AN ADAPTIVE IMPACT MONITORING AND MANAGEMENT STRATEGY FOR RESOURCE DEVELOPMENT PROJECTS

by

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ABSTRACT

This thesis advances a conceptual model of adaptive impact monitoring that is designed to overcome many of the criticisms plaguing conventional monitoring strategies. The potential for applying the adaptive model is demonstrated for the Peace River Site C dam proposed for northeastern British Columbia.

Environmental impact assessment (EIA) has progressed considerably from its early biophysical orientation to a more comprehensive, interdisciplinary process concerned with the breadth of environmental and socio-economic impacts of development. Impact monitoring, an essential EIA component, has also progressed but in a less innovative fashion. Consequently, conventional monitoring strategies often contain significant deficiencies including insufficient use of past experience, poor monitoring design, and failure to recognize the learning opportunity offered by each project.

Adaptive impact monitoring offers significant advantages over traditional strategies. An adaptive strategy is based on a series of impact hypotheses established and tested by an interdisciplinary design team and has two fundamental stages: design and evaluation.

A review of the potential environmental impacts of hydroelectric production indicates that the reservoir impact paradigm is beginning to provide a comprehensive basis for assessing development effects. Although the Site C EIA adequately reflects the reservoir impact paradigm, it has three significant weaknesses. First, the potential impacts on downstream ecology and distant downstream users are ill-considered. Second, the potential for increased Site C fisheries parasitism is neglected. Finally, estimates of maximum sustainable yield for the Site C reservoir and Peace River fisheries are unreliable.

While opportunities for future impact monitoring were recognized through the Site C panel hearings, they lacked flexibility. The potential impacts on downstream water temperature and fisheries resources are used to illustrate the applicability of the adaptive strategy and the advantages derived from collecting only relevant, statistically credible data to permit testing impact hypotheses in a cost-effective manner. On the basis of these findings, six major policy recommendations are provided for improving the effectiveness of impact monitoring and management for future resource developments.

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CHAPTER 1
INTRODUCTION

Environmental Impact Assessment (EIA) is a process which attempts to identify, predict and assess potential development impacts before irrevocable decisions are made (E.C.E., 1982). Monitoring is an essential EIA component. It describes the repetitive qualitative observation, or more preferably measurement, of environmental variables (Munro *et al.*, 1986). By designing monitoring to test impact hypotheses, it can be used to establish cause-effect relationships between project-induced impacts and affected environmental components. An adaptive monitoring approach allows for the adjustment of monitoring design if frequent data evaluation suggests that it is appropriate.

From its formal introduction in the early 1970s, approaches to EIA have progressed considerably. EIA has evolved from a narrowly focused effort concerned solely with the geophysical effects of development to an interdisciplinary activity considering wider-ranging implications: geophysical, ecological, and socio-economic. However, a review of the EIA literature reveals a recurring dissatisfaction with the design, implementation and, consequently, the results of impact monitoring. If satisfaction with monitoring as an EIA component is to improve, it is necessary to examine its current deficiencies and provide opportunities for their resolution. Unfortunately, monitoring has matured in a less innovative fashion than have general approaches to EIA. While innovative conceptual approaches to impact monitoring exist, they are only at the initial stages of being applied in practice. This thesis examines one such approach, adaptive monitoring, and suggests opportunities for its use with regard to the proposed Peace River Site C hydroelectric development. Its objectives are threefold:

1. To evaluate the EIA completed for the proposed Peace River Site C dam based on the current reservoir impact paradigm;
2. To evaluate the monitoring that was completed for the Site C EIA and the monitoring requirements arising from the Site C Panel hearings; and

3. To recommend opportunities for employing an adaptive impact monitoring strategy for future Site C investigations and illustrate its potential benefits.

Based primarily on a series of literature reviews, file reviews and interviews the thesis is divided into two sections: (1). *A Theoretical Framework* and (2). *A Case Study.*

I. THEORETICAL FRAMEWORK (Chapters 2 - 3)

Chapter 2 traces the evolution of EIA prior to its formal adoption in the early 1970s to the present. Accompanying a discussion of EIA legislation is a description of its evolving focus: from an early emphasis on geophysical impacts, to a recognition of the importance of socio-economic factors, to more recent applications of the principles of Adaptive Environmental Assessment and Management (AEAM), (Holling, 1978). Chapter 2 provides an historical perspective on general EIA development that supports a discussion of both its evolution in British Columbia (Chapter 5) and the particular assessment undertaken for Site C (Chapter 6).

Chapter 3 analyses monitoring approaches in EIA. It begins with a description and conceptual model of conventional monitoring practices. Major criticisms characteristic of many contemporary monitoring strategies are discussed: a poor reflection of environmental system understanding, an excessive collection of often statistically invalid data, and a failure to treat each project as a learning process. Two innovative approaches to impact monitoring that depart from conventional practices are then described. Both are based on the principles of AEAM and contribute significantly to the adaptive monitoring approach detailed at the end of the chapter. The adaptive monitoring discussion is based on a conceptual model emphasizing frequent data evaluation throughout the monitoring process. Its potential benefits are highlighted. Chapter 3 provides a necessary foundation for analysing the early monitoring completed for the Site C EIA and recommending opportunities for employing an adaptive monitoring approach for future investigations.

II. CASE STUDY (Chapters 4 - 8)

The case study draws from the theoretical background developed in the preceding section to examine the evolution of EIA in British Columbia and, in particular, to analyse the EIA and monitoring completed for Site C. In addition, and perhaps most importantly, the theoretical framework permits the application of the conceptual model of adaptive monitoring to Site C. Potential opportunities for the practical use of adaptive monitoring are illustrated.

Chapter 4 provides an overview of the current reservoir impact paradigm. It focuses primarily on northern-temperate reservoirs and the aquatic impacts associated with hydroelectric development. Five main categories of impacts are described including those on climate, morphometry and hydrology, water quality, lower trophic levels and fish. An understanding of the types of impacts currently known to occur with reservoir development is critical to evaluating the effectiveness of the Site C EIA in Chapter 6. It also supports the application of the adaptive monitoring model to specific Site C impacts in Chapter 8.

In Chapter 5 two specific Acts authorizing EIA in British Columbia are described: the *Environment Management Act* and the *Utilities Commission Act*. The latter is discussed in greater detail since it provided the legislative authority for the Site C EIA and public hearings. An example of an assessment completed under the *Utilities Commission Act* demonstrates the importance of legislative authority to EIA. Chapter 5 provides a foundation for the detailed analysis of the context of the Site C project and its EIA.

Chapter 6 begins with a description of the context of the Site C project including the respective roles of the main actors involved. The twelve-year period from initial feasibility studies to the present is divided into four phases: Project Initiation (1975 - 1976), Project Analysis (1977 - 1980), Project Evaluation and Recommendations (1981 - 1983), and Cabinet Decision to Present (1984 - 1987). The EIA completed for Site C is then examined. Based on the reservoir impact paradigm, the effectiveness of the Site C EIA in utilizing current environmental system understanding is evaluated. While emphasis prior to Chapter 6 is placed on the geophysical and biophysical effects of development, this chapter also details potential Site C socio-economic impacts. Although it lies beyond the scope of this thesis, their diversity and complexity suggest that socio-economic impact monitoring would also benefit from an adaptive approach.

In Chapter 7 attention is focused toward examining how well monitoring opportunities were identified through the Site C Panel hearings and report. It also analyses recommendations that were suggested for future monitoring research and design. As with Chapter 6, potential environmental and socio-economic impacts are both considered. However, emphasis is placed on the latter category of impacts as they provide an illustration for adaptive monitoring in the following chapter.

Chapter 8 applies the adaptive monitoring principles developed in Chapter 3 to potential Site C impacts on downstream water temperature and fisheries resources. These impacts span the range of difficulty in impact prediction and both were recognized as requiring monitoring to obtain sufficient information to permit effective project management. Recommendations for utilizing adaptive monitoring in relation to the above impacts are provided and the potential advantages of so doing are illustrated.

To conclude, Chapter 9 summarizes the major findings of both the theoretical and case study sections. Recommendations for improving impact monitoring strategies for both Site C and other resource development projects are provided.

I. THEORETICAL FRAMEWORK

The term theoretical, in the context of this thesis, describes a concept without reference to its practical application. The theoretical framework provides a foundation for analysing the case study in the following section. First, it establishes the general evolution of EIA approaches. This supports a more detailed discussion of its role in British Columbia with particular reference to the Site C EIA. Second, the framework describes conventional monitoring practices and criticisms surrounding them and illustrates two recent, innovative approaches to impact monitoring. Finally, the framework offers a conceptual model of adaptive impact monitoring which is later applied to potential Site C impacts.

CHAPTER 2
EVOLUTION OF EIA APPROACHES

2.1 LEGISLATION AND POLICIES

The introduction of the Canadian EIA process is one of the more innovative government initiatives introduced in recent times. EIA is innovative for two main reasons: (1). a decision-making process has been institutionalized to assess the impacts of development on geophysical, ecological, and socio-economic systems, and (2). in most jurisdictions public concerns in determining standards of environmental quality are recognized (Whitney and Maclaren, 1985).

A combination of 1960's influences, including a heightened ecological awareness, resulted in the U.S. Congressional passage of the *National Environmental Policy Act (NEPA)* in 1969. A powerful legislative tool, *NEPA* requires evidence that environmental considerations have been taken into account in relation to both federal projects and private development involving federal property or funding (Doremus *et al.,* 1978). This evidence must be submitted as an Environmental Impact Statement, the contents of which should include (1). a description and justification of the proposed action, and (2). an evaluation of the potential environmental impact (Fischer and Davies, 1973).

In 1971, the Canadian Federal Department of the Environment was established to ensure that federal departments and agencies considered the potential environmental impacts of proposed developments (Effer, 1984a). Its creation was facilitated by various factors including the U.S. adoption of *NEPA*, a political desire to pacify a vocal environmental movement, the increasing scale and complexity of public project developments, and the previously inadequate consideration of environmental and social concerns by existing project appraisal methods (O'Riordan and Sewell, 1981; Dorcey, 1984). A Federal Department of Environment task force, under the auspices of its first minister The Hon. Jack Davis, examined the *NEPA* policies and procedures and prepared a report that eventually led to the establishment of the

Canadian Environmental Assessment and Review Process (EARP) in 1973 (Lucas, 1981).

EARP was initially established by a Cabinet order, and was strengthened by a second Cabinet directive in 1977. In 1979 the *Government Organization Act* reaffirmed the federal Minister of the Environment's responsibility for the EIA of federal projects, programs and activities (Hurtubise and Wolf, 1980). In 1984, following ten years of evolution and a Cabinet directed evaluation of *EARP*, process improvements were proclaimed by an Order-In-Council. The Order-In-Council replaces and is stronger than previous Cabinet directives, but does not possess the legislative authority of *NEPA*, its U.S. predecessor (Marshall, 1987).

EARP's mandate is to ensure that the environmental and directly related social impacts of federal proposals are examined for potential adverse effects early in the planning process before irrevocable decisions are made. Federal proposals are categorized in four classes: (1). those undertaken directly by a federal initiating department [1], (2). those having an environmental effect on an area of federal responsibility, (3). those for which the federal government has a financial commitment, or (4). those located on lands, including the offshore, under federal government administration (C.C.R.E.M., 1985). *EARP* procedures provide for both preliminary and, if necessary, comprehensive project assessment and review. The initial assessment or screening stage involves an analysis of existing information, expert opinion and any additional studies that can be accomplished in the available time (Figure 1). It describes and evaluates the environmental consequences of the project and distinguishes those proposed actions without environmental consequence. Upon screening one of three decisions can result:

1. insignificant adverse effects or small mitigable effects, so project proceeds;
2. effects or ability to mitigate unknown, more detailed assessment required; or
3. significant environmental effects, comprehensive EIA required, FEARO establishes a panel to review the project.

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[1]. An initiating department is defined as "a federal department that has the decision-making authority for a proposal" (C.C.R.E.M., 1985:9).

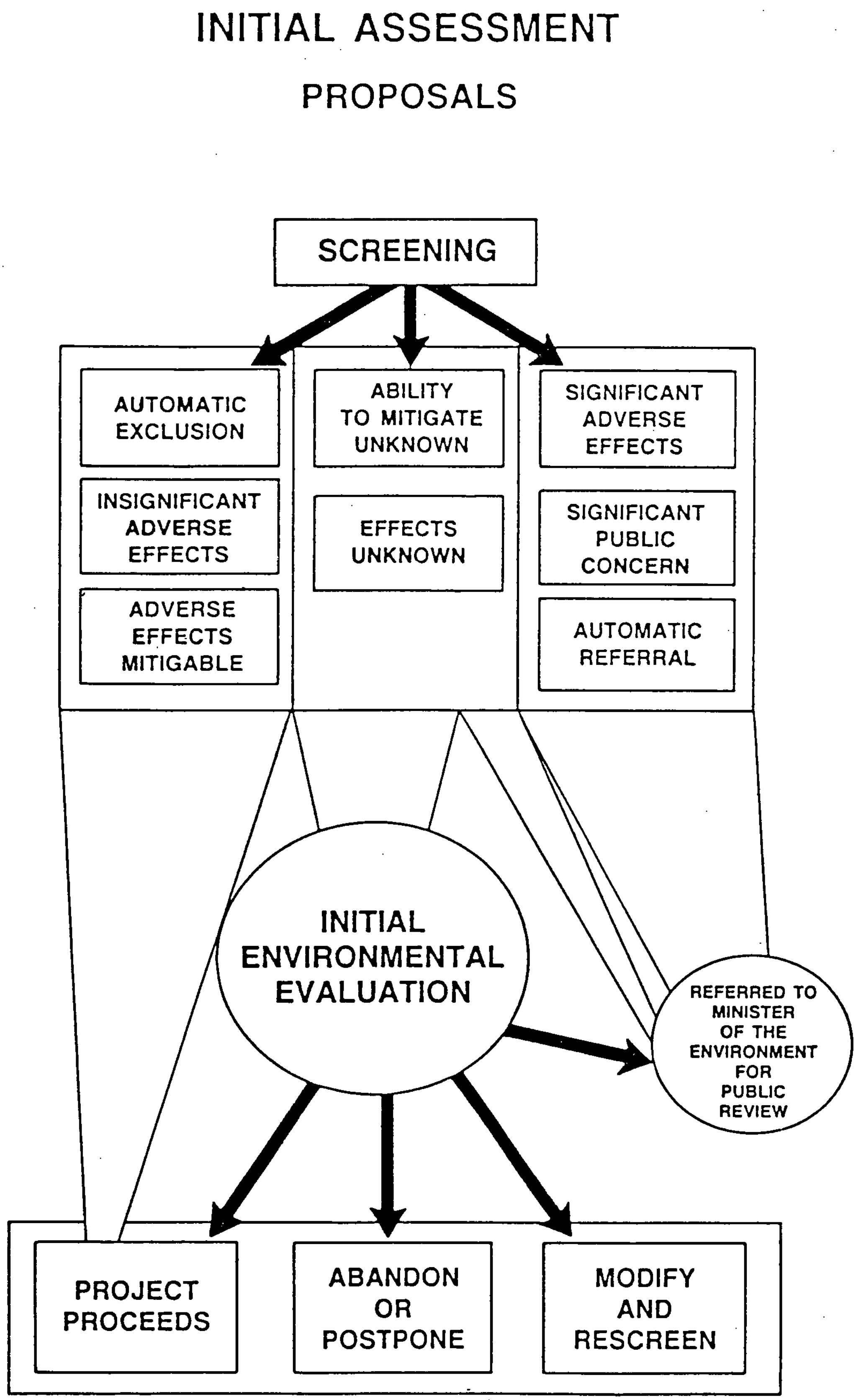

Figure 1. Federal Environmental Assessment Review Process: Initial Assessment Phase (FEARO, 1987).

Should there be potential for significant adverse effects an EIA is prepared by the proponent and submitted for panel review. The comprehensive assessment and review stage describes the environmental consequences of development in sufficient detail to permit the panel to make a recommendation on the proposal (Effer, 1984a). During the panel review public comment is invited either informally through written or oral submission, or formally through written submissions and their subsequent defense at a public hearing. Finally, the panel provides a recommendation on the acceptability of the proposal to the federal Minister of the Environment for a political decision whether or not to proceed with the project. If approval is granted it is usually with certain regulatory conditions as recommended by the review panel.

EARP is administered through the Federal Environmental Assessment and Review Office (FEARO) and its Executive Chairman reports directly to the federal Minister of the Environment (Couch *et al.*, 1983). Since 1984 FEARO has administered research on ways to improve the scientific, procedural and technical basis for EIA through its appointed Canadian Environmental Assessment Research Council (CEARC).

Provincial governments and their agencies derive their authority to carry out EIAs on projects involving provincial resources and financing from a variety of legal bases. Despite their obvious geographical, social, institutional and economic diversities, similarities exist with both the evolution and structure of provincial legal authorities (C.C.R.E.M., 1985). In 1975, Ontario was the nation's first province to pass an *Environmental Impact Assessment Act*. Quebec followed, amending the *Environmental Quality Act* in 1978 to include environmental assessment legislation. In 1980 Saskatchewan and Newfoundland also passed *Environmental Assessment Acts*. British Columbia strengthened EIA practices within existing statutes by passing the 1980 *Utilities Commission Act* and 1981 *Environment Management Act*. Provincial statutes provide authority for EIA in Alberta and Nova Scotia, while Manitoba, Prince Edward Island and New Brunswick EIA processes are based on government policy directives. The Northwest and Yukon Territories fall under FEARO administration. While similarities exist in their evolution, provincial EIA policies neither lagged behind nor directly reflected federal legislation. Indeed, several provinces' EIA policies progressed beyond the federal government's *EARP*. British Columbia, for example, witnessed its first major assessment independent of federal policy in 1974 for a hydroelectric proposal on the Pend-d'Oreille River. The assessment was completed under comprehensive guidelines established by the provincial Environment and Land Use Committee Secretariat (Dorcey, 1987a)

2.2 AN EVOLVING FOCUS

The evolution of EIA procedures may be conveniently grouped into four time periods: *prior to 1970, early to mid-1970s, mid-1970s to 1980, and 1980 to present.*

2.2.1 Prior to 1970

As evidenced by a lack of formal legislation or policy prior to 1970, environmental concern over development was not widespread. Economic and technological considerations, unencumbered by environmental interests, were the primary determinants of project feasibility. Economic cost-benefit techniques provided the principal tools for project assessment.

2.2.2 Early to Mid-1970s

Largely in response to a vocal environmental movement EIA became institutionalized in the early 1970s. Initially EIA was dominated by a "technocratic perspective" (Boothroyd and Rees, 1984:2). Concentrating on biophysical science, the early focus of EIA was on the product rather than the planning process. It became apparent that a major difficulty that resulted from the EIA requirement of *NEPA* was that a corresponding EIA methodology did not exist.[2] Consequently, the EIA process was established as a hybrid of existing planning methods being applied in a variety of fields: urban, regional, and transportation studies; and

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2. For a detailed examination of evolving EIA methodolgies please refer to McHarg, 1969; Leopold *et al.*, 1971; Dee *et al.*, 1973; Coleman, 1977; Sondheim, 1978; Munn, 1979; and Wathern, 1984.

water resources management projects (Pushchak, 1985). EIAs were often lengthy statements on the environment, incorporating extensive baseline data often insignificant to future analysis.[3] Schindler (1976:509), in his highly acclaimed critique of contemporary EIA practices, concluded that the information collected through monitoring often resulted in "...large, diffuse reports containing reams of uninterpreted and incomplete descriptive data [4], and in some cases, [the construction of] "predictive" models, irrespective of the quality of the data base."

Initially, social implications were not considered as significant and the overriding concern was with geophysical and ecological impacts in EIA. No opportunities existed for public participation in project screening or evaluation.

2.2.3 Mid-1970s to 1980

A dissatisfaction with convoluted, superficial EIAs encouraged practitioners to produce more focused, relevant studies during this period. EIAs began to reflect interdisciplinary concerns, however, emphasis was still directed toward geophysical and ecological impacts. Indeed, efforts were made at improving the scientific credibility of EIAs based on the predictive nature of the physical sciences. Boothroyd and Rees (1984:2) explain it thus:

> The assumption was that complex environmental and social systems are completely knowable: given sufficient information, we should be able to discover the basic laws governing their behaviour, and from this both predict and manage the negative impacts of any development proposal.

An extension of the prediction approach based on the physical sciences was reflected in the systems analysis research conducted in the mid to late-1970s. Computer models were

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3. Baseline data can also be described as pre-project monitoring. They are collected for environmental variables likely to be affected with project development.

4. Dorcey (1986) defines descriptive knowledge as that describing the elements of an ecosystem versus functional knowledge which describes cause-effect relationships between elements or processes.

developed in interdisciplinary workshop environments and were used as components of Adaptive Management strategies (Walters, 1975). Adaptive Management includes two approaches: manipulating existing facilities, or developing and analysing simulation models with similar characteristics to the proposed project, to obtain information on the potential effects of development; and/or observing the effects on the natural system as development proceeds so adaptive alterations can be imposed (Dorcey, 1987b). Adaptive management capitalizes on the reality that management decisions must be made. It involves testing specific project-related impact hypotheses by implementing management decisions and monitoring their results in a 'learn with development' fashion (Dorcey and Hall, 1981). Adaptations to management policy can then be arranged to help meet overall project objectives.

By the end of the 1970s it became apparent that despite the best efforts of qualified participants EIA was not meeting its initial expectations. While ecologists provided a much better understanding of complex natural systems, they were unable to offer a coherent theory of ecosystem behavior under stress (Boothroyd and Rees, 1984). Furthermore, biologists had difficulty both quantifying the natural system and correspondingly subjecting their data to rigorous analysis.

In the mid-1970s social scientists began to express an interest and become involved in impact assessment processes (Boothroyd and Rees, 1984). EIA started to consider the impacts of project-related changes on community development and infrastructure, life-styles, and regional economic opportunities. This period witnessed the first comprehensive examination of socio-economic impacts, directly related to environmental impacts, in project EIAs. Both the Mackenzie Valley Pipeline Inquiry (Berger, 1977) and the Lancaster Sound Offshore Drilling Project, Northwest Territories, considered socio-economic impacts and invited public participation for their evaluation (Marshall, 1987).

2.2.4 1980 to Present

The 1980s are witnessing more integrative approaches to EIA. Interdisciplinary teams linking scientists, project and government managers, and technicians are increasingly producing EIAs that transcend the earlier voluminous reports on the environment. The focus of EIA is progressively turning toward integrated project management equally addressing potential geophysical, ecological, and socio-economic impacts of development. However, the recent conceptual advances in EIA are only beginning to be reflected in practice.[5] Boothroyd and Rees (1984) suggest that a new EIA paradigm may be emerging, particularly in Canada. The new paradigm places EIA as a component of the development planning process rather than simply a regulatory response-to-proposal or scientific research activity. The development planning process is an evolving political activity by which society makes choices concerning resources management. The extent to which this will develop is yet unknown. Rees (1980:373) cautions that:

> In short, since EARP remains largely a reactive mechanism with a questionable record even in merely assessing the environmental consequences of individual undertakings, it cannot realistically be expected to assume successfully the lead role in what should be regional development planning.

Despite a perceived federal commitment to *EARP*, and firm *NEPA* legislation, there is widespread disenchantment surrounding the greater influence on project approval enjoyed by traditional institutional, political, and economic issues than ecological or social concerns identified through EIA. Pushchak (1985) describes a resistance to legislate EIA in Canada due to a desire to maintain flexibility to balance environmental concerns with political needs. The perceived benefits to government(s) of discretionary powers were enforced by the political difficulties experienced in the U.S. over the delay in the Trans-Alaska Pipeline development due to *NEPA* requirements bound in legislation. Initially delayed while EIAs and native land claims were settled, the 1973-74 oil shock made it politically imperative for the U.S. to

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5. For example the proposed Beaufort Sea Hydrocarbon Development EIA and subsequent monitoring program (to be discussed further in Chapter 3).

increase energy self-sufficiency by approving the pipeline. *NEPA* lacked flexibility so Congress, under public criticism, overrode it and obtained project approval (Jackson, 1976; Pushchak, 1985). Debate exists over the contentious issue of project exemption from a review process characteristic of all Canadian federal and provincial jurisdictions. Some jurisdictions utilize explicit 'exemption provisions', others, including the federal and British Columbia governments, make exemptions informally at the screening and terms of reference stage. The difficulty with Canadian discretionary power, as opposed to *NEPA's* rigid legislation, is well described by Emond (1985:71):

> ... EIA is a concept that is still not well accepted by government. The theory may be persuasive, but if the practice inconveniences a proponent and requires that decision-making be restructured, the pressure to dispense with EIA [by either formal or informal exemption] is almost irresistable.

While the above EIA deficiencies require attention, it is important to remember that EIA is yet in its infancy, but has matured considerably over its relatively short, but continuing evolution (Slaymaker, 1987).

Experience with EIA is providing an increasing awareness that instability is an inherent characteristic of any ecosystem. Thus it is only prudent to maintain flexibility to react to unexpected impacts or events. The concept of Adaptive Environmental Assessment and Management (AEAM) recognizes this fundamental ecosystem characteristic and has begun to be reflected in recent EIAs (Holling, 1978; Jones and Greig, 1985). AEAM principles are exploited in the development of an adaptive impact monitoring strategy and therefore require further discussion.

AEAM challenges the assertion that more information necessarily leads to better decision-making. Rather, this approach argues that the main function of impact assessment is not cataloguing data on every conceivable impact but to more rigorously analyse potential critical impacts of development. It has two major components: (1). the orchestration of key scientists, managers and decision-makers in a series of interdisciplinary workshops; and (2). the use of dynamic systems modeling to "...limit the scope of the environmental assessment to relevant factors affecting decisions" and "...help identify important gaps in data and understanding that must be filled before an important decision can be taken" (Everitt, 1983:294). The latter is especially important to monitoring design and implementation.

A series of modeling workshops provide the foundation for AEAM. They are facilitated by a workshop staff experienced in computer modeling, systems and policy analysis, and group dynamics (Holling, 1979). The first workshop, two to five days in duration, attended by all participants, defines the problem and establishes its limits or boundaries (scoping and bounding). The system under consideration is divided into a small number of usually disciplinary subsystems. Participants then enlist in groups and develop a submodel associated with their particular subsystem. Before each group fulfills their individual tasks a 'looking outward' exercise is performed where interdisciplinary communication is encouraged by "...requiring each subgroup to specify the information it requires from each of the other subgroups, to make predictions concerning the indicators of relevance to that subsystem" (Jones and Greig, 1985:31). A crude outline of the model is then developed and its information requirements are determined.

By the end of the first workshop preliminary model testing may occur by subjecting it to various management actions (scenarios) and noting the response of model variables. It can then be adjusted according to group consensus (Everitt, 1983). Everitt further emphasizes that the model, while only a caricature of the real world, has a group perspective far superior to that of an individual. It also develops communication avenues and identifies information gaps and research priorities.

Research required to fill information gaps and better operate the model is conducted prior to the second workshop. The information is then incorporated into the model and it is tested more rigorously during the second and possibly additional workshops. Initial workshops focus on technical matters, subsequent workshops concentrate on communicating results to managers and decision-makers. Some workshop members may be involved in monitoring activities resulting from the assessment (Holling, 1979). Everitt (1983:296) summarizes the key factors of AEAM:

> a. Ecological and environmental knowledge is incorporated with economic and social concerns at the beginning of a strategic analysis rather than at the end of a design process;
>
> b. Since linked resource/social systems are dynamic rather than static and linear, techniques of simulation modelling, qualitative modelling, and policy design and evaluation are used to reflect these features;
>
> c. Scientists, managers, and policy people are involved and interact from the beginning and throughout the process of synthesis, analysis, and design so that learning becomes as much of a product as does problem solving;
>
> d. Direction, design, and understanding are in the hands of those from the region who analyze, select and endure policies rather than in the hands of a separate group of analysts who lack the knowledge of needs, the responsibility and the accountability; and
>
> e. Although prediction can be improved, AEAM recognizes that the uncertain and unexpected lie in the future of every design. Hence policies are designed both to explore opportunities and pitfalls as well as to fulfill immediate social needs.

The principles of AEAM are fundamental to the adaptive monitoring strategy advanced in Chapter 3.

