CRIEMP II

COLUMBIA RIVER INTEGRATED ENVIRONMENTAL MONITORING PROGRAM

Data Gap Analysis & Study Design Considerations

Final Report

Submitted to:

CRIEMP Committee

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1.0 INTRODUCTION

The lower Columbia River, from Hugh Keenleyside Dam to the US border, has been the subject of much monitoring over many years, both industry-specific and routine in nature. In the early 1990's, the need for a coordinated, integrated approach to assessing Columbia River health was recognized, in part to overcome duplication of efforts and increase communication among stakeholders, and in part to recognize the complex and dynamic nature of the river. The Columbia River Integrated Environmental Monitoring Program (CRIEMP) was established in 1991 to identify, monitor and address aquatic environmental impacts of the many human activities in the lower Columbia River watershed in a coordinated manner.

Participants included government agencies, major industries, dam operators and local governments. Current membership, described in Table 1-1, has changed since the original program (CRIEMP I), with addition of Columbia Power Corp. (CPC), UtiliCorp (formerly West Kootenay Power), City of Nelson, Columbia Basin Trust, First Nations and Lake Roosevelt Water Quality Council. The Ministry of Water, Land and Air Protection (MWLAP, formerly Ministry of Environment, Lands and Parks, MELP) currently chairs the committee.

A broad-based study plan was developed and implemented in 1992 to assess environmental impacts on the Columbia River, and several recommendations for future directions emerged (Aquametrix, 1994). Major initiatives to improve environmental performance of industries and dams have occurred since then, accompanied by substantial commitment of monetary resources. Consumption advisories for sportfish, issued in 1989, were lifted in 1995 for mercury levels in walleye and 1996 for organochlorine levels in mountain whitefish and lake whitefish, reflecting considerable improvement in contaminant levels in the river. Water quality monitoring programs and objectives have been developed (MELP, 2000). The committee convenes regularly to share information and discuss issues related to Columbia River health. However, given substantial industrial upgrades and changes in environmental standards, the need for an integrated river health assessment and improved coordination of monitoring efforts has become apparent. As a result, an examination of current information and issue-specific study plans was undertaken to identify data gaps and to recommend a rejuvenated framework for integrated environmental monitoring. G3 Consulting Ltd. (G3) was retained by CRIEMP to identify current data gaps (this document) and recommend a study design to assess overall river health (the companion document, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Study Design*).

The concept of integrated environmental monitoring has at least three relevant aspects. The first is integration of stakeholder efforts to yield coordinated study plans and sharing of valuable spatial and temporal data. This avoids duplication of efforts, reduces associated expenses, eliminates or reduces confusion regarding site location and sampling times and considers consistent quality assurance/quality control programs. The second aspect involves integration of study results into an ecosystem-based assessment to address the question of overall river and watershed health. This approach has philosophical, theoretical and ecological validity, yet is more complicated to address. A third involves integration of study results with resource and environmental management in the watershed, i.e., maintaining feedback between scientifically sound investigations and daily management and long-term decision-making regarding land and water uses.

TABLE 1-1:
Columbia River Integrated Environmental Monitoring Program, Committee Members (February, 2002)

Organization	Representative	Role
BC Hydro, Castlegar	Gary Birch Dean denBiesen	
Celgar Pulp Co. Ltd., Castlegar	Fiona McKay	
City of Castlegar	Andre Buss Pat Mawhinney	Treasurer
City of Nelson	Dave Cherry	
City of Trail	Gordon Gattifoni	
Columbia Basin Trust	Kindy Gosal	
Columbia Power Corp., Castlegar	Wally Penner	
Environment Canada Environmental Effects Monitoring Coordinator Environmental Conservation Branch	 Mike Hagen Andrea Ryan	
First Nations (CCRIFC/Ktunaxa/Kinbasket Tribal Council)	Bill Green	
Fisheries and Oceans Canada	Melanie Sullivan	
Lake Roosevelt Water Quality Council, Washington	Patti Stone	
Ministry of Water, Land and Air Protection Environmental Impact Assessment Section, Nelson Water Quality Branch, Standards & Protocols Victoria	 Julia Beatty Les Swain	Chair
Pope and Talbot Ltd., Castlegar	Gordon Brougham	
Teck Cominco, Trail	Bill Duncan	
UtiliCorp (formerly West Kootenay Power)	Sue Dyer Margaret Trenn	

1.1 Relevance of Watershed Health Assessment

Assessing river health becomes more relevant and urgent over time, as population growth increases and human influences and pressures on watersheds continue to grow. Health can be considered in a number of contexts, but can be taken to include both environmental and societal considerations. Hence, river health assessments provide information about the current state of the river ecosystem, sustainability of natural resources and associated activities of the surrounding watershed.

The emphasis on monitoring and assessing river health has changed over the last one hundred years. Karr (1999), in a paper "Defining and Measuring River Health", summarized progress made in identifying and resolving environmental impacts on rivers:

> *"We need a new approach, one based on new conceptual models of how rivers, landscapes, and human society interact. In the USA, models for what ails rivers, and how to protect or restore rivers, began with passage of the 1899 Refuse Act; the model then was to stop dumping raw sewage and oil into waterways. Successive generations of laws attempted to ensure that the human-waste-absorbing capacity of rivers was not exceeded. Several decades ago, the model changed to chemical contamination: rivers would be healthy if we would just avoid discharging excessive toxic chemicals into them.*

The latest model seems to be watershed analysis: a more comprehensive approach to the interactions of landscapes, rivers, and humans. Each of these models is only as good as its ability to reflect the primary societal goals regarding water resources, and those goals, too, have been changing: from taking water for granted, to "beneficial use", to protecting biological integrity. The challenge before us now is to apply the more useful models and to make progress towards actual protection." (page 225)

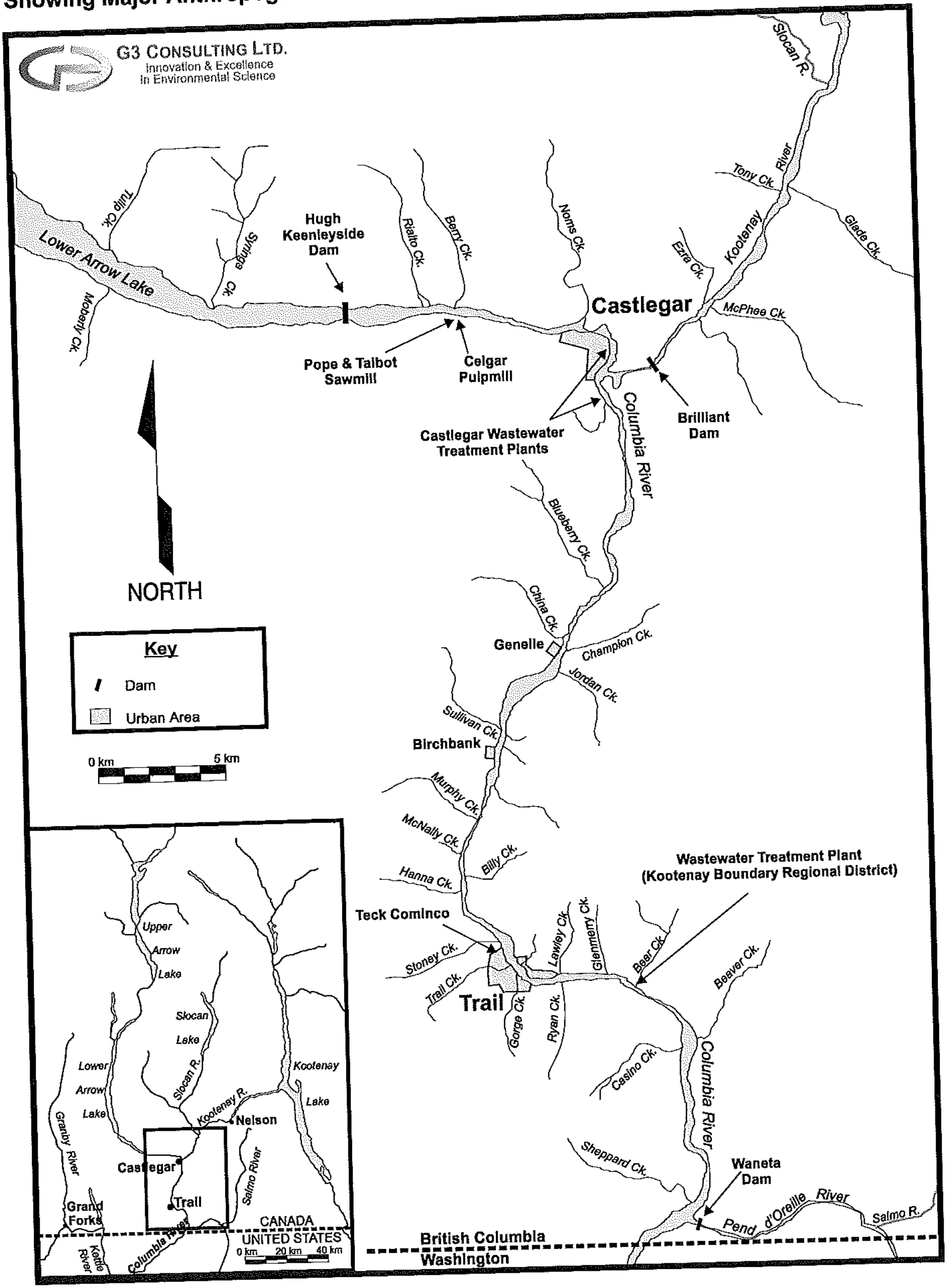
There are several challenges specific to an integrated health assessment of the Columbia River. It can be difficult to define a "healthy" river when sections have been dammed and otherwise affected by human activities, leaving no comparable undisturbed areas to use as reference areas. The question of whether water quality objectives adequately protect the river remains. What is a healthy Columbia River and who defines it? Decisions about acceptable standards are based at least partly on societal attitudes, values and preferences (Lackey, 2001). Knowledge and standards change over time, making flexibility and responsiveness an essential part of management. Competing and conflicting input often needs to be considered in policy and goal development. Decisions made in the past have human benefits and costs, as well as long-term effects on the river. Although scientific input about current conditions is an important component in the process, it is only part of the solution. A forum such as CRIEMP can enable stakeholders in the region to discuss issues of policies and goals openly, identify differing and shared viewpoints and values and develop a system of evaluation and adaptation (feedback loops). As Rykiel (1998, quoted in Lackey, 2001) explained: "*In a simplistic sense, science deals with true and false, whereas society deals with good and bad. Science can delineate the possibilities and describe the system that is likely to result from a policy, but it cannot decide if the resulting system is good or bad.*" An unstated implication of river health assessment is that the answer is provided in terms of "good and bad", with an underlying basis in "true and false."

1.2 Study Region

The Columbia River originates in Columbia Lake at Canal Flats, BC, flows northwest through the Rocky Mountain Trench, then south through several impoundments to form the Arrow Lakes, between the Selkirk and Monashee mountain ranges. Hugh Keenleyside Dam, completed in 1968, forms the outlet of the Arrow Reservoir. Downstream of the dam, the river flows past the cities of Castlegar and Trail, and enters Washington State approximately 60 km downstream of the dam. It flows into the Pacific Ocean along the Washington-Oregon border. The river is 1900 km long, with 750 km in BC, and the watershed is large, 155,000 km^2 in area, with approximately 103,200 km^2 in BC. The provincial government designated the Columbia River a Heritage River in 1998.

The study area lies between Hugh Keenleyside Dam and the US border (Figure 1-1). Distances from the dam to Birchbank and from Birchbank to the border are approximately 28 km and 32 km, respectively. Two major tributaries enter in the study area, the Kootenay at Castlegar and Pend d'Oreille just upstream of the US border. Based on mean annual flow, average water velocities and travel times were established (12 to 16 hours from dam to border, Aquametrix, 1994). This was divided into ~ four to six hours from the dam to the Kootenay River (0.5 m/sec), ~ four to six hours from the Kootenay to Birchbank (1.6 m/sec) and ~ four hours from Birchbank to the US border (1.6 m/sec).

FIGURE 1-1:
Lower Columbia River between Arrow Lakes and the Canada - USA Border, Showing Major Anthropogenic Influences



There are many human influences in this region, the most significant being regulation by dams built for water storage and hydroelectric power generation. Private and crown corporations are involved (BC Hydro, Columbia Power Corp., UtiliCorp, City of Nelson Power, Teck Cominco). There are three dams within the study area proper (Hugh Keenleyside, Brilliant and Waneta) and several further upstream on the mainstem and tributaries (Hirst, 1991). 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 Kootenay River and 27% through Waneta Dam and Pend d'Oreille River (Aquametrix, 1994). The remaining 4% flows in from small tributaries. Effects of regulation are substantial in terms of altered physical (flow regimes, velocity, water depth, temperature, habitat) and chemical (total dissolved gas pressure, nutrient cycling, effluent dilution) characteristics. Run of river dams such as Brilliant and Waneta were created for power generation and do not tend to hold back river flow or alter annual hydrographs to the same extent as storage dams such as Hugh Keenleyside. However, passage of water through turbines, over spillways, or via low-level ports generates dissolved gases (TGP) in both types of dams.

Hugh Keenleyside dam forms the outlet of the Arrow Lakes and upstream end of the study area, 8 km upstream of Castlegar. Mica and Revelstoke dams further upstream also regulate river flows. Keenleyside Dam was completed in 1967 under the *Columbia River Treaty* for downstream hydroelectric generation and flood control. It is 58 m high and 869 m long, formed of concrete and earth (Hirst, 1991). BC Hydro holds the water license and owns and operates this dam. Water is discharged through a combination of spillways and low-level ports. The natural hydrograph of the Columbia River has been greatly modified, with reduced peak flows, increased minimum flows and altered seasonal flow patterns.

Brilliant Dam, near Castlegar, is located on the Kootenay River 3 km upstream of the Columbia River. This is a run of river dam, the final in a series on the lower Kootenay River, including Corra Lin, Upper Bonnington, Lower Bonnington, South Slocan and Kootenay Canal (RL&L, 2000a). Brilliant Dam was built in 1944 by Cominco is operated by UtiliCorp (Hirst, 1991). The dam is 39 m high and 190 m long. Facilities were upgraded in 1949 and 1967 and are again being upgraded (Brilliant Upgrade, proposed Brilliant Expansion Project). Currently, Columbia Power Corporation owns the dam and UtiliCorp is responsible for spillway operation and power distribution. There are various combinations of ownership and operation of the other dams on the Kootenay. For example, the City of Nelson is responsible for Upper Bonnington and BC Hydro is responsible for Kootenay Canal.

Waneta Dam, located on the Pend d'Oreille River 0.5 km upstream of its confluence with the Columbia, is close to the US border (Figure 1-1). This run of river dam was constructed in 1954 by Teck Cominco to provide power for its smelter and is operated by UtiliCorp. The dam is 76 m high and 290 m long. Additional turbines were added in 1963 and 1966. There are two other run of river dams upstream, Seven Mile Dam (10 km upstream, owned and operated by BC Hydro) and Boundary Dam (in the US).

Consumptive uses of Columbia River water in the study area include 33 water licenses (MELP, 2000), the largest of which is for BC Hydro (water storage of 8.76 x 109 m^3 in the Arrow Lakes Reservoir). The City of Trail and Village of Warfield have licenses for drinking water (7.7 x 106 m^3/yr and 0.6 x 106 m^3/yr, respectively). In addition, there are nine licenses for domestic use, twelve for irrigation, one for industrial use (5.5 x 107 m^3/yr for

Teck Cominco) and two for fire protection. The City of Castlegar and Celgar Pulp Co. withdraw water from Arrow Reservoir for drinking and process water, respectively. Nonconsumptive uses include hydroelectric power generation in upstream areas and on major tributaries and recreational uses (sport fishing, swimming, boating).

Several industries (Celgar Pulp Company, Pope and Talbot Sawmill, Teck Cominco Metals Ltd.) and municipalities (Castlegar, Trail) are point sources of wastewater discharge and, as such, are regulated through permits. Table 1-2 lists relevant discharge permits. In addition, non-point sources related to stormwater runoff, other urban activities, agriculture and forestry activities contribute a diverse range of potential contaminants that can influence river health. Monitoring and recognizing specific impacts in a complex physical system is difficult due to their interactions and cumulative nature.

TABLE 1-2:
Effluent Discharge Permits for the Lower Columbia River

Permit number	Entity	Details
PE 1272 PE 1273	Celgar Pulp Company Pope and Talbot Sawmill (treated sewage effluent discharged through Celgar's effluent treatment works)	treated process and sewage effluent, main diffuser, 3.3 km downstream of Hugh Keenleyside Dam (177,000 m^3/d industrial effluent, 70 m^3/d landfill leachate, 114 m^3/d domestic sewage)
PE 80, PE 4008	City of Castlegar (municipal wastewater discharge, primary and secondary treatment)	two discharges, north side of river 1 km d/s of railway bridge and south side of river 2 km d/s of Kootenay confluence (2,300 m^3/d total discharge)
PE 141	Selkirk College (Castlegar, Robson area)	small amounts of treated sewage
PE 7622	Lion's Head Neighbourhood Pub (Castlegar, Robson area)	small amounts of treated sewage
	City of Nelson (upstream on Kootenay River)	treated sewage goes into Kootenay R. just below Grohman Narrows
PE 2753	Teck Cominco Metals Ltd.	Combined Outfall IV enters at Stoney Cr. Combined Outfall III discharges upstream of New Bridge and Combined Outfall II discharges at New Bridge
PE 133 PE 71	Fruitvale Beaver Falls Montrose	small amounts of secondary treated sewage enter river via discharge to Beaver Cr.
No permit number found	Stralaeff's Mobile Home Park	small amounts of treated sewage
PE 2174	City of Trail (RDKB) (municipal wastewater discharge, primary treatment)	east bank, downstream of Bear Cr., ~ 10 km d/s Trail 7,300 to 11,000 m^3/d

Source: Butcher (1992), MacDonald Environmental Services (1997)

Fish and fish habitat studies conducted by RL&L for BC Hydro in the early 1990s identified and mapped seven reaches for fisheries purposes (BC Hydro *et al.*, 1995; RL&L, 2001). These are described in Table 1-3 and Figure 1-2 in terms of flow, depth, substrate and habitat type. Four reaches were identified and used for CRIEMP I (Aquametrix, 1994). Survey sites and reaches used for CRIEMP I are shown in Figure 1-3.

