Toward the Development of a Cumulative Effects Monitoring Program for the Lower Columbia River

Technical Report

Prepared for:

Columbia River Integrated Environmental Monitoring Program
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Prepared – September 2003 – by:

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Technical Appendix

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List of Acronyms

ADMT/d	air dried metric tonnes/day
BCMWLAP	British Columbia Ministry of Water Land and Air Protection
CEA	cumulative effects assessment
CEIs	cumulative effects indicators
CEM	cumulative effects monitoring
COPCs	chemicals of potential concern
CRIEMP	Columbia River Integrated Environmental Monitoring Program
EDCs	endocrine disrupting chemicals
EEM	environmental effects monitoring
EIA	environmental impact assessment
GAP	geographic approach
GBT	gas bubble trauma
GIS	geographic information system
NPS	non-point sources
OCs	organochlorines
PAHs	polycyclic aromatic hydrocarbons
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
PCDDs/PCDFs	polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans
SAP	sampling and analysis plan
STPs	sewage treatment plants
TCDD TEQ/g	tetrachlorodibenzo-*p*-dioxins toxic equivalents
TGP	total gas pressure
TOC	total organic carbon
TSS	total suspended solids
WQOs	water quality objectives

Chapter 1 Introduction

The Columbia River drains an area of 669 500 km^2 in British Columbia, Washington, Oregon, Idaho, and Montana, making it the dominant river system in the Pacific Northwest. While the Columbia was once a free-flowing river, it is now characterized by a proliferation of impoundments, both in Canada and the United States. From its headwaters at Columbia Lake on the west slope of the Rocky Mountains near Canal Flats, the Columbia River flows some 760 km to its confluence with the Pend d'Oreille River at the international border. Three major dams have been constructed on the Canadian portion of the Columbia River mainstem, creating Kinbasket Lake behind Mica Dam, Revelstoke Lake behind Revelstoke Dam, and the Arrow Lakes behind the Hugh Keenleyside Dam. Over that distance, the Columbia River is also joined by several major tributaries, including the Kootenay and Pend d'Oreille rivers (both of which have also been impounded). Together, these two tributaries account for 60% of the mean annual flow of the Columbia River at the International boundary.

The transboundary reach of the Columbia River extends some 60 km from the Hugh Keenleyside Dam to the international border (Figure 1.1). This portion of the Columbia River and its tributaries, which is commonly referred to as the lower Columbia River basin, generates a host of benefits to the people of the Northwest, both in Canada and the United States. In addition to myriad instream water uses (i.e., fish and aquatic life), the Columbia River provides an important source of raw water for municipal water supplies, irrigation, livestock watering, and industrial water uses. The Columbia River and its tributaries have also been impounded extensively to support hydroelectric power production, water storage, and flood control. Importantly, the river has also been used to dispose of municipal and industrial wastes, including pulpmill and smelter effluents. Recreation and aesthetics also represent important uses of the aquatic environment that generate social and economic benefits to area residents.

Balancing the diverse and often conflicting uses of the Columbia River represents a formidable management challenge. This task is complicated by the various federal, provincial, and international water management agreements that have been established on the river, which influence water release strategies and water levels in the lakes and reservoirs. This task has been further complicated by the lack of clear management objectives for the aquatic ecosystem (e.g., ecosystem goals and objectives), which would enable environmental managers to establish priorities and make decisions accordingly. In the absence of an integrated environmental management plan, managers have had to address environmental issues and concerns as they arise. While this approach has been effective for managing the impacts of individual development projects, it has not provided a basis for coordinated management of aquatic resources.

Recognizing that the issues and concerns in the lower Columbia River basin cannot be effectively addressed by a single organization, key stakeholders initiated the Columbia River Integrated Environmental Monitoring Program (CRIEMP) in 1991. The objectives of this program were to share environmental information, co-ordinate the monitoring activities of the participating organizations, evaluate the state-of-the environment in the lower Columbia River by means of field monitoring, and communicate the results of environmental monitoring programs to the public. Between 1991-1993, CRIEMP investigated water quality conditions in the lower Columbia River. The information gained from this initiative has substantially improved our understanding of environmental conditions in the lower Columbia River basin.

Due to the success of the CRIEMP initiative, CRIEMP II was launched in 2001 with a broader mandate than was the case for the original program. More specifically, the objectives of the CRIEMP II initiative are to:

- Encourage and support stewardship and conservation of the lower Columbia River ecosystem;
- Provide a means of co-ordinating the integration of environmental monitoring programs being conducted or considered on the lower Columbia River [water quality objectives (WQOs), fish health surveys, environmental effects monitoring (EEM), water use planning, permit monitoring, etc.];
- Develop ecosystem goals and objectives which support cumulative effects assessment (CEA);
- Encourage partnerships that optimize the efficient use of monitoring resources;
- Share CRIEMP information with the public, agencies and industries on the state of environment of the lower Columbia River to support management decisions; and,

- Recognize the importance of traditional cultural values and incorporate those values in its work.

Importantly, the participants in CRIEMP II recognize that there are an array of factors that have the potential to adversely affect beneficial water uses (i.e., stressors) in the lower Columbia River basin. Moreover, CRIEMP II Committee members recognize that interactions among these stressors can produce cumulative effects on aquatic organisms, aquatic-dependent wildlife, and/or human health. Such cumulative effects are important to assess and manage because they have the potential to impair beneficial water uses in a manner and to an extent that would not be predicted based on the environmental assessments for single activities or development.

This report was prepared in response to the need for a monitoring program to assess the cumulative effects of multiple disturbance activities in the lower Columbia River basin. More specifically, this report, which summarizes the input provided by CRIEMP II Committee members at several workshops (Appendix 1), supports the development of a cumulative effects monitoring (CEM) program by:

- Presenting a framework for ecosystem-based management in the lower Columbia River basin (Chapter 2);
- Reviewing the existing approaches to CEA (Chapter 3);
- Proposing a framework for CEA in the lower Columbia River basin (Chapter 4);
- Presenting the ecosystem goals and objectives for the lower Columbia River basin (Chapter 5);
- Predicting the cumulative effects of multiple disturbance activities in the lower Columbia River basin (Chapter 6); and,
- Describing the key elements of a CEM program for the lower Columbia River basin (Chapter 7).

In addition, the next steps that need to be undertaken to facilitate implementation of the CEM program for the lower Columbia River basin are discussed in the report.

Chapter 2 A Framework for Ecosystem-Based Management in the Lower Columbia River Basin

2.0 Introduction

In recognition of the need to effectively manage human activities, an ecosystem approach has been developed to facilitate environmental planning, research, and management in Canada (CCME 1996; Environment Canada 1996). The ecosystem approach to planning, research and management is the most recent phase in an historical succession of environmental management approaches. Previously, humans had been considered to be separate from the environment in which they lived. This *egocentric approach* viewed the external environment only in terms of human uses. However, overwhelming evidence from many sources indicates that human activities can have significant and far-reaching impacts on the environment and on the humans who reside in these systems. Therefore, there was a need for a more holistic approach to environmental management, in which humans were considered as integral components of the ecosystem. The ecosystem approach provides this progressive perspective by integrating the *egocentric view* that characterized earlier management approaches, with an *ecocentric view* that considers the broader implications of human activities.

Based on the input provided at two major international conferences (which were held in 1998 and 2002), it is apparent that there is considerable support for transitioning toward an ecosystem-based approach to the management of natural resources in the lower Columbia River basin. This chapter describes the key elements of ecosystem-based management, discusses the main benefits of adopting an ecosystem approach to natural resource management, and presents the elements of a framework for ecosystem-based management. This information is provided to support the development of an ecosystem-based approach to CEA and management in the lower Columbia River basin.

2.1 Definition of Ecosystem-Based Management

The primary distinction between the environmental and ecosystem approaches is whether the system under consideration is external to (in the environmental approach) or contains (in the ecosystem approach) the population under study (Vallentyne and Beeton 1988). The conventional concept of the environment is like that of a *house* - external and detached; in contrast, ecosystem implies *home* - something that we feel part of and see ourselves in, even when we are not there (Christie *et al.* 1986). The transition from the environmental approach to the ecosystem approach necessitates a change in the view of the environment from a political or people-oriented context to an ecosystem-oriented context (Vallentyne and Beeton 1988). The essence of the ecosystem approach is that it relates *wholes* at different levels of integration (i.e., humans and the ecosystems containing humans) rather than the interdependent parts of those systems (i.e., humans and their environment; Christie *et al.* 1986). The identifying characteristics of the ecosystem approach include (Vallentyne and Hamilton 1987):

- A synthesis of integrated knowledge on the ecosystem;
- A holistic perspective of interrelating systems at different levels of integration; and,
- Actions that are ecological, anticipatory, and ethical.

This expanded view then shapes the planning, research, and management decisions that are made within and pertaining to the ecosystem. Importantly, the ecosystem approach also provides a basis for integrating social, economic, and environmental interests into a decision-making framework that embraces the concept of sustainable development.

2.2 Benefits of the Ecosystem Approach

The ecosystem approach is superior to the approaches to environmental management that have been used previously for a number of reasons. First, the ecosystem approach provides a basis for the long-term protection of natural resources, including threatened and endangered species. In the past, management decisions were typically made with a short-term vision (i.e., within a single political mandate). In contrast, the ecosystem approach necessitates a long-term view of the ecosystem which necessarily considers the welfare of its biotic components. Hence, management decisions are more likely to be consistent with sustainable development goals.

Second, the ecosystem approach provides an effective framework for evaluating the real costs and benefits of developmental proposals. Previously, decisions regarding the development of industrial and municipal projects were heavily weighted toward financial benefits and job creation. Neither the long-term impacts of these projects nor the sustainability of the resources upon which they depended were fully considered. In contrast, implementation of the ecosystem approach assures that the long-term effects of developmental activities are incorporated into the assessment process. Therefore, management decisions are less likely to be made based solely on political considerations, such as job creation.

The ecosystem approach also enhances the prospects for the multiple use of natural resources. In the past, governments have often allocated water and other natural resources for the exclusive use of single industrial interests. Implementation of the ecosystem approach ensures that all stakeholders have an opportunity to participate in the establishment of management goals for the ecosystem and that governments do not make political decisions that benefit a single interest group, at the expense of other beneficial uses of natural resources.

Environmental research and monitoring activities are essential elements of any management program. The ecosystem approach provides a basis for focussing these activities by establishing very clear management goals for the ecosystem. Therefore, research and monitoring activities are driven by the needs of the program (i.e., to determine if the management goals are being met), rather than by the interests of individual scientists or by political expediency.

One of the most important benefits of the ecosystem approach is that it directly involves the public in decision-making processes. Specifically, this approach provides a forum for public input at a non-technical level (i.e., during the establishment of management goals and ecosystem objectives), which is both effective and non-threatening. The detailed technical issues are then left to those who are charged with the management of these ecosystems. The framework for implementing the approach also assures that these managers can be held accountable for the decisions that they make.

Traditionally, environmental impact assessments (EIAs) have not consistently provided reliable information for evaluating the effects of anthropogenic developments on the ecosystem. In the ecosystem approach, however, the functional relationships between human activities, changes to the physical and chemical environment, and alterations in the biological components of the ecosystem are established before making important management decisions. Therefore, management decisions are more likely to be consistent with the long-term goals that have been established and subsequent monitoring activities can focus on the ecosystem components that are most likely to be affected.

The ecosystem approach also facilitates the restoration of damaged and degraded natural resources. By explicitly identifying the long-term impacts of degraded ecosystems on designated land and water uses, this approach more clearly delineates the benefits of restoration and remedial measures. Therefore, limited resources can be focussed on restoration projects that are likely to yield the greatest benefits to the ecosystem as a whole.

2.3 Implementation of Ecosystem-Based Management

Implementation of the ecosystem approach requires a framework in which to develop and implement management policies for the ecosystem. In general, this framework is comprised of three functional elements (CCME 1996). The first element of the framework is a series of broad management goals (i.e., ecosystem goals), which articulate the long-term vision that has been established for the ecosystem. These goals must reflect the importance of the ecosystem to the community and to other stakeholder groups. The second element of the framework is a set of *objectives* for the various components of the ecosystem which clarify the scope and intent of the ecosystem goals. These objectives should include a target schedule which indicates when each objective should be achieved. The final element of the framework is a set of *ecosystem indicators* (including specific *metrics and targets*), which provide an effective means of measuring the degree to which each of the ecosystem goals and objectives are being attained (Figure 2.1).

First Nations and government agencies have agreed to adopt the ecosystem approach for managing human activities in northern ecosystems. However, implementation of the ecosystem approach in the lower Columbia River basin will require a long-term commitment to the implementation process. The key steps in the implementation process include:

(i) Conduct a preliminary assessment of the knowledge base and identify key management issues;

(ii) Develop and articulate ecosystem goals and objectives;

(iii) Identify and evaluate candidate indicators of ecosystem health (including physical, chemical, and biological indicators);

(iv) Select a suite of key indicators of ecosystem health;

(v) Establish metrics and targets for each key indicator;

(vi) Identify data gaps and research needs;

(vii) Incorporate key indicators, metrics, and targets into watershed management plans and decision-making processes;

(viii) Design and implement focussed environmental research and monitoring programs;

(ix) Reapply key indicators to assess effectiveness of decisions (i.e., to evaluate progress towards the ecosystem goals and objectives); and,

(x) Refine key indicators, metrics, and targets, if necessary.

The first step in the implementation process involves identification of key management issues and a preliminary assessment of the knowledge base. This assessment is intended to provide stakeholders with a common basis for identifying management issues and priorities in the system under consideration. In the case of lower Columbia River basin, the existing information on the status of the physical, chemical, and biological components of the ecosystem have been compiled by Butcher (1992), Aquametrix Research Ltd. (1994), MESL (1997), R.L.&L. Environmental Services Ltd. (2001), and several other reports. This information provides a general understanding of the structure and function of the ecosystem and, therefore, a common basis for establishing broad management goals and ecosystem objectives (Ryder and Edwards 1985).

Next, candidate indicators of ecosystem health must be identified and evaluated to determine their applicability to the lower Columbia River basin. Candidate ecosystem health indicators frequently include water chemistry, sediment chemistry, tissue chemistry, sediment toxicity, benthic invertebrate community structure, fish community structure, and others. Typically, selection criteria are identified and applied to provide a consistent basis for evaluating candidate indicators. However, traditional knowledge and local experience are critically important for establishing a suite of indicators that adequately reflects the goals and objectives that have been established. A procedure for identifying a suite of indicators of ecosystem health is described by MacDonald (1994), and MESL (1995).

Ecosystem metrics are also required to support the implementation of the ecosystem approach. These metrics identify quantifiable attributes of the indicators and define acceptable ranges or targets for these variables. To assess sediment chemistry, for example, the concentrations of total copper in whole sediment (i.e., the metric) are compared to the sediment quality objective (i.e., the target) that has been established for copper in the lower Columbia River (MESL 1997). If all of the measured attributes or metrics fall within acceptable ranges, then the ecosystem as a whole would be considered to be healthy and vital. The information collected during the selection of metrics and targets will also provide a basis for identifying data gaps and research needs to support implementation of the ecosystem approach.

A key element of the implementation process involves incorporation of the management goals, ecosystem objectives, indicators, and metrics into management plans and decision-making processes that coordinate the decisions and activities of all participants. In addition, focussed environmental research and monitoring programs must be developed to evaluate the status and trends of the key indicators. The results of these research and monitoring programs provide a scientific basis for further evaluating the relevance of the indicators, refining the ecosystem metrics, and determining if the goals and objectives for the watershed are being achieved.

The foregoing framework for implementing ecosystem-based management has been successfully applied in numerous watersheds throughout Canada (e.g., Great Lakes Basin, Mackenzie River Basin, Coppermine River Basin, etc.). In addition to its traditional applications, this approach can be refined to support an important element of ecosystem management-CEA. The following sections of this document are intended to support the development of a CEM program for the lower Columbia River basin. These sections include a review of the existing approaches to CEA, a framework for implementing CEA, and a recommended approach to CEA in the lower Columbia River basin.

Chapter 3 A Review of the Existing Approaches to Cumulative Effects Assessment

3.0 Introduction

Cumulative effects assessment is a relatively new discipline that has been developing over roughly the past 15 years. Over that time, a variety of approaches have been developed to support the assessment of cumulative environmental effects, each of which have certain advantages and limitations. Based on the results of a review of the published literature (Brown *et al.* 1999), seven major approaches to CEA were identified, including:

- Environmental checklist approach;
- Interactive matrices approach;
- Network analysis approach;
- Environmental auditing approach;
- Landscape perspective approach;
- Spatial analysis approach; and,
- Ecological modelling approach.

The discussions of each of the approaches, which have been taken directly from MacDonald *et al.* (1999), are divided into four main sections, including a brief description of the procedure, the major advantages and limitations of the approach, and the current uses of the methodology (Table 3.1). This information is presented to provide a basis for selecting an approach or elements of various approaches that could be used to assess the cumulative effects of multiple disturbance activities in the lower Columbia River basin.

3.1 Environmental Checklist Approach

The environmental checklist approach is one of the least complicated procedures for conducting CEA. As the name suggests, application of this procedure involves the development of series of lists that identify the possible outcomes of various types of disturbance activities (Figure 3.1). In their simplest form, environmental checklists identify the effects that could be associated with an activity and indicators that could be used to quantify the effects. In some cases, the potential for an effect is merely acknowledged, with no attempt to conduct either a qualitative or a quantitative assessment. More commonly, a qualitative assessment of the severity and extent of the effect is offered, typically based on subjective evaluation (Cocklin *et al.* 1992).

One of the principal advantages of the environmental checklist approach is that it can highlight the potential for cumulative impacts of multiple human activities. That is, the activities that have the potential to produce similar types of effects on target resources (i.e., valued ecosystem components) can be identified using this approach. In this way, the need for a more quantitative assessment to evaluate cumulative effects can be identified (i.e., checklists can be used during the project scoping stage of the overall assessment).

While checklists represent potentially useful tools for focussing an investigation, their overall contribution to CEA is extremely limited. One of the main limitations of this approach is that cause and effect relationships between stressors and receptors are implied only, and even then only in the simplest of terms (Cocklin *et al.* 1992). In addition, this approach does not provide a means of identifying the functional linkages by stressors and receptors nor a basis for evaluating interactions between disturbance activities. Moreover, checklists do not support quantitative evaluations of cumulative effects.

Environmental checklists are commonly used in the scoping stage of CEAs, typically to identify the factors that should be considered during the investigation (Stakhiv 1988; ESSA Technologies Ltd. 1994; MacViro Consultants Inc. 1995). However, this approach does not provide a basis for conducting a scientifically-defensible assessment of the cumulative effects of human activities.

3.2 Interactive Matrices Approach

The interactive matrix approach to CEA is explicitly designed to establish linkages between disturbance activities and the responses of key environmental receptors (e.g., valued ecosystem components; Bain *et al.* 1986; Shopley *et al.* 1990). As described by Irving and Bain (1993), the approach consists of four main steps, including geographic scoping, resource scoping, multiple project assessment, and documentation. In the geographic scoping step, a meeting of key stakeholder groups is convened to define the study area for the assessment. The stakeholders define the geographic extent of the study area based on their knowledge of the locations of various projects, their understanding of the environmental changes that could be associated with each project, and their perceptions regarding the potential effects of such changes on important resources (i.e., valued ecosystem components).

The second step of the process involves identification of target resources (e.g., steelhead trout) and resource components (e.g., spawning/incubation habitat) that are likely to be affected by the disturbance activities. To complete this step, a resource scoping meeting is convened with the stakeholder groups to determine the types of changes to the environment that could result from the disturbance activity (e.g., changes in streamflow are likely to result from hydroelectric developments) and how such changes could affect target resources (e.g., dewatering incubation habitats after spawning). In addition, impact level criteria are established for each type of effect to support subsequent evaluation of the magnitude of effects that are observed or predicted. For example, an impact level of 0 would be assigned if streamflow changes would not alter the available spawning/incubation habitat (i.e., no impact), whereas a value of 4 might be assigned if > 25% of the useable spawning/incubation habitat would be lost due to reductions in streamflow (i.e., very high impact; Irving and Bain 1993). By establishing a common scale for evaluating the impact of each type of disturbance, it is possible to combine the results of individual evaluations later in the assessment.

In the third step of the process, a multiple project assessment is conducted using the information on target resources, resource components, and impact levels that were compiled during the scoping meetings. For each target resource, the impact levels associated with each project and/or project activity are determined for each resource component and presented in a matrix (disturbance activities listed in rows and resource components listed in columns; Figure 3.2). The cumulative effects on each resource component are then determined by summing the impact levels assigned to each project (i.e., summing down columns). The cumulative effects of individual projects are determined by summing the impact levels assigned for each resource component. A preliminary cumulative effects score for each target resource can then be calculated by summing the cumulative scores for each resource component evaluated. Interactions among the projects can be accounted for by applying interaction coefficients (which range from 0 to 1) to the resource component matrices. The interaction score is then added or subtracted from the preliminary cumulative effects score to determine a total cumulative effects score. The total score provides a relative index for determining which target resources are most at risk of being adversely affected by the disturbance activities.

The documentation stage of the assessment involves the preparation of a detailed description and a concise summary of the impacts that are likely to be associated with the disturbance activities. Importantly, the results of the multiple project assessment are converted into terms that are meaningful to stakeholders and the public (i.e., converted from a total cumulative effects score, which corresponds to, for example, an *x* reduction in the population of steelhead trout). This summary also provides an indication of the probability of occurrence of such effects on each target resource. For proposed projects, the results of the assessment can be presented for scenarios that include no mitigation or various types of mitigation activities.

One of the principal advantages of the interactive matrices approach is that it provides a clear linkage between project activities and effects on valued ecosystem components. This approach is particularly useful because it provides a means of considering multiple linkages between disturbance activities and target resources to assess cumulative effects. It also provides a means of evaluating the cumulative effects of multiple disturbance activities on one or more target resources. Furthermore, the methodology enables users to consider interactions among disturbance activities to evaluate cumulative effects.

While this approach has several important advantages, it also has a number of features that can limit its application in CEA. First, the results of assessments conducted using the interactive matrices approaches do not provide any spatial or temporal resolution (i.e., it is not possible to determine where or when effects on target resources are likely to occur). While deficiencies in temporal resolutions can, at least in part, be rectified by constructing matrices that consider the timing of each project activity (i.e., construction, operation, etc.), the lack of procedures for resolving the spatial extent of the effects on each target resource presents formidable challenges for conducting regional assessments (Cocklin *et al.* 1992). Another limitation of the approach is that the impact level criteria that are established for the various types of effects have consistent scales (e.g., 0 to 4; Irving and Bain 1993). However, the actual significance of the impact may differ among the various types of effects considered. For this reason, the total cumulative effects score, calculated by summing the columns, may not accurately express the magnitude of the total impact. Finally, the cumulative effects are not differentiated by type and parameter values rely extensively on expert judgement (Spaling and Smit 1995).

The interactive matrices approach to CEA has been used in a number of applications. For example, this approach has been used to evaluate the cumulative effects of multiple hydroelectric development projects on fish and wildlife resources (Bain *et al.* 1986; Emery 1986; Irving and Bain 1993). It has also been used to evaluate the effects of human activities on the atmosphere (Clark 1986). Furthermore, this approach has been used to support other types of approaches to CEA, particularly during the scoping stage of the process (Crutzen and Graedel 1985; Cocklin *et al.* 1992).

3.3 Network Analysis Approach

The network analysis approach to CEA is similar in many ways to the interactive matrices approach. However, network analysis provides a basis for more clearly describing and analysing cause-process-effect associations in the system under investigation. Application of this approach involves the use of a diagramming technique, with tree diagrams representing the relationships between the stressor, the primary effects, and the higher order effects (Figure 3.3). The disturbance activity is depicted on the far left of the diagram, with the various processes that link the activity to the various effects branching out from this origin. In this way, the core structure of the system and complex interactions between stressors and receptors can be clearly identified (Smit and Spaling 1995). By assigning conditional probabilities to the various branches of the network, it is possible to calculate the probability of individual impacts occurring in the system (Cocklin *et al.* 1992).

While network diagramming is a very useful tool for describing the structure and function of the system under investigation, its application can be restricted because it assumes unidirectional causality (Sorensen 1971). For this reason, the basic network analysis approach has been refined to facilitate the development of conceptual models of the system that account for the presence of feedback mechanisms. Application of the refined procedures involves the development of a series of loop diagrams, which describe the structure and function of the system, including the linkages and feedback mechanisms that operate at specific time intervals. The networks that are developed for each time interval are then integrated to construct a representative composite diagram of the system. The resultant composite loop diagram is then used to determine the effects of a disturbance activity on system variables and interactions, to identify the ecosystem components and pathways that are most sensitive to environmental change, and to select the linkages for more quantitative modelling (Smit and Spaling 1995). By characterized linkages and feedback mechanisms, loop analysis provides a basis for explicitly analysing the processes that link stressors to receptors (i.e., cause and effect), including the processes that result in the accumulation of effects within a system.

One of the main advantages of network analysis, in general, and loop analysis, in particular, is that the resultant networks describe the cause and effect relationships that occur within a system. This feature provides analysts with an ability to understand how the system is likely to function under various development scenarios over time. This enhanced understanding of the system better enables analysts to identify the key linkages that require further analysis to support quantification of cumulative effects. Importantly, networks display complicated relationships among ecosystem components and processes in a graphical manner, which makes the information much more accessible to the stakeholders (Dixon and Montz 1995).

