensively in spring, though also at other times of year;
- there is a synchrony in near field modelling activities among the physical/chemical and biotic fate subgroups (integrated near field model revised based on new results each odd year);
- the identification of chemical characteristics, dose-response studies, and trophic flux studies are done in the years prior to intensive near field modelling, to provide input data, revised hypotheses, and dose-response modules to the modellers;
- dose-response studies and trophic flux studies follow field studies (upstream/downstream comparisons) that identify the status of populations and communities;
- ecosystem quality criteria are iteratively updated as knowledge advances (1992, 1994, 1997);

- ecosystem quality criteria are iteratively updated as knowledge advances (1992, 1994, 1997);
- there is synchrony in regional scale monitoring of different ecosystem components (even years, bottom of Figure 6.3); and
- development of an integrated regional model proceeds in synchrony with near field model development.

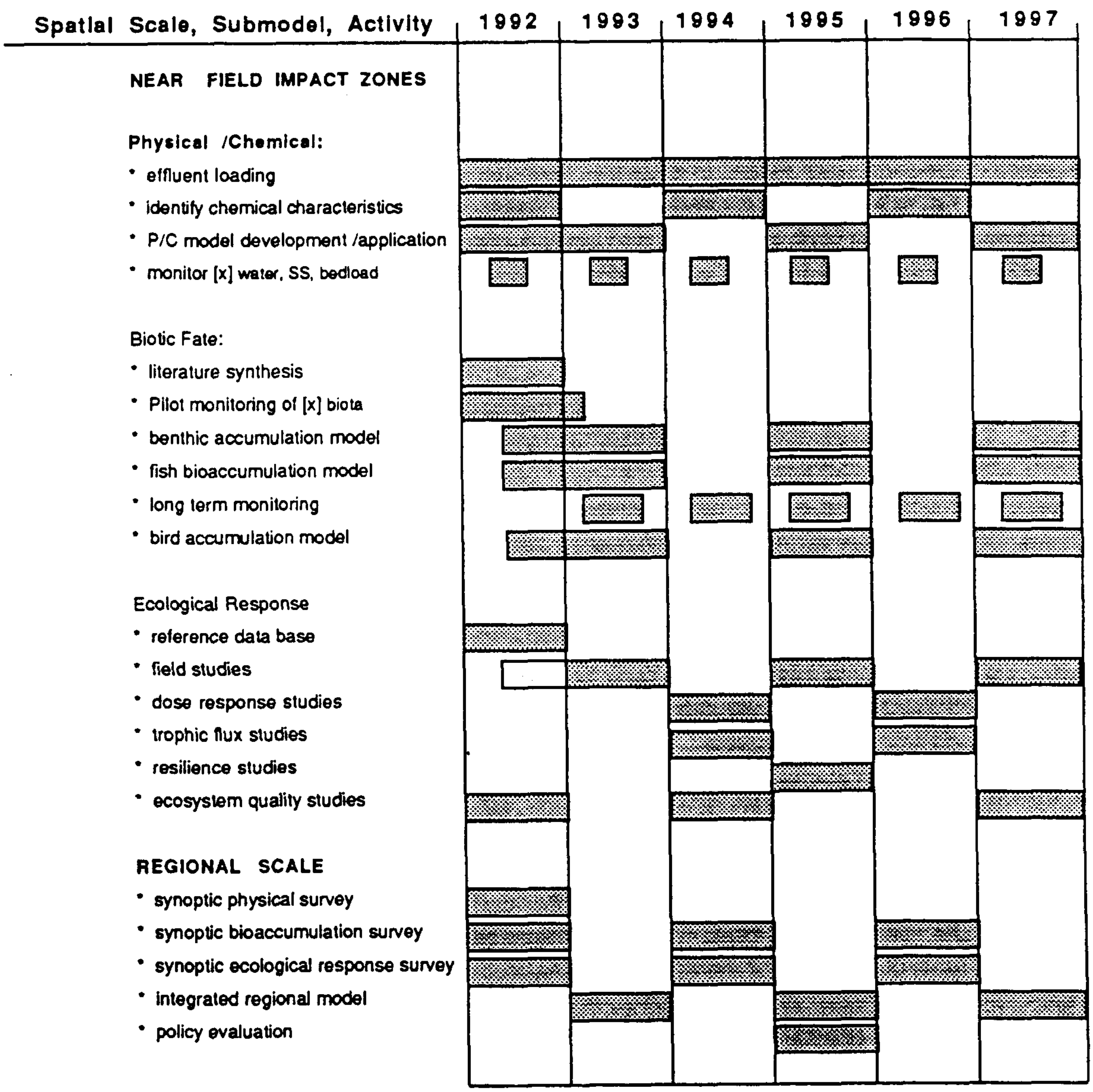

Figure 6.3: Straw-man schedule of research, monitoring, and modelling activities.

6.5 Priorization Strategies

Even after a well-integrated research strategy is developed, there comes the difficult question of how to priorize among competing directions for limited research dollars. There are at least four strategies which can be applied to this task:

1. detailed analysis how each component will yield the products and answers required by the FRAP objectives;

2. realistic appraisal of what can be delivered by each component of the research program in 2, 4 and 6 years;

3. design of a pilot study to evaluate the feasibility of competing options; and

4. an appraisal of the generality of each program component (use in evaluating stressors other than pulp mills).

With respect to the first priorization strategy (comparison with objectives), we need to carefully examine the FRAP objectives and choose research elements that are absolutely essential to each objective, or meet multiple objectives. In other words, which combination of research components come closest to tackling the Assessment and Ecosystem Quality Criteria objectives listed in the first section of this report? Some connections are already apparent:

- the Assessment and Ecosystem Quality Criteria objectives both need to have endpoints that are clearly linked to stressors, and validated conceptual models are particularly valuable;

- the synoptic monitoring and associated dose-response work can help to determine environmental quality criteria;

- integrated models can be used to assess how well different loading scenarios meet ecosystem quality and human health criteria; and

- the upstream/downstream work at near field impact sites, and the synoptic monitoring at far field bioaccumulation sites, can help in the identification of current levels of contamination and monitoring the effects of pollution abatement measures over time.

For the fourth priorization strategy, we need to step back from pulp mills and look at other stressors. Would the response indicators, spatial resolution, modelling and monitoring strategies capture the effects of other stressors? What confounding effects would occur if the program were designed to do this? What types of studies could serve multiple benefits in terms of evaluating effects of changes in different stressors?

The next section describes the results of a technical meeting at which these priorization strategies were applied.

7.0 Priorization of Research and Monitoring Activities

7.1 Process Used for Priorization

A technical meeting was held June 9 and 10, 1992 to continue the process initiated at the first model-building workshop. The objective of the technical meeting was to convert the overall research, modelling and monitoring strategy developed at the April workshop into a more priorized conceptual plan. It was desired that this plan would, to the greatest degree possible, address the three major objectives of the EQTC (see Section 1.1) and provide guidance to the EQTC on which research activities to initiate first.

The initial presentations at the meeting were structured to provide participants with the appropriate context for priorizing research and monitoring activities, namely:

- *a review of the objectives of the EQTC*, by Fred Mah (EC), Taina Tuominen (EC) and Colin Gray (CWS) (incorporated into Section 1 of this report);
- *a summary of expected changes in Fraser River pulp mill technology and effluent quality over the next decade*, by Jim Wearing of PAPRICAN;
- *a summary of existing federal and provincial research and monitoring programs in the Fraser River*, by Taina Tuominen (EC); Les Swain, Doug Walton and Dave Sutherland (BC MELP); Mike Nassichuk and Jim Servizi (DFO); and Max Bothwell (NHRI); and
- *a classification of chemicals in pulp mill effluent based on their properties and toxicities*, by Nadene Henderson (BC MELP).

After these presentations (the three last groups are very briefly summarized in Appendix 5), the participants split into subgroups: a Near Field subgroup; and a Regional Scale or Far Field subgroup. These subgroups were charged with developing an overall strategy for meeting the EQTC Assessment and Criteria objectives, and priorizing the previously identified research and monitoring activities (as described in Section 3.4-3.6, Table 4.4, and Table 5.3). In developing their strategies, both subgroups ended up considering both spatial scales (i.e. the regional subgroup discussing near field issues, and vice versa). Though the discussions in these two subgroups followed different paths, they led to largely similar conclusions. We present below both sets of perspectives (Sections 7.2.1 and 7.2.2), and then present the overall consensus on priorities for research and monitoring. We have taken care to note differences in priorities between the two subgroups, but there were remarkably few.

An informal post-meeting discussion was held to consider how to incorporate other stressors into the Fraser River Action Plan. The participants' impressions are recorded in Appendix 6.

7.2 Linking Research and Monitoring Activities to Assessment and Environmental Quality Criteria Objectives

7.2.1 A Regional Perspective

The regional subgroup began by developing a hierarchical set of questions, beginning with the management questions most closely related to the EQTC objectives and evolving into a set of scientific questions and supportive activities. They then suggested candidate indicators appropriate on a regional scale.

Linking Objectives to Questions

The first questions considered were:

- What is the status of the system?
- How is its status affected by pulp mills?
- How much change has occurred in system status since pollution abatement was implemented?
- What are the most likely causes of observed changes in system status?"

The subgroup felt that we should consider system *status* and not system *health*, to avoid getting bogged down in definitions of health. The scientific questions and activities recommended to address these questions are listed in Table 7.1.

The second question considered was: "*How do we develop and revise operational definitions of system status?*" It was recognized that these definitions might be different for human use, ecosystem structure and function, and biological populations and communities. The current system used by BC MELP involves establishing water quality parameter ranges for different uses (e.g. drinking water, agriculture, aquatic life), and then setting objectives sufficient to protect all uses. Another approach suggested would be to solicit stakeholders' perceptions of environmental values, and then develop a set of ecosystem goals, objectives and indicators in support of these values. Some of the public concerns identified included:

- Are the fish (and fish livers) safe to eat? If they are not safe to eat now, when will they be?
- What parts of the system have poor status?
- Is fish production affected?
- Is ecosystem integrity being maintained?

Table 7.1: Scientific questions and activities proposed to address the questions of ecosystem status, trends and causes.