TABLE 1-3:
Habitat Reaches in the Lower Columbia River

Reach	Distance	Description
1	km 0 to km 8	Hugh Keenleyside Dam to upstream end of Tin Cup Rapids low gradient, low water velocity, relatively deep (18 to 20 m), lake-like conditions during low discharge sand/silt substrates
2	km 8 to km 14	upstream end of Tin Cup Rapids to downstream of Kinnaird Bridge high water velocities, shallow (2 to 6 m), some channel braiding cobble/boulder substrates
3	km 14 to km 23	downstream of Kinnaird Bridge to Champion Cr. lower flows than Reach 2, moderate depth (6 to 10 m), comparatively straight, confined channel between steep, eroding valley walls cobble/boulder/coarse gravel substrates with small localized areas of sand deposition
4	km 23 to km 27	braided depositional island complex downstream of Champion Cr. moderate velocity, shallow (1 to 4 m), abundant near-shore habitat (gently sloping sand bars, many shallow side channels) cobble/gravel substrates
5	km 27 to km 38	downstream of island complex to upstream of Trail moderate to high velocity, narrow, deep channel (6 to 12 m) confined between high steep valley walls, bedrock outcrops along banks, with limited shallow water habitats
6	km 38 to km 51.5	upstream of Trail to upstream of Fort Shepherd Eddy moderate velocities (also areas of low and high velocities), shallow (3 to 8 m), relatively uniform habitat, moderate amount of shallow-water habitat Rock Island (km 43.5) – traverse escarpment of bedrock that produces a localized area of deep turbulent habitat cobble/small boulder substrates with localized areas of gravel
7	km 51.5 to km 56.5	Fort Shepherd Eddy to the Canada/US border high water velocities with rapids, shallow (3 to 6 m), limited nearshore shallow-water habitat Ft. Shepherd Eddy (at km 51.5, 50 m deep), low velocity Waneta Eddy (at km 55.0, 20 m deep) boulder/cobble substrates

Source: BC Hydro *et al*, 1995

FIGURE 1-2:
Habitat Reaches in the Lower Columbia River, adapted from BC Hydro *et al.* (1995)

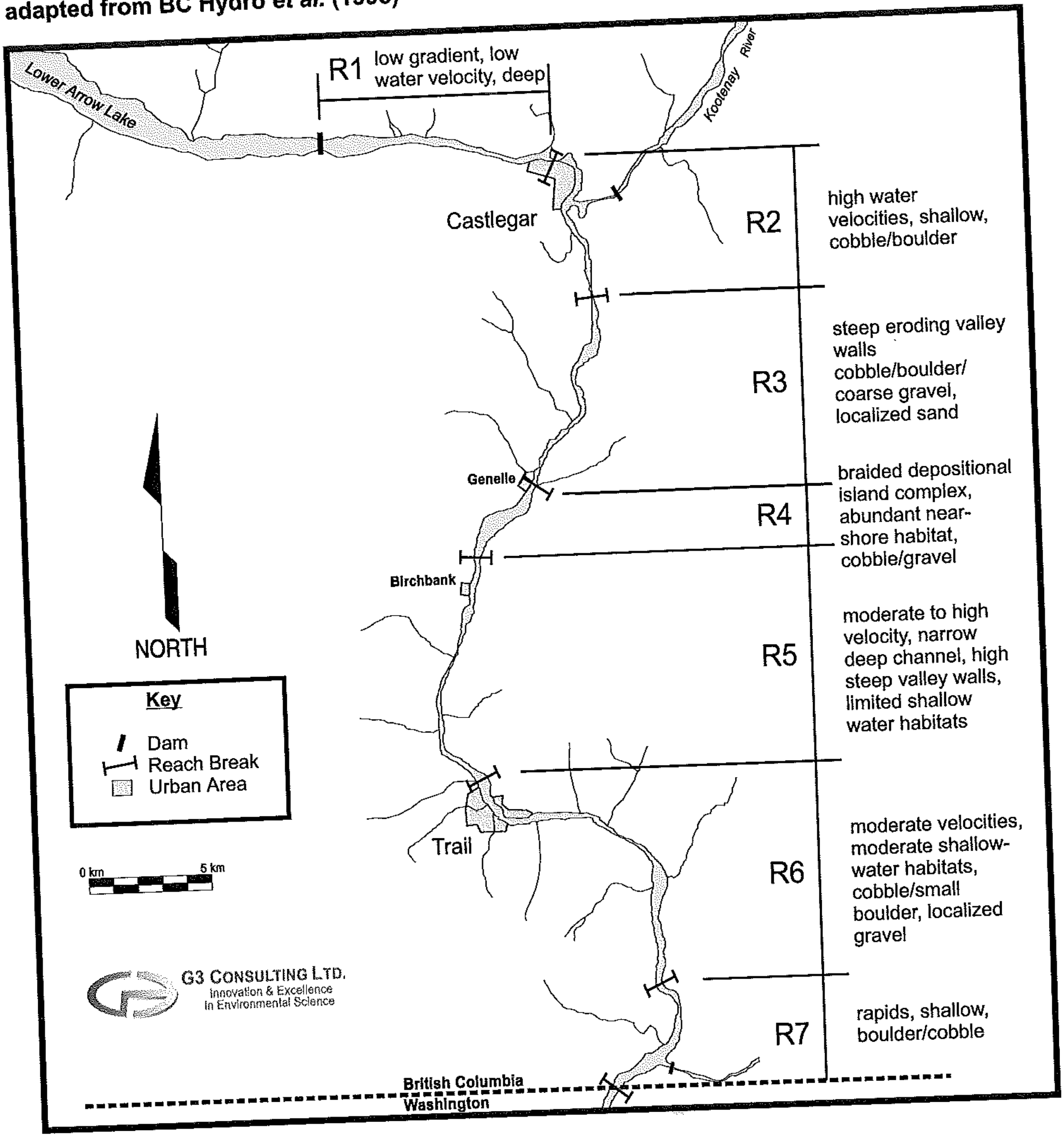
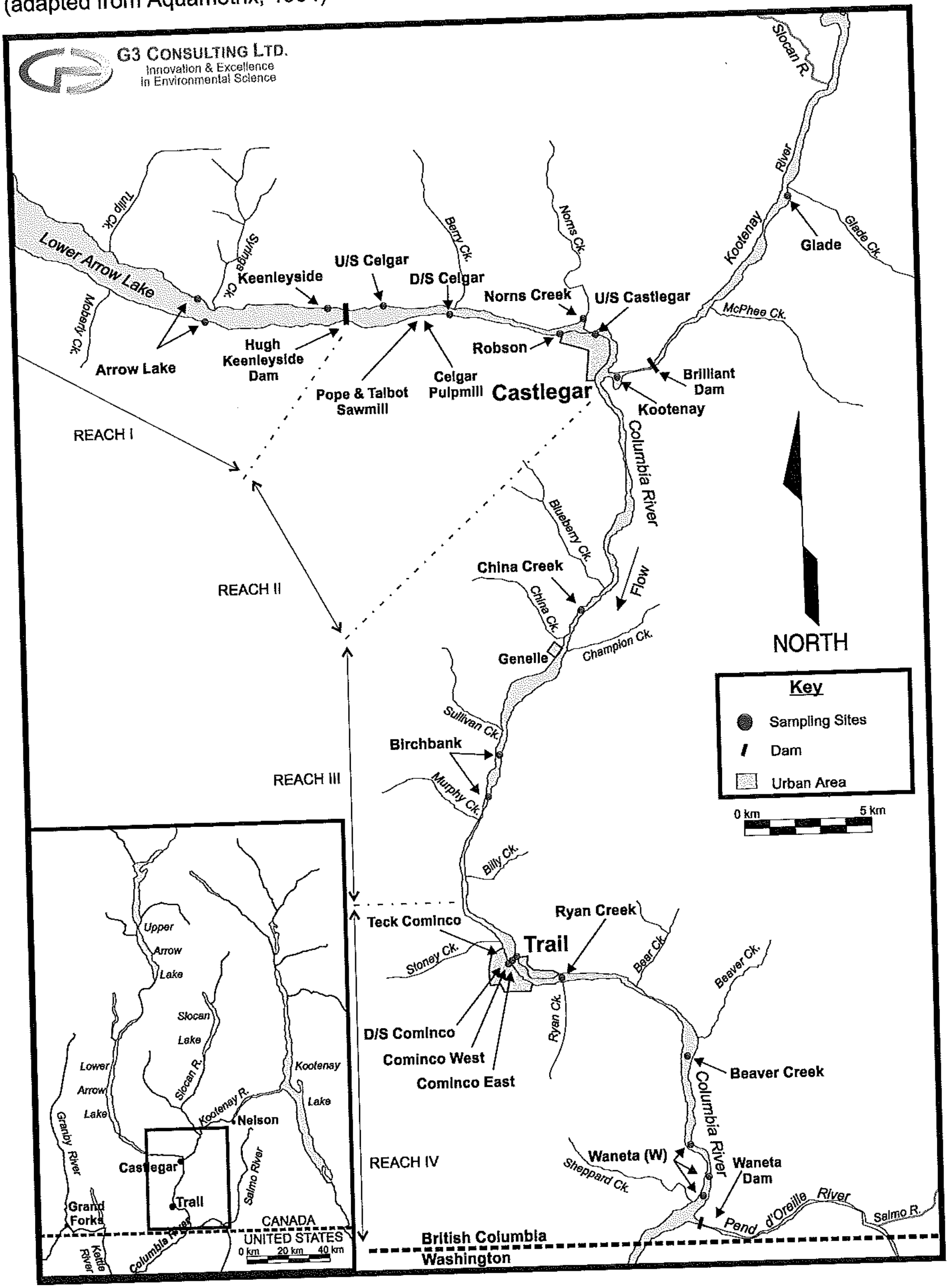


FIGURE 1-3:
CRIEMP I Sampling Sites, Lower Columbia River
(adapted from Aquametrix, 1994)



Federal and provincial agencies established permanent water quality monitoring stations at Birchbank and Waneta and have conducted sampling since the 1980s. Environment Canada (EC) monitors flow at Birchbank. Three regulatory agencies have jurisdiction (MWLAP, EC, Fisheries and Oceans Canada - DFO) through the *Fisheries Act, Waste Management Act* and *Canadian Environmental Protection Act.*

1.3 Ongoing Issues

Questions remain regarding overall health of the Columbia River. What are the degree and magnitude of identifiable effects on ecosystem health? Is enough being done and is it being evaluated adequately? The recommended monitoring program for the lower Columbia River and original CRIEMP study were intended to address these issues mainly from the perspective of the chemical contamination model described by Karr (1999). These studies provide answers to specific issues, yet are not designed to assess overall river health. For example, productivity and habitat quality, particularly affected by river regulation and adjacent land development, were recognized as not addressed in CRIEMP I, nor are they addressed directly in the water quality monitoring program.

Recent and ongoing issues and initiatives are discussed in detail in Sections 2.0 and 4.0 and summarized here. Many issues are related to existence and operation of dams. Altered hydrologic regimes resulting from water storage and release at Hugh Keenleyside Dam have affected physical, chemical and biological aspects of the river, and will continue to do so, although operational changes continue to be made to address these issues. BC Hydro has conducted many studies over the years to identify environmental impacts and has developed and implemented several mitigation and compensation plans, described most recently in the *Water Use Plan* created for Hugh Keenleyside Dam (RL&L, 2001). As both the federal *Fisheries Act* and the international *Columbia River Treaty* are considered when making decisions about dam operations, there are times when conflicting water uses arise, but it is not always clear which statute should take priority. For example, flows may be held back in response to downstream power or flood control needs in the US, resulting in dewatering of habitat and stranding of fish.

Several issues related to dam operation have been identified. Oligotrophication of the Arrow Lake Reservoir involves reduced nutrient supply and productivity in the reservoir and downstream portion of the Columbia River. The issue is being addressed through the Arrow Reservoir Fertilization Program (ARFP). The program began in 1998, and fertilization has occurred annually since 1999 (RL&L, 2001).

Altered habitat quality and availability is related to fluctuating water levels and dewatering, leading to stranding of fish and eggs and, perhaps, also affecting periphyton and benthic invertebrate populations. Fish mortality and stranding continue to occur when water levels drop rapidly. Fish community studies and other broad-based studies may provide more complete reflections of ecosystem health, as may studies of particular species. BC Hydro has commissioned a study to develop an indexing system for fish populations in the Columbia and Peace Rivers, to consider broader statistical, biological and ecological relevance of observed changes in fish populations (D. Schmidt, RL&L, pers. comm.). Recommendations have been made to include performance measures related to habitat issues in the MWALP water monitoring program (Gary Birch, BC Hydro, pers. comm.).

Elevated dissolved gas levels generated downstream of dams do not dissipate quickly, so tend to increase cumulatively downstream. High gas levels may affect fish populations, with greatest potential effects on survival and behaviour of fish species predicted in shallow water. The Transboundary Gas Group was established in 1998 to further investigate total gas pressure issues and coordinate efforts in BC and Washington State; several members of the CRIEMP TGP (total gas pressure) subcommittee sit on the Transboundary committee. A hydroelectric generating plant is being installed at Hugh Keenleyside Dam and upgrades to the Brilliant Dam are being made (RL&L, 2001), which are predicted to reduce generation of dissolved gas in the river. Laboratory studies to further define biological effects of TGP on juvenile rainbow trout are being undertaken by DFO (Bonnie Antcliffe, DFO, pers. comm.).

The status and fate of white sturgeon (*Acipenser transmontanus*) populations appears to be a good indicator of complex factors affecting the Columbia, as well as long-term effects of past and current watershed activities, particularly impoundment. These fish can live for at least a hundred years. White sturgeon populations in the region are now red-listed (endangered), along with burbot and Umatilla dace and blue-listed (rare) species such as bull trout, shorthead sculpin, mottled sculpin and chiselmouth chub (BC CDC, 2000; COSEWIC, 2000). BC Hydro and MWLAP have conducted several studies, although definitive solutions have yet to be found (RL&L, 1998a, 1998b, 1999, 2000a; Hildebrand *et al.*, 1999). Given that their typical migration patterns and habitats have been limited by dam construction, several isolated sturgeon populations now exist. Although mature fish continue to reside in this part of the Columbia, the youngest fish now reported are older than the 1966 age class, prior to construction of the Hugh Keenleyside Dam (RL&L, 2000). Spawning occurs in a limited number of areas (typically downstream of dams), but no larvae and no young of the year have been seen. Increased predation by introduced species such as walleye, water quality issues related to specific contaminants, and decreased sedimentation, nutrient supply and productivity related to impoundment have been suggested as contributing factors. Maintenance of sustainable sturgeon populations may or may not be an ecologically feasible goal for this region of the Columbia River. However, there is merit to considering sturgeon a macroscopic indicator or "canary in the coal mine," which indicates an awareness of long term consequences of past and current decisions and the need for broader-based ecosystem health assessments. A white sturgeon recover plan being developed by BC Hydro and MWLAP focuses on data gap analysis, review of current dam operations and development of short-term measures (a conservation aquaculture program), while considering long-term measures to maintain populations (RL&L, 2001).

The fate and effect on biological communities of compounds released from point sources (e.g., Celgar, Teck Cominco, municipal wastewater plants) and non-point sources is of continual interest. Notable improvements in industrial processes and effluent treatment have occurred since CRIEMP I, at substantial costs to the industries involved. The Celgar pulpmill underwent 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 and closed the phosphate fertilizer plant (1995), constructed a new

KIVCET lead smelter with improved air and water treatment systems (between 1997 and 1999), and installed a seepage collection system in the Stoney Creek watershed (completed in 1999). Improvements at Teck Cominco were designed to reduce metal loads to the Columbia River and the air.

Site-specific objectives for water, sediment and fish have been revised or established and a monitoring program for receiving waters developed for the area (Butcher, 1992; MELP, 2000). The question of whether currently achieved levels are acceptable and whether all relevant compounds are being measured can always be asked. For example, release of endocrine disrupting compounds (EDCs) from pulp mill and municipal effluent treatment plants is being studied (Julia Beatty, MWLAP, pers. comm.).

Both federal (EC, DFO) and provincial (MWALP) agencies are concerned with and involved in transboundary (BC-US) river health issues, including total gas pressure and compounds such as organochlorines and metals. Several conferences (1994, 1998) and committees (Transboundary Gas Group, BC-Washington Environmental Cooperation Council) have been organized to increase information sharing, cooperation, and planning regarding these issues. A representative of the Lake Roosevelt Water Quality Council sits on the CRIEMP committee, aiding communication at this level. In 1995, the State of Washington Department of Ecology, Eastern Regional Office and the Province of British Columbia Ministry of Environment Lands and Parks, Kootenay Region signed a Memorandum of Understanding (MOU). The agencies agreed to provide timely communication and information sharing on issues likely to have transboundary effects. This includes notification of proposed significant changes in discharges, consumptive water use, planning activities or significant spills likely to affect water quality of the Columbia River.

1.4 Adaptive Management Strategies

River health can mean several things, depending on point of view. As discussed in Section 1.2, it is often assumed that a scientific study can answer the question in an unbiased way. However, the benchmark or reference from which to compare and evaluate the river needs to be considered. How is a regulated river evaluated? Is the only healthy area a pristine area? Can an undisturbed area be found for comparison? Who decides on standards and water quality objectives? Hence, a consideration of river health goes beyond scientific veracity to underlying societal goals and attitudes and incorporation of results into a responsive management system.

A basic link between activities on the land (watershed, landscape) and responses in the river is essential. Tools continue to be developed to address this issue. Watershed-based plans, Official Community Plans (OCP), Land and Resource Management Plans (LRMP), *Water Use Plans* (WUP), Land Use Plans (LUP), Ecologically Sensitive Area (ESA) designations, Sensitive Habitat Inventory and Mapping (SHIM), Best Management Plans (BMP) and multi-stakeholder watershed councils are common concepts and processes now being used to guide land use decisions and protect watersheds. Public and First Nations interest and participation are becoming more common, with involvement of stewardship and conservation organizations. Awareness of, and integration with, these initiatives is another important component in assessing river health.

At present, the CRIEMP committee provides a forum for communication of monitoring data, sharing of information, planning and funding studies of the Columbia River, mostly science-based activities. However, acknowledgement of a role, already present that incorporates societal viewpoints will arise from river health studies. An understanding and acceptance by CRIEMP, as an entity, of its role in an ongoing, flexible, adaptive process is essential for study results to have meaning. Many management processes occur both formally and informally. Making them more apparent and maintaining communication among committee members and the community at large encourages accountability, responsibility and involvement regarding river health, highly relevant to a successful outcome to CRIEMP II.

Science & Monitoring vs. Decision-Making

Adaptive management strategies provide feedback between science and decision-making, the "true and false" "good and bad" framework. Scientists monitor, regulate, raise concerns. Does this process have the desired effect? Scientists can become caught between wanting to invent or implement something to measure everything exactly (a set of balances to measure the intangible), while knowing that river science is an inherently inexact science, and wanting decision-makers to make the right decisions, when results are less than definitive. *Integrated Watershed Management*, linking land activities with river responses, and directing information to decision-making and planning, is a well-established approach, and can be very effective when adapted and applied continuously to specific systems.

Currently, results of MWLAP- and industry-sponsored monitoring of water quality, sediment and fish tissue in receiving waters are reviewed, along with industry-organized monitoring of effluents for discharge permits and federal government monitoring programs for pulpmills. Results are used to determine compliance with permit conditions and to consider needs for additional studies or process modifications. An ecologically based study, such as CRIEMP II, will help assess, for example, whether meeting the water quality objectives are effective in protecting river health. A system for organizing the large amount of data from many sources and making it available to CRIEMP members and other interested organizations in a timely fashion is a first priority. Next is a need for condensing this information into reliable, easily understood assessments of river or ecosystem health. Methods for communicating data and interpreting results in terms of river health are discussed further in Section 5.0. Ultimately, though, the real goal is application of these assessments to day-to-day decisions and long term planning for the region.