While network analysis is a useful tool for conceptualizing and illustrating relationships and pathways to support CEA, it has a number of limitations which restrict its utility. One of the most important of these is that the networks that are developed are essentially aspatial and atemporal (Cocklin *et al.* 1992). While the development and evaluation of networks that apply to specific time intervals mitigates this limitation to some extent, the lack of temporal and spatial dimensions of the network restricts the analysts ability to precisely identify and quantify the structure and functional changes that could occur in the system. Additionally, integrated networks can be very complex, which can make it difficult for stakeholders to focus on the key functions and interactions that are actually driving the accumulation of effects in the system (Dixon and Montz 1995).

Although it is rarely identified explicitly, network analysis is a fundamental component of many of the CEAs that have been completed to date. That is, simplified network diagrams are often constructed during the scoping stage of the assessment (i.e., flow charts that depict the relationships between disturbance activities and environmental receptors). For example, Spaling and Smit (1995) developed a system diagram to illustrate the interactions between agricultural land drainage and the environment. Similarly, flow diagrams have been used to illustrate the relationships between land use, regulatory interventions, and the cumulative effects of dredge and fill activities on waterways, shore zones, and wetlands (Stakhiv 1988). However, its application for conducting detailed CEAs remains largely untested (Smit and Spaling 1995). Nevertheless, this type of conceptual modelling provides an enhanced understanding of the system attributes, functions, and linkages; therefore, it is likely to represent an essential element of comprehensive CEAs, particularly when linked to procedures that facilitate the quantification of effects on spatial and temporal bases.

3.4 Environmental Auditing Approach

The environmental auditing approach to CEA is a synoptic approach which provides a framework for making comparisons between landscape subunits (e.g., watersheds, ecoregions, counties, etc.), thereby facilitating consideration of cumulative impacts in management decisions (Abbruzzese and Leibowitz 1997). The approach was developed in response to the general lack of tools that can be used to address cumulative impacts within regulatory constraints. Hence, the methods were designed to make use of available information and best professional judgement to provide relevant information on four general synoptic indices of cumulative effects, including function index (i.e., the rate at which material or energy is added or removed from the active landscape pool), value index (i.e., the relative value among subunits that serve a socially-relevant function; such as flood control), functional loss index (which represents the cumulative effects on a particular valued function), and replacement potential index (which provides a measure of the potential for replacing a particular valued function (Abbruzzese and Leibowitz 1997).

Application of the environmental auditing approach to CEA involves five major steps (Figure 3.4; Abbruzzese and Leibowitz 1997). The first step in the process (i.e., Definition of Goals and Criteria) involves determination of the objectives of the assessment, the intended use of the results, the level of accuracy required in the results, and the constraints under which the assessment will be conducted. Next, a set of specific synoptic indices are selected that will meet the objectives of the assessment and support its intended use. This involves replacing the four general synoptic indices with a set of specific indices that supports the objectives of the assessment (e.g., percent wetland loss, loss of hydrologic function, etc.). Identification of the specific indices that are most relevant to the assessment requires characterisation of the functional attributes system, the human disturbances that have taken or could take place, and the potential responses of the system to such disturbances. In addition, the boundaries of the landscape and relevant subunits must be defined, along with the rules for analysing the data (i.e., how the data will be combined to assess cumulative effects).

The third step in the process involves the selection of landscape indicators, which provide the actual measures that will be used to estimate the synoptic indices. For example, estimation of percent wetland loss requires information on the historical wetland area and the current wetland area, which are both termed index components. As historic wetland areas can not be measured directly, surrogates must be used to estimate the status of this index component. For example, the area of hydric soils, which is estimated from the results of historic soil surveys, can be used as an indicator of historic wetland area. Similarly, the current wetland areas can be estimated from aerial photographs or current land cover maps. Some of the activities that need to be undertaken during this step of the assessment include compilation of the existing data, evaluation of the costs and benefits of collecting additional data, selection of appropriate indicators, description of indicator assumptions, finalization of subunit selection, and completion of the pre-analysis review of the terms of reference of the investigation (Abbruzzese and Leibowitz 1997).

Once the necessary information has been assembled and reviewed, it is possible to initiate the actual CEA. The first step in the assessment stage of the process involves the development of a quality assurance and quality control plan which includes the protocols for designing the synoptic database and for screening, archiving, and documenting the data. Then, the available data are analysed to determine values for the synoptic indices for each landscape subunit. These results are then plotted on maps to present the information in a form that makes it easily accessible to stakeholders. The final steps in the assessment process involve evaluating the accuracy of the assessment (i.e., determining if assumptions have been violated and the effects of such violations on the assessment results) and conducting a post-analysis review to determine if the objectives of the assessment have been met (Abbruzzese and Leibowitz 1997).

The final step in the overall CEA involves the preparation of synoptic reports. Abbruzzese and Leibowitz (1997) recommended that two types of reports be prepared, including a user's guide and a detailed report. The user's guide is intended to provide the results of the assessment and guidance on how the results can be used to satisfy the original management objectives. The second report should provide complete documentation of how the assessment was conducted, including the objectives, constraints, rationale for index definition and indicator selection, assumptions, data sources, detailed descriptions of the procedures used in evaluating and analysing the data, and recommendations for future assessments (i.e., lessons learned).

The environmental auditing approach has a number of features which make it attractive for conducting CEAs. First, as a landscape analysis-based procedure, the approach provides a means of determining the relative severity of cumulative environmental effects on virtually any number of landscape subunits. Hence, it is possible to attain a level of spatial resolution that is not possible for many other approaches (that is, assuming that the requisite data are available and the system is divided into multiple subunits). In addition, the results of the assessment are presented on maps in terms of the ecosystem functions that have the greatest social values. Hence, the results are likely to be directly relevant for use in decision-making activities. Furthermore, this procedure can be implemented using existing information, in conjunction with professional judgement. Therefore, the costs associated with conducting the assessment can be relatively low.

In spite of these advantages, the environmental auditing approach has a number of limitations which restrict its application in CEA. Most importantly, the approach is neither quantitative nor rigorous, which makes it difficult to apply in regulatory programs. Another disadvantage of this approach is that a great deal of information is lost in the translation of raw data into synoptic indices. Finally, the approach does not provide adequate temporal resolution to fully evaluate effects that accumulate over time.

Several investigators have recommended this type of synoptic approach for assessing cumulative effects to wetlands. For example, Bedford and Preston (1988) argued that procedures that provide a conceptual and qualitative understanding of cumulative effects are legitimate approaches (that is, they improve our understanding of relationship and indicate the direction of the cumulative effects). Consistent with this recommendation, USEPA's Wetlands Research Program has developed a methodology that supports synoptic assessment of cumulative effects, which has been tested using a series of case studies (Leibowitz *et al.* 1992). The results of these field validation studies demonstrate that the approach provides an efficient, cost-effective, and timely bases for evaluating cumulative effects. The approach is most useful in situations when accurate, quantitative data are not available, the costs associated with obtaining additional data are high, the cost of the wrong answer is low, there is a high demand for the information, and the situation calls for setting priorities between multiple decisions rather than optimizing a single decision (Abbruzzese and Leibowitz 1997).

3.5 Landscape Perspective Approach

In recent years, interest in methods for assessing the effects on human activities at a landscape level has increased dramatically. According to Lee and Gosselink (1988), interest in landscape level approaches to CEAs has increased because cumulative impacts are usually landscape level phenomena, a landscape focus can conserve valued attributes that are not manageable at a finer scale, and landscape conservation also conserves the valued functions and biota of smaller subsystems. The landscape perspective approach, which is also known as the biogeographical analysis approach, provides a basis for evaluating the cumulative effects of human activities at the landscape level (Smit and Spaling 1995). This approach recognizes that ecosystem structure and ecosystem function are inextricably linked. Hence, changes in ecosystem structure are likely to adversely affect the ecosystem functions that are valued by society (e.g., role of wetlands in preventing floods and maintaining good water quality Figure 3.5; Whigham *et al.* 1988).

There are two phases in the evaluation of the cumulative effects of disturbance activities using the landscape perspective approach, including structuring the evaluation and conducting the evaluation. The first step in structuring the evaluation is the establishment of the spatial (i.e., the impact area) and temporal (i.e., the impact period of duration) boundaries of the study (Preston and Bedford 1988). Establishing the boundaries of the evaluation is important because it provides a means of deciding which disturbances, structural characteristics, and functional attributes to consider in the evaluation. The second step in this process is the identification of the measurement variables that will be used in the evaluation. These variables should include descriptive measures of existing and proposed human activities, descriptive measures of ecosystem structural characteristics, and specific measures of the functional attributes of the systems, which in turn can be used to describe alterations in system function. Finally, the relationship among the three types of variables must be defined, including the relationships between various human activities and ecosystem structure and between ecosystem structure and ecosystem function (Preston and Bedford 1988).

The selection of specific indicators of ecosystem structure and function is critically important because the information on changes in the status of these variables is used to measure the severity and extent of cumulative environmental change (Smit and Spaling 1995). For this reason, it is essential to ensure that the indicators that are selected are relevant to the important functional attributes that need to be conserved at a landscape level. To support the selection of suitable indicators, ecosystem goals and objectives (i.e., desired future condition of the system) must first be established to provide a frame of reference for determining if human activities are altering or are likely to alter the system in a way that compromises valued ecosystem functions (Salwasser and Samson 1985; Lee and Gosselink 1988; Minns 1995).

A study that was conducted to evaluate the cumulative effects of human activities on bottomland hardwood forests in the southern United States provides a good example of the indicator selection process (Lee and Gosselink 1988). This study was focussed on evaluation of the cumulative effects of agriculture, aquaculture, mining, stream channelization, logging, and stream impoundment on the valued ecosystem functions of bottomland hardwood forests, including flood storage capacity, water quality conditions, and wildlife population status. By evaluating the linkages between these disturbance activities, ecosystem structure, and these valued ecosystem functions, the investigators were able to identify eight types of indicators for use in the CEAs, including fraction of forest remaining, forest patch size distribution, connectivity of forest habitats, water quality, nutrient loadings, stage discharge relationships, water retention, and wildlife population attributes.

Subsequently, more specific indicators that could be measured directly were established (e.g., flow adjusted phosphorus concentration was used to evaluate water quality conditions).

After the evaluation has been structured, it is possible to conduct the evaluation of cumulative effects. Implementation of the cumulative effects evaluation involves three steps, including cataloguing the relevant measures of human activities, determining their effects on the system attributes (i.e., on the structure of the system), and subsequently estimating the changes in system functions in response to these alterations in system characteristics (Preston and Bedford 1988). As a first step in the assessment process, the relative potential for cumulative effects of each type of disturbance activity is determined by considering the area affected (i.e., spatial extent of the activity), the intensity of the impact within the affected area, and the permanence of the activity (i.e., the degree to which the activity involves lasting or irreversible changes; Lee and Gosselink 1988). The evaluations of the effects of the disturbance activities on the structure and functional attributes of the system are conducted using data and information on the indicators that were selected previously. By selecting indicators that effectively integrate the effects of multiple activities in time and space, it is possible to use this landscape perspective approach to measure cumulative effects directly (i.e., through comparisons to reference conditions, as determined by the ecosystem goals and objectives; Gosselink and Lee 1987).

The landscape perspective approach has a number of attributes that make it attractive for assessing cumulative environmental effects. First, this approach explicitly recognizes that assessment of cumulative effects requires a frame of reference against which changes in ecosystem structure and function can be compared. In addition, this approach provides a basis for resolving cumulative effects on both temporal and spatial scales. As such, the methodology is likely to support both regulatory and policy decisions. Furthermore, both single and multiple sources of perturbations can be considered in the analysis, with functional effects that are characterised by time-crowding and time-lags discernable using this method (Smit and Spaling 1995). Finally, the selection of appropriate indicators of ecosystem structure and function (i.e., cumulative effects indicators; CEIs) provides a basis for estimating cumulative effects on the system as a whole, based on measurements of selected variables. Hence, the underlying complexity of the system can be recognized without unduly complicating the assessment procedures. This attribute makes the methodology both efficient and cost-effective.

In spite of the important advantages, there are several features that limit the applicability of this approach. First, implementation of the approach requires a comprehensive regional inventory of detailed data on ecological components and processes at a landscape scale (Smit and Spaling 1995). Collection and compilation of such data can be time-consuming and expensive. In addition, triggers and thresholds for cumulative effects are not explicitly considered in these methods (Smit and Spaling 1995).

This approach is a promising methodology for assessing cumulative environmental effects, especially where the focus is on spatially variable land surface phenomena (Smit and Spaling 1995). It has been applied successfully to assess the effects of various human activities on wetland functions (Preston and Bedford 1988; Klopatek 1988), stream water quality and quantity (Johnston *et al.* 1990), and on the functions provided by bottomland forests (Lee and Gosselink 1988). This approach is likely to be useful for assessing cumulative effects in many northern river basins, particularly where ecosystem goals and objectives have been established, human activities have not yet caused landscape level effects, and a commitment to long-term monitoring activities has been established.

3.6 Spatial Analysis Approach

The spatial analysis approach is a geographic information system-based procedure for assessing the cumulative environmental effects of human activities. Application of this approach involves the collection and collation of data on the environmental attributes of the system under investigation. Information on the distribution of human activities within the study area are also captured in electronic database format. These spatially-referenced data are stored, manipulated, and displayed using computerized data systems. Analysis of the relationships between stressors and receptors and of the changes in specific environmental attributes over time provides a basis for estimating the cumulative effects of disturbance activities (Figure 3.6). By inputting generated data that reflects the possible changes to system attributes in response to developmental activities, it is also possible to evaluate future development scenarios in the CEA.

Implementation of the spatial analysis approach to CEA is a multi-stepped process. The first step in the process involves delineation of the boundaries of the study area. Next, the various data layers of the CEA are identified. For the natural environment, two major types of data layers are often identified, including valued ecosystem components (such as water quality, atmospheric quality, flora, fauna, and aesthetic qualities) and physical environmental characteristics (such as geology, soils, hydrology, vegetation, and climate; Parker and Cocklin 1993). Two types of data layers are also identified for the human environment, including social/political characteristics (such as cultural sites, land ownership, and administrative boundaries) and human activities (such as agriculture, mining, forestry, and other land and water uses; Parker and Cocklin 1993). Subsequently, measurement variables for each major data type are identified (e.g., phosphorus concentration could be used as a measurement variable for water quality). Then, relevant data sources are identified and contacted to obtain the available information on each measurement variable, which is georeferenced and compiled in electronic database format. The information in the electronic database provides the basis for conducting the CEA.

Several types of analyses can be used to evaluate the cumulative effects of human activities using the spatial analysis approach. One of the main objectives of these analyses is to quantify the rates of regional resource loss by comparing data layers representing different years (i.e., using time series analysis; Johnston *et al.* 1988; Cocklin *et al.* 1992). Empirical relationships between resource loss and environmental degradation can also be established using geographic information system (GIS) techniques. Multivariate statistical techniques, such as principal components analysis and step-wise multiple regression analysis, are often used to identify the factors that are most strongly correlated to changes in the status of valued ecosystem components. The information contained in the GIS database can also be used to support management decisions, through such techniques as GAP analysis, which provides a means of identifying the actions needed to achieve certain ecosystem objectives (Scott *et al.* 1993).

The spatial analysis approach represents a valuable procedure for assessing cumulative environmental effects for several reasons. One of the most obvious contributions of GIS technology to CEA is its explicit consideration of the spatial dimension, which facilitates resolution of effects on either a local or regional scale (Smit and Spaling 1995). It is also possible to assess temporal trends using this approach. Furthermore, this approach does not provide any practical limitations on the number of stressors or receptors that can be considered in the analysis. This feature makes GIS-based procedures broadly applicable for assessing the cumulative effects of human activities. That the underlying data are georeferenced makes it possible to quickly display and overlay the data on maps. In this way, it is relatively easy to make the relevant information accessible to stakeholders and the public.

There are also a number of limitations of the spatial analysis approach which could restrict its application, particularly in northern river basins. First, causal linkages between stressors and receptors can not be established using this approach (Cocklin *et al.* 1992). Rather, this approach provides a means of establishing associative relationships only. In addition, GIS analysis focusses on the structural attributes of the system. Hence, it must be used in conjunction with other techniques to assess effects on ecosystem functions (Smit and Spaling 1995). Perhaps the most important limitation of this approach is its reliance on large quantities of data on a wide range of ecosystem attributes, with broad spatial and temporal coverage. While such data sets are commonly available on temperate ecosystems, they are rarely available for northern river basins. Therefore, GIS-based procedures are likely to be costly to implement and provide little information on northern ecosystems in the near-term.

GIS-based procedures have been used in recent years, alone and in conjunction with other procedures, to support several types of CEAs. For example, Parker and Cocklin (1993) and Jensen *et al.* (1993) described the applications of GIS for assessing cumulative effects on wetlands. Similarly, Johnston *et al.* (1988; 1990) and Detenbeck *et al.* (1990) evaluated the cumulative effects of wetlands on water quality and quantity conditions in stream and lake ecosystems. However, the published literature does not suggest that GIS-based CEA has been widely undertaken, either in Canada or elsewhere in the world.

3.7 Ecological Modelling Approach

In the ecological modelling approach (which is also known as the input-out approach and the meta-modelling approach), the cumulative effects of disturbance activities are evaluated through the use of dynamic system models. These models provide a simplified representation of dynamic, complex systems which can be used to predict the behaviour of a system or a system component under a variety of conditions (e.g., Figure 3.7). The development of reliable mathematical simulation models is dependent on a clear understanding of the relationships between the stressors and the receptors in the ecosystem under investigation. For this reason, ecological modelling is likely to be most effective when used in conjunction with other approaches that facilitate the identification of cause and effect relationships between system variables (e.g., matrix and network approaches).

The ecological modelling approach provides a means of rapidly evaluating the effects of potential development scenarios on important system attributes. For example, Ziemer *et al.* (1991) evaluated the potential cumulative effects of various forest management activities (i.e., cutting pattern and timing) on fish habitat quality in several coastal watersheds in Oregon and California. The model that was developed enabled the investigators to examine linkages between the various land use patterns, precipitation, mass wasting of soils, tributary sediment transport, and, ultimately, streambed elevation change, which was used as a surrogate for alterations in fish habitat quality. By simulating conditions over a 200 year period, it was possible to evaluate differences in the frequency of bed elevation changes among various treatment groups. In turn, this information was used to determine the relative effects of each treatment, as well as the spatial and temporal distributions of effects. In this way, the modelling procedure was able to provide information that can be used directly in resource management decision-making activities.

The principal advantage of the ecological modelling approach is its ability to provide rapid predictions of the cumulative effects of disturbance activities. Depending on the degree of sophistication of the models, it can also provide a high degree of spatial and temporal resolution in CEA. Ecological modelling can consider either single or multiple perturbation and evaluate their potential effects on system attributes or functions at a local, regional, or global scale. As simulation models focus on cause-effect relationships, they provide one of the best prospects for analysing specific pathways of cumulative environmental change (Smit and Spaling 1995).

In spite of the aforementioned advantages, there are a number of limitations of the ecological modelling approach. First, simulation models are of little value unless they are based on reliable data and have been thoroughly validated, both of which require substantial resources and expertise. Second, the models that have been developed thus far generally enable investigators to predict effects of disturbance activities on one environmental attribute only (i.e., streambed elevation in the above example). As most CEAs consider impacts on multiple system attributes, numerous simulation models would be needed to fully evaluate the potential for cumulative effects. Finally, simulation models are only applicable to ecosystems for which system organization and behaviour are reasonably well understood (Smit and Spaling 1995). This third limitation is likely to restrict the application of ecological modelling in the assessment of cumulative effects in northern river basins.

While simulation modelling has been used extensively in EIA, its application in CEA has been limited to date. Apart from the example described above, specific applications of this approach in CEA have not been described in the literature.

Chapter 4 A Framework for Cumulative Effects Assessment in the Lower Columbia River Basin

4.0 Introduction

There are numerous human activities within the lower Columbia River basin that have the potential to adversely affect the aquatic ecosystem and its uses. Human activities include municipal development, infrastructure and linear developments (i.e., road, rail), pulp manufacturing, metal smelting, timber harvesting, renewable energy development, flood control, and recreational endeavours. Individually, and in combination, these human activities have the potential to adversely affect physical, chemical, and biological processes in the river basin.

Conventional environmental management in the lower Columbia River has focussed on the effects of single-issue development activities by means of environmental impact assessment (EIA) and environmental monitoring. However, the potential for interaction among human activities means that environmental managers need to evaluate cumulative effects, in addition to conducting traditional EIAs. The previous section of this report (Chapter 3) provides an overview of the various approaches that have been used to conduct CEAs. However, it is difficult to determine which approach or approaches are likely to be most relevant for use in the lower Columbia River basin. For this reason, criteria for evaluating candidate CEA procedures were compiled from MacDonald *et al.* (1999) and applied to support the selection of an approach that could be used to assess cumulative environmental effects in the lower Columbia River basin

4.1 Criteria for Evaluating Methods for Assessing Cumulative Environmental Effects

This study was initiated to provide guidance on the selection of procedures for assessing the cumulative effects of human activities in the lower Columbia River basin. To this end, the available information on the various procedures that have been developed was collated and reviewed to facilitate the preparation of a brief description of each method. In addition, the various procedures were critically evaluated to identify their advantages, their disadvantages, and their potential applications. However, the selection of specific approaches and procedures for conducting CEAs requires criteria against which the various methods can be evaluated.

There is no general agreement in the published literature on how to evaluate the various procedures for conducting CEAs. Nevertheless, several investigators have identified a number of attributes or characteristics of CEA methodologies that are considered to be desirable (Bain *et al.* 1989; Cocklin *et al.* 1992). This information on the desirable characteristics was used to develop the following criteria that could be used in the selection of specific methods for assessing the cumulative effects of human activities in the environment:

- ***Practicality*** **–** It is not possible nor practical to conduct comprehensive, all-encompassing assessments of the effects of human activities on the environment. For this reason, CEA procedures should provide a means of conducting assessments that are focussed on key ecosystem processes and receptors and minimizes the need to collect large quantities of new data.

- ***Simplicity*** **–** The results of CEAs are intended to provide environmental managers and policy-makers with the information needed to make rational decisions on the use of aquatic and terrestrial resources. For this reason, the assessment process should be structured so that it is easy for informed laypersons to follow. In addition, the assessment results should be brief and easily understood by decision-makers and the public.

- ***Flexibility*** **–** By their very nature, a multidisciplinary approach is needed to conduct scientifically-defensible CEAs. For this reason, the assessment process should be flexible enough to accommodate a wide range of environmental issues, support the evaluation of multiple activities and development, and permit diverse technical practitioners to conduct analyses that are specific to their disciplines.

- ***Consistency* –** CEA involves the use of information from diverse sources and of variable quality to evaluate the cumulative effects of human activities. For this reason, the assessment process should provide a means of assuring that a consistent level of scrutiny is applied to analytical methods and underlying data that are used to conduct the various elements of the assessment.

- ***Sensitivity to Detail* –** Because CEAs are used to support decision-making and policy development, the assessment process must be sufficiently rigorous to inspire confidence in the final results. For this reason, the assessment process should consider the underlying complexity of the ecosystem under study (i.e., both structure and function), identify the linkages between causal factors and cumulative effects, and provide quantitative results that can be summarized without losing essential details.

- ***Resolution* –** By their very nature, cumulative effects tend to accrue over specific time periods and within defined spatial boundaries. For this reason, the assessment process should provide accurate results that have a high level of temporal and spatial resolution.

Application of these criteria in a preliminary evaluation of the various approaches suggests that no single procedure is likely to fully meet the needs for CEA in the lower Columbia River basin. Nevertheless, elements from several of these approaches can be incorporated into a broad framework for assessing cumulative effects in this river system. In addition, many of the specific procedures and tools that are applied within the individual approaches could be used in the CEA process that is ultimately recommended for use in the lower Columbia River basin. Some of the key elements of a CEA process are described below.

4.2 Key Elements of the Cumulative Effects Assessment Process

Effective and efficient assessment of the cumulative effects of human activities in the lower Columbia River basin will require the development of a framework that can be applied consistently by environmental assessors and managers. Several types of generic frameworks have already been established to support CEAs which provide a basis for developing a framework that can be used in the lower Columbia River basin (e.g., Lane *et al.* 1988; Abbruzzese and Leibowitz 1997). The key elements of such a cumulative effects framework are likely to include:

- Identification of ecosystem goals and objectives;
- Definition of the scope of the assessment;
- Definition of the boundaries of the assessment;
- Identification of the human activities that could affect the study area;
- Identification of the types and probable locations of the environmental changes that could occur in response to the human activities;
- Identification of the types and probable locations of receptors that could be affected by the environmental changes;
- Identification of the types of ecosystem functions that could be altered by the environmental changes and the locations of such alterations;
- Selection of CEIs from the list of receptors and ecosystem functions that were identified previously;
- Implementation of a retrospective or a predictive CEA, depending on the goals of the assessment;
- Identification of data gaps and uncertainties in the CEA;
- Preparation of a cumulative effects assessment report, including maps, to communicate the results of the assessment;
- Development and implementation of research programs to reduce data gaps and uncertainties to acceptable levels;
- Refinement of the CEA based on the results of the research programs;
- Design and implementation of an ongoing CEM program; and,

- Assessment of cumulative environmental effects based on the results of the ongoing monitoring program.

The first step in the CEA process involves the identification of ecosystem goals and objectives. This step in the overall framework is essential because it provides a means of identifying a long-term vision for the future that is shared by the participants in the process (e.g., government agencies, First Nations, other residents, etc.). This long-term vision enables us to determine the desired future state of the ecosystem (Hartig *et al.* 1998). The existing and predicted future state of the ecosystem can then be compared to the desired state to determine if unacceptable cumulative effects have or are likely to occur as a result of human activities. Hence, the desired state of the ecosystem defines the conditions against which to measure or predict cumulative environmental effects (see Section 7.0).