CHAPTER 3
MONITORING APPROACHES IN EIA

3.1 TRADITIONAL PRACTICES

As defined earlier, monitoring refers to the repetitive qualitative observation, or more preferably measurement, of environmental variables (Munro *et al.,* 1986). While many variations exist, Figure 2 illustrates the common relationship between project development and monitoring; it also depicts the information requirements of each monitoring phase. Baseline monitoring is defined here as pre-impact studies conducted at the potential development site which are later contrasted with construction and operation monitoring to determine changes attributable to project development. Information for mitigation and compensation purposes is required throughout all stages of development. Similarly, experimental information, not necessarily related to project management may be desired. In general, the latter would advance the scientific understanding of the environment but would not necessarily contribute to immediate project management. Inspection information is necessary to ensure that project construction and operation comply with prescribed regulations.

Rosenberg *et al.* (1981) suggest that current monitoring practices may be the most critical element of EIA because the information collected from monitoring determines the value of assessment techniques and the accuracy of impact predictions. It also indicates excessive impacts requiring immediate mitigation, and provides information for regulating project operation. Holling (1978) describes the importance of monitoring for providing essential experience and data to advance the scientific basis for EIA. Current monitoring strategies can also provide useful case-history information to improve the basis for examining future developments.

During and immediately following the 1972 U.N. Conference on the Human Environment (Stockholm Conference) substantial resources were devoted to monitoring design

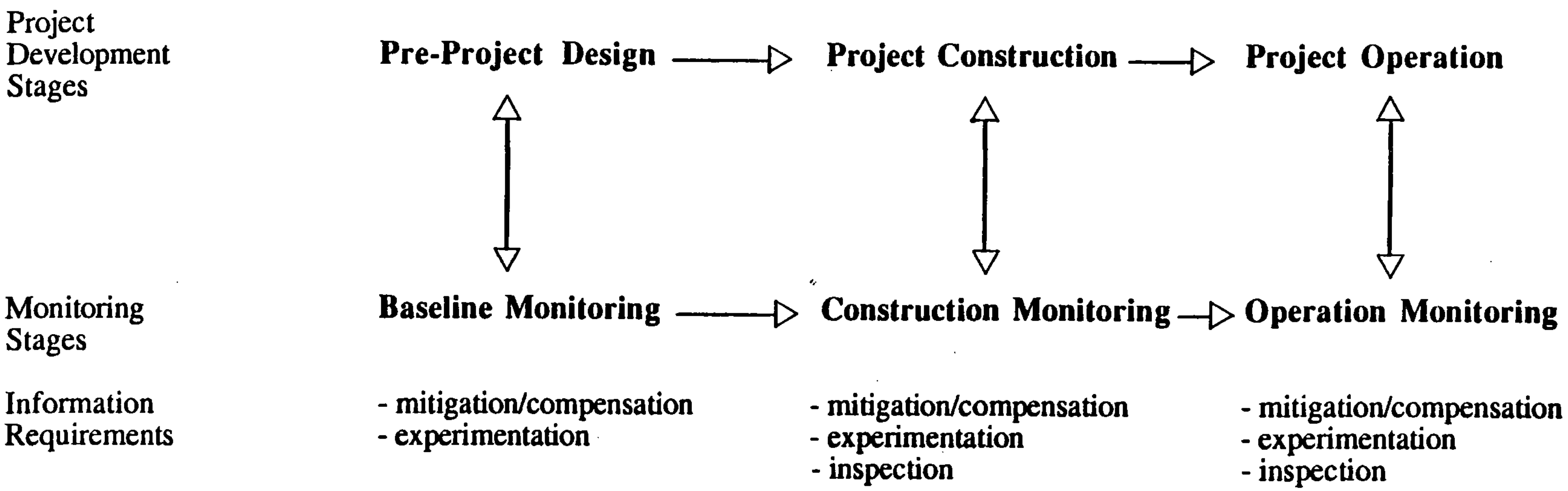

Figure 2. The Common Relationship Between Project Development and Monitoring.

and operation (Sors, 1984). This effort was primarily aimed at the international level (e.g. Global Environmental Monitoring System), but there was optimism that consequent procedural improvements and increased understanding would facilitate the refinement of more regional, even local monitoring practices. Despite the "considerable resources" devoted to monitoring, Sors (1984:366) among others (Schindler, 1976; Munn, 1979; Rigby, 1985) stress that monitoring practices have failed to meet initial expectations.

3.1.1 Criticisms of Traditional Monitoring Practices

Although there is currently a strong emphasis being placed on developing effective monitoring procedures, criticisms surrounding their design and implementation remain numerous. A principle factor contributing to the current dissatisfaction with monitoring is that in relation to its parent EIA process, a disproportionately small amount of attention has been afforded to better define and develop monitoring strategies (Rosenberg and Bodaly, 1986). Rather, early monitoring programs were very ambitious and consumed considerable resources but were designed without clear objectives and were therefore of limited value. The scientific and technical complexity of monitoring design has emerged gradually, and it is clear that the questions of what, where, when and how to monitor are more difficult to answer than was originally anticipated (Sors, 1984). These problems and the criticisms to follow, result from inadequate consideration being given to the fact that monitoring "...is not an end in itself, but an essential step in the process of environmental management" (The Rockefeller Foundation, 1977).

While the relationship illustrated in Figure 2 is commonly followed, much too frequently serious deficiencies such as omitting baseline or operation monitoring occur. Comment Rosenberg *et al.* (1986:773): "...there are few examples of e.i.a.'s for which both predictive and monitoring phases are available. Unfortunately the monitoring and assessment phase is usually deleted." The authors refer to the common problem of EIAs offering many pre-development impact predictions but failing to verify them through post-development monitoring. Duinker (1985:125) concurs describing the "dismal" record of effects [construction and operation] monitoring in Canada. When monitoring is completed it is often plagued by one or more of the following criticisms.

1. Monitoring programs fail to adequately utilize past experience, such as existing case studies and, thus, do not reflect the current state of environmental system understanding.

Holling (1979:5) describes a traditional myth of impact assessment: *"Each new assessment is unique."* he adds "In fact, all ecological systems face some common problems, and the ecological literature can throw some light on them." However, as Andrews (1978) suggests, there is insufficient use of the existing literature which results in poor environmental system understanding during monitoring design. Dorcey and Hall (1981:9) describe the utilization of existing comparative case studies as "desk analyses." Desk analyses exploit the results of previous monitoring efforts to help fill information gaps and contribute to the effective design of future monitoring programs. One of the fundamental difficulties with monitoring design is selecting and quantifying specific biotic conditions while allowing for natural variability in time and space (Hinds, 1984). Comparative case studies--especially those in the same geographical region--would greatly facilitate choosing variables for analysis and designing a monitoring strategy to measure how they are affected by development. Adequate desk analyses, using existing development information, would increase environmental system understanding during monitoring design. It would also improve the overall cost-efficiency of monitoring design and implementation by reducing duplication of effort.

Although useful insights can be gained, Rosenberg *et al.* (1986) caution against placing too much confidence in analogy--comparative case studies--due to often overriding factors of site-specificity. Holling (1979:4) adds that the ecological effects of development are not uniform, "Different areas react in different ways." thus increasing the uncertainty surrounding analogy.

In addition to the insufficient use of existing information and consequential poor reflection of environmental system understanding, Beanlands and Duinker (1983) report that there has been little regard to the incorporation of ecological principles in EIA. This lack of ecological perspective in EIA was partially a result of the little experience available to draw upon in drafting initial legislation and policies. Furthermore, there was initially little incentive to incorporate ecological principles in EIA for two reasons: (1). its objectives and the roles of participants were so poorly defined that there was little interest in technical details, and (2). "...it is generally accepted that decisions on project approval are often based on social, political and economic factors, and secondarily on environmental concerns" (Beanlands, 1985:4). He further argues that the major impediments to improved ecological consideration in EIA and monitoring are (1). Technical - the limits of ecological knowledge, natural system variation, a tendency to only refer to familiar, previously-managed systems, a focus on the population level, and a lack of supporting research; and (2). Political - the arm's length philosophy of government-industrial proponent relations, the intertia of bureaucracy and resistance to immediate change, and financial and manpower constraints.

2. *Poor monitoring design often results in two deficiences.*
    A. *excessive data collection, much of which is of little use to managers or decision-makers because their needs were not considered from the outset.*

Poor monitoring design often results in studies being produced that are "...generally lengthy descriptions of the existing biological system" (Valiela, 1984:143). While scientifically interesting, such studies rarely answer questions important to impact and project management. This is primarily because monitoring strategies are not designed from the outset to answer specific management questions or to test specific impact hypotheses. Hollick (1981) states that there is a mismatch between the needs of the proponent and those of the reviewers. As a result excessive data, often insignificant to future analysis, is collected. Hirsch (1980) agrees, adding that more functional and relevant studies are required describing the important components and processes comprising environmental ecosystems.

B. statistically invalid data collection due to a lack of consideration of spatial-temporal controls, analytical techniques and methods of data analyses.

Similar to the problem with data irrelevance, statistically invalid data is often collected largely because the question of what is necessary to maintain statistical credibility is not posed during monitoring design, implementation and operation. Similarly, the question of what is required of the data for future statistical analyses is ill-considered. The question of what degree of statistical power is necessary to test impact hypotheses must be addressed to ensure that the data collected will contribute to subsequent analyses so that monitoring effort is not extended unnecessarily.

A fundamental difficulty results from trying to differentiate development-related impacts from natural system variability. To do so, both time-series (temporal) and spatial controls are necessary. Baseline monitoring--data collection prior to development--provides one source of temporal control. Hilborn and Walters (1981:266) argue that most EIAs involve one or two years of fieldwork prior to development which is "...not nearly enough time to observe the natural variability in the system. Baseline studies must be of a much longer duration." Furthermore, baseline monitoring is often not designed in relation to construction and operation monitoring. Hence, rather than strengthening the statistical validity of the baseline monitoring, construction and operation monitoring measure entirely unrelated variables. This results in the cost-ineffective compilation of unnecessary descriptive data.

In an analysis of the data collected for numerous reservoir impact assessments Rosenberg *et al.* (1981) state that often no control conditions were established, no accounts were made to explain variance in baseline data, and sampling site selection was often determined by convenience at the expense of ecological rationale. Furthermore, physical and biological data were often collected at 'grossly' different times which precluded the possibility of even correlation.

The deficiencies in designing statistically credible monitoring programs become especially important since, as Hammond *et al.* (1983) suggest, scientific statements are usually probabilistic while policy decision-makers prefer singular, discrete choices from fixed, mutually exclusive alternatives. Although such requirements can seldom, if ever, be fulfilled, it emphasizes the need to provide information that is at least statistically defensible. Furthermore, both the relevance and statistical credibility of the data collected play major roles in determining the monitoring program's cost-effectiveness. Hinds (1984:13) explains it thus: "...where many years of effort and expense may be involved. If a biologically significant change cannot be determined to be real, the monitoring effort is a failure."

3. Monitoring strategies are neither designed to treat each project as a learning process nor to improve the basis for examining future developments.

Another major deficiency of current monitoring practices is the failure to use the results of each project through desk analyses to improve the basis for future developments. Currently, a principal reason for the inadequate use of past experience in monitoring design is that past performance is rarely evaluated or documented (Beanlands and Duinker, 1983; AIM Ecological Consultants Ltd., 1985). In addition to facilitating future monitoring design, the information derived from previous monitoring efforts can improve capabilities in impact prediction, assessment, and mitigation. Clearly, the failure to treat each project as a learning process and take advantage of past experience results in an unnecessary duplication of monitoring effort with each new development.

The Adaptive Management principles discussed in Chapter 2 provide considerable opportunities to treat each project as a learning process. Particularly useful is the technique of manipulating existing facilities or projects to simulate effects that will be caused by the proposed development on equivalent temporal and spatial scales. Impacts can be assessed and extrapolated. Even if not perfectly transferable--due to site-specific factors--they will give a very good indication of potential impacts and their magnitude. Such experimental approaches are especially beneficial in relation to "all-or-none" projects such as hydroelectric developments because their scale and the complexity of the system affected often limit the effectiveness of simulation modeling, comparative studies, or limited development (Valiela, 1984:157).

Monitoring is often perceived as being prohibitively costly. Buffington (1978) indicates that environmental monitoring consumed approximately seven to eight-hundred million dollars in the U.S. alone in 1977. He does not contrast this figure to total project expenditures. However, Munn (1979) suggests that the total preparation of an EIA (including monitoring, but excluding screening of alternatives and design) probably absorbs about 0.1% of the capital cost of a project. In contrast, engineering fees and project design may require up to 10% of the total project cost. Thus, the cost of monitoring does not appear exhorbitant. However, Duinker (1985) describes the large amount of debate within the Canadian EIA community over who should fund, carry out and review project monitoring. While there is little argument that the proponent should fund pre-project approval EIA studies, the financial burden of operation monitoring is much disputed. Proponents are reluctant to fund research primarily oriented toward increasing scientific knowledge. Therefore, a principal difficulty that is impossible to resolve completely, but essential to recognize while developing monitoring strategies is the diverse, often opposing perspectives held by those who design, fund, and subsequently use the results of monitoring programs. The major participants usually include *industrial proponents (including provincial utilities), government regulators, scientists,* and *consultants.*

Industrial Proponents (including Provincial Utilities)

Miller (1984) asserts that many proponents' standard set of operating procedures, policies, deadlines and long-range plans will cause certain preconceptions to be reflected in the way they direct and respond to the EIA and its monitoring component. Beanlands and Duinker (1983) add that proponents will normally only establish monitoring programs when required to under permit/licence conditions, as a reference base to determine adequate compensation, as a basis to dispute project over-regulation, or perhaps most importantly, to expeditiously facilitate project approval. The inclusion of long-term monitoring strategies, beyond those required to pacify government regulators in the initial EIA are neglected. Understandably, proponents are reluctant to fund monitoring to obtain information that they feel is simply improving scientific knowledge.

Government Regulators

Beanlands and Duinker (1983:22) state that "Government administrators tend to view environmental impact assessment as the fulfillment of required procedures as set by policy or legislation." Terms of reference for the study are often lists of tasks with insufficient consideration of scientific direction or performance standard requirements. Unfortunately, analysis of technical/scientific quality is only considered when the monitoring is completed and submitted for review. Government regulators tend to focus on a wide range of issues and make value judgements, particularly when confronted with alternatives (Turnbull, 1983). They especially value operational monitoring for assessing the efficacy of mitigation, and for inspection purposes. Government regulators are responsible for representing the general public interest during monitoring design and implementation.

Scientists

Despite their apprehension to become involved in EIA due to time and political constraints, scientists are often consulted in the preparation of EIA guidelines. These constraints, however, usually preclude the adoption of acceptable science in EIA. Scientists view monitoring as a means of hypothesis testing or verification of impact predictions; both of which lead to increased understanding of the effects of development on the environment. As opposed to government regulators, scientists tend to focus on specific sets of variables and their relationships, and discredit value judgements as being unscientific (Turnbull, 1983). Miller (1984) adds that the scientific usefulness of the final report (EIA) is reflected in the acceptable presentation of quality data in a sound analytical framework. Unfortunately, such stringent requirements are infrequently established during monitoring design.

Consultants

Most often consultants, retained by proponents, have the task of preparing EIAs. They must translate vaguely stated direction into short-term lab and field studies. Under proponent scrutiny, they must minimize their efforts to that required for project approval, while ensuring that the data collected are acceptable so that project delay does not result. Thus, a compromise is necessary between the approval required by the government, the time and budgetary constraints imposed by the proponent and the "...scientific and technical standards they [consultants] would like to adopt to ensure acceptance within a process that is essentially a peer review" (Beanlands and Duinker, 1983:22).

The difficulty in establishing effective monitoring strategies is further aggravated by the fact that EIA is a relatively young discipline (only institutionalized for approximately 15 years). Thus, although new and innovative impact monitoring strategies have evolved, there are always associated time lags between the development of new ideas to their assimilation in common practice and incorporation into formal guidelines.

3.2 RECENT INNOVATIVE APPROACHES

Two innovative approaches to impact monitoring which remedy many of the above criticisms have recently emerged: the Beaufort Environmental Monitoring Project (BEMP) and Environmental Effects Monitoring (EEM). Both utilize the principles of AEAM described in section 2.2, and the concept of valued ecosystem components (VEC). Beanlands and Duinker (1983) define VECs as resources that are important to local human populations or are of national or international significance, and if affected, will be important in evaluating the impacts of development and in focusing management policy.

EEM is a conceptual strategy for impact monitoring developed by Environment Canada. The EEM concept was recently evaluated in a series of workshops attended by government managers and technicians, industry representatives, and consultants. EEM provides draft guidelines and policies for Environment Canada that:

1. are relevant to operational, middle and senior managers within Environment Canada;

2. provide technical direction for the design of EEM programs within Environment Canada;

3. provide management direction on the establishment and management of EEM programs within Environment Canada; and

4. improve Environment Canada's role as an advocate and advisor in EEM when reviewing EISs, intervening at Panel hearings, advising other government departments on the design and management of EEM programs, establishing baseline information needs, etc. (Conover, 1987:408).

EEM, like the BEMP, has considerable potential for advancing the state of impact monitoring. Unlike the BEMP, however, EEM [1] has not been applied in practice. The BEMP has and, thus, provides the following illustration of recent innovative approaches to impact monitoring.

Beaufort Environmental Monitoring Project

The BEMP was initiated in 1983 and continues to "...provide INAC [Indian and Northern Affairs Canada] and Environment Canada with the technical basis for design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany phased hydrocarbon development in the Beaufort Sea" (LGL Ltd. *et al.*, 1985:xx). It considered a multitude of potential environmental issues while realizing a limited financial budget. The BEMP:

1) addresses those impacts that could be most significant if they occurred;

2) is based on the best current understanding of industrial development scenarios and ecological processes;

3) has the capability to respond to changing industrial development scenarios and new information regarding ecological processes in the region; and

4) represents the majority viewpoint of a broad range of disciplinary specialists with the necessary experience

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1. For a detailed discussion of the EEM concept please refer to Conover (1987).

> in research and environmental management in the Beaufort Sea (LGL Ltd. *et al.*, 1985:xx).

Following the AEAM interdisciplinary framework, an initial BEMP workshop convened in 1983. Through it, and a series of discipline-specific technical meetings, a computer simulation model was developed and refined. A conceptual model formed the foundation for developing the simulation model, and also provided a framework for establishing a set of impact hypotheses. Impact hypotheses are sets of statements linking development activities with their associated environmental effects. Everitt *et al.* (1986:253) describe their three primary components:

1. The action (development activity) - that which is the potential cause of an effect.
2. The valued ecosystem component (VEC) or indicator - that which is the measure of the effect.
3. The linkages - that set of statements that link the action to the VEC.

Impact hypotheses are determined by tracing through a set of linkages from development activity to VEC.[2] They offer two principal advantages: (1). the reasons for the prediction are explicitly stated in the hypothesis, and (2). they provide a consistent framework for comparison with other developments if adequate information is available (Sonntag, 1987).

A second workshop rigorously evaluated the impact hypotheses which provided the basis for monitoring design. The systematic evaluation proceeded through five steps:

Step 1. Clarification of the Hypotheses: achieving consensus within the working group over the structure of hypotheses and, if necessary, restating the hypotheses and/or their associated linkages.

Step 2. Documentation of Existing Knowledge: the following information was collected for all linkages constituting the hypotheses:
- a. evidence for and against,
- b. uncertainties,
- c. other potentially useful information, and
- d. description of model projections (when appropriate).

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2. For a more detailed description and examples of impact hypotheses determination please refer to LGL Ltd. *et al.* (1985).

Step 3. Conclusion: based on Step 2 working group participants arrived at one of four conclusions. They were that a given impact hypothesis:
   a. was extremely unlikely and not worth testing,
   b. was possible, but too difficult to detect,
   c. required more information prior to monitoring plan development, or
   d. should be tested with a detailed monitoring program.

Step 4. Monitoring and Research: if either conclusion c. or d. were reached in Step 3 a discussion focussing on the linkages of the hypotheses was initiated. In order to design a monitoring plan to test the impact hypotheses the discussion addressed the following questions:
   a. what do we monitor ?
   b. what do we want to know ?
   c. what do we actually measure to achieve a. and b. ?
   d. what information will we get from these measurements ?
   e. how does this achieve our goal of what we want to know ?

Step 5. Documentation: a recorder from each working group was responsible for ensuring that documentation of discussions surrounding the impact hypotheses were submitted daily (LGL Ltd. *et al.*, 1985).

Monitoring, defined as the repetitive measurement of variables designed to detect changes directly or indirectly related to development, was used to test impact hypotheses (LGL Ltd. *et al.*, 1985). The BEMP was not established to address all of the fundamental knowledge gaps existing in association with Beaufort development, but rather to identify and implement the monitoring and research necessary for effective environmental management. Following a recent workshop (December, 1986), Duval (1987) suggests that the BEMP--in its fourth year of operation--has proven very successful in achieving its goals. Indeed it provided a foundation for a similar program studying potential development impacts on the Mackenzie River, N. W. T. (Mackenzie Environmental Monitoring Program, 1985). Although the above description of the BEMP is incomplete, it does illustrate the project's innovative use of adaptive principles.

3.3 ADAPTIVE MONITORING

The following adaptive approach is based on the principles of AEAM and borrows significantly from the BEMP framework. Until the application of the BEMP, monitoring strategies were either reactive or proactive with little flexibility to change. Adaptive monitoring encourages adjusting monitoring practices should frequent data evaluation suggest that it is appropriate.

The development of an adaptive monitoring strategy requires the participation of an interdisciplinary monitoring design team. The membership of the team will vary with the project under consideration, but should include representation from all of the parties involved with project development: government managers and technicians, industry representatives, the affected general public, and consultants. An interdisciplinary setting facilitates disciplinary specialists gaining an appreciation of another's view of the problem and encourages a more comprehensive coverage of the potential impacts of development. The most appropriate monitoring team members will likely include those involved in the project EIA since they will be most familiar with the potential project-related impacts.

Once assembled, the interdisciplinary team can begin to develop an adaptive monitoring strategy. Adaptive monitoring has two fundamental stages: *Adaptive Monitoring Design and Adaptive Monitoring Evaluation.*

Figure 3 illustrates the steps required for Adaptive Monitoring Design. The sequence of adaptive monitoring design steps will vary with the project being considered and the background information that exists describing the local environment. These steps advance the monitoring strategy from an initial identification of VECs to the development and evaluation of impact hypotheses and specific monitoring programs designed for their testing. Included is the desk analysis (review) of comparative case studies to facilitate the monitoring design process. Experimental design and statistical requirements for impact hypothesis testing must be clearly identified (steps 4, 5, and 8). The identification of potential mitigation options relevant to each impact hypothesis is also necessary.

Upon completion of the design steps (Figure 3), adaptive monitoring to test impact hypotheses can be initiated. Once it has begun, the second fundamental requirement of an

1. Identification of Valued Ecosystem Components (VEC)
2. Review of probable industrial development scenarios and comparative case studies
3. Identification of impact hypotheses relating development activities to VECs
4. Definition of the study area
5. Definition of the temporal horizon for monitoring
6. Preliminary screening of impact hypotheses for validity, relevance, and credibility
7. Selection of impact hypotheses to be monitored
8. Establish monitoring requirements for impact hypotheses testing
9. Identification of potential mitigation options available relevant to the respective impact hypotheses
10. Initiation of adaptive monitoring

Figure 3. Adaptive Monitoring Design Steps (after LGL Ltd. et al., 1985).

adaptive monitoring strategy is required: Adaptive Monitoring Evaluation (Figure 4). The following four questions are reiterated throughout all stages of monitoring:

1. Are the data being collected relevant ?
2. Are the data being collected statistically valid ?
3. Do the data provide sufficient information to permit the application of mitigation measures ?
4. Should monitoring continue (more information is necessary to test the hypothesis), should it be modified (a different type of information is required), or should it be terminated (sufficient information exists to test the hypothesis or it is no longer desirable to do so) ?

The frequency of adaptive monitoring evaluation will be determined by the interdisciplinary design team and will vary with the respective impact hypotheses being tested.

Table I compares some key characteristics of conventional and adaptive monitoring strategies. In so doing, it demonstrates the potential benefits of an adaptive approach. Principal among them is the use of comparative case studies to gather information on the potential effects of development and their implications for monitoring design. The interdisciplinary nature of adaptive monitoring design encourages a comprehensive evaluation of impact hypotheses. Furthermore, by coupling those who will collect and analyse the data with those who must use it for project management, the monitoring design team can ensure the monitoring strategy's relevance. This is particularly important since otherwise there is a tendency to follow the intuitive notion that all learning is valuable. This can lead to monitoring effort being expended collecting data of scientific interest which may be irrelevant to project management (Walters, 1986).

"Ecosystems are highly complex...posing a variety of choices for ecological monitoring measurements" (Hinds, 1984:12). As Larkin (1984:1124) suggests, we cannot "...count on long-term, large-scale, beforehand studies to reveal all." Ecosystem complexity coupled with our lack of understanding of ecological systems often results in the improper choice of variables and/or poor design for their monitoring. Both support the need for a flexible,

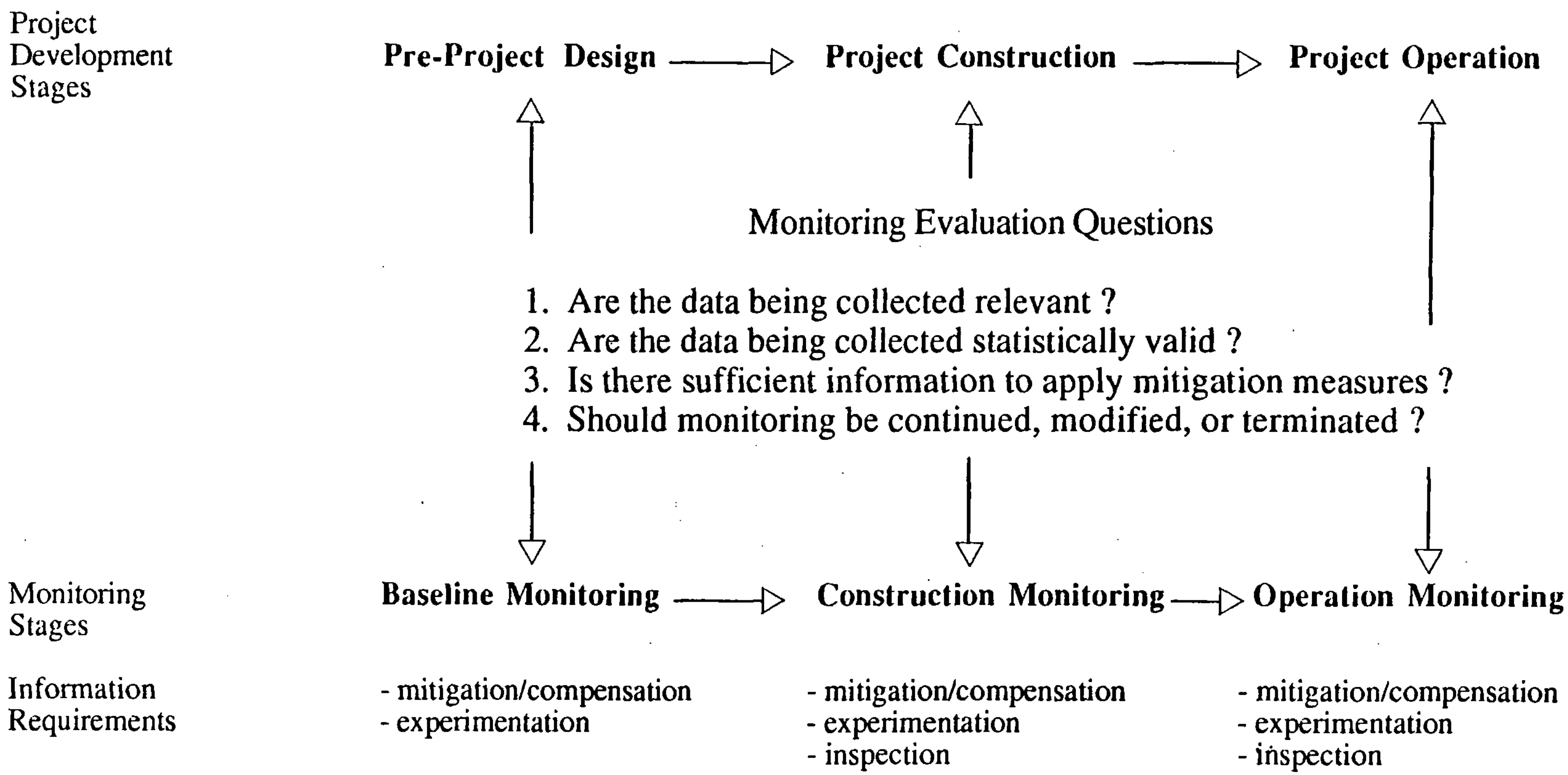

Figure 4. Adaptive Monitoring Evaluation.