The international implications and urgency of these issues have been discussed at two Canada - United States Technical Workshops on the Upper Columbia River Basin. The first, "An International Dialogue", was held in Spokane in 1994. The second, "Toward Ecosystem-based Management in the Upper Columbia River Basin", was held in Castlegar in 1998. A third is planned for 2002, again in Spokane. The need for ecosystem-based, watershed-wide (Canada and US) planning, monitoring and assessing has been emphasized repeatedly at these conferences. Goebel (1994) quoted Albert Einstein (from 1956) in describing the problem and possible approaches to solutions:

> *"Albert Einstein had two ideas that are appropriate as we reflect upon the current challenges we deal with. The first idea is 'the significant problems we face today cannot be solved at the same level of thinking we were at when we created them.' Secondly, in response to a reporter asking 'what hopes and fears does the scientific method imply for mankind?' Einstein said, 'perfection of means and confusion of goals seem – in my opinion – to characterize our age.' Hence, we continue to use the same thinking to solve problems which were created by the very decision making model that created these*

problems. Even deeper, we are a society which focuses on means versus goals. It is time to begin the transition to successfully sustain the ecosystem." (page 23)

A major challenge of CRIEMP II is and will be to not fall into a similar trap of planning, implementation and evaluation.

1.5 CRIEMP II: Goals

Ongoing changes in watershed activities and a continued desire to assess health of the Columbia River study area and associated watersheds has led to the current review of data and issues and a proposed study design. The current study was designed to address the following:

- provide a critical review and assessment of existing environmental information (1990 to the present);
- identify gaps in current information;
- recommend a study design to fill these gaps, address the state of ecological health of the river, define cumulative environmental impacts and assign cause and effect relationships between human activities on the river (i.e., an integrated environmental assessment); and,
- propose mechanisms and options for combining a proposed integrated environmental assessment with other studies planned for 2002/2003 by individual agencies and entities in the watershed.

The first step was to contact committee members for their views on current issues, recent initiatives, strengths and limitations of the original study and the value of various communication tools (e.g. databases, web site, library, GIS system) for conveying data and other information among stakeholders and, possibly, the general public. Of particular relevance was the vision of individual members regarding what an integrated environmental monitoring program should provide. A questionnaire was circulated, and a wide range of responses obtained, reflecting the backgrounds, expertise and jurisdictions of members (Appendix 1). However, common themes were apparent (cooperation, coordination, communication, cost-effectiveness), as they were for CRIEMP I. These themes make a good focal point for establishing and maintaining direction for CRIEMP II and ongoing committee processes.

Successful implementation of a new study will involve addressing as complete a set of environmental concerns as possible. Previous investigations have yielded much useful information regarding difficulties studying this large regulated river, as well as baseline data with which to assess temporal changes. However, the power of the recommended study will lie as much in how results are integrated into ongoing resource management structures as in their scientific validity. Hence, an indication of the interest and degree of involvement of the various stakeholders in design and implementation of a new integrated study is relevant. The study design is presented in the companion document, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Study Design.*

1.6 CRIEMP I: Findings & Action Points

The original CRIEMP study was intended to provide information about the "state of the environment" and a framework for an integrated environmental monitoring program. The study area, then as now, was the lower Columbia River from Hugh Keenleyside Dam to the

International Border (Figure 1-3). Several objectives were identified by Baturin (1993): providing statistically valid and quality assured data; assessing trends and cumulative effects of Celgar, Teck Cominco, municipalities and other sources of pollution; identifying sentinel species for short and long term bioaccumulation assessments; and providing information on contamination of non-migratory indicator fish species. Study results from the 1992 field program were summarized by Aquametrix (1994) and below.

Water Quality

Compounds traceable to Celgar (organochlorines, resin acids) were below prevailing provincial and federal water quality criteria and guidelines at all stations sampled. Cadmium, chromium, mercury, lead, copper and zinc were reported in concentrations higher than water quality criteria at sites downstream of Teck Cominco in up to 40% of the water samples, although mean concentrations were frequently within criteria. Coliform levels, associated with municipal wastewater discharge, were below criteria established for drinking water and recreational use. Controlled flows resulting from operation of Hugh Keenleyside and Brilliant dams affected physical conditions and habitats, determined the dilution potential for contaminants and created supersaturated water (total gas dissolved pressure, TGP). Provincial water quality criteria (110% TGP) were exceeded between November and July each year, with average values of 114% TGP reported.

Sediment Quality

The lack of identifiable depositional areas made it difficult to design spatial sampling protocols specific to industrial discharges. Resin acid concentrations were elevated immediately downstream of Celgar and at Waneta. An up to 40-fold increase in trace metal concentrations was reported at Beaver Creek, downstream of Teck Cominco. Differences in acid volatile sulfide (AVS) and total organic carbon (TOC) levels among sites were speculated to account for some differences in contaminant levels. For example, AVS affected bioavailability of metals, whereas TOC was associated with binding capacity of organic compounds. A lack of sediment quality criteria or guidelines at the time of the study made it difficult to assess potential impacts of contaminants in sediment to aquatic life.

Biota

Plant communities on natural substrates (periphyton, macrophytes) were studied. Some spatial differences in metal bioaccumulation in macrophytes were noted, but statistical reliability could not be assessed due to insufficient replication. Periphyton and macrophyte studies did not yield relevant data, due to difficulty sampling representative communities.

Spatial differences in benthic invertebrate communities were considered to reflect flow regulation, substrate type and industrial discharge. Three community types were identified. The first was from Hugh Keenleyside Dam to 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 Cr. and Waneta sites), where lower invertebrate abundance and diversity were considered to reflect effects of smelter discharges.

Bioaccumulation of metals and organochlorines in adult caddisflies and indigenous mussels yielded inconclusive results, partly a result of low replication and number of sampling sites. Caddisflies showed elevated metal, dioxin and furan levels at Waneta compared to other sites. Mussels showed metal accumulations at Waneta, but results were inconclusive for organochlorines due to high concentrations at the reference site (Kootenay River), suggesting other sources in that watershed.

Sediment bioassays using amphipods (*Hyalella azteca*) were useful for assessing industrial effluent toxicity. Survival was reduced in sediments sampled downstream of Celgar and Teck Cominco.

Limitations & Recommendations Arising from CRIEMP I

Identified study design issues included difficulty establishing good reference stations, a limited number of sites upstream and downstream of effluent outfalls, lack of concurrent sampling of water, sediment and biota (making it difficult to correlate results), and insufficient field replication for statistical purposes (Aquametrix, 1994). A focus on river quality at the International Border was recommended. The use of hypothesis testing (that no measurable, statistically reliable differences in river characteristics result from operation of dams, Celgar and Teck Cominco, as measured in water, sediment and biota) was suggested as a statistically valid approach. The importance of defining quality assurance/quality control (QA/QC) criteria prior to study implementation, including standards, detection limits, use of trip and laboratory blanks, field and laboratory replicates and certified reference materials was also identified.

Specific suggestions for future studies included concurrent sampling of all components at low flow (late summer), sampling of some components at high and moderate flow, omission of organochlorine and resin acid analysis in water (usually below detection limits) and use of sediment sampling to define temporal rather than spatial changes. More extensive benthic invertebrates sampling (more replication, use of consistent substrate and habitat types) and expansion of bioaccumulation studies to all sites (adult caddisflies at erosional sites, mussels at depositional sites) were recommended. Other suggestions included assessment of periphyton growth on artificial substrates, an expanded program of sediment toxicity bioassays (behaviour and survival, increased replication, inclusion of all sediment sampling sites), and habitat assessments, including substrate particle size, at each site.

Three sites were suggested upstream of Tin Cup Rapids (upstream of Celgar, immediately downstream of Celgar in the mixing zone, further downstream of Celgar) in the slow moving region downstream of the dam. Eight sites were suggested downstream, in the more riverine stretches (downstream of Castlegar, downstream of China Cr., Birchbank, upstream of Teck Cominco, immediately downstream of Teck Cominco, further downstream of Teck Cominco, downstream of Beaver Cr., Waneta). Two reference areas on other regional river systems (slow-flowing and riverine) were recommended.

1.7 Summary

Actions that followed publication of the CRIEMP study (Aquametrix, 1994) are discussed in Section 2.0. Progress is being made on transboundary issues. Water quality objectives were developed for contaminants in water, sediment and fish. A recommended sampling regimen was developed and is being conducted by MWLAP with some modifications. Cooperation on investigation of identified issues such as total gas pressure, flow regulation and effluent toxicity occurs. Celgar and Teck Cominco have undertaken major facility upgrades and conducted issue-specific studies to assess changes in the receiving environment. Committee members continue to meet to share information and discuss watershed issues. Industry-specific studies have been done for BC Hydro (RL&L, 2001), Celgar (Hatfield, 1997, 2000) and Teck Cominco (Duncan, 1999; G3 Consulting Ltd., 2001). However, since 1994, there has been no integrated or coordinated study or process to assess overall river or watershed health, and no baseline or ambient definition of health.

The current CRIEMP II proposal is intended to build on successes and lessons of the past to address some of these questions and provide a framework for future resource management decisions in the watershed. This can be accomplished through a combination of scientifically sound study and focus on committee functionality and information exchange.

2.0 INITIATIVES & STUDIES SINCE CRIEMP I

Several industry initiatives to reduce environmental effects and increase productivity were identified as being in the planning or construction phase (Aquametrix, 1994); hence their effects on river health could not be assessed in the original CRIEMP study. Initiatives and studies undertaken since 1993 are summarized in Table 2-1 and discussed below.

TABLE 2-1
Initiatives Undertaken Since CRIEMP I

Organization	Initiative	Year
Min. Water, Land and Air Protection	water quality objectives & monitoring program for sediment, fish and water, Birchbank to US border	2000
Environment Canada	Pulp and paper mill Environmental Effects Monitoring (EEM) automated water quality monitoring at Waneta	since 1992
Fisheries & Oceans Canada	mountain whitefish health studies studies into effects of TGP on fish	1992 to 1996 2001
BC Hydro	*Water Use Plan* maintain flows during rainbow trout spawning period, salvage of exposed eggs, fry, adults maintain flow during mountain whitefish incubation fish community assessment	2001 since1992 begun 2001
Columbia Power Corp.	Arrow Lakes Generating Station Brilliant Upgrade, proposed Brilliant Expansion Project	2002 2002
Teck Cominco Metals Ltd.	closure of the phosphate fertilizer plant; construction of zinc electrolytic and smelting plants, zinc pressure leaching plant, cadmium plant, cessation of slag discharge construction of KIVCET lead smelter construction of Stoney Cr. seepage collection system wide-area Ecological Risk Assessment 1995/1999 receiving environment study	1995 1997 to 1998 1997 to 1999 ongoing 2001
Celgar Pulp Company	upgrade and expansion completed (lime kiln, recausticizing plant, ClO_2 generator, effluent treatment system, pulp machine, evaporators, recovery boiler, Kamyr fibre line) elemental Cl_2 for bleaching replaced with 100% ClO_2 Environmental Effects Monitoring, now into Cycle 3	1993 1993 since 1993
Multi-partner projects	habitat compensation projects White Sturgeon Recover Plan Transboundary Gas Group Arrow Lake Fertilization and Monitoring Program	 since 1998 since 1998

2.1 Regulatory Agency Responsibilities

The federal government is responsible for enforcing the *Fisheries Act*, with DFO regulating most aspects and EC responsible for the *Pulp and Paper Effluent Regulations* in the *Fisheries Act*. EC is also responsible for the *Canadian Environmental Protection Act*. River flows are monitored at Birchbank (ENVIRODAT site BC08NE049). Since the 1980's, EC has conducted routine biweekly monitoring at Birchbank (provincial EMS Site 0200003, ENVIRODAT Site BC08NE005) and Waneta (provincial EMS Site 0200559, ENVIRODAT Site BC08NE001). Monitoring results were summarized by Holms and Pommen (1999a, 1999b) in *State of Water Quality of Columbia River* reports for Birchbank (1983 to 1997) and Waneta (1979 to 1996). Low-level analysis of metals in fish muscle and liver tissue was performed in 1999 and automated monitoring of some parameters has begun at Waneta (Andrea Ryan, EC, pers. comm.). EC is responsible for overseeing the pulpmill Environmental Effects Monitoring (EEM) programs conducted at Celgar and other pulpmills in the province, in cooperation with provincial agencies. Mountain whitefish health studies were conducted by DFO in 1992 (Nener *et al.*, 1995), 1994 (Antcliffe *et al.*, 1997a) and 1996 (Antcliffe *et al.*, 1997b). Indices of fish health and levels of metals and organochlorines in muscle and liver tissue were assessed and compared over time, with substantial improvements noted over time for several parameters (Antcliffe *et al.*, 1997b). DFO is also examining the effects of total dissolved gas pressure on rainbow trout in laboratory experiments (Bonnie Antcliffe, DFO, pers. comm.).

The *Waste Management Act* and *Contaminated Sites Regulations* are administered by MWLAP. The Ministry monitors receiving water relative to water quality objectives, administers industrial permits, conducts or directs specific investigations and helps coordinate environmental studies and decision-making in the watershed. Data stored in the provincial EMS (Environmental Monitoring System) database are only available to the public through Freedom of Information requests, but there are plans for wider accessibility in the future (Robyn Roome, MWALP, pers. comm.). In 2000, MWALP published site-specific water quality objectives and recommended monitoring protocols for the Columbia River between Birchbank and Waneta, following consultation with CRIEMP stakeholders (MELP, 2000).

Members of MWALP, DFO, EC, BC Hydro and Columbia Power Corp. have participated in the Transboundary Gas Group, a committee formed to address elevated total gas pressure issues in the Columbia River on both sides of the Canada-US border, since its formation in 1998. The committee coordinates studies and efforts at reducing levels of total dissolved gas, which tend to accumulate progressively downstream of dams, resulting in higher levels in the Washington portions of the river than in British Columbia. The committee has developed long term plans to address this issue .

2.2 Site-Specific Water Quality Objectives & Protocols

Water quality has been evaluated based on provincial criteria (Nagpal *et al.*, 1995) and federal guidelines (CCME, 2001), which typically list maximum or mean contaminant concentrations in water recommended for particular water uses (e.g., aquatic life, wildlife, recreation, drinking water, irrigation). Although not legally enforceable, except where included as part of discharge permits or a regulation, objectives can be invaluable in assessing water quality and providing policy direction for resource managers.

CRIEMP I identified a lack of water quality guidelines for contaminants in sediment and fish tissue with which to compare Columbia River results (Aquametrix, 1994). At that time, there were site-specific water quality objectives and monitoring programs for the section from Hugh Keenleyside Dam to Birchbank (Butcher, 1992) but not from Birchbank to the Canada-US border. MacDonald Environmental Services (1997) provided technical guidance and data review to 1997 for development of objectives for the lower section, which were published in 2000 (MELP, 2000). Objectives for metals in water were based on mean values over one-month periods at low flow (winter, spring, fall), rather than previously defined maximum values. Small adjustments were made to some values relative to provincial levels and objectives modified for cadmium (short and long-term) and established for thallium. Section 3.0 describes objectives and the recommended receiving water monitoring program.

Water quality objectives are linked to activities for which discharge permits are required under the *Waste Management Act* (pulpmill, smelter, wastewater treatment plants) and, therefore, have a degree of required monitoring and compliance associated with them. Parameters specifically linked to dam operations include dissolved oxygen and total gas pressure. Those related to Celgar discharges include dioxins and furans (in water, sediment and fish), total organic carbon, substrate sedimentation, pH, temperature, colour, suspended solids, turbidity, chlorinated phenols, resin acids, chlorinated resin acids and receiving water toxicity. Parameters relevant to Teck Cominco discharges include ammonia and pH in water and arsenic, cadmium, chromium, copper, lead, mercury, thallium and zinc in water, sediments and fish tissue. Parameters relevant to municipal wastewater discharge include fecal coliform, *Escherichia coli* and enterococci.

2.3 Dams & Hydroelectric Facilities

Issues related to operation of the Hugh Keenleyside, Brilliant, and Waneta dams were identified in the original CRIEMP study (Aquametrix, 1994). Both BC Hydro and Columbia Power Corp. have undertaken several initiatives since CRIEMP I, summarized in BC Hydro's *Water Use Plan* for Hugh Keenleyside Dam prepared by RL&L (2001). In addition to large-scale habitat and fisheries assessments, there were numerous other reports summarizing annual monitoring programs at Hugh Keenleyside and Brilliant Dams. The creation of a *Water Use Plan*, required by the provincial government for all dams, was a large undertaking and summarized studies and initiatives to date (RL&L, 2001). This process involved consultation with various stakeholders to consider and balance competing water uses such as hydroelectric, industrial, recreational, community, flood management and fish habitat values. Environmental issues relevant to the Columbia River include oligotrophication of the reservoir, elevated dissolved gas levels downstream of the dam and altered habitat quality and availability (related to fluctuating water levels, dewatering of nearshore areas, stranding of fish, eggs and benthic invertebrates).

Oligotrophication

Oligotrophication has been identified as a long-term consequence of impoundment for reservoirs around the world, as well as Arrow Lake Reservoir. Typically, increased nutrient supply and productivity (eutrophication) initially accompany impoundment, as nutrients in soils of the flooded lands are released. After several years, the reservoir begins to act as a nutrient sink, as particulate inorganic and organic material and associated nutrients are settled out to the sediment rather than flushed downstream (Stockner *et al.*, 2000). This sedimentation reduces primary (plant) and secondary (animal) productivity, nutrient recycling and transport downstream, while increasing nutrient storage in the sediment. It also reduces turbidity in downstream water, which can have several biological effects, including increased light penetration for algae and increased visibility of prey (e.g., white sturgeon larvae). Reduced productivity of the Arrow Lake reservoir, as well as the Columbia River downstream of the dam, was documented as an important issue related to overall ecosystem health subsequent to CRIEMP I, with declines in kokanee populations during the 1990s considered an indicator of reduced productivity (RL&L, 2001).

The Arrow Lake Fertilization and Monitoring Program was begun in 1998, following several years of reservoir study (Pieters *et al.*, 1998, 1999, 2000). It is funded and conducted by BC Hydro, Columbia Power Corp., MWALP, Ministry of Agriculture, Food and Fisheries, BC Ministry of Transport Marine Branch, Columbia Basin Trust and Columbia Basin Fish and Wildlife Compensation Program. The program is modelled on the Kootenay Lake fertilization program, which involved nine years of fertilization. A ferry traversing the upper lake disperses nitrogen and phosphorus weekly from late April to late August. Responses of Arrow Reservoir biota to increased nutrient supply are being monitored and observed (CPC website, 2001) and significant increases in size and abundance of kokanee were documented in 2001 (CBFWCP website, 2001). However, effects on downstream river communities, not currently assessed, are essential to understanding river health.

Total Gas Pressure

The force of water discharged from a dam entrains additional air (nitrogen, oxygen, etc.), resulting in supersaturated water as hydrostatic pressure forces the bubbles into solution. Supersaturation is measured as elevated dissolved gas levels or total gas pressure (TGP), the sum of partial pressures of all gases, relative to local atmospheric pressure. Levels remain elevated for long distances downstream and tend to increase cumulatively when there are several dams on a system. The many routine monitoring studies done by CRIEMP, BC Hydro, CPC and UtiliCorp are listed in RL&L (2001).

Several approaches to address this problem, which affects health and survival of fish, have occurred since CRIEMP I. Water quality guidelines were established to protect fish from high TGP levels. The BC guideline 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 (MELP, 1998; CCME, 2001). Currently, the objective is met most of the year, but generally not in late summer, when flows are greatest. The 110% TGP level also applies in the US (USEPA, 1986). The Transboundary Gas Group was established in 1998 to coordinate efforts in BC and Washington State to reduce TGP levels.