Project scoping is also an important element of the overall CEA. During the scoping phase, the goals of the assessment, key issues, and questions are defined. In addition, the level of detail of the assessment, the logistical support that is needed to complete the assessment, and the resources necessary to undertake the project are identified. In this way, it is possible to design a CEA that will respond directly to the needs of decision-makers and stakeholders, will provide the appropriate degree of accuracy and resolution, and can be completed with the allotted budget.

Human and natural stressors occur at different spatial and temporal scales within an ecosystem, as do the biological responses to these disturbances (Abbruzzese and Leibowitz 1997). For this reason, it is necessary to consider both the geographic and temporal scales of the various stressors that could influence the ecosystem under consideration. In this way, it is possible to define the boundaries of the CEA. While an attempt should be made to define the boundaries at the outset of the process, it should be recognized that the boundaries are likely to be modified as more information is collected during the course of the assessment.

Identification of the human activities that can affect the ecosystem provides a means of cataloguing the stressors that could precipitate cumulative effects within the study area. As a first step in this process, the existing activities within the study area should been identified (i.e., types of developments and associated activities). Next, the activities that have been proposed or are likely to be proposed in the future should be listed. Importantly, the activities that occur outside the study area, but have the potential to influence environmental characteristics within the study area, should be identified. Together, the list of existing and proposed developmental activities should provide a comprehensive basis for identifying the stressors on the system that are not naturally occurring (see Section 3.0).

In natural ecosystems, stressors are linked to receptors through a series of pathways that influence the characteristics of the system under investigation. Therefore, it is critically important to accurately identify the types and probable locations of environmental changes that could occur in response to the human activities. For existing developments in the system, the available monitoring data can be used to identify the changes that have occurred to the physical and chemical characteristics of the system. However, such information will not be available for proposed activities and may not even be available for the existing activities. For this reason, relevant case studies, assembled from investigations in other areas, should be collected and reviewed to obtain the information needed to predict the changes that are likely to occur within the study area in response to disturbance activities. In addition to identifying the types of changes that could occur, this information should be used to identify the spatial and temporal scales of such alterations to the physical and chemical characteristics of the system. The degree and timing of natural variability in these ecosystem characteristics should also be determined at this stage of the process. In this way, it is possible to determine the areas and times that interactive effects among the various human and natural stressors are likely to occur [see MESL (1997) for an overview of environmental conditions in the lower Columbia River basin].

Information on the structure and function of the ecosystem under investigation is a required element of the overall CEA process. More specifically, information is needed on the types of organisms that utilize habitats within the study area, on the distribution and abundance of these organisms, and on the life history strategies that are utilized by these species [e.g., spawning timing and location for fish; see MESL (1997) for information on the aquatic organisms that utilize habitats within the lower Columbia River basin]. In addition, information is needed on the relative sensitivity of the various receptors that occur within the study area to the human and natural stressors that have been identified. Collectively, this information can be used, in conjunction with the information on changes to the physical and chemical environment, to identify the types and probable locations of receptors that could be affected by the environmental changes. The types of ecosystem functions that could be altered by the environmental changes and the locations of such alterations can also be identified using a similar procedure.

The information collected during the previous step in the process provides a basis for identifying the receptors and ecosystem functions that are most likely to be affected by the interactive effects of human and natural stressors. These receptors and ecosystem functions can be termed candidate CEIs (Section 7.3). While it would be informative to assess the cumulative effects of these stressors on all of the candidate CEIs, it is neither practical nor necessary to do so. Instead, a suite of CEIs should be selected that provides a means of assessing cumulative environmental effects on the ecosystem as a whole. Criteria for evaluating candidate CEIs, which are considered to be applicable for use in the lower Columbia River basin, are described in Section 7.4. The ecosystem goals and objectives that were initially established provide a frame of reference for establishing targets for each CEI which, if met, would preserve ecosystem structure and function.

Two types of CEAs can be conducted, depending on the needs of environmental managers and the public. The first type is a retrospective CEA, which provides a means of evaluating the effects of disturbance activities that already occurred in response to human and natural stressors. In this type of assessment, historical and contemporary data on the selected CEIs are collected and reviewed to assess temporal trends for these receptors and ecosystem functions (e.g., distribution, abundance, etc.). Similar data may be collected in a suitable reference area to provide a basis for comparison if historical baseline data are not available. Changes in the status of the CEIs over time or space indicate that effects have occurred. Comparison of the current status of the CEIs to the targets that have been established previously provides a quantitative means of determining whether unacceptable cumulative effects have occurred in the system (i.e., cumulative environmental impacts).

The second type of assessment that may also be undertaken is termed a predictive cumulative environmental effects assessment. In this type of assessment, historical and/or contemporary data on the status of the selected CEIs is collected and reviewed to identify baseline conditions. Next, the future status of the selected CEIs is predicted based on the information that has been assembled on the anticipated future state of the physical and chemical environment. Interactions among the biological components of the ecosystem and compensatory mechanisms should also be considered during this evaluation. Such predictive assessments are generally qualitative, with the direction of the change identified (i.e., positive or negative effect). However, it is difficult to accurately predict the magnitude of such changes in the status of the CEIs in this type of assessment. Nevertheless, it is possible to determine if the changes to the CEIs are likely to be acceptable, relative to the ecosystem goals and objectives that have been established previously.

Both retrospective and predictive CEAs are likely to be limited, to a certain extent, by the availability of information. Specifically, the available historic and contemporary information may be limited on the nature of human activities, on the physical and chemical alterations that have or could occur, on the natural variability within the system, and on the CEIs that have been selected. As a result, a number of data gaps and uncertainties will be identified during the course of conducting the CEA. It is important to fully document these data gaps and uncertainties to maintain transparency in the CEA process and to provide a basis for designing research programs to reduce these limitations in the future.

Communication of the results of the CEA to decision-makers and to the public represents a critical component of the overall CEA process. For this reason, it is necessary to prepare a cumulative effects assessment report that describes the methods that were used, the results of the assessment, its limitations, and how the results should be used by decision-makers. Because CEA is a complicated process, it is necessary to communicate the results of the assessment in a manner that makes the information easily accessible to decision-makers and the public. Maps, figures, tables, and clear language should be used to identify the changes that have occurred or are expected, nature, severity, and duration of effects of CEIs, and the locations within the study area that are most severely affected. To the extent possible, management options for limiting or mitigating the cumulative effects should also be identified.

Due to the types and quantities of information that are needed to conduct comprehensive CEA, it is virtually certain that data gaps and uncertainties will be identified during the process. In some cases, these limitations will be relatively minor and fall within acceptable levels. In other cases, however, these data gaps and uncertainties will be sufficient to severely limit the applications of the CEA. In such instances, it will be necessary to develop and implement research programs to reduce data gaps and uncertainties to acceptable levels. The results of these studies can then be used to refine the CEA.

The results of the CEA should be used by decision-makers to identify the management options that are most appropriate for the system under investigation. These management options could include no immediate action, implementation of remedial measures within the basin to reduce or eliminate unacceptable effects, or implementation of broader management actions to reduce the effects of activities that are occurring outside the basin. Regardless of which option or options are selected, it is necessary to evaluate the effectiveness of these actions in terms of reducing cumulative effects. For this reason, the design and implementation of an ongoing CEM program is an important component of the overall CEA framework. Such monitoring programs should focus on the CEIs that were identified earlier in the process. The results of such monitoring programs provide a basis for assessing cumulative environmental effects in the study area and determining if the situation is improving in response to the management actions.

Chapter 5 Ecosystem Goals and Objectives for the Lower Columbia River Basin

5.0 Introduction

Frameworks for ecosystem-based management and CEA in the lower Columbia River basin were presented in Chapter 2 and 4, respectively. Both of these frameworks stress the importance of compiling the available knowledge base on the study under consideration and identifying the issues and concerns that are associated with natural resource management. In addition, the establishment of ecosystem goals and objectives represents a fundamental step toward the assessment of cumulative environmental effects, which is an important element of ecosystem-based management.

This chapter of the report is intended to provide critical information for assessing cumulative environmental effects in the lower Columbia River basin. More specifically, a synopsis of historic and current environmental conditions in the lower Columbia River basin is provided. Additional information on the existing knowledge base has been compiled in Butcher (1992), Aquametrix Research Ltd. (1994), MESL (1997) and, R.L.&L. Environmental Services Ltd. (2001). In addition, the environmental issues and concerns that were identified by the CRIEMP Committee during a recent CEA Scoping Workshop are presented. Furthermore, the CREIMP II vision statement is presented. Finally, the ecosystem goals and objectives that have been established for the lower Columbia River basin are summarized.

5.1 Synopsis of Historical and Current Environmental Conditions in the Lower Columbia River Basin

The lower Columbia River ecosystem has undergone dramatic changes since the last recession of the glaciers, approximately 10,000 years ago. Most of these ecosystem changes occurred relatively recently during the 20^{th} century as direct or indirect consequences of human activities. Prior to 1850, there were probably some modest environmental impacts associated with the Gold Rush and development of the fur trade. By 1900, most of the local Lakes Indian people had emigrated away from the lower Columbia River to a reserve at Fort Colville in the U.S.

During the 1900's, ecosystem changes reflected the region's resource-based economic development and the associated human population growth. After a small smelter was established at Trail during 1896 to process ore from the Rossland Mine, the population of Trail grew steadily, peaking at over 10,000 during the 1950's and 1960's. Cominco (now Teck Cominco Metals Ltd.) developed and modernized eventually to become (by about 1980) the largest integrated zinc and lead smelter in the world.

Castlegar developed primarily during the first half of the 20th century following construction of a railway bridge across the Columbia River (linking the CPR, Columbia and Kootenay Railways), and the establishment of a regional airport in 1950.

Watershed changes during the 1900's included the development of a road transportation network as well as logging to support local sawmills and a pulpmill (Celanese Corp. of America, the precursor of Celgar). Initially established to produce 450 air dried metric tonnes/day (ADMT/d), the pulpmill expanded and modernized after 1989 and at full production, currently produces 1200 ADMT/d of pulp.

The region's hydropower industry began after construction of Brilliant Dam on the Kootenay River in 1944, and expanded with the construction of the Waneta Dam on the Pend d'Oreille River in 1954, and the Hugh Keenleyside Dam on the Columbia River mainstem in 1967. The latter facility was established as a component of the Columbia River Treaty (1961), and was initially developed for downstream flood control. While the Keenleyside Dam is a storage facility which impounds water upstream in the Arrow Reservoir, the Brilliant and Waneta Dams are run-of-the- river facilities which operate without a water storage reservoir. The Keenleyside Dam was upgraded to facilitate hydropower production in 1998. Presently, approximately 96% of the river flow at the Canada-US border is regulated, with about 39% of total annual flow at the border passing through Hugh Keenleyside Dam, 30% through Brilliant Dam, and 27% through Waneta Dam. The remaining 4% flows in through small tributaries.

Historically, salmon populations were important components of the lower Columbia River ecosystem. Overfishing combined with the construction of numerous hydro installations throughout the Columbia River, led to the demise and extirpation of the migratory salmon populations from the lower Columbia River by the middle portion of the 1900's. In addition to blocking salmon migrations, other ecosystem consequences from hydro operations include the stranding of eggs, fish and benthic invertebrates due to fluctuating water levels and the dewatering of nearshore areas, as well as dissolved gas supersaturation.

Gas supersaturation frequently occurs in the lower Columbia River during certain periods of the year. Elevated dissolved gas levels generated downstream of dams do not dissipate quickly, and tend to increase cumulatively downstream. High gas levels may affect fish populations, with greatest potential effects on survival and behaviour of fish in shallow waters. The BC water quality guideline for total gas pressure (TGP) is 110% TGP (110% total saturation at sea-level conditions) for water greater than 1 m depth and 103% TGP for water shallower than 1 m. Currently, the objective is met most of the year, but generally not in late summer, when flows are greatest.

The most common effect of elevated gas pressure is gas bubble trauma (GBT), appearing as bubbles in the gills, vascular system, fins and eyes, and as overinflation of the swim bladder producing both lethal or sublethal effects (disorientation, reduced feeding efficiency). Management of TGP is an ongoing concern in the lower Columbia River. A number of hydro operational changes have been implemented, or are under consideration, so as to minimize TGP at sensitive times of the year.

The two largest point sources of liquid contaminants in the lower Columbia River are Teck Cominco and Celgar. Up until the late 1980's, discharges from both facilities produced local water and sediment pollution impacts which led to fish consumption advisories and actions to reduce the contamination levels. Consumption advisories for sportfish, issued in 1989, were lifted in 1995 for mercury levels in walleye and in 1996 for organochlorine levels in mountain whitefish and lake whitefish, reflecting considerable improvement in contaminant levels in the river by the mid-1990's.

During the early 1990's, CRIEMP I was established, and undertook an aquatic contamination monitoring program in the lower Columbia River. Results from CRIEMP I included:

Water Quality: Compounds traceable to Celgar (organochlorines, resin acids) were below prevailing provincial and federal water quality guidelines at all stations sampled. Cadmium, chromium, mercury, lead, copper and zinc concentrations were higher than water quality guidelines at sites downstream of Teck Cominco in up to 40% of the water samples, although mean concentrations were frequently below guidelines. Coliform levels, associated with municipal wastewater discharges, were below criteria established for drinking water and recreational use.

Sediment Quality: Resin acid concentrations were elevated immediately downstream of Celgar and at Waneta. Up to a 40-fold increase in trace metal concentrations were measured in sediments at Beaver Creek, downstream of Teck Cominco. Differences in total organic carbon (TOC) levels among sites may have accounted for some of the differences in contaminant levels. The lack of sediment quality guidelines at the time of CRIEMP I made it difficult to assess potential impacts of contaminants in sediment to aquatic life.

Biota: With respect to the influence of contaminants on biota, plant data collected during CRIEMP I were inconclusive. Three benthic invertebrate community types were identified in the lower Columbia River: The first was from Hugh Keenleyside Dam to a point upstream of Celgar, where the river was slow and deep. The second was a faster flowing section between the Kootenay River confluence and Teck Cominco (Robson and Birchbank sites). The third was from Teck Cominco to the International Border (Ryan Creek and Waneta sites), where lower invertebrate abundance and diversity was interpreted as effects from smelter discharges. Sediment bioassays using amphipods *(Hyalella aztec*a) showed that survivals were reduced in sediments sampled downstream of both Celgar and Teck Cominco.

Since CRIEMP I, there have been significant environmental improvements associated with more effective effluent treatment and process upgrades at both Celgar and Teck Cominco. Celgar pulpmill undertook a major facility upgrade and expansion between 1990 and 1993, improved the effluent treatment system and switched from elemental chlorine to chlorine dioxide for pulp bleaching, which reduced discharge of dioxins and furans from the mill to below analytical detection limits. Teck Cominco ceased discharging slag (a by-product of smelting) to the river (July 1995) and closed the phosphate fertilizer plant (mid-1994), constructed a new KIVCET lead smelter with improved air and water treatment systems (commissioned in 1997-98), and installed a seepage collection system in the Stoney Creek watershed (1997). The old landfill has been capped with an impervious layer to provide source control.

Conditions in the Vicinity of Teck Cominco Metals Ltd.: British Columbia Ministry of Water Land and Air Protection (BCMWLAP) measured water quality at a number of stations in the lower Columbia River during 2000. Physical conditions met WQOs at all sites and concentrations of most contaminants were below WQOs. However, at several sites cadmium concentrations exceeded the WQO. Several metals (cadmium, copper, lead, thallium, zinc) immediately adjacent to Teck Cominco were elevated during October, 2000. The elevated levels of contaminants were interpreted as the consequence of smelter malfunction prior to water quality analysis.

Metal levels in bottom sediment were considerably higher at Waneta than Birchbank, the two main depositional areas in this region of the river, in both 1995 and 1999. However, metal contaminant levels at Waneta decreased substantially by 1999, likely reflecting cessation of slag discharge. Results from sediment analysis (which was conducted by BCMWLAP) showed that sediment contaminants (arsenic, cadmium, copper, mercury, lead and zinc) continued to decrease during 2000, although arsenic, copper, lead and zinc continued to exceed sediment quality objectives. During toxicity studies, thallium was suggested as a toxic component to fish of effluent from Teck Cominco. Subsequent research indicated that thallium did not cause acute toxicity to rainbow trout at levels found in the effluents. However, thallium is phytotoxic, and the company has developed processes for its removal and recycling.

Conditions in the Vicinity of Celgar: The zone of 1% effluent concentration extends a maximum of 6 km downstream of the diffuser under minimum flow conditions. A fibre mat downstream of the diffuser, containing wood fibre, flyash and process chemicals (resin and fatty acids, dioxins and furans), has been decreasing in size since 1975. The fibre mat contains higher levels of compounds related to pulpmill effluent (resin acids, fatty acids, TOC, chlorinated phenolics, dioxins and furans), than in a reference area. Near field sediments, outside the historic fibre mat area, reflect a low impact of pulpmill effluent relative to downstream stations.

During EEM Cycle 2 (1997-2001), sublethal effluent toxicity tests showed little or no impact of effluent and indicated potential zones of sublethal effects up to 121 m from the diffuser. Water testing showed no toxic or nutrient enrichment effects attributable to pulpmill effluent. A healthy and diverse benthic invertebrate community was reported for each site, with high numbers of *Hydra* sp. at the reference area. The near field Area had lower numbers of invertebrates than other areas, but higher diversity, equitability and richness indices. Mountain whitefish from the near field Area were in better condition than those from the reference area in terms of size, age and weight, suggesting enhanced growth in the near field.

During the Celgar EEM program, low levels of various dioxins and furans were measured at all stations, including the reference area. Mountain whitefish muscle tissue (n=5) tested for dioxins and furans in 1998 contained 0.28 to 0.60 pg/g TCDD TEQ/g wet weight, well below the WQO of 1 pg TCDD TEQ/g wet weight and lower than in 1994. Monitoring of mountain whitefish and rainbow trout muscle tissue undertaken by BCMWLAP in fall 2000 indicated that the dioxin/furan objective (<1 pg TEQ/g wet weight) was met in samples from Genelle and Beaver Creek. Organochlorine concentrations are expected to decline further in future, as organochlorine levels in the fibre mat continue to decline.

At present, the state-of-the aquatic ecosystem in the lower Columbia River can be summarized as follows:

Altered Hydrograph: The regulation of flow discharges from the Hugh Keenleyside Dam, has greatly altered the seasonal hydrograph of the lower Columbia River, as illustrated in Figure 5.1. Prior to flow regulation in 1967, there was a pronounced early summer freshet, and an order-of- magnitude variation in flow discharge between summer and winter. The Keenleyside Dam is operated to effectively store a portion of the summer run-off and release water during the winter, thereby greatly modifying the seasonal hydrograph (Figure 5.1).

Improving Water Quality: Since the identification of water quality problems during the early 1990's, there have been numerous water quality monitoring programs undertaken by BCMWLAP, Celgar, Teck Cominco, Environment Canada, Department of Fisheries and Oceans, and other agencies. The BC government has established WQOs for the lower Columbia River, and both Celgar and Teck Cominco have implemented major improvements in industrial processes and effluent treatment. Consequently, the levels of contamination from these 2 major point sources is decreasing, and most (but not all) contaminants are below WQO concentrations. Major groups of aquatic contaminants present in the lower Columbia River include dissolved metals, organic compounds and elevated levels of total dissolved gases (TDG).

Fish Community Changes: There are 27 fish species in the lower Columbia River, 18 of which are listed in Table 5.1. Historically, several species of salmon were abundant members of the aquatic community (juveniles and adults), including chinook, coho and sockeye salmon. Recently, a number of introduced species have increased in abundance. Walleye, for example, are now one of the most abundant species in the lower river; abundance indices indicate that their numbers have increased 35-fold over the past 2 decades. As piscivores, walleye can exert major influences on aquatic community structure.

Concern over Rare and Endangered Species: A number of lower Columbia River fish species are either red-listed or blue-listed and there are a number of conservation efforts currently underway (e.g., white sturgeon recovery program). White sturgeon in the lower Columbia River have been described as "critically imperiled" due to their inability to reproduce successfully below the Keenleyside Dam. Protection of rare and endangered species requires a concerted effort to ensure that suitable habitat conditions are maintained in the lower Columbia in the future.

Climate Change Effects: While climate change is an acknowledged fact of the 21^{rst} Century, there is only meagre information available about the hydrological and aquatic community consequences of climate change for specific watersheds. Under a warmer climate, the seasonal freshet of the Columbia River is expected to occur earlier in the year as more of the total annual precipitation falls as rain which discharges to the river rather than being stored as snow pack. Increases in annual average temperature conditions can have important implications for aquatic community structure, favouring warm-water species, and negatively affecting cold-water species.

5.2 Environmental Issues and Concerns in the Lower Columbia River Basin

A wide range of environmental issues and concerns have been identified in the lower Columbia River basin, (i.e., from the Hugh Keenleyside Dam to the international boundary; MESL 1997). To better define the current issues and concerns within the lower Columbia River basin, CRIEMP convened a CEA Scoping Workshop on June 27, 2002. Based on the input provided by workshop participants, the priority environmental issues and concerns within the study area were identified. With respect to the management of instream water uses, some of the most important issues include:

- Flow regulation and operational strategies at the Hugh Keenleyside Dam on the lower Columbia River, Brilliant and West Kootenay Power dams on the Kootenay River, and Seven Mile, Libby, and other dams on the Pend d'Oreille River. All of these operations have the potential to contribute to fluctuating water levels and elevated levels of dissolved gases. Additionally, changes in streamflows can influence the concentrations of chemicals of potential concern (COPCs) in the water column (i.e., by reducing dilution);

- Both historic and present discharges of toxic substances (including heavy metals and chlorinated substances) into receiving waters from the Cominco Ltd. lead-zinc smelter at Trail, the Celgar pulpmill at Castlegar, municipal wastewater treatment plants, and various sources in the United States (i.e., within the Pend d’Oreille River and Kootenay River basins). In addition, gaps in the understanding of the relationships between sources, environmental fate, and effects was identified as an issue;

- The effects of TGP/TDG on fish and other aquatic organisms;

- The effects of historic water management decisions on our ability to optimize the use of aquatic resources (i.e., dam construction and historic releases of COPCs);

- The effects of temperature changes (i.e., associated with flow alteration and climate change) on aquatic organisms;

- The communication gap between industries, government agencies, communities;
- Losses of nutrients and turbidity due to hydro construction and operations;
- Maintenance of healthy and productive traditional and recreational fisheries;
- Status of Columbia River white sturgeon;
- Lack of effort on the assessment and management of the cumulative effects of multiple disturbance activities. Top predators (osprey, mink, otter) were considered to be particularly susceptible to cumulative effects; and,
- A number of administrative and technical issues are impeding progress on the transition toward ecosystem-based management, including geographic boundaries, selection of measurement endpoint or detecting effects, limitations on budgets, political (social) limitations that may preclude adequate protection, and enforcement and monitoring of the river may not be sufficient.

5.3 Vision Statement

During the recent CEA Scoping Workshop, the CRIEMP Committee articulated its long-term vision for the future of the lower Columbia River basin, as follows:

> *"Our vision of the lower Columbia River embodies a productive ecosystem that enhances the natural aquatic and terrestrial environments and balances these values with human-based values (economic, traditional, cultural, recreational, social, aesthetic, and health). The vision recognizes existing constraints which are a result of historical decisions. A collaborative integrated monitoring approach to accurately understand and communicate the status and changes in the ecosystem is the role of CRIEMP."*

Importantly, the CRIEMP Committee also developed a set of guiding principles for activities that are undertaken under CRIEMP II. These guiding principles or objectives are presented in Section 1 of this report.

5.4 Ecosystem Goals

Ecosystem goals are broad narrative statements that define the management priorities that are established for a specific ecosystem. Definition of management goals for the aquatic ecosystem is a fundamental step in support of a long-term vision and for developing strategies that will maximize the opportunities for achieving that vision. Ecosystem goals that are developed for the lower Columbia River need to reflect societal values and public concerns related to the ecosystem.

During the CEA Scoping Workshop, participants developed the following ecosystem goals for the lower Columbia River:

- Maintain a productive and diverse aquatic ecosystem that supports the uses of aquatic resources by humans and aquatic-dependent wildlife;
- Protect drinking water supplies;
- Protect aquatic and aquatic-dependent resources to ensure that traditional culture and lifestyles are preserved; and,
- Decisions regarding the management of aquatic and aquatic-dependent resources in the Columbia River basin should not compromise the ability of future generations to meet their needs, considering at minimum, the next seven generations.

5.5 Ecosystem Objectives

To be useful for monitoring purposes, these ecosystem goals need to be further clarified and refined to establish ecosystem objectives that are linked more closely to measurable monitoring parameters. In turn, such ecosystem objectives can support the identification of CEIs, which provide important information for evaluating the integrity of the ecosystem, as a whole.

During the CEA Scoping Workshop, participants developed the following ecosystem objectives for the lower Columbia River:

- E01 - The aquatic, riparian, and wetland resources within the lower Columbia River should be of sufficient quality and quantity to support productive, diverse, and self-sustaining communities of aquatic organisms and aquatic-dependent wildlife;
- E02 - The aquatic, riparian, and wetland resources within the lower Columbia River should be of sufficient quality and quantity to support recreational and aesthetic uses;
- E03 - The productivity and diversity of aquatic organisms should be consistent with current and future fisheries management goals and objectives;
- E04 - The Columbia River should be of sufficient quality and quantity to provide potable water supplies to users in the lower Columbia River and downstream areas;
- E05 - The aquatic and aquatic-dependent resources within the Columbia River basin should be of sufficient quality and quantity to support traditional cultures and subsistence lifestyles; and,
- E06 - Multiple uses of aquatic resources within the Columbia River basin should be balanced such that unacceptable cumulative effects, as a result of multiple human activities, are minimized and mitigated.