Table I. A Comparison of Key Conventional and Adaptive Monitoring Characteristics.

CONVENTIONAL	ADAPTIVE
• developed by a core group of scientists/consultants	• developed by an interdisciplinary design team
• inflexible	• adapted when necessary
• comprehensive baseline, often excessively descriptive	• baseline limited to that required to test impact hypotheses
• often completed for variables insignificant to later analyses	• conducted only for variables necessary to test impact hypotheses
• evaluation only after development, rare assessment of program effectiveness	• frequent data evaluation to ensure data relevance and statistical validity, comprehensive evaluation following monitoring program completion
• often not cost-effective	• cost-effective

adaptive approach to impact monitoring. Should frequent data evaluation determine that the information being collected is irrelevant, monitoring efforts could be ceased or altered. Ecologically, such flexibility would improve the chances of selecting and quantifying the appropriate biotic conditions for testing impact hypotheses.

An adaptive approach also offers statistical advantages. Individuals designing the monitoring program, collecting the data, and subsequently analysing it would be combined in an interdisciplinary arena. This would promote the recognition of each other's requirements and limitations. Adaptive monitoring emphasizes the importance of considering two major factors influencing the credibility of the data collected: sampling design and the subsequent statistical analyses of the data. During the earliest stages of monitoring design it is crucial to recognize that the method of data collection limits the range and types of statistical analyses that can be used; conversely, the use of a particular method of analysis necessitates the appropriate methods of data collection. Thus, the accuracy and precision of sampling techniques along with their detection limits have significant implications for future data analyses. Similarly, the number, frequency, size, and spatial-temporal controls surrounding data sampling must be considered in relation to future statistical analyses. Skalski and McKenzie (1982) agree, suggesting that failing to do so often results in the collection of data that are inadequate for the quantitative assessment of relatively small changes. Equally cost-ineffective, failure to consider sampling design in conjunction with future statistical analyses can result in excessive monitoring--more data is collected than is necessary. Adaptive monitoring is designed to overcome these difficulties by considering sampling design and the requirements of future statistical analyses in concert, prior to the initiation of data collection. Frequent data evaluation would then ensure that experimental design requirements, established in the monitoring design stage, were being met to permit testing impact hypotheses. Should data evaluation suggest that the information being collected is not sufficient to permit confident statistical analyses, then monitoring effort may need to be increased to improve the power of the statistical test. Should it be revealed that the data is irrelevant to impact hypotheses testing then monitoring would be terminated for the variable under consideration. Monitoring effort would then be conserved or diverted elsewhere if necessary. Construction and operation monitoring would enhance the usefulness of baseline monitoring since all three stages would be designed to test respective impact hypotheses. This would improve the ability to differentiate project-related impacts from the effects of natural variability.

Financially an adaptive approach encourages cost-effectiveness by ensuring that monitoring effort is only exerted to collect statistically credible information relevant to future analyses: testing impact hypotheses. As Rigby (1982) and Bankes and Thompson (1980) suggest, it is better to initially focus on several very significant potential project impacts than to be all inclusive. Recognizing limited budgets, a smaller, well-defined monitoring program could permit the necessary sampling effort to verify or reject an impact hypothesis while a larger, less-intensive program may not. Focusing monitoring effort to test impact hypotheses also provides a convenient stopping rule. Monitoring for a particular hypothesis can cease when sufficient information exists to permit its testing. Thus effort is not wasted gathering excessive amounts of data.

If the earlier described diversity of perspectives held by practitioners confounds reaching consensus on the focus of monitoring efforts, then it enforces the need for an adaptive approach. Combining participants in an interdisciplinary arena would encourage drawing out differing perspectives and increase the general understanding of each others' interests and reasoning. Testing impact hypotheses would contribute to improved scientific understanding, thus satisfying scientists and consultants. Doing so in a cost-effective manner would please both proponents and government agencies responsible for funding monitoring efforts. Therefore, adaptive monitoring provides considerable opportunites for achieving symbiosis between parties with fundamentally opposing objectives.

Finally, adaptive monitoring strategies are designed to treat each project as a learning process to improve the basis for examining future developments. This is ensured by a comprehensive evaluation, and the subsequent documentation of impact monitoring efforts. Such documentation would provide a foundation for improving both the effectiveness and overall cost-efficiency of future impact monitoring strategies. The above advantages of adaptive monitoring are primarily derived from its ability to overcome the earlier described criticisms of conventional monitoring programs.

II. CASE STUDY

The preceding theoretical framework provides a basis for the following analysis of the proposed Site C dam case study. It begins with a general overview of the impacts often associated with hydroelectric development. The evolution of EIA in British Columbia is then described, followed by an evaluation of the EIA and monitoring completed for Site C. Finally, the advantages of applying adaptive monitoring to specific Site C impacts are demonstrated.

CHAPTER 4
AN OVERVIEW OF THE RESERVOIR IMPACT PARADIGM

The development of major hydroelectric projects is a relatively recent phenomenon. Hoover Dam, built in 1936 on the Colorado River in the American Southwest, was the world's first. Their popularity did not grow suddenly: by 1960 there were still only 13 dams over 150 m high. By 1980 the number of large dams globally had escalated to 65 and are expected to exceed 110 with as many more in planning by 1990 (Brooks, 1987). Thus, long-term experience with reservoirs is limited. This inexperience is exacerbated by the common lack of post-development monitoring and audits described in the preceding chapter. There exists, however, a reservoir impact paradigm which provides a basic framework for assessing the potential effects of reservoir development. The reservoir impact paradigm is the current, generally accepted body of knowledge describing the potential impacts of reservoir development on the environment. To follow is an overview of the reservoir impact paradigm in relation to northern-temperate hydroelectric production. It provides a basis for subsequently evaluating the EIA completed for the proposed Site C dam. The discussion is generally limited to the geophysical, biochemical, and ecological effects of development. Reservoir impacts are described under the broad headings of climate and seismicity, morphometry and hydrology, water quality, lower trophic levels, and fish.

4.1 CLIMATE AND SEISMICITY

The climatic effects of reservoir development have not been researched extensively and are generally considered to be very site-specific and localised (Bandler, 1986). Figure 5 illustrates the generic reservoir-related impacts on climate. In general, induced climatic changes are proportional to reservoir size (Baxter, 1977).

With increasing size water bodies tend to absorb and dissipate heat at a decreasing rate (Marmorek *et al.*, 1986). Water has a high energy storage capacity and maintains surface

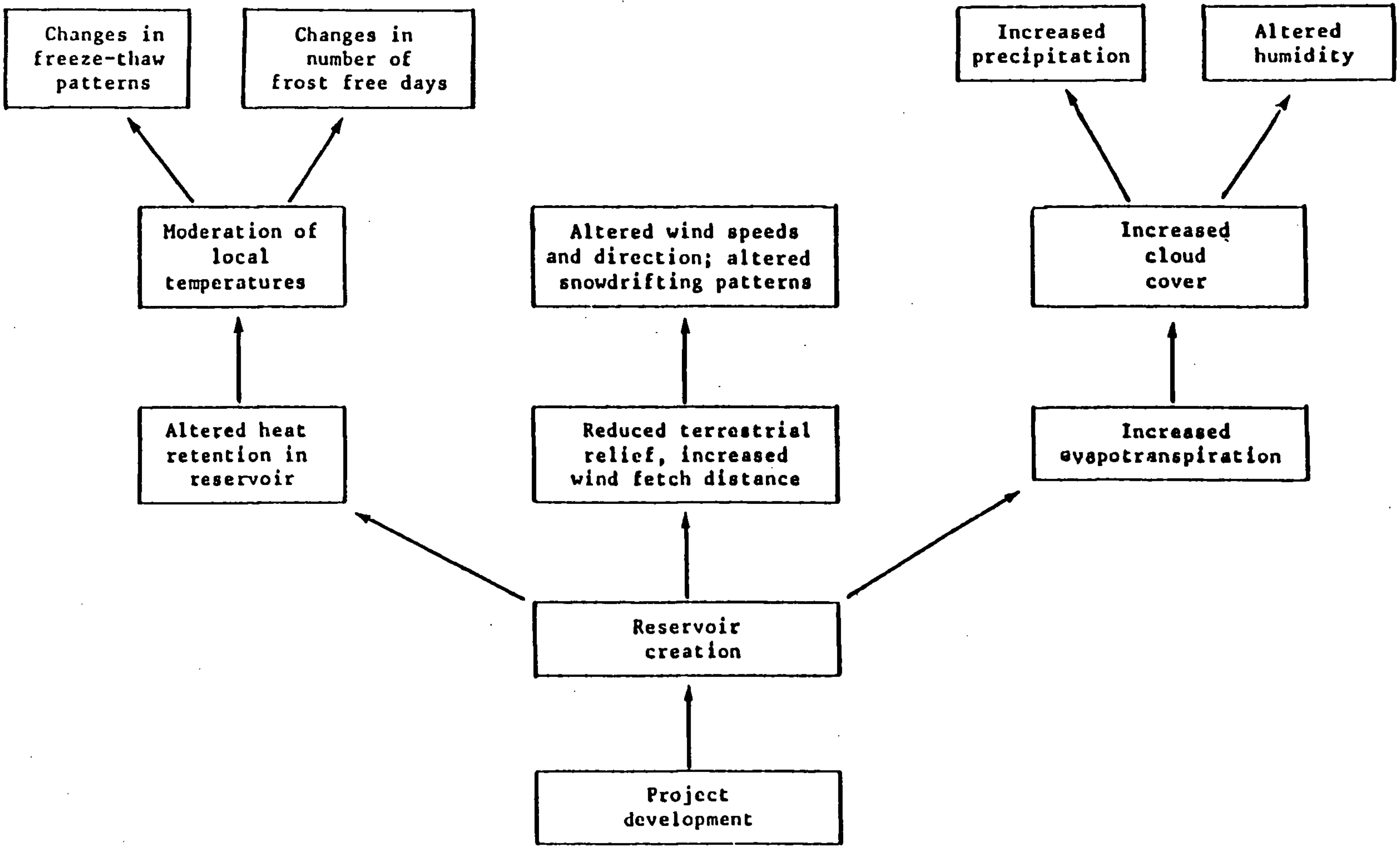

Figure 5. Generic Reservoir-Related Impacts on Climate (Marmorek et al., 1986).

temperature during times of radiation loss (Thurber Consultants Ltd., 1979a). Consequently, reservoir development can result in the modification of local temperatures: decreasing air temperatures in the spring and increasing them in the fall. Such modification can delay the beginning and end of the growing season (frost-free days) and significantly affect local agricultural operations.

Another major climatic impact of reservoir creation is the effect on wind speed and direction. Critical to the estimation of the impact is the degree of confinement (i.e. river valley vs. plains) of the proposed study area. Generally, reservoir flooding reduces vegetation and terrain relief and increases wind fetch distances thus increasing wind speed and possibly altering its direction. Such a phenomenon would result in increased wave action, water mixing and nutrient cycling, snow drifting, and windchill in exposed areas.

Reservoir creation may also result in increased evaporation rates. Evaporation depends upon a number of factors including a supply of energy to vaporize the water and turbulent motion to carry the vapor into the atmosphere (Ripley, 1987). The previously indicated potential for greater wind speed contributes to the potential for increased evaporation. Contrasting reservoir to natural riverine conditions leads to the logical conclusion that a reservoir's much greater surface area would permit increased evaporation relative to a river. The argument is not as simple when contrasting reservoir to pre-flooding crop or forested conditions. Cropped and forested lands provide a greater surface area than a horizontal water surface thus permitting higher evaporation rates. This is countered by the higher albedo of vegetation and stomata regulation of evapotranspiration. Conflicting evaporation trends for vegetation compared to open water exist in the literature (Thurber Consultants Ltd., 1979a).

Increased evaporation rates may result in fog and cloud formation, increased precipitation, and altered local humidity (Marmorek *et al.*, 1986). All of these factors could adversely affect local agricultural operations, especially crop drying conditions.

A potential geophysical impact of reservoir development is that on local seismicity. Baxter (1977) suggests that the stress induced by the weight of impounded water, even in large reservoirs, is too small to exert any geophysical effects alone. Rather, the effect is likely due to increases in the groundwater pressure in rock fissures encouraging slippage or the addition of a critical increment to pre-impoundment stresses. The latter implies that reservoirs have potential for releasing existing stresses as well as creating new ones (Goldsmith and Hildyard, 1984). However, the seismic activity that occurs is usually small and it is very difficult to attribute any seismic shocks to impoundments.

4.2 MORPHOMETRY AND HYDROLOGY

When a reservoir is produced by damming a river both its shape and hydrology are usually irregular in contrast to natural lakes. Figure 6 illustrates some generic impacts of impoundment on morphometry and hydrology.

Reservoirs, especially those with a dendritic morphometry, generally experience a high degree of shoreline development (ratio of length of shoreline to the circumference of a circle of the same area as a natural lake), (Baxter, 1977). This characteristic of impoundments provides significant potential for pronounced shoreline erosion and sedimentation processes (Northcote,1987). Immediately upon flooding, reservoir shorelines begin to be eroded by waves, currents, and ice in northern-temperate regions. Erosion can often cause very severe bank sloughing and consequently substantial amounts of vegetation (including trees) and shoreline materials can be deposited into the reservoir. Erosion rates depend upon reservoir morphometry, runoff, currents, turbulent water flow, shoreline soil and rock characteristics, and stream channel slopes (Carstens and Slovik, 1980). Shoreline erosion will continue in northern-temperate reservoirs until bedrock underlying backshore materials is exposed and restabilization can occur (Newbury and McCullough, 1984). In high latitudes with shorelines consisting of muskeg overlying permafrost, the changes may be especially extensive and prolonged as the permafrost melts (Baxter, 1977).

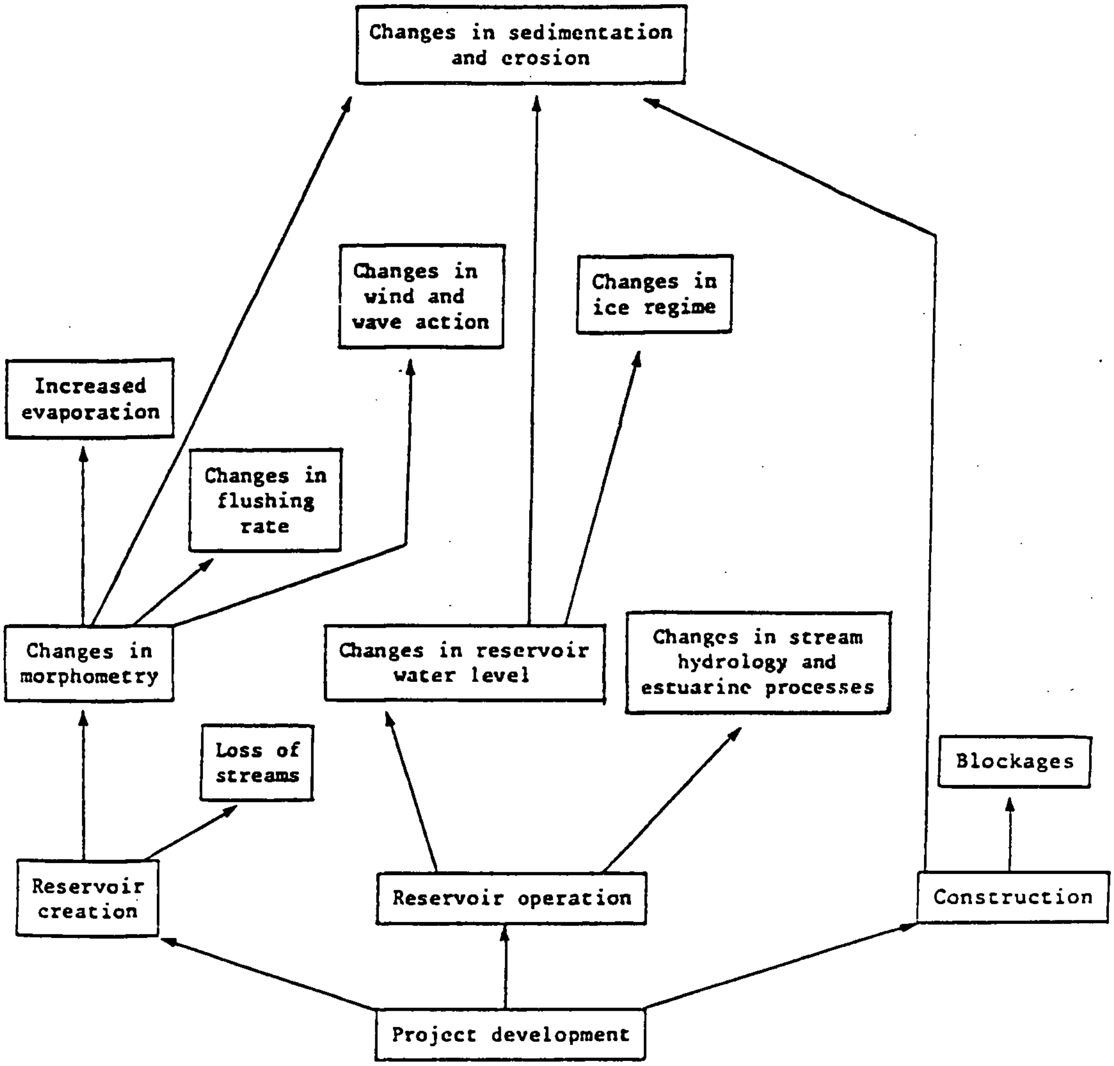

Figure 6. Generic Reservoir-Related Impacts on Morphometry and Hydrology (Marmorek *et al*., 1986).

Once eroded, sediment is transported in suspension, as bed load (rolling or sliding along the reservoir bottom), or as a combination of both transporting mechanisms. The extent of sediment movement depends upon a number of factors including particle size, shape, adhesion, and specific gravity with respect to current velocity and reservoir morphometry (Baxter and Glaude, 1980). When inflowing water owes its greater density to suspended sediments, underflow known as turbidity currents result upon its meeting reservoir water. Turbidity currents can carry sediments for extended distances into a reservoir (Baxter, 1977). Sediment retention (from both internal and external loading) depends upon several factors including flushing rates, morphometry, and operating procedures. Reservoir erosion and sedimentation rates are very difficult to quantify due to the extreme variability of the above contributing factors.

A reservoir's morphometry also affects its flushing rate. However, Baxter (1977) suggests that the retention time of water in reservoirs is short and is likely to be more greatly affected by inflow and discharge factors than processes such as thermal circulation and wind-generated currents.

Reservoir operation significantly affects water levels, ice regimes, productivity, shoreline plant succession, erosion and sedimentation processes. Reservoirs constructed for hydroelectric generation are usually filled during periods of high flow and drawn upon (drawdown) in dry periods. Drawdown depends upon the reservoir storage capacity in relation to generation requirements. It can vary from 1 or 2 m up to 20 - 40 m for run-of-the- river reservoirs depending upon the ratio of water demand to storage capacity (Langford, 1983). In some cases, such as for Lake Winnipeg, Manitoba, regulation has caused a reduction in seasonal water level fluctuations (Hecky *et al.,* 1984). Ice regimes could be affected by fluctuating water levels delaying fall freeze-up and inducing earlier spring break-ups. Decreased reservoir levels upon drawdown could also result in water freezing to a greater depth in winter. Furthermore, changing levels could increase ice scouring of the shoreline and consequently contribute to sediment loading.

Reservoir discharges also significantly affect downstream hydrologic processes. Normally, winter river flow is relatively low, followed by a dramatic increase in water volume after spring melt, followed by intermediate summer levels. Following impoundment, for most northern-temperate reservoirs, the peak flow will occur in winter (peak electricity demand) with relatively lower flows in the spring, summer, and fall (Berkes, 1981). Along with downstream water velocity, river width and depth are characteristics that may be affected by impoundment.

4.3 WATER QUALITY

Reservoir construction and operation have serious implications for both impounded and downstream water quality (Figure 7). The quality of reservoir water is a function of the quality of the waters feeding it and the changes that occur to it as a result of impoundment. Both vary with time. The quality of inflowing waters depends upon both natural factors (climate, topography, soils, etc.) and human-induced factors (resource development, waste discharges, etc.). Water quality changes within the reservoir vary with the character of water movement, the nature of flooded soils and vegetation, biological activity, and climate (Canadian Bio Resources Consultants Ltd., 1979a), (henceforth C.B.R.C. Ltd.). The potential impoundment impacts on water quality will be discussed in relation to physical and chemical changes.

Physical Impacts

The main temperature change resulting from impoundment is that from a uniformly distributed, diurnally fluctuating river to a seasonally stratified lake. The temperature regime of a reservoir depends upon numerous factors: climate, reservoir depth, physical configuration, surface area, flushing rate, amount of shade, transparency, riverine temperature inputs, and depth of intake and discharge structures. Commonly, especially for deep reservoirs, a thermocline exists between the epilimnion (warmer) and the hypolimnion (cooler) waters. Reservoir operation

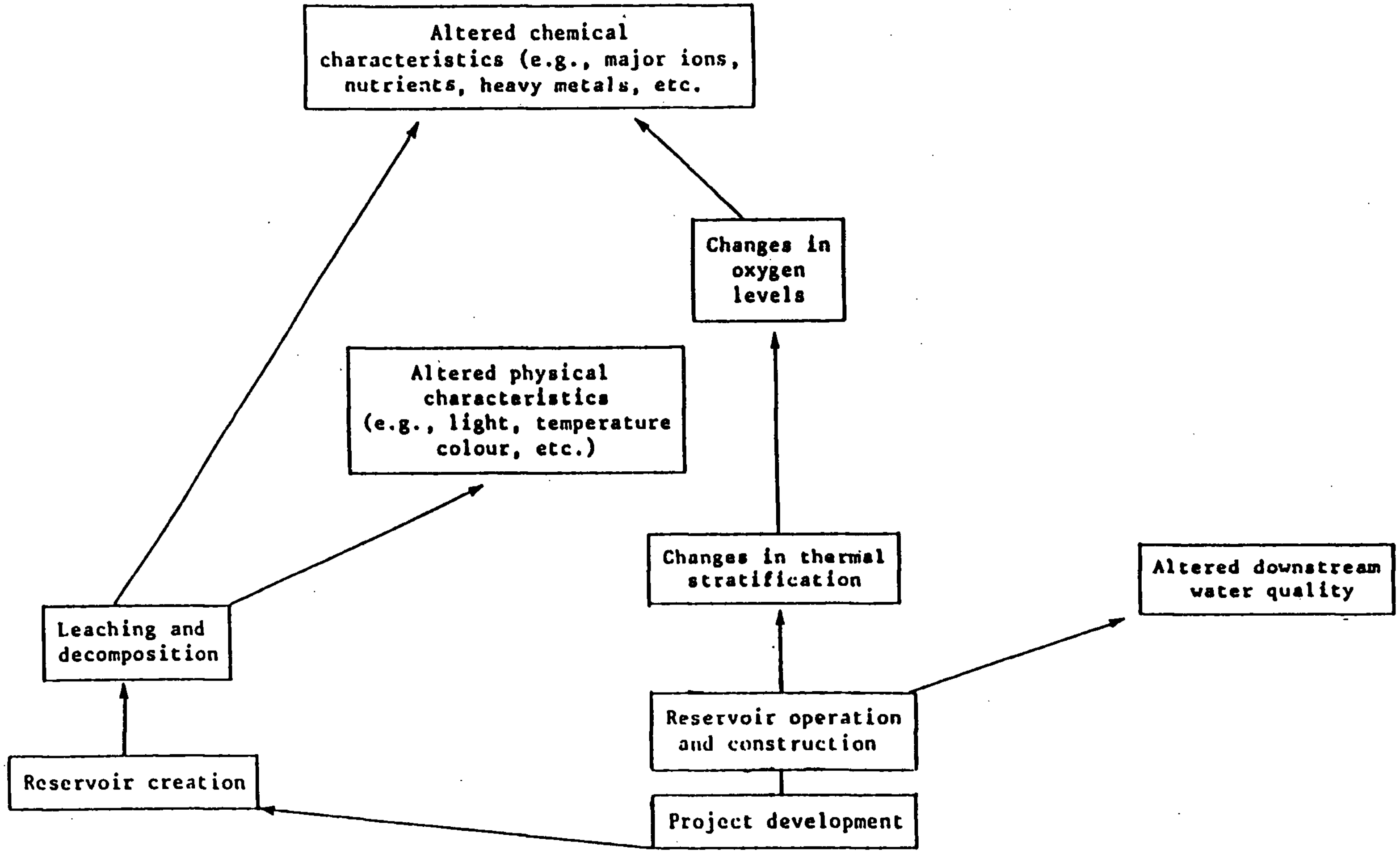

Figure 7. Generic Reservoir-Related Impacts on Water Quality (Marmorek et al., 1986).

markedly affects thermal stratification depending upon the depth of discharge outlets. They are often in the hypolimnion which results in cold water release thus expanding the epilimnion and lowering the thermocline. Increasingly, discharge outlets are being placed at varying depths to minimize adverse downstream temperature and chemical changes (Langford, 1983). Furthermore, variable level outlets permit water discharge from both the hypolimnion and epilimnion levels of the reservoir to maintain stratification if so desired. For relatively shallow reservoirs that usually experience complete mixing, or those with a fast flushing rate, thermal temperature gradients may not exist. The previously illustrated problem of high suspended sediment levels resulting from flooding and erosion also affects reservoir temperature by reducing transparency and increasing reflective backscatter of solar irradiance (Hecky *et al.,* 1984). Similar to the turbidity currents described under sedimentation effects, temperature-related density currents also exist in reservoirs. Density currents result when inflowing water has a different temperature, and therefore density, than water existing in the reservoir. The inflowing water does not immediately mix with the reservoir water but moves downstream and laterally above it (overflow), below it (underflow), or within it (interflow) depending upon the differences in density (Baxter, 1977). Various models exist permitting reservoir temperature prediction. They generally depend upon whether the reservoir will stratify or remain uniformly well mixed (C.B.R.C. Ltd., 1979a).

Among other things, reservoir transparency is affected by suspended sediments and organic particulate matter resulting from flooding and erosion. In addition, organic matter production within the reservoir will contribute to its increased turbidity. Reservoir turbidity is difficult to predict due to the diversity and complexity of contributing factors: reservoir flushing rate, turbidity of inflowing streams, flooding and shoreline erosion processes, morphometry, reservoir mixing and currents, etc. Water color is also affected by the leaching and decomposition of inundated soils and vegetation resulting from impoundment. This effect may be minimized for reservoirs with relatively short retention times (C.B.R.C. Ltd., 1979a).

Chemical Impacts

The macronutrients nitrogen and phosphorus are contributed to reservoir waters from a variety of natural and human-induced sources. Leaching from flooded agricultural and forested soils is principal among them. The decomposition of submerged vegetation; agricultural, forest and urban storm runoff; and riverine inputs also contribute (C.B.R.C. Ltd., 1979a). If the nutrient load is low and the reservoir flushing rate is high the effects may be small. However, if the loading is high and the retention time is long, the chemistry of the impoundment water may be significantly altered (Baxter, 1977).