Management Question	Scientific Question	Scientific Activities
What is the status of the system? How is its status affected by pulp mills?	What benthos, fish, birds, and mammals are resident in different parts of the system?	! describe basic life history ! assess current population status
	Are there changes in fish populations?	! upstream/downstream comparisons ! before/after comparisons
	What is the significance of high contaminant concentrations in birds?	! dose-response work
	What is the status of key indicators on a regional scale?	! stratified random sample ! statistically based extrapolation to regional populations
How much change has occurred in system status since pollution abatement was implemented?	How long will it take to clean out the system?	! model suspended sediment movement
	What is the history of changes in system status?	! review historical data ! obtain lake sediment cores
What are most likely causes of observed changes in system status?	How can we improve our ability to predict changes?	! decision support systems ! models ! hypothesis tests
	How do we relate changes in the system to changes in stressors?	! develop conceptual and quantitative models to link loadings, contaminant levels and responses

Peter Hodson suggested that organizing all of the above issues systematically would help to priorize research and monitoring activities (Table 7.2). The approach would follow through four steps: 1) learn the public's concerns; 2) express them in a more detailed and manageable set of questions; 3) devise appropriate monitoring and assessment activities to answer these questions; and 4) develop research programs to answer questions as they arise.

Table 7.2: Method of organizing public concerns, management questions, monitoring/ assessment activities, and research questions.

Public Question	Managerial Question	Monitoring/Assessment Activities	Research Question
Are the fish safe to eat?	What are the levels of specific chemicals? Where is the problem? Is it getting better or worse? What is the source? How long will the system remain perturbed?	Analysis of chemicals in edible portion of fish Taste/odour testing Sampling in relation to known sources, plus controls Choice of species based on fisheries	What are pathways of contamination? Why are some species more contaminated than others?
How many fish are there?	What species are present? What is their annual production? What is the annual catch? Where are the problems? Are they getting better or worse? When will fish production recover? What are the causes of problems?	Describe community structure Describe population dynamics (growth, reproduction, mortality, biomass, size structure) Choose species based on both fisheries and keystone species	What is the history of fish population? If changes in numbers apparent, what are the most sensitive life history stages? What stressors affect these stages, and how?
What is the status of the ecosystem?	What components of system are contaminated? Are all species present that should be, in their expected relative abundance? Are pollution tolerant/sensitive species present/absent? Where are problems, and what are trends? What are causes?	Benthic population surveys Productivity estimates (1^o, 2^o, 3^o) Contamination studies: sediment, benthos, fish tissues Water quality Sediment quality <Parameters chosen to match stressors>	Developed from observed situation to explain causes, and link back to stressors

Selecting Appropriate Indicators

The regional subgroup proposed the following principles for indicator selection:

- use of a local species with consistent life history (i.e. little year to year variation in spatial and temporal patterns of distribution);

- using the Environmental Effects Monitoring Program to build up a reliable data base;

- using indicators that are easily understood by the public and by managers;

- sampling indicators at a frequency proportional to their rate of change (e.g. persistent contaminants in fish change slowly, MFO changes quickly); and

- applying power analysis to assess the tradeoffs between sampling intensity and detectable effect size, based on estimates of spatial and temporal variation.

The recommended activities associated with these indicators are presented in Section 7.3.

7.2.2 A Near Field Perspective

Decision Process

The near field subgroup agreed that it would be very difficult and even inappropriate to look at questions or research needs with respect to assessment and environmental quality objectives separately. Participants developed a flow-chart of questions and activities integrating monitoring, assessment and the development of environmental quality objectives (Figure 7.1).

The flowchart begins with some very fundamental questions: What are the **valued ecosystem components** which comprise the system and what is the **state** of the system? It was agreed that concepts like "ecosystem health" are currently too vague to be used as the basis for formulating questions for research or monitoring. Questions about the state of the system are easier to answer than questions about its "health".

Once these questions have been addressed, research should provide information about useful indicators for assessing and monitoring the state of the system, and for tracking valued ecosystem components. There are two groups of indicators, those focused purely on the ecosystem and those focused on man's use of the ecosystem. Given limited resources, it was suggested that fish should be used as initial indicators; they were seen as good integrators of impacts, representing important components both with respect to the ecosystem and to people.

Specific indicators proposed in the first workshop were discussed with respect to experimental design issues, existing data and/or monitoring programs, and priorities for developing new monitoring programs. These indicators may be arranged according to our power of detecting change in them. In general, population-level indicators (no community- or ecosystem-level indicators were proposed) such as numbers or productivity, have low power while organismal/physiological indicators have much higher power. Unfortunately, the indicators with the greatest (direct) ecological relevance often have the lowest power.

while organismal/physiological indicators have much higher power. Unfortunately, the indicators with the greatest (direct) ecological relevance often have the lowest power.

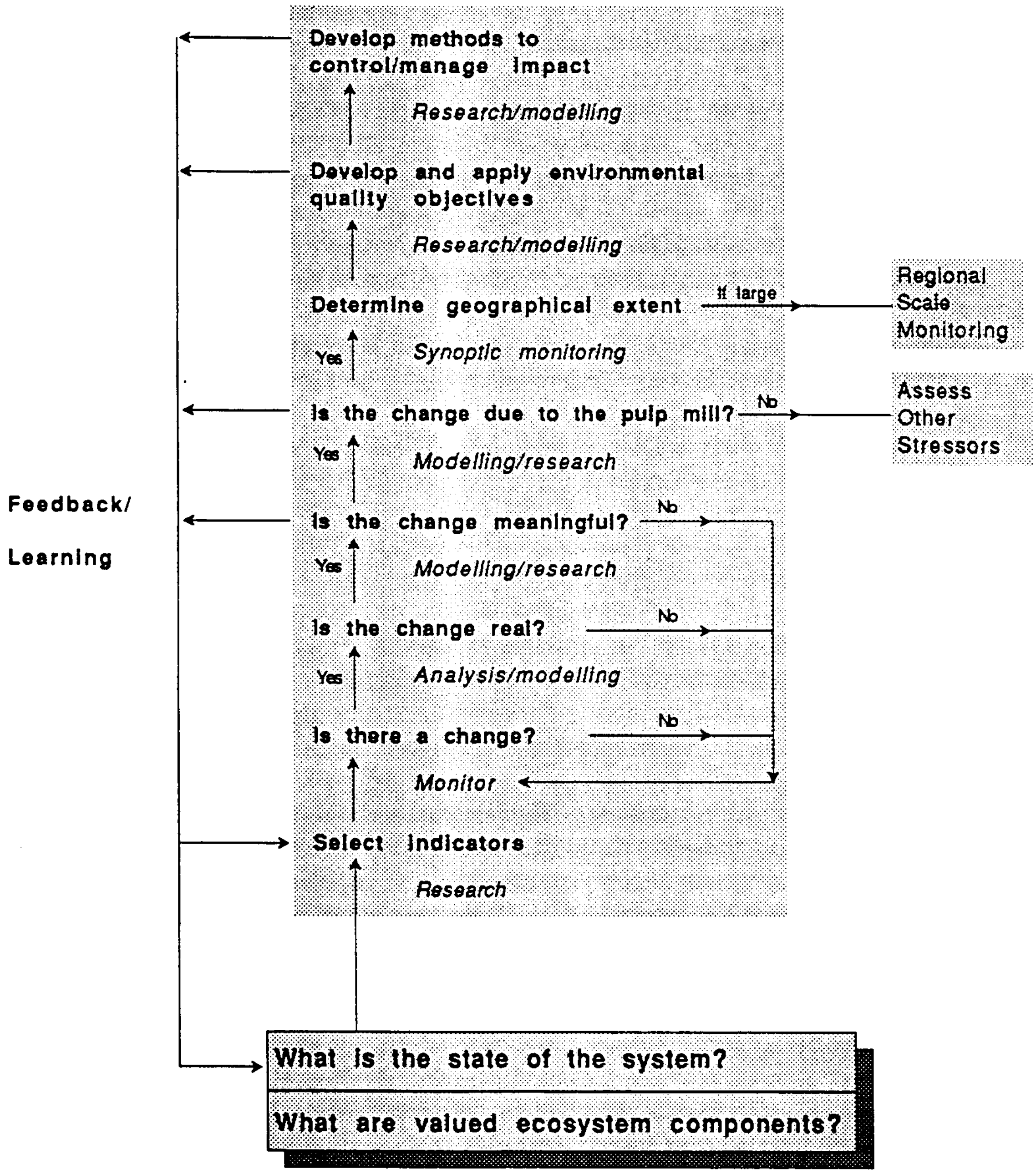

Figure 7.1: Flowchart developed during the June technical meeting to assist in priorizing indicators, and research monitoring and modelling activities (words in italics designate activities in support of next question in sequence).

desired because of their ecological relevance or meaningfulness with respect to societal values (e.g. human health) may prove too costly to monitor in a statistically defensible fashion.

Once the required number of sample sites (including reference sites) and sampling intensity have been determined for the indictors with the lowest power, subsets of the total individuals sampled may be used to measure higher-power variables (e.g. physiological indicators). It was argued that once a commitment has been made to monitor one variable, data on other variables can be collected at very little additional cost. More reference sites would increase the meaningfulness of any sampling program. Different sampling regimes will be required for most physical indicators. A preliminary sampling program will probably be required before the experimental design questions of a full-scale monitoring program can be addressed for many of these variables.

If a change in system state or the state of a valued ecosystem component is observed, the next task is to determine if the change is indeed *real* (i.e. statistically defensible as beyond the limits of natural fluctuations) through additional monitoring and analysis using a combination of mesocosm, laboratory and field studies. An appropriate experimental design taking into account a priori analyses of power for each indicator should facilitate this step. If the change is judged to be within the range of natural fluctuation (i.e. not real), then monitoring continues, with a reassessment of the overall monitoring strategy (e.g. review of the experimental design to increase the power to detect change, or a risk assessment of the value of prudently reducing loadings even though impacts have not yet been observed).

If the change turns out to be real, the next step is to determine if it is *meaningful*. That is, does the change have *ecological significance* or implications for *valued ecosystem components* (including human health)? Is the degree of detected change beyond some acceptable threshold? This step is necessary since many of the indicators which will be feasible to monitor (in terms of cost and statistical power) will likely not have an immediate or direct relationship to the ecological property or valued ecosystem components (including human health) of interest. Modelling and research (e.g. dose-response studies) are two tools for answering these questions. If the current observed level of change is judged not to be ecologically significant, then monitoring continues, but with a reassessment of the overall strategy.