Chapter 6 Prediction of the Cumulative Effects of Multiple Disturbance Activities in the Lower Columbia River Basin

6.0 Introduction

The framework that was presented in Chapter 4 describes the procedures that are recommended for assessing the cumulative effects of multiple disturbance activities in the lower Columbia River basin. Assessment of cumulative environmental effects using the framework involves several steps that link stressors to receptors in the river basin. These steps include: identification of the human activities that could affect the study area; identification of the types and probable locations of the environmental changes that could occur in response to the human activities; identification of the types and probable locations of receptors that could be affected by the environmental changes; identification of the types of ecosystem functions that could be altered by the environmental changes and the locations of such alterations; selection of CEIs from the list of receptors and ecosystem functions that were identified previously; and, implementation of the CEA.

This chapter of the report is intended to present the results of a prospective CEA that was conducted by the CRIEMP Committee at the CEA Scoping Workshop that was convened in September, 2002. More specifically, stressor groups that were identified by the CRIEMP Committee are described. In addition, linkages between each stressor group and key receptor groups are presented. Furthermore, the potential interactions between various stressor groups are illustrated through the development of a series of cumulative effects hypotheses. Finally, candidate indicators of cumulative environmental effects are identified. These CEIs, then, provide the basis for identifying the elements of a CEA monitoring program for the lower Columbia River basin (Chapter 7).

6.1 Stressor Groups in the Lower Columbia River Basin

Participants at the CEA Scoping Workshop recognized that there are a substantial number of human activities that have the potential to adversely affect aquatic ecosystems within the lower Columbia River basin. The environmental issues and concerns that were identified by workshop participants are listed in Chapter 5 of this report. Furthermore, it was recognized that these activities give rise to numerous stressors, each of which has the potential to cause or substantially contribute to adverse effects on the aquatic ecosystem and/or its uses. Rather than address each of these stressors individually, the workshop participants elected to identify a series of stressor groups to simplify the process of establishing linkages between stressors and receptors.

A total of five stressor groups were identified in the lower Columbia River basin by clustering the issues and concerns that were presented in Chapter 5, including:

- Aquatic Contamination;
- Flow Regulation;
- Climate Change;
- Introduced Species (e.g., walleye); and,
- Land Use Change.

In the lower Columbia River basin, aquatic contamination can arise from numerous sources (Figure 6.1). First, there are two large industrial developments (i.e., Celgar and Cominco) that release or have released toxic and/or bioaccumulative substances into the river. In addition, discharges from municipal sewage treatment plants (STPs) and from stormwater runoff have released a variety of COPCs into the lower Columbia River and/or its tributaries. Receiving waters in the basin have also been contaminated by a number of non-point sources (NPS), such as agriculture, mining, and forestry. Hydropower operations also have the potential to release certain COPCs into the river. Other potential sources of toxic and bioaccumulative substances include long range transport of atmospheric pollutants (e.g., persistent organic pollutants) and historical releases of persistent COPCs into the river system. Together, these sources give rise to four classes of COPCs, including toxic substances that partition into air, toxic substances that partition into water, toxic substances that partition into sediments, and bioaccumulative substances (Figure 6.1). To facilitate the

CEA, these stressors were combined into a single stressor group, which was termed aquatic contaminants.

Hydropower construction and operations can also give rise to a number of stressors on the aquatic ecosystem (Figure 6.2). More specifically, the construction of hydropower facilities can result in streamflow alterations, changes in nutrient dynamics, and the establishment of physical barriers to migration. Operation of hydropower facilities can also alter streamflows on daily or seasonal bases, increase the levels of dissolved gases in water (i.e., TDG, TGP), alter the temperature regime of stream systems, and entrain organisms during power production. Collectively, these stressors have been grouped together under the stressor group of flow regulation.

The term climate change describes a complex array of processes that alter climate patterns at the global level. In general, these processes result in the release of greenhouse gases (e.g., carbon dioxide) into the atmosphere. The accumulation of such gases in the atmosphere tends to increase the retention of energy from the sun and, in so doing, alter climate patterns. For the Columbia River basin, climatologists have predicted cooler, drier summers and warmer, wetter winters. In turn, these climatic changes have the potential to alter stream hydrology, specifically by decreasing water levels and flows during the summer and fall, increasing water levels and flows during the winter, increasing the variability in water levels and flow, and decreasing flood frequency (Figure 6.3). Collectively, these stressors on the aquatic ecosystem have been grouped together under the stressor group of climate change.

A wide variety of non-native species have been introduced to the lower Columbia River and/or its tributaries (Figure 6.4). Some of these species, such as Gerrard rainbow trout, walleye, brook trout, and tiger muskies, have been introduced to enhance recreational fishing opportunities, while other species have been introduced accidentally (e.g., eurasian milfoil, purple loosestrife). Introduced species posed a threat to aquatic ecosystems because they can out-complete and displace native species, thereby altering the structure and/or functioning of these systems. Accordingly, these and other introduced species are considered to be stressors on the aquatic ecosystem. This group of stressors is termed introduced species for the purposes of CEA in the lower Columbia River basin.

There are a variety of human activities that can result in changes in the use of lands in riparian and/or upland areas, and, in so doing, create stresses on aquatic ecosystems (Figure

6.5). For example, linear developments, such as road building and construction of rights-of-way for power lines, can alter the physical characteristics of stream systems. Certain forest management practices, such as timber harvesting and prescribed burning, result in the removal of forest cover and associated exposure of the underlying soils. Similarly, forest cover is often removed as a result of agricultural practices, urban development, and mining. Accelerated runoff and erosion are two effects that are frequently observed when forest soils are exposed to the elements, both of which can cause stresses on aquatic ecosystems. Collectively, these stressors on the aquatic ecosystem have been grouped together under the stressor group land use change.

6.2 Linkages Between Stressor Groups and Receptors in the Lower Columbia River Basin

Participants at the CEA Scoping Workshop recognized that selection of the most effective CEIs necessitates a clear understanding of the types of physical and chemical changes that are likely to be associated with various disturbance activities (i.e., stressor groups). For this reason, workshop participants endeavoured to illustrate these linkages through the preparation of linkage diagrams (Figures 6.1 to 6.5). These diagrams describe the physical and chemical changes that are likely to be associated with each of the five stressor groups. In addition, the linkage diagrams illustrate which receptor groups (e.g., benthic invertebrate community) are likely to be most severely affected by each stressor group, as well as the type of adverse effects that could occur in response to such changes in the physical or chemical characteristics of the aquatic ecosystem.

A wide range of receptor groups could be adversely affected by releases of COPCs into the environment within the lower Columbia River basin. For the toxic substances that are released into air, wildlife and humans were identified as the receptors at risk. By comparison, aquatic plants, aquatic invertebrates, and fish were identified as the key receptor groups that could be adversely affected by releases of toxic substances that partition into water. For toxic substances that partition into sediments, benthic invertebrates and benthic fish were identified as the most important receptor groups in the lower Columbia River basin. Finally, benthic invertebrates, benthic fish, aquatic-dependent wildlife, and humans were considered to be the receptor groups at greatest risk due to releases of bioaccumulative substances into the environment. Some of the adverse effects that could occur on these receptor groups in response to exposure to COPCs include decreased survival, growth, and reproduction, increased susceptibility to disease, increased incidence of genotoxic, mutatoxic, or teratogenic effects, changes in community structure, decreased abundance of focal species, changes in behaviour, and increased frequency of fish consumption advisories (Figure 6.1).

The construction and operation of hydropower facilities has the potential to alter a variety of physical and chemical characteristics of aquatic ecosystems. Some of the physical changes that are often observed include changes in the seasonal hydrograph, increased variability in streamflows, changes in water temperature regimes, increased levels of total dissolved gases, alteration of nutrient dynamics, and the establishment of barriers to migration. In turn, these physical and chemical alterations have the potential to adversely affect several aquatic receptor groups, including aquatic plants, aquatic invertebrates, fish. Some of the adverse effects that could occur in response to alterations in the physical and/or chemical characteristics of the aquatic ecosystem include changes in the structure of aquatic communities and reduced abundance of focal species. In turn, reductions in the availability of fish or other aquatic organisms can adversely affect aquatic-dependent wildlife and humans, both from a cultural and recreational perspective (Figure 6.2).

The processes that are associated with climate change are likely to result primarily in changes to the physical characteristics of the aquatic ecosystem. More specifically, the types of physical changes that could occur in response to climatic changes include alteration of the stream flow regime (i.e., annual hydrograph), increased variability in streamflow, reduction of the frequency of flooding, and changes in the temperature regime. In turn, these physical changes can adversely affect the biological components of the aquatic ecosystem by stranding fish eggs or fry, increasing drift rates for benthic invertebrates, changing riparian plant communities, decreasing the quality of streambed substrates (which results in lower benthic productivity and lower egg-to-fry survival rates for fish), increased mortality of fish, and increased productivity of aquatic plants. Therefore, the key receptor groups that could be affected by climate change include aquatic and riparian plants, benthic invertebrates, and fish.

In contrast to the other stressor groups, introduced species generally do not cause changes in the physical or chemical characteristics of aquatic ecosystems (i.e., with the exception of carp that can increase turbidity in the side channel habitats that they prefer). Rather, introduced species can adversely affect native species through direct competition for food resources or habitats. In addition, certain introduced species represent effective predators, particularly on the juvenile life stages of native species. As a result, proliferation of introduced species can reduce the survival, growth, and reproduction of indigenous species. In some cases (e.g., walleye), introduced species may be more effective at accumulating bioaccumulative COPCs into their tissues (i.e., by being top predators) and, in so doing, pose risks to aquatic-dependent wildlife or human health. Accordingly, the receptors of greatest concern relative to non-native species introductions are native fish species (Figure 6.4).

Changes in land use can result in a variety of physical and chemical changes in aquatic ecosystems (Figure 6.5). Some of the effects that are commonly observed in response to land use changes include loss of wetland habitats, changes in channel morphology, alteration of hydrological conditions (i.e., increased peak flows and decreased low flows), increased levels of total suspended solids (TSS), water quality degradation (i.e., increases in loadings of nutrients, metals, and microorganisms), and decreased streambed substrate quality loadings. In turn, these physical and chemical alterations can adversely affect aquatic plants, benthic invertebrates, fish, and aquatic-dependent wildlife. The types of effects that are commonly observed in these receptors include decreased primary and secondary production, decreased survival, growth and reproduction of fish, and changes in fish behaviour. These effects are most likely to be observed in the tributaries to the lower Columbia River.

6.3 Potential Interactions Among Stressor Groups in the Lower Columbia River Basin

The linkage diagrams that were developed for each of the stressor groups (i.e., Figures 6.1 to 6.5) provide a basis for identifying the receptors that are likely to be adversely affected in response to exposure to these stressors individually. However, such linkage diagrams do not provide a basis for identifying the effects that could occur in response to multiple stressor challenges. For this reason, it is necessary to consider the combined effects of multiple stressors on individual receptor groups to support an assessment of the cumulative environmental effects.

In this analysis of cumulative effects in the lower Columbia River basin, the participants at the CEA Scoping Workshop evaluated the potential effects of multiple stressors on key receptor groups using a simplified version of the interactive matrices approach. Briefly, this approach involved considering how two or more stressor groups, when acting together, could exacerbate changes in the physical and/or chemical characteristics of the aquatic ecosystem. In turn, this information was used to develop cumulative effects hypotheses, that can be used to identify the receptor groups that are most likely to be affected and the effects that are most likely to be observed in response to the noted physical and/or chemical alterations of the aquatic ecosystem (Table 6.1).

There are a total of ten 2-way interactions between the five stressor groups (Table 6.1). This matrix depicts the combined effect of stressor ***X*** on stressor ***Y***, as well as stressor ***Y*** on stressor ***X***. These interactions are further developed below and serve as the basis for generating cumulative effects linkage diagrams. Each cumulative effect depicted below is presented in the form of a linkage diagram and is summarized by a cumulative effect hypothesis. Key linkages are evaluated and classified into one of three categories: likely, unlikely, and uncertain.

6.3.1 Flow Regulation - Contamination Interaction

Cumulative Effects Hypothesis 1: Interactions between flow regulation and aquatic contamination are likely to cause cumulative effects on aquatic plants, aquatic invertebrates and fish in the lower Columbia River basin. Aquatic-dependent wildlife and/or human health could also be adversely affected if bioaccumulative COPCs increase in the aquatic ecosystem as a result of changes in flow regulation.

> *Rationale:* The construction and operation of hydropower developments have the potential to degrade water quality conditions in several ways. First, these developments can result in direct releases of COPCs into the aquatic environment (e.g., TSS, TDG, etc.). In addition, these developments can alter streamflow conditions in the system. Under extreme low flow conditions, these streamflow alterations can also reduce the assimilative capacity of the receiving water system and, in so doing, result in increased concentrations of water-borne COPCs. Furthermore, increases in water temperature associated with low flow conditions can increase the toxicity of the COPCs that are released from other sources. Finally, extreme high flows can result in the mobilization

of COPCs that had been released historically (e.g., fiber mat near Celgar or slag near Cominco). Therefore, the combined effects of flow regulation and aquatic contamination would tend to exacerbate the effects that are associated with aquatic contamination (Figure 6.6).

This hypothesis is of high priority to evaluate because the interaction between the two stressors is highly relevant, there is a strong linkage to CEIs, and the resulting information on CEs can be used to support management decisions.

6.3.2 Contamination – Climate Change Interaction

Cumulative Effect Hypothesis 2: Interactions between aquatic contamination and climate change are likely to cause cumulative effects on aquatic plants, aquatic invertebrates, and fish in the lower Columbia River basin. Aquatic-dependent wildlife and/or human health could also be adversely affected if bioaccumulative COPCs are increasingly mobilized in the aquatic ecosystem.

Rationale: Climate change has the potential to alter stream hydrology in the lower Columbia River basin. Reductions in streamflow and increases in water temperature have the potential to exacerbate the effects of aquatic contamination by reducing assimilative capacity (i.e., dilution) and increasing the toxicity of water-borne contaminants. In addition, climate change could result in increased concentrations of certain COPCs in receiving water systems by releasing the persistent organic pollutants that are currently sequestered in glaciers or high elevation snow pack and increasing the potential for erosion (i.e., increasing TSS levels). Therefore, the combined effects of climate change and aquatic contamination would tend to exacerbate the effects that are associated with aquatic contamination (Figure 6.7).

This hypothesis is of high priority to evaluate because the interaction between the two stressors is highly relevant, there is a strong linkage to CEIs, and the resulting information on CEs can be used to support management decisions.

6.3.3 Contamination – Introduced Species Interaction

***Cumulative Effect Hypothesis 3*:** Interactions between aquatic contamination and introduced species could result in cumulative effects on aquatic-dependent wildlife or human health in the lower Columbia River basin.

> *Rationale:* Releases of bioaccumulative substances have resulted in the accumulation of the COPCs in the tissues of aquatic organisms. In the past, the concentrations of certain COPCs, such as mercury and polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans (PCDDs/PCDFs), in fish tissues have reached levels of concern with respect to human health and, hence, the issuance of fish consumption advisories. Although reductions in contaminant loadings in recent years have resulted in lower levels of tissue-associated COPCs, certain recently introduced species, such as tiger muskies, represent top predators in the aquatic food web (Figure 6.8). As a result, the concentrations of bioaccumulative COPCs in their tissues could reach levels of concern with respect to human health or aquatic-dependent wildlife (e.g., otters), particularly if they prey upon walleye or mountain whitefish (i.e., for which previous fish consumption advisories were issued). While such interactive effects between aquatic contamination and introduced species are possible, they are unlikely to occur in the lower Columbia River because loadings of bioaccumulative COPCs have been decreasing and because tiger muskies have not yet reached the lower Columbia River.

This hypothesis is of low priority to evaluate because the interaction between the two stressors is weak.

6.3.4 Land Use Change – Contamination Interaction

Cumulative Effect Hypothesis 4: Interactions between land use changes and aquatic contamination are likely to cause cumulative effects on aquatic plants, aquatic invertebrates and fish in the lower Columbia River basin, particularly in the tributaries.

> *Rationale:* Land use changes have the potential to influence contaminant concentrations in several ways (Figure 6.9). First, land use changes can increase the loadings of certain COPCs to receiving waters (e.g., TSS). In addition, land use changes can result in the discharge of other COPCs into aquatic ecosystems (e.g., pesticides, herbicides,

fungicides). Increases in COPC loadings and the interactive (i.e., synergistic or additive) effects of multiple COPCs are likely to adversely affect a variety of aquatic receptors, including aquatic plants, aquatic invertebrates, and fish, especially in the smaller tributaries.

This hypothesis is of high priority to evaluate because the interaction between the two stressors is highly relevant, there is a strong linkage to CEIs, and the resulting information on CEs can be used to support management decisions.

6.3.5 Flow Regulation – Climate Change Interaction

Cumulative Effect Hypothesis 5: Interactions between flow regulation and climate change are likely to cause cumulative effects on aquatic plants, aquatic invertebrates, and fish in the lower Columbia River basin.

Rationale: The effects of flow regulation on aquatic organisms has been well documented in the scientific literature (e.g., R.L.&L. Environmental Services Ltd. 2001). Climate change will exacerbate these effects by altering precipitation patterns in the basin (Figure 6.10). In turn, such changes in the volume and timing of water that is delivered to the Columbia River and its tributaries may necessitate changes in the operation of hydropower facilities. As a result, streamflows are likely to increase during the winter and decrease during the summer. In addition, short-term variability in streamflows is likely to increase. Such changes in stream hydrology and the associated water temperature regime will result in increases in the magnitude and duration of adverse effects on fish and other aquatic organisms. Importantly, the frequency of such effects is also likely to increase, providing aquatic receptors with fewer opportunities to recover from previous events.

This hypothesis is of lower priority to evaluate because the interaction between the two stressors is weak, the linkage to the CEIs is uncertain, and the types of management decisions that could be taken are difficult to define.

6.3.6 Flow Regulation – Introduced Species Interaction

Cumulative Effect Hypothesis 6: Interactions between flow regulation and introduced species are likely to cause cumulative effects on native fish species in the lower Columbia River basin.

> *Rationale:* Flow regulation tends to create relatively high winter flows and low summer flows in the lower Columbia River (Figure 6.11). Water temperature regimes can also be altered as a result of flow regulation. In turn, these changes in stream hydrology and water temperatures result in habitat alterations that are advantageous to species that are adapted to slower flowing water and less extreme discharge fluctuations than would occur in the absence of flow regulation. Because a number of introduced species are adapted to such conditions (e.g., eurasian milfoil, carp), interactions between flow regulation and introduced species could adversely affect native species of fish (i.e., carp could replace suckers) and, to a lesser extent, other aquatic organisms in the lower Columbia River basin.

This hypothesis is of lower priority to evaluate because the interaction between the two stressors is weak and the types of management decisions that could be taken are difficult to define. The linkage to the CEIs is strong, however.

6.3.7 Land Use Change – Flow Regulation Interaction

Cumulative Effect Hypothesis 7: Interactions between flow regulation and land use changes have the potential to cause cumulative effects on fish and other aquatic organisms in the lower Columbia River basin.

> *Rationale:* As was indicated previously, the effects of flow regulation on aquatic organisms have been well documented in the scientific literature and are most relevant to those species that utilize habitats within the lower Columbia River mainstem (e.g., R.L.&L. Environmental Services Ltd. 2001). In contrast, changes in land use are more likely to affect those species that use habitats in the tributaries for all or a portion of their life history. In addition to affecting the physical and/or chemical characteristics of tributaries to the lower Columbia River, land use changes degrade water quality conditions in the mainstem (i.e., through accelerated sediment transport associated with

deforestation). When combined with decreased streamflows and flood frequency, such changes can alter critical habitats (i.e., reduce streambed substrate quality in critical spawning habitats) in the vicinity of the tributary mouths (e.g., Norns Creek fan) and, in so doing, adversely affect fish and other aquatic organisms in the lower Columbia River basin (Figure 6.12). In some cases, such habitat alterations could favour introduced species.

This hypothesis is of low priority to evaluate because the interaction between the two stressors is weak.

6.3.8 Climate Change – Introduced Species Interaction

Cumulative Effect Hypothesis 8: Interactions between climate change and introduced species are likely to cause cumulative effects on native fish species in the lower Columbia River basin.

Rationale: As was the case for flow regulation, climate change is predicted to result in relatively high winter flows and low summer flows in the lower Columbia River (Figure 6.13). Water temperature regimes can also be expected to increase in response to climate change. In turn, these changes in stream hydrology and water temperatures result in habitat alterations that are advantageous to species that are adapted to slower flowing water and to less extreme discharge fluctuations. Because a number of introduced species are adapted to such conditions (e.g., eurasian milfoil, carp), interactions between climate change and introduced species could adversely affect native species of fish and, to a lesser extent, other aquatic organisms in the lower Columbia River basin.

This hypothesis is of moderate priority to evaluate because the interaction between the two stressors is strong and there is a strong linkage to the CEIs. The management actions that could be taken to mitigate such CEs are uncertain, however.

6.3.9 Land Use Change – Climate Change Interaction

Cumulative Effect Hypothesis 9: Interactions between climate change and land use changes have the potential to cause cumulative effects on fish and other aquatic organisms in the lower Columbia River basin, particularly in the tributaries to the lower Columbia River.

> *Rationale:* As was the case for flow regulation, climate change is predicted to result in relatively high winter flows and low summer flows in the lower Columbia River mainstem and its tributaries. Stream temperatures are also expected to change in response to an altered climate signal. The types of effects that are associated with these changes in the physical characteristics of aquatic ecosystems are summarized in Figure 6.3. Changes in land use can also influence habitat conditions through alteration of the timing and magnitude of extreme high and low flow events in the tributaries to the lower Columbia River. Therefore, the cumulative effects of climate change and land use can result in changes in stream hydrology and associated effects of the quality and quantity of habitat in tributary streams. Such physical effects will likely affect the carrying capacity of these streams and, in so doing, the structure and functioning of aquatic plant, benthic invertebrate, and fish communities (Figure 6.14).

This hypothesis is of high priority to evaluate because the interaction between the two stressors is highly relevant, there is a strong linkage to CEIs, and the resulting information on CEs can be used to support management decisions.

6.3.10 Land Use Change – Introduced Species Interaction

Cumulative Effect Hypothesis 10: Interactions between land use changes and introduced species have the potential to cause cumulative effects on fish and other aquatic organisms in the lower Columbia River basin.

> *Rationale:* As indicated previously, land use changes have the potential to alter the physical and chemical characteristics of aquatic ecosystems, particularly in the tributaries to the lower Columbia River mainstem. Such changes in flow regime and/or water temperatures could favour introduced species that utilize aquatic or riparian habitats in these systems.

This hypothesis is of low priority to evaluate because the interaction between the two stressors is weak, the linkages to the CEIs are weak, and the management actions that could be taken to mitigate CEs are uncertain.

6.3.11 Multi-Way Interactions

In addition to the 2-way interactions described in Sections 6.3.1 to 6.3.10, there are a series of possible 3-way and a single 4-way interaction between the 5 stressor groups. Since many of the 2-way interactions are uncertain, Occam's razor (law of parsimony) implies that highest priority attention should be directed towards the 2-way interactions.

6.4 Identification of Candidate Cumulative Effects Assessment Indicators

The ecosystem objectives that have been recommended (Section 5.5) are narrative statements that are intended to reflect and focus the ecosystem goals for the lower Columbia River basin. However, it is not possible to measure attainment of these objectives directly. For this reason, implementation of ecosystem-based management in the lower Columbia River basin, including CEM, necessitates the development of physical, chemical, and biological indicators which will provide more direct measurements of the most important attributes of the ecosystem.

The term '**indicator**' is used in a variety of environmental applications and is, generally, defined as a feature of the environment which provides managerially and scientifically useful information on the quality of the ecosystem as a whole. If measurements of these attributes (i.e., metrics) fall within acceptable bounds (i.e., targets), it is assumed that the ecosystem as a whole is being protected. In the lower Columbia River basin, prevention of cumulative environmental effects has been identified as an ecosystem management priority because residents are highly dependent on aquatic and riparian resources. For this reason, specific indicators, termed '**cumulative effects indicators (CEIs)**,' will be developed to support the design of a CEM program for the lower Columbia River basin. In this study, CEIs are defined as components of aquatic and riparian ecosystems which provide information on the cumulative effects of multiple disturbance activities on the ecosystem as a whole (e.g., indicator species).

In the context of this study, CEIs are required to provide timely information on the integrity of aquatic and riparian ecosystems relative to existing and future developmental activities in the basin. In this application, it is essential that the suite of indicators be selected to facilitate the identification of adverse environmental conditions ***before*** significant impacts occur on the structure or function of the ecosystem. The monitoring data that will be collected on the status of the CEIs will provide a basis for assessing trends in environmental quality and determining if the long-term goals and objectives for the ecosystem are being met.

At the recent CEA Scoping Workshop, participants were asked to identify the physical, chemical, and biological indicators that could be used to assess the cumulative effects of multiple disturbance activities in the lower Columbia River basin. Based on the results of the various assessments of interactions among stressor groups (Section 6.3.1 to 6.3.10) and an in-depth understanding of the other types of developmental activities that are either occurring or could occur in the basin, workshop participants identified a wide variety of candidate CEIs that could be employed in the lower Columbia River basin. From this list of candidate CEIs, the types (or classes) of CEIs that should be considered for inclusion in a CEM program for the lower Columbia River basin were identified and included:

- Aquatic plant community;
- Riparian plant community;
- Benthic invertebrate community;
- Fish community;
- Aquatic-dependent wildlife community;
- Fish health;
- Health of aquatic-dependent wildlife;
- Hydrology;
- Water chemistry;
- Physical characteristics of water;

- Sediment chemistry;
- Tissue chemistry;
- Aquatic habitat; and,
- Climate.