Dissolved oxygen (D.O.) levels in a reservoir are balanced by the consumption of chemical and biological constituents (chemical and biological oxygen demand) against uptake from the atmosphere, inflowing waters, and photosynthesis from aquatic plants (Langford, 1983). In reservoirs with a thermocline, oxygen stratification often parallels temperature. In the epilimnion, algal photosynthesis coupled with wind and wave action maintains high D.O. levels. In the hypolimnion, aerobic decomposition can result in anoxic conditions. With no mixing the deoxygenated layer increases in both depth and volume if there is sufficient organic matter to consume appreciable amounts of oxygen. D.O. mixing follows the seasonal overturn pattern characteristizing the reservoir. It is thus significantly affected by reservoir operation which can dramatically affect thermoclines as discussed in the previous section. Extended ice cover reduces mixing and contact with atmospheric oxygen sources and can result in decreased D.O. levels.

Anoxic hypolimnion conditions also permit the accumulation of reduced substances such as sulfide, and ferrous ions which can cause disagreeable odors and taste in drinking water. Total hardness also determines the quality of water for domestic use. With impoundment, increased water hardness can result from the erosion and solution of minerals in flooded soils. Both of these effects will be minimized if relatively fast reservoir flushing rates occur. Potential mercury and other heavy metal implications will be discussed in relation to reservoir fish populations in section 4.5.

Along with impacts on the reservoir itself, impoundment will significantly affect downstream water quality. Similar to reservoir implications both physical and chemical properties will be affected. Conversely, many of the downstream effects experienced from impoundment are the opposite of those produced in the reservoir above them. Heat, sediment, and nutrients retained by the reservoir are lost to the stream (Baxter and Glaude, 1980). One significant effect of water discharge downstream is the phenomenon of gas supersaturation which occurs in two ways. First, turbines may force gas into solution by mixing air and water under great pressure. Second, water plunging over spillways into deep basins can carry air bubbles to a considerable depth where hydrostatic pressures may also be great enough to force gas into solution (Baxter, 1977). As will be demonstrated in the following sections, gas supersaturation has important biological implications.

During reservoir construction the introduction of toxic substances including oils, greases, and related chemicals, along with sewage, can appreciably affect water quality. In addition to chemical impacts such as oxygen depletion, they may cause direct mortality to both fish and fish prey species (Renewable Resources Consulting Services Ltd., 1979), (henceforth simply R.R.C.S. Ltd.). Effer (1984b) suggests, however, that the assimilative capacity of both the inflowing river and reservoir would require major chemical inputs to appreciably alter water chemistry.

The biological implications of impoundment impacts on reservoir and downstream water quality will be discussed in the following sections.

4.4 LOWER TROPHIC LEVELS

Reservoir development fundamentally affects the physiological, structural, and behavioral characteristics of lower trophic level organisms (Figure 8). Reservoir habitat is markedly

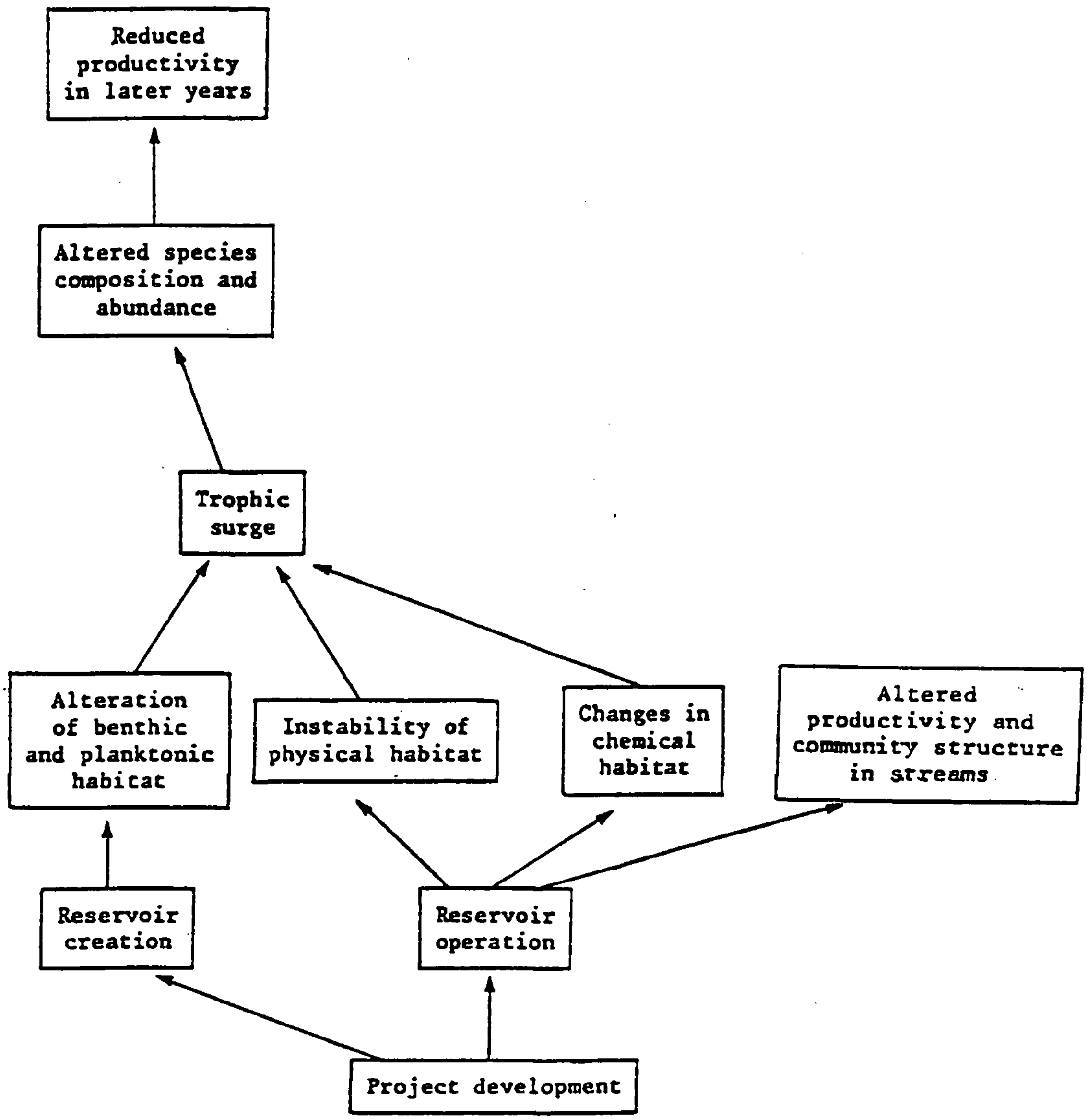

Figure 8. Generic Reservoir-Related Impacts on Lower Trophic Levels (Marmorek et al., 1986).

different from that in the original river. Northern-temperate rivers rarely experience thermal stratification or oxygen depletion due to their turbulent nature. Biologically, riverine plankton populations are generally low since they are continually swept away. Benthic populations are more abundant.

Generally, reservoirs and rivers depend upon different primary sources of energy: standing water communities rely mainly on photosynthesis, stream communities depend upon the heterotrophic metabolization of organic materials. Therefore, when a river is dammed two events may be expected to result. First, lotic benthos will be replaced by lentic species. And second, plankton populations will proliferate and the importance of photoautrophic activity will increase (Baxter, 1977).

A fundamental postulate of the reservoir impact paradigm is that impoundment will result in a trophic surge, or short-term increase in productivity, followed by consequent changes in community structure (C.S.E.B., 1985). As previously discussed, nutrients are released into a reservoir through the leaching and decomposition of soil and vegetation following flooding. Phosphorus and nitrogen are especially important since they are often limiting factors in productivity (Grimard and Jones, 1982). The increase in nutrient availability coupled with an enlargement of aquatic habitat can greatly stimulate primary productivity. Phytoplankton production is limited to the photic zones--the epilimnion, littoral, and sub-littoral zones depending upon turbidity. Reservoir flushing rates significantly affect phytoplankton community species composition: high flushing rates promote species with short life cycles (Marmorek *et al.*, 1986). Permanent phytoplankton communities develop in most reservoirs with sufficient water retention times (Langford, 1983). Generally, several years after impoundment, nutrient levels in the reservoir decline as nutrients are assimilated, lost to bottom sediments, and lost to outflow. After the initial nutrient pulse is exhausted phytoplankton production usually decreases to a point below that of natural lakes (Marmorek *et al.*, 1986). This period of trophic decline is affected by human activities in the watershed. For example, nutrient-rich runoff from agricultural operations may result in its delay and reduced magnitude.

Aquatic macrophytes will also be affected by reservoir development. Hynes (1970) divides them into three classes: those rooted in the substrate, free-floating forms and attached forms fixed to solid objects such as rocks. Changes in current velocity, light penetration, sedimentation, and chemical factors such as nutrients and pH may eliminate species specially adapted to riverine habitats (Geen, 1974). The development of rooted macrophytes following impoundment also depends upon the type of substrate, shoreline erosion, and the effects of drawdown. The extent to which macrophytes inhabit the sub-littoral zone is primarily determined by light penetration. In oligotrophic reservoirs floating species such as duckweed (*Lemna spp.*) may develop and be maintained throughout all regions. In more eutrophic, turbid reservoirs algal blooms can limit macrophyte production in deeper waters (Langford, 1983). Macrophytes rooted in the substrate are negatively affected by shoreline erosion. Conversely, Little and Jones (1979) describe methods for controlling shoreline erosion by introducing and maintaining suitable macrophytes in the drawdown zone. When drawdown is prolonged, aquatic macrophytes in the littoral zone can be eliminated either by heating and desiccation in the summer or freezing and desiccation in the winter, depending upon the use of the reservoir. For many northern-temperate reservoirs the latter is particularly important as drawdown is most pronounced during times of peak electricity demand in the winter months.

In response to greater phytoplankton levels zooplankton populations also usually increase following impoundment. The abundance and diversity of zooplankton species is also greatly affected by increased aquatic habitat and influx from upstream sources (Langford, 1983). Following impoundment, plankton-feeding zooplankton including cladocerans, rotifers, and copepods, especially the latter, usually dominate (Duthie and Ostrofsky, 1975). A contradiction exists in the literature as some sources report that zooplankton production is greater in the upper sections of a reservoir (Zhadin and Gerd, 1973), cited in R.R.C.S. Ltd. (1979), while others including Martin and Stroud (1975) suggest that it is greater near the dam.

The effects of impoundment on zoobenthos have been studied extensively. Generally, reservoir creation eliminates most of the naturally occurring riverine species due to siltation, altered substrate types, reduced current velocity, and other changes in the physical and chemical environment. Baxter (1977) suggests that chironomids will likely be the first colonizers of a newly flooded area. They are well adapted for the task: they can reach the area as winged adults or larvae, they have a high fecundity (r-selected organisms), and some species are tolerant to the low D.O. levels likely to characterize new impoundments. Lyakov (1973), cited in R.R.C.S. Ltd. (1979), identified three major stages of benthic invertebrate development following impoundment. The first is the alteration of the former biotic community where aquatic invertebrates adapted only to moving water would be substantially reduced. This stage results primarily from reduced currents, siltation, and the alteration of substrate type. The second phase witnesses a marked increase in chironomid and oligochaete populations. The final stage which may require up to ten years to achieve, involves the establishment of permanent, more stable benthic populations. Benthic invertebrates usually undergo a succession from organisms favoring eutrophic conditions to those preferring relatively oligotrophic environments, which corresponds to the natural reservoir maturation process. However, as illustrated for trophic decline periods, reservoir maturation is greatly affected by human influences in the watershed. For example, seasonal agricultural runoff into a reservoir can result in nutrient pulses which greatly prolong the eutrophication stage.

Reservoir drawdown will significantly affect benthic communities. Generally, drawdown occurs too quickly for benthos to follow the receding water level. Thus, as Langford (1983) suggests, drawdown zones are sparsely populated and only periodically recolonized.

Reservoir creation also affects downstream lower trophic level populations. The impacts can be both positive and negative. Negative effects usually result when reservoir discharges are reduced or are only taken from the hypolimnion. This correspondingly limits the amount of nutrients and fauna released downstream. D.O. levels, temperature, and other chemical and physical characteristics can also be adversely affected. Positive effects of reservoir development occur when cool, clear, well-oxygenated, nutrient-rich waters are released below generating facilities (Marmorek *et al.*, 1986). Benthic communities downstream of a dam are affected, at least partially, by three factors: (1). the alteration of the temperature regime, (2). the alteration of substrate surfaces, and (3). the outflow of organic matter, particularly phytoplankton and zooplankton, from the impoundment (R.R.C.S. Ltd., 1979).

4.5 FISH

The general sequence of biological events that occur following impoundment can be summarized as follows:

1. the decay of flooded vegetation [especially if the area is not properly cleared] and leaching of soils releases nutrients into the reservoir;
2. the nutrient pulse is assimilated by bacteria, phytoplankton and zooplankton production;
3. rising fish prey species populations are reflected in increased fish production;
4. after a period of years (usually 4 - 30), fish production decreases as a result of the loss of nutrients to bottom sediments or outflow. The resulting long-term productivity is usually approximately 50% of the initial levels ; and
5. a shift in fish species composition from early populations of predatory game fish to coarse fish often results (R.R.C.S. Ltd., 1979).

These general trends will be discussed in fuller detail. Figure 9 illustrates the potential impacts of impoundment on fish.

Reservoir creation alters fish habitat and prey populations which consequently changes fish community structure. Resident riverine (rheophilic) species decline or disappear and are replaced by lacustrine (limnophilic) species as the reservoir fills and matures. A principal contributor to the common initial increase in fish productivity is the availability of large numbers of zooplankton resulting from greater primary production. As previously discussed, however, this is a relatively short-term phenomenon. Increased cover provided by flooded

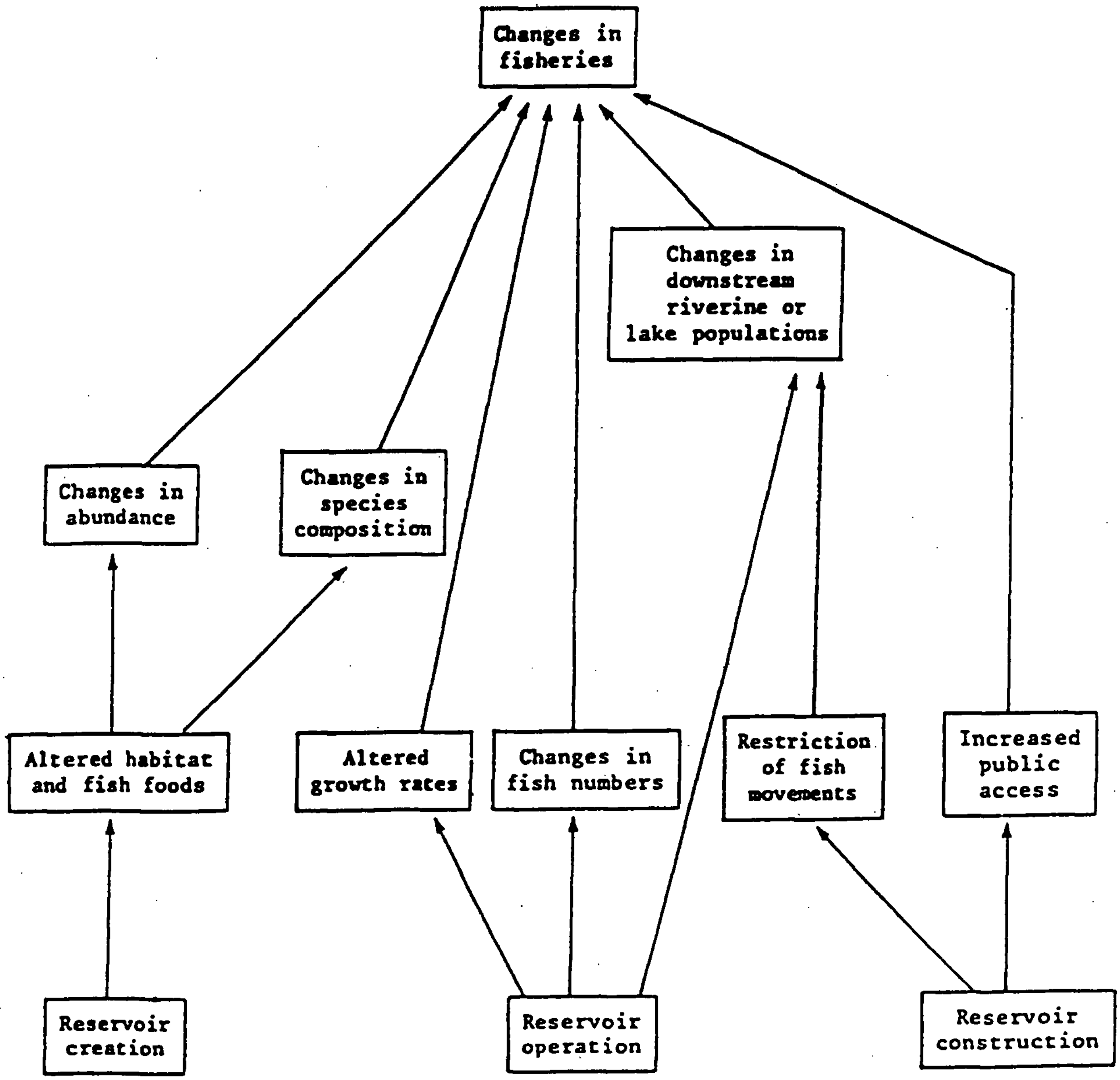

Figure 9. Generic Reservoir-Related Impacts on Fish (Marmorek et al., 1986).

vegetation also contributes to greater fish yields in new impoundments (Baxter, 1977).

Negative changes to fish habitat may also result with impoundment. Spawning habitat may be lost and areas suitable for spawning may be exposed during drawdown resulting in the death of eggs or young fish. Hall (1971) states that in many stratified reservoirs fish are restricted to the epilimnion for much of the summer by food and oxygen availability. Baxter (1977) indicates that substantial fish kills can result from anoxic hypolimnetic waters quickly mixing with the epilimnion as a result of a change in weather conditions. Furthermore, increased fish concentrations in the upper water levels can result in large-scale mortalities with reservoirs using epilimnion turbine intakes.

Impoundment affects fish growth rates depending upon their adaptability to changing food sources and competition from other fish species. Furthermore, depending upon the location within the reservoir, fish growth rates are affected by fluctuating water levels producing turbid habitats with low primary productivity and consequently reduced prey species populations (Marmorek *et al.*, 1986). Fish growth rates in large reservoirs may vary considerably owing to the absence or presence of suitable food resources.

Reservoir creation may also alter the diversity and abundance of fish parasites. In addition, mercury and other heavy metal bioaccumulation may result. Both impacts can seriously affect fish stocks. The latter has only been incorporated into the reservoir paradigm relatively recently (Abernathy and Cumbie, 1977; Bodaly *et al.*, 1984a; Marmorek *et al.*, 1984). Bodaly *et al.* (1984b) describe the collapse of the lake whitefish (*Coregonus clupeaformis*) commercial fishery on Southern Indian Lake (SIL), Manitoba. Prior to impoundment, catch was almost entirely (99%) comprised of light colored, export (A) grade fish, only lightly parasitized with muscle cysts of *Triaenophorus crassus*. In the four years following impoundment heavily parasitized, continental (B) grade whitefish increased to 12 - 72% of total summer catch. Baxter (1977) suggests that increased parasitism can be encouraged by larger numbers of zooplankton acting as intermediate hosts and altered fish feeding habits. Exacerbating the SIL parasite problem, fish muscle mercury levels also increased. Indeed, walleye (*Stizostedion vitreum vitruem*) and northern pike (*Esox lucius*) mercury levels exceeded the Canadian marketing standard of 0.5 ppm and approached or surpassed U.S. levels of 1.0 ppm following impoundment. Hypotheses explaining causes of mercury bioaccumulation in new impoundments emphasize either increasing amounts of potentially available mercury due to the flooding of soils and vegetation, or increasing retention of naturally transported mercury found in sediment. Bodaly *et al.* (1984a) further submit that the flooding of vegetation and soil organic matter promotes bacterial production which may in turn increase inorganic mercury methylation, converting it into its organic form and permitting bioaccumulation. Due to the complexity of the impact, mercury and other heavy metal bioaccumulation in fish species is very difficult to predict with any degree of certainty.

Reservoir operation also affects fish abundance and diversity. Unfavorable temperatures, D.O. levels, and entrainment can have the respective consequences of thermal stress, suffocation, and stranding or elimination of fish from the reservoir (Marmorek *et al.*, 1986). Rosenberg *et al.* (1987) also describe the following two potential impacts as a result of the SIL, Manitoba, impoundment. First, fish stocks depending upon sight for feeding may be disadvantaged as a result of increased turbidity within the reservoir (as stated earlier, turbidity levels will depend upon the suspended solid levels in the original river and the problems created by shoreline erosion in the reservoir). Second, stock migrations--lake whitefish in this case--could result in less fish being available for commercial fishery enterprises. Another major impact of reservoir operation on fish communities is drawdown. As described earler, drawdown can expose spawning areas and result in high egg and juvenile fish mortalities. It can also result in considerable zooplankton and benthic fish prey species loss in littoral regions. Furthermore, drawdown reduces macrophyte populations which provide cover and spawning habitat for fish populations. Baxter (1977) offers three forms of mitigation against the negative impacts of drawdown: (1). the construction of sub-impoundments which retain water when the level in the main reservoir drops, (2). floating fish-nesting platforms, and (3). drawdown regimes designed not to expose the littoral zone at critical times. Drawdown may not always have entirely negative impacts on the total fish population. Langford (1983) describes the process of deliberate drawdown, a management technique used to reduce stocks of undesirable fish species or thin out unwanted aquatic vegetation.

The littoral zone is critically important for fish production. As illustrated in the preceding section zooplankton and benthic organisms, major sources of fish food, are usually most abundant in shallow littoral zones where aquatic plants proliferate and provide suitable habitat. Littoral areas also support aquatic macrophytes required by some species, such as northern pike, for successful spawning. Finally, littoral vegetation provides cover for both juvenile and adult fish stocks. Reservoir development generally increases the amount of littoral zone available for fish development relative to natural riverine conditions. Again, however, this is often countered by the negative effects of drawdown.

Reservoir operation also affects downstream fish populations with both positive and negative consequences. Most impacts relate to discharge effects on river flow (increased and decreased), temperature, D.O. and nitrogen levels, siltation, nutrients, and prey species. As described earlier, many of the downstream effects of impoundment are the opposite of those in the reservoir. For example, while sedimentation problems may exist in the reservoir, they act as efficient traps so discharges may be relatively clear. Furthermore, as Edwards (1984) suggests, reservoirs produce and discharge organic particles (phytoplankton and zooplankton) which provide food sources for fish populations. Benthos and terrestrial and aquatic insects also spill over from the reservoir and are important fish food resources. Reservoir discharges may, however, create the earlier described problem of gas supersaturation. If a fish takes in water that is supersaturated with gases, the excess gas may come out of solution, lodge in various parts of the fish's body and result in death or injury. The degree of supersaturation required to cause mortality depends on the age and species of fish affected (Baxter, 1977).

The obstruction of fish migration by dams poses serious problems for the upstream movement of anadramous species along with the downstream movement of smolts (juveniles). Baxter (1977), using Pacific salmon (*Oncorhynchus spp.*) for an example, suggests the former is probably the more serious. Since some salmon species spend as little as two years in the sea, the blockage of a river for even as short a time as required for reservoir construction could eliminate their population from the river. Even partial blockages could disrupt their olfactory and tactile homing devices by which they are guided to spawning grounds. Furthermore, as Idler and Clements (1959), cited in Baxter (1977) suggest, the salmons' energy reserve is slightly more than sufficient to carry them to their destination. They may not be able to afford to expend extra energy wandering in a region of slack water above a dam. Other migrating species may also be adversely affected by stream blockages. Most diadromous fish move downstream during one phase of the life-cycle and upstream in another. Catadromous species, such as eels, show the reverse pattern from salmon species (Langford, 1983). Fish ladder construction is a well-developed form of mitigation but its success has not been established in all cases (Baxter, 1977).

Due to the complexity of factors determining the effects of impoundment on upstream and downstream conditions it is exceedingly difficult to predict the net effect on fisheries resources (Mundie and Bell-Irving, 1986). For example, decreased downstream turbidity may increase primary production which will likely increase the available food supply and improve fishes' ability to discover it; however, it will also make it easier for predators to find the fish. Cooler downstream temperatures--resulting from hypolimnion discharges--may improve chemical and other habitat conditions for cold-water species. Concurrently, however, it may decrease the number of benthic food organisms whose numbers may further decline as a result of short-term variations in water levels (Baxter, 1977). The difficulty in assessing impacts is thus apparent.

The reservoir impact paradigm has progressed considerably from its initial experience with hydroelectric development and is continually evolving. Thus, potential exists for overcoming its remaining uncertainties with the systematic monitoring and documentation of future hydroelectric development impacts. The reservoir impact paradigm provides a basis for evaluating the comprehensiveness of the EIA completed for the proposed Site C dam.

CHAPTER 5
EVOLUTION OF EIA APPROACHES IN BRITISH COLUMBIA

This chapter outlines the legislative authority for EIA in British Columbia. It traces the evolution of provincial environmental assessment and management and provides a description of two specific Acts: the *Environment Management Act* and the *Utilities Commission Act*. This permits a comparison with the general evolution of EIA processes described in Chapter 2. Furthermore, coupled with Chapter 4, this chapter provides a basis for evaluating the Site C EIA and monitoring program in Chapters 6 and 7. Chapter 5 concludes with an illustration of an assessment carried out under the *Utilities Commission Act* to demonstrate the importance of legislative authority to EIA.

5.1 EIA LEGISLATIVE AUTHORITY IN BRITISH COLUMBIA

In 1971, vocal public concerns for the environment resulted in the establishment of an Environment and Land Use Committee (ELUC) under the *Environment and Land Use Act* (RSBC 1979). A committee of Cabinet, ELUC was chaired by the Minister of Lands, Forests and Water Resources and included representatives of all major natural resource using departments. The Committee's objectives were to establish programs to foster public concern and awareness about the environment; to minimize and, where possible, prevent negative impacts of resource and land-use development; and to report to Cabinet on environmental and land-use issues (C.C.R.E.M., 1985). ELUC was authorized to override any other provincial Act or regulation (Dorcey, 1987a).

A secretariat was added to ELUC in 1973 to facilitate coordination between government departments. No formal regulations have yet appeared under the *Environment and Land Use Act*, however, the secretariat established a systematic, four-stage process for assessing the impacts of major projects such as hydroelectric dams, transmission lines, mines, and highways. The stages consist of a review of project justification, a broad evaluation of alternative development sites, a detailed evaluation of chosen sites, and a provision for impact mitigation and compensation (Dorcey, 1987a). The sector guidelines outline procedures for proponents to coordinate their project planning with an assessment of the potential environmental, social and economic impacts of development. Complying with the guidelines greatly enhances the proponent's chances of collecting and assembling the appropriate information to secure government approval for their proposal (C.C.R.E.M., 1985). Formal guidelines for mitigation and compensation and cost/benefit analyses were also developed during the secretariat's existance along with an interagency review system for major projects. They continue to be used despite the secretariat's disbandment in 1980 (Roberts, 1987).

Prior to 1980--and only for water resource developments--the *Water Act* (RSBC 1979 C.429) was the single legislative authority for providing public hearings to consider project assessments. These hearings were conducted by, and at the discretion of, the Water Comptroller and placed primary emphasis on the quantity of available water supply. As it was not a legal requirement, comparatively little attention was given to assess the environmental and social implications of development in determining whether to grant a water licence. However, environmental and social implications were addressed for developments with considerable associated public concern, such as the comprehensive EIA completed for the Revelstoke Dam in 1976, or when written submissions were received by the provincial Comptroller of Water Rights. The *Water Act* does not include formal monitoring requirements.

Bankes and Thompson (1981) describe numerous deficiencies with the 1976 Revelstoke Dam public hearings that were held under the auspices of the Water Comptroller by authority of the *Water Act*. Foremost is the fact that the expertise of the Water Comptroller and his staff were primarily in the field of engineering. Thus their environmental and socio-economic expertise was questionable. Other criticisms contributing to a general mood of disenchantment revolve around the hearing procedures: intervenors were neither funded nor allowed sufficient time for preparation, inadequate environmental information was provided for public review, and important issues were deferred for future consideration and resolution.