Elevated TGP has the potential to affect survival and behaviour of fish and, perhaps, benthic invertebrates (Aquametrix, 1994). The effect of elevated TGP on fish is somewhat like the "bends" in human divers – most apparent when moving from deep to shallow water. Fish are most susceptible in shallow nearshore waters, whereas in deeper water (below the compensation depth) they can benefit from increased hydrostatic pressure. The most common effect is gas bubble trauma (GBT), appearing as bubbles in the gills, vascular system, fins and eyes, and as overinflation of the swim bladder (US Dept. of Interior, 2000), which develop when excess air in the circulatory system moves into tissues. GBT can lead to lethal or sublethal effects (death, disorientation leading to increased predation or reduced feeding efficiency), depending on gas levels, species and life cycle stage, exposure time, water depth and temperature (Bonnie Antcliffe, DFO, pers. comm.).

Biological implications of GBT on fish populations downstream of the Keenleyside Dam are not clear (RL&L, 2001). Laboratory and *in situ* studies (using fish in cages) have documented mortality in rainbow trout, mountain whitefish and walleye exposed to elevated TGP in shallow (less than 1.5 m) but not deeper water (3 m). However, the reported incidence of GBT in fish collected downstream of the dam is low, perhaps because the species or life stages studied spend little time above the compensation depth or in shallow near-shore areas. A minor impact of TGP on some species has been suggested for this part of the Columbia River, given the stable or increased numbers of rainbow trout and mountain whitefish during the 1990s, a time of relatively high TGP during at least part of the year (RL&L, 2001). Likewise, white sturgeon adults do not appear susceptible, as they inhabit water below the compensation depth, nor do larvae, although the possibility of bubble formation in the buccal cavity during the pelagic dispersal phase was not ruled out (Shrimpton *et al.*, 1993). Laboratory studies to further define biological effects of TGP on juvenile rainbow trout are being undertaken by DFO, with emphasis on mortality from GBT and sublethal effects such as susceptibility to predation (Bonnie Antcliffe, DFO, pers. comm.).

Historically, TGP levels downstream of Hugh Keenleyside Dam have been high compared to other rivers in BC (Hirst, 1990). Levels greater than 140% TGP have been measured over extended periods during the summer (Aquametrix 1994). BC Hydro has conducted many TGP studies in the Columbia River under varying dam operations since the early 1990s, and has modified operations to reduce levels at sensitive times of year (RL&L, 2001). At Hugh Keenleyside Dam, use of spillways to discharge water result in the highest TGP levels, and use of low level ports result in lower TGP levels. However, the spillway facilities are used most consistently during the high flow period, July to October. Aspen Applied Sciences Ltd. (1995; 1997a,b; 1998; 1999; 2000a) developed and refined a computer model that recommends real-time operations to reduce TGP and indicates hazards in areas of the river known to be used extensively by sportfish. Decisions to modify discharge patterns are affected by structural safety issues of the dam as well as health of downstream aquatic communities.

The situation on the Columbia River is complicated by addition of water from the Kootenay and Pend d'Oreille Rivers, which also contribute TGP, mainly from May to late June, when tributary flows are maximal (RL&L, 2000b). TGP levels are elevated in the Arrow Reservoir itself, likely associated with upstream dam operations (Mica and Revelstoke dams), and increase downstream of the dam. The 1999 TGP monitoring study was conducted from April to November at four sites, from within the reservoir to immediately downstream of the US border (RL&L, 2000b). TGP levels ranged from 98 to 111% in the reservoir, 104 to 147% at Robson downstream of the dam, 103 to 130% upstream of the Pend d'Oreille, and 102 to 127% downstream of the US border. Although maximum TGP levels have not changed over the years, the duration has decreased as a result of operational changes.

BC Hydro and Columbia Power Corp. continue to adjust operations to reduce TGP levels. Reductions are expected to accompany operation of Columbia Power Corp.'s newly constructed and proposed hydroelectric facilities on the Keenleyside Dam (Arrow Lakes

Generating Station, ALGS) and Brilliant Dam (current Brilliant Upgrade Project, proposed Brilliant Expansion Project). Reduced TGP is expected to accompany use of turbines rather than spillways for water discharge (CPC website, 2001).

Fish Habitat Quality & Quantity

Seven distinct habitat reaches, described in Section 1.3, were identified in the study area (Aquametrix, 1994; BC Hydro *et al.*, 1995; RL&L, 2001). These reports also provide fish species, abundance, life history and habitat preference information. Most studies were designed to document specific impacts related to flow regulation rather than overall significance to ecological health. In 2001, BC Hydro commissioned a study to provide a broader assessment of fish community health by developing population abundance indices (PAI) for target fish species (D. Schmidt, RL&L, pers. comm.). These indices will incorporate historical data and ongoing monitoring, with the goal of providing statistically reliable assessments of fish populations, which can then be used to attribute temporal changes to natural (variability, events) or anthropogenic (flow regulation, other) influences.

Fluctuating and low water levels particularly affect nearshore, shallow water habitat and the fish species and life stages that use such habitats. Fry of many species, rainbow trout and mountain whitefish eggs, and adult sucker, northern pikeminnow, redside shiner and sculpin are most susceptible (RL&L, 2001). Productivity and survival of benthic invertebrate and fish communities in nearshore habitat are affected when water levels drop. Details of studies and programs to address habitat alteration, entrainment of fish over spillways, passage of fish upstream and downstream through navigational locks at Hugh Keenleyside dam, stranding of fish eggs, juveniles and adults, and potential effects on benthic invertebrate productivity are described in RL&L (2001). Particularly sensitive habitats have been identified in terms of fish usage and susceptibility to fluctuating water levels.

BC Hydro has developed two operational plans to address fisheries concerns (RL&L, 2001). Flows are maintained to keep consistent depth at Norns Creek fan during rainbow trout spawning, April to June and minimize dewatering and exposure of redds. Since 1992, flows have been reduced in late March to discourage spawning in areas that could become dewatered, then kept stable or higher until after juveniles emerge in late spring. Exposed eggs are salvaged in late March, if needed. The second plan is to maintain consistently low discharges during mountain whitefish incubation and emergence, late December to late March, to prevent dewatering of redds. In addition, shallow areas are checked following flow reductions and stranded fish salvaged.

Other mitigation and compensation projects have been conducted by BC Hydro directly, or indirectly through the Columbia Basin Fish and Wildlife Compensation Program (CBFWCP) in partnership with MWALP (RL&L, 2001). Compensation for loss of rainbow trout spawning habitat due to flow fluctuations was done at Norns Creek fan (not successful due to lateral movement of the creek channel and bedload deposition) and Genelle (exclusion fencing in shallows worked one year but not the next in high water). Compensation for mountain whitefish habitat included an experiment in scarification in fall 1999, involving flow reduction to expose substrate, followed by mechanical disruption of compacted substrates near shore to provide enhanced retention of eggs. Habitat restoration on Norns, Champion, Blueberry and Murphy Creeks has involved bank stabilization, instream cover and log weir placement, improved fish passage through culverts and side channel enhancement.

Mitigation for habitat disturbance related to stability work at the base of the dam included riparian planting in 2000. The Ministry of Transport provided compensation work by installing rubble piles to increase habitat diversity near Norns Creek in 1995.

White Sturgeon

White sturgeon populations in the study area are considered endangered (BC CDC, 2000). Angling, with size restrictions, was allowed until 1993, at the time of CRIEMP I, then allowed on a catch and release basis until 1996, when a total ban was established (RL&L, 2001). The endangered status is based on low population levels (an estimate of 1120 fish below dam in 1995), impacts of hydroelectric development and lack of recruitment since the mid-1960s. Abundance, distribution, movement, life history and locations of critical habitat in the lower Columbia River have been the focus of several MWALP and BC Hydro studies (RL&L, 1998a, 1998b, 1999, 2000a). Hildebrand *et al.* (1999) provided a major review of status and management of white sturgeon in the Columbia River in BC.

White sturgeon can live for over a hundred years. Given that their typical migration patterns and habitats have been limited by dam construction on the Columbia River, several isolated populations now exist. Adults prefer deep-water, low-flow, riverine habitats and are found immediately below the Hugh Keenleyside Dam, at the confluence of the Kootenay and Columbia Rivers, and near the US border at the Ft. Shepherd and Waneta Eddies (Hildebrand *et al.*, 1999). Since construction of Hugh Keenleyside Dam, spawning has been observed only in the Pend d'Oreille River, downstream of the Waneta Dam tailrace, during June and July. Although mature fish continue to reside in the system, there has been no recruitment of young sturgeon for many years. The youngest fish now reported are older than the 1966 age class, prior to completion of the dam in 1968 (RL&L, 2000a). Although spawning is observed and eggs found, very few larvae and no young of the year are seen. Study and speculation into factors contributing to lack of recruitment have yielded several possibilities (RL&L, 2001). The 2 to 3°C temperature difference between the Columbia River, where fish congregate prior to spawning, and the lower Pend d'Oreille River, where spawning occurs, may affect egg viability and larval survival, as temperatures rise more quickly in the Pend d'Oreille and may reduce viability. Increased predation on larvae by species such as walleye (introduced into Lake Roosevelt) may occur, due to increased walleye abundance and increased efficiency in predation in the clear water (a consequence of impoundment). Altered water quality characteristics related to impoundment, such as decreased sedimentation, elevated TGP or reduced nutrient supply and productivity, or related to specific contaminants may affect larval survival as well.

A white sturgeon recovery plan being developed by BC Hydro and MWALP focuses on data gap analysis, review of current dam operations and development of short-term measures, while considering long term measures to maintain populations (RL&L, 2001). The Hill Creek hatchery on Upper Arrow Reservoir, constructed in 1993 for bull trout and rainbow trout enhancement, is now used for conservation aquaculture of sturgeon.

2.4 Celgar Pulp Company

Celgar Pulp Company is located northwest of Castlegar, approximately 3 km downstream of Hugh Keenleyside Dam and upstream of the Kootenay River confluence (Figure 1-1). The mill began operation in 1961 as a bleached Kraft pulpmill with a capacity of 454 ADT/d of pulp. Facilities were upgraded and expanded in 1993, with a current target production capacity of 1,200 ADT/d. Effluent is discharged from a submerged diffuser, with annual effluent flows of 109,000 to 113,000 m^3/d (1996 to 1999).

Major mill upgrades began in February 1991 and were completed in June 1993 (Hatfield, 1994), including construction of a lime kiln, recausticizing plant, chlorine dioxide (ClO_2) generator, effluent treatment system, pulp machine, evaporators, recovery boiler and Kamyr fibre line. The use of elemental chlorine (Cl_2) for bleaching was replaced with 100% ClO_2. These actions resulted in substantial effluent quality improvements, with reductions in total suspended solids, biological oxygen demand, absorbable organic halides, chlorinated organic compounds (e.g., dioxins and furans) and effluent toxicity (Hatfield, 1994). No major changes to mill processes or treatment operations have occurred since 1993, although a by-pass valve on the storm sewer system was installed in 1996 to divert spills to the effluent treatment system, following small spills of chemicals or effluent to the river.

Many studies conducted for Celgar relate to Environmental Effects Monitoring (EEM) programs required by EC and regulated under the *Pulp and Paper Effluent Regulations* (PPER) of the federal *Fisheries Act*. Cycle 1 was conducted between 1994 and 1996, with field work done in fall 1994 (Hatfield, 1994, 1997). Cycle 2 was conducted between 1997 and 2000, with field work conducted in 1998 and 1999 (Hatfield, 2000). A third cycle began in 2001, with field work for Celgar anticipated in 2002. These studies helped delineate the effluent plume and monitor conditions in the river. The zone of 1% effluent concentration is estimated to extend 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 reported to be decreasing in size since 1975 (Hatfield, 1994).

Cycle 1 Environmental Effects Monitoring

Relevant aspects of Cycle 1 monitoring include effluent bioassays (no chronic toxicity reported for rainbow trout, *Ceriodaphnia dubia*, algae, *Daphnia magna*) and sediment bioassays (no toxicity for *Chironomus tentans*, *Hyalella azteca*). Water quality objectives were met, with the occasional exception of dissolved oxygen (high due to dam operations), pH and chlorinated resin acids. Sediment assessments showed elevated chlorinated resin and fatty acids, chlorinated phenolics, TOC, dioxins and furans near Celgar.

Biological studies included benthic invertebrate, periphtyon and adult fish surveys. Benthic invertebrate communities showed no statistically significant correlation with pulpmill effluents; however, differences related to dam operations and substrate characteristics led to difficulties making comparisons with Reference Area data. Facultative species (worms, chironomids, molluscs), which tolerate clean and moderately polluted water, were predominant. Periphyton chlorophyll *a* and species composition also showed little difference between reference and exposed areas. Dioxin/furan levels in mountain whitefish and largescale suckers exceeded objectives (1 pg TCDD toxicity equivalence/g wet weight, or TEQ/g). Associated problems included poor health conditions of fish and low number of suckers collected in the fish Reference Area (Upper Arrow Lake).

Cycle 2 Environmental Effects Monitoring

The Cycle 2 design was modified with a change in Reference Area for fish surveys (Slocan River) and use of only mountain whitefish due to insufficient number of suckers (Hatfield, 2000). Locations of some sampling stations within the Reference Area downstream of the dam were moved to accommodate construction of the hydroelectricity generating facility. Sublethal effluent toxicity testing again 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.

Studies of the fibre mat and dioxin and furan levels in fish tissue and sediment, not required as part of EEM, were done at the request of MWLAP. The fibre mat continued to contain higher levels of compounds related to pulpmill effluent (resin acids, fatty acids, total organic carbon or TOC, chlorinated phenolics, dioxins and furans), reduced survival in toxicity bioassays and less robust benthic communities than the Reference Area. However, the mat was smaller and levels of several compounds had decreased since 1994 (Hatfield, 2000). Depositional sediments in the Near Field contained elevated levels of resin acids and fatty acids and trace levels of chlorinated phenolics. Low levels of various dioxins and furans were measured at all stations, including the Reference Area. There was some lack of clarity regarding application of the water quality objective (0.7 pg TEQ/g) in relation to normalizing to percent (%) TOC. All stations were in compliance with the objective when values associated with more than 1% TOC were normalized, but not when values associated with less than 1% TOC were normalized. Near Field sediments, outside the historic fibre mat area, showed a low impact of pulpmill effluent relative to downstream stations. Mountain whitefish muscle tissue (n=5) tested for dioxins and furans contained 0.28 to 0.60 pg/g TCDD TEQ/g wet weight, well below the water quality objective of 1 pg TCDD TEQ/g wet weight and lower than in 1994. Levels are expected to decline further, as Cl_2 has not been used since 1993 and levels in the fibre mat continue to decline.

The consumption advisory for mountain whitefish and lake whitefish, related to dioxins and furans, in effect since 1989, was lifted in 1996 (Julia Beatty, MWLAP, pers. comm.). Levels of other chlorinated compounds in river water have met provincial water quality objectives since the Celgar upgrade and are no longer monitored routinely (Robyn Roome, MWALP, pers. comm.).

Organochlorine Trends Since 1988

Dioxin and furan levels in mountain whitefish muscle tissue have declined since 1988, prior to mill upgrades (Table 2-2). Differences in sample size (composites, or up to 12 individual samples), quality assurance and analytical methods (USEPA, DFO) make comparisons difficult. The variation in age range among studies was also of concern, as Antcliffe *et al.* (1997b) reported that older fish (present before mill improvements in 1993) tended to have higher TCDD TEQs than younger fish. The TEQ reporting method also varied (for values less than detection, MELP uses half the detection limit and EC uses a value of 0). Normalizing of dioxin and furan levels to lipid levels has not been reported consistently but is relevant, due to their lipophilic nature. In addition, there are ongoing problems confirming duration and level of exposure to mill effluent, as fish are capable of travelling large distances. Despite these constraints, large decreases in TCDD TEQs in fish muscle tissue are apparent since Celgar converted from Cl_2 to ClO_2 in 1993. The objective of 1.0 pg TEQ/g fish muscle has not been exceeded in mountain whitefish muscle since 1996.

TABLE 2-2: Decline in 2,3,7,8-TCDD TEQ In Mountain Whitefish Muscle Tissue, 1988 To 2000

Year	Species[1]	Reference Site TEQ (pg/g wet wt) (mean)	Downstream of Celgar TEQ (pg/g wet wt) (mean)	Study Reference
1988	LWF	4.5 Arrow Reservoir n=7 composites	89.6 near Celgar n=7 composites	Mah *et al.*, 1989
1990	MWF	No reference given	10.6 to 27.5 (several sites) composites of 6	Crozier, 1991
1991	MWF	0.17 Brilliant Reservoir n=6 fish	55 Genelle n=6 fish	Boyle *et al.*, 1992
1992	MWF	0.04 Slocan River n=14 fish	10.7 Genelle n=12 fish 8.9 Beaver Cr n=12 fish	Nener *et al.*, 1995
1994	MWF	0.35 Slocan River n = 10 fish	4.9 Genelle n=10 fish 4.7 Beaver Cr. n=10 fish	Antcliffe *et al.*, 1997a
1994	MWF	No reference given	7.9 Genelle n=6	MELP, 1995
1994	MWF	0.0 Upper Arrow Lake n=6	5.4 near Celgar n=6 fish 3.2 Genelle n=6 fish	Hatfield, 1997
1996	MWF	0.21 Slocan River n=10 fish	5.05 Genelle n=10 fish 1.62 Genelle n=10 fish	Antcliffe *et al.*, 1997b[2]
1998	MWF	No reference given	<1 near Celgar n=5 older fish range of 0.28 to 0.60	Hatfield, 2000[2]
2000	MWF	No reference given	0.76 Genelle n=10 fish 0.98 Beaver Cr n=10 fish	MWALP, pers.comm[2]

1. LWF = lake whitefish, MWF = mountain whitefish
2. confirmed use of MELP method for detection limit (nondetect values=1/2 detection limit)

Dioxin and furan levels have declined in sediments downstream of Celgar since 1993. The presence of organochlorines in sediments and fibre mat reflect historic inputs and subsequent declines. Given that the dioxin/furan objective (0.7 pg total TEQ/g sediment) is normalized for 1% TOC and varies with organic content of the sediment, results are not easily tabulated. There appears to be lack of clarity regarding application of normalizing procedures when TOC levels are less than 1%.

In addition to 1998 sediment and fibre mat analyses discussed for Cycle 2 EEM, MWALP measured dioxins and furans in Birchbank and Waneta sediments in fall 2000 as part of routine provincial monitoring (Robyn Roome, MWALP, pers. comm.), but did not sample closer to Celgar. Sediments again contained primarily sand (92 and 95% at Birchbank and Waneta, respectively) with very little organic carbon (0.6 and 0.06% TOC, respectively). Levels of several congeners (e.g., 2,3,7,8-TCDD) were below the detection limit, but 2,3,7,8-T4CDF levels were measurable at Birchbank (4.7 pg/g), as were levels of some higher substituted dioxins. Although TEQs were not calculated by MWALP, subsequent calculations by G3 indicated low TEQs (0.79 and 0.38 pg TEQ/g at Birchbank and Waneta, respectively, MWLAP method). The EC values were even lower (0.49 and 0.07 pg/g). As found in 1998, very low TOC levels limited comparisons with the normalized objective. Birchbank (0.79 pg TEQ/g) was slightly above the objective when the objective was not normalized (i.e., 0.7 pg/g used) but was higher when the objective was normalized for TOC (0.42 and 0.042 pg/g for Birchbank and Waneta respectively).