These CEIs, then, provide a basis for developing a CEM program for the lower Columbia River basin. The key elements of such a monitoring program are described in Chapter 7.

Chapter 7 Development of a Cumulative Effects Monitoring Program for the Lower Columbia River Basin

7.0 Introduction

Design and implementation of an ongoing CEM program are essential steps in the overall CEA process. To facilitate this step in the process, participants at a recent CEA Scoping Workshop identified five stressor groups that could work interactively to produce cumulative environmental effects in the lower Columbia River basin. In addition, the linkages were identified between these stressor groups and receptor groups in the basin. Subsequently, a series of cumulative effect hypotheses and linkage diagrams were prepared that describe the potential interactive effects between pairs of stressor groups (see Section 6.3) . Thereafter, a list of cumulative effect indicators were identified that correspond with the cumulative effects hypotheses (see Section 6.4).

Following the identification of the key classes of CEIs, workshop participants endeavoured to integrate the results of previous discussions in a way that would facilitate the identification of the essential elements of a CEM program. To facilitate this process, the members of the CRIEMP Committee were asked to consider the following four questions to support the identification of the key elements of a CEM program:

- What are the physical indicators that have the greatest potential to be affected by multiple land and/or water use activities?
- What are the variables (metrics) that should be measured to assess the status of each physical indicator?
- In which geographical areas are such alterations most likely to occur?
- At which times of the year are such alterations most likely to occur?

Thereafter, participants undertook parallel exercises to consider chemical indicators, as well as biological indicators.

This chapter is intended to present the results of the CEM program design work that was undertaken at the CEA Scoping Workshop. More specifically, key considerations for CEM are discussed. In addition, the essential elements of a CEM program for the lower Columbia River basin are identified. Finally, the next steps in the CEM program design process are recommended.

7.1 Considerations in Cumulative Effects Monitoring

Workshop participants identified a number of overarching considerations that must be taken into account during the design of a CEM program in the lower Columbia River basin, as follows:

- It is anticipated that several types of monitoring programs will be implemented in the lower Columbia River basin to assess the effects of developmental activities. First, EEM will be conducted in the immediate vicinity of developmental activities (i.e., pulp mill and smelting sites) in the watershed. The information generated in such programs will be critically important for evaluating the localized effects of these activities. In addition, federal/provincial and other routine monitoring programs will be conducted to assess the status and trends of key environmental characteristics in the basin. Furthermore, CEM will be conducted at selected locations throughout the watershed. The information generated from this type of monitoring program will be used to assess the broader effects of human activities on ecosystem integrity. To be effective and efficient, these three types of monitoring programs need to be closely linked.

- There is a need to establish regional reference areas in the basin. There will also be a need to sample at multiple reference sites in order to obtain sufficient baseline data in the areas that could be targeted for developmental activities in the future.

- The data collected at the regional reference sites will augment the information that is generated by baseline monitoring programs (i.e., EEM) in the areas that are being affected by regional developments in the watershed.

- It is important to consider both the concentrations of contaminants in environmental media (i.e., water, sediment, and biota) and the loadings of contaminants into aquatic ecosystems when assessing cumulative environmental effects. In addition, it is important to be able to quantify both natural and anthropogenic loadings of contaminants.

- Understanding the hydrology of the system is essential for understanding the fate and effects of environmental contaminants in the watershed.

- It is important to identify good indicators of cumulative effects at the outset of the monitoring program design process. This will facilitate the inclusion of good accumulators of change into the program, even if we are unable to identify clear linkages right now. Inclusion of such indicators in the monitoring program may enable us to detect unexpected changes that would otherwise go unnoticed.

7.2 Components of the Cumulative Effects Monitoring Program

Workshop participants recognized that the development of a CEM program would be an iterative process, with implementation taking place over several years. Nevertheless, it is possible to identify the core elements of a CEM program for the lower Columbia River basin with the information that is currently available. The following monitoring program elements were identified as essential by workshop participants:

- **Climate Monitoring** - It was recommended that ground level climate data be collected at a variety of locations in the watershed. It was recommended that Class A station data be collected at each of the monitoring sites in the basin. Key variables that should be monitored include air temperature, precipitation (including form, quantity, and quality), and snow surveys (i.e., at multiple sites and at frequencies of greater than once per month).

- **Hydrological Monitoring** - It was recommended that a hydrometric program be implemented at a number of sites within the lower Columbia River basin (Table 7.1). In addition to the variables that are traditionally included in hydrometric programs, it was recommended that water temperature, sediment transport and deposition rates be measured at these locations. It was recognized that extreme events have the potential to cause significant changes in the biological components of the ecosystem. For this reason, quantification of extreme events was identified as a key component of the monitoring program.

- **Aquatic Habitat Monitoring** - Because the physical characteristics of aquatic habitats can change in response to multiple disturbance activities, stream morphology and habitat diversity were identified as key metrics for including in the CEM program (Table 7.1).

- **Water Quality Monitoring** - Water quality monitoring was identified as an important element of the CEM program (Table 7.2). It was agreed that a standard suite of water quality variables should be included in the program, including conventional variables (i.e., pH, major ions, dissolved organic carbon, alkalinity, conductivity, etc.), dissolved oxygen, nutrients, trace metals (dissolved and total), suspended solids, and turbidity, microbiological variables, oils, lubricants, and hydrocarbons (i.e., total petroleum hydrocarbons). Suggested monitoring locations and frequencies are listed in Table 7.2).

- **Sediment Quality Monitoring** - Sediment chemistry was identified as a key indicator of sediment quality conditions in the lower Columbia River basin. Several variables were recommended for inclusion in the sediment quality monitoring program, including the physical characteristics of bed sediments (i.e., calcium, magnesium, particle size distribution, TOC, acid volatile sulphides) and sediment chemistry (primarily total metals and simultaneously extracted metals). In addition, the recommended metrics for sediment chemistry included trace metals, mercury, methyl mercury, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides (OC pesticides), PCDDs and PCDFs, chlorophenols, toxaphene, and endocrine disrupting compounds. It was further recommended that certain evaluations of bioavailability (e.g., bioaccumulation tests) also be included in the monitoring program (Table 7.2).

- **Tissue Monitoring** - Because the interactive effects of multiple stressor groups have the potential to result in elevated levels of bioaccumulation, tissue chemistry was identified as a key element of the CEM program for the lower Columbia River basin. The key metrics that were identified included trace metals, mercury, and organic COPCs [i.e., organochlorines (OCs), PCBs, polybrominated diphenyl ethers (PBDEs), toxaphene, endocrine disrupting chemicals (EDCs), and PCDDs/PCDFs in fish and invertebrate tissues (Table 7.2]. Mercury in otter, raccoons, and human hair was also considered to be important metrics.

- **Biological Monitoring** - Workshop participants generally agreed that biological monitoring would represent an essential element of a CEM program for the lower Columbia River basin. In particular, information needs to be collected to assess the status of aquatic plant, benthic invertebrate, fish, riparian plant, and aquatic-dependent wildlife communities. The selected metrics for each of these indicators are presented in Table 7.3. In addition, it was recommended that fish health be assessed to evaluate the effects of multiple disturbance activities (Table 7.3).

7.3 Selection of Targets for Assessing Cumulative Effects

A wide variety of CEIs and associated metrics were identified for inclusion in the CEM program for the lower Columbia River basin (see Tables 7.1 to 7.3). While the data collected on each of the selected metrics can be used alone to evaluate trends in environmental quality conditions, it is difficult to assess cumulative effects without information that defines acceptable ranges for each of these metrics. For this reason, the identification of targets represents a key element of the CEM program development process.

There are two main approaches to the definition of targets for the metrics that have been selected for inclusion in the lower Columbia River basin CEM program (Table 7.1 to 7.3). First, environmental quality objectives can be established using the procedures that have been developed by the Canadian Council of Ministers of the Environment (MacDonald *et al.* 2002) and the BCMWLAP (BCMOE 1984). Alternatively, acceptable ranges for certain metrics can be established from the results of monitoring activities (i.e., by establishing baseline conditions and/or reference conditions). In either case, cumulative effects are identified based on the results analyses that demonstrate statistically significant departures from the environmental quality objective or the baseline conditions. Again, the ecosystem goals and objectives are considered to be met if the measured value of each metric falls within the target range (i.e., no cumulative effects are identified).

7.4 Selection of Sites and Monitoring Frequencies for Cumulative Effects Monitoring

Workshop participants recognized that there are a number of sources of variability in environmental data that need to be accounted for in the design of the CEM program. These sources include the natural variability within a sub-basin that is associated with differences in environmental conditions over space (e.g., increased gradient in headwater areas), variability within a sub-basin over time due to activities that are conducted within the area (e.g., mining activities), variability within a sub-basin over time due to activities that are external to the watershed (e.g., global climate change), natural variability between sub-basins due to differences in underlying environmental conditions, and variability between sub-basins due to differences in the nature and extent of disturbance activities. In other words, conditions in a sub-basin can change over space and/or time and these changes can result from either natural factors or anthropogenic activities. To be effective, CEM programs need to provide information that enables investigators to distinguish among the various types of variability and thereby determine if cumulative environmental effects are occurring within a watershed.

Workshop participants indicated that two types of sampling sites need to be established to support long-term CEM in the lower Columbia River basin. First, cumulative effects sampling sites need to be established to collect data on the status and trends of the CEIs that are included in the monitoring program. In addition, reference sites need to be established to provide the information needed to interpret the data that are collected at the CEM sites. The recommended monitoring locations and sampling frequencies for each of the selected metrics for the CEM program are listed in Tables 7.1 to 7.3.

7.5 Next Steps

Although a substantial amount of progress has been made on the development of a CEM program for the lower Columbia River basin, several important steps need to be completed to facilitate its implementation. First, ongoing environmental monitoring programs in the basin need to be reviewed, along with any programs that are currently being planned. The purpose of this review is to identify elements of the CEM program and to determine if the ongoing monitoring is appropriate for CEA. Upon completion of this review, it should be possible to identify the elements of the CEM program that are already being conducted and those that need to be implemented under CRIEMP CEA initiative.

Second, the existing monitoring data, collected between 1991 and present, should be compiled into a relational database in MS Access format. This data archiving system should be designed to facilitate a broad range of data analyses and should be GIS-compatible. In addition to facilitating the compilation of existing water, sediment, and biological data, this database should be used to capture any new data that are generated to assess the CEs of human activities in the lower Columbia River basin.

Third, the CEM program elements that have been identified by the CRIEMP Committee (i.e., in Tables 7.1 to 7.3) need to be translated into a monitoring program design. Such a design would explicitly identify the sampling locations and sampling timing for each of the metrics that were selected for inclusion in the CEM program. In some cases, power analyses will be required to determine the sampling intensity needed to detect cumulative effects of a specified magnitude (e.g., 10% difference from reference) with a specified level of confidence (e.g., $p<0.1$). The design would also indicate which program elements are being undertaken under existing monitoring programs and under the CRIEMP II initiative.

Fourth, a sampling and analysis plan (SAP) needs to be prepared to address the components of the CEA monitoring program that will be undertaken by the CRIEMP Committee. Such a SAP should include background information on the study area, the objectives of the monitoring program, field sampling methods, sample handling methods, selected provisions for technical oversight and auditing, quality assurance and quality control procedures (i.e., a quality assurance project plan), data validation and quality control methods, data analysis, record keeping and report procedures, health and safety procedures, and the responsibilities of each member of the monitoring team. The SAP will then provide the detailed guidance needed to implement the CEM program.

Fifth, numerical or narrative targets need to be established for each of metrics that were selected for inclusion in the CEM program for the lower Columbia River. As numerical environmental quality objectives have already been established for many metrics (i.e., Butcher 1992; MESL 1997), many of the required targets have already been established. However, there may be a need to update these targets to reflect our current understanding of relationships between concentrations of COPCs and responses of ecological receptors. For other metrics, the results of ongoing and prospective monitoring programs will need to be reviewed to identify baseline conditions. This information on baseline conditions can then be used to establish the normal range of measurements for the metric (e.g., mean $\pm$ 2 standard deviations).

Finally, the results of the CEM program should be applied to assess the cumulative environmental effects of multiple disturbance activities in the lower Columbia River basin. The results of this assessment should be used to identify the management actions that are needed to mitigate or eliminate any cumulative effects that are identified (note: this step would be completed by the CRIEMP II Committee and its member organizations, probably through workshopping and other means). In addition, these results should be used to identify critical data gaps and to design research programs to fill these data gaps. Furthermore, these CEM program results and any other relevant information should be used to refine the program to make it more efficient and effective (i.e., within an adaptive management framework).

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Tables

Table 3.1. Summary of existing approaches to cumulative effects assessment.

Approach / Description	Advantages	Limitations	Reference
Environmental Checklist Approach			
• Provides a means of identifying the possible outcomes of specific activities; • Involves the development of checklists of ecosystem characteristics or processes to identify appropriate indicators and assess environmental effects.	• Highlights potential impacts;	• Qualitative or subjectively quantitative; • Cause and effect is implied only; • Provides no facility for expressing interactions and linkages.	Cocklin *et al.* 1992
Interactive Matrix Approach			
• Involves the construction of matrices of interactions between disturbance activities (listed on the horizontal axis) and environmental conditions (i.e., effects; listed on the vertical axis). Results can range from descriptive to quantitative.	• Incorporates an association between cause and effect; • Relevant for assessing multiple disturbances and interactions.	• The method fails to record the magnitude, structure, or importance of linkages; • Nature and significance of impacts are not identified; • Absence of spatial and temporal resolution.	Williamson *et al.* 1987; Dixon & Montz 1995
Network Analysis (Causal Analysis) Approach			
• Diagraming technique in which tree diagrams represent the relationships between the stressor, the primary effects, and the higher-order effects; • Conditional probabilities may be assigned to the branches of the network to support quantitative assessments.	• Networks represent cause-effect sequences.	• Feedback linkages are not explicitly accounted for, linkages among impacts are not clearly demarcated, and networks do not identify spatial or temporal scales.	Cocklin *et al.* 1992; Smit & Spaling 1995; Spaling & Smit 1995; Stakhiv 1988; Dixon & Montz 1995
Environmental Auditing Approach			
• Based on comparisons between landscape subunits using landscape variables (synoptic indices), including function index, value index, function loss index, and replacement potential index; • Conducted with existing information and professional judgement.	• Provides timely information; • Relies on existing data; • Supports assessment at the landscape scale, with high spatial resolution.	• Not quantitative or rigorous; • Information is lost during the translation of raw data into synoptic indices; • Spatial resolution is relatively low.	Abbruzzese & Leibowitz 1997

Table 3.1. Summary of existing approaches to cumulative effects assessment.

Approach / Description	Advantages	Limitations	Reference
Landscape Perspective (Biogeographical Analysis) Approach			
• Involves three steps, including cataloging the relevant measures of human activities, estimating effects on system attributes (using attribute-action relationships), and estimating changes in system function (using function-attribute relationships).	• Recognizes the underlying complexity of the system; • Addresses temporal and spatial scales.	• Requires a comprehensive regional inventory of detailed data on ecological components and processes; • Data collection is time-consuming and expensive.	Preston and Bedford 1988; Lee and Gosselink 1988; Johnston *et al.* 1990
Spatial Analysis (Geographic Information System) Approach			
• This approach involves superimposition of data on human activities and valued ecosystem components; • It can be used to analyse spatial relationships between stressors and receptors, spatial and temporal trends, and possible future scenarios.	• GIS provides a means of spatially representing data (i.e., at landscape level) and integrating data from many sources, scales, and time periods.	• Causal linkages between stressors and effects are not established; • Does not consider effects on ecosystem functions; • Therefore, GIS must be used together with other approaches in CEA; • Data requirements are extensive.	Cocklin *et al.* 1992; Parker & Cocklin 1993; Johnston *et al.* 1988
Ecological Modelling (Input-Output; Meta-Modelling) Approach			
• Involves the development of dynamic system models; • Originally developed to determine the economic effects of changes in demand for products; • Later used to quantify linkages between the economy and the environment using modelling techniques.	• Models provide a means of predicting effects based on quantitative linkages between stressors and receptors; • Can have high spatial and temporal resolution; • Can consider either structural or functional elements of the system.	• Utility of models is reduced by data limitations, structural features of model (e.g., linear relationships), and an inability to consider effects on multiple receptors; • Requires a detailed understanding of the system under study.	James & Boer 1988; Smit & Spaling 1995; Ziemer *et al.* 1991

Table 5.1. List of abundant, common and fish species at risk in the lower Columbia River.
Source: R.L.&L. Environmental Services Ltd. (2001).

Abundant	Common	At Risk
Rainbow trout	White sturgeon	White sturgeon
Mountain whitefish	Kokanee	Bull trout
Walleye	Pikeminnow (squawfish)	Burbot
Largescale sucker	Longnose dace	Umatilla dace
Redside shiner	Torrent sculpin	Shorthead sculpin
Prickly sculpin	Mottled sculpin	Mottled sculpin

Table 6.1. Matrix illustrating the interactions among stressor groups, and associated physical, chemical, and biological effects, in the lower Columbia River Basin

	Contamination	Hydro Construction and Operations	Climate Change	Introduced Species	Land Use Change
Contamination					

Hydro Construction and Operations	* Dilution
	* Temperature
	* Fate of Contaminants
	  * Movement
	  * Mobilization ↑↓
	* Total gas pressure x Other Contaminants
	* Turbidity x Other Contaminants				

Climate Change	* Release of persistent organic pollutants (Glaciers) * Dilution * Hydro impact * Total suspended solids in tributaries	Change in flow regulation * Winter Flows ↑ * Summer Flows ↓ * Variability ↑ * Adaptive Operations			
Introduced Species	* Bioaccumulation Hg - Walleye * Accumulation Potential - Carp * Change community structure * Plants - fate / uptake of contaminants	* Change in habitat suitability - water clarity * Change in temperature - favours introduced species * Change in species composition * Tolerance to total gas pressure?	* Warm water species ↑ * Cold water species ↓		

Land Use Change	* Change in temperature
	* Urban run-off including sediment
	* Ground water
	* Dilution issues (e.g., sewerage)
	* Agricultural contaminants
	* Pesticide use right of ways's
		* Hydro x Land Use Change Interaction - Critical Habitats
		* Low flow induced change - temp (Celcius)
		* Sediments↑ embedded
		* Temperature change interaction
			* Flow interactions / hydrology
			  * Flashiness
			* Forest fire / insects
			  * Fire retardants / toxicity
			* Weather changes
			* Agriculture changes: More irrigation demand
				* Disturbance favours exotic plants
				* Rip rap (Riparian Zone changes)
				* Temperature increase favours introduced species	

Climate Change - 3-way interaction: Change is ↑↓ -

Table 7.1. Elements of the cumulative effects monitoring program for the lower Columbia River Basin - Physical indicators.

Cumulative Effects Indicator	Selected Metrics	Potential Targets	Monitoring Locations	Monitoring Times	Ecosystem Objective (EO) Addressed
Physical Characteristics	Total Dissolved Gases	WQOs	U/S and D/S of each dam and the international border; Robson, Kootenay River, Birchbank, Pend d'Oreille, Waneta	Continuously during spill periods and spot sampling at other times	E01, E03, E06
	Water temperature	WQOs	U/S and D/S of each dam; tributaries, key fish habitats (i.e., shallow high use areas)	Continuously	E01, E03, E06
	Total Suspended Solids	WQOs	Birchbank; Waneta	During flow events	E01, E03
	Embeddedness (% fines) in streambed substrates	WQOs	Tributary Mouths & Mainstem	Key times of year	E01, E03
Stream Hydrology	Discharge	Baseline (5 years)	Out of dams; Birchbank; Beaver Creek; Blueberry; Border, Other Tributaries	Continuously	E01, E02, E06
Aquatic Habitat	Stream morphology (mapping)	Baseline	Tin Cup Rapids; Norns Creek; Genelle	Every 3 years	E01, E03, E06
	Habitat diversity (pool-riffle ratio)	Baseline	Tin Cup Rapids; Norns Creek; Genelle	Every 3 years	E01, E03, E06

WQOs = water quality objectives.

Table 7.2. Elements of the cumulative effects monitoring program for the lower Columbia River Basin - Chemical indicators.

Cumulative Effects Indicator	Selected Metrics	Potential Targets	Monitoring Locations	Monitoring Times	Ecosystem Objective (EO) Addressed
Water Chemistry	Concentrations of metals, oils, lubricants, hydrocarbons, microbiological variables, conventions, nutrients, major ions,	WQOs	U/S and D/S of point sources, D/S (No Suggestions), D/S Celgar, D/S Castlegar STP, Kootenay River D/S of Brilliant, Pend d'Oreille D/S of dam, D/S Trail, Birchbank, Waneta, Beaver Creek, Norns Creek, Blueberry Creek	In mainstem, during low flow for most variables, high flow for certain variables; In tributaries, during low elevation snow melt, winter low flow	E01, E02, E04, E06
	Endocrine disrupting compounds	TBD	TBD	TBD	E01
	Mercury loadings	TBD	Point Sources	Continuously	E02, E05
Sediment Chemistry	Organics (OCs, PAHs, PCBs, EDCs, PCDDs/PCDFs, toxaphene, chlorophenols), Metals, Hg, methyl Hg, Conventionals (Ca, Mg, SEM-AVS, TOC, particle size	WQOs	Depositional areas	At same time and place as biological samples for benthos and sediment toxicity; late summer (August, not September); 1x/1to3 years (depending on results of power analyses)	E01, E02, E05, E06
	Bioavailability evaluations	TBD	As above	As above	E01

Table 7.2. Elements of the cumulative effects monitoring program for the lower Columbia River Basin - Chemical indicators.

Cumulative Effects Indicator	Selected Metrics	Potential Targets	Monitoring Locations	Monitoring Times	Ecosystem Objective (EO) Addressed
Tissue Chemistry	Hg in walleye, carp, sturgeon, crayfish, metty	WQOs	Celgar, Birchbank, Genelle, Reference Area, Kootenay U/S/ Brilliant, Pend d'Oreille U/S of dam, D/S Seven Mile dam	At times when other biological sampling is done; not during winter for walleye	E02, E03, E05
	Metals in walleye, mountain whitefish, rainbow trout, crayfish, emergent caddisflies	WQOs	Celgar, Birchbank, Genelle, Reference Area, Kootenay U/S/ Brilliant, Pend d'Oreille U/S of dam, D/S Seven Mile dam	At times when other biological sampling is done; not during winter for walleye, July for mountain whitefish	E02, E03, E05
	Organics (OCs, PCDDs/PCDFs, PBDEs, PCBs, Toxaphene, EDCs) in muscle, liver and whole fish	WQOs	Celgar, Birchbank, Genelle, Reference Area, Kootenay U/S/ Brilliant, Pend d'Oreille U/S of dam, D/S Seven Mile dam	At times when other biological sampling is done; not during winter for walleye, July for mountain whitefish	E02, E03, E05
	Organics (OCs, PCDDs/PCDFs, PBDEs, PCBs, Toxaphene, EDCs) in clams, crayfish, and emergent caddisflies	WQOs	Celgar, Birchbank, Genelle, Reference Area, Kootenay U/S/ Brilliant, Pend d'Oreille U/S of dam, D/S Seven Mile dam	At times when other biological sampling is done	E02, E03, E05
	Hg in otter, raccoons, and human hair	TBD	TBD	TBD	E01, E06

WQOs = water quality objectives; U/S = upstream; D/S = downstream; TBD = to be determined; OCs = organochlorine; PAHs = polycyclic aromatic hydrocarbons.
PCBs = polychlorinated biphenyls; EDCs = endocrine disrupting chemicals; PCDDs/PCDFs = polychlorinated dibenzo-*p*- dioxins; polychlorinated dibenzofurans;
SEM-AVS = simultaneously extracted metals - acid volatile sulfides; TOC = total organic carbon; PBDEs = polybrominated diphenyl ethers; STP = sewage treatment plant.

Table 7.3. Elements of the cumulative effects monitoring program for the lower Columbia River Basin - Biological indicators.

Cumulative Effects Indicator	Selected Metrics	Potential Targets	Monitoring Locations	Monitoring Times	Ecosystem Objective (EO) Addressed
Aquatic Plant Community	Community structure, standing crop (ABA modelled and measured)	Baseline	U/S and D/S of point sources, D/S (No Suggestions), D/S Celgar, D/S Castlegar STP, Kootenay River D/S of Brilliant, Pend d'Oreille D/S of dam, D/S Trail, Birchbank, Waneta, Beaver Creek, Norns Creek, Blueberry Creek; Whole river for modelling and random cross-sections for measurements	1 to 4x/year (as with WQOs)	E01, E02
Benthic Invertebrate Community	Macroinvertebrate Index of Biotic Integrity; Abundance of Key Taxa (e.g., EPT taxa)	Comparison to Reference Conditions	Depositional Areas	1x/1 to 3 years (Based on power analysis: sample in August)	E01, E06
	Mollusc distribution	Baseline	Survey to identify key locations	TBD	E01, E06
	Sediment toxicity (28-d survival and growth test with *Hyalella azteca*)	Comparison to reference conditions	Depositional Areas	1x/1 to 3 years	E01, E06
Fish Community	Abundance and age structure of walleye, rainbow trout, and mountain whitefish	Baseline	At historic sampling locations	1x/1 to 3 years (Based on power analysis: sample in Sept./Oct for highest catch rates)	E01, E02, E03, E05, E06

Table 7.3. Elements of the cumulative effects monitoring program for the lower Columbia River Basin - Biological indicators.