Furthermore, the only avenue for public participation was through a complex series of official committees that were not obligated to recognize public concerns. Finally, emphasis was placed on impact monitoring during the review phase but no system was subsequently developed to follow the process through. Thus, the monitoring programs that were established through a committee process had no mechanism to feedback into project planning, construction, or operation (Phillips and Langford, 1987).

In the early 1980s, recognizing both the potential for a series of future energy projects and the public dissatisfaction with existing review procedures, the B.C. government introduced two comprehensive pieces of legislation: the *Environment Management Act* (RSBC 1981) and the *Utilities Commission Act* (RSBC 1980 C.60). Together these Acts are very widely encompassing: "...the Utilities Commission Act applies to energy projects, and the Environment Management Act can be applied to any other project" (Dorcey, 1986:152).

5.1.1 Environment Management Act

The *Environment Management Act* uniquely provides direct statutory reference to EIA as a requirement when the Minister of Environment considers that activities may have negative environmental effects that cannot be assessed with available information (C.C.R.E.M., 1985). The EIA must consider both detrimental and beneficial impacts upon water quality, air quality, land use, water use, aquatic ecology, terrestrial ecology and other impacts as specified in the terms of reference. Measures to mitigate negative and maximize positive effects are also to be included.

The Act empowers the Minister of Environment to order the delay or cessation of operations in progress which could seriously affect the environment. It authorizes the minister to hold inquiries on any matter within his/her jurisdiction and provides for the establishment of an Environmental Appeal Board to address appeals to decisions based on environmental legislation (C.C.R.E.M., 1985). In addition, the Act facilitates the development of management plans to integrate environmental priorities and interests of both the Ministry of Environment (MOE) and other concerned ministries. Formal monitoring guidelines are not provided by the Act nor are comprehensive monitoring strategies required.

5.1.2 Utilities Commission Act

The *Utilities Commission Act* provides a policy that integrates approaches to approval procedures for energy projects and energy removal from the province (B.C. Ministry of Energy, Mines and Petroleum Resources, 1982). The Act establishes the British Columbia Utilities Commission (BCUC) as the body responsible for the regulation of public utilities, including B.C. Hydro; the review and certification of energy projects; and the review and certification of proposals to remove energy resources from the province. The Minister of Energy, Mines and Petroleum Resources (EMPR) administers the *Utilities Commission Act.*

Certification of energy projects includes the issuance of Energy Project Certificates, specifying the terms and conditions of construction, prior to the initiation of development. In addition, Energy Operation Certificates, specifying operational requirements which include compliance monitoring, must be issued prior to the commencement of project operation (B.C. Ministry of Energy, Mines and Petroleum Resources, 1982). However, as Bankes and Thompson (1980) suggest, no contractually enforceable obligations exist to ensure that information is fed back to government departments and agencies that may be responsible for impact management.

Figure 10 illustrates the BCUC energy project review process. Prior to the formal initiation of the review, consultation usually occurs between the proponent--primarily B.C. Hydro for hydroelectric development--and provincial government agencies. The purpose of these meetings is to determine, generally, government's major concerns with the proposed development. They are especially important to the proponent since they are interested in meeting regulations so as not to unnecessarily delay construction. Having the project approved

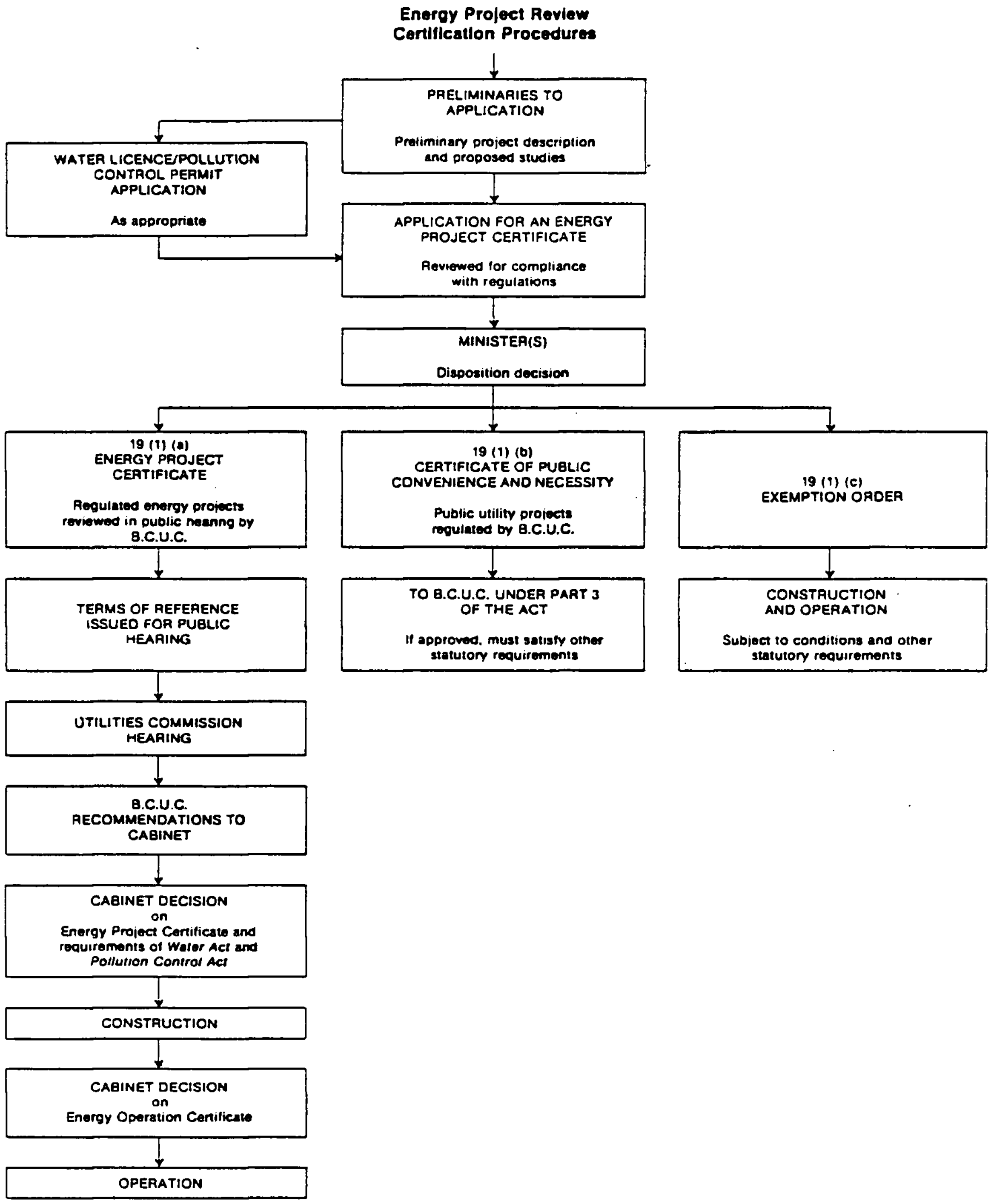

Figure 10. British Columbia Utilities Commission Energy Project Review Process (C.C.R.E.M., 1985).

without unnecessary delay will contribute to the proponent's more general goals of profit, survival and growth (Stanbury,1986). If there is major opposition, the proponent may reconsider the project's viability (Thompson *et al.,* 1981).

The formal review procedures then begin with the proponent's application for an Energy Project Certificate. The Energy Project Coordinating Committee (EPCC), comprised of senior government staff, is responsible for directing the proponent on matters of information requirements. These include siting preference, benefit/cost analyses, EIA, compensation and mitigation proposals, and all other information necessary for the preparation of an application. At this stage the proponent is not obligated to include plans for a monitoring program should the project be approved (Thompson *et al.,* 1981). Three working committees coordinate information transfer and feedback between the proponent and appropriate government agencies. The EPCC may review the proponent's application before it is formally submitted to the Minister of EMPR. Applicants requiring a Water Licence and/or Pollution Control Permit are requested to submit additional information with the application for an Energy Project Certificate.

Once formally submitted, the Minister of EMPR reviews the application and requests the remedy of any information deficiencies. The EPCC then advises the Ministers of Environment and EMPR on recommended project dispositions based on available *Utilities Commission Act* options: section *19 (1) a,* a review and public hearing by the BCUC and decision by the Cabinet; section *19 (1) b,* a review and decision by the BCUC (Certificate of Public Convenience and Necessity); or section *19 (1) c,* an exemption order (Figure 10).

19 (1) a

Under section 19 (1) a the Minister of EMPR with the concurrence of the Minister of Environment may refer the application for an Energy Project Certificate to the BCUC for review, based on a terms of reference drafted by the EPCC and approved by both ministers.

The Minister of EMPR may also designate a commissioner to act as a chairman of the review. The BCUC then conducts a public hearing and produces a report and recommendations based on the established terms of reference. The BCUC hearing process is significantly improved from those held under the *Water Act.* They permit the preparation of a broad terms of reference, including an assessment of the benefits and costs of development, and allow for intervenor funding (Roberts, 1987). The report and recommendations are then submitted to the Lieutenant Govenor-In-Council (the Cabinet). The Cabinet either accepts or rejects the BCUC recommendations and may order that an Energy Project Certificate be issued--with specified terms and conditions--or may deny the application. In addition, the Cabinet may order that a Water Licence and/or Pollution Control Permit be granted (B.C. Ministry of Energy, Mines and Petroleum Resources, 1982). Following their decision the Cabinet also decides whether to release the BCUC report and recommendations publicly and when to do so. Thompson *et al.* (1981:29) suggest that "It is unlikely that the Cabinet will long delay in publishing the Commission's report since the public nature of the review process will be discredited if the resulting recommendations are not disclosed."

Unless recommended in the BCUC report to the Cabinet, the proponent is not required to provide a comprehensive monitoring strategy.

Upon completion of construction the proponent must demonstrate compliance with the specifications of the Energy Project Certificate. If compliance is established the Cabinet will allow project operation by issuing an Energy Operation Certificate which may specify further terms and conditions including the requirements for inspection monitoring.

19 (1) b

Under section 19 (1) b if a public utility applies for an Energy Project Certificate the Minister of EMPR may refer the proponent to the BCUC for regulatory review and decision. Under part 3 of the Act, any public utility must obtain a Certificate of Public Convenience and Necessity from the BCUC prior to the initiation of development. The Commission may also hold a public hearing on the application.

If approved, the applicant will receive a Certificate of Public Convenience and Necessity with specified terms and conditions, which may include a requirement for inspection monitoring. As in section 19 (l) a, a comprehensive monitoring strategy <u>is not</u> legally required unless recognized as essential by the BCUC or the ministry.

For public utilities referred to section 19 (1) a the issuance of an Energy Project Certificate constitutes the issuance of a Certificate of Public Convenience and Necessity.

19 (1) c

Finally, under section 19 (1) c the Ministry of EMPR in concurrence with the Ministry of Environment may choose to exempt an application from the provisions of the Act. The EPCC would then draft the necessary terms and conditions to be contained in the Exemption Order subject to ministry approval.

The Ministers' order may specify any terms or conditions that could be included in an Energy Project or an Energy Operation Certificate. The proponent must also satisfy any other statutory requirements (e.g. *Canada Fisheries Act, B.C. Forest Act, B.C. Highway Act*) and permitting procedures.

Specifically regarding comprehensive project monitoring the *Utilities Commission Act* holds considerable promise. As Thompson *et al.* (1981:18) state:

> The terms and conditions of the energy project certificate, the operating certificate and any other certificates, permits or licences issued for the project will contain the requirements for monitoring, mitigation and compensation. Because these are based on a comprehensive assessment process and a public hearing, and are approved by the cabinet, an overall monitoring and enforcement program can be structured coordinating the efforts of the proponent and various regulatory agencies and government authorities.

The Peace River Site C hydroelectric project was one of the first proposals submitted to the BCUC for review under the *Utilities Commission Act*.

5.2 THE IMPORTANCE OF LEGISLATIVE AUTHORITY TO EIA

Langford (1986) among others (Bankes and Thompson, 1981; Rees, 1987) stresses the importance of legislative authority in determining the success of project management. He provides an example of the Kelly Lake-Nicola transmission line which was designated a "regulated project" under the *Utilities Commission Act* in 1980. Under section 19 (1) c of the Act a Ministerial Order was signed by the Ministers of Environment and EMPR establishing the conditions of the project. It formed the basis for the project's environmental management program. A project steering committee, comprised of various government personnel and the B.C Hydro project engineer, was formed with the authority to access any B.C. Hydro information necessary for proper environmental management (Phillips and Langford, 1987). Full authority was delegated to the steering committee for regulating project construction, including the monitoring and environmental management components.

The project was completed on time and on budget and there was consensus by all parties that it was managed successfully (Phillips, 1984). Phillips further states that the project's monitoring and environmental management were particularly successful, primarily due to two functions: B.C. Hydro's efforts in designing and implementing an environmental management program, and the firm legislative authority governing project planning and construction. Langford (1986) suggests that when the proponent is required, rather than recommended, to cooperate with the Ministry of Environment in project monitoring and environmental management, the potential for successful development is much enhanced.

In summary, the EIA process in British Columbia progressed considerably in relation to the general Canadian EIA experience. Specific provincial legislation exists authorizing EIAs for resource development projects Furthermore, the legislation carries provisions for ensuring that impact monitoring is adequately completed. The importance of legislation to the success of EIA and environmental management was described for the Kelly Lake-Nicola project. Its EIA was completed under the authority of the *Utilities Commission Act* which also provided the legislative basis for the Peace River Site C EIA.

CHAPTER 6
SITE C EIA ANALYSIS

The Site C dam is proposed for northeastern British Columbia downstream of the Site One Dam, W.A.C. Bennett Dam and Williston Reservoir. Site C would lie approximately 6 km southwest of Fort St. John, with the Town of Taylor approximately 12 km downstream (Figure 11). The dam would be 75 m high and develop a 50.3 m drop in river elevation from the Site One dam. The reservoir would have a normal level of 461.8 m elevation, surface area of approximately 9,440 ha, and total volume of 2.31 billion m^3. Drawdown would normally be less than 1.0 m due to the run-of-the-river operation of the generating station (B.C. Hydro, 1980a). Site C is designed to provide 900 MW of power at an estimated cost of $ 3.2 billion (The Globe and Mail, June 13, 1986).

6.1 CONTEXT OF THE SITE C PROJECT

B.C. Hydro, a Crown Corporation responsible for supplying the province's energy requirements, first proposed the Peace River Site C dam and generating station in 1975 to offset perceived energy demands for the 1990s. The main participants in the proposed Site C development were B.C. Hydro (proponent), the B.C. Utilities Commission (review agency), the Society for Promotion of Environmental Conservation (SPEC) and the Peace Valley Environmental Association (PVEA). The latter two interest groups, opposed to development primarily on environmental grounds, articulated their position very persuasively by using a unified front and expert consultation (Sewell, 1987). Other interest groups both in favor of development (local chambers of commerce, industrial interests, etc.) and opposed (local rod and gun clubs, native indian bands, etc.), played active, but less significant roles. Government agencies also played an important role in submitting evidence concerning project implications such as environmental impacts. These reports often disagreed with those provided by B.C. Hydro and its consultants.

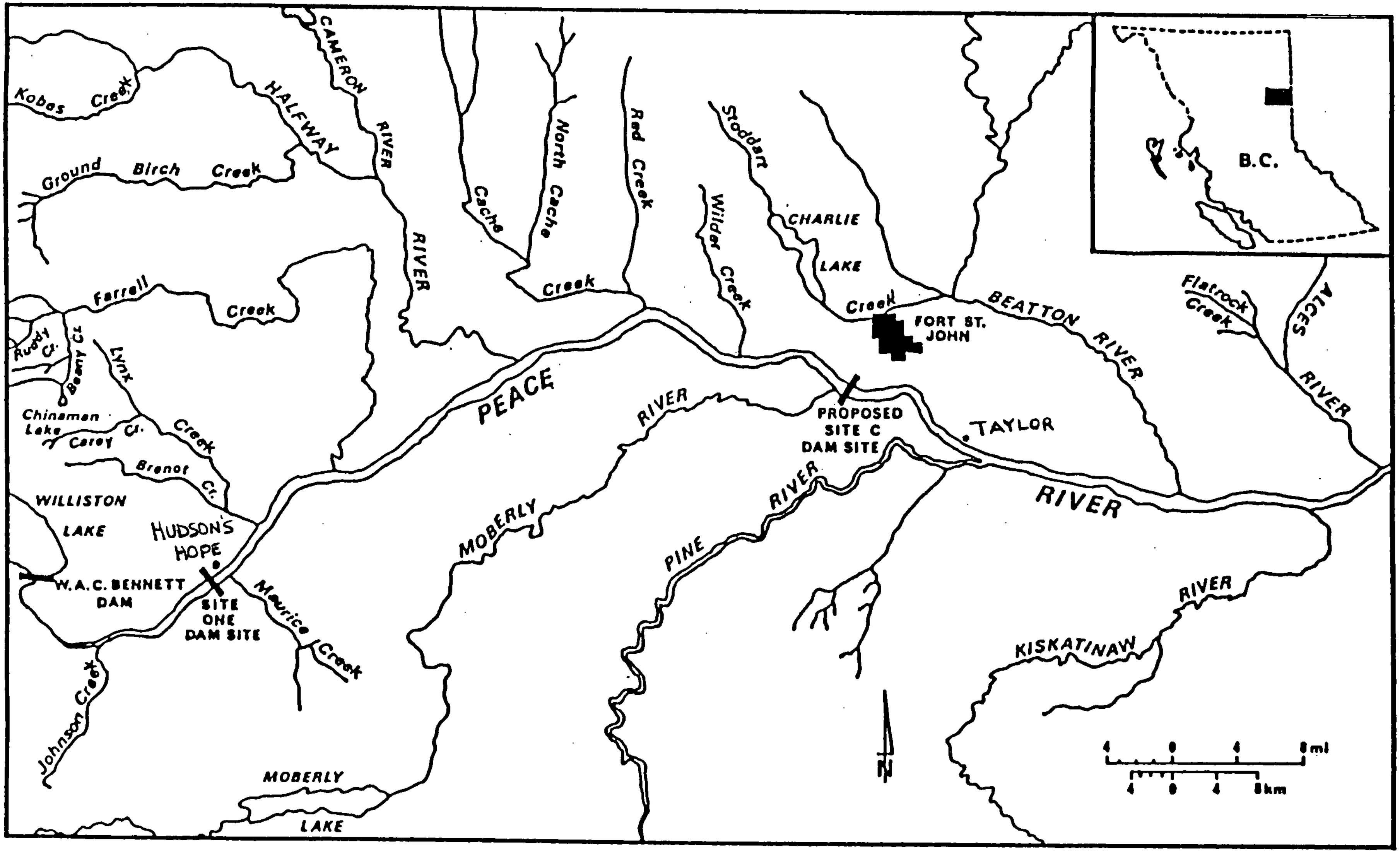

Figure 11. Map of the Site C Study Area (R.R.C.S. Ltd., 1979).

The twelve-year period from initial feasibility studies (1975), including Cabinet decision and recommendations (1983), to the present is divided into four phases (after Riek, 1987). *Project Initiation (1975 - 1976)*, the first phase, began with B.C. Hydro's announcement to build the Site C dam. The announcement met immediate vocal opposition, and a demand for a formal environmental review. The second phase, *Project Analysis (1977 - 1980)*, included the articulation of arguments both for and against development and the introduction of legislation governing the proposal, the *Utilities Commission Act* (1980). *Project Evaluation and Recommendations (1981 - 1983)*, the third phase, is characterized by the BCUC public hearings and subsequent Cabinet decision in November, 1983 not to issue an Energy Project Certificate. Finally, *Cabinet Decision to Present (1984 - 1987)*, describes the Site C-related events that have occurred thus far following Cabinet's decision.

Project Initiation (1975 - 1976)

Following their 1975 announcement of the potential for the Site C dam, B.C. Hydro (henceforth simply Hydro) frequently consulted with government agencies to identify, at least generally, their major concerns (Thompson *et al.*, 1981). Various potential environmental, economic, and social impacts were identified and Hydro, through independent consultants and corporate staff, conducted preliminary investigations on their implications.

Initial opposition was primarily voiced by environmental interest groups (The Province, October 29, 1976; The Vancouver Sun, October 29, 1976). The adequacy of existing hydroelectric review and evaluation processes were particularly questioned.

Project Analysis (1977 - 1980)

The second phase included more comprehensive arguments both in favor of and opposing development. As Riek (1987:103) states,

> Opponents, led by PVEA and SPEC, were active in disseminating information about their positions and the project, raising funds, producing pamphlets and remaining vocal in the media. They challenged B.C. Hydro's decision to build Site C by asking 1. if

> additional power was needed in the province, and 2. if so, if Site C was the best energy project to meet those needs.

Hydro, primarily through private consultants, conducted numerous impact studies including the Peace Site C Project Environmental Impact Statement (B.C. Hydro, 1980a) and benefit/cost analysis (B.C. Hydro, 1980b). All of their studies generally indicated that both economic and social benefits outweighed project costs. These studies were contested by environmental groups and critics such as John Helliwell, University of British Columbia economist:

> Hydro's never very explicit of how they arrive at load forecasts and most experts with their own analytical framework accept Hydro's estimates are too high...[he added]...like many other North American utilities, Hydro has been over-building recently and now has excess capacity (The Province, October 4, 1979, p. A4).

In 1979, based on their estimates of Site C being the "most feasible, lowest cost supply relative to all other alternatives" (The Province, October 3, 1979, p. A1), Hydro applied for the appropriate licences and permits to begin construction under the *Water Act*. In 1980 the *Utilities Commission Act* was introduced detailing energy project review guidelines. Subsequently, Hydro reapplied to the provincial Department of Energy, Mines and Petroleum Resources for an Energy Project Certificate to allow it to build the Site C dam, generating station and related transmission facilities. Due primarily to environmental concerns and questions over electricity demand, the Minister of EMPR referred Hydro's application to the BCUC under the *Utilities Commission Act* for review and recommendations. It was determined that the application would be reviewed under section 19 (1) a, through public hearings under the auspices of a BCUC appointed Site C Panel. The terms of reference included examination of project justification, design, impacts and other relevant matters. It specifically required the Panel to recommend whether or not an EPC should be issued and if so with what, if any, conditions (BCUC, 1983).

Project Evaluation and Recommendations (1981 - 1983)

The hearings included formal (116 days), local community, and special native sessions to hear evidence on all aspects of the proposal. They were held from April, 1981 (Site C Panel appointment) to May, 1983 (Site C final report released publicly) at an estimated cost of four to five million dollars (Sewell, 1987). Intervenor funding was provided. It is widely accepted that the Panel Chairman, Mr. Keith Henry, was committed to a fair and open process. He ensured that adequate time was allowed to prepare and submit evidence; a thorough review of provincial government policy occurred; and that, when necessary, the Panel had input from independent consultants (Roberts, 1987).

The hearings were divided into six stages: (1). provincial energy demand, (2). provincial energy supply, (3). project cost and adequacy of design, (4). land use, environmental, economic and social impacts, and economic benefit/cost evaluation, (5). financial impacts on B.C. Hydro and electricity users, and (6). final arguments.

In its final Site C Report (BCUC, 1983) submitted to the Cabinet the BCUC, upon the recommendation of their appointed Site C Panel, concluded that insufficient evidence existed justifying project development, particularly concerning energy demand. Furthermore, Site C had not been proven to be the best alternative should energy demand justify development. The BCUC therefore recommended against granting an Energy Project Certificate at that time. In addition, the Commission suggested that prior to issuing the EPC monitoring would be required to obtain a better understanding of the possible impacts on, among other things, downstream water temperature and fisheries resources to permit effective project management and compensation determination.

The Cabinet reviewed the Commission's report and released it publicly in November, 1983. Concurrently the Minister of EMPR announced the Cabinet's decision to place a ten-year moratorium on the Site C project and not to grant an EPC until project development could be justified. They reasoned that the excess existing provincial power capacity coupled with the economic downturn (1981 - 83 recesssion) made the project infeasible (Sewell, 1987). The

Cabinet added that any future public review would be unnecessary (The Vancouver Sun, November 9, 1983).

Cabinet Decision to Present (1984 - 1987)

Several months after Cabinet's decision B.C. Hydro applied to the National Energy Board for increased export licences for surplus power from the Revelstoke dam. This aroused suspicion by environmental interest groups that this application may provide a basis for reconsidering the development of Site C. Their suspicions were justified. On August 29, 1985, less than two years following Cabinet's decision not to build, Premier Bill Bennett announced that Site C would be constructed if export markets should become available. Furthermore, he reiterated that no public review would be held regarding the matter (Riek, 1987).

Interest in the Site C development still exists and B.C. Hydro remains confident that it will be the next project added to its system (The Vancouver Sun, February 21, 1987). To increase electricity demand export markets are currently being sought in the U.S., particularly in California. Although many contractual and legislative difficulties exist surrounding such an arrangement (The Province, June 4, 1986; Fox, 1986a) the possibility of developing Site C for power export remains realistic (Fox, 1986b).

6.2 SITE C EIA

B.C. Hydro submitted an environmental impact statement to the BCUC in support of its EPC application in July, 1980. The statement was compiled, generally, from the research and analyses of retained private consultants. For the purpose of the following evaluation the Site C EIA is defined in broad terms. It includes the impact investigations completed by B.C. Hydro, the MOE, and private intervenors, along with the analyses provided by the Site C Panel. The information upon which this section is based is derived from three principal sources: (1). The Site C Report (BCUC, 1983), (2). private consultant reports and B.C. Hydro's Peace Site C Project Environmental Impact Statement (1980a), and (3). B.C. MOE (1981) Site C Public

Safety, Fisheries and Wildlife Considerations. The latter two documents were submitted to the Site C Panel for review. The former summarizes their main points, along with those of intervenors, and includes the Site C Panel's recommendations.

While the forthcoming discussion of adaptive monitoring focuses on the environmental effects of development, the adaptive approach also has potential for measuring socio-economic impacts. Therefore, a description of the potential socio-economic implications of Site C development is included in the following discussion. A variety of potential environmental and socio-economic effects were recognized by the Site C Panel including land-use impacts and impacts on heritage resources, terrain and mineral resources, general outdoor recreation, forestry, wildlife and recreational hunting, climate and agriculture, water quality and downstream users, and fisheries resources. Of the potential environmental impacts considered, emphasis has been placed on downsteam water temperature and fisheries resources in the following analysis as they are central to the adaptive monitoring application in Chapter 8.

Land-Use Impacts

In total Site C is expected to directly affect approximately 6,000 ha. of land between the dam site and Site One dam through flooding, construction, and transmission line clearing. In addition, 840 ha of land adjacent to the reservoir will be affected. Furthermore, the habitat and water quality of over 100 km of the Peace River and its tributaries (with a total combined surface area of approximately 3,400 ha) will be altered, along with the Peace River downstream of the reservoir (BCUC, 1983).

Heritage Resources

B.C. Hydro conducted a comprehensive, $ 600,000 impact study, "...the most comprehensive ...by any developer in the province to date" (BCUC, 1983:211). It resulted in the location of significant heritage sites in the reservoir area. The majority of artifacts identified were stone tools and/or flakes resulting from their manufacture (B.C. Hydro, 1978). The Commission concluded that Hydro's analysis was sufficient to provide the necessary information to assess the potential loss of heritage resources with development. In addition, they recommended that Hydro be obliged to match government funds for the extra cost of a heritage recovery program, up to a maximum of $ 500,000 (this and subsequent compensation figures in 1981 dollars).

Terrain and Mineral Resources

Hydro argued that effects on terrain and mineral resources would be minimal. Of slight concern were local coal resources. However, Hydro claimed that they have no economic significance since with the presence of more accessible deposits their extraction is currently uneconomical; formations exist at depths of over 200 m below the Peace River (Thurber Consultants Ltd., 1979b). This conclusion, however, disregards the option value of maintaining the deposits. Gravel deposits would also be flooded, but only represent 6% of the approximately 2.0 billion m^3 total estimated volume of sand and gravel in the region.

There was general agreement that Site C-induced impacts would be minimal and the Commission therefore decided that neither mitigation nor compensation measures were warranted.

General Outdoor Recreation

The principal impact of reservoir development is the replacement of river-based recreation opportunities with reservoir-based activities. The magnitude of the loss depends on both the relative access and relative quality of these two types of opportunities (BCUC, 1983).