Once a real and meaningful change has been confirmed, the next question (within the context of the program under discussion at this workshop) is whether the change is due to a *pulp mill*. Again, this will have to be determined through a combination of modelling and research. If the pulp mill is found responsible for the change, the geographic extent and temporal trend of the effect must be determined. This will require additional monitoring over larger spatial and temporal scales.

Near field subgroup participants did not support regional monitoring prior to identification of real and meaningful changes in the near field zone. Once such impacts are identified, the indicators developed in the near field could be applied regionally. Regional studies would also be useful for identifying keystone and resident species as well as for providing base-line data regarding physical variables and processes (e.g. temperature, ice cover, river morphology, sediment transport and deposition, etc.). Essentially, regional studies should provide knowledge about the system as a whole. The regional group had a different perspective, and felt that it was not necessarily true that the absence of impacts in near field zones meant that there were no impacts in the far field zones. In particular, it is important to consider contaminant transport to distant deposition zones, where different trophic structures may lead to a different types and magnitudes of impacts.

Once impacts from pulp mills have been identified, the next step is to develop and apply environmental quality objectives. All of the previous steps provide a foundation for this task. Information regarding valued ecosystem components, the state of the system, and the geographic extent and temporal trend of the impact provide inputs for setting these environmental quality objectives. These objectives should be focused on valued ecosystem components and determined by the most sensitive use. There are currently no objectives for many compounds we may be interested in controlling. Setting environmental quality objectives for such compounds may, unfortunately, be beyond the scope of the five-year framework for this project.

Once the objectives have been developed, then research and modelling is required to come up with methods to control and manage the effluent components causing the impact. The whole process described in Figure 7.1 is adaptive, incorporating learning at each step into subsequent iterations.

7.3 Priorization of Research and Monitoring Activities

One of the objectives of the June technical meeting was to priorize research/monitoring activities proposed by the ecological response (Section 3.4-3.6) and biological (Table 4.4) and physical/chemical (Table 5.3) fate subgroups during the April workshop. To do this, the near and far field subgroups determined which of these activities would need to be undertaken in the first year of FRAP-funded research and monitoring. As each activity was discussed, key issues regarding sampling and interagency coordination were discussed. The section synthesizes the findings from both near and far field subgroups. In general, there was a high level of consensus among the two groups. Differences in priorities between the two subgroups for specific activities are highlighted.

7.3.1 Ecological Response Activities

The need for studies describing the basic biology of fish, benthos, birds and mammals was emphasized by both the near and far field subgroups. These investigations would describe the geographic distribution, behaviour and growth, as well as population level characteristics (e.g. age structure, reproductive success, survival). It was also felt that it will be necessary to determine the keystone species within different communities through trophic structure investigations. These basic studies must be conducted at both reference sites and potentially affected areas.

Birds/Mammals

It was felt that population studies being conducted by CWS will provide enough information to describe the basic biology of potential bird/mammal ecological response indicators. The subgroups agreed that because of these ongoing CWS studies, bird and mammal population studies should be placed relatively low on the FRAP priority list. It was noted that it will be important to ensure congruency among contaminants being investigated within the FRAP and CWS programs. Laboratory dose-response experiments were given a low priority for initial stages of the FRAP program as the selection of contaminants to be investigated will be dependent on preliminary results of the biotic fate studies.

Fish

Determining the distribution and basic biology of fish species to be used as response indicators was given a very high priority by both subgroups. Selection of indicator species will be dependent on their geographic distribution (i.e. found in upstream and downstream zones) and behaviour, characteristics defined through basic biological studies. For example, rocky mountain whitefish may be useful for near field studies, but may move too much to be useful on a regional scale. Such investigations would also be of interest to the BC MELP fisheries branch and would include studies beyond the dose-response level. Cooperation and integrated planning between FRAP and MELP fish studies will be required to maximize the efficient use of FRAP resources. Investigations of the behaviour of selected fish species to pulp mill effluent plumes was given a very high priority, since this behaviour will greatly affect exposure for some species (e.g. juvenile chinooks).

Reviewing PAPRICAN work on toxicity equivalents was considered to be a worthwhile step towards the definition of environmental quality objectives. Ideally, a set of small resident fish could be used as indicators throughout the system. Examining the differences in contaminant burdens among such fish was given a high priority.

Trophic Studies

Trophic studies examining the relative importance of food web transmission of contaminants in fish (as opposed to direct uptake) were given a low priority in terms of initial FRAP investigations. The relative importance of bioaccumulation pathways will be highly dependent on the chemical characteristics of the contaminant, thus such investigations should be conducted only after biotic fate studies identify the compounds of interest.

On the other hand, investigation of the effects of dissolved nutrient and carbon concentrations on rates of bioaccumulation in the Thompson River were considered to warrant continued support. Do nutrient additions in pulp mill effluent increase the level of food web contamination, or are they critical in supporting the food web? This is a key question which needs to be addressed. Analysis of the abundant past nutrient enrichment data in the Thompson River could help design optimum sampling frequencies and spatial patterns at other locations. There is currently considerable research on benthic biofilm in the Thompson (Bothwell 1992). Of interest is the amount being produced and the interaction between the biofilm, benthic invertebrates and dace. The need to investigate application of such studies to the Fraser River was highlighted.

Benthos

Prior to any field investigations of benthic community response, it was felt that scientists should conduct a review and compilation of existing data on benthic distribution and abundance in the Fraser and Thompson Rivers. This review should focus on habitat availability in potential upstream and downstream study locations, seasonal changes in community structure, and year-to-year variability in abundance. Data compiled in this review could also be used to examine various statistical and experimental design issues (e.g. rapid assessment techniques) for future studies. It was felt that these activities are high priority in terms of initial FRAP investigations and must be conducted prior to any benthic field investigations.

Once these reviews are completed, an assessment of near field sediment toxicity in relation to deposition zones was considered to be an important activity.

7.3.2 Biological Fate Activities

Benthos

It was felt that benthic investigations of the biological fate of contaminants requires a good understanding of the community structure by spatial unit within near and far field zones. Some of this information would be compiled in the benthic review discussed above. The spatial and temporal benthic sampling strategies should be developed in conjunction with fish studies (e.g. rocky mountain whitefish). Aside from this activity, the other research items listed in Table 4.4 related to benthic fate were given low priority. Model development was considered expensive requiring detailed laboratory studies of uptake of specific contaminants. Such research should only be conducted once the contaminants of interest have been identified.

Fish

The preliminary and high priority activities for assessing the biological fate of contaminants in fish should focus on determining the general distribution of selected species within near/far field zones on a seasonal basis. The diet of these species within each study location must also be determined. Modelling activities for biotic fate of contaminants in fish were given a medium level of priority and should only be commenced once:

1. the compounds of concern are identified and enough data for calibration and development is available; and when

2. a reliable physical model(s) is developed to drive the biotic fate models.

BC MELP is currently funding Dr. Frank Gobas to apply an existing biotic fate model to the Fraser River. The results of this study should be examined and integrated with any future biotic fate modelling funded through FRAP.

Determining a standardized length and age for different fish species to compare contaminant concentrations on a regional basis was considered to be a high priority. Since this information is being compiled as part of the BC MELP dioxin and furan program, few FRAP resources will be required. The far field subgroup identified measurements of MFO activity in caged fish located at increasing downstream distances from effluent discharges as a good way to determine the spatial extent of potential biological impact. This approach has been applied successfully in other locations (Berlin, Espanola). Contaminant concentrations at locations showing elevated MFO activity would have to be determined in order to validate the results in the laboratory.

Birds/Mammals

Investigations related to the biotic fate of contaminants in birds and mammals were given a medium-low priority because many of activities are being conducted by CWS. Congruency among contaminants, indicator species and sampling protocols between CWS programs and the fish and benthic biotic fate investigations of FRAP should be ensured. Adapting an existing herring gull bioenergetics model (Norstrom et al. 1986) to species on the Fraser was considered to be a useful activity by the near field subgroup even though considerable modification of the model would be required. The near field subgroup felt that developing a new mammal-biotic fate model should be given a low priority because data used to develop and calibrate such a model would be unreliable or very expensive to collect. The regional subgroup felt that, notwithstanding these problems, it would still be worth investigating the availability and quality of mammal data during the initial phases of FRAP investigations.

Physical/Chemical Fate Activities

Both subgroups agreed that the majority of activities evaluating the physical/chemical fate of pulp mill contaminants (Table 5.3) should be given a high priority. Characterizing the physical environment and chemical behaviour of different contaminants in the effluent is critical for the design and interpretation of most of the biotic fate and ecological response studies.

Loadings

Synthesizing existing loading information in a readily accessible data base was considered high priority by the near field subgroup. Loading by size fractions should be monitored as soon as possible as should the total amount of carbon (dissolved and particulate) being discharged from each source. It is very important that the mills collect data on a consistent set of contaminants in a consistent manner. Both subgroups agreed that existing data on dissolved and suspended sediment concentrations of contaminants should be compiled and synthesized. Empirical analyses of these data may help define where major deposition and erosion zones are located and characterize loadings at multiple sites.

Physical Processes

Both subgroups agreed that all the hydrodynamic and dispersion/dilution activities and most of the sediment transport studies should be given high priority. The key results from these activities will be to characterize the extent and area of effluent plumes and sediment movement. The far field group did not consider the measurement of shear stress coefficients or flocculation studies to be high priority for initial FRAP investigations. The near field group considered all sediment-related activities to be high priority although it was recognized that flocculation studies would be of lesser priority than the other activities. Most of the sediment transport investigations could be conducted independently of information gathered on loadings. Once loadings for a particular contaminant of interest were calculated, chemical burdens and transport could be defined.

Monitoring Water and Suspended Sediment Quality

Continued monitoring of water quality at the four BC MELP stations (Hansard, Stoner, Marguerite, Hope) is essential to obtaining a reliable regional picture. This sampling should be extended to include suspended sediment and leeches, and perhaps two additional stations should be added to the network. Daily sampling of suspended sediment, analyzed in weekly composites, is necessary to characterize sediment transport processes.

Physical/Chemical Characterization

Characterization of physical/chemical properties of pulp mill contaminants through literature reviews and laboratory/field measurements were considered very high priority by both subgroups. The selection of indicator compounds is discussed in Section 2.1.