Cumulative Effects Indicator	Selected Metrics	Potential Targets	Monitoring Locations	Monitoring Times	Ecosystem Objective (EO) Addressed
Fish Community (cont.)	Abundance of various non-native fish species	Baseline	At historic sampling locations	1x/1 to 3 years (Based on power analysis: sample in Sept./Oct for highest catch rates)	E03
	Egg-to-Fry Survival Rates	Baseline (or calculate expectations based on %fines)	Norns Creek Fan, Genelle, etc.	As relevant for species of concern	E01, E03, E06
Fish Health	Fish Health Index, Gas Bubble Trauma, Genotoxicity	Baseline	Same as tissue sampling locations for fish	Same as tissue sampling	E01, E02, E03, E05, E06
Riparian Plant Community	Structure of riparian plant community, abundance of indicator species	Baseline	Tributaries, Genelle, Others (e.g., black cottonwood stands)	TBD	E01
Wildlife Community	Reproductive success and abundance of osprey	Baseline	Nesting sites	1x/year	E01, E06
	Distribution and abundance of frogs and turtles	Baseline	TBD	TBD	E01, E06
	Changes in species composition and wildlife behaviour	Baseline	TBD	Every 3 years	E01, E06

U/S = upstream; D/S = downstream; EPT = ephemeroptera, plecoptera, tricoptera; 28-d = 26-days; TBD = to be determined; STP = sewage treatment plant.

Figures

Figure 1.1. Lower Columbia River between Arrow Lakes and the Canada - USA Border, Showing Major Anthropogenic Influences (G3 Consulting Ltd. 2002).

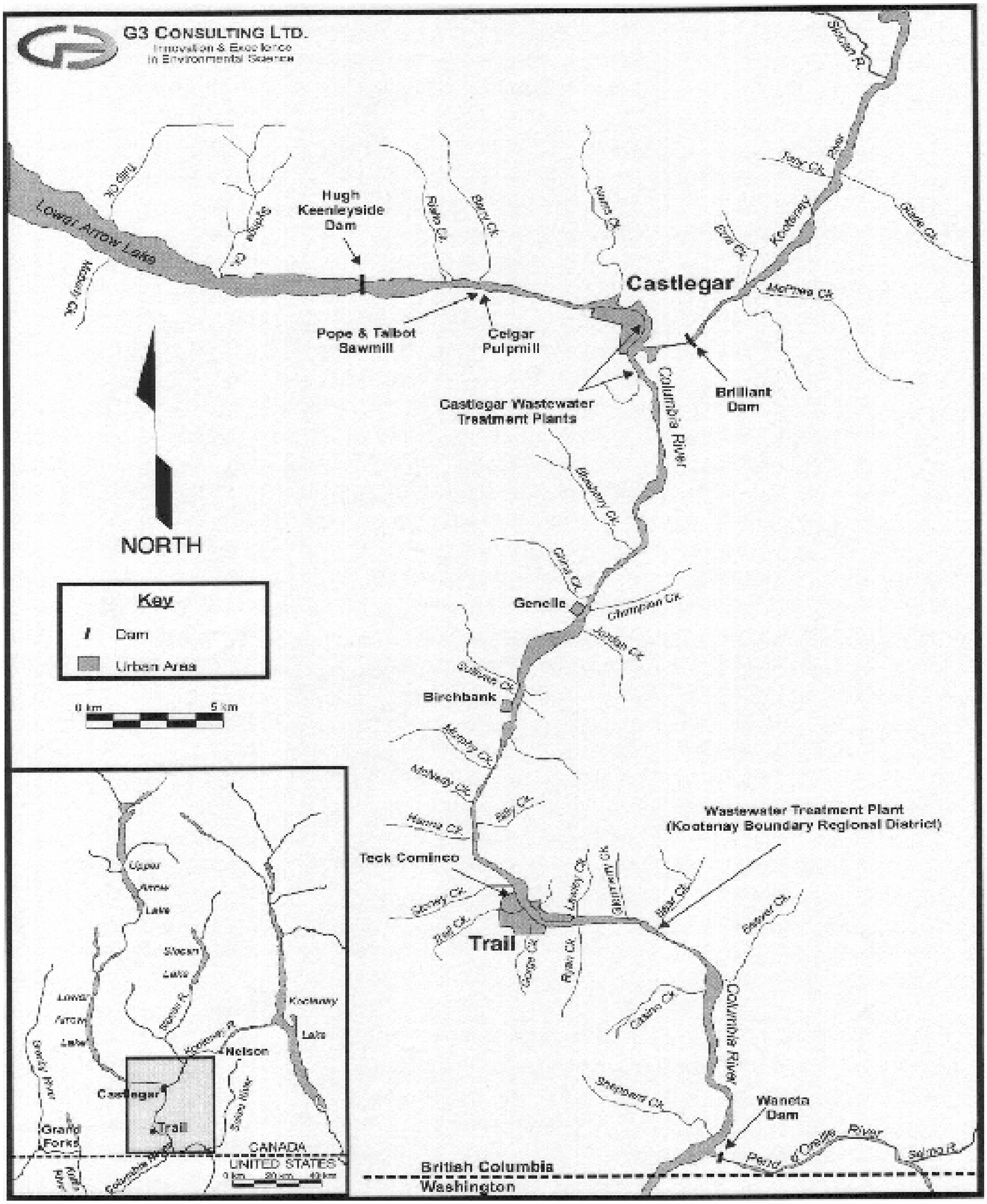


Figure 2.1. Relationship between ecosystem goals, objectives, indicators, metrics, and targets.

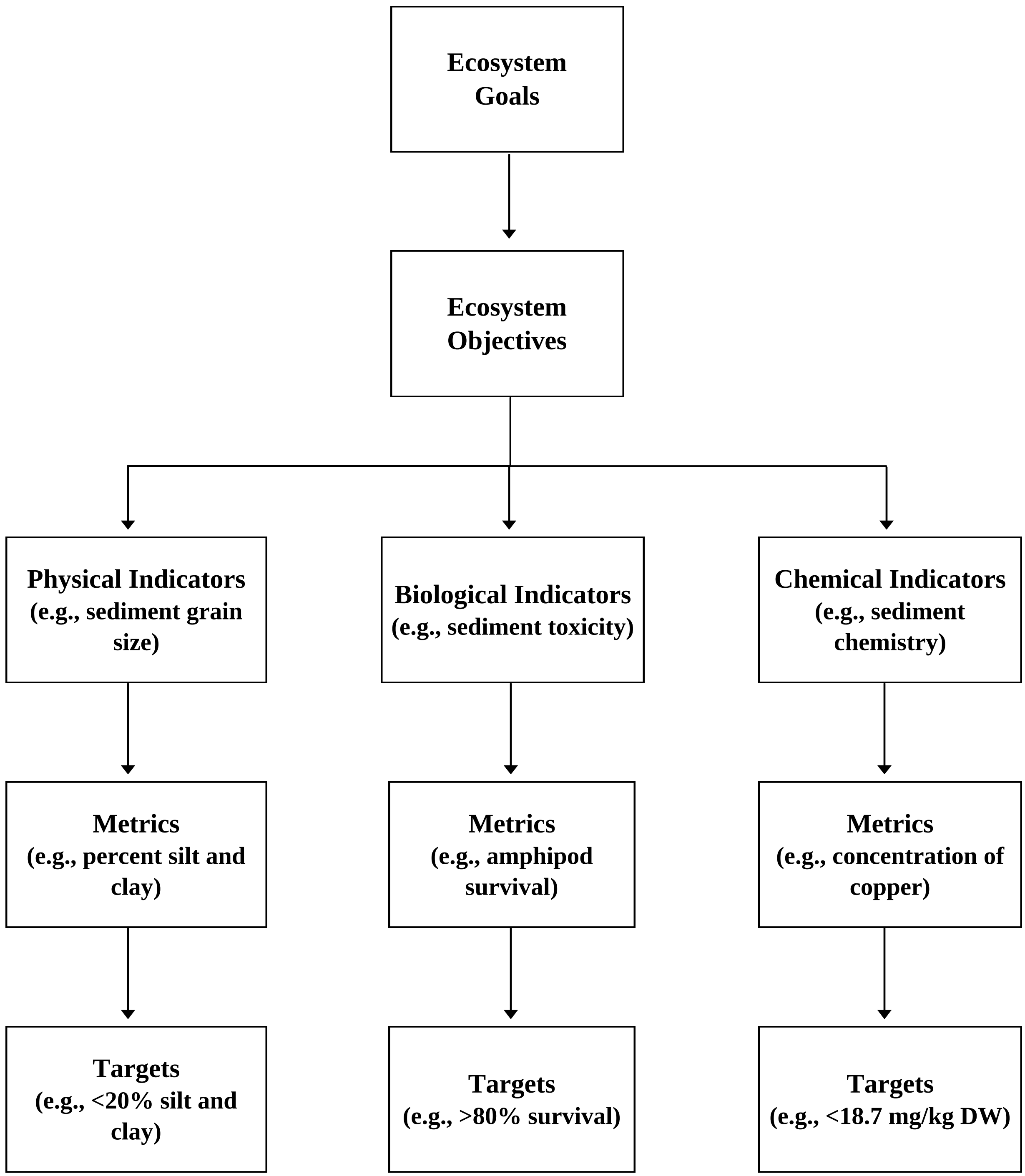


Figure 3.1. An example of a checklist for cumulative effects assessment (from Cocklin *et al.* 1992).

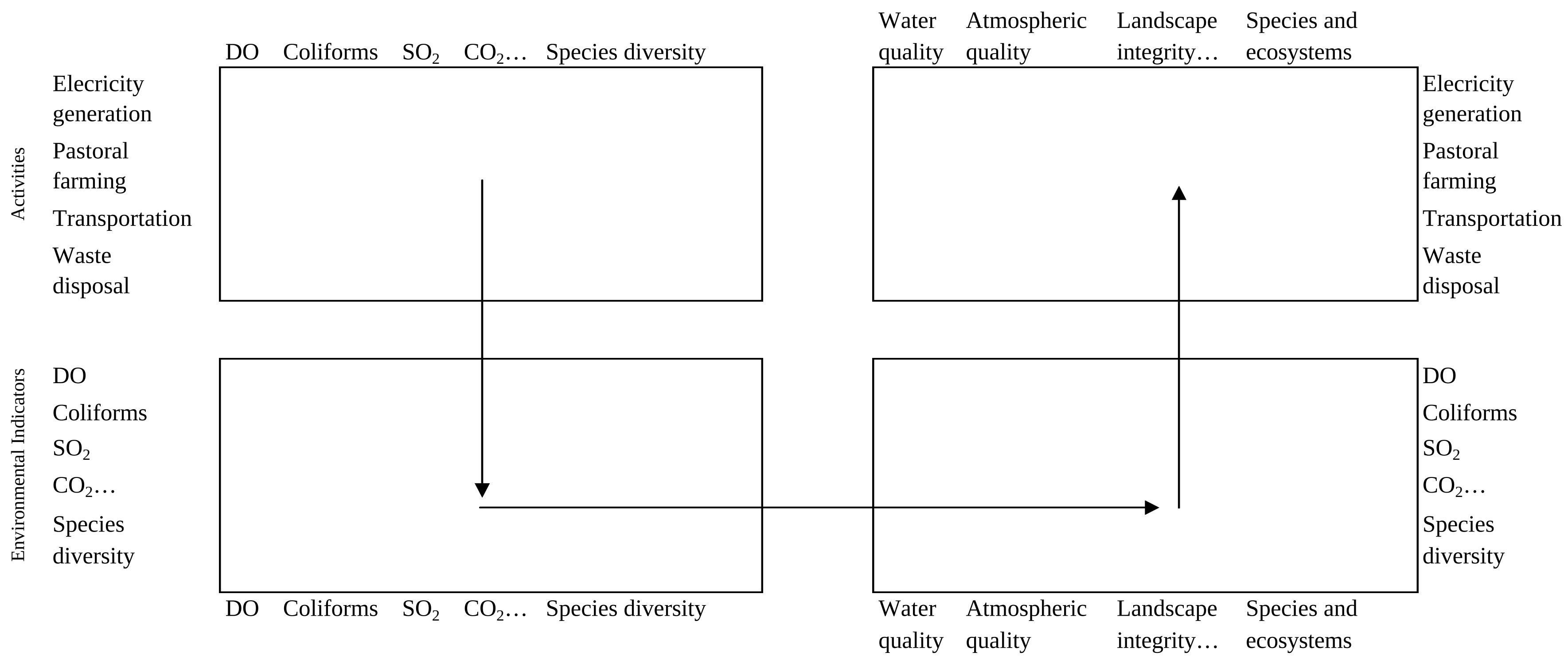
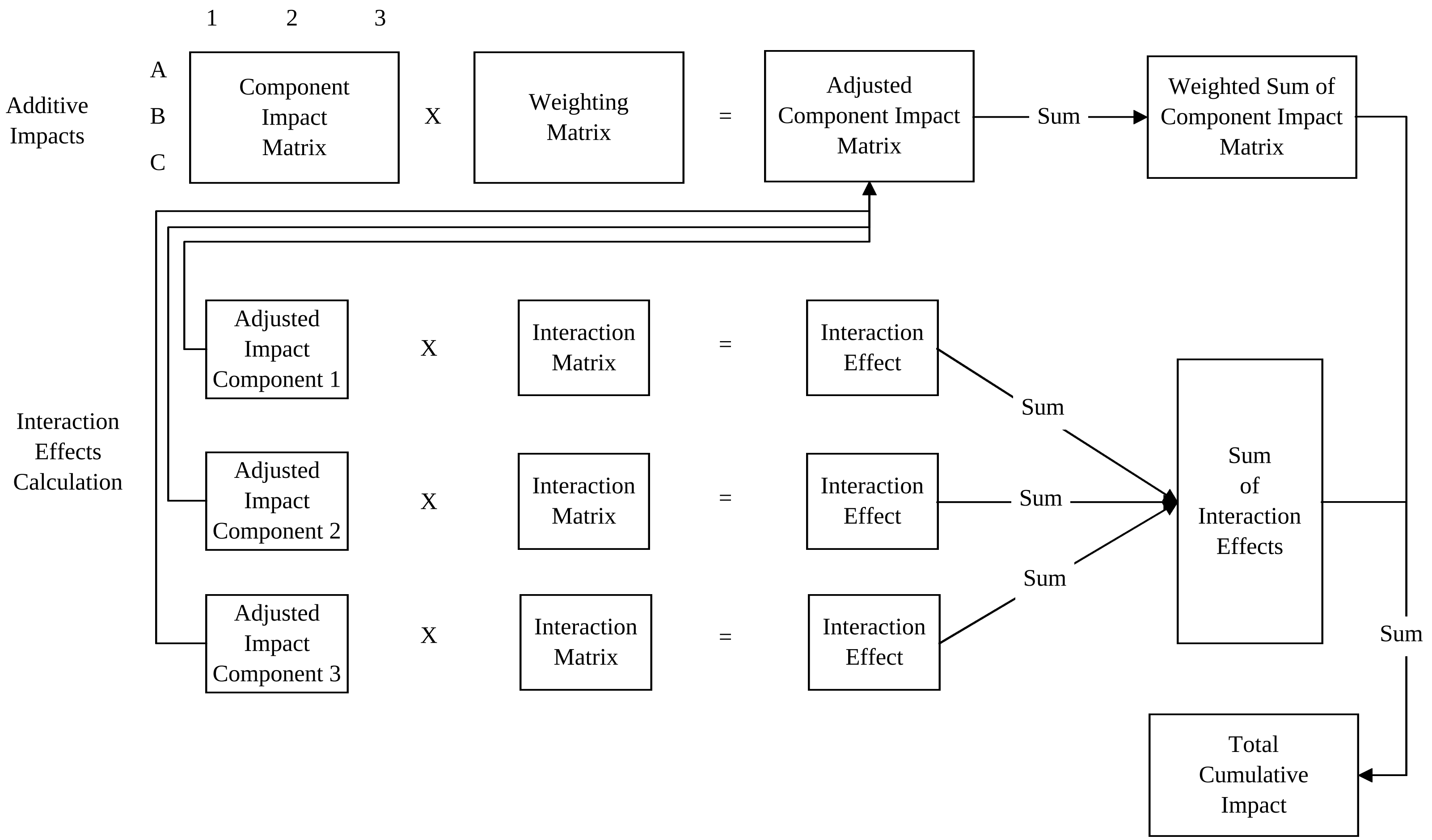


Figure 3.2. An example of the application of interactive metrices in cumulative effects assessment (from Bain *et al.* 1989).



Note: This example illustrates the use of interative matrices for three types of activities (A, B, and C) and a target resouce with three ecosystem components (1, 2, and 3).

Figure 3.3. An example of a network diagram, which illustrates the relationships between a disturbance activity and the associated primary and higher order effects (from Cocklin 1989).

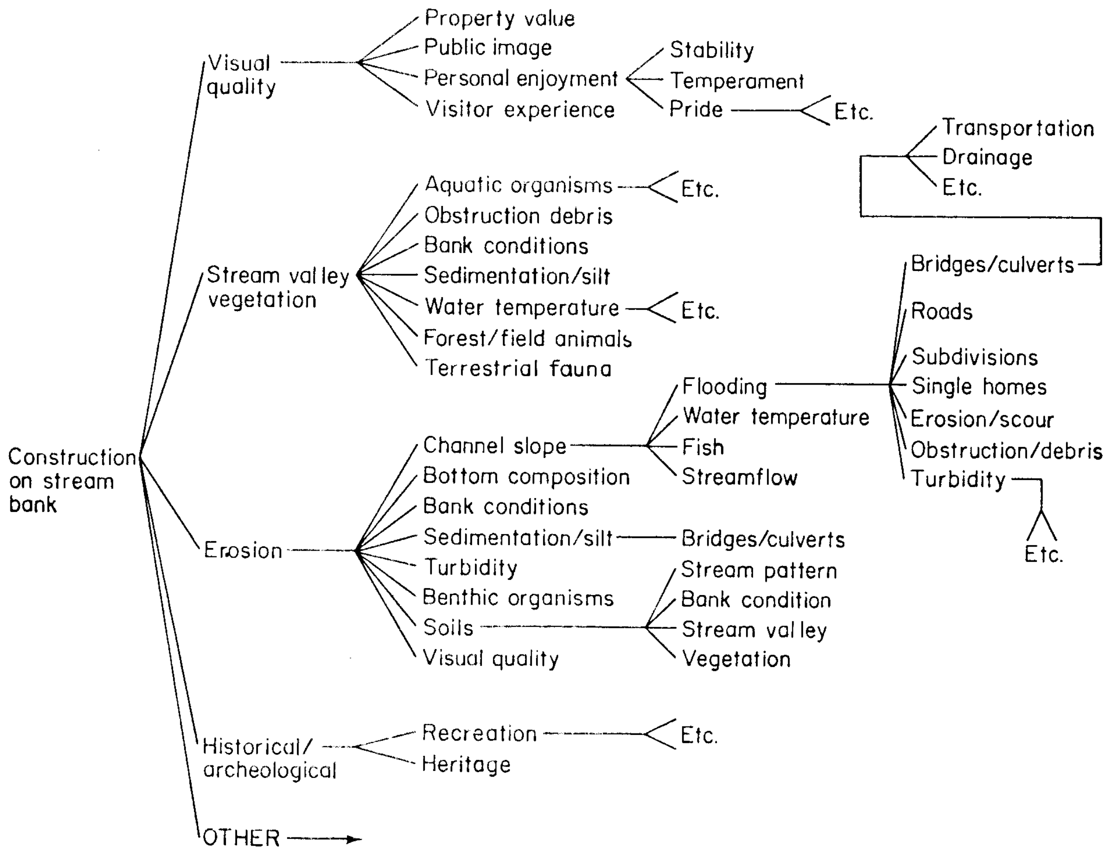


Figure 3.4. **An overview of the environmental auditing approach to cumulative effects assessment (from Abbruzzese and Leibowitz 1997).**

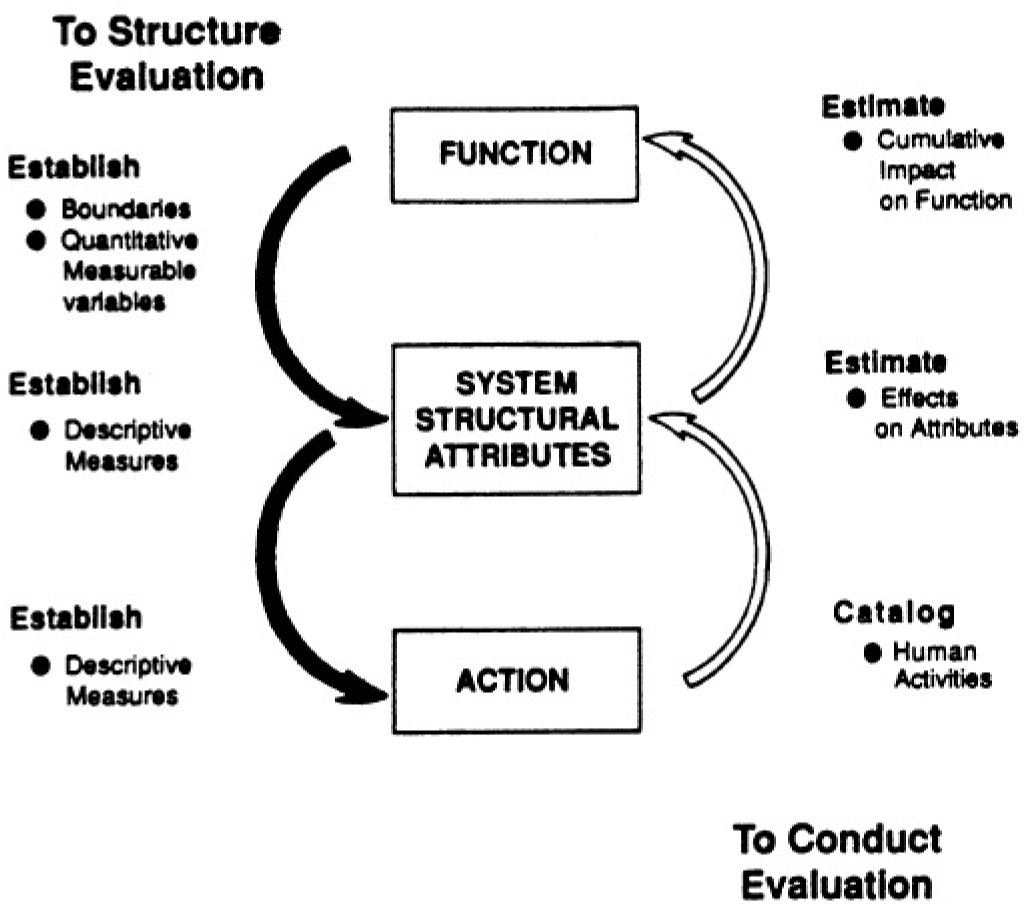


Figure 3.5. Relationship of landscape and regional variables to wetland landscape functions (from Bedford and Preston 1988).

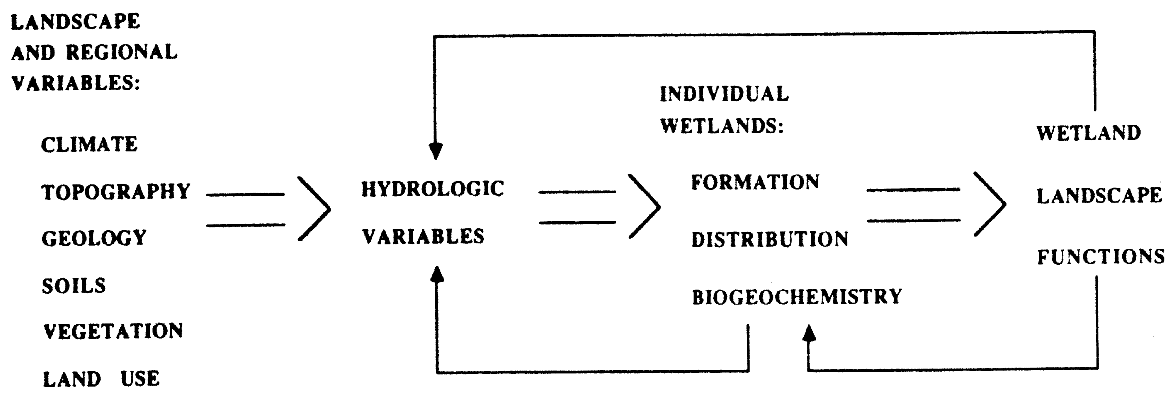


Figure 3.6. **An overview of the spatial analysis of approach to assessing cumulative effects change using geographic information systems (from Parker and Cocklin 1993).**

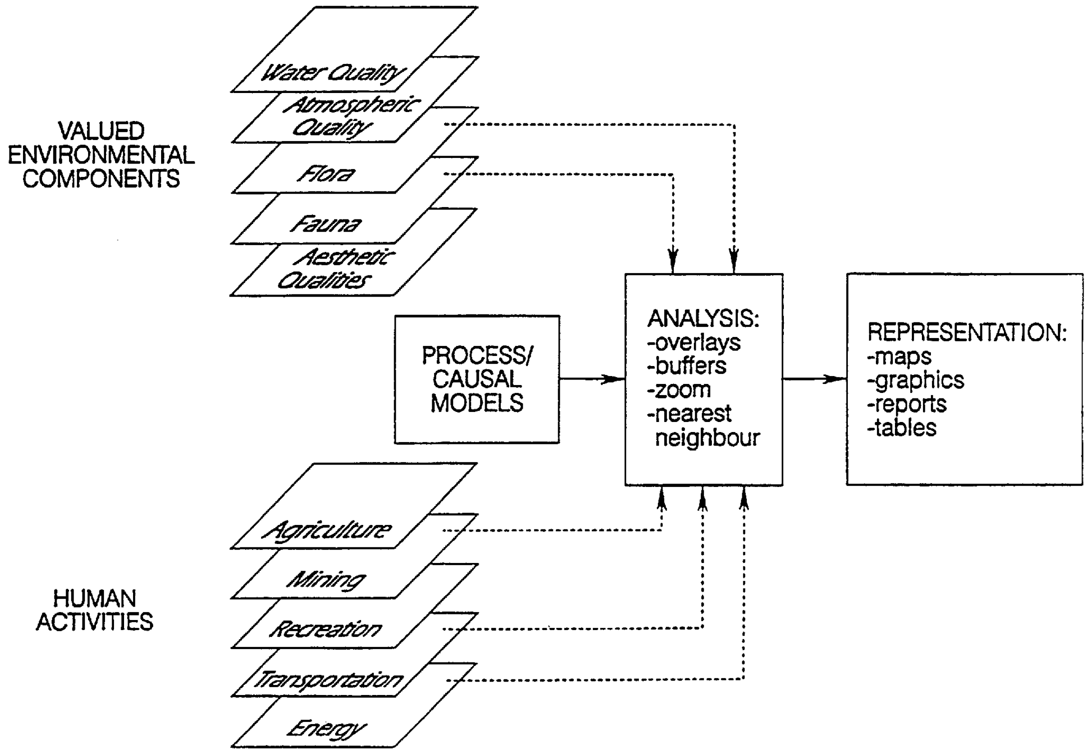


Figure 3.7. A conceptual model of the cumulative effects of land drainage, which illustrates the ecological modelling approach (from Spaling and Smit 1995).