The difficulties with reservoir-based recreation include safety issues such as water debris, shore stability problems, fluctuating water levels, rough water conditions, and the loss of river-based activities such as canoeing. The Commission concluded that reservoir creation will provide significantly lower quality recreation opportunities than exist currently.

Forestry

An estimated 1,724 ha of forested land will be flooded. The reservoir will be cleared of all accessible timber below an elevation of 461.8 m and of all growth extending above 452 m for aesthetic and recreational purposes. Most of the merchantable timber will be sold. Stumps will be removed between elevations of 457 and 461.8 m along recreation sites. Forest cover buffers will be left along all shorelines and provisions will be made to clear areas where wind or sloughing may cause trees to fall. Timber debris will be removed during project construction (Thurber Consultants Ltd., 1979c). Clearing has major ecological significance by reducing organic matter deposition into the reservoir.

The Commission concluded that Hydro would be required to pay $ 1.0 million in compensation less the stumpage from clearing operations (approximately $ 4 per m^3); the funds should be directed toward Ministry of Forests regional enhancement activities.

Wildlife and Recreational Hunting

The Site C region occupies approximately 0.8% of B.C.'s land base but supports approximately 8.0% of the provincial moose harvest, 7.0% of the sharp-tailed grouse harvest and 4.0% of the ruffed grouse, wolf and black bear harvest. Flooding would affect critical winter moose habitat. It would also affect elk, deer, coyotes, wolves, Canada geese, bald eagles, and possibly lynx and black bear. Additional habitat losses, up to 10% of total flooding losses, could result from dam and transmission line construction, highway relocation, bank sloughing and shoreline erosion, increased fog windchill, and greater hunting pressures (Donald A. Blood & Associates, 1979).

The Commission decided that Hydro should be required to pay $ 2.8 million in compensation for recreational hunting loss; the funds should be directed to regional wildlife-enhancement programs developed by MOE in consultation with local interests. In addition, the following mitigation measures were outlined:

- habitat would not be needlessly disturbed during clearing, and particular effort would be made to avoid damage to island riparian habitat downstream of the dam site;

- a clearing schedule would be developed in consultation with Fish and Wildlife officials to minimize wildlife impacts;

- trees in strategic locations, as identified by Fish and Wildlife officials, would be left for bald eagle nesting;

- habitat disturbed during construction would be rehabilitated to its original state unless otherwise dictated by the government's land-use plan;

- construction camp garbage would be incinerated or disposed of by deep burial within a fenced area;

- firearms would be banned in construction campsites;

- transmission line clearing would be done by hand on the north side of the Peace River, and not be undertaken between mid-May and mid-July, and disturbance of drainage patterns would be minimized;

- transmission line rights-of-way would be managed to maximize browse where not in conflict with agricultural activity or other uses under the government's land-use plan;

- for transmission line maintenance, herbicide applications would be minimized, and sensitive areas as indicated by the Ministry of Environment would be hand cleared; and

- construction of access roads would be minimized and public access restricted or controlled (BCUC, 1983).

Climate and Agriculture

Agricultural activities have been favored by a desirable microclimate within the Peace River Valley between Site C and Site One. Floodplain characteristics such as wind protection and a slightly longer frost-free period distinguish the valley from the surrounding plateau (Thurber Consultants Ltd., 1979d). Site C development may cause climatic impacts such as air temperature decreases, increased wind speed, increased fog density, and greater frost risk in the early spring. Each of these impacts may negatively affect local agriculture. They might result in longer crop drying and ripening requirements, crop deterioration and consequent price decreases, and reduced yields of both grain and feed crops (Canadian Bio Resources Consultants Ltd., 1979b), (henceforth simply C.B.R.C. Ltd.). Although agricultural impacts were determined to likely be minimal, the Commission recognized that they may be important to some regional farmers, especially regarding crop drying. Therefore, they recommended that the Ministry of Agriculture and Food consider this while establishing a regional compensation program. Hydro agreed in principle that crop-drying facilities could serve as an appropriate compensation measure.

The Commission, based on Hydro and Ministry of Agriculture and Food estimates, determined that 2,960 ha of agricultural land would be lost to flooding; of this total 400 ha is suitable for vegetable production with 2,560 ha appropriate for other crops. Hydro agreed to pay the market price for all lands required for the project but was unwilling to compensate for undeveloped Crown lands; they argued that the market value of such lands is negligible after development costs are deducted. The Commission disagreed and recommended that Hydro pay $ 18.6 million compensation toward regional agricultural programs, to be administered by the Ministry of Agriculture and Food.

The Commission also recommended that mitigation measures be implemented including reclamation for disturbed lands during construction, and amalgamating fractioned parcels with adjacent agricultural units where possible. While constructing transmission lines it was recommended that tower placement be coordinated with existing towers on cultivated land, that work be scheduled to minimize coincidence with the growing and harvesting seasons, and that herbicide usage be minimized. Such activities would be coordinated by a recommended land-use plan that would be developed by the appropriate ministries. Hydro would be required to fund the project-induced incremental costs of plan development, and was encouraged to participate in its formulation.

Water Quality and Downstream Users

The Site C dam would back up the Peace River as far as the Site One dam, flooding 76 km of the Peace and 30 km of its tributaries. The reservoir would be operated on a run-of-the-river principle, with a normal 1.5 m fluctuation level and flushing rate of 23 days (B.C. MOE, 1981). B.C. Hydro consultants estimate a 1.0 m fluctuation level and reservoir flushing rate of 18 days (C.B.R.C. Ltd., 1979a). The Site C drainage area totals approximately 85,000 km^2; the Williston Reservoir drainage basin accounts for approximately 82% of this total. The Halfway and Moberly River tributaries, downstream of Bennett Dam, exhibit typical seasonal flood and low flow characteristics, along with flooding produced by summer rainstorms. On average they represent approximately 10% [1] of the total inflow into the Site C region with the Peace River accounting for 90% (1,044 m^2/s), (C.B.R.C. Ltd., 1979a).

The present water quality of the Peace River within the Site C region is a function of the quality of Williston Reservoir releases and of its tributary inflows. The latter have their greatest influence during spring freshet and summer rainstorms.

Based on studies of existing Peace River conditions, as well as comparisons with other impoundments including Williston Reservoir, the principal effects of the Site C impoundment on water quality were estimated as follows:

- Reservoir stratification will occur only transiently. The appreciable current (1.1 - 1.4 m/s) of water entering the reservoir will cause regular mixing and temperatures will be similar from top to bottom. During warmer summer periods, with near windless conditions, some cooler water may collect at the bottom of the reservoir near the dam (B.C. Hydro, 1980a).

- Peace River inflows will be relatively clear due to sediment retention in the Williston and Site One Reservoirs. However, the Moberly and Halfway Rivers will contribute high suspended sediment loads during high flow periods (freshet and summer rainstorms). Suspended sediments and turbidity will be reduced due to the tendency of sediments to settle out in the calmer waters of the reservoir. However, shoreline erosion may increase turbidity in some regions. Potential exists for turbidity and density currents especially during summer rainstorms

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1. The Halfway and Moberly Rivers contribute up to 20% of the spring flow of the Peace River at Site C (Thurber Consultants Ltd., 1979b).

when inflows could be higher in suspended sediment and cooler than reservoir receiving waters (C.B.R.C. Ltd., 1979a).

- Generally, dissolved nutrient levels are expected to drastically increase after flooding due to inputs from the erosion and leaching of forested and agricultural soils. Secondary sources include sewage discharge, urban storm runoff, and atmospheric input. Nutrient levels are expected to decline relatively quickly (within 3-5 years). Due to Site C's rapid flushing rate (23 days compared to 2.2 years for Williston Reservoir) the nutrient contribution by development sources is thought to be insignificant when compared to existing sources (C.B.R.C. Ltd., 1979a). Therefore macronutrients such as nitrogen and phosphorus are expected to be similar to the present river levels: less than 250 ug/l N and less than 10 ug/l P.

- Supersaturation of water with dissolved gases may occur occasionally, primarily during periods of severe flooding when spillways and plunge pools are in operation. This has implications for water entering Site C from Bennett Dam and water discharged downstream of Site C.

- Dissolved oxygen levels are expected to remain near saturation throughout the year, with some reduction in stagnant bays near late summer.

- Total dissolved solids, hardness and iron are all expected to remain similar to existing river conditions (C.B.R.C. Ltd., 1979a).

- The possibility of mercury methylation is considered under fisheries resources implications, not water quality.

Other than for the potential negative effects of increased downstream water temperatures, the Commission concluded that water quality for downstream users would not vary appreciably from existing conditions. Indeed it was estimated that conditions may improve, particularly regarding decreased suspended sediment levels. No consideration was given to the impact of impoundment on downstream ecology. Conspicuous by its absence, there was no recognition of the potential effects of Site C on the Peace-Athabasca Delta of Alberta by the Panel, B.C. Hydro, the MOE, or any intervenors. Considering the severe impacts of Bennett Dam on the region [2] it seems only prudent that the potential for cumulative impacts resulting from Site C be considered. It is unclear whether the Peace-Athabasca Delta was not discussed due to a limited provincial perspective, or because any potential effects were considered to be insignificant in relation to the existing impacts of Bennett Dam. It is likely that the latter judgement prevailed. Due to the run-of-the-river operation of Site C the cumulative impacts may indeed be minimal. However, in the event that a significant impact does occur, provisions should be made to permit impact monitoring so that appropriate mitigation measures can be applied.

Water Temperature

As a principal focus for the application of an adaptive monitoring framework, water temperature will be subjected to a more detailed analysis.

The estimated transient nature of stratification causing reduced temperatures at the reservoir depths has been mentioned. Assuming conditions of complete mixing [which may be invalid during summer periods] Hydro consultants selected the Troxler-Thackston mathematical model to predict summer (May - September) temperature changes within the Site C reservoir (C.B.R.C. Ltd., 1979a). The parameters used were Q_t, the average rate of energy transfer between water and atmosphere (Btu/hour/ft^2); f, flow through time (hours); and d, average depth (ft). Values for f and d were calculated using Site C reservoir morphology data.

Q_t values could not be calculated directly. The variable has many components including absorbed solar radiation, absorbed long wave atmospheric radiation, long wave backscatter, heat lost by evaporation, and heat gains or reduction through conduction. Q_t was derived from 1977 Peace River conditions. The observed water temperature changes between the Site One and Site C dams result primarily from atmospheric and tributary inflow heat

2. For a description of the impacts of Bennett Dam on the Peace-Athabasca Delta please refer to Peace-Athabasca Delta Project Group (1973) and Rosenberg *et al.* (1987).

additions. An estimate of effective Q_t was therefore derived by subtracting tributary heat input from the gross heat input recorded between Site C and Site One. The data bases utilized in calculating effective Q_t were 1977 Peace River flows recorded by Environment Canada at Site One and Taylor, and daily river temperatures recorded at Site One and Site C by B.C. Hydro during various periods from 1972 - 1974 (C.B.R.C. Ltd., 1979a). From 1976 to 1983 Hydro recorded daily minimum, maximum, and mean temperatures in the Peace River at Taylor.

The summer water temperature changes in the main body of the Site C reservoir were projected (Table II) and estimated reservoir temperatures were contrasted to 1977 Peace River mean monthly temperatures (Table III). The comparison suggests that average water temperatures within the Site C reservoir during the summer months will be higher than in the existing river at the same locations. The MOE agrees that reservoir temperatures will increase but suggests that they will do so to a lesser extent primarily due to the cooling effects of evaporation (B.C. MOE, 1981). Thus, they disagree with the evaporation provision in the model chosen by Hydro for water temperature estimation.

The same model was used to project reservoir temperature changes for the Moberly and Halfway areas of the Site C reservoir. However, a greater chance of stratification exists in these regions, due to relatively lengthy, late summer retention times. The reader will recall that the model assumes complete mixing (no stratification). The temperature measures would be misleading with stratification since the epilimnion (upper layer) would realize greater temperature changes while the hypolimnion (bottom layer) would remain cooler (C.B.R.C. Ltd., 1979a). Furthermore, if retention times will vary, the model should have been run at different flow times to provide an array of temperature changes (Hall, 1987).

Regarding water releases downstream of Site C, Hydro estimates that July water temperature will increase from 2.5 - 3.2 ^{o} C near the Town of Taylor. Figure 12 illustrates the 1976 recorded average monthly river temperatures near Taylor. The Westcoast Transmission

Table II. Projected Water Temperature Changes for the Main Body, Site C Reservoir (C.B.R.C. Ltd., 1979a).

Month	Δ Temp, °C
May	+4.2
June	+5.6
July	+4.5
August	+4.8

Table III. Projected Reservoir Water Temperatures Near the Site C Dam Compared to 1977 Peace River Temperatures at Site C (C.B.R.C. Ltd., 1979a).

Month	Projected Reservoir Temp Near Dam, °C	Recorded River Temp, °C
May	7.0	5.7
June	12.0	9.3
July	13.5	10.4
August	13.0	10.0

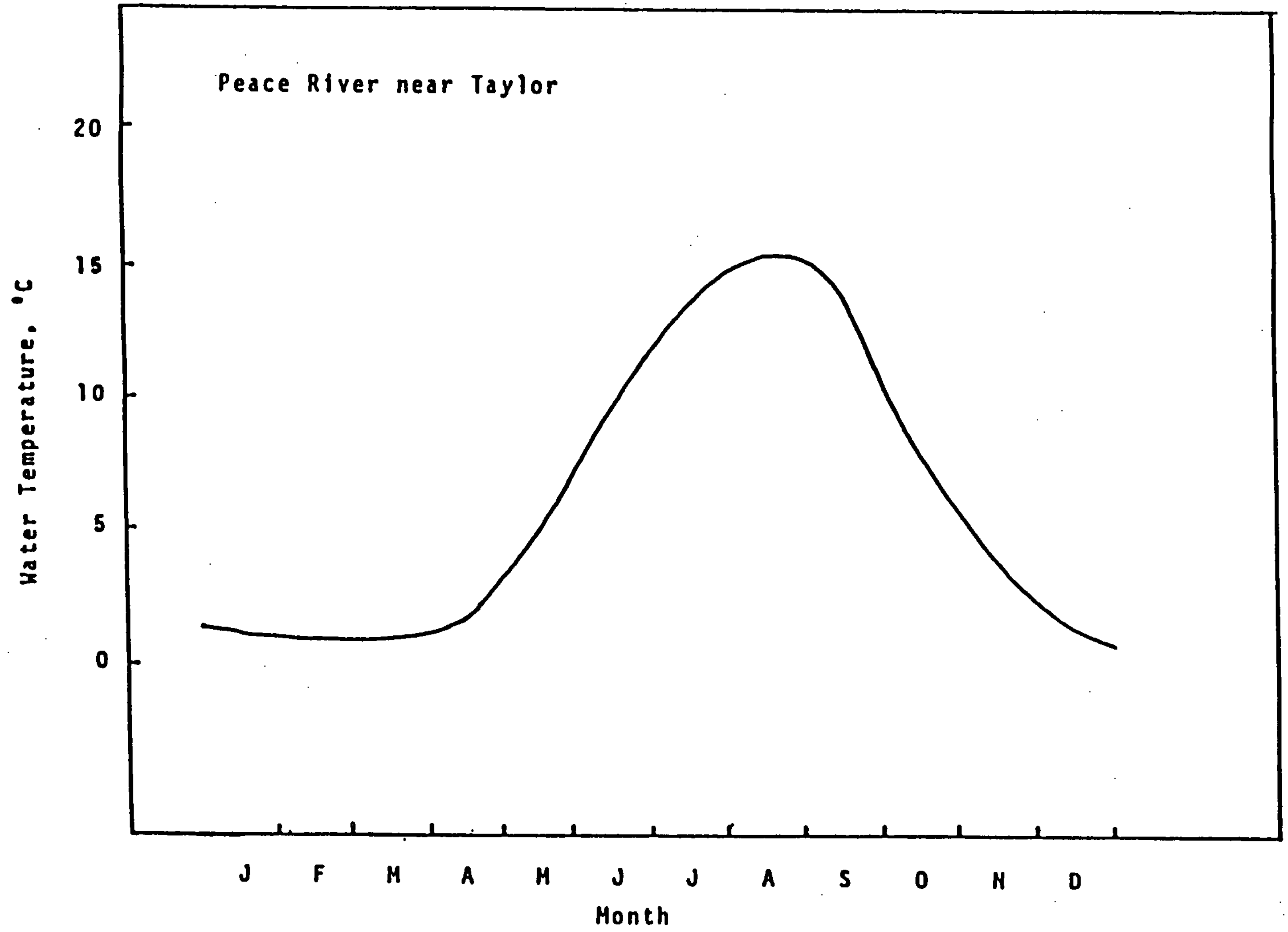

Figure 12. Average Monthly 1976 Peace River Temperatures Near Taylor (C.B.R.C. Ltd., 1979a).

Company (henceforth simply Westcoast) submitted evidence, in concurrence with Figure 12, that the highest average monthly temperature recorded near Taylor is 16.7 ^{o} C. This is particularly important since Westcoast currently uses 173,000 m^3 of Peace River cooling water at its Taylor natural gas processing plant and oil refinery 15 km downstream of Site C. It operates a once-through cooling system designed for 15.6 ^{o} C intake water (Waller, 1982). Given this design specification, the projected 2.5 - 3.2 ^{o} C temperature increase could have negative consequences for Westcoast's operations.

Westcoast further argued that if the problems are serious enough it would be forced to expend several million dollars to mitigate by either (1). installing a water refrigeration system upstream of operations, (2). installing a larger heat exchanger, or (3). installing larger oil-gas compression and cooling systems in the oil refinery.

The Commission recognized the potential seriousness of the impact and, although it constitutes a private matter between Westcoast and Hydro, they recommended that Hydro be required to develop a monitoring program to identify and measure impacts in consultation with Westcoast. The information could then be used to determine appropriate compensation.

<u>Fisheries Resources</u>

"The development of large-scale hydroelectric projects over the past thirty years has had the greatest single impact on the Province's fish and wildlife resources" (B.C. MOE, 1981:6). Since 1960, over 1,190 km of mainstream river have been flooded, exclusive of thousands of km of tributaries. These substantial impacts have generally been accepted as an unpaid price for the development of abundant and cheap sources of electrical energy. Both Williston and Site One Reservoirs have significantly changed the sport fisheries of the Peace River; the MOE fears Site C development will have similar results (B.C. MOE, 1981).

Extensive research was conducted by both Hydro consultants and the MOE on Site C implications for fisheries resources. Both parties reached significantly different conclusions concerning many of the issues considered. In addition, valuable information was presented to the Site C Panel by interest groups, particularly the PVEA.

B.C. Ministry of Environment

The MOE was primarily concerned with matters related to potential fisheries management and they placed a great deal of emphasis on estimating fisheries maximum sustainable yield (MSY) both with and without the project (B.C. MOE, 1981). Compensation measures, particularly in the form of post-development enhancement were also examined.

Participants included members of the Fish and Wildlife Branch at Fort St. John, Prince George, Vancouver, and Victoria. Based on extensive field officer experience the MOE concluded that Site C would significantly decrease sport fishing opportunities. This directly contradicted Hydro's estimates. The ministry estimated the river's MSY would be approximately 18,000 fish.[3] With the Site C reservoir this value would be reduced 25% to 13,500 fish (Table IV). The MOE suggested that the principal reason for angling reduction would be the predicted 30% decline of strongly preferred rainbow trout (*Salmo gairdneri*), Arctic grayling (*Thymallus arcticus*) and Dolly Varden (*Salvelinus malma*) sport species (B.C. MOE, 1981).

Interest Groups

The PVEA retained the services of fisheries/reservoir expert Dr. R. Bodaly from the Department of Fisheries and Oceans, Freshwater Institute, Manitoba. Dr. Bodaly presented evidence of the likely occurrence of mercury bioaccumulation in the food chain resulting from reservoir development in a cool northern-temperate environment. This may result in predatory

3. MSY was, in turn, used to estimate reservoir angling yield. For example, an MSY of 12,000 fish at an average of one fish per angling day provides an angling yield of 12,000 angling days/year (BCUC, 1983).

Table IV. B.C. Ministry of Environment's Estimates of Maximum Sustainable Fish Yield for the Peace River and Site C Reservoir (BCUC, 1983).

	Without the Project	With the Project (1987 in-service date)
1977	11,400	11,400
1987	18,000	4,300
1988	18,000	8,000
1989	18,000	11,300
1990	18,000	14,300
1991	18,000	13,500
1992	18,000	13,500
1995	18,000	13,500
2000-2056	18,000	13,500

fish, especially walleye and northern pike, mercury levels in excess of the 0.5 ppm Canadian marketing standard. Dr. Bodaly suspected that such an event will occur with Site C since the extent of flooding and soils are typical of reservoirs exhibiting the mercury contamination phenomenon (P.V.E.A., 1982).

B.C. Hydro

Hydro contracted Thurber Consultants Ltd., who in turn commissioned Renewable Resources Consulting Services Ltd. to prepare its impact assessment concerning fisheries resources. Field studies were conducted at various times throughout 1974 and 1975, in the fall of 1976 and in the spring and early summer of 1977 (B.C. Hydro, 1980a).

Field Studies

Field studies included the gathering of physio-chemical data on water quality, temperature, stream habitats, and an estimate of the extent of major potential littoral regions. Water quality results were discussed in the previous section. Stream habitat analysis included the assessment of stream morphometry, bank stability, substrate types, and potential siltation sites. Stream gradient diagrams were also produced (Renewable Resources Consulting Services Ltd., 1979), (henceforth simply R.R.C.S. Ltd.). A littoral area estimation for the proposed reservoir was completed by air-photo interpretation and the planimetry of National Topographic Systems maps. A helicopter reconnaisance of the proposed site was also undertaken to verify potential littoral areas; altitude and slope were determined at spot locations (R.R.C.S. Ltd., 1979).

The second component of the field studies consisted of biological analyses including fish collection, analysis, tagging, spawning area determination, and benthic macroinvertebrate collection and analysis. Fish sampling was conducted by a mechanized beach seine, hand seines, gill nets, fish shocking, angling, a boat-mounted electrofisher, and two-directional fish traps. Fish samples provided information concerning age (scale samples), growth, feeding habits, and the sex and state of maturity. Stomach contents were organized in taxonomic groups. Fecundity (total number of eggs) was recorded for both mountain whitefish (*Prosopium williamsoni*), and rainbow trout samples. Spawning areas were determined by the presence of both ripe and spent fish (of both sexes) or the presence of fertilized eggs over suitable substrates (Thurber Consultants Ltd., 1979b).

Zoobenthos were sampled and classified in taxonomic groups. In general, chironomids and the mayfly *Rhithrogena sp.*, were the most important [prominent] benthic organisms in the standing crop during the study period. The latter was significant only in areas with suitable rocky substrate. Chironomids were found in abundance at almost all sites (Thurber Consultants Ltd., 1979b).

Resource Utilization Surveys

Anglers, boaters and recreationists encountered in the field from May to July, 1977 were surveyed. A creel census was concurrently implemented in June and July (total creel 536 fish). In addition, members of the Peace River Rats Association were questioned on their recreational use of the fishery resource (Thurber Consultants Ltd., 1979b).

Regional Fish Resources

The completion of the W.A.C. Bennett Dam and consequent creation of Williston Reservoir in 1967 dramatically affected regional fisheries resources and their utilization. Due to the silt-retaining characteristics of Williston Reservoir, Bennett Dam discharges provide clear, high quality water to the lower Peace River; a marked contrast from historic conditions. Consequently, significant increases in cold-water sport species including rainbow trout and Arctic grayling have resulted. The construction of the Site One dam has caused the delay and blockage of upstream migrations of local species including mountain whitefish, Arctic grayling, and rainbow trout. These and other species now congregate just below the construction site, and face heavy angling pressure from locals and construction workers; it is not known whether the fishing is sustainable at present levels of utilization (Thurber Consultants Ltd., 1979b).

Site C Area Fish Resources

Presently, mountain whitefish are the most abundant sport species in the Site C area. Other sportfish species in decreasing order of abundance are Arctic grayling, rainbow trout, Dolly Varden, northern pike, and walleye (B.C. Hydro, 1980a). Longnose (*Catostomus catostomus*) and largescale suckers (*Catostomus macrocheilus*) appear to be the most abundant non-sport species.

Anglers consider the sport fishery in the Site C area to be good. The majority of angling effort is concentrated just downstream of the Site One construction site; mountain whitefish were indicated as the dominant catch in the creel census.

Potential Site C Development Effects

Hydro's consultants acknowledged that the main effects upon fisheries would result from the alteration of the present river system into a reservoir (lake-type habitat), and the blockage of upstream fish migration by the Site C dam. Large areas of spawning habitat would be lost and fish species adapted only to flowing (riverine) conditions would be reduced or eliminated (BCUC, 1983).

Construction Phase

The principal impacts during project construction will include the blockage of fish migrations past the dam or diversion tunnels, increased suspended loads in the water, decreased water quality, direct fish mortality caused by explosives, increased angling pressure by construction crews, and impacts associated with the construction of ancillary facilities (e.g. transmission lines, work-crew camps), (R.R.C.S. Ltd., 1979).

During construction, gravel washing and related activities could cause increased suspended sediment loads, increased turbidity and increased downstream substrate siltation. Increased suspended sediment loads can have an especially negative impact as they may cause decreased primary productivity which, coupled with substrate siltation, would cause reduced zooplankton and benthic invertebrate production. Consequently, fish feeding on such food sources would be impaired. Due to the relatively turbid nature of the water below Site C the impact is expected to be short-term and slight, especially if precautionary mitigation measures are applied. Downstream siltation may also affect mountain whitefish egg survival. Due to the diversity of locations where mountain whitefish spawn within the Peace River and its tributaries, the effect is expected to be small. Again, appropriate mitigation would help ensure its minimization.

A decrease in water quality may result with the introduction of toxic substances such as oil, greases, and related chemicals, along with sewage into the river. They may result in direct fish mortality, or indirectly reduce both oxygen levels (through aerobic breakdown) and fish food abundance (R.R.C.S. Ltd., 1979). However, due to the Peace River's assimilative capacity and fast flow it would require a massive spill or excessive amounts of sewage to significantly affect water quality (Hall, 1987).

Operation Phase

The primary effects on fish populations during the operation phase will result from a blockage of fish migration, loss of spawning areas, and altered water quality conditions. All have significant implications for fisheries biology.

Without effective fish passage facilities, upstream migration would be permanently blocked by the Site C dam. Fish species in the area known to migrate considerable distances include: rainbow trout, Arctic grayling, northern pike, and white sucker (*Catostomus commersoni*). Any walleye or mountain whitefish migrations that might occur between Site C and downstream would also be permanently blocked without the inclusion of fish passage facilities with project development (R.R.C.S. Ltd., 1979).

Impoundment would also result in the loss of large areas of spawning habitat for stream-spawning fish species. Those expected to be most adversely affected are mountain whitefish, rainbow trout, Arctic grayling, and sucker species. Northern pike spawning habitat would likely increase with development since greater areas will exist for aquatic macrophyte production.

Potential water quality effects were discussed in the previous section.

Biological productivity implications resulting from the transfer from a river to reservoir system are difficult to assess. Hydro's consultants, based on previous case studies, predicted the following general trends.

The littoral zone, extremely important for fish production, was estimated at 2,618 ha. While this figure is believed to be an over-estimation, it does serve as an indicator of littoral development. The littoral zone is expected to be less than 25% of the reservoir's total area. It would be restricted to an area above 10-15 m in reservoir water depth (R.R.C.S. Ltd., 1979).

The Site C reservoir will likely follow the pattern characteristic of new reservoirs with an initial large increase in productivity due to nutrient leaching from flooded soils and vegetation, followed by a sharp decline in productivity with reduced nutrient levels (Etter, 1984). Due to Site C's estimated rapid flushing rate nutrient levels are expected to decline relatively quickly and remain close to existing Peace River conditions, as stated in the water quality section. Phytoplankton production is expected to increase initially in response to nutrient loading and over the long-term due to the greater amount of aquatic habitat available. It is interesting to note that Site C primary productivity is not expected to be the principal source of energy for biotic systems due to the relatively short flow through time, and the continued source of phytoplankton and zooplankton entering Site C from the Williston and Site One Reservoirs (R.R.C.S. Ltd., 1979).