In the final plenary session it was emphasized that most of the high priority physical/chemical activities should be conducted as soon as possible.

Geographic Information Systems

Creating a GIS for the Fraser River was suggested as one means for organizing and synthesizing existing and future data in order to determine spatial variability and temporal trends in indicators. This would provide useful information in the design of a monitoring program. There are also historical data available for some variables which would provide input into experimental design of monitoring programs. For example, there are historical data on benthic communities prior to increases in mill output; however, this data will have to be organized into an appropriate form and analyzed in order to provide input into the design of a monitoring program. The first step is to review the forms of existing data bases, including existing GIS's (e.g. Westwater, ongoing work at the University of Victoria, and Environment Canada), and systematically analyze how these systems can best be configured to meet the EQTC's needs.

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Appendix 1

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WT indicates attendance at both workshop and technical meeting
W indicates attendance at workshop only
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Appendix 2

Review of Existing Hydrologic and Sediment Transport Models

This appendix presents the results of B.G. Krishnappan's review of existing models which could be applied to the Fraser River to predict the physical fate of contaminants throughout the system. Figure A2.1 provides a schematic overview of these models.

The MOBED model is a fairly well established model for predicting flow characteristics and sediment transport under unsteady and non-uniform flows in mobile boundary channels, thus it is ideally suited for the Fraser. The model can predict flow characteristics such as velocity, stage and bed shear stress that are needed for near field and far field mixing models. It also calculates the sediment transport rates as bed load and suspended load and predicts zones of erosion and deposition. Recently, the wash load component has been incorporated into the model. This aspect of the model requires critical shear stresses for erosion and deposition of cohesive sediment which can only be measured in specialized equipment such as in rotating flumes.

The LAEM model can predict salt wedge intrusion and hence may be suitable for the Fraser River estuary. This model has been applied to the Lower Mississippi River to predict the salinity intrusion and was found to yield reasonable predictions for this case. However, the sediment transport processes in the estuary are very complex and there is a definite need for research in this area. The process of flocculation of fine sediment and the contaminant interactions with the flocculating sediment in the presence of salinity need to be understood before modelling of the processes can be attempted.

The RIVMIX model predicts the spreading of dissolved contaminants in the near field. Both conservative and non-conservative contaminants can be handled by this model. The Cohesive Sediment Transport Model has recently been developed to model the wash load sediment in the near field zone by coupling the RIVMIX model with a sediment flocculation model. This model is still in the development stage and more research is needed to fully understand the flocculation process.

The FETRA model can be used to predict both the dissolved and particulate contaminant transport in the far field. This model has been applied to the James River estuary to predict the transport of Kepone (Onishi 1981). The model needs parameters such as distribution coefficients, chemical and biological degradation rate constants and critical shear stresses for erosion and deposition of fine sediment. More research is required to establish these parameters for various contaminants of interest.

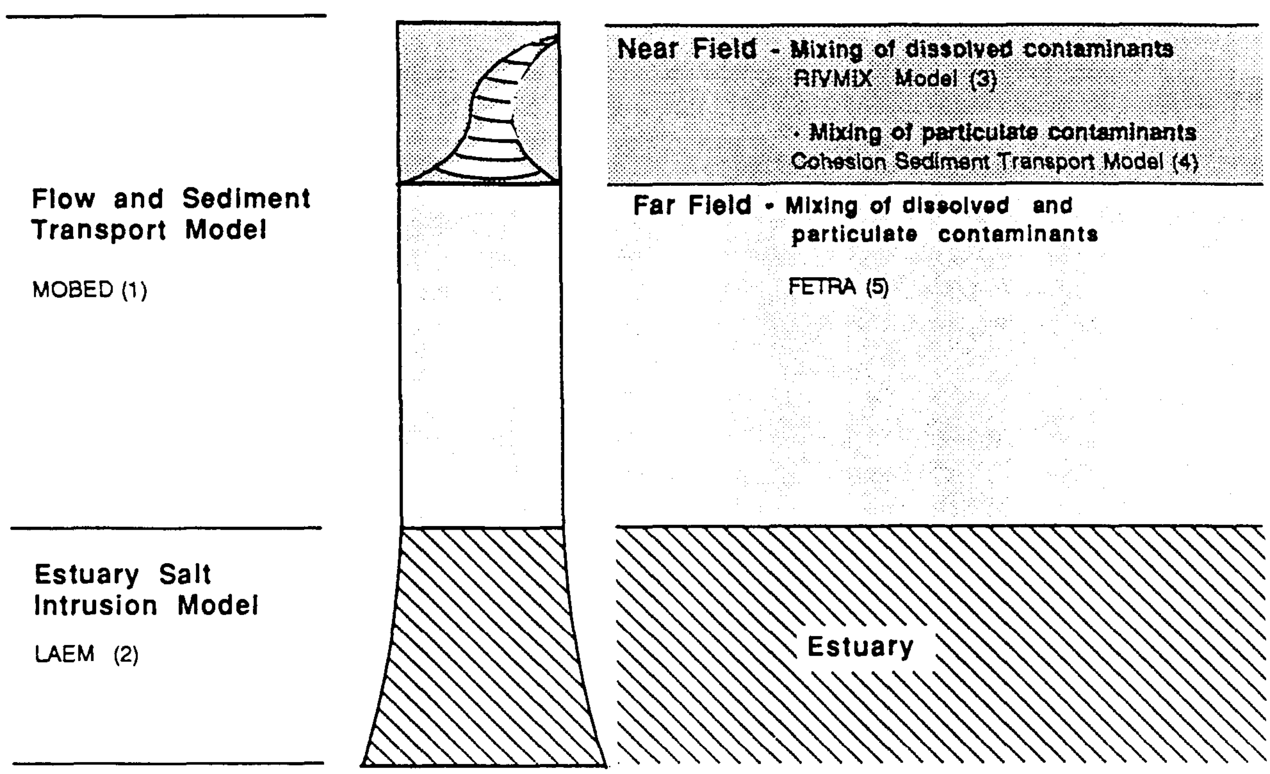

Figure A2.1: Schematic overview of models.

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Appendix 3

Near-field Dilution of Pulp Mill Effluents

This appendix presents a review of the major processes influencing near field dilution conducted by Leslie Gomm following the April workshop.

The mixing zone below a pulp mill discharge may extend for many kilometres downstream of the discharge. In the simplest case the mixing distance from a centerline discharge is given by:

$$L_m = 0.1\ w^2 u/\varepsilon_t \qquad \text{[A3.1]}$$

where
w = width
u = mean river velocity
g = transverse dispersion coefficient

For the Cariboo discharge in the Fraser River, this results in a mixing distance of approximately 165 kms in January and 74 kms in June. These numbers are based on river flow from the Water Survey station one kilometre before the confluence with the Quesnel River.

Obviously this is a first approximation since in reality velocity (u) and width (w) vary, but more importantly g_t varies. The transverse mixing coefficient is often written in the form:

$$\varepsilon_t = \alpha d u* \qquad \text{[A3.2]}$$

where d is the depth, the shear velocity u* = $\%gr_hS$, g is the gravitational acceleration, r_h the hydraulic radius, and S the hydraulic gradient. The coefficient " is dependent on channel morphology and curvature, values given in Fischer et al. 1979 vary from 0.1 for straight laboratory channels to 10 for rivers with significant channel curvature.

In addition, due to the high temperature of the pulp mill effluent, buoyancy effects may play an important role. When an effluent is lighter than the receiving water, vertical mixing is inhibited while transverse mixing is enhanced. Finally, the presence of ice on the river reduces turbulence which reduces mixing.

Once the above parameters and effects have been characterized, there are a variety of models that can be used to determine downstream concentrations of conservative substances. However, many constituents in pulp mill effluent are in fact non-conservative and chemical and biological processes need to be considered in some depth.

Appendix 4

Fraser River Pulp Mill Effluent - Research Planning Workshop

Workshop Agenda

Workshop Agenda

Tuesday, April 14th

Plenary Session

8:30 a.m.	Introductions; Logistics (David Marmorek)
8:45	Historical Context; Overall Objectives of this Project (Fred Mah or Bev Raymond)
9:00	Overview of Model Building/Research Planning Process (Marmorek)
9:25	Discussion
9:40	Problem/Model Bounding: Indicators, Actions, Space and Time
10:15	BREAK
10:30	Bounding Cont'd
11:30	A Simple Model of Contaminant Fate in the Fraser River (Frank Gobas)
12 noon	LUNCH
1:00 p.m.	Looking Outward Exercise; Charge to Subgroups
3:30	BREAK
3:45	Subgroup Discussions
5:00	Adjourn

Wednesday, April 15th

8:30 Subgroup Discussions cont'd

10:15 BREAK

12:00 LUNCH

1:00 Subgroup Discussions cont'd

3:00 BREAK

5:00 Adjourn

Thursday, April 16th

8:30 a.m. Subgroup Presentations

- 15-20 minute presentations of each subgroup's recommended approaches, perceived research priorities, followed by 10-15 minutes discussion

10:15 BREAK

10:30 Where do we go from here?

- major tasks, responsibilities identified at workshop
- priorities for model development, testing, analysis
- discussion of data and conceptual gaps, research priorities, strategies for filling gaps

1 p.m. Adjourn

Appendix 5

Summary of Presentations Given During the June Technical Meeting

At the beginning of the June technical meeting a number of brief descriptions of relevant monitoring/research currently being conducted in the Fraser River Basin were presented. This appendix, in an informal and very brief format, summarizes the presentations made by the following individuals:

Name	Affiliation	Subject
Jim Wearing	PAPRICAN	Alternative Pulp Mill Technologies
Taina Tuominen	Environment Canada	Canada/BC Water Quality Agreement
Les Swain	BC MELP	Monitoring for Water Quality Objectives
Doug Walton	BC MELP	FREMP Water Quality Plan
Dave Sutherland	BC MELP	BC EEM at Pulp Mills
Mike Nassichuk	DFO	Habitat Management in the Fraser Basin
Jim Servizi	DFO	Summary of Fraser River Fisheries Research
Max Bothwell	Environment Canada	Thompson River Trophodynamics
Nadene Henderson	BC MELP	Ranking of Compounds in Treated Effluents

Alternative Pulp Mill Technologies

Jim Wearing
PARPRICAN

- Wide variety of technologies could be applied to meet the 0.5 kg AOX/ADT regulation.