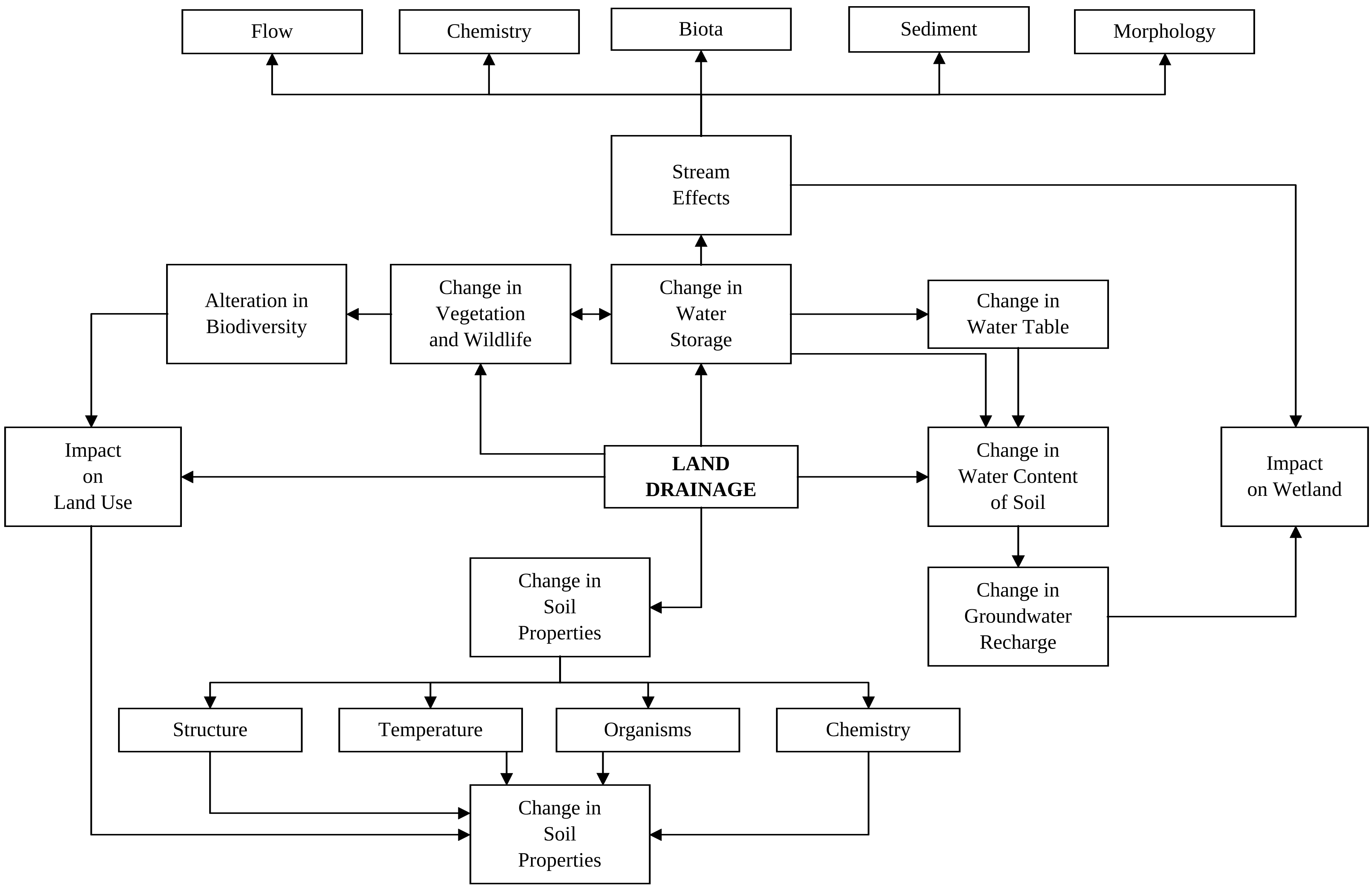


Figure 5.1. Seasonal hydrograph of the lower Columbia River measured at Birchbank during different periods. Source R.L.&L. Environmental Services Ltd. 2001.

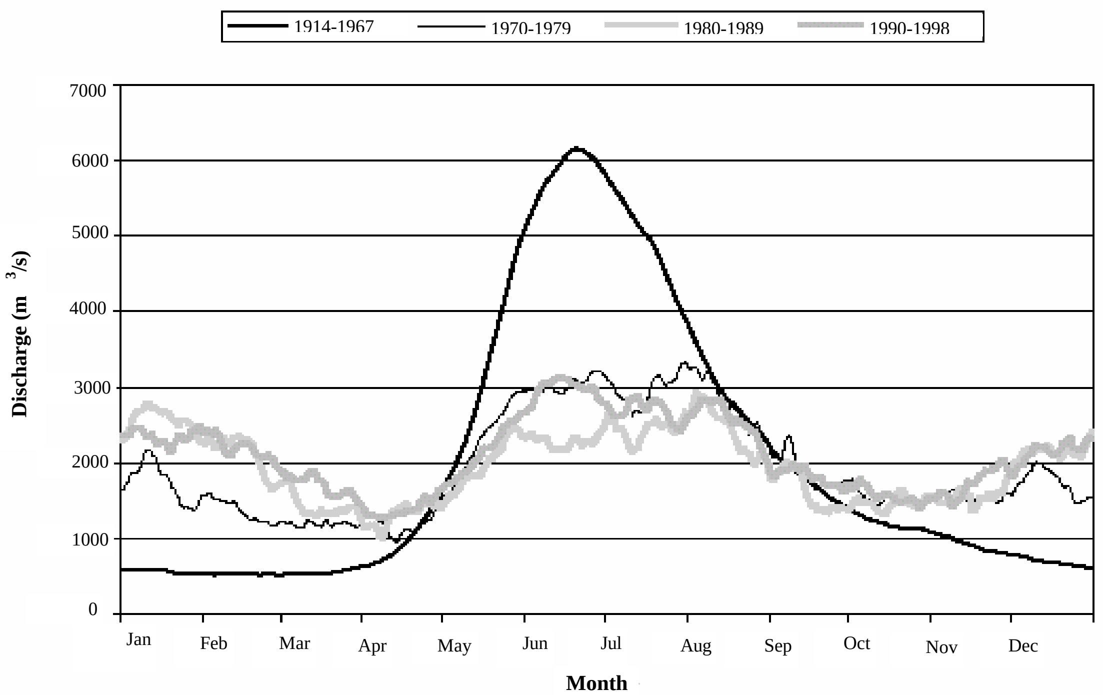
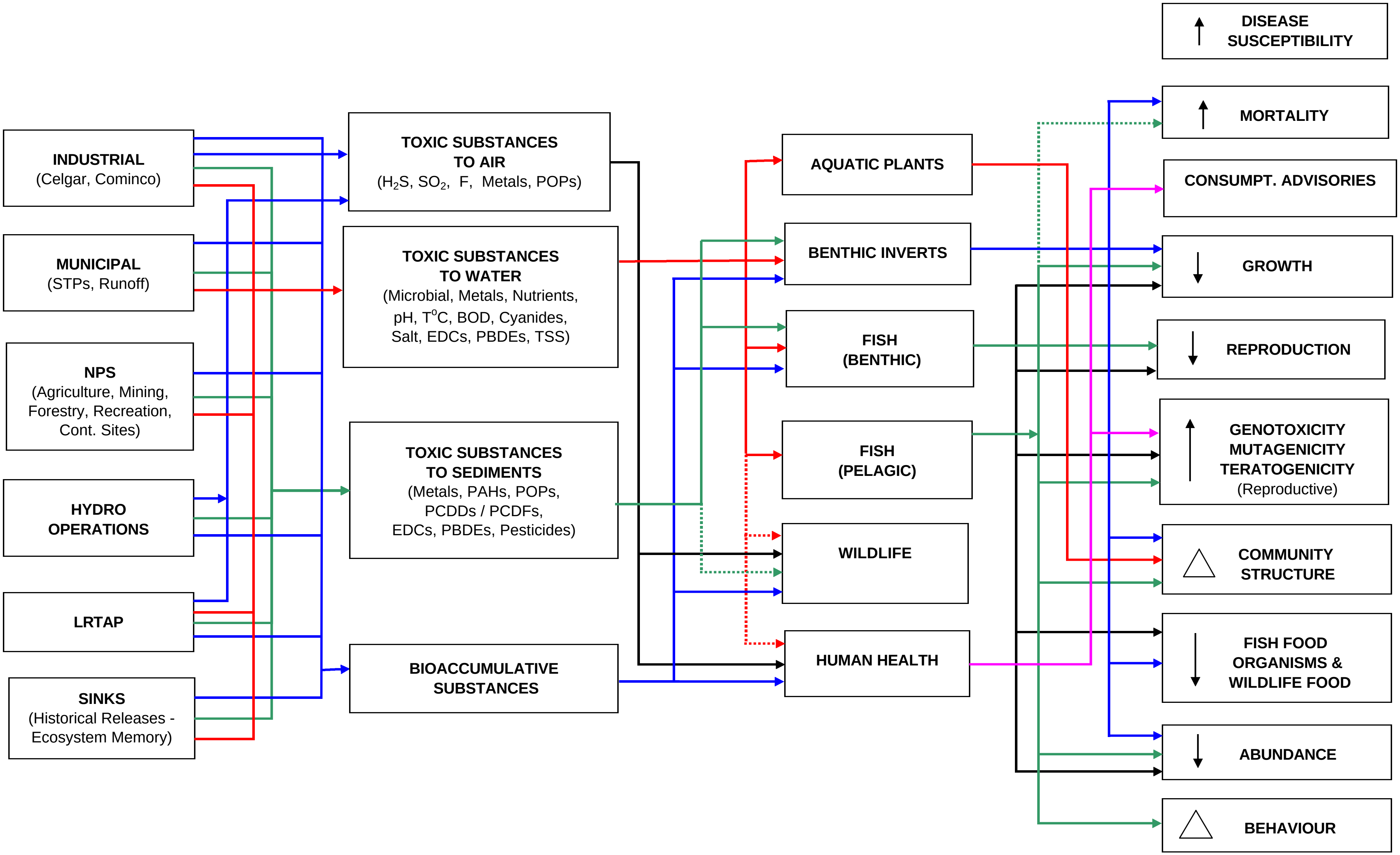


Figure 6.1. Linkages between various sources of aquatic contamination[1] (i.e., stressors) and various receptors, in the Columbia River Basin, showing the types of cumulative effects that could occur.



[1]F= fluoride; POPS = persistent organic pollutants; BOD = biological oxygen demand; EDC = endocrine disrupting chemicals; PBDEs = polybrominated diethyl ethers; TSS = total suspended solids; PAHs = polycyclic aromatic hydrocarbons; PCDDs and PCDFs = polychlorinated dibenzo-*p*- dioxins and polychlorinated dibenzofurans.

Figure 6.2. Linkages between flow regulation and various receptors, in the Columbia River Basin, showing the types of cumulative effects that could occur.

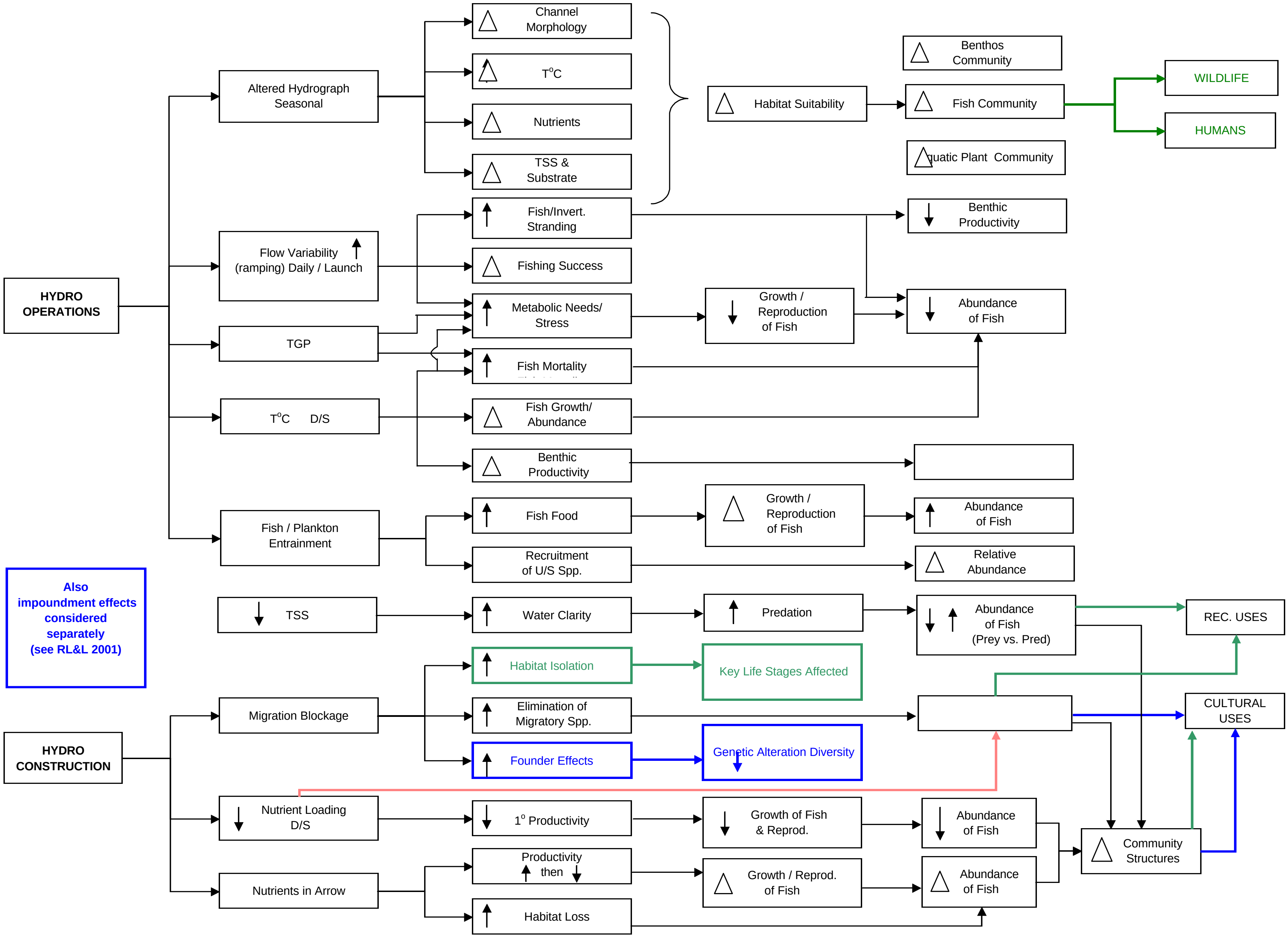


Figure 6.3. Linkages between the various processes that cause climate change and receptors in the Columbia River Basin, showing the types of cumulative effects that could occur.

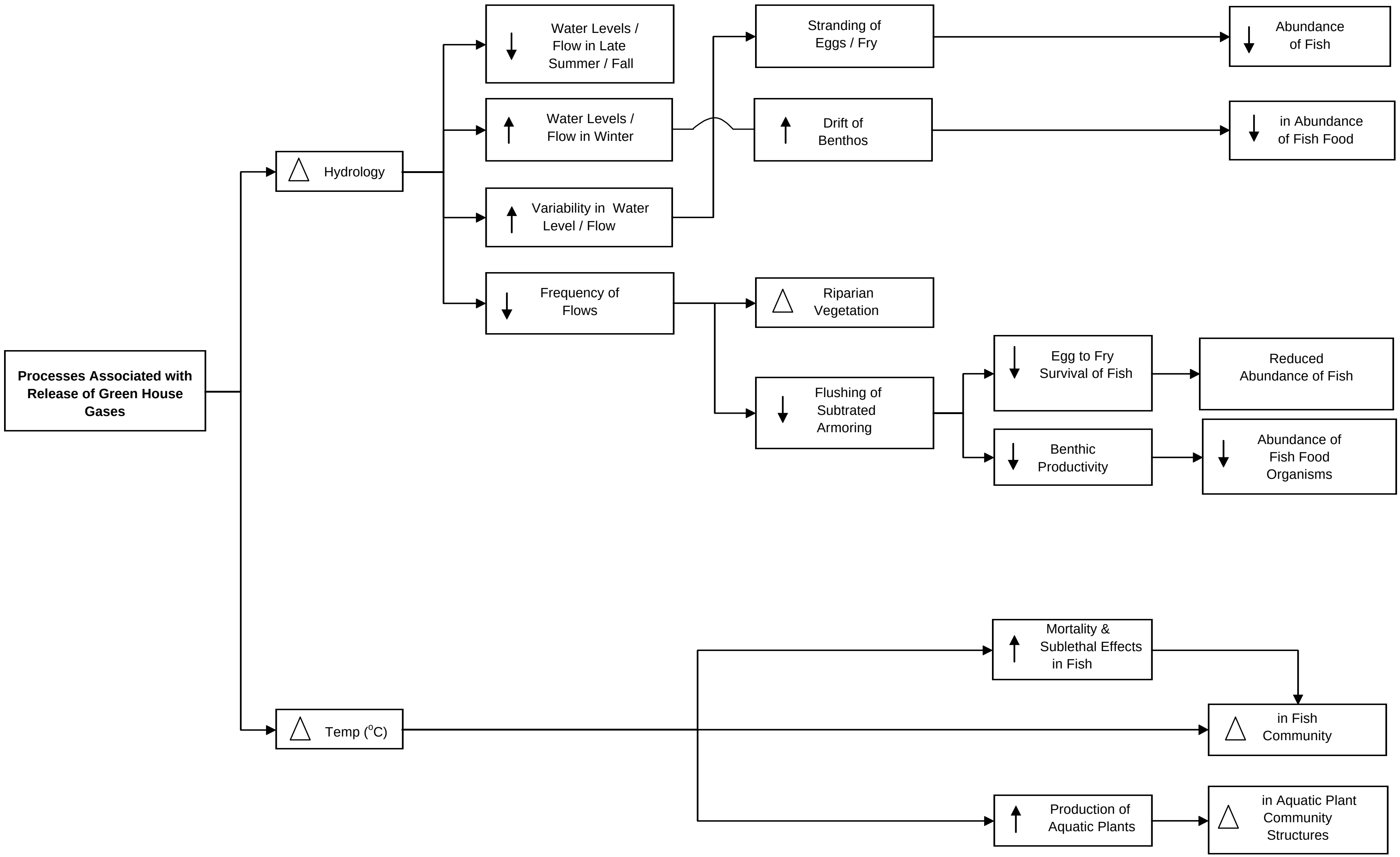


Figure 6.4. Linkages between the various introduced species (i.e., stressors) and receptors in the Columbia River Basin, showing the types of effects that could occur.

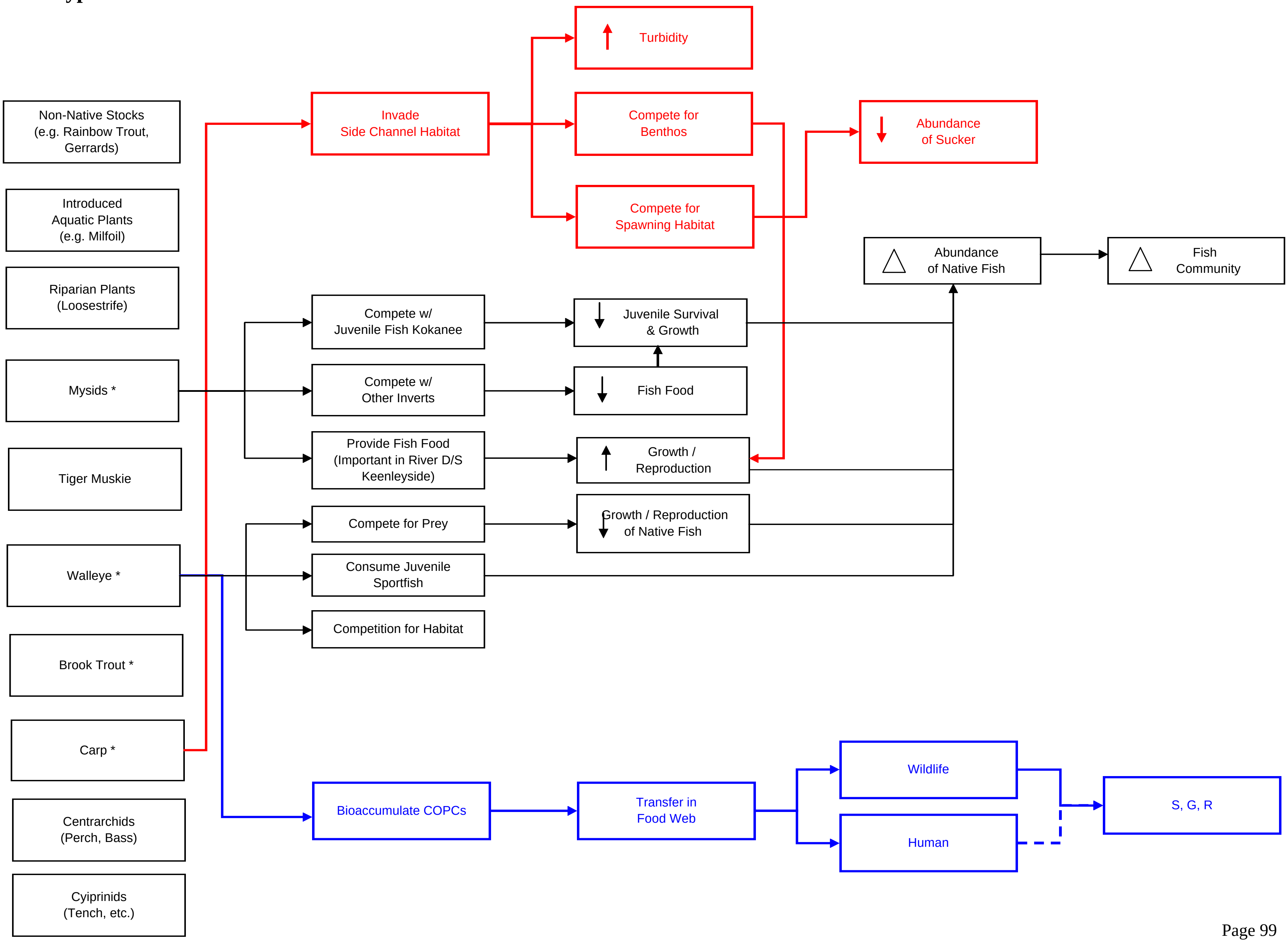
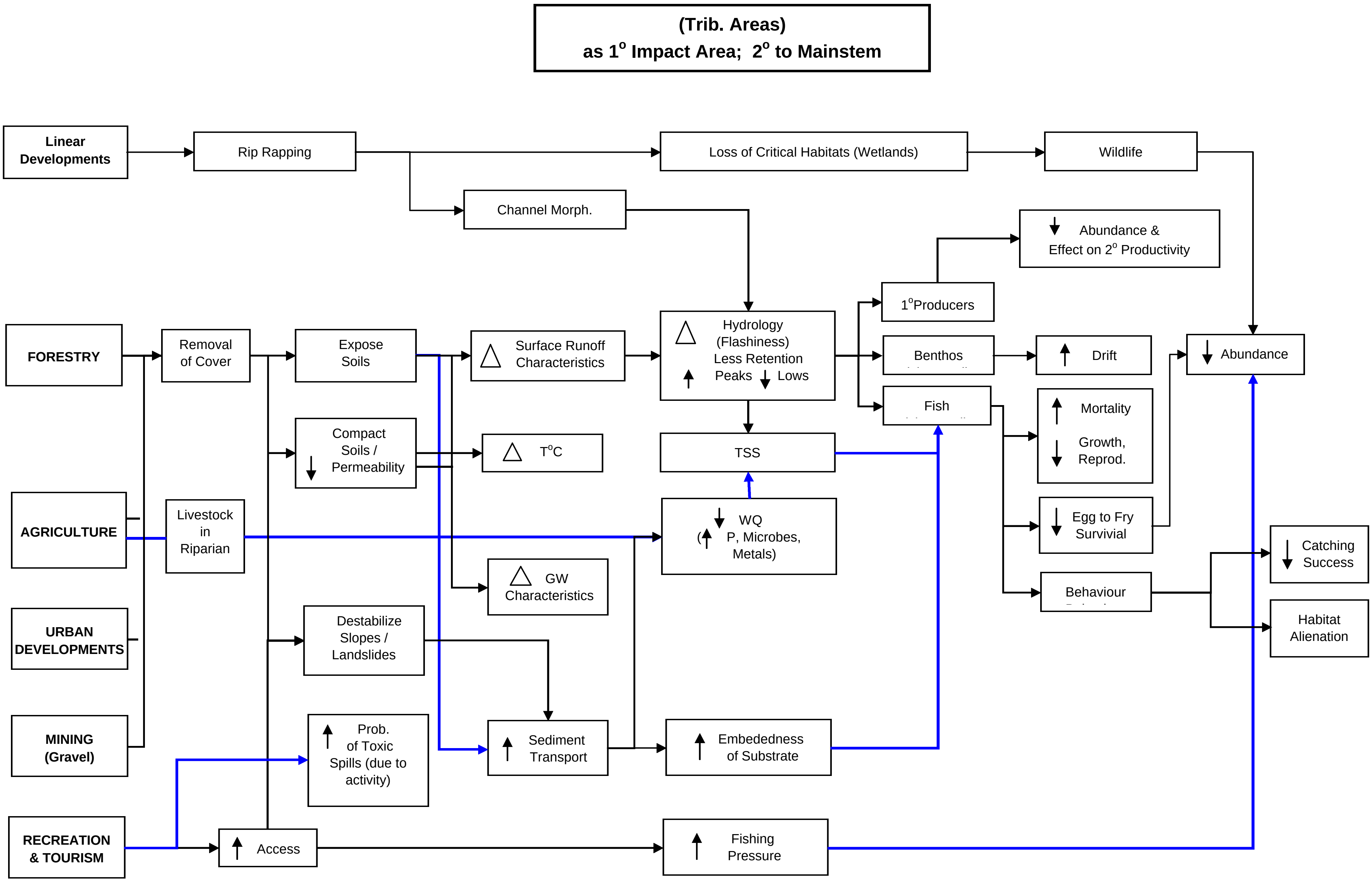


Figure 6.5. Linkages between the various land use change (i.e., stressors) and receptors in the Columbia River Basin, showing the types of cumulative effects that could occur.