In response to greater phytoplankton levels and increased habitat, zooplankton production is also estimated to increase following impoundment. Calanoid copepods are expected to dominate and provide an abundant source of food for zooplankton-feeding fish species. Downstream zooplankton populations are also expected to increase.

Due to the projected minimal fluctuations in reservoir level because of its run-of-the-river design, zoobenthic communities are expected to be comparable to those existing in the area's natural lakes. Standing-water organisms, such as oligochaetes and chironomids are expected to dominate.

Fish Populations

In response to aquatic vegetation growth in shallow littoral areas surrounding the reservoir, northern pike populations are expected to increase. Dolly Varden populations will likely increase initially, then decrease to relatively low levels. Both spawning habitat and angling effort will be limiting factors. Arctic grayling and mountain whitefish populations are expected to remain abundant and possibly increase. Due to limited spawning habitat rainbow trout numbers are expected to be low and the potential for their enhancement is poor. Significant sucker populations will likely result with development.

Based on 1981 survey data Hydro's consultants estimated that the long-term MSY for the Site C reservoir would increase 64% to 8,800 fish in contrast to 5,600 fish in the undeveloped river. These figures were estimated for 1997 based on a 1987 Site C in-service date (BCUC, 1983). Hydro's estimated 64% increase in MSY with Site C development is in marked contrast to the MOE's estimate of a 25% decline.

A self-sustaining walleye population in the Site C reservoir is unlikely, however, considerable potential exists for their enhancement. Due to the lower costs required, and the presence of other existing regional trout fisheries, a walleye-enhancement program appears promising. Table V summarizes the factors contributing to the choice of walleye for post-impoundment enhancement (B.C. MOE, 1981).

The Utilities Commission reviewed the Hydro, MOE, and interest group submissions on potential fisheries impacts and reached the following conclusions. First, the evidence on MSY is unreliable. Hydro's estimate was hypothetical and could not be supported; similarly the MOE's estimates were not substantiated with hard data. The appropriate compensation cannot be determined until the magnitude of the loss of fisheries resources has been accurately estimated. A description of the types of research recommended to provide the necessary information is given in the following section. Second, following an accurate estimation of MSY, the Commission recommended that Hydro be required to pay the MOE compensation equal to the magnitude of the loss of fisheries resources. The funds would be administered for regional fisheries enhancement. Third, in addition to any subsequently recommended mitigation measures the following conditions must be imposed:

- sediment loads to water bodies during construction are to be minimized;
- waste material must be suitably handled to prevent water pollution;

Along transmission lines:

- uncleared forest buffer strips are to be left where the line parallels the river;
- vegetation clearing must be minimized;
- access roads are to be minimized;
- road cuts and steep grades must be stabilized to minimize erosion, using special techniques where necessary;
- adequate culverts are to be provided (BCUC, 1983).

To conclude, based on the understanding of reservoir impacts developed in Chapter 4, the EIA completed for Site C was very comprehensive. It reflected most of the

Table V. Summary of Factors Bearing on the Choice of Walleye for Initial Post-Impoundment Enhancement (B.C. MOE, 1981).

	ANGLER APPEAL	ENHANCEMENT DRAWBACKS				
		1	2a	2b	2c	3
Rainbow trout	preferred		P	P		X
Arctic grayling	very high	P		P	X	X
Dolly Varden	very high	X		P		
Mt. whitefish	low	X		P		X
L. whitefish	low			P		X
N. pike	low					
Burbot	medium	X				P
Kokanee	very high		P	P		X
L. trout	very high			P		X
Walleye	high					

X denotes definite problem.

P denotes possible problem.

Enhancement Drawbacks

1. Hatchery technology is undeveloped or poorly developed.
2. Poor suitability of species to anticipated reservoir situation:
   A. cold temperature,
   B. turbidity (moderate turbidity is still anticipated below the Halfway River),
   C. lake environment vs. river environment.
3. Competition for food with coarse fish.

impacts recognized in the reservoir impact paradigm in sufficient detail to permit the Site C Panel to make decisions on their management, mitigation, and compensation. Omissions in B.C. Hydro's environmental impact statement were usually compensated for by intervenor submissions including the provincial MOE, and private interest groups. For example, the potential for fish mercury bioaccumulation was neglected in Hydro's analyses, but was brought to the Panel's attention by an expert retained by the PVEA. However, the Site C EIA was not without deficiencies. Little attention was afforded to the potential downstream ecological disruption that may result with impoundment. As Chapter 4 indicates, these effects can be very significant. While they may not be of great economic importance that does not justify neglecting them in an EIA. Similarly, failure to consider the possible cumulative effects of Site C development on the Peace-Athabasca Delta, Alberta, may prove to be a serious oversight. The potential for increased fish parasitism following impoundment was another omission of the Site C EIA. Finally, both B.C. Hydro's and the MOE's estimates of fisheries MSY were inadequate. As illustrated earlier, however, few EIAs adequately cover all of the implications of development. Relative to the criticisms of past attempts, and the reservoir impact paradigm, the Site C EIA and Panel hearings provided a comprehensive analysis of the potential effects of Site C development.

CHAPTER 7
SITE C MONITORING ANALYSIS

7.1 MONITORING OPPORTUNITIES

Considerable promise exists for developing monitoring strategies for the Site C dam. The Site C Panel recognized the potential benefits of establishing a monitoring committee and recommended that an Energy Project Certificate should not be issued prior to the acquisition of information required for several key, potential impacts of development.

7.1.1 Site C Monitoring Program

Hydro and several intervenors, with the BCUC's concurrence, proposed that a socio-economic impact monitoring program be established in the City of Fort St. John. The Professional Development Advisory Committee (PDAC), a hydro-funded interest group representing several local social services, prepared the monitoring proposal. It was accepted in principle by all parties.

The objectives of the monitoring program outlined in the PDAC submission include assessing community needs, identifying and measuring actual impacts, impact management, providing information to the community, and verifying compliance with imposed mitigation (BCUC, 1983). The Commission recommended that the program be designed to achieve the above objectives, and that Hydro should fund and be subject to monitoring program decisions as a condition of the Energy Project Certificate.

Personnel would include a three-person staff; a monitoring committee representing local services and communities; and an impact management board consisting of representatives of senior Fort St. John officials, provincial government agencies, Hydro, and the monitoring committee. The staff would report to the monitoring committee, which would be responsible for program direction including choosing appropriate mitigation measures. The impact management board would convene to resolve committee disagreements and verify compliance with mitigation standards. The PDAC further suggested that an arbitration board be established, consisting of one to three top level Cabinet appointees or Utilities Commission members, to issue binding orders to Hydro and provincial ministries when necessary (BCUC, 1983). Hydro would be required to fund their base operations and salaries; additional funding requests would be reviewed by the BCUC based upon the monitoring committee's recommendation. Furthermore, the monitoring committee could authorize Hydro to pay for (1). additional staff or special studies as required for impact assessment, (2). mitigation measures, and (3). compensation measures. Hydro would retain the privilege of having any of these orders reviewed by the BCUC.

Based on previous experience the Commission concluded that the purpose of the monitoring program is to deal with project impacts not resolved by specific terms and conditions of the EPC; usually because they can be best resolved as they arise during project construction and operation. This reactive approach is necessary when (1). the nature of the impact is inherently uncertain, and can only be assessed with development; or (2). the impact can be assessed, but the data are insufficient to derive well-informed conclusions on its nature and magnitude and, the costs of advance assessment would be great relative to its significance; or (3). unanticipated impacts may arise that can only be resolved once identified.

The impacts referred to in the monitoring program were primarily socio-economic. However, two of the eight impacts result from environmental implications: (1). the identification of and appropriate compensation for impacts of highway relocation and transmission line development on wildlife, and (2). determination of compensation for the impact on fisheries.

It was also determined that the monitoring program should be conducted as an open process, capable of receiving public input. More specifically, when the construction phase of development causes unanticipated impacts the Commission recommends that the program be capable of responding to public concerns. The costs incurred are not to be compensated by Hydro unless the monitoring commissioner retains the complainant as a technical consultant or the complainant successfully argues that the costs should be a part of an impact compensation award. It is likely due to the numerous complications and criticisms of the Revelstoke dam monitoring program [1] and the introduction of the *Utilities Commission Act* that public concerns over Site C were given higher priority.

The Commission concluded that the long-term effects of development should not be subject to ongoing review under the program. With the exception of the issues to be specifically considered by the monitoring program, the Commission has already determined the appropriate compensation for development impacts. The monitoring program was furthermore not designed to deal with private matters, although its information would be readily available if it would aid disagreement in negotiations.

Concerning compliance, the Commission concluded that the scope of the program should include all impacts requiring monitoring as a condition of the Energy Project Certificate. Although the program would not perform an inspection function, it would be available to settle disputes should disagreement arise over whether accepted conditions have been met.

Finally, the Commission suggested that most of the matters referred to the program would arise from the construction phase. Consequently, they recommended that the monitoring program terminate upon the completion of project construction.

7.1.2 Future Research and Design

Various opportunities for monitoring research and design were recognized by the Commission,

1. For a detailed description of the Revelstoke dam monitoring program please refer to Bankes and Thompson (1980).

as illustrated in its final report. Most resulted from a need for more or better information to provide a sufficient database for mitigation and compensation decision-making. The Commission's Site C Report (BCUC, 1983) is the principal source of the following discussion. Again, the implications for water quality and fisheries resources are emphasized.

Heritage Resources

Hydro is not obligated to institute any monitoring programs in addition to the previously mentioned compensation arrangement. The Commission recognized the unique scientific, historic and cultural values of the area's heritage resources, but concluded that their value can only be determined by subjective judgement. Adequate information exists to do so.

Terrain and Mineral Resources

Due to the minimal nature of potential impacts the Commission concluded that no monitoring, mitigation or compensation would be required of Hydro, or any other party. Hydro, however, is investigating possible mitigation measures to prevent natural gas well flooding, or pipeline disruption.

General Outdoor Recreation

The Commission recommended that Hydro be required to pay $ 6.9 million to compensate for the value of lost river-based recreational opportunities. The funds should be used to enhance recreational opportunities on both the reservoir and remaining rivers in the region. They added that $ 883,000 of the total should be diverted toward wildlife programs, to be administered by the Fish and Wildlife Branch, B.C. MOE.

Monitoring could play an important role in determining how effective wildlife-enhancement programs were, and if they should be continued in their current fashion. If ineffective, programs could be modified (e.g. from habitat restoration to artificial feeding facilities) to ensure the efficient use of compensation funds.

Forestry

Opportunities exist, though not explicitly recognized by the Commission, for monitoring research and design with reference to potential forestry impacts.

The Commission considered clearing the area to be flooded essential. Monitoring will be required to determine whether the clearing, in concert with a clean-up program, had been adequate so that the reservoir is not materially affected by debris. In addition, monitoring will be required to assess the rate of shoreline erosion; if too great, mitigation will be necessary to prevent sloughing and tree deposition into the reservoir. Selective clearing to maximize the potential for recreational use, but not significantly affect wildlife, will also require monitoring to determine the most appropriate location.

The Commission also concluded that an information gap exists concerning transmission line development. Both reference to previous developments (e.g. Williston-Kelly Lake line) and monitoring can rectify this deficiency for both the Site C proposal and future developments in general.

Wildlife and Recreational Hunting

The Commission concluded that Hydro should be required to pay $ 2.8 million in compensation, to be directed to wildlife-enhancement programs organized by MOE in consultation with local interests. The ministry's compensation proposal included (1). a biophysical analysis of Crown and private lands, (2). moose radio collaring to determine migration patterns, (3). the acquisition of private lands to increase high-capability wildlife habitat, and (4). the enhancement of existing wildlife habitats following comprehensive land-use plan development. They proposed that a monitoring and surveillance program be included as a part of the compensation package personnel requirement (B.C. MOE, 1981). A well-designed monitoring program would be essential to ensure that the appropriate information is being gathered to permit informed management decisions, and to encourage doing so in a cost-effective manner.

The identification and compensation for highway relocation and transmission line development impacts on wildlife was also specifically recognized as requiring monitoring. It was referred to the formal monitoring program to be established and administered through the Fort St. John office.

Climate and Agriculture

Hydro did not propose compensation measures for climatic effects as they determined their potential to be minimal. Indeed, they submitted that compensation for any such impacts would be less costly than implementing a monitoring program to determine whether they do in fact occur. The Commission agreed, and encouraged Hydro's initial proposal for providing crop-drying facilities when developing an agricultural compensation package for the region.

The recommended land-use plan to be established by the appropriate government agencies, in consultation with Hydro, may also require monitoring programs to provide data for its informed development.

Water Quality and Downsteam Users

The main impacts on water quality including those of reservoir temperature stratification, suspended sediments and turbidity, nutrients, dissolved oxygen, total dissolved solids, hardness and iron were all considered in the Site C EIA. Generally, agreement existed between Hydro and the MOE that they would not be appreciably altered from existing Peace River conditions. The Commission concurred and monitoring programs were not recommended.

Due to the contribution of many factors, reservoir water temperature is difficult to predict. In addition, few northern-latitude case studies exist allowing extrapolation to suit the proposed Site C reservoir character. This is particularly true of flushing rates. Site C's estimated 23 day rate is much quicker than the 1.2, 1.4, and 2.2 year respective rates for the Arrow Lakes, M[c]Naughton Lake, and Williston Reservoir (C.B.R.C. Ltd., 1979a).

As a result of these difficulties, and the disagreement between B.C. Hydro and the Westcoast Transmission Company over potential water temperature levels downstream of Site C, the Commission concluded that a downstream monitoring program should be developed by Hydro in consultation with Westcoast. The monitoring program would be developed to both identify and measure impacts associated with increased downsteam water temperature. Impacts may range from simply rendering current cooling facilities inadequate to the effects of increased biological growth on plant operating efficiency. The impact on general downstream ecology would not be considered.

Fisheries Resources

Identified as a component of the Site C monitoring program, fisheries resources hold the most potential for monitoring research and design. It was generally agreed at the hearing that the initial assessment work carried out was sound, and reflected the current state-of-the-art in environmental system understanding. Exceptions were both the MOE and Hydro estimates of maximum sustainable yield. The Commission concluded that Hydro's studies were unsubstantiated, and that the MOE's estimates were also not supported by hard data.

The Commission added that studies necessary to obtain definitive maximum sustainable yield estimates for the Peace River are impractical and instead recommended a three-pronged monitoring approach.

The first component requires Hydro to conduct a detailed angling and creel survey. It should recognize and rectify the criticisms of their earlier efforts, especially concerning early morning and late evening fishing, fishing by local residents beyond public access points, and winter ice-fishing.

Secondly, Hydro would monitor sport fish migrations in the Peace River and tributaries to assist in determining flooding impacts and the prospect for existing stock survival. Additionally, the Commission recommended that life-history patterns be investigated in relation to habitat association to permit the identification of both critical habitat limiting factors and appropriate post-impoundment enhancement methods.

The third component of the fisheries resource monitoring program consists of studies by Hydro, in consultation with MOE, to determine the most effective method of shoreline and tributary enhancement programs. Shoreline investigations would identify potential spawning areas using existing maps and data. Follow-up field studies would determine the feasibility of pre-impoundment enhancement methods (BCUC, 1983).

The Commission stressed that this monitoring program is not a component of a compensation package but, rather, it is the responsibility of the applicant (Hydro) for the purposes of determining compensation. Finally, the Commission concluded that once the monitoring program has been completed, and adequate information is available to determine fisheries resource losses, that Hydro would be required to pay the government an amount equal to the loss to be used for regional fisheries enhancement.

Other opportunities for monitoring were identified. Hydro agreed to monitor waste material deposition (including sediment loading) during construction to ensure that they were suitably handled. The MOE was concerned with the potential for walleye mercury bioaccumulation and agreed to both monitor mercury levels should construction proceed, and to post warning signs if levels are found to be hazardous. Furthermore, the Commission was concerned about the lack of existing information describing the impacts of northern-temperate reservoir development in British Columbia. They considered it important that this information gap be filled to improve the basis for future EIA efforts. They also suggested that the appropriate government agencies undertake the necessary studies to do so. The Commission did not, however, provide any direction by offering examples of studies that might be useful for such experimental monitoring purposes.

To conclude, similar to its EIA, the monitoring proposed for Site C development was generally comprehensive. Although they offered no specific examples, the Site C Panel even recognized a need for experimental monitoring to improve the understanding of reservoir development on the northern-temperate British Columbia environment. However, the following deficiencies existed with the impact monitoring proposed to coincide with Site C development. The official Site C Monitoring Program establishes an effective framework for analysing the impacts of development but, other than for wildlife and fisheries resources, its focus is strictly socio-economic. It, or a similar mechanism should also be required to assist in developing effective monitoring strategies for other potential environmental impacts. Furthermore, the Site C Panel's decision to cease monitoring following construction is unfortunate. This will cause the monitoring program to commit one of the major criticisms of conventional monitoring programs: failing to verify impact predictions with post-development monitoring. Without information from the operation stage of Site C development, it is highly unlikely that adequate data will exist to permit sound, long-term project management.

Chapter 7 advances the case study to a point where the conceptual model of adaptive monitoring, advanced in the theoretical framework, can be applied to potential Site C impacts.

CHAPTER 8
POTENTIAL FOR SITE C ADAPTIVE MONITORING

The preceding chapter detailed both the monitoring that was undertaken for the Site C EIA and the opportunities that were recognized for future monitoring research and design. This chapter examines the potential for employing the adaptive monitoring principles advocated in Chapter 3 for potential Site C impacts and describes the benefits expected to result. The recommendations provided, although hypothetical, provide a basis for critically assessing the requirements and expectations of future Site C monitoring strategies.

The potential impacts on *downstream water temperature* (DWT) and *fisheries resources* are chosen to illustrate the benefits of an adaptive monitoring approach for two principal reasons:

1. the relative simplicity of determining downstream water temperature changes, compared to the complexity of assessing impacts on higher order biological systems such as fisheries resources, spans the range of difficulty in impact prediction and assessment; and
2. both potential impacts were recognized by the Site C Panel as requiring monitoring to acquire sufficient information to permit both compensation determination and effective project management.

The impacts chosen for analysis are environmental, however, this category is not singularly appropriate for the adaptive monitoring approach. The numerous socio-economic impacts that would arise with Site C development could also be measured in an adaptive fashion. Indeed, the biophysical effect of DWT change has a major socio-economic implication: the cost of implementing mitigation at Westcoast Transmission Company's Taylor operations.

8.1 DOWNSTREAM WATER TEMPERATURE

As illustrated in Chapter 6, the Site C Panel determined that Hydro, in consultation with Westcoast, would be required to design and implement a DWT monitoring program. The program would be necessary to establish whether Westcoast's cooling facilities at Taylor would be adversely affected by predicted DWT increases associated with Site C development.

Summer downstream discharges--particularly for July--are expected to increase from 2.5 - 3.2 ^{o} C. This would have two major impacts: ecological and physical. The former impact category was ill-considered in the Site C EIA. The latter was examined in relation to its implications for Westcoast's cooling facilities and provides a focus for the following analysis.

Given the 15.6 ^{o} C design specification of Westcoast's current cooling facility, and the 16.7 ^{o} C average July DWT recorded at Taylor in 1976, a 2.5 - 3.2 ^{o} C increase could seriously affect their operations. The degree of impact would depend upon the frequency and duration of high water temperature periods during the summer months. Three major impacts could result from warmer cooling water temperatures: (1). decreased efficiency of operations, (2). increased maintenance requirements, and (3). increased temperature of cooling water discharges back to the Peace River, which could result in non-compliance with Westcoast's Pollution Control Permit (Waller, 1982). Westcoast suggests that if the DWT problem is serious enough it would have to mitigate by either (1). installing a water refrigeration system upstream of operations, (2). installing a larger heat exchanger, or (3). installing larger oil-gas compression and cooling systems in the oil refinery. Each option would require the expenditure of several million dollars. Assuming occasional periods of reservoir thermal stratification, DWT increases could also be minimized by designing reservoir discharge outlets to draw from cooler hypolimnion waters. DWT monitoring is thus necessary to determine whether changes do result with Site C development and, if so, to permit choosing the most appropriate form of mitigation. Establishing whether DWT increases is relatively straightforward and does not require adaptive monitoring. Choosing the best mitigation option, however, requires a better understanding of the spatial and temporal temperature variations in the system. As the following section illustrates, DWT monitoring would thus benefit from an adaptive approach.

Currently there is inadequate monitoring of Peace River water temperature being conducted at Taylor. From 1976 to 1983 Hydro recorded daily minimum, maximum and mean temperatures. Since 1984, with the reduced potential for Site C development following the hearings, monitoring has faltered (B.C. Hydro, 1984). Presently, Hydro only records temperature sporadically, usually for internal purposes (Kartha, 1987). Similarly, while Westcoast continues to monitor river water temperature, their measurements are only taken sporadically--sometimes daily, sometimes weekly--with no reference to minimums, maximums or means. Reliable, automatic measuring devices exist for measuring water temperature with an accuracy of +/- 0.5 ^{o} C (Canter, 1985; Quinby-Hunt *et al.*, 1986). Indeed, the necessary sampling equipment is already installed at Taylor but is not currently being utilized. Such equipment could record daily DWT minimums, and maximums and thus permit the calculation of mean daily temperatures and temperature ranges. These values could be compared with the design specifications of the three mitigation options available. Mitigation measures could then be chosen on the basis of their operating specifications relative to the maximum, mean, and duration of recorded DWT increases. The cost of implementation and maintenance would also be a criterion in evaluating mitigation options.

8.1.1 Adaptive Monitoring Applied

The application of adaptive monitoring begins by forming an interdisciplinary monitoring design team. For this example its membership would include employees of both Westcoast and B.C. Hydro. Experience with water quality measurement and the technical requirements of the mitigation options would be essential. A technical consultant may be retained if necessary for added expertise. Due to the straightforward nature of the impact the monitoring design team would be maintained at a minimum.

The interdisciplinary team must complete the adaptive monitoring design steps (Figure 3). The equivalent of steps 1 and 2 have already been completed through the Site C Panel hearings. Unlike most ecological impacts where valued ecosystem components (VEC) are easily recognizable an obvious VEC does not exist for this example. Rather, DWT can be considered a parameter of concern. To clarify, if increased DWT affected a downstream fish species important to human populations then the fish species would be the VEC and DWT the linkage to development activities. However, according to the definition provided in Chapter 3, DWT is not in itself a VEC.

Step 3 involves identifying impact hypotheses that relate development activities to VECs or, in this case, DWT. The hypothesis can be clearly stated: reservoir discharges will increase summer DWT between 2.5 - 3.2 ^{o} C at Westcoast's cooling facilities 15 kilometers from Site C.

Step 4 requires determining the study area. As indicated in the impact hypothesis it would encompass Westcoast's cooling facility intake structures at Taylor, 15 km downstream of Site C. It would also be necessary to monitor water temperature in other streams to ensure that potential Peace River changes downstream of Site C were indeed due to impoundment and not a result of natural variability.

In step 5 the design team must determine the necessary temporal horizon for monitoring. Minimum, maximum, and mean daily DWT data at Taylor exists from 1976 to 1983. The highest average monthly temperature was 16.7 ^{o} C recorded in July, 1977. Unfortunately, monitoring effort was terminated in 1984. However, should the project be initiated within the next few years, and monitoring was continued for at least 2 - 3 years prior to construction, the cumulative baseline that would exist should be adequate to assess DWT changes. The amount of pre-impoundment monitoring required to assess impacts versus natural variability would be determined by the monitoring design team. It is likely that monitoring effort would be limited to the summer months (May - September) since they alone, especially July, have the potential for adversely affecting Westcoast's cooling operations. It would be necessary to continue monitoring for several years concurrent with reservoir operation to determine its extended effects on DWT and to permit choosing the appropriate form of mitigation. Holden (1979) supports such a commitment since water volume and flushing rate continued to significantly affect DWT in the Colorado River for up to six years following initial water release.

Steps 6 and 7, while necessary when a series of hypotheses are generated, have already been considered through the Site C Panel hearings.

Step 8, in this instance, has also been partially completed. Monitoring is required for three major reasons:

1. to establish a baseline with which to contrast post-impoundment DWT and verify whether a 2.5 - 3.2 ^{o} C increase has resulted,
2. to permit choosing the appropriate mitigation option based on DWT change in relation to their respective operating specifications, and
3. to verify that longer-term post impoundment DWT increase does not exceed the estimated 2.5 - 3.2 ^{o} C and limit the mitigation option's operating efficiency.

Ensuring the statistical validity of data collection for this example is relatively straightforward. As illustrated in Chapter 3, prior to the initiation of monitoring care must be taken to address the statistical requirements for both sampling design and the subsequent data analyses. Regarding sampling design a fundamental concern is that the accuracy of the DWT recording equipment must be suitable (a range of +/- 0.5 ^{o} C is adequate for this example). It must also be maintained and periodically calibrated. Steps 4 and 5 indicate the requirements for maintaining spatial and temporal data validity. Spatially, the data to be analysed must be collected at the proposed cooling water intake locations to be statistically credible. Temporally, the monitoring design team would determine what amount of pre-impoundment data would be necessary to permit a valid comparison with post-impoundment data to test the increased DWT impact hypothesis. Continual DWT data collection would permit testing the impact hypothesis to determine whether an impact did indeed result from impoundment. From the outset the types of statistical analyses that will be applied should also be considered. A further consideration that must be taken into account is the effect of climatic conditions on DWT. Both pre and post-impoundment monitoring data must be assessed in terms of existing climatic conditions and contrasted with historic conditions to estimate what might happen to DWT with climatic extremes (Hall, 1987).

Identifying possible mitigation options, step 9, has also been completed. Three options exist: (1). installing a water refrigeration system upstream of operations, (2). installing a larger heat exchanger, or (3). installing larger oil-gas compression and cooling systems in the oil refinery. Mitigation would be chosen according to two principal criteria: DWT increase in relation to the operating specifications of each mitigation measure, and the cost of implementing and maintaining the respective mitigation options. The duration of maximum temperature increases is also important. Should it be determined that critical DWT increases only exist for a relatively short time period, it may be more cost-effective for Westcoast to suffer the impact and have B.C. Hydro compensate for any damages that might result. Another form of mitigation that might be considered is varying reservoir releases, should thermal stratification occur, to take advantage of cooler hypolimnion waters. Variable discharge outlets would have to be a part of the reservoir design. Monitoring would also be necessary to determine if reservoir stratification did indeed occur. It would likely be a component of other impact hypotheses testing programs related to post-impoundment fish habitat. Reservoir stratification is expected to exist only transiently. However, if it does occur it is expected during hot, windless conditions which would permit using hypolimnion discharges in concert with cooling facilities to mitigate summer DWT increases.

Once monitoring has begun (step 10), the four questions required for adaptive monitoring evaluation must be reiterated (Figure 4).

1. Are the data being collected relevant ?

As mentioned above, monitoring and the subsequent daily composite recording of downstream minimum, maximum, and mean temperatures is necessary for three major reasons:

1. to establish a baseline with which to contrast post-impoundment DWT and

verify if a 2.5 - 3.2 ^{o} C increase has indeed resulted,

2. to permit choosing the appropriate mitigation option based on DWT change in relation to their respective operating specifications, and

3. to verify that longer-term post impoundment DWT change does not exceed the estimated 2.5 - 3.2 ^{o} C and limit the mitigation option's operating efficiency.

Clearly, monitoring in the area of cooling facility intake structures is relevant. In addition, monitoring in other streams, and possibly upstream of Site C, would permit the separation of natural variability from a project-induced impact.

2. Are the data being collected statistically valid ?

As illustrated in Step 8, ensuring the data's statistical validity is, for this example, relatively easy. The existing Peace River DWT recording equipment at Taylor is appropriate and needs only to be initiated, maintained and periodically calibrated. Spatially, monitoring must be conducted at proposed cooling water intake structures. In addition, monitoring other local streams and the Peace River upstream of Site C will allow the differentiation of reservoir impacts from natural variability. Temporally, the continual collection of data ensures its credibility. The credibility of the data will permit using it for subsequent statistical testing of the impact hypothesis that DWT increased between 2.5 - 3.2 ^{o} C at Westcoast's cooling facility following the Site C impoundment.