- Many technologies will employ chlorate rather than chlorine. Chemical suppliers will need time to accommodate this change in demand.

- BC's target of 0 kg AOX/ADT is a research question. 40% of total PAPRICAN resources ($ 30 million) are allocated to environmentally-oriented research as follows:

environmental quality assessment	8%
new bleaching systems	15%
effluent systems	7%
waste management	7%
fibre recycling	3%
	40%

- Specific projects currently conducted by PAPRICAN include:

Continuous flow bioassays	$472,000
Mixed function oxidase laboratory and field studies	$834,000
Online monitoring for AOX, resin acids, and chlorinated phenolics to develop effective control strategies for biologically treated systems.	$995,000
Chlorine-free bleaching technologies using O_2, O_3, hydrogen peroxide.	$800,000

- Currently, a very narrow segment of the European market is interested in chlorine-free pulp.

- There are major difficulties in building close-cycle plants even if no chlorine is used in the processes.

Environmental Quality Assessments and Water Quality Monitoring

Taina Tuominen
Environment Canada

Environment Canada's objectives for environmental quality assessment in the Fraser River Basin are to:

- determine the current condition of river;
- measure changes in condition of river over time as a result of abatement measures;
- develop information to anticipate and avoid problems;
- produce data in support of the development of environmental quality objectives; and
- advise the research component of understanding required to more effectively conduct environmental monitoring/surveys in the basin and interpret the results of the monitoring.

The proposed elements of monitoring or surveys required to meet the objectives include an examination of:

- contaminant levels in media;
    - water
    - suspended sediment
    - bed sediment
    - biota
- biological/ecosystem health indicators;
    - fish
    - invertebrates
    - plants/algae
    - higher trophic levels

and

- bioassay testing methods.

The Canada-British Columbia Water Quality Monitoring Network:

- consists of seven jointly monitoring federal-provincial stations

1) Fraser River at Hope
2) Thompson River at Spences Bridge
3) Salmon River near Salmon Arm
4) Fraser River at Marguerite
5) Nechako River at Prince George
6) Fraser River at Hansard
7) Fraser River at Red Pass

(+ Fraser River at Sumas = federal station)
(+ Fraser River at Stoner = provincial station)

- uses a biweekly monitoring frequency.
- measures parameters in water only.
- measures up to 42 parameters are measured including temperature, pH, turbidity, conductivity, alkalinity, hardness, major ions, filterable/non-filterable residue, colour, nutrients, total metals.
- measures no organic parameters with the exception of some bacterial counts and chlorinated organics conducted by BC MELP measured at the Marguerite, Stoner and Hope stations.
- measures flow at 40, 36, 49, and 67 stations in the upper, middle and lower Fraser River and Thompson River, respectively.
- has the following objectives:
  - assess water quality conditions at locations in B.C.
  - assess trends in water quality

Monitoring for Water Quality Objectives

Les Swain
BC Ministry of Environment Lands and Parks

- BC has been producing summaries regarding the attainment of ambient water quality objectives for the Fraser River since 1982. There are complete documents for approximately 10 tributaries and main stem locations (See Figure A5.1 for site locations and completion dates).

- The analysis includes water, sediment and biota.

- The total annual program cost is $250,000, of which $150,000 is spent on laboratory analyses. Figure A5.2 shows the location of sampling stations and the resources used at each site.

- An additional $100,000 from BC is channelled to FREMP.

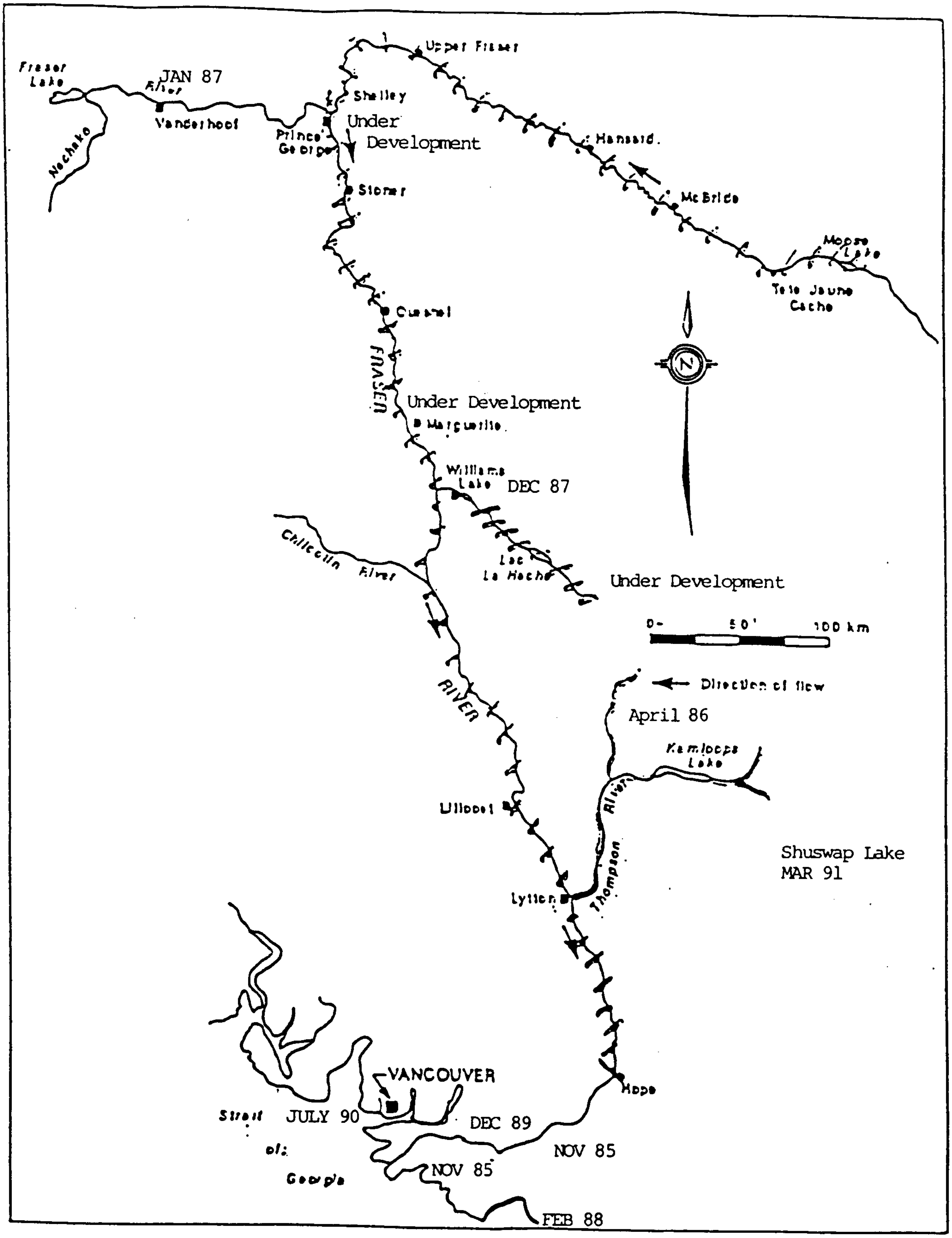

Figure A5.1: Water quality objectives in the Fraser River Basin.

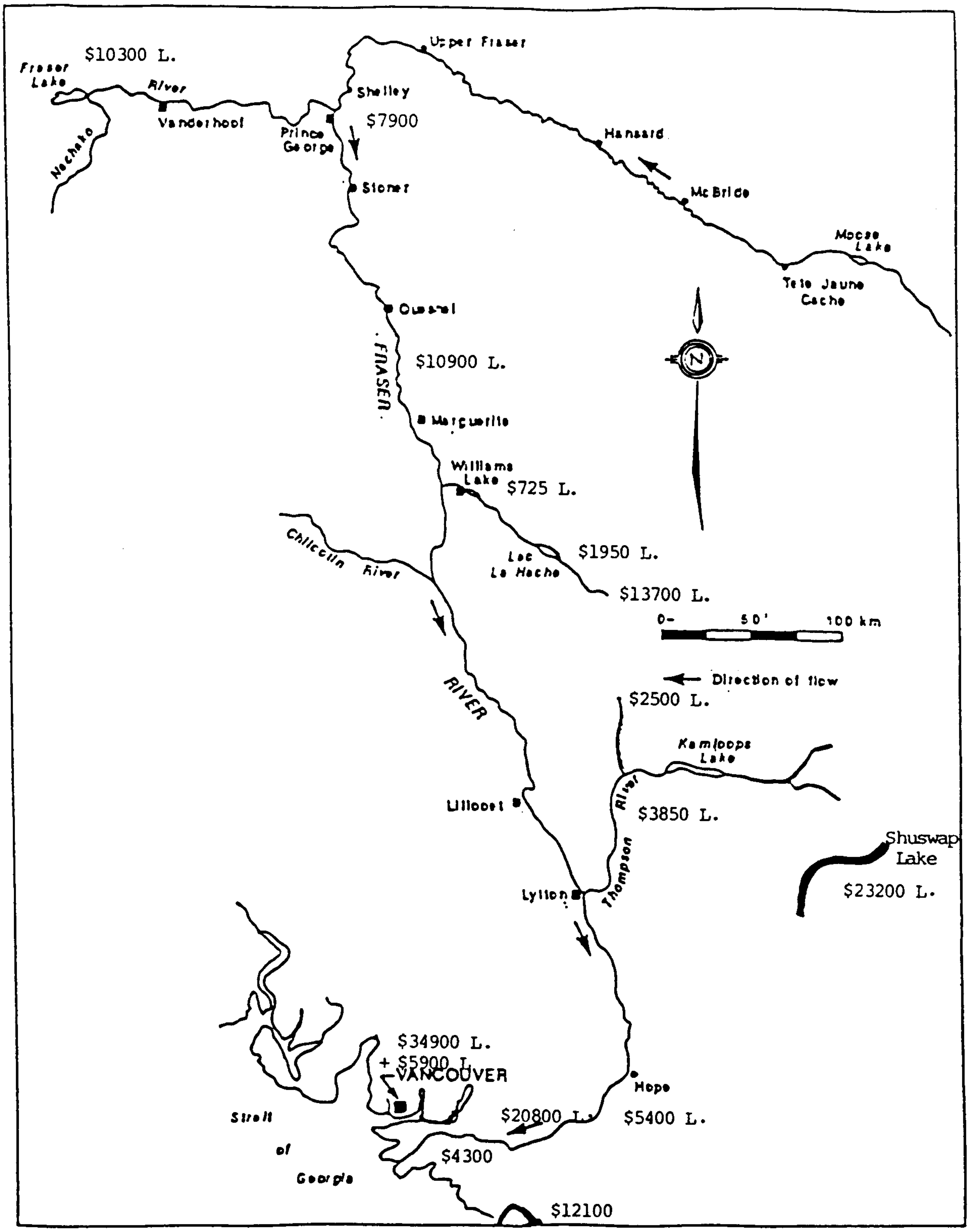

Figure A5.2: Water quality objectives monitoring costs in FY 92/93. "L" denotes laboratory costs only. Costs presented do not include: 1) $100,000 spent annually by BC MELP on monitoring in the estuary; 2) $ spent by BC Ministry of Health on monitoring of bathing beaches; and 3) $ spent by GVRD (and others) under permits for ambient monitoring.