This situation, found in both 1998 and 2000, raises the question of whether organochlorine levels in sediment are a reliable indicator of levels in the environment when organic carbon levels are low. Organochlorines are hydrophobic and tend to have an affinity for organic substrates, not sand. Levels may be low given insufficient organic matter on which to adhere, or low and not accumulating in deposited sediment, or buried or flushed downstream. The question of long-range transport and deposition remains unclear and potential uptake may occur in areas of higher organic contents (e.g., Lake Roosevelt).

2.5 Teck Cominco Metals Ltd.

Smelter operations have been underway in Trail (Figure 1-1) since 1896, with the Consolidated Mining and Smelting Company of Canada Ltd. (Cominco) formed in 1906 and restructured to form Teck Cominco Metals Ltd. in 2001. The original facility smelted lead, zinc and other metals from nearby mines and currently smelts zinc, lead, cadmium, silver, gold, copper and other products from ores mined in various regions of North and South America.

Teck Cominco has undertaken major upgrades since CRIEMP I, designed to increase economic productivity and reduce environmental impacts on air and water quality (Duncan, 1999; Cominco, 2000; G3 Consulting, 2001). The phosphate fertilizer plant was closed in 1995, resulting in significant decreases in nutrients discharged to the river. New zinc electrolytic and smelting plants, zinc pressure leaching plant and higher capacity cadmium plant were also constructed in 1995. Slag (a glassy metal-rich by-product of smelting) discharge to the river ceased in mid-1995, but previously had been up to 1450,000 tonnes annually. Potential and documented impacts of slag discharge to the river included increased metal loads, bioaccumulation, toxicity, scouring or damaging of river biota and smothering of habitat. Processed slag is now supplied to the cement industry. A state-of-the-art KIVCET lead smelter was constructed between 1997 and late 1998. Improvements to air and effluent treatment systems resulted in significant reductions in metal loads. Between 1997 and late 1999, a collection system was installed in the Stoney Cr. watershed to divert seepage and groundwater to the effluent treatment system. Historic Teck Cominco activities in the Stoney Cr. watershed had resulted in elevated metal concentrations in creek water. Teck Cominco is undertaking a wide-area Ecological Risk Assessment to better define risks to human, plant and animal communities resulting from air and effluent emissions. Occasional plant upsets are reported, such as that involving release of thallium and other metals to the Columbia River in spring 1999. Reductions in metals discharged through air, water and slag were documented between 1995 and 1999 (Table 2-3).

TABLE 2-3:
Reduction in Metals Discharged from Teck Cominco, 1995 to 1999

Metal	Total (air+water+slag)	Water
Zinc	92%	63%
Lead	77%	87%
Copper	99%	NA*
Arsenic	90%	85%
Cadmium	84%	81%
Mercury	95%	67%

*NA = total values not available for comparison
Source: G3 Consulting Ltd. (2001)

Public health investigations regarding mercury contamination led Health and Welfare Canada, MELP and the BC Health Ministry to issue fish consumption advisories for walleye (limit of one or two servings per week) in 1989. This advisory was lifted in 1995, following major reductions in mercury emissions from Teck Cominco (Duncan, 1999) and in mercury levels in walleye (Julia Beatty, MWLAP, pers. comm.).

Rainbow trout bioassays conducted in the mid-1990s reported toxicity for effluents from several discharges and Stoney Cr. water (Duncan and Antcliffe, 1996). Substantial improvements were reported by 2000, with effluents passing toxicity bioassays most of the time (Duncan and Heinz, 2001). Occasional toxicity related to process upsets at the smelter or procedural problems at the bioassay laboratory have been reported and occasional toxicity of Stoney Cr. water continues to be investigated (Duncan and Heinz, 2001). Thallium was identified as a toxic component (Duncan and Antcliffe, 1996). With little information available about its toxicity to aquatic organisms, Teck Cominco initiated research into thallium toxicity for several organisms (Pickard *et al.* 2001) and developed processes for its removal and recycling.

1995 / 1999 Receiving Water Study

The most substantial improvements to the smelter subsequent to CRIEMP I were elimination of slag discharge and operation of the KIVCET lead smelter, with associated improvements in effluent treatment. Teck Cominco designed and conducted studies of Columbia River water quality, sediment quality and biota in spring 1995, before upgrades (Duncan, 1999) and spring and fall 1999, after upgrades (G3 Consulting 2001). Six sampling sites were established, including reference sites at Birchbank (10 km upstream of the smelter) and Waneta (16 km downstream) and four sites directly influenced by smelter activities. The latter included D/S Stoney Creek (downstream of Combined Outfall IV and the Stoney Cr. confluence), D/S Island (downstream of Combined Outfall III), New Bridge (downstream of Combined Outfall II and the slag disposal site) and Old Bridge (0.7 km downstream of New Bridge).

Substantial decreases in metal levels were measured in downstream receiving waters between 1995 and 1999. Water quality objectives established in 2000 for sites outside effluent mixing zones describe 30-day average values for metals in water, sediment and fish tissue (MELP, 2000). In 1995, zinc, copper, lead, cadmium and thallium objectives were exceeded at Old Bridge and zinc, copper and cadmium objectives were exceeded at Waneta (Table 2-4). In addition, zinc and cadmium objectives were exceeded at D/S Stoney Cr. Improvements were noted in 1999, with objectives met for copper, lead and arsenic at sites outside the effluent mixing zone and zinc, cadmium and thallium levels exceeding objectives by only small amounts.

TABLE 2-4:
Columbia River Water, Total Metal Levels (μg/L) Relative to Water Quality Objectives[1]

Metal	Water quality objective[2]	Year	Birch-bank	D/S Stoney Creek	Old Bridge	Waneta
As	5	1995	1.1	4.8	1.0	1.1
		1999	<1	1.0	<1	<1
Cd[3]	0.05 / 0.03	1995	<0.1	0.67	0.49	0.25
		1999	0.05	0.08	0.11	0.07
Cu	2	1995	1.1	1.8	2.4	3.0
		1999	0.7	1.0	0.9	1.0
Hg	NA	1995	0.09	0.08	<0.05	<0.05
		1999	<0.05	<0.05	<0.05	<0.05
Pb	4.8	1995	0.3	0.6	8.0	2.4
		1999	<0.5	0.6	<0.5	0.6
Tl	0.8	1995	<0.05	0.10	1.68	0.52
		1999	<0.1	<0.1	1.1	0.5
Zn	7.5	1995	3	47	22	9
		1999	10	13	13	13

1. G3 Consulting (2001), 5 samples taken in spring, 30-day mean
2. MELP (2000)
3. 0.05 μg/L is the short-term objective and 0.03 μg/L is the long-term objective

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, levels at Waneta decreased substantially by 1999, likely reflecting cessation of slag discharge and either movement downstream or burial by cleaner sediment. Issues of residual toxicity and exposure, burial, re-exposure or transport of slag remain undefined. Despite improvements, sediment objectives continued to be exceeded at Waneta in 1999. Suspended sediment collected in traps set for four-week periods indicated elevated metal concentrations downstream of smelter outfalls in both years, although total amounts were much reduced in 1999, following cessation of slag discharge.

Water and sediment were studied in 22 tributaries and Kootenay Boundary Regional District (KBRD) wastewater treatment plant, and indicated additional metal sources to the river in both years. Stoney Cr., in a watershed historically used by Teck Cominco, was a source of zinc, arsenic and cadmium. Trail Cr., immediately downstream of the smelter was a source of copper. The wastewater treatment plant downstream of Bear Cr. was a source of copper, lead and thallium. Beaver Cr., further downstream, was a source of copper and thallium. In some tributaries, metal levels decreased between 1995 and 1999. The presence of metals in tributary water and sediment upstream and downstream of the smelter is expected, given past mining activity in the area, possible air-borne transport of metals from Teck Cominco and urban activities that contribute metals and natural sources.

Receiving water bioassays showed no acute (*Daphnia magna* 48 h LC_{50}) or chronic (Microtox 22 h light loss) toxicity in samples taken in spring 1995 from sites upstream and downstream of the smelter, suggesting very rapid effluent dilution (Duncan 1999). This test was not repeated in 1999. Chronic toxicity of river sediment (*Chironomus tentans* 14-day bioassay) was assessed in 1995 and 1999 using sediment from Birchbank and Waneta (G3 Consulting Ltd., 2001). There were no significant differences in *Chironomus* survival at the two sites in either year, but growth was lower at Waneta than Birchbank in both years. Decreased growth at Waneta may have been related to presence of slag in sediment, which would reduce food availability and may have caused physical damage to larvae (Duncan, 1999). Slag-laden suspended sediment collected immediately downstream of discharge in 1995 produced significant mortality and decreased growth of *Chironomus*.

Periphyton growth on artificial substrates was reduced at sites immediately downstream of smelter discharges in both years; however, improvements at Old Bridge in 1999 suggested a smaller zone of influence than in 1995. Species composition was more similar among sites in 1999 than 1995. This was accompanied by large increases in biomass at D/S Stoney Creek and Waneta in spring 1999, suggesting that as metal loads decreased, the effect of other watershed influences, such as nutrients, became more important.

Benthic invertebrate responses were less clear, as samples were collected on suspended Hester-Dendy substrates. These communities (more blackfly larvae, mayfly nymphs and caddisfly larvae) differed greatly from those collected historically from natural bottom substrates (more chironomid larvae and oligochaetes), as the Hester-Dendy substrates tended to collect organisms drifting in the water. Invertebrate abundance and species richness was lower at sites immediately downstream of smelter discharges, relative to upstream and downstream reference sites. The community at Waneta differed from that at Birchbank, likely related to distance downstream of Hugh Keenleyside Dam, as well as other watershed influences.

Muscle tissue of rainbow trout and mountain whitefish (n=5 per species) was analyzed. Arsenic, cadmium, mercury and lead levels were below objectives in both 1995 and 1999. Mercury and cadmium were below detection in most fish in 1999, although higher levels were measured in three of the ten fish. Ecological relevance is limited by the ability of fish to travel considerable distances and inability of any study to establish effluent exposure.

The wide area Ecological Risk Assessment currently under development by Teck Cominco is designed to assess impacts on terrestrial and aquatic ecosystems. Hence examination of links between measured physicochemical parameters and biotic components is highly relevant, particularly in relation to river health.

Metal Trends Since 1992

Trends for Columbia River receiving water for 1995 and 1999 are shown in Table 2-4. Table 2-5 shows sediment metal levels for 1992 (Aquametrix, 1994), 1995 and 1999 (G3 Consulting Ltd., 2001) and 2000 (Robyn Roome, MWALP, pers. comm.) Levels have decreased considerably at Waneta since 1995, following major smelter upgrades. Caution is emphasized when comparing 1992 data with subsequent data, given that insufficient information was published about analytical procedures and QA/QC procedures for field, laboratory and reporting stages (Aquametrix, 1994). The reason for lower reported levels of metals such as arsenic, copper and zinc at Waneta in 1992 than 1995 was not clear. The results for 2000 (MWALP) show further declines from 1999, although levels of arsenic, copper, lead and zinc continue to exceed objectives.

TABLE 2-5: Columbia River Metal Trends in Sediment Relative to Water Quality Objectives (μg/g dry weight)

Metal	Water quality objective[1]	Site	1992[2]	1995[3]	1999[3]	2000[4]
As	5.7	Birchbank	NA	1.14	1.00	<8
		Waneta	18	41.8	23.5	16
Cd	0.6	Birchbank	NA	0.168	0.147	<0.8
		Waneta	9.8	4.1	1.19	<0.8
Cu	35.1	Birchbank	NA	10.1	13.2	10.9
		Waneta	466	3,740	1,100	279
Hg	0.16	Birchbank	NA	<0.05	<0.02	0.01
		Waneta	1.48	<0.05	0.02	0.092
Pb	33.4	Birchbank	NA	8.48	8.29	19
		Waneta	535	312	237	154
Zn	120	Birchbank	NA	58.1	40.3	97
		Waneta	1,990	21,400	5,660	900

NA = Not Analyzed
1. MELP (2000)
2. Aquametrix (1994) - μg/g, reference was Arrow Lake sediment, Birchbank not sampled (n=3)
3. Duncan (1999); G3 Consulting Ltd. (2001) - μg/g dry sediment, April samples (n=3)
4. MWALP (Robyn Roome, pers. comm.) - μg/g dry sediment, number of replicates not stated, November samples

Metal levels in fish tissue have declined since 1995, with results for mountain whitefish and rainbow trout obtained from Beaver Cr. provided in Table 2-6. Results for mountain whitefish sampled in 1992, 1994 and 1996 (Nener *et al.*, 1995, Antcliffe *et al.*, 1997a, 1997b) also showed declining trends for many metals, but were not compared given that they were reported on a dry rather than wet weight basis. Results of MWALP sampling for water quality objectives were available for rainbow trout and walleye, but not mountain whitefish, but it was not clear whether results were reported on a wet or dry weight basis, as detection limits often were higher than objectives. Arsenic, cadmium and lead were not detected in any samples of rainbow trout (n=8, three to five year old fish) from Genelle or Beaver Cr. in 2000. Low mercury levels were reported (means of 0.38 and 0.18 µg/g at Genelle and Beaver Cr., respectively). Reasons for higher mercury levels in fish upstream of the smelter, at Genelle, than downstream, at Beaver Cr., was unclear.

TABLE 2-6:
Metal Trends in Fish Tissue Collected from Beaver Cr., Relative to Water Quality Objectives (µg/g wet weight)

Metal	Water quality objective[1]	1995[2] (µg/g wet wt)	1999[2] (µg/g wet wt)	2000[3] (µg/g)
Mountain whitefish				
As	0.471	0.11±0.03	0.07±0.02	Not available
Cd	0.900	0.03±0.02	0.012±0.011	Not available
Hg	0.100	0.08±0.05	0.04±0.04	Not available
Pb	0.160	0.05±0.05	0.06±0.09	Not available
Rainbow trout				
As	0.471	0.18±0.03	0.08±0.05	<4
Cd	0.900	0.006±0.002	0.008±0.010	<0.4
Hg	0.100	0.04±0.03	0.01±0.00	0.18±0.07
Pb	0.160	0.03±0.02	0.05±0.03	<4

1. MELP (2000)
2. Duncan (1999); G3 Consulting Ltd. (2001) - µg/g wet weight, downstream of Cominco (n=5)
3. MWALP (Robyn Roome, pers. comm.) - µg/g, at Beaver Creek, DFO method, appear to be calculated on dry weight basis. Hg level at Genelle upstream was higher (0.38± 0.14) (n=8)

2.6 Pope & Talbot Sawmill

Pope and Talbot Sawmill is located on the south bank of the Columbia River, immediately upstream of Celgar Pulpmill and upstream of Castlegar. Sewage from the sawmill is treated at the Celgar effluent treatment plant and discharged through the Celgar diffuser (Aquametrix, 1994). Pope and Talbot has a tree farm license covering much of the area adjacent to the Arrow Reservoir, with up to eleven log dumps on the reservoir (RL&L, 2001). Approximately 85% of the log supply arrives by booms towed through the reservoir and navigational locks to the mill downstream of the dam. Four permits for this facility (effluent discharge, cyclone emissions, waste management and open burning) require visual monitoring only (Gordon Brougham, Pope and Talbot, pers. comm.). There are no currently reported environmental concerns regarding mill operations, although surface runoff to the river or deposition of wood waste on the river or reservoir bottom, resulting from log handling, may affect the river. The mill conducted a contaminated site clean-up in 1999/2000 (Julia Beatty, MWLAP, pers. comm.).

2.7 Municipalities (Castlegar, Trail, Nelson)

Little information is available regarding recent environmental initiatives in Castlegar, Trail or Nelson. Nelson, located upstream on the Kootenay River, has a less direct effect on conditions on the Columbia River than do the other communities. Nelson owns the Upper Bonnington dam and generating facility on the Kootenay River, with UtiliCorp operating it, but the dam does not generate much TGP (Julia Beatty, MWLAP, pers. comm.). Treated municipal wastewater is discharged to the Kootenay River downstream of Grohman Narrows (Butcher, 1992).

Castlegar, on the banks of the Columbia (Figure 1-1), is part of the Regional District of Central Kootenay. Its Official Community Plan was updated in 1999 and will be re-evaluated in 2004 (City of Castlegar website, 2002). The plan mentions consideration of environmental concerns, such as protecting and enhancing Columbia River water and aquatic life and tributary areas in planning processes. Municipal drinking water is drawn from Arrow Reservoir. Treated municipal wastewater is discharged from two locations, the north side of the river 1 km downstream of the railway bridge and the south bank 2 km downstream of the Kootenay River confluence. Castlegar is currently applying to enlarge its wastewater treatment plant and has had no reported spills or fines (Andre Buss, City of Castlegar, pers. comm.).

The City of Trail, on the Columbia River, is part of the Regional District of Kootenay Boundary (RDKB) and has an Official Community Plan in place (City of Trail website, 2002). Municipal drinking water is extracted from the river upstream of the city, near Oasis, and treated before distribution. Hence, river water quality is of direct concern to Trail. Municipal wastewater is treated and discharged at the RDKB treatment plant, 5 km downstream at Bear Cr.

Water quality concerns are related to discharge of municipal wastewater, for which discharge permits are associated. Receiving water is monitored periodically for bacteria (fecal coliform, *Escherichia* coli, and enterococci), which typically are well below objective levels (MELP, 2000). Nutrients, metals and other compounds are not assessed routinely. There may be local water quality impacts related to runoff from landfill sites or stormwater or habitat impacts related to riverside development. Local impacts from unincorporated areas such as Genelle and other small communities are not assessed but are expected to contribute some non-point source compounds.

3.0 WATER QUALITY OBJECTIVES & MONITORING PROGRAM FOR RECEIVING WATERS

A water quality monitoring program and objectives for the lower Columbia River has been developed by MWLAP in consultation with EC and other stakeholders (Butcher 1992; MacDonald Environmental Services, 1997; MELP, 2000). Water quality objectives are set to protect the most sensitive designated uses of the water body (MELP, 2000). The range of designated uses include raw drinking water, public water supply and food processing; fish and other aquatic life; wildlife; agriculture (livestock watering and irrigation); recreation and aesthetics; and industrial water supplies. Designated water uses for the Columbia River study area are drinking water, aquatic life, wildlife, agriculture and primary-contact recreation.

3.1 Water Quality Objectives

Parameters and objectives listed in Table 3-1 were condensed from documents for the dam to Birchbank (Butcher, 1992) and Birchbank to the US border (MELP, 2000). Some objectives are specific to a single point source, such as dams, pulpmill, smelter or municipal wastewater discharges. Total gas pressure (TGP) relates to operation of dams. Fecal coliform, *Escherichia* coli, and enterococci objectives apply to municipal wastewater discharges. Parameters related to pulpmill operations include colour, suspended solids, turbidity, substrate sedimentation, effluent toxicity, resin acids, chlorinated organic compounds (phenols, resin acids, dioxins and furans) and periphyton standing crop. Those related to smelter discharges include metal levels and ammonia. Dissolved oxygen, temperature and pH are relevant to most activities.