3. Do the data provide sufficient information to permit the application of mitigation measures ?

Based on the analyses of temperature data collected over the necessary time period following development the appropriate mitigation option can be chosen. Two main factors will determine which is the most attractive: the mean and maximum DWT temperatures recorded in relation to the mitigation options' operating specifications, and the respective costs of implementing and maintaining each mitigation option.

4. Should monitoring continue, should it be modified, or should it be terminated ?

When sufficient information exists to permit the installation of the appropriate mitigation measures monitoring could be terminated for DWT increases. However, Westcoast would likely prefer to continue monitoring to ensure that DWT remains within the cooling system design specifications. Furthermore, should hypolimnion discharges be used as a form of mitigation, monitoring would be required to determine to what degree it was reducing DWT at Taylor. It would be neither difficult nor costly for Westcoast to install a permanent temperature recorder at its cooling facility intake. Indeed, considering the cost of mitigation, it seems only logical.

Benefits of the Adaptive Monitoring Approach

Applying adaptive monitoring to the physical component of DWT impacts can result in numerous benefits. Only data relevant to future analyses would be collected: in this case minimum, maximum, and mean daily DWT. This would be encouraged by combining those collecting the data and those using it in the monitoring design team. A convenient stopping rule would also be provided as monitoring could be terminated once enough data existed to test the impact hypothesis and choose the most appropriate mitigation option. However, as stated above it may be beneficial to continue DWT monitoring to establish longer-term effects and mitigation effectiveness. This may be particularly important if it is determined that climatic variability has significant effects on DWT. Statistically, the data collected would be both spatially and temporally valid. Ensuring data relevance and statistical validity overcomes many of the criticisms of traditional monitoring programs. Furthermore, both of these factors significantly contribute to the overall cost-effectiveness of the adaptive monitoring program. The adaptive approach would also encourage the use of adaptive management techniques by varying the level of reservoir discharge should thermal stratification occur. Finally, the experience gained, including data collection and choosing the appropriate mitigation method, would improve the basis for designing DWT monitoring programs for future projects.

8.2 FISHERIES RESOURCES

As illustrated in Chapter 4, a variety of potential impacts on fisheries resources are associated with reservoir development (Figure 9). Prior to applying the principles of adaptive monitoring to a particular impact, a brief summary of the results of the Site C Panel hearings and subsequent fisheries investigations will be provided.

Due to the lack of credible estimation of Site C fisheries maximum sustainable yield the Site C Panel was unable to reach a conclusion on the amount or form of compensation that would be appropriate to offset projected fisheries losses. Rather, the Panel suggested three component studies be undertaken as a condition of the Energy Project Certificate (EPC):

1. a detailed angling and creel survey,
2. sportfish migration and general life-history/capability studies, and
3. an evaluation of shoreline and tributary enhancement opportunities for the reservoir.

B. C. Hydro would be required to fund each component study to permit the Site C Panel to make an informed decision on the appropriate type and amount of compensation to be awarded following development. No compensation was to be provided while the studies were being completed.

Following the Cabinet decision not to grant an EPC for Site C development Hydro had little incentive to initiate the required investigations. Consequently, none of the above studies has thus far been completed and the Site C regional fisheries data base remains inadequate. However, the MOE is now beginning to look at what information would be required for monitoring should the studies be initiated. For the third study component, evaluating sportfish enhancement opportunities, Hydro was recommended to design the program in consultation with the MOE. Following a description of both its potential and information requirements, post-impoundment fisheries enhancement will provide a second example for the application of the adaptive monitoring approach.

Post-Impoundment Enhancement

The following discussion of post-impoundment enhancement opportunities for the Site C reservoir, and the information that would be required for its implementation, is derived from Hydro consultants' and MOE reports. The MOE suggests that of the indigenous sportfish in the Peace Site C valley, walleye have the greatest potential for enhancement (Table V). Five reasons form the basis for this decision:

1. walleye are already well-accepted by local anglers,
2. an established technology exists for their enhancement,
3. they are native to the Peace River and have established spawning populations in its Halfway River tributary,
4. biologically, they are well-suited to anticipated Site C reservoir physical and chemical water conditions, and
5. walleye are highly piscivorous and are expected to benefit from the abundant populations of coarse fish expected to inhabit the reservoir (B.C. MOE, 1981).

Hydro's fisheries consultants suggested stocking the reservoir with eyed eggs or walleye fry. The MOE disagreed. Following an extensive literature analysis of existing North American walleye-enhancement facilities they concluded that stocking the reservoir with fingerlings produced from local rearing ponds would be more effective. The suggested stocking rate was 60 - 70 fingerlings/hectare. Stocking with eyed eggs had been rejected as an enhancement method across North America, and stocking fry would be ineffective due to the projected low zooplankton levels and high reservoir flushing rate. There is, however, uncertainty surrounding potential zooplankton levels. Hydro estimates that zooplankton populations will remain abundant as in existing river conditions (R.R.C.S. Ltd., 1979). In early life stages walleye feed primarily upon zooplankton and benthic organisms. As they grow older walleye are highly piscivorous and thus feed upon a large proportion of fish (R.R.C.S. Ltd., 1979). In 1981 MOE estimated that the construction of the necessary walleye-enhancement facilities would cost approximately $ 995,000 and require operating costs of $ 100,000/year.

The MOE suggests that initially, a series of pre-impoundment studies would be necessary to determine the appropriate compensation value. Subsequently, as recommended by the BCUC, Hydro would be required to pay the government an amount equal to the magnitude of the loss. The funds would be used for regional fisheries enhancement.

Pre-impoundment projection of potential enhancement opportunities requires completing the following steps.

1. Determining the NET LOSS to fisheries production as a result of impoundment:
    - a) projected quantification of spawning habitat losses *
    - b) projected quantification of rearing habitat losses *
    - c) projected quantification of critical adult habitat losses *
    - d) valuation of net loss +

    * obtained from data collected in the pre-impoundment life-history/capability study
    + obtained from pre-impoundment creel survey study

2. Determining stream enhancement opportunities and estimates of the production potential to be gained:
    - a) potential to enhance stream-resident fisheries
    - b) potential to enhance species-specific recruitment to the reservoir
    - c) estimation of production potential, angling opportunity, and reservoir fishing valuation (based on stream enhancement)

3. Calculating the OVERALL NET LOSS (i.e. NET LOSS minus stream enhancement potential)

4. Considering additional opportunities to offset OVERALL NET LOSS:
    e.g. a) shore-spawning enhancement
    b) hatchery production
    c) tail-race fishery, etc. (B.C. MOE, 1986).

As indicated, much of the field data necessary for determining post-impoundment enhancement opportunities will be derived from the other study components: angling and creel survey and sportfish migration and life-history/capability studies. This information will be integrated with project design criteria to estimate post-impoundment enhancement opportunities.

The B.C. MOE (1986) also suggested that the following post-development studies will be necessary to determine the most effective method of walleye enhancement.

1. An evaluation of opportunities and techniques for sites identified prior to flooding to verify/deny their potential.
2. Monitoring the total fishery resource (sportfish and non-sportfish) for
   a) species composition
   b) species abundance
   c) species growth rates [and size class distribution]
   d) reproduction
   e) migration, movement patterns
   f) diet
3. Sampling for mercury levels and parasites in all top-level piscivores
4. Determining zooplankton (prey) distribution and abundance
5. A creel survey to document angling effort, harvest, and the biological characteristics of the harvest (this step is especially important for estimating angling pressure on both the enhanced and other sportfish species)

8.2.1 Adaptive Monitoring Applied

The diversity of the required information alone indicates that numerous opportunities exist for designing monitoring strategies to determine the best method of post-impoundment walleye enhancement. To follow are recommendations for applying adaptive monitoring in practice. It focuses on the potential impacts of Site C development on walleye fry prey species, particularly zooplankton.

As with the DWT example, the application of adaptive monitoring begins with the completion of the design steps (Figure 3) by an interdisciplinary design team. Due to the complexity of the potential impact, relative to DWT changes, a larger design team would be required for this example. It would be most appropriately staffed by a B.C. Hydro project engineer and fisheries consultant, MOE fisheries and aquatic biologists, and a MOE Fish and Wildlife Branch manager who would be responsible for administrating the post-impoundment enhancement process. It would be necessary to ensure that the team reflected an adequate level of both scientific and managerial expertise in relation to post-impoundment walleye enhancement.

Step 1 requires the identification of the valued ecosystem component (VEC): walleye in this instance.

Step 2 involves reviewing project development scenarios. For Site C this requires examining design specifications to estimate the extent and effect of flooding and proposed operational regimes on walleye populations. Currently, a self-sustaining walleye population does not exist in the proposed reservoir area. Therefore the analysis would focus on potential habitat production rather than on the possible negative impacts on existing populations.

Step 3 identifies impact hypotheses which relate development activities to VECs. Such hypotheses might relate Site C development to increased angling effort which will decrease potential walleye populations, or to decreased spawning habitat which will reduce the potential for walleye enhancement. Another impact hypothesis might relate Site C development to an increase in the diversity and abundance of zooplankton prey species thereby providing generous food sources for walleye enhancement. It is the latter example that will provide a focus for applying the adaptive monitoring approach. The impact hypothesis is based on the assumption that flooding will initially increase the reservoir's nutrient level which will in turn result in increased phytoplankton (primary production) levels. Partially in response to increased primary production, phytoplankton-feeding zooplankton such as copepods, cladocerans, and rotifers are expected to proliferate. Increased zooplankton levels resulting from an initial nutrient pulse may be relatively short-lived. However, increased habitat relative to existing river conditions and influx from upstream reservoirs are also expected to contribute to greater zooplankton levels. Copepods are expected to dominate and serve as important diet components for walleye fry. Walleye are also expected to feed upon cladocerans and, as they grow older, a large proportion of fish (R.R.C.S. Ltd., 1979).

Step 4 requires defining the spatial boundary for monitoring. Zooplankton production is expected to be highest in the upper section of the Site C reservoir because of expected greater suspended sediment levels near the dam (R.R.C.S. Ltd., 1979). Therefore, monitoring effort will primarily be concentrated in this area. As described in Chapter 4 littoral zones are critical to fish production. B.C. Hydro estimates that approximately 2,600 hectares of litoral zone above 10 - 15 m in depth will result from Site C development. Initially monitoring should be completed in both the pelagic and littoral zones. However, following their introduction, should data evaluation indicate that walleye prefer littoral zones monitoring could be diverted away from pelagic regions accordingly. It is necessary that the data collected be representative of the areas that the young, introduced walleye are expected to inhabit.

In step 5 the monitoring design team must determine what amount of pre-impoundment monitoring is necessary to permit testing for a change in post-impoundment zooplankton populations. It is likely that at least three sampling seasons would be required prior to development to determine preferred walleye prey species and estimate their diversity and abundance. Following development, monitoring would continue until the impact hypothesis could be verified or refuted. Monitoring will be required for several years following impoundment to determine whether a trophic decline results. As illustrated in Chapter 4, declines often follow the trophic surges characteristic of most new impoundments and have considerable potential for reducing zooplankton levels.

In step 6 the monitoring design team screens all impact hypotheses for validity, relevance and credibility. In step 7, facing a limited monitoring budget, important, testable impact hypotheses are chosen for monitoring.

The necessary monitoring program to test the chosen impact hypothesis is designed in step 8. Wherever possible, monitoring efforts will be combined for the three major components of the fisheries investigations. Much of the monitoring information necessary for pre-impoundment conditions will be derived from the second component of the study program: sportfish life-history/capability studies. For example, through stomach content analysis the pre-impoundment diet of walleye populations will be determined. Copepods are expected to dominate as a food source for young fish. The complexity of assessing the impact of impoundment on zooplankton relative to DWT makes ensuring the statistical validity of data collection procedures much more difficult. Again the appropriate questions must be addressed for both sampling design and the subsequent statistical analysis of the data collected. The monitoring design team would need to determine the accuracy and precision of zooplankton sampling techniques in relation to the statistical requirements for testing for a significant change in species diversity and abundance. Similarly, questions of sampling frequency and sample size and numbers must be considered. Step 4 would determine the necessary spatial controls. Monitoring effort must represent the area that young, introduced walleye are expected to inhabit. The required amount of pre-impoundment monitoring (temporal control) necessary to assess a change in zooplankton populations would be established in step 5. In concert with sampling design, the types of statistical analyses that will subsequently be applied to the data must be determined. This will ensure that their requirements are given adequate consideration. Following development continued monitoring will permit testing the impact hypothesis that Site C development increased both the diversity and abundance of zooplankton prey species.

Step 9 will be completed following the testing of the above and other post-impoundment enhancement related impact hypotheses. Based on the combination of results obtained from testing each impact hypothesis the most appropriate form of walleye enhancement will be chosen and implemented. This particular hypothesis, if verified, will contribute knowledge that adequate zooplankton exist to support enhanced walleye fry populations. Should the hypothesis be rejected--conditions are not suitable to support a walleye population--other compensation options will be necessary. They might involve introducing mitigation to support other sportfish populations or other forms of compensation.

As with the preceding DWT example, once monitoring begins (step 10) the four questions necessary for adaptive monitoring evaluation must be repeated (Figure 4).

1. Are the data being collected relevant ?

To test the impact hypothesis it is necessary to measure both pre and post-impoundment zooplankton diversity and abundance. What must be ascertained is that the sampling locations are indeed appropriate. Emphasis would likely be placed on monitoring zooplankton development in littoral areas. Other questions of data relevance would arise as monitoring information was being gathered and contrasted with that collected for other impact hypotheses. For example, through stomach content analysis, concurrent with prey species diversity and abundance monitoring, it may be determined that the walleye are selecting certain prey species with a virtual disregard for others. It would then be advantageous to focus the monitoring effort to determine factors affecting the preferred prey species' distribution and abundance so that only information relevant to walleye enhancement is collected.

2. Are the data collected statistically valid ?

Assertions about the effect of reservoir development on critical walleye prey species must be statistically credible before the appropriate mitigation can be confidently applied. Step 8 illustrates the statistical considerations that must be addressed by the monitoring design team to permit testing the impact hypothesis. They can generally be grouped into two categories: sampling design and subsequent statistical data analysis. If the appropriate concerns of sampling design and statistical analysis are considered in conjunction, both from the outset and during frequent data evaluation, the data collected will be statistically valid and permit impact hypothesis testing.

3. Do the data provide sufficient information to permit the application of mitigation measures ?

More specifically: do we have sufficient data to permit the choice and application of walleye-enhancement facilities ? Following the adequate monitoring of walleye diet and prey species distribution and abundance, along with other related impact hypotheses, the appropriate form of post-impoundment enhancement can be chosen and applied.

4. Should monitoring continue, should it be modified, or should it be terminated ?

Following the implementation of walleye-enhancement facilities monitoring will be necessary to verify their survival. It is expected that after several years of enhancement a self-sustaining walleye population will inhabit the Site C reservoir (B.C. MOE, 1981). Monitoring will also be required to ensure that a trophic decline several years after impoundment does not result in a significant zooplankton reduction. Furthermore, monitoring will be necessary to permit an estimation of maximum sustainable yield so that post-impoundment angling effort and walleye populations can be managed effectively. Finally, monitoring will be required to sample for mercury poisoning, parasite infestation, and other biological characteristics of the walleye harvest.

Benefits of the Adaptive Monitoring Approach

For the above example, as with DWT, one of the principal benefits of employing an adaptive monitoring approach lies in its cost effectiveness. Only data relevant to the impact hypothesis relating reservoir development to preferred walleye prey species would be collected. This would be ensured by frequent data evaluation and by coupling those collecting the data and those who must use it for project management in the monitoring design team. Frequent data evaluation would also permit maintaining its statistical validity. Both of these efforts would discourage collecting data insignificant to testing the impact hypothesis. Perhaps the most significant benefit would be realized following impact hypothesis testing, with the the choice and implementation of the most effective post-impoundment enhancement method. The above impact hypothesis will not determine the choice of post-impoundment enhancement alone. However, along with the results of numerous other monitoring requirements, it will provide a valuable contribution. Finally, but not of lesser importance, the information gathered and experience gained could greatly benefit the design of monitoring programs and post-impoundment fisheries enhancement for future developments.

The above recommendations are limited to the potential Site C impacts on DWT and fisheries resources. However the remaining, more intermediate potential Site C impacts also provide considerable opportunities for adaptive monitoring. And, as with DWT and fisheries resources, numerous benefits could be expected to result.

This chapter offers an approach and describes the advantages of using adaptive monitoring to examine the potential impacts of a proposed hydroelectric development. By doing so it demonstrates the transferability of adaptive monitoring principles from an investigation of the potential effects of offshore drilling (BEMP) to an analysis of potential Site C reservoir impacts. Both were advantaged by the groundwork that was completed in preparing their respective EIAs. This study provides the necessary foundation for proceeding one step further: designing an adaptive monitoring strategy for a future, previously unstudied development. The sequence of steps taken to design an adaptive monitoring strategy will vary with the nature and specifics of the proposed project. However, the adaptive principles that have been advocated, particularly the requirement of frequent data evaluation, are generic and can be effectively utilized for any type of resource development.

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

The theoretical framework developed in Section I began with an analysis of the evolution of EIA processes. This provided a foundation for a more extensive investigation into the role and practice of traditional impact monitoring procedures. A traditional model of monitoring was described and criticisms surrounding it were discussed. Two recent innovative monitoring approaches were then illustrated. This provided a basis for advancing a conceptual model of adaptive monitoring and highlighting its potential advantages.

The case study, Section II, began with an overview of the reservoir impact paradigm. It permitted the evaluation of the Site C EIA in terms of its reflection of current environmental system understanding. The legislation for EIA in British Columbia was then discussed with a particular emphasis on the *Utilities Commission Act* which provided the authority for the Site C EIA and Panel hearings. The Site C EIA was then evaluated and opportunities for future impact monitoring arising from the Site C Panel hearings were described. Finally, using DWT and fisheries resources for examples, the potential advantages of employing adaptive monitoring for future Site C investigations were illustrated.

To conclude, this chapter summarizes the major findings of both the theoretical framework and case study. It then offers recommendations for improving future impact monitoring strategies for the Site C dam and other resource development projects.

9.1 MAJOR FINDINGS

9.1.1 Theoretical Framework

1. The EIA and monitoring literatures were found to be fragmented and replete with the use of inconsistent terminology. Three separate stages of monitoring can be identified: baseline, construction, and operation. Each stage requires information for

various purposes including mitigation/compensation, experimentation, and inspection.

2. EIA has progressed considerably from its early geophysical orientation to a more comprehensive, interdisciplinary process concerned with the breadth of environmental and socio-economic impacts of development.

3. Impact monitoring practices have also evolved but in a less innovative fashion than EIA. Consequently, three major criticisms characterize traditional monitoring efforts:
   - A. Monitoring programs fail to adequately utilize past experience, such as existing case studies, and thus do not reflect the current state of environmental system understanding.
   - B. Poor monitoring design results in two deficiencies:
     - i. excessive data collection, much of which is of little use to managers or decision-makers because their needs were not considered from the outset.
     - ii. statistically invalid data collection due to a lack of consideration of spatial and temporal controls, analytical techniques, and methods of data analyses.
   - C. Monitoring strategies are neither designed to treat each development as a learning process nor as opportunities to improve the basis for examining future developments.

4. Recent EIAs have benefited from the AEAM concept first advocated in the mid to late-1970s. Based largely on the principles of AEAM, two innovative approaches to impact monitoring have been developed: the BEMP and EEM. The former has been successfully applied in practice. Both overcome many of the criticisms plaguing conventional monitoring approaches.

5. An adaptive monitoring approach can be advanced that offers significant advantages over traditional monitoring strategies. Adaptive monitoring is based on a series of impact hypotheses established and tested by an interdisciplinary team. An adaptive monitoring strategy has two fundamental stages: adaptive monitoring design and adaptive monitoring evaluation. The former requires completing a series of adaptive monitoring design steps;

the latter requires the frequent reiteration of the following questions while adaptive monitoring is being conducted:

A. Are the data being collected relevant ?

B. Are the data being collected statistically valid ?

C. Is there sufficient information to apply mitigation measures ?

D. Should monitoring be continued, modified, or terminated ?

6. An adaptive monitoring approach offers significant advantages over conventional efforts. An adaptive monitoring strategy would be developed by an interdisciplinary team linking those who would collect the data (technicians, consultants) with those who must subsequently use it (project managers). Ecologically, a flexible monitoring approach facilitates selecting and quantifying the appropriate biotic conditions for testing impact hypotheses. Statistically, the appropriate spatial-temporal controls, sampling design and subsequent statistical analyses would be established for each monitoring program. Both of these factors ensure that only credible data, relevant to impact hypotheses testing is gathered. Financially, an adaptive approach encourages cost-effectiveness by ensuring that monitoring effort is not extended to collect information irrelevant to testing impact hypotheses. The practicality of the adaptive approach is supported by concentrating monitoring effort on those impact hypotheses most significant to project management. Finally, through comprehensive evaluation and documentation at the completion of the program, adaptive monitoring would facilitate effective monitoring design and project management for future developments.

9.1.2 Case Study

1. The reservoir impact paradigm is beginning to provide a comprehensive basis for assessing the potential effects of reservoir development. However, it is continually evolving and its applicability is site-specific. Thus, while increasing experience with hydroelectric development has considerably refined the reservoir impact paradigm uncertainties remain.

2. Legislative authority governing EIA for provincial hydroelectric proposals exists in the British Columbia *Utilities Commission Act* (1980). However, it does not explicitly provide for project-related impact monitoring.

3. The EIA completed for the Site C proposal was very comprehensive in its utilization of the prevailing reservoir impact paradigm. There were, however, three significant weaknesses. First, the potential impacts on downstream ecology and distant downstream users were ill-considered. Second, the potential for increased reservoir fish parasitism following impoundment was neglected. Finally, estimates of Site C reservoir and Peace River fisheries maximum sustainable yield were unreliable.

4. The Site C Panel recognized the need for future impact monitoring. They were deficient, however, in their emphasis on regional socio-economic concerns at the expense of the potential environmental effects of development. Furthermore, for the environmental impacts that were considered, insufficient time was committed to permit their effective monitoring. Finally, while they recognized the potential benefits of experimental monitoring to improve the understanding of reservoir impacts in northern-temperate British Columbia, the Site C Panel offered no examples of studies that might be beneficial. By providing more specific direction, there would have been greater potential for the Site C Panel's recommendation to be followed.

5. The following benefits would result from using an adaptive monitoring strategy for testing impact hypotheses regarding potential Site C impacts on downstream water temperature and fisheries resources.

   Downstream Water Temperature

   Mechanical temperature recorders currently exist to collect relevant, statistically valid data for testing the impact hypothesis that following Site C impoundment DWT will increase by

2.5 - 3.2 $^{\circ}C$ at Westcoast's Taylor operations. The combination of data relevance and statistical credibility remedies many of the criticisms characterizing conventional monitoring practices. It also encourages cost-effectiveness by ensuring that the data collected is subsequently used for testing the impact hypothesis. Should thermal stratification occur within the Site C reservoir, adaptive management techniques would be encouraged by varying the level of discharge to take advantage of cooler hypolimnion waters to offset DWT increases. Finally, the experience gained from designing and implementing the DWT monitoring program would facilitate similar attempts for future developments.

Fisheries Resources

The potential benefits to be gained from using adaptive monitoring to collect information for fisheries resources impacts was demonstrated for the impact hypothesis that Site C development would increase the diversity and abundance of walleye prey species. This information would contribute to the broader objective of choosing the best option for post-impoundment walleye enhancement. Frequent data evaluation, coupled with an examination of the results of concurrent monitoring efforts, would help ensure that only data relevant to testing the impact hypothesis would be gathered. This would be supported by coupling those collecting the monitoring data with those who would ultimately use it, in the monitoring design team. Careful attention to both sampling design and subsequent statistical analyses requirements would encourage collecting statistically valid data. Its validity would be maintained by frequent data evaluation as monitoring progressed. Therefore, the information collected through adaptive monitoring would cost-efficiently contribute to choosing the most effective post-impoundment walleye enhancement option. It may also advance the reservoir impact paradigm by providing new information on the effects of impoundment on walleye prey species. Finally, similar to the DWT example, the experience gained from designing the adaptive monitoring strategy would facilitate comparable future efforts.

To conclude, the comparative advantages of an adaptive monitoring strategy over conventional practices were evident through the analyses of only two potential Site C impacts. Therefore, the cumulative benefits of employing adaptive monitoring for the entire complement of a project's monitoring requirements are expected to be substantial.

9.2 RECOMMENDATIONS

Through its theoretical development, and subsequent application for potential Site C impacts, it has been demonstrated that an adaptive approach holds considerable promise for improving the effectiveness of impact monitoring strategies. Therefore, it is recommended that the following conditions be incorporated into EIA policy and that regulatory agencies require that these conditions be met by proponents applying for project development permits.

- *Adaptive monitoring should be exploited in all future resource development projects.*

  The successful completion of adaptive monitoring for new projects would serve two fundamental purposes. First, it would heighten the concept's visibility and, consequently, its acceptance. Second, through incremental experience, it would contribute toward adaptive monitoring's progressive evolution.

- *Proponents should be required to develop a comprehensive environmental management plan to accompany development as opposed to simply submitting a predictive EIA.*

  The plan should outline what monitoring will be undertaken and what mitigation options are available to reduce identified impacts. The plan should also have financial provisions to permit monitoring and mitigation of unexpected impacts that may result with development. As Lee (1982) suggests, changing circumstances and additional information necessitate monitoring flexibility to react to dynamic situations and correct assessment components subsequently shown to be defective.

- *The stages of adaptive monitoring and the information requirements of each should be identified along with provisions for their financing. Furthermore, financial provisions should be separated into appropriate categories: those reflecting the costs of data collection necessary to test impact hypotheses for project management, and those reflecting the costs associated with scientific research.*

  Categorizing costs would permit including monitoring as an integral component of the project development budget (Howells and Gammon, 1984). Although cost is an essential component of any monitoring program, it is rarely considered in the design effort. Furthermore, when considered, it is usually as a fixed constraint, rather than as a variable that can be manipulated and controlled. Costs may change if monitoring is adapted as a consequence of data evaluation. However, proper categorization will facilitate reaching agreement over the proportion of responsibility for monitoring between proponents and government agencies.

- *Desk analyses of existing case study data shold be required in the design of adaptive monitoring strategies.*

  Far too frequently new monitoring programs begin with the systematic collection of baseline data with insufficient desk analyses of existing information to help streamline the monitoring process. This is often due to consultants being afforded too little time to examine comparative case studies. The above recommendation would overcome this problem.

- *Authorization to proceed with development should be conditional upon appropriate minimal requirements for baseline data collection prior to the initiation of project construction.*

  Upon having applications for development permits rejected, as was the case for Site C, proponents' will generally choose not to continue funding baseline monitoring efforts

(Etter, 1986). Their stance is reasonable. It is clearly not in their corporate interest to fund studies for a project that may never come into effect. However, valuable baseline data that was accumulated for the project EIA will become of limited use should a certificate to proceed with development be issued several years after the baseline monitoring program was terminated. With minimal baseline requirements, however, it may become advantageous for proponents' to continue baseline monitoring programs. This would ensure that sufficient baseline data is available upon receiving permisson to proceed with project construction. Otherwise, project development could be delayed for several years while monitoring is initiated and the required baseline is established.

- *The evaluations upon which decisions to adapt monitoring are based should be completely documented. Furthermore, upon its completion, the adaptive monitoring strategy should be required to undergo a fully documented, comprehensive assessment.*

The effectiveness of monitoring efforts should be documented and disseminated to a wide audience including government agencies, resource development industries, provincial utilities, and the consulting and academic communities. The obscurity and confidentiality of many existing monitoring studies is another major factor contributing to insufficient desk analyses in monitoring design. Therefore, the importance of distributing the information and experience gained from adaptive monitoring can hardly be overstated. Organizations such as the Canadian Electrical Association and the Canadian Petroleum Association could play pivotal roles in providing respective information management centres for hydroelectric and petroleum development monitoring programs. To maximize their usefulness, caution must be taken to document monitoring results in a language readily comprehended by scientists, technicians, consultants, project managers and administrators alike. Overly technical reports will contribute little to the improved use of past case studies for desk analyses purposes. Improved information access and management between all parties involved in impact monitoring would help reduce the duplication of effort and make project development a better learning process.

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