Fraser River Estuary Monitoring Program Water Quality Plan

Doug Walton
BC Ministry of Environment Lands and Parks

- FREMP is funded by BC MELP at $100,000/yr in an agreement with the Fraser River Harbour Commission.

- The past focus of monitoring within FREMP is outlined below:

Year 1:	effluents (1986)
Year 2:	sediments/insects (1987)
Year 3:	fish in the river (1988)

- Special studies have been funded through FREMP, some are complete (e.g. stormwater quality study).

- The standing committee on the Fraser River Estuary water quality plan under FREMP developed a draft water quality plan in 1990 which was designed to establish agreed upon water quality objectives and guide an environmental monitoring program in the Fraser Estuary. A summary of recommended monitoring program activities and cost estimates for the proposed three-year cycle is given in Tables A5.1 and A5.2, respectively

Table A5.1: Summary of recommended monitoring program activities for the three-year cycle.

	Effluents	Water	Sediment	Fish	Invertebrates
Year 1					
Sites	Sewage treatment plants Major industrial Minor industrial	Upstream Reference Main River[1] Slough			
Activities	Sampling, analyses and data interpretation	Sampling, analyses, and data interpretation			
Year 2					
Sites		Upstream Reference Main River[1] Slough	Upstream Reference Main River[1] Slough Tributary[2] Marine[3]		Slough Marine[3]
Activities		Sampling, analyses, and data interpretation	Sampling, analyses, and data interpretation Sediment bioassays		Sampling
Year 3					
Sites		Upstream Reference Main River [1] Slough		Upstream Reference Main River[1] Slough Marine[3]	
Activities		Sampling, analyses, and data interpretation		Sampling, analyses, and data interpretation	Analyses and data interpretation

[1] Main River = Main Stem, North Arm, and Main Arm
[2] Tributary = Campbell River, Nicomekl River, Serpentine River, and Brunette River
[3] Marine = Boundary Bay, Roberts Bank, and Sturgeon Bank

Table A5.2: Monitoring program total cost estimates[1] ($000's)[2].

	Year 1	Year 2	Year 3	3-Year Costs
Analytical Costs	204	465	685	1,354
Field Collection Costs	100	110	121	331
Nonroutine Quality Assurance/Quality Control @ 15% of Analytical and Field Costs	45	85	120	250
Data Analysis and Interpretation	30	15	20	65
Reporting	10	25	30	65
Capital Costs	50	25	60	135
Totals	439	730	1,036	2,220

[1] Costs are estimates only, funding has not yet been approved
[2] 10% inflationary costs have been added per annum

BC Environmental Effects Monitoring at Pulp Mills on the Fraser River

Dave Sutherland
BC Ministry of Environment, Lands and Parks

! Environmental effects monitoring (EEM) has been conducted at a number of mills (2-3 yr cycle) over the last decade.

! The program originally focused on nutrients but eventually progressed to examining contaminant levels in fish by 1989. Based on these latter analyses, public advisories were issued for high contaminant concentrations in rocky mountain whitefish and livers of other fish.

! The program is still in the planning stage and there is a need to coordinate with the federal EEM program.

! Currently, effluent water quality parameters which are monitored include AOX, TSS, BOD, acute toxicity, and dioxin/furan concentrations. In future monitoring, chronic toxicity tests based on whole and particle fractions of effluent will be conducted.

DFO Habitat Management Studies in the Fraser River Basin

Mike Nassichuk
Department of Fisheries and Oceans

- Habitat management efforts in the Fraser focus on stock enhancement and enforcement. There is a limited program to look at contaminant concentrations in fish in the upper Fraser River.

- As part of the Toxics Green Plan, a small program is underway to look at the recovery of the foreshore area near the Iona Island sewage plant.

Summary of Fraser River Fisheries/Stressor Research

Jim Servizi
Department of Fisheries and Oceans

The objectives of seven projects being conducted in the Fraser River Basin to assess the impact of various stressors and habitat changes are summarized below.

1) Iona Island Project (1975 - 1992)

- The objective of the project is to compare present epifauna, meiofauna, macrofauna, and sediment C/N and heavy metal levels with levels measured prior to operation of the deep water sewage outfall.

2) Chinook Rearing Capacity: Upper Fraser Project

- The objective of the project is to compare rearing in Nechako and Stuart Rivers using fry and smolt trapping.

3) Fish Production from Developed Estuarine Habitats Project

- The objectives of the project are to:
    - Determine the carrying capacity of the Fraser estuary for chinook and chum salmon and other fish species;
    - Determine the effect of residency in various wetland types on survival rate of fry to the adult stage; and
    - Measure invertebrate productivity to determine if food availability limits fish production.
- Study areas:
    - tidal freshwater; main stem, sloughs, remnant lakes
    - inner estuarine zone (brackish marshes)
    - outer estuarine zone (eel grass habitat)
    - outside the estuary in the Fraser River plume
    - restored and developed habitats

4) Fish/Forestry Project

- The objective of the project is to determine the effects of forest practices on interior fish stocks and the carrying capacity of their habitat.

- The issues addressed:

    - rate of cut
    - cumulative impacts from long-term forest industry activities (e.g. water, temperature, sedimentation, fish growth)
    - winter vs. summer logging activities
    - role of LOD in interior streams
    - downstream effects
    - long-term impacts on interior ecosystems

5) Bio-Concentration and Bio-Indicators Project

- The objectives of the project are:

    - measurement of contaminant body burdens primarily in salmonids, but including other fish species and fish food organisms; and

    - development and application of specific and non-specific bio-indicators to detect pollutant or contaminant induced stresses among feral fish.

- Bio-Indicators include:

    - proximate analysis
    - interregnal nuclear diameter
    - hepatic EROD activity
    - differential WBC
    - serum alanine amino transferase (ALT)
    - macrophage assay (latter developmental stages)
    - recombinant DNA probe for P451A1 in chinook salmon (under development)

6) Productive Capacity: Pink Habitats

- The objective of the project is to explain the disparate pink salmon production from the upper and lower Fraser River basin and the implications of Global Warming on pink production.

- Issues to be examined:

    - Are the productive capacities of upriver habitats naturally lower than those below Hell's Gate?

    - Have the productive capacities of upriver habitats been lowered by the following human activities:

        - water withdrawal: reduced spawning and incubation areas, altered temperature regimes, fish passage survival
        - pollution: potential for reduced survival

  - physical alteration: (e.g. CN twin tracking and Hell's Gate) reduced spawning and incubation areas, degraded incubation habitats, fish passage problems

7) Migration/Habitat Quality Project

- The objectives of this project are to:

  - determine the influence of variation in Fraser flow and temperature on upriver salmon travel times and energy expenditures; and

  - determine the cumulative effect of stressors, including exposure to contaminants and sub-optimal habitats on the spawning success of adult salmon.

Thompson River Trophodynamic Investigations

Max Bothwell
Environment Canada

- During 1973-75 a Federal-Provincial Task Force study of the Thompson River system in the vicinity of Kamloops identified phosphorus in effluent from the pulp mill and the City municipal sewage treatment plant as responsible for the increased algal production in the river.

- The Thompson River has been identified as a classic P-limited system.

- Current investigations are focusing on nutrient-trophodynamic interactions in the lower Thompson River, downstream of the Weyerhaeuser Canada Ltd. pulp mill.

- Specifically, investigations focus on gradients in nutrients and productivity which will vary across seasons and can influence benthic invertebrate community structure and fish productivity. See Bothwell (1992) for more detail on past and current investigations.

Ranking of Compounds in Treated Effluent

Nadene Henderson
BC Ministry of Environment, Lands and Parks

- The environmental Protection Division, Industrial Waste & Hazardous Contaminants Branch of BCELP is compiling information on organochlorine and non-organochlorine compounds.

- These compounds have been ranked based on a number of criteria including Kow values, effluent levels for compounds that have been measured, and fish and mammalian toxicity.

- Tables A5.3, A5.4, A5.5, and A5.6 rank compounds found in treated pulp mill effluent based on based on Efraim Halfon's (1989) vectorial analysis ranking program:

    - Effluent levels and log Kow
    - Effluent levels and fish toxicity
    - Effluent levels, log Kow, and fish toxicity
    - Effluent levels, log Kow, and mammalian toxicity

Table A5.3: Rankings of compounds found in treated effluents based on effluent levels and log Kow.

A	trichlorosyringol	**G**	chloroguaiacols trichloroethane
B	2,3,7,8-tetrachlorodibenzodioxin	**H**	6-chlorovanillin 1,1,1-trichloroethane
C	2,3,4,5-tetrachlorophenol 2,3,4,6-tetrachlorophenol tetrachlorophenol pentachlorophenol 3,4,5-trichloroveratrole	**I**	2,6-dichlorophenol bromodichloromethane tetrachloroethene
D	3,4,5-trichloroguaiacol tetrachloroguaiacol 3,4,5-trichlorocatechol tetrachlorocatechol	**J**	2,3,7,8-tetrachlorodibenzofuran
E	2,4-dichlorophenol 2,4,6-trichlorophenol 2,3,5,8-tetrachlorophenol 4,5-dichloroguaiacol 4,5,6-trichloroguaiacol 5,6-dichlorovanillin chlorobenzene	**K**	chlorophenols 2,4,5-trichlorophenol dibromochloromethane
F	4,6-dichloroguaiacol 4,5-dichlorocatechol 1,1-dichlorodimethyl sulfone dichloromethane chloroform carbon tetrachloride 1,2-dichloroethane	**L**	o-chlorophenol p-chlorophenol
		M	dichlorodimethyl sulfone trichloroethene

Table A5.4: Ranking of compounds found in treated effluents based on effluent levels and fish toxicity.