Site-specific objective levels were derived from existing federal guidelines and provincial criteria and have comparability to other areas of the province and Canada. Objectives can be updated in response to newly available information. For example, the thallium objective was developed following identification in toxicity testing of Teck Cominco effluents (Duncan and Antcliffe, 1996) and subsequent studies into toxicity for several aquatic organisms (algae, invertebrates, fish) (Pickard *et al.*, 2001). Likewise, DFO is conducting studies into ecological aspects of TGP guidelines for protection of fish (Bonnie Antcliffe, DFO, pers. comm.), which may have relevance to low level objectives.

The possibility of impacts from unrecognized and unregulated compounds is always a concern. The influence of endocrine disrupting compounds (EDCs), detected in pulpmill and wastewater treatment plants, on aquatic organisms (ATW conference, October 2001) is currently being investigated locally (Julia Beatty, MWLAP, pers. comm.). These compounds may result from a variety of processes or sources, including bacterial activity in effluent treatment systems or concentration from influent material. Among concerns about EDCs is their resemblance to reproductive hormones and, hence, potential to affect reproduction and growth of fish in the receiving environment (Mike van den Heuvel, UBC Environmental Engineering Seminar, 27 Sept. 2001). Flexibility in incorporating newly evaluated information into the objectives is essential in maintaining their relevance. Laboratory studies are being conducted by MWLAP to investigate effects of EDCs on biota (Julia Beatty, MWLAP, pers. comm.), and further studies into their presence and pathways in the receiving environment would be relevant to river health assessments.

TABLE 3-1: Water Quality Objectives, Hugh Keenleyside Dam to Waneta

Characteristic	Objective
Designated water use	Drinking water (partial treatment + disinfection), aquatic life, wildlife, livestock, irrigation, primary-contact recreation
Fecal coliform *Escherichia coli* Enterococci	≤ 100/100 mL (90^{th} percentile) ≤ 100/100 mL (90^{th} percentile) ≤ 25/100 mL (90^{th} percentile)
Dissolved oxygen	Dam to Birchbank 10 mg/L minimum Birchbank to Waneta May to October ≥ 5 mg/L instantaneous minimum ≥ 8.0 mg/L or 80% sat (whichever is higher), 30 day mean November to April ≥ 9 mg/L instantaneous minimum ≥ 11 mg/L, 30 day mean
TGP	≤ 110% saturation
Temperature	≤ 1°C increase, maximum (dam to Birchbank sites)
pH	6.5 to 8.5
Colour	15 TCU maximum
Suspended solids	10 mg/L maximum increase
Turbidity	5 NTU maximum increase
Substrate sedimentation	No increase in sediment TOC between u/s and d/s, at 95% confidence level
Toxicity, Celgar effluent	[%] of mill effluent in river water < 0.05 of the 96 h LC_{50} after complete mixing
Chlorinated phenols	TCP < 0.5 µg/L TTCP < 0.1 µg/L PCP < 0.05 µg/L
Dioxins and furans	In fish 1 pg TCDD TEQ/g maximum (1992) ≤ 0.25 pg TCDD TEQ/g wet weight (normalized to lipid content (2000) In water 0.2 pg TCDD TEQ/L maximum (1992) In sediment 0.7 pg TCDD TEQ/g sediment TOC maximum (1992) ≤ 0.25 pg TCDD TEQ/g (normalized to 1% organic C) (2000)
Resin acids	pH 6.5 4 µg/L DHA, 9 µg/L total pH 7.0 8 µg/L DHA, 25 µg/L total pH 7.5 12 µg/L DHA, 45 µg/L total pH 8.0 13 µg/L DHA, 52 µg/L total pH 8.5 14 µg/L DHA, 60 µg/L total
Chlorinated resin acids	In water, 6.0 µg/L maximum, monochloro- and dichloro-DHA
Periphyton standing crop	< 50 mg/m^2 chlorophyll *a*, mean
NH_3	Temperature and pH dependant (see ammonia objectives, MELP 1986) e.g. at pH=6.5, T= 5°C 26.8 mg/L max 1.94 mg/L mean at pH=6.5, T= 15°C 24.3 mg/L max 1.77 mg/L mean at pH=8.5, T= 5°C 1.99 mg/L max 0.384 mg/L mean at pH=8.5, T= 15°C 1.90 mg/L max 0.365 mg/L mean

Metal	Water (µg/L), mean of 5 in one month	Sediment (u/g dry weight)	Fish muscle tissue (µg/g wet weight)
As	5	5.7	0.471
Cd	0.03 / 0.05[1]	0.6	0.900
Cr	1	36.4	0.940
Cu	2	35.1	none
Pb	4.8	33.4	0.160
Hg	none	0.16	0.100
Tl	0.8	none	none
Zn	7.5 (33 maximum)	120	none

1. Cd: 0.03 µg/L long term, 0.05 µg/L short term)
Source: combined from Butcher (1992) and MELP (2000)

Routine monitoring has been conducted biweekly by federal and provincial agencies at Birchbank and Waneta since the 1980s for trend assessment. At Waneta, water samples are currently taken weekly and continuous monitoring is being developed for TGP, temperature, pH and conductivity (Andrea Ryan, EC, pers. comm.). Data are contained in the ENVIRODAT database, available on request from EC staff. Flow and TGP are monitored at Birchbank. General water quality parameters are measured at both Birchbank and Waneta (alkalinity, chloride, colour, fluoride, fecal colifom, hardness, non-filterable residue, pH, silicon, specific conductivity, sulphate, air and water temperature, turbidity). Nutrients (ammonia, nitrate, nitrite, total dissolved nitrogen, total phosphorus, total dissolved phosphorus, dissolved ortho-phosphate) are measured at both sites some of the time, but only ammonia was included in the EMS database results for 1999 and 2000. Likewise, metals (aluminum, arsenic, barium, beryllium, calcium, cadmium, chromium, cobalt, copper, iron, potassium, lithium, molybdenum, magnesium, manganese, nickel, lead, selenium, strontium, vanadium, zinc) are measured at both sites.

3.2 Recommended Water Quality Monitoring Program Relevance

The water quality monitoring program recommended by MWLAP (Butcher, 1992; MELP, 2000) is described in Table 3-2. This table outlines sampling sites, timing, frequency and parameters and includes integration with EC biweekly monitoring at Birchbank and Waneta. The monitoring design includes many parameters relevant to point-source discharges and dam operation. However, some aspects necessary for river health assessment are missing. For example, full spectrum nutrient analysis is not included for all sites and is measured only at Birchbank and Waneta. Periphyton standing crop measurements are recommended upstream and downstream of Celgar and at Birchbank. Metals and other compounds from non-point sources such as seepage, groundwater, leachates and runoff sources are not assessed; however, these sources often contribute to cumulative effects and confound attempts to make accurate correlations between biota and water quality.

As conditions related to industrial upgrades improve on the Columbia River, other influences, such as nutrients, are likely to become more noticeable. Fertilization experiments are underway in Arrow Reservoir in an attempt to restore productivity (CPC website, 2001), which may affect the Columbia River downstream. Historically, the phosphate fertilizer plant at Teck Cominco was a significant source of phosphate, but the plant was closed in 1995; likewise, treatment of effluent from the ammonia fertilizer plant has reduced quantities discharged to the river. Nutrients from urban and agricultural activities may now have more significant local or long distance effects. For example, the Teck Cominco study into river conditions before (1995) and after (1999) smelter upgrades documented increases in periphyton abundance on artificial substrates downstream of Stoney Creek and, notably, at Waneta in 1999, but no change at Birchbank (G3 Consulting, 2001). The most likely factor in increased productivity at these sites was considered to be nutrients, either from an increase between 1995 and 1999 or elimination of suppression accompanying reduction in metal concentrations, or some combination, but the study was not designed to assess broader watershed influences. Discharge from the municipal wastewater treatment plant at Bear Creek is a likely nutrient source between Trail and Waneta. Recent reports of periphyton growth include *Didymosphenia* (diatom) mats that resemble pulpmill fibre (Julia Beatty, MWLAP, pers. comm.) and accumulations of filamentous green algae in nets used for scientific fish collecting (Dana Schmidt, RL&L., pers. comm.). These observations suggest that interactions of nutrients and biota need to be investigated and guidelines for acceptable levels developed more fully.

TABLE 3-2: Recommended Receiving Water Monitoring, Hugh Keenleyside Dam to Waneta

Where		What	When	Why
0200183	u/s Celgar	Water TGP	5 weekly samples in 30-day period	BC Hydro, CPC
0200183	u/s Celgar	Temp, DO, pH, susp. solids, turbidity, colour, Na, foam/floatables/odour	5 weekly samples in 30-day period	Celgar
0200183	u/s Celgar	fecal coliform, *E. coli*, enterococci	5 weekly samples in 30-day period	Castlegar wastewater
0200183	u/s Celgar	Water & Sediments resin acids, chlorinated resin acids, guaiacols, phenols, AOX, dioxins, furans	Once, April	Celgar
0200183	u/s Celgar	Periphyton standing crop	Once, summer	Celgar
0200183	u/s Celgar	Substrate sedimentation (TOC), n = 3	Once, any time	Celgar
213039	100 m d/s Celgar	Water TGP	5 weekly samples in 30-day period	BC Hydro, CPC
213039	100 m d/s Celgar	Temp, DO, pH, susp. solids, turbidity, colour, Na, foam/floatables/odour	5 weekly samples in 30-day period	Celgar
213039	100 m d/s Celgar	fecal coliform, *E. coli*, enterococci	5 weekly samples in 30-day period	Castlegar wastewater
213039	100 m d/s Celgar	Water & Sediments resin acids, chlorinated resin acids, guaiacols, phenols, AOX, dioxins, furans	Once, April	Celgar
213039	100 m d/s Celgar	Substrate sedimentation (TOC), n = 3	Once, any time	Celgar
0200200	Castlegar	Water TGP	5 weekly samples in 30-day period	BC Hydro, CPC
0200200	Castlegar	Temp, DO, pH, susp. solids, turbidity, colour, Na, foam/floatables/odour	5 weekly samples in 30-day period	Celgar
0200200	Castlegar	fecal coliform, *E .coli*, enterococci	5 weekly samples in 30-day period	Castlegar wastewater
0200200	Castlegar	Water & Sediments resin acids, chlorinated resin acids, guaiacols, phenols, AOX, dioxins, furans	Once, April	Celgar
0200200	Castlegar	Periphyton standing crop	Once, summer	Celgar

TABLE 3-2: Continued

Where		What	When	Why
New site	Between Celgar & Kootenay R.	Sportfish & Sediments dioxins, furans, n=4 (minimum of one reference site)	Once, any time	Celgar
0200003	Birchbank (west bank)	Water quality & flow (EC)	Biweekly	
		Water & Sediments Resin acids, chlorinated resin acids, guaiacols, phenols, AOX, dioxins, furans	Once, April	Celgar
		Periphyton standing crop	Once, summer	Celgar
		Water TGP Temp, DO, pH, susp. solids, turbidity, colour, Na, foam/floatables/odour fecal coliform, *E. coli*, enterococci NH_3, hardness, As, Cd, Cr, Cu, Pb, Tl, Zn	5 weekly samples in 30 days (Jan. Apr. Sept.)	BC Hydro, CPC Celgar Castlegar wastewater Teck Cominco
		Fish Species, age, sex, condition, abnormalities, % lipid, % moisture As, Cd, Cr, Cu, Pb, Hg, Tl, Zn PCDD, PCDF	Once, July (n=12)	Teck Cominco Celgar
New site	Between Birchbank & Stoney Cr.	Sediments TOC, AVS, particle size total and SEM metals (As, Cd, Cr, Cu, Pb, Hg, Tl, Zn) dehydroabietic and total resin acids, PCDD, PCDF, fatty acids Bioassay acute and short term chronic toxicity (*Chironomus*, *Hyalella*)	Once, Sept. (n=5)	Teck Cominco Celgar Teck Cominco, Celgar
223892	100 m d/s Stoney Cr. (west bank)	Water Temp, DO, pH, turb., hardness As, Cd, Cr, Cu, Pb, Tl, Zn	5 weekly samples in 30 days (Jan. Apr. Sept.)	Teck Cominco

TABLE 3-2: Continued

Where		What	When	Why
200558	Trail, New Bridge (west bank)	Water Temp, DO, pH, turb, hardness NH_3, As, Cd, Cr, Cu, Pb, Tl, Zn	5 weekly samples in 30 days (Jan. Apr. Sept.)	Teck Cominco
216137	Trail, Old Bridge (west bank)	Water Temp, DO, pH, turb., hardness NH_3, As, Cd, Cr, Cu, Pb, Tl, Zn	5 weekly samples in 30 days (Jan. Apr. Sept.)	Teck Cominco
223893	100 m d/s KBRD (outfall)	Water NH_3, turbidity fecal coliform, *E. coli*, enterococci	5 weekly samples in 30 days (Jan. Apr. Sept.)	KBRD sewage
New site	Between West Trail bridge & Waneta	Fish Species, age, sex, condition, abnormalities, % lipid, % moisture As, Cd, Cr, Cu, Pb, Hg, Tl, Zn PCDD, PCDF	Once, July (n=12)	Teck Cominco Celgar
		Sediments TOC, AVS, particle size total and SEM metals (As, Cd, Cr, Cu, Pb, Hg, Tl, Zn) dehydroabietic and total resin acids, PCDD, PCDF, fatty acids Bioassays acute and short term chronic toxicity (*Chironomus, Hyalella*)	Once, Sept. (n=5)	Teck Cominco Celgar Teck Cominco, Celgar
0200559	Waneta (east bank)	Water (EC)	Biweekly	
		Water TGP Temp, DO, pH, susp. solids, turb, colour, NH_3, hardness As, Cd, Cr, Cu, Pb, Tl, Zn fecal coliform, *E. coli*, enterococci	5 weekly samples in 30 days (Jan. Apr. Sept.)	BC Hydro, CPC Teck Cominco KBRD wastewater

Habitat issues are not addressed directly in the recommended water quality objective monitoring program, although indirect (turbidity, suspended solids, periphyton standing crop) and area-specific measures (substrate sedimentation in relation to Celgar discharges, sediment metal levels in relation to Teck Cominco discharges) are included. Habitat issues related to specific large and small-scale activities (e.g. upgrades at Brilliant Dam, river scarification by BC Hydro, highway and railroad maintenance) are assessed individually, through the referral system, with input from relevant government agencies. However, this program is not designed to address larger questions of habitat alteration resulting from presence and operation of dams, although there has been discussion of incorporating performance measures (Gary Birch, BC Hydro and Julia Beatty, MWLAP, pers. comm.). Habitat alteration results directly from regulated flow regimes, increased and decreased water velocities and volumes, and resulting erosion, substrate alteration and biotic responses. BC Hydro and Columbia Power Corp. have conducted many fish population assessments, some of which identify sensitive fish habitat and health of endemic populations. These studies are valuable for documenting current conditions regarding specific issues, but linkages to river health assessments are not clear. The fish population assessment index (PAI) study being undertaken by RL&L for BC Hydro is designed to consider broader ecological relevance of observed changes in fish populations (Dana Schmidt, RL&L, pers. comm.). There appears to be no current process addressing local effects of land use decisions affecting riverfront property (e.g., logging, agriculture, urban or industrial development, mining, historic activities), although the Castlegar OCP mentions protecting water quality and aquatic resources of the Columbia River. These activities can contribute to sedimentation, altered water quality and habitat disturbance.

3.3 Monitoring Data vs. Water Quality Objectives

Water quality objective monitoring is conducted by MWLAP during three low flow periods, winter (Jan.-Feb.), spring (Mar.-Apr.) and fall (Oct.-Nov.) (MELP, 2000). Water samples are taken five times over a one-month period, resulting in monthly mean values for comparison with objectives (Table 3-1). Sediments are sampled in fall at Birchbank and Waneta. Fish are sampled during fall in the Genelle and Beaver Cr. areas.

Data are compiled in the provincial EMS database, currently only available to Ministry staff directly. Water quality data for Birchbank and Waneta, collected by EC, are included in the federal ENVIRODAT database. Permit holders have access to the EMS database to enter and access their own data. At this time, interested parties (other CRIEMP members, proponents, consultants, public, etc.) have access to the EMS and ENVIRODAT databases through *Freedom of Information* requests (Robyn Roome, MWLAP, Andrea Ryan, EC, pers. comm.). There is interest in integrating other data such as continuous flow, total gas pressure and temperature measurements into the EMS database in allowing wider public access to the database at some point.

Details useful to QA/QC evaluation, such as variation among field and laboratory duplicates, presence of trace levels in field and travel blanks, and recovery rates obtained for Certified Reference Materials are not easily obtained. This is highly relevant, as these factors can have a significant effect on results (*cf.* metal results for 1995/1999 reported by Teck Cominco, G3 Consulting 2001; evaluation of chlorinated organic compounds in relation to recovery rates, TOC or lipid levels). Information about recovery rates is relevant when making spatial and temporal comparisons, and particularly relevant when comparing studies, where differences in laboratories and analytical methods are factors.

Results for 2000, the last year for which data were supplied (Robyn Roome, MWLAP, pers. comm.), are summarized in Table 3-3 and compared with water quality objectives (MELP, 2000). There is some time lag between sampling, analysis and posting of results on the database, so results for 2001 have not been assessed here. Water samples have not been taken at sites between Hugh Keenleyside Dam and Birchbank since 1995 because objectives, with the exception of TGP, were met for the first three years following objective establishment (Robin Roome, MWLAP, pers. comm.). Sediments and fish tissues are monitored some years by MWLAP or through the pulpmill EEM program.

TABLE 3-3: Water Quality Objective Monitoring Program (2000)

Where		What	When	Exceed?
0200183 213039 0200200	u/s Celgar 100 m d/s Celgar Castlegar	Not done Not done Not done	Not done Not done Not done	Not done Not done Not done
0200003	Birchbank (west bank)	Water + flow (Fed-Prov monitoring site)	Biweekly	Not assessed
		Water pH, hardness, TGP, NFR, turbidity, NH_3, fecal coliform, enterococci, *E. coli*, As, Cd, Cr, Cu, Pb, Tl, Zn Sediments Bioassays	Monthly mean Jan/Feb Mar/Apr) Oct/Nov Fall Fall	 None Not done None Slight, TEQ None
New site	Genelle	Fish	Fall	None
E223892	100 m d/s Stoney Cr., west bank	Water pH, hardness, As, Cd, Cr, Cu, Pb, Tl, Zn	Monthly mean Jan/Feb Mar/Apr Oct/Nov	 None Not done None
0200558	New Bridge, Trail *(mixing zone, compliance not expected)*	Water pH, hardness, NH_3, As, Cd, Cr, Cu, Pb, Tl, Zn	Monthly mean Jan/Feb Mar/Apr Oct/Nov	 Cd Not done Cd Pb Zn
E216137	Old Bridge, Trail (west bank)	Water pH, hardness, NH_3, As, Cd, Cr, Cu, Pb, Tl, Zn	Monthly mean Jan/Feb Mar/Apr Oct/Nov	 None Not done Cd
E223893	100 m d/s RDKB outfall	Water pH, NH_3, turbidity, NFR, fecal coliform, *E. coli*, enterococci,	Monthly mean Jan/Feb Mar/Apr Oct/Nov	 None Not done None
New site	Beaver Cr.	Fish	fall	None
0200559	Waneta	Water (Fed-Prov monitoring site)	biweekly	
		Water pH, hardness, TGP, NFR, turbidity NH_3, fecal coliform, enterococci, *E. coli*, As, Cd, Cr, Cu, Pb, Tl, Zn Sediments Bioassays	Monthly mean Jan/Feb Mar/Apr Oct/Nov fall fall	 None Not done None As Cu Pb Zn Yes

Data from Birchbank to Waneta were assessed for completeness of sampling regimens and exceedance of water quality objectives. No water sampling was done in spring 2000, due to lack of staff resources (Robin Roome, MWLAP, pers. comm.). However, all three seasons had been sampled in 1998 and 1999. Results were available for winter and fall 2000 for the following sites: Birchbank, D/S Stoney Cr., New Bridge, Old Bridge, D/S RDKB wastewater discharge and Waneta. The New Bridge site was added subsequent to publishing of the recommended water quality monitoring program (MELP, 2000).