Note: The tributaries are likely to be the primary locations where adverse effects would occur.

Figure 6.6. Potential cumulative effects associated with interactions between flow regulation and aquatic contamination.

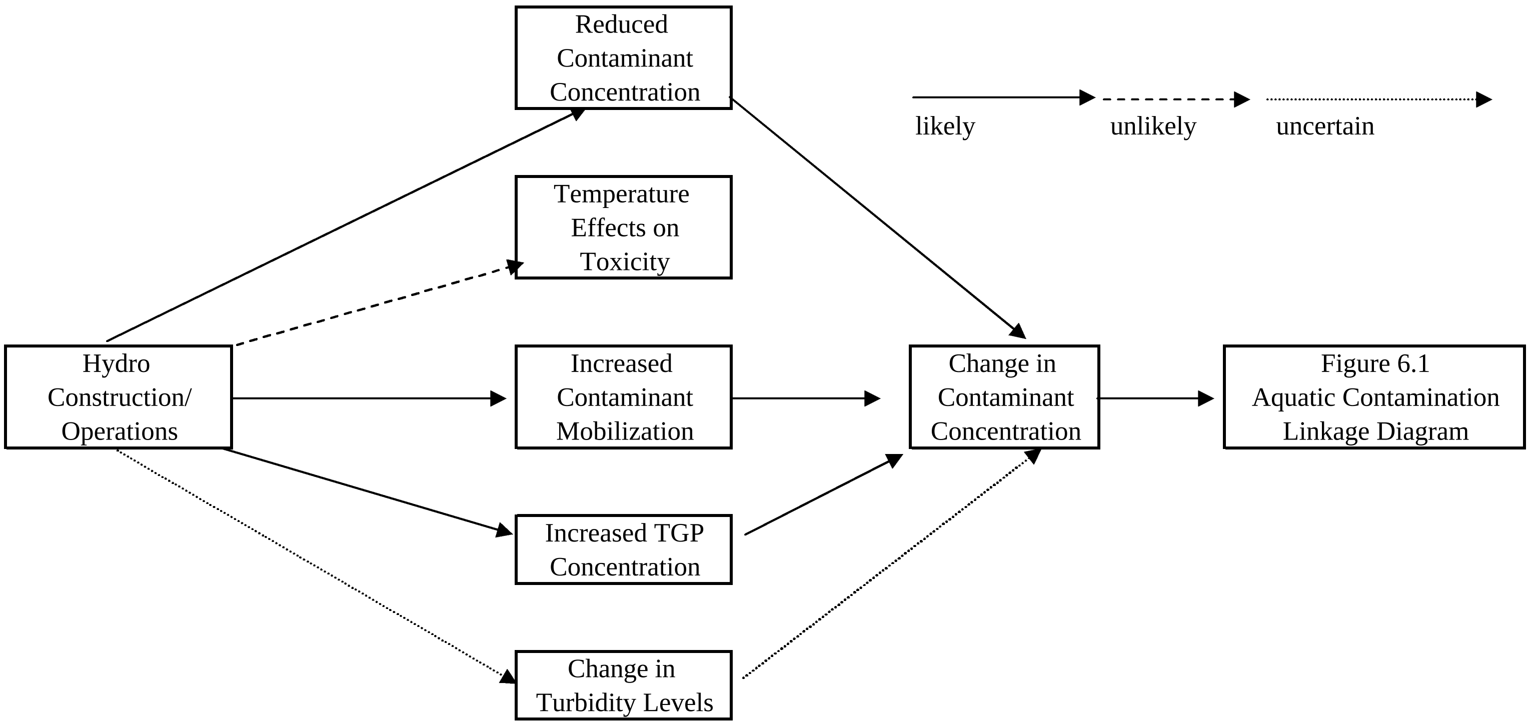


Figure 6.7. Potential cumulative effects associated with interactions between aquatic contamination and climate change.

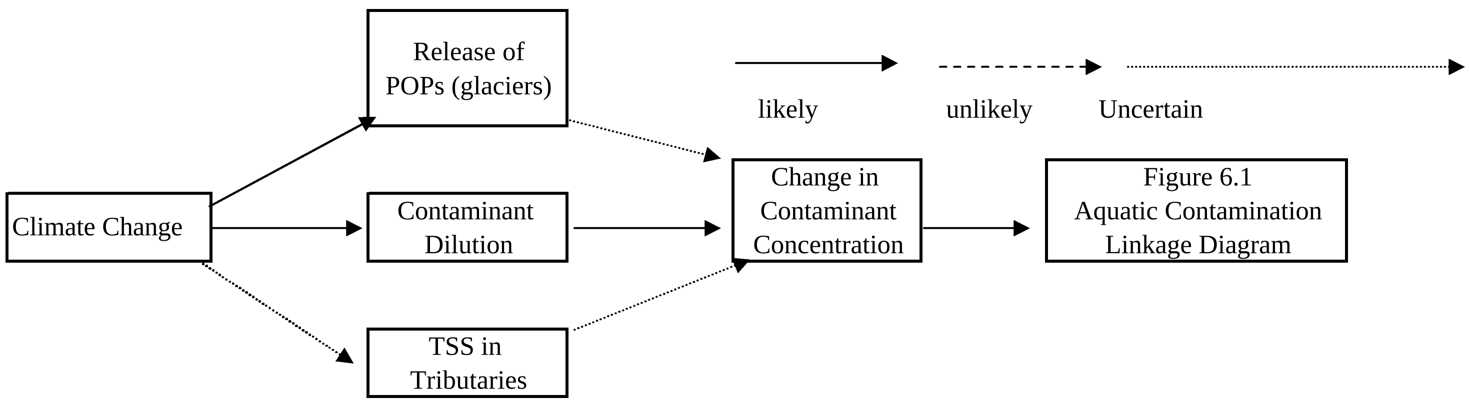


Figure 6.8. Potential cumulative effects associated with interactions between aquatic contamination and introduced species.

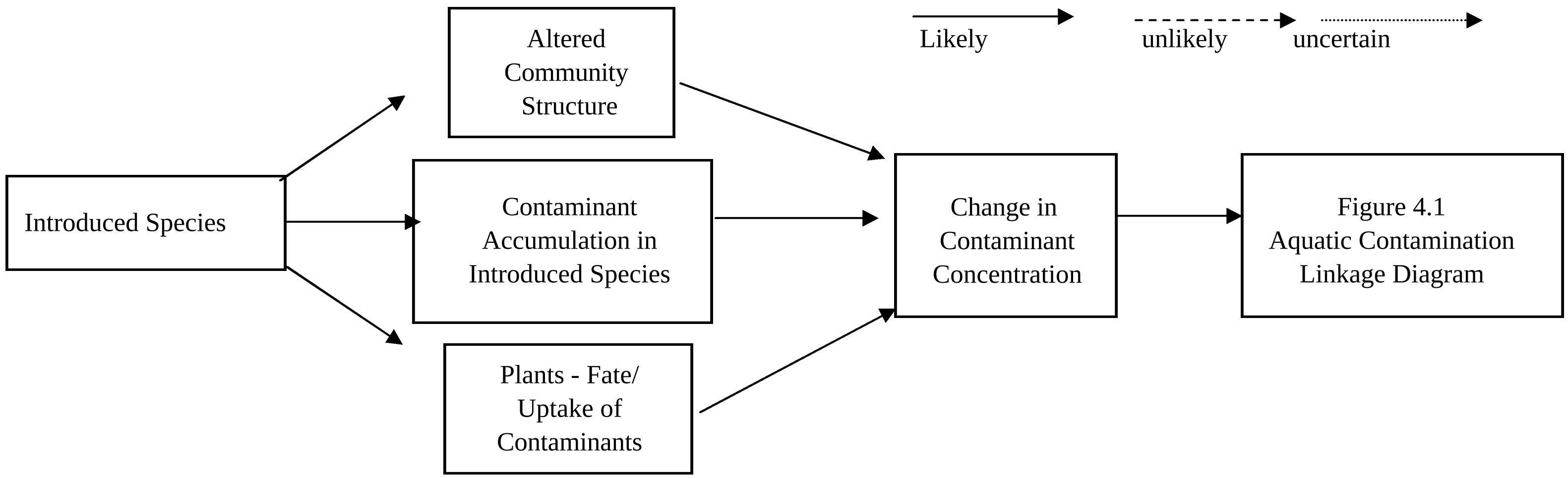


Figure 6.9. Potential cumulative effects associated with interactions between land use change and aquatic contamination.

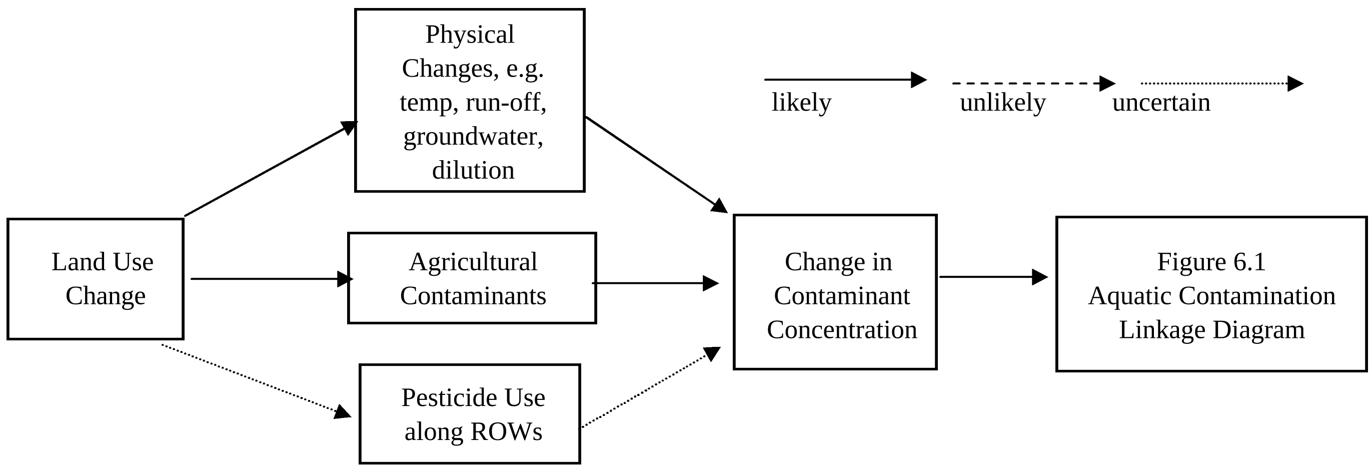


Figure 6.10. Potential cumulative effects associated with flow fluctuations and climate change.

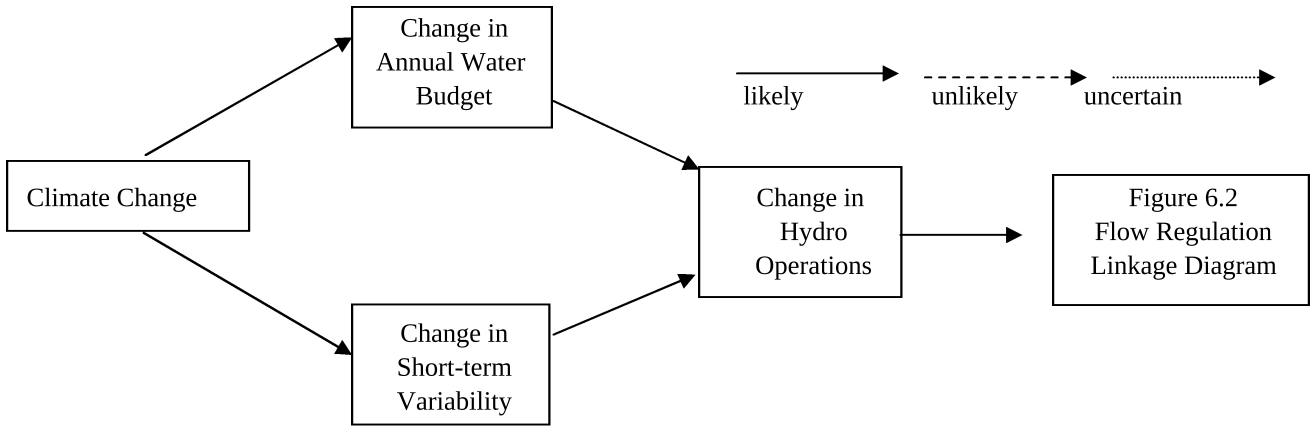


Figure 6.11. Potential cumulative effects associated with interactions between flow regulations and introduced species.

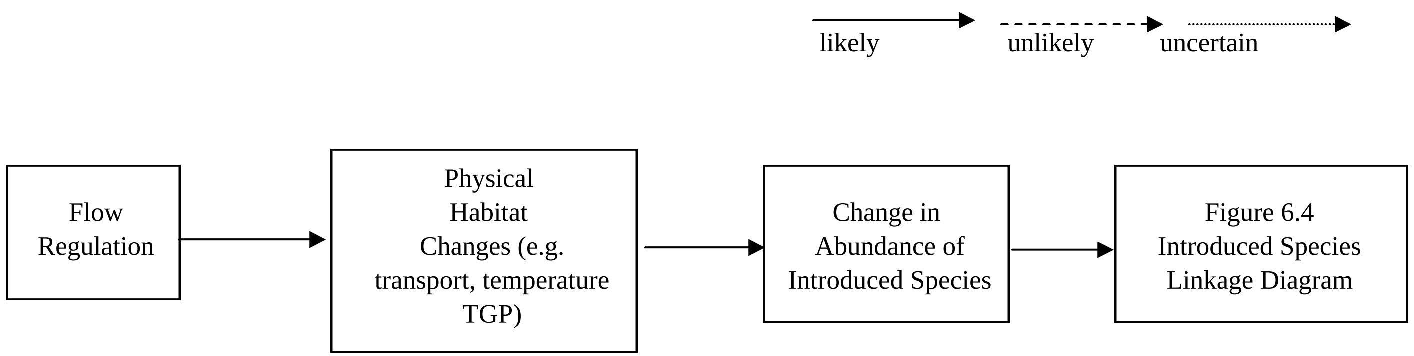


Figure 6.12. Potential cumulative effects associated with interactions between land use changes and flow regulation.

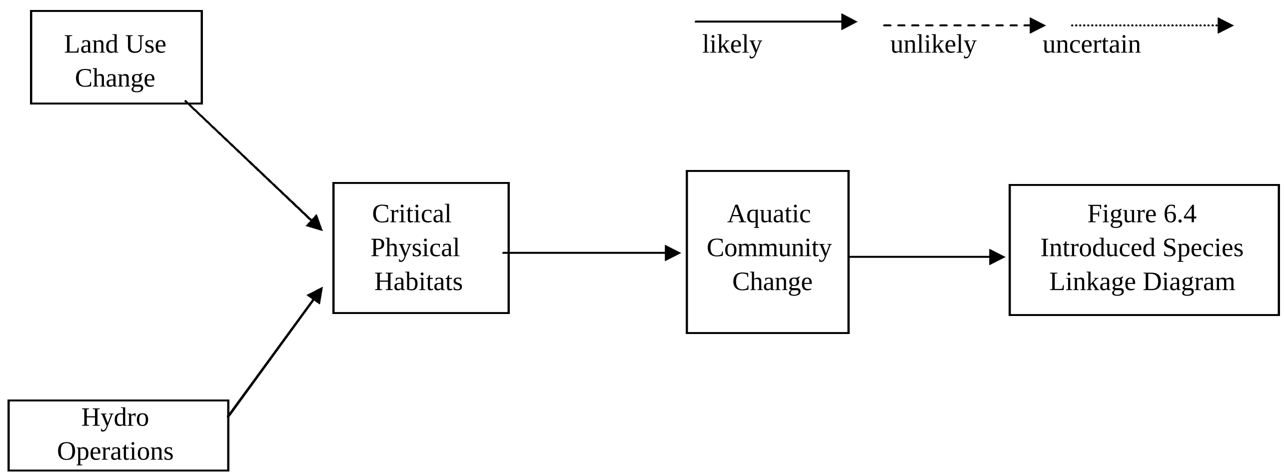


Figure 6.13. Potential cumulative effects associated with interactions between climate change and introduced species.

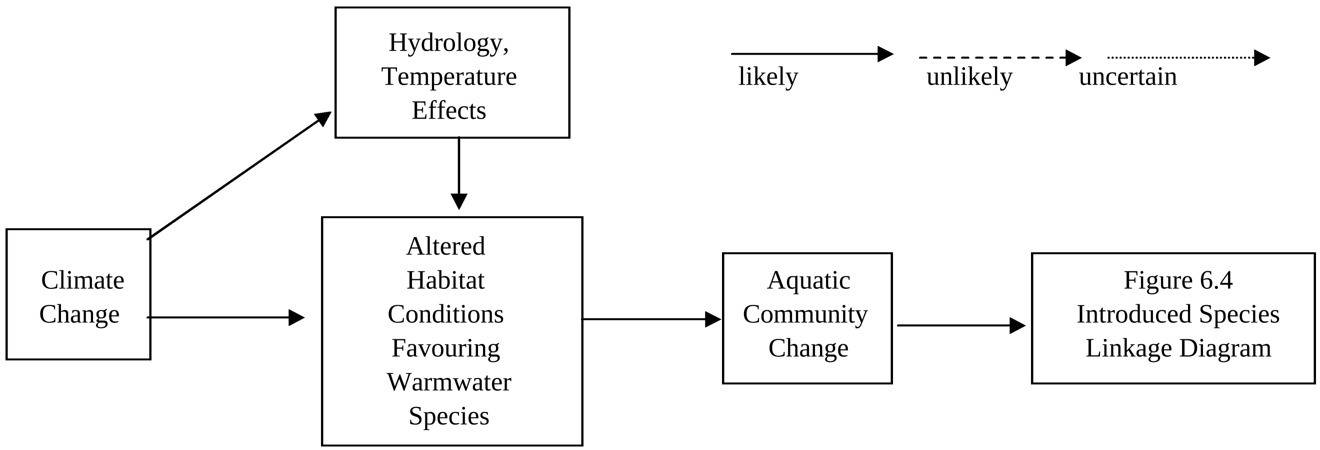


Figure 6.14. Potential cumulative effects associated with interactions between land use changes and climate change.

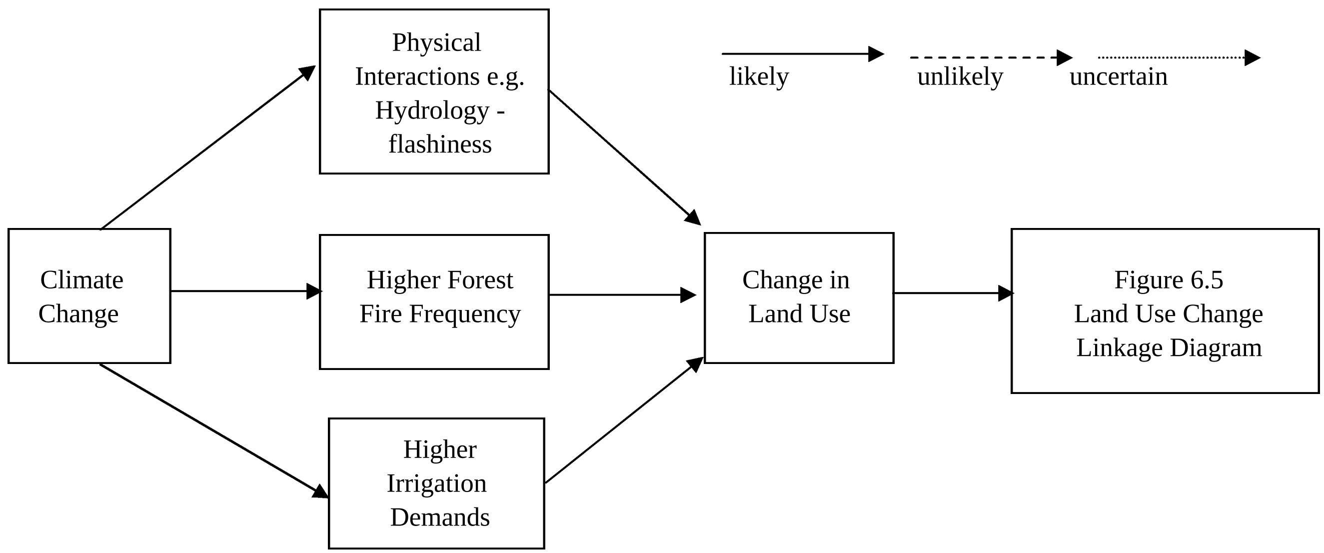
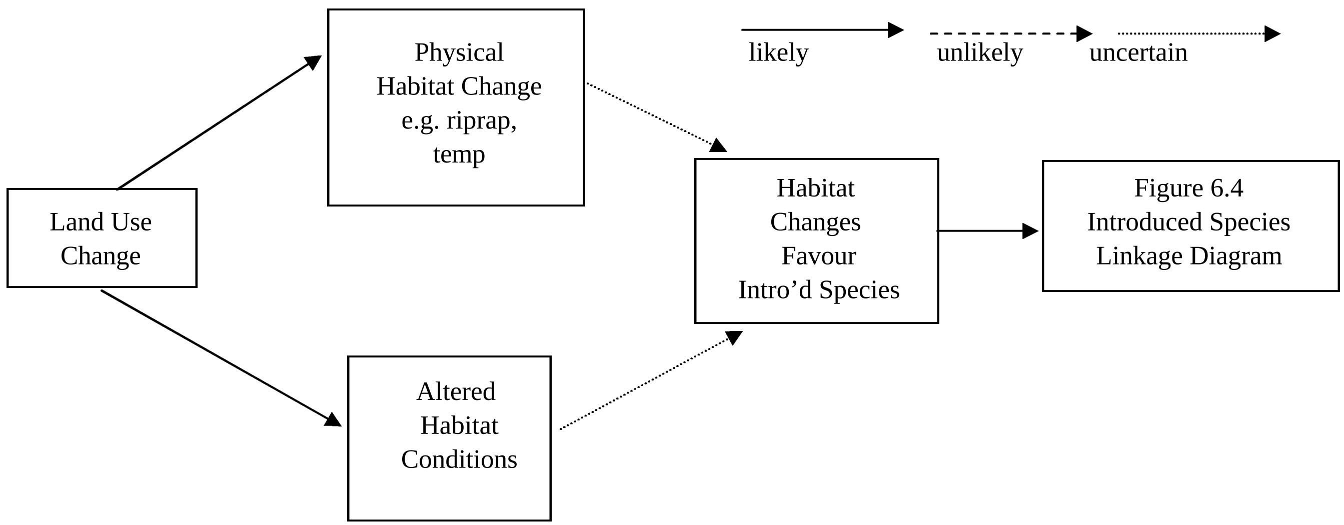


Figure 6.15. Potential cumulative effects associated with interactions between land use changes and introduced species.



Appendix 1

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