A	trichlorocatechol 12,14-DiCDHA	**(F)**	2,4,6-trichlorophenol 4,5-dichloroguaiacol 3,4,5-trichlorosyringol
B	trichloroguaiacol 3,4,5,6-tetrachloroguaiacol tetrachloroguaiacol 3,4,5-trichlorocatechnol tetrachlorocatechnol 12-CDHA CDHA	**G**	2,3,5-trichlorophenol
		H	chloroform
		I	3,4-dichlorocatechnol
		J	dichloromethane
C	dichlorocatechnol	**K**	1,1,1-trichloroethane
D	2,3,4,5-tetrachlorophenol 2,3,4,6-tetrachlorophenol 2,3,4,5-tetrachlorophenol pentachlorophenol 4,5,6-trichloroguaiacol 3,4,5-trichloroveratrole 14-CDHA	**L**	trichloroacetic acid
		M	o-chlorophenol p-chlorophenol 2,6-dichlorophenol chlorocatechol
E	3,4,5-trichloroguaiacol 4,5-dichlorocatechnol 3,4,5,6-tetrachlorocatechol trichlorosyringol dichlorostearic acid DICDHA 1,1-dichlorodimethyl sulfone	**N**	trichloroethane
		O	chlorophenols 2,4,5-trichlorophenol dichlorodimethyl sulfone
		P	tetrachloroethene
F	2,4-dichlorophenol	**Q**	trichloroethene

Table A5.5: Ranking of compounds found in treated effluents based on effluent levels, log Kow, and fish toxicity.

A	2,3,4,5-tetrachlorophenol 2,3,4,6-tetrachlorophenol pentachlorophenol 3,4,5-trichloroveratrole	**H**	2,6-dichlorophenol
		I	trichloroethane
		J	chloroform
B	tetrachloroguaiacol 3,4,5-trichlorocatechol tetrachlorocatechol	**K**	dichloromethane
		L	o-chlorophenol p-chlorophenol
C	trichlorosyringol		
D	2,3,5,6-tetrachlorophenol 4,5,6-trichloroguaiacol	**M**	2,4,5-trichlorophenol
		N	1,1,1-trichloroethane
E	2,4-dichlorophenol 3,4,5-trichloroguaiacol	**O**	tetrachloroethene
F	2,4,6-trichlorophenol 4,5-dichloroguaiacol	**P**	chlorophenols
		Q	dichlorodimethyl sulfone
G	4,5-dichlorocatechol 1,1-dichlorodimethyl sulfone	**R**	trichloroethene

Table A5.6: Ranking of compounds found in treated effluents based on effluent levels, log Kow, and mammalian toxicity.

A	2,3,4,5-tetrachlorophenol 2,3,4,6-tetrachlorophenol tetrachlorophenol pentachlorophenol	**G**	dichloromethane chloroform carbon tetrachloride
B	3,4,5-trichloroguaiacol	**H**	1,1,1-trichloroethane
C	tetrachlorocatechol	**I**	trichloroethane
D	p-chlorophenol	**J**	2,6-dichlorophenol
E	tetrachloroguaiacol	**K**	o-chlorophenol
F	2,4-dichlorophenol 2,4,6-trichlorophenol 4,5,6-trichloroguaiacol chlorobenzene	**L**	2,4,5-trichlorophenol
		M	tetrachloroethene
		N	trichloroethene

Appendix 6

Informal Post-Meeting Discussion: Incorporating Other Stressors into the Fraser River Action Plan

The Fraser River System is subject to multiple stresses. Cumulative effects could confound both efforts to monitor and assess the state of the system and to detect the effects of any single stressor. This informal discussion focused on three questions:

1. Does the existing or planned monitoring network allow assessment of stressors both individually and synergistically?

2. Is there a unique environmental indicator to use to track a particular stressor?

3. What research is needed to identify indicators to track stressors both individually and synergistically in order to support assessment and meet environmental quality objectives?

These questions were addressed in the context of individual stressors and cumulative effects. This appendix summarizes the discussions which addressed these questions in an informal and brief style.

Mining and Mineral Processing

Existing Information/Activities

No systematic, province-wide monitoring network exists for mining and mineral processing in the province. There is, however, inspection of individual mines in order to ensure compliance with regulations. In some case, larger mines are required to do their own monitoring; however, each program is quite site-specific. The Environmental Protection Service is currently developing an environmental effects monitoring program for mines. A report (Keith Ferguson) on acid mine drainage in the Fraser Basin is due for release in the near future. Both alkaline mine drainage (e.g. Jack of Clubs Lake, east of Quesnel, Willow River) and acid mine drainage are an issue.

Both operating and abandoned mines are of concern. There is only one operating mine in the Cariboo Region and two mines near Prince George. There are two abandoned mines on the Thompson and Nicola of concern - the Highland and Samotosun.

There is currently no evidence of impacts from heavy metals released during the mining process. Historically, this has been a concern with processing, especially in the Lower Fraser. There are, however, high background levels of heavy metals in the Fraser River due to basin geology. For example, in Pinchy Lake there are high natural background levels of mercury as well as high concentrations in fish. Some concern was raised, however, about the relative contribution of mining. Other potential issues include elevated ammonia levels and direct impacts on fish habitat. DFO may be able to provide additional information regarding these concerns.

Research Issues

No research issues were identified in relation to mining and mineral processing. There was some concern about the potential impact of Molybdenum concentrations on cattle. In general, the greatest priorities were a province-wide system for monitoring impacts from mining and mineral processing, and mitigation of known impacts in existing or abandoned mines and mineral processing plants.

Municipal Sewage Treatment Plant Effluents

Existing Information/Activities

Information regarding municipal sewage treatment plants (STPs) is limited to the types of STPs (primary, secondary or tertiary), their locations (e.g. Kamloops, Prince George, Salmon Arm, Chilliwack Lilloet, and Lytton), and potential effluent constituents.

Research Issues

The greatest long-term research need identified was determining the capacity of the Fraser River to accept continuing discharges. There is an upper limit to the amount of material that can be processed by the system. Moreover, increased effluent discharges are likely based on projected population increases in the Fraser Basin. There is a modelling need to examine what is being released and the effects of these discharges. How will effluent discharge change (both quantitatively and qualitatively) with population growth? What is the impact of changing methods and levels of treatment on the quantity and composition of STP effluent? What is the capacity of the system to absorb effluent?

Shushwap Lake was suggested as one site for study of the effects of STP effluent and population growth on aquatic ecosystems. This could be compared with similar studies in Lake Washington near Seattle.

It will be difficult to separate out the impacts of STPs from other stresses like pulp mills. At Prince George, sewage effluent represents one-tenth the loading from the pulp mill. At Quesnel sewage is actually treated in the pulp mill along with its own effluent. To date the only problem has been elevated faecal chloroform counts in mill effluent.

The loading question may also be addressed through mesocosm studies. In turbid systems such as the Fraser River, nutrients may be less of an issue due to light limitations, especially in the lower Fraser. Some questions were raised about the effects of nutrient inputs from the Fraser to Georgia Strait. Jim Servizi did an analysis of this two decades ago; it would be worth revisiting his work. Paul Harrison (UBC Oceanography) has also done work on the Fraser River plume. He may be able to provide historical data on loadings and changes in productivity in this area of Georgia Strait. FREMP may be able to provide additional insight and ideas on these issues.

In the Thompson there are questions about the synergism between pulp mill effluent and sewage discharge. There are also questions about the implications of differences in the form of phosphorous found in each of these effluent types.

STP effluent is not just a nutrient issue; there is also concern about organics, metals (e.g. copper, cadmium and zinc) and other toxic compounds (e.g. PAHs). Copper does not contribute to acute toxicity in fish but may be affect plants in some areas. Ian Hutchinson at SFU is studying the uptake and accumulation of heavy metals in aquatic macrophytes.

Chloramine, used as an alternative to chlorine disinfection in drinking water, was also identified as a potential threat to fish. Chloramine is acutely toxic to fish. Most of the chloramine is broken down by the end of sewage treatment; however, concern was raised regarding water main breaks, leaks or spills (e.g. Fergus Creek).

Resident fish populations are non-specific integrators of many of these impacts. For example, fish MFOs respond to both pulp mill effluent and STP effluent. STP effluent can be more acutely toxic. For example, ammonia levels are often high enough to kill fish. Bioassays are not a provincial requirement for STPs, but LC50s are done regularly. The GVRD is the only place with an exemption for secondary treatment; however, unlike many plants upstream, effluent is dechlorinated.

Agriculture

Existing Information/Activities

The greatest problems identified were pesticides and nutrients in agricultural runoff. There needs to be an assessment of the actual input from agriculture and an examination of the management prescriptions for minimizing these inputs. It was pointed out that, unlike forestry or railroads, no permits are currently required for chemical use in agriculture so it is much more difficult to control. There is also no systematic monitoring or enforcement of regulations regarding chemical use.

DFO's toxic chemical program under the Green Plan is assessing many substances used in agriculture. Environment Canada is examining pesticides and nitrates in ground water in Abbotsford (Fish Trap Creek) where a problem is known to exist. Feedlots were identified as a problem along the Thompson (e.g. nutrient loading, sedimentation and habitat destruction in riparian zones). The Lower Mainland has a manure management system in place. The province does not see agricultural runoff as an issue in the mainstem Fraser.

Research Issues

A number of research and monitoring needs were identified. An inventory of the types and amounts of chemicals being used is needed (Mike Wong at Environment Canada should be able to provide some information on this). There is a need to begin to distinguish between loading from non-point and point sources. Some idea of total loadings is also required. This information is necessary if comparisons are to be made between agricultural runoff and pulp mill inputs.