Parameters recommended in Tables 3-1 and 3-2 were measured, with some exceptions. Data for temperature, DO, and turbidity were not supplied from the EMS database, but are likely included in the federal-provincial data for Birchbank and Waneta. Compounds related to pulpmill discharges (foam, floatables, odour, colour, resin acids, chlorinated resin acids, guaiacols, phenols, AOX, dioxins, furans), described in the water monitoring program as required at Birchbank and Waneta, were not measured, but are expected to be below objectives. Periphyton standing crop was not measured at Birchbank (similarly related to pulpmill objectives).

Objectives were met in all but a few instances in the 2000 data set. Fecal coliform, *E. coli* and enterococci levels measured downstream of the RDCK wastewater treatment plant were consistently lower than the objective (e.g., for colifoms, mean of 3 CFU/100 mL vs. objective of 100/100mL). TGP measured at Birchbank was lower than the objective (110% TGP), with a mean of 105% in winter and 104% in fall (in summer 1998 and 1999, TGP typically exceeded the objective). Ammonia levels were below the objective at all sites.

Metal levels (arsenic, cadmium, chromium, copper, lead, thallium, zinc) measured in water downstream of Teck Cominco were lower than objectives, with one exception. The mean cadmium level at Old Bridge was 0.06 µg/L in fall 2000 (objective is 0.05 µg/L). In the same period, mean cadmium, lead and zinc levels exceeded objectives upstream at New Bridge, within the effluent mixing zone, where compliance was not expected. Cadmium, copper, lead, thallium and zinc levels were substantially elevated on 19 October, likely in response to an incident at the smelter, which influenced 30-day mean values at New Bridge and Old Bridge, leading to the exceedance.

Birchbank and Waneta sediments were sampled in November 2000 (Robyn Roome, MWLAP, pers. comm.). Levels of many metals, including arsenic, copper, lead and zinc, continued to be substantially higher at Waneta than Birchbank. Levels at Waneta have declined notably since 1995 (Table 2-5), though they still exceed objectives (MELP, 2000). Mercury levels were below the objective at both sites. Cadmium levels were below detection; however, the MWLAP detection limit (0.8 µg/g) was higher than the objective (0.6 µg/g). Dioxin/furan monitoring showed low furan levels at Birchbank (2,3,7,8 T4CDF of 4.7 pg/g) and very low organic content (0.6% and 0.06% TOC, Birchbank and Waneta, respectively). TEQs calculated by G3 for this report were low (0.79 and 0.38 pg TEQ/g at Birchbank and Waneta, respectively; MWLAP method of half the detection limit). As discussed in Section 2.2, very low TOC levels made comparisons with the water quality objective speculative. The TEQ objective is 0.7 pg/g sediment at 1% TOC and objectives normalized to ambient TOC are 0.42 and 0.042 pg/g for Birchbank and Waneta, respectively. This situation, found in both 1998 and 2000, raises the question of whether organochlorine levels in sediment are a reliable indicator of levels in the environment when organic carbon levels are low and suggests the need for further discussion of ecological relevance and choice of suitable sampling areas.

Sediment toxicity at Birchbank and Waneta was assessed in November 2000 using *Hyalella azteca* growth and survival bioassays (Robyn Roome, MWLAP, pers. comm.). Results are presented in Table 3-4. There was no toxicity associated with sediment from either site in 14-day bioassays, but significant mortality for Waneta sediments in the 28-day bioassay (28% survival, significant at $p<0.05$, t-test). *Hyalella* growth rates were also reduced at Waneta compared to Birchbank in both the 14-day and 28-day bioassays, suggesting either sediment toxicity at Waneta, or low levels of food for growth (*cf.* very low TOC levels). Since the *Hyalella* diet typically consists of organic matter, the latter is a distinct possibility. Slag discharged from Teck Cominco for many years settled at Waneta, but discharge stopped in 1995. *Chironomus tentans* bioassays (14-day tests) done for Teck Cominco in spring of 1995 and 1999 showed similar results to the recent *Hyalella* bioassays, as well as low sediment TOC levels (0.06 to 0.1% TOC at Birchbank, 0.12 to 0.21% TOC at Waneta; G3 Consulting Ltd., 2001).

TABLE 3-4:
Sediment Toxicity Bioassays using *Hyalella azteca*, November 2000[1]

Parameter	14-day bioassay		28-day bioassay	
	Birchbank	Waneta	Birchbank	Waneta
survival	100%	98%	100%	27.7%
growth	0.226 mg	0.149 mg	0.655 mg	0.126 mg
TOC	0.6%	0.06%	0.6%	0.06%

1. MWLAP water quality objective monitoring, 2000

Monitoring of mountain whitefish and rainbow trout muscle tissue done in fall 2000 (Robyn Roome, MWLAP, pers. comm.) indicated that the dioxin/furan objective (<1 pg TEQ/g wet weight) was met in samples from Genelle and Beaver Creek. Results for metals in mountain whitefish were not available. It was difficult to compare metal levels in rainbow trout with provincial objectives, as they appeared to be reported on a dry weight rather than wet weight basis. Arsenic, cadmium and lead levels were below analytical detection limits. Low mercury levels were measured (0.38 and 0.18 μg/g at Genelle and Beaver Cr.) (Table 2-6). The reason for higher levels at Genelle, upstream of the smelter, was not clear, but fish do tend to move about in the watershed. Metals objectives had been met in 1995 and 1999 when Teck Cominco conducted similar analyses (Table 2-6).

In general terms, objectives and monitoring programs are behaving as designed, i.e., to show general trends, raise concerns regarding isolated high values, and provide feedback; however, areas such as Hugh Keenleyside Dam to Birchbank are no longer monitored, under the assumption that levels continue to be low in the receiving environment. Most importantly, direct links to impacts on biological communities or ecosystem health, including bioavailability and cumulative effects, are not apparent in this monitoring system. The situation with *Hyalella azteca* bioassays showing impaired growth and survival at Waneta relative to Birchbank reflects the problem of linking results to underlying causes. Waneta sediments may contain toxic components or may retain such low percent TOC that growth is limited by food availability, which may in turn reflect historical deposition of slag from Teck Cominco. The role of erosion or burial of historic sediment and contaminants remains unclear using current monitoring methods.

Table 3-5 shows trends in relation to water quality objectives between 1998 and 2000. Metal levels downstream of Teck Cominco exceeded objectives in spring 1998, winter, spring and fall 1999 and fall 2000. Mean TGP levels were higher than objectives in the spring 1998 and fall 1999 sampling periods. Levels of some metal were higher than objectives at Birchbank in spring 1999, which identifies analytical issues needing a closer examination of QA/QC and statistical procedures at this and all sites. Birchbank results are particularly significant as this site is considered the upstream reference for Teck Cominco and is 10.5 km upstream of smelter discharges. Likewise, high ammonia levels reported in fall 1999 at Birchbank as well as downstream of Teck Cominco may have reflected analytical issues on two of the five dates.

TABLE 3-5:
Compliance with and Exceedance of Water Quality Objectives (1998 to 2000), Birchbank to Waneta

Sample Period	Sampling Site					
	Birchbank	D/S Stoney Creek	New Bridge, Trail[1]	Old Bridge, Trail	D/S RDKB wastewater	Waneta
1998 winter	None	None	Cd Pb Tl Zn	None	None	None
1998 spring	TGP	Cd Zn	Cd Zn	Cd	None	Cd
1998 fall	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
1999 winter	None	Cd Zn	Cd Pb Zn	Cd	None	None
1999 spring	Cd Cr Zn	Cd Cr Zn	Cd Cr Tl Zn	Cd Cr Tl Zn	None	Cd Zn
1999 fall	TGP NH_3 Cu	Zn	NH_3 Cd Tl Zn	NH_3 Cd Zn	None	TGP Zn
2000 winter	None	None	Cd	None	None	None
2000 spring	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled	Not sampled
2000 fall	None	None	Cd Zn Pb	Cd	None	None

1. mixing zone site, compliance with water quality objectives not expected at New Bridge

In addition to water quality monitoring by MWLAP, industry-specific effluent and receiving water studies have been conducted for BC Hydro and Columbia Power Corp. (RL&L, 2001) Celgar (Hatfield, 1997, 2000) and Teck Cominco (Duncan, 1999; G3 Consulting, 2001).

TGP monitoring has been done for CRIEMP (RL&L, 2000). DFO conducted fish health studies in 1992, 1994 and 1996 (Nener *et al.*, 1994, Antcliffe *et al.*, 1997a, 1997b). Information from these studies can also be compared to water quality objectives, as was done in Section 2.0 for most parameters.

4.0 RECENT ISSUES & DATA GAPS

Previous studies have tended to focus on aspects specific to one industry, section of river or component (e.g., BC Hydro fish and TGP studies, Celgar EEM, Teck Cominco river monitoring). As a result, these programs usually lack a broader watershed perspective, such as river health, consideration of cumulative or confounding influences, and associated ecological risk. The original CRIEMP study was designed with a broad perspective in mind, but had certain identified weaknesses, such as lack of concurrent sampling and insufficient replication, inconsistency of site usage and insufficient relevance of some data such as periphyton and macrophyte data (Aquametrix, 1994). Since that time, there has been no integrated study to incorporate identified issues or assess improvements likely to be associated with industrial upgrades.

Despite identified weaknesses of the original CRIEMP study, much can be applied to a renewed assessment. One main weakness of studies to date is the absence of linkages between recognized measurable parameters (i.e., water quality objectives) and *in situ* biotic components that reflect individual and cumulative effects, bioavailability and persistence in the receiving environment and, hence, overall river or ecosystem health. The water quality objectives monitoring program includes sediment bioassays, which does attempt to link sediment chemistry with biological responses.

4.1 Issues & Data Gaps

Identified scientific issues and data gaps include TGP reduction, difficulty assessing habitat alteration, difficulty assessing biotic responses to changed river conditions, river health at Waneta, transboundary issues, developing an integrated measure of river health, and integrating monitoring results into resource management decisions. These issues need to be addressed in an integrated assessment of river health.

TGP Issues

TGP levels are cumulative in nature, do not dissipate readily and become a transboundary issue. Additions from Hugh Keenleyside, Brilliant and Waneta dams come at different times of year. The CRIEMP committee and individual stakeholders have monitored TGP for many years and some members sit on the Transboundary Gas Group. BC Hydro has modified operating procedures to reduce levels. Columbia Power Corp. is constructing power generation facilities on the Hugh Keenleyside Dam and is upgrading the Brilliant Dam, anticipating that changing operational conditions will reduce TGP levels. DFO is conducting laboratory experiments to better define fish responses to elevated TGP under various conditions (Bonnie Antcliffe, DFO, pers. comm.). Although being addressed in several ways, this issue is not yet resolved.

Habitat Alteration

Habitat alteration issues include those related to dams (periodic loss of habitat arising from river regulation, including fluctuating levels, bank erosion and fish stranding), Celgar fibre mat, possible benthic habitat alteration at Pope and Talbot sawmill and sediment quality at Waneta following cessation of slag discharge from Teck Cominco.

Assessing Biotic Responses

Biological integration, assessing biotic responses to changing river conditions, is difficult for two main reasons. The first relates to obtaining statistically reliable data about plants and animals in a spatially and temporally dynamic environment. The second relates to linking observed changes in biota to specific causes. For example, benthic invertebrate communities reflect current river conditions and past impacts. On the Columbia River, it is difficult to obtain truly representative benthic invertebrate samples due to fluctuating river levels and inaccessible deep-water habitats. Most samples are taken from near-shore riffle areas. Natural substrate sampling has shown predominance of facultative organisms (worms and chironomids, which tolerate a range of habitat conditions), rather than pollution sensitive organisms (Ephemeroptera, Plecoptera, Trichoptera or EPT). There are, however, other indicators of EPT presence (emergences, presence on Hester-Dendy substrates suspended in the water column) that suggest fair to good water quality in general. Options for resolving this issue include continuing to use previous methods while considering their limitations and establishing a more representative sampling program while considering physical difficulties. Another example is measurements of contaminant levels in fish, which was done historically for human health reasons. Although levels can be measured accurately, interpretation can be difficult, given that fish move, making it difficult to quantify exposure or duration of exposure to specific discharges. Measurements in liver tissue may be more relevant to fish health. Changes noted in health of fish caught in the study area may be linked to changes in habitat, predation, food sources or water quality conditions elsewhere in the watershed. For example, sources of metals in addition to Teck Cominco include drainage from historic and active mining operations in Canada and US, and from urban runoff or wastewater treatment plants.

Assessing River Health at Waneta

Understanding river health at Waneta is very relevant for a number of reasons. It is one of a few good depositional sites on the river, a final sentinel area upstream of the Canada-US border, and may reflect potential for transport of compounds downstream. The installation of automated samplers at Waneta by EC was done, in part, to measure and assess spills. For example, it takes approximately four hours for water to travel from Trail to Waneta; slag and particulate metals have been deposited at Waneta. Slag discharge ceased in 1995, which could have several net effects on metals and other compounds, depending on whether it is buried by fresh sediment or eventually re-exposed and transported further downstream. Slag may have historically diluted or masked other compounds, such as organochlorines (a synergistic or cumulative impact), and either type of constituent can be re-exposed over time. The suitability of Waneta for measuring organochlorines has been discussed in terms of low organic content of the sediment. For these reasons, a clearer understanding of issues is needed relative to short and long-term slag deposition, exposure, re-exposure, residual toxicity and bioaccumulation (i.e., ecological risk). Conditions at Waneta are also relevant for white sturgeon populations.

Transboundary Issues

Organochlorine and mercury levels in fish and sediment were a concern in the 1990s for the US portion of the Columbia River (Bortleson *et al.*, 1994, Munn *et al.*, 1995). Celgar and Teck Cominco were considered important sources in addition to sources in the northwest states. Mercury and organochlorine levels in fish tissues measured in 1998 had declined from 1994 (Munn, 2000). Given that Lake Roosevelt is a large stable depositional area downstream of the Canada-US border, interest in conditions upstream of the border will continue. Other areas between the border and Lake Roosevelt may warrant study (for example, near Osborne, at the upstream end of impoundment influence, where river flow decreases and depositional areas develop). Concerns regarding elevated TGP levels are addressed above. Fish such as walleye and rainbow trout migrate across the border to spawn and rear. Although differences in environmental protection and endangered species legislation in the two countries are beyond the scope of this document, they do illustrate concerns. White sturgeon populations are red-listed (endangered) in the CRIEMP study area but viable enough to support a sport fishery in Washington State downstream of Lake Roosevelt, reflecting effects of impoundment, predation and other aspects of river health. Bull trout populations currently are considered at risk in both jurisdictions (RL&L, 2001).

Coordinated initiatives and sharing of information help to maintain a watershed view of the Columbia River and to recognize cumulative impacts of land and water use. The low number of depositional areas in the study region results in settling of suspended compounds (e.g., contaminants) far downstream of their place of origin, making sediments in Arrow Lakes and Lake Roosevelt important places to monitor river health and look for improvements. Reservoirs likely act as sinks for nutrients, contaminants and other constituents and should be included in an examination of river health. This requires an effective and accessible database in both countries, with consistent, or at the least, well documented sampling and analytical methods to enable temporal and spatial comparisons to be made.

An Integrated Measure of River Health

An integrated measure of river health is the goal of the current CRIEMP initiative. It includes issues identified above, quantifying impacts associated with specific activities and measuring cumulative impacts. Given the limited number of depositional sites on the river, impacts of specific point source compounds may not be expressed for some distance downstream. Also, as discharge levels from various industries are reduced, potential effects related to other, previously unidentified sources may become apparent. Also, over time, the effects of low levels may become recognized as significant, making it important to avoid judging using past standards but, rather, to evaluate considering future requirements.

The few depositional sites (downstream of Hugh Keenleyside Dam, downstream of Celgar, Birchbank, Waneta) are preferred locations for some river health assessments. Accumulations of compounds of concern (e.g. chlorinated organics, metals, etc.) have been studied in these areas for many years, enabling ongoing temporal and spatial comparisons. Their pathways into biota can be studied directly and indirectly (bioassays, bioaccumulation). Other integrative studies can be done using ongoing fish community studies to better define ecosystem health and assess habitat alteration and other impacts of river regulation, with potential correlation to other issues such as white sturgeon as a broad indicator of ecosystem sustainability. A weight-of-evidence approach has been shown to be a useful way of interpreting biological, chemical, and physical data from a number of perspectives. Various indices of ecosystem health assessment have been developed and can be adapted to the Columbia River (e.g., index of biotic integrity, benthic index of biotic integrity).

Integrating Monitoring & Resource Management

Integrating monitoring and management considers values used in overall assessment of river health, the human and social, public and private viewpoints to be considered as well as the basic scientific findings and results in an action plan. Ideally, suitable benchmarks of ecosystem health (e.g., biotic integrity, compliance with water quality objectives, sustainable fish populations, sturgeon recruitment), people involved in such decisions and feedback from assessment and monitoring are incorporated into decision-making.

4.2 Pros & Cons of Component Monitoring

Environmental assessments often include measurements of industry-related (air, effluent, wastewater) and receiving environment (water, sediment, plants, animals) components. Relevant results depend directly on effective study design, knowledge of biological significance of results and ability to establish statistically sound linkages among parameters and related physical, climatic and confounding factors. For example, TGP, metals or organochlorines may be measured precisely and accurately, with good replication and frequency, and results may be compared to established water quality objectives. However, questions may remain regarding biological significance of results or objectives, given insufficient knowledge of organism behaviour, intrinsic thresholds for effects, natural variability within species, subtle or chronic effects and overall impact on river health. The previous use, advantages and limitations of including measurements of various parameters in an integrated assessment of Columbia River health are discussed below.

Effluent & Wastewater

Industries with discharges regulated under provincial permit conduct routine chemical analyses and bioassays of final effluents. Knowledge of concentrations, flows and total loadings is essential to understanding sources of compounds found in the receiving environment. Toxicity bioassays have shown substantial reductions in mortality of fish and other organisms following improvements to effluent quality at Celgar and Teck Cominco. Such bioassays can also be used to identify particular toxic components or reflect process upsets. Ability to assess data from point sources is essential when evaluating receiving water conditions and river health.