Two areas were also suggested for initial study: the Salmon River in Langley and the Serpentine River. Both experience numerous agricultural stresses. DFO is already doing work on the Salmon River which is a major coho producer. It is also subject to creeping urbanization. The Serpentine River is surrounded by farmland (nonpoint sources). Ken Hall (Westwater Research Institute) has done work on both rivers.

Modelling was also suggested as a potential tool in examining this problem. Basin-wide or regional land use models which incorporate information about the chemical composition and quantity of runoff from various land uses would provide a means of assessing the relative contribution of various non-point sources of contamination. They would also provide a tool for policy analysis and trend projection since the impact of changes in land management, areal extent and spatial configurations could be examined.

Concerns were also raised about traditional react-and-cure approaches to managing agricultural impacts. We cannot just keep up with manure piles, we have to implement remedial action plans. The economic situation of individual farmers will require financial support to implement many of these remedial actions. Developing and implementing a code of farm practice was also suggested as part of the solution for these problems.

Urban Runoff

Existing Information/Activities

Concerns regarding urban runoff span a wide range of contaminants (e.g. road salt to PAH's). A number of constituents of concern were discussed including asbestos (from brake casings) and dust suppressants, metals, nutrients, PAH's and material with high BOD's. There may also be information available from FREMP, GVRD and the Burrard Inlet Action Plan (which are all supposed to be looking at storm sewer discharges). Paul Whitfield has been doing real time monitoring of storm water discharge quantity and quality on the Serpentine River.

One of the most important needs which were identified was a monitoring program and inventory of current runoff including quantities, chemical content and physical characteristics (e.g. temperature and turbidity). The province is doing *in situ* bioassays on suspended sediment taken from urban streams. These tests provide some indication of hot spot locations.

Research Issues

There are a battery of tests which may be performed on urban runoff. The greatest challenge, however, is to develop some standard (e.g. toxicity equivalents) to show the contribution of each constituent to overall toxicity. Burnette River is an important salmon stream (used by juvenile chinook) and was suggested as a good area to study the impacts of urbanization.

The development of storm sewer codes of practice was suggested as one possible mechanism for mitigating the impacts of urban runoff. Research may also be required on feasible options for treating storm sewer runoff.

Petrochemicals

Existing Information/Activities

There are a number of sources of petrochemical inputs into the Fraser River. Urban runoff is a substantial contributor. Inactive industrial sites are also believed to be a major source. For example, there is ground water contamination under the Kamloops refinery. Ground water is an important conduit for petrochemicals from contaminated sites (e.g. industrial facilities and service stations) to the Fraser River and its tributaries.

Research Issues

No specific research needs were identified with respect to petrochemicals. The most important issues were identification, monitoring and remedial clean-up of both non-point and point sources of petrochemical inputs to the Fraser River.

Forestry

Existing Information/Activities

The greatest concern with respect to forestry seemed to be the impact of harvesting. Questions were also raised about the effects of various silvicultural treatments such as fertilization (both with chemical fertilizers and potentially sewage), pesticide application (both herbicides and insecticides), road building, and possible changes in disturbance regimes. Impacts range from changes in timing and quantity of runoff to changes in water quality (e.g. nutrients, sediment, or toxins from slash burning or pesticides).

There is virtually no system-wide monitoring of these impacts taking place on the Fraser or its major tributaries. Furthermore, what monitoring is being done generally focuses on impacts on fish and wildlife habitat. Impacts on water quality has received relatively little attention. DFO's fish/forestry interaction project in the Stuart/Takla region is designed to assess the impacts of forestry on interior anadromous stocks.

Research Issues

The need for watershed studies similar to Carnation Creek was identified. These would provide more information on actual water quality impacts to help identify potential indicators for regional (i.e. synoptic) monitoring programs oriented towards both assessment and the development and implementation of water quality objectives.

Historical data is needed in order to determine variability and trends in impacts from forestry. Paleoecological data such as core samples (in order to determine historical trends in sedimentation) might provide a useful source of historical information. Spatial replicates (i.e. similar watersheds with different areal extents of logging) could provide one method for determining correlations among various impacts to rivers (e.g. annual nutrient export or sediment inputs) and the areal extent of logging.

An additional research need was identified with respect to technological changes. For example, aspen left on site can generate very toxic leachate (aspen leaching). However, aspen has recently become a "useful" species which may reduce this threat on site but increase impacts through waste left at mills. How will further changes in desirable species alter impacts from forestry?

Sawmills

Existing Information/Activities

There are a number of impacts associated with toxics used by sawmills. These toxics include wood preservatives, hog fuel leachate, preservatives, and anti-sapstain chemicals. There are also impacts associated with wood waste. The only monitoring program currently in place is for anti-sapstain chemicals.

Research Issues

Research needs which were identified include information about the toxicity of wood preservatives, alternatives to current anti-sapstain chemicals, and other uses for wood waste.

Landfills and Contaminated Sites

Existing Information/Activities

Contaminated sites are a major problem in the Upper Fraser River Basin. They also represent an important source of dioxins.

Research Issues

There is a need to assess problems related to landfills and contaminated sites in the lower Fraser. Some research is also required on the extent and impact of special waste disposal through storm sewers. Finally, there is a need to examine the management and impact of toxic waste disposal sites and current methods for controlling these impacts (e.g. EARP Panel Reviews).

Atmospheric Toxics

Existing Information/Activities

Deposition of atmospheric contaminants was identified as a major issue in the basin. Sources include incinerators, industrial emissions, and volatilization from non-point sources such as agricultural pesticide use and automobiles. Air quality monitoring is currently done by the GVRD and the province.

Acid precipitation was not identified as much of a problem due to high natural buffering capacity in interior streams. Isolated sensitive spots do exist, however (e.g. Pitt Lake and low pH lakes in the Prince Rupert region). It was pointed out that monitoring of acid precipitation should be part of an integrated air quality monitoring program.

Research Issues

While air quality was identified as an important issue, there were also serious information gaps identified. The most pressing research question seemed to be: Is atmospheric contamination having an impact? Research into Long-Range Transport of Atmospheric Pollution was also given high priority. For example, organic chlorines from pesticides such as lindane have been found in Kamata Creek, some distance from their suspected source. Analogies were drawn with studies of contaminant deposition in the Yukon (e.g. toxaphene) far from suspected sources. Studies of fish in Fraser Headwaters was suggested as one area of needed research.

Research into atmospheric toxics would be facilitated by an all-weather sampler for such things as organochlorines.

Hydroelectric Development and Reservoirs

Existing Information/Activities

A number of potential synergisms between hydroelectric development or river diversions and sewage treatment plants or pulp mills exist. For example, flow reductions may enhance the impact of nutrient loadings from these sources. They may also result in increased contaminant concentrations not to mention direct impacts on fish habitat and aquatic ecology. Water shortages may increase pressures on the resources of the Fraser River. Old diversion schemes could also be resurrected (e.g. diversions from the Thompson River and Shushwap Lake). Diversions into the Fraser River system (e.g. Kemano II) may pose a threat to stream ecology through the introduction of exotics.

Research Issues

Research is required regarding the interaction between flow reductions and other impacts. This may be achieved through a combination of research into current impacts from nutrient loadings and toxic discharges, laboratory/field studies to examine dose-response relationships and modelling to determine the impact of flow reductions on both water quality and, ultimately, stream ecology.

Socioeconomic studies regarding the likelihood, timing and degree of hydroelectric development or water diversions would also be useful. For example, how will current low flows in the Columbia River and existing or planned international water agreements affect flows in the Fraser?

Climate Change

Existing Information/Activities

According to existing models of climate change a plausible scenario for future climate would be increased rain in coastal regions and decreased precipitation in the interior. This will likely alter flows. Lower flows could contribute to desiccation of eggs and increased concentrations of contaminants from all sources. It would also increase water temperatures and possibly exceed the thermal tolerance of many fish species (many of which already tend to be close to their thermal limits).

Changes in sea level could produce profound impacts on the estuary including changes in deposition patterns. These impacts could be propagated up the Fraser (through, for example, changes in gradient). Ozone depletion, an associated global change issue, was identified as an important potential impact in the Fraser (work on this issue is being studied in the Thompson by Max Bothwell). There are numerous potential synergisms between these two global change issues. There is a need to develop and assess different scenarios of the nature and impact of global change.

Indirect, yet significant impacts also exist. For example, changes in climate will likely alter disturbance regimes (and therefore physical and chemical inputs to the Fraser River and its tributaries), species composition and forestry in general. Changes in species composition (both through introductions, natural turnover and planting) may alter silvicultural and pulping technologies. What are the implications of such changes for impacts from forestry and pulp mills?

Research Issues

Temperature is one variable which seems to be common to many of the impacts identified in the post-meeting discussion. Thus, research on the impacts of water temperature on various components and processes would also provide information to assess the potential impacts of climate change. Questions were raised regarding the potential implications of increased effluent concentrations **and** high water temperatures.

There is a definite need for modelling to assess both potential scenarios for climate change and their associated impacts. These impacts include both physical and ecological effects as well as indirect impacts through changes in forestry and pulp mills. Changes in flow and other stream characteristics may alter the assimilative capacity of the Fraser River system for pulp mill effluents and sewage treatment effluents among others.

Cumulative Impacts

Existing Information/Activities

Very little research into the nature and extent of cumulative impacts is currently being undertaken. Most research is focused on a single or limited range of subjects. Research into cumulative impacts, however, was seen as extremely important.

Research Issues

Demonstration watersheds were identified as the most useful means of carrying out interdisciplinary, integrated studies of cumulative effects (so-called eco-watch areas). One specific site already suggested was the Salmon River. At least two additional sites should be selected (one in northern B.C. and another in the Thompson area).

One existing mechanism for defining areas (Environmentally Sustainable Development Task Force within DFO), divides the Fraser Basin into 16 Habitat Management Areas (HMAs). The Thompson is composed of 2 HMAs. These areas were originally delineated to examine habitat sensitivity for anadromous fish stocks on a regional scale.

Based on experience with Carnation Creek watershed studies, it was pointed out that intensive monitoring and research in one location is often not enough. Such activities must be supplemented by extensive monitoring and research in other tributaries and along the main stem. Mobile testing labs were suggested as one tool for gathering data for multi-tributary cross-correlations of stress. In addition, some cumulative effects questions may be best examined through a combination of laboratory studies and modelling exercises.