Receiving Environment Water

Water quality is typically assessed in terms of concentrations in receiving water. Such measurements enable temporal and spatial comparisons of general water chemistry parameters and those related to specific industries. Weaknesses associated with these measurements often relate to use of discrete rather than continuous measurements (e.g., sampling once a week may omit relevant events) or to QA/QC issues and statistical power, which can be addressed by examining underlying data or increasing replication. In addition, measurements in water may not be accurate or easily obtained for compounds such as organochlorines (low concentrations, hydrophobic tendency) or mercury (low concentrations, volatile).

At present, MWLAP analyzes water samples during winter, spring and fall (five samples over a one-month period) at several sites between Birchbank and Waneta. Sampling is no longer done upstream of Birchbank. Nutrient analyses are done at some but not all sites. EC samples biweekly at Birchbank and Waneta (Table 3-2). The CRIEMP II sampling design discussed in the companion document recommends analyzing a full complement of potentially relevant parameters at all sampling locations, concurrently with biological sampling, using appropriate detection limits.

Receiving Environment Sediment

Many compounds settle in depositional areas, making sediment sampling a highly relevant medium, particularly for measuring compounds that occur in low concentrations in water. The presence of only a few long-term depositional areas on the lower Columbia River (downstream of Hugh Keenleyside Dam, downstream of Celgar, Birchbank, Waneta) has historically made establishing reference areas and linking sources with sedimentation difficult. Teck Cominco studies attempted to overcome this problem by collecting suspended sediment over a one-month period (G3 Consulting, 2001); however, there were conceptual difficulties comparing concentrations and quantities at sampling sites. In general, benthic sediment sampling has provided much useful information about trends.

Currently, MWLAP analyzes sediments from Birchbank and Waneta in the fall for metals, organochlorines and TOC. CRIEMP II study design must expand assessment to more sites and increase replication (n=3, minimum) to assess variability and improve statistical reliability (companion document). In particular, it is desirable to study sediments in more detail at Waneta to understand whether declining levels of metals, organochlorines and slag result from deposition of clean (overlying) sediment or re-exposure and transport of these compounds further downstream beyond the Canada-US border. This can be addressed by wider spatial sampling and, perhaps, visual assessments of sediment cores. Links to ecological risk and relevance should be made, through sediment bioassays and bioaccumulation and concurrent biological sampling. Implications of very low organic carbon levels should be investigated, particularly in relation to sediment toxicity bioassays. Assessments of biota specifically associated with sediment (e.g. benthic invertebrates) may not yield relevant data, as many of these organisms typically tolerate a range of environmental conditions.

Toxicology Bioassays

Industries conduct effluent toxicity bioassays several times a year as part of the permit process and have also conducted acute and chronic toxicity bioassays of river water and sediment in the past. MWLAP conducts *Hyalella azteca* toxicity bioassays using sediment collected at Birchbank and Waneta in the fall of each year. These laboratory tests are useful for general assessment of conditions, but often do not relate to river health directly. For example, reduced growth and survival of *Hyalella azteca* associated with Waneta sediments were reported in 2000 for 28-day but not 14-day bioassays, although biological significance of the findings was not assessed. Further study of conditions at Waneta might be able to relate this finding to current toxicity, historic slag deposition, lack of food or some other factors and, perhaps, provide reasons. Bioaccumulation of organochlorines and metals in organisms following bioassay would provide a link between concentrations, survival and growth, and uptake. CRIEMP II study design recommends expanding sediment toxicity bioassays and bioaccumulation measurements to more sites.

Biota – Aquatic Plants

Aquatic plant assessments done on the lower Columbia River include monitoring of periphyton on natural and artificial substrates and surveys of mosses and aquatic macrophytes. Bioaccumulation of metals, but not organochlorines, was reported for macrophytes sampled as part of CRIEMP I, but the method was not recommended for future studies (Aquametrix, 1994).

Periphyton respond rapidly to changing river conditions, with growth, accumulation and species composition controlled by a wide range of factors (e.g., flow, light, temperature, nutrients, toxic compounds). Natural substrates were sampled in summer 1992 for CRIEMP I (Aquametrix, 1994) and autumn 1994 for Celgar Cycle One EEM (Hatfield, 1997), but did not yield useful results. Sampling natural substrates is usually the most environmentally relevant method, but has not worked well for the Columbia, given fluctuating water levels and difficulty accessing stable deep habitat (Aquametrix, 1994). Sampling artificial substrates is frequently considered to yield representative samples (Aloi, 1990; Stevenson and Bahls, 1999). Artificial substrates were used with success in 1995 and 1999 Teck Cominco studies (spring and fall), although substrates were lost on occasion or moved into slower flow areas (G3 Consulting Ltd, 2001). The periphyton component of the Teck Cominco study showed recovery (increased abundance and similarity of communities) associated with reduced metal levels and suggested interactions with other factors such as nutrients (not assessed directly). These observations point to usefulness of periphyton in integrating environmental effects; however a well designed, statistically sound study with concurrent water monitoring is required to discern competing influences. Expertise in sampling, analyzing and interpreting the data is essential. For the Columbia River, lack of comparable reference sites can be an issue, although it can be addressed through temporal and spatial comparisons and a weight-of-evidence approach. The CRIEMP II study design recommends use of artificial substrates exposed for approximately four weeks during late summer and spring.

Biota – Benthic Invertebrates

Benthic invertebrate studies were conducted on the Columbia River for Celgar (Hatfield, 1997, 2000), CRIEMP (Aquametrix, 1994), Teck Cominco (G3 Consulting Ltd., 2001) and BC Hydro (RL&L, 2001). Typically, natural substrates have been sampled, with several problems clouding interpretation (samples taken from near-shore habitat affected by fluctuating water levels, difficulty sampling deep water, lack of suitable reference areas). Teck Cominco employed Hester-Dendy substrates in an attempt to overcome these problems, with limited success (samples showed impact of metal discharges downstream of discharges, but did not reflect community composition on natural substrates, as samplers were suspended in the water column).

Benthic invertebrate communities reflect many environmental influences and are important components in the food web. Interactions between metal levels, available food (i.e., periphyton, influenced also by nutrients) and benthic invertebrate populations were shown in the Teck Cominco study, despite limitations imposed by use of artificial substrates. These organisms also provide food for many fish and terrestrial species, hence are important in assessing environmental risk and river health. The CRIEMP II study design recommends including benthic invertebrate sampling, while acknowledging already identified limitations. There are historic data for temporal comparisons and much ecological information to aid interpretation. Samples can be taken in late summer from natural substrates near shore, with care taken to sample stable wetted habitats. Attempts to sample deeper habitat can be made, but might require use of divers or other more involved techniques. Use of other types of artificial substrates can be considered, such as baskets of rocks anchored into the bottom, but some issues would remain whether natural or artificial substrates are used (access, fluctuating water levels, reference areas, etc.).

Bioaccumulation of metals and organochlorines in adult caddisflies and endemic freshwater mussels was measured at a limited number of sites as an initial screening tool in CRIEMP I (Aquametrix, 1994). This technique is useful in demonstrating links between compounds in river substrates and aquatic and terrestrial food webs. Bioaccumulation in caddisflies is recommended for CRIEMP II, with increased replication (n=3) and number of sites.

Biota - Fish

Many fish studies have been conducted over the years. Organochlorines and metals have been measured in muscle tissue, mainly to assess human health risks (Aquametrix, 1994; Nener *et al.*, 1995; Antcliffe *et al*, 1997a, 1997b; Hatfield, 1997, 2000; G3 Consulting, 2001; MWLAP water quality objectives monitoring). Most of these studies have included general fish health assessments (condition factor, presence of deformities, damage or parasites. Habitat and population studies have been done in relation to operation of dams (RL&L, 2001). Much of the emphasis has been on sport fish species and white sturgeon. The CRIEMP study design recommends adapting the MWLAP monitoring program to measure compounds in liver rather than muscle, where compounds are likely to accumulate, and to include a site closer to Celgar. Information from the BC Hydro fish population assessment index study and white sturgeon recovery program can also be incorporated into a river health assessment.

4.3 Assessing What Is Missing

This is the main question of focus for assessment of Columbia River health. There may be compounds missing from the list of parameters that should be measured. Physical effects of river regulation on biological productivity may still be difficult to assess, but inferences can be drawn from comparisons of Columbia River data with those of unregulated rivers. Long-range transport of certain compounds may be difficult to assess. All these factors are relevant to assessing ecological risks associated with many types of industrial activities in the watershed. Many studies raise as many questions as they answer. However, an integrated study of physical and chemical parameters and biota characteristics, if defined and executed properly, will reveal enough about changes since the early 1990s and conditions, similarities and differences at sites along the river to provide a river health assessment. Questions regarding applicability of water quality objectives to protecting aquatic life may also be answered. It is equally important to have a system of periodic evaluation and feedback to the decision-making process, so that information about newly identified compounds or impacts can be incorporated proactively. Hence, the importance of non-scientific as well as scientific aspects of operation of the CRIEMP committee.

5.0 AN INTEGRATED APPROACH

An integrated approach to river health must incorporate study design through ecosystem-based assessment to implementation of recommendations and management strategies. Philosophical and theoretical aspects of integration were discussed in Section 1.0 of this report and details of study design and implementation are discussed in the companion report, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Study Design*. Integration of monitoring, data interpretation, assessment of cumulative and watershed impacts with communication of results and development of adaptable action plans is discussed below. The integrated river study is concerned primarily with science (true and false), whereas the river health assessment and subsequent management decisions are concerned with both science and society (good and bad).

5.1 Integration of Monitoring & Components

A coordinated approach to monitoring is proposed, based on sites currently used in the MWLAP water quality objective monitoring program, Celgar EEM program, Teck Cominco initiatives, BC Hydro studies and other federal and municipal initiatives. Beyond these, additional program features reflect a more complete assessment of river health. Study rationale, approach and details are discussed in the companion document, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Study Design*. Major components to be studied in CRIEMP II include water, sediments, benthic invertebrates, periphyton and fish.

The MWLAP monitoring program currently includes water sampling during three low-flow periods of the year (winter, spring, fall) and sediment and fish tissue sampling during the fall. The EC program involves biweekly water sampling at Birchbank and Waneta and continuous monitoring of TGP and temperature at Waneta. Celgar EEM work is typically conducted in late summer, a suitable time to assess biota (benthic invertebrates, periphyton), as reported in CRIEMP I. Field work for Cycle 3 EEM is anticipated for summer 2002. Teck Cominco may address aspects of river quality as part of ongoing wide-area Ecological Risk Assessments. It is the intention of CRIEMP II to integrate these programs, together with other studies scheduled by BC Hydro and Columbia Power Corp., into a more complete study of overall river health through the use of appropriate sampling sites, statistically-based replication, rigorous QA/QC evaluation and concurrent sampling for water, sediment and biota. Data will then be assessed to address questions regarding overall river health within the defined study area.

The CRIEMP II study design describes individual components and their integration. Components include those measured in the past, as well as additional parameters at some sites, to gain a more complete and relevant evaluation of watershed impacts (e.g., nutrients at selected sites, complete analysis of sediment data at depositional areas). Particular attention is paid to consistent evaluation of biological communities in a statistically defensible manner, as well as rigorous QA/QC evaluation of biological and chemical data. Sufficient replication and site representation is essential.

Periphyton sampling is particularly useful as an indicator of primary productivity, localized and general nutrient inputs, toxicity and ecosystem sustainability. In the Teck Cominco study of river responses to metal levels, periphyton appeared to be a more sensitive indicator of changing metal levels than did benthic invertebrates (G3 Consulting, 2001).

Given fluctuating river levels, natural substrate sampling for periphyton has not provided reliable data in the past. Well-anchored and maintained artificial substrates may yield more consistent information. Periphyton sampling during spring will provide ecological relevance and continuity with Teck Cominco data and MWLAP water quality objective monitoring. Sampling during late summer-early fall will provide critical information integrated over the growing season and correlate with benthic invertebrate communities.

Benthic invertebrate communities on natural substrates provide a good indication of ecosystem health (contaminants and habitat issues), provided sampling of representative stable substrates can be achieved. Given the large reductions in compounds discharged from Celgar and Teck Cominco since CRIEMP I, repeating and expanding the studies of metal and organochlorine bioaccumulation in adult caddisflies may assist in assessing improvements over time in addition to providing evidence of ecosystem processes (e.g., food web, water-land links).

Sediment toxicity bioassays (growth and survival) using sediment from depositional areas will relate measured levels of compounds in sediment to potential biological responses. Both *Hyalella azteca* and *Chironomus tentans* have been used in the past, with *Hyalella azteca* used currently in MWLAP monitoring. Measuring bioaccumulation in *Hyalella* following the bioassays will provide another link between measured levels of compounds, survival and growth, and uptake by the organisms.

Information from ongoing BC Hydro fish population and community studies (Dana Schmidt, RL&L, pers. comm.) and use of performance measures for water quality objectives may be incorporated into an integrated assessment of river health in a number of ways.

5.2 Integration of Information

Information integration involves several important aspects. The first is to identify data gaps from historic and ongoing monitoring and assessment. Gaps arise from analytical issues, inaccessible sites, loss of samplers, fluctuating river levels, omission of parameters that later become relevant, and post-study evaluation of data and QA/QC issues. Some problems can be addressed in advance. For example, decisions can be made on how to handle low or high recovery rates from Certified Reference Materials, outliers in the analytical data, or possible contamination suggested in trip and travel blanks. Particularly sensitive sampling locations and issues can be identified in advance (e.g., metal levels at Birchbank, handling of water and sediment samples for mercury analysis, organochlorine levels at sites with low organic carbon content, maintaining consistent flow over artificial substrates). The second aspect involves ability to interpret the data, based on a full complement of parameters and sufficient sample replication to draw statistically sound conclusions. The third relates to communication of data within CRIEMP or to the general public. This is essential for CRIEMP II, which will incorporate data from several studies and ongoing monitoring. The fourth involves integrating data and conclusions from ongoing monitoring and special studies into the decision-making process. Success at this stage relies on accuracy, precision and statistical validity of underlying data, reliable interpretation and recommendations (true vs. false), as well as a framework that recognizes societal goals in the river health assessment (good vs. bad).

5.3 Integration Tools for Assessing Ecological Relevance

Interpretation & Statistical Tools

Evaluation of river health requires verified, statistically reliable data from a well-designed study as a starting point. Interpretation then incorporates approaches and tools grounded in ecological processes avoiding or identifying any introduced bias. The need is recognized for consultation and consideration of standards used (e.g. water quality objectives, community or societal values), long term goals and sustainability, whether defined socially, economically or ecologically.

Several tools under a weight-of-evidence approach will be used to interpret and integrate results to provide a realistic assessment of ecosystem health. Trends in individual characteristics (univariate analysis) and interactions (multivariate analysis) will be examined. Indices reflecting one or several endpoints will be used judiciously, given the intrinsic assumptions associated with them and that some have wider applicability and ecological relevance than others, as discussed below. Statistical approaches that apply spatial and temporal comparisons based on biological patterns (e.g., similarity indices, cluster analyses) will be considered to integrate large amounts of taxonomic data from periphyton and benthic invertebrate data, compare communities among sites and distinguish affected areas. Fish habitat assessments used in the Watershed Restoration Program (Slaney and Zaldokas, 1997) and rapid bioassessment protocols developed by USEPA for streams and wadeable rivers (Barbour *et al.*, 1999) may also be considered to assist in documenting features and data important to an overall assessment of river health.

Weight-of-Evidence

Weight-of-evidence integrates structural components (effluent, bioassays, water, sediments, periphyton, benthos, fish) and functions (underlying ecological relationships and processes such as productivity, ecological tolerances, diversity, recruitment of species) into a spatial analysis of potential effects. Qualitative and quantitative aspects of a parameter are compared (e.g., chemical composition, flow, operational activities, dominance hierarchy, rare and indicator species compared with total abundance). Relationships among various endpoints of a single component (e.g., relative abundance hierarchy and species richness) are examined. Relationships among different components, (e.g., periphyton standing crop and nutrient or sediment metal levels) are also explored. Different perspectives of the same components (e.g., standing crop or biomass and total abundance) may also be compared. This enables a more accurate picture of the receiving environment to be constructed and trends identified. This is essential for understanding ecological consequences resulting from the complex issues that affect the Columbia River (e.g., flow regulation, slag burial or re-exposure, long-range transport of compounds from the pulp mill, smelter, and wastewater treatment plants).

Indices

Several single factor biotic indices have been developed for use in ecological studies, including similarity, diversity, equitability, evenness, dominance, EPT (Ephemeroptera, Plecoptera, Trichoptera). Each index reflects an aspect of underlying structure or function, but taken alone provides an overly simplified view of the ecosystem and its health. More complex, multivariate indices have been developed to overcome this bias and to link observed responses more directly to the environment.

Index of Biotic Integrity

The concept of *biological integrity* has been developed as a broad-based reflection of environmental health. It is defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region" (Karr and Dudley, 1981). The Index of Biotic Integrity (IBI) is a multivariate index developed for assessment of river health, based on studies of fish communities (Karr, 1981) and later adapted for benthic invertebrate communities (B-IBI). The IBI asks a series of ecologically relevant questions about the data and has been successfully applied to identify a broad range of stressors on stream ecosystems (Karr, 1998; Simon, 1999; Barbour *et al.*, 1999). Several aspects of species richness, indicator taxa, trophic structure, abundance and condition are assessed and compared at "reference" and "impaired" sites, allowing conclusions to be drawn about deviation from "ideal" conditions and, hence, ecosystem integrity. Originally developed for warm streams in the US midwest (Karr, 1981; Karr *et al.*, 1986), the IBI has been adapted to many other regions (Simon, 1999), including cold streams (Mundahl and Simon, 1999) and flow-regulated rivers (Bowen *et al.*, 1998). A similar index incorporating information about benthic invertebrates (B-IBI) has been developed for the Pacific Northwest and other areas (Karr, 1998; Barbour *et al.*, 1999) and an index is being proposed for periphyton (Stevenson and Bahls, 1999). This approach is valuable for its ecological basis and integration of biological responses. It asks the types of questions (metrics) researchers typically ask of data in a formal, quantifiable way and can be evaluated statistically.

For example, the index is calculated using a simple scoring system: 5 if the metric at the study site is similar to that for reference areas, 3 for moderate deviation, and 1 for great deviation (Karr, 1998). Scores for each metric are totaled and compared to a ranking scheme (*excellent* to *very poor*). Appropriate statistical tests can be performed and individual metrics examined to understand underlying biological reasons for a score.

The IBI and B-IBI approach is offered here as an example of an integrated biological tool, designed to assess reflect river health, that might be adaptable to local conditions and tested using Columbia River data. For example, the current BC Hydro fish population abundance index study may provide a suitable depth and breadth of information for use in an IBI. The same limitations apply to any study of this river – difficulty establishing reference conditions, problems sampling a large system and flow regulation. Another consideration is the development of a set of metrics adapted to the specific ecosystem, in this case a cold, regulated river. An IBI adapted for assessing coldwater streams in the US midwest, derived from 300 data sets from reference and impaired sites, is shown in Table 5-1 for comparison (Mundahl and Simon, 1999). Twelve metrics were chosen based on their ability to show statistical differences related to impaired conditions and to be most strongly discriminating when several metrics were correlated. Table 5-2 shows a B-IBI developed for benthic invertebrate communities in the Pacific Northwest (Karr, 1998).

TABLE 5-1:
Metrics for an Index of Biotic Integrity (IBI) for Fish in Coldwater Streams of the Midwest United States

Characteristic	Metric
Species Richness & Composition	Number of fish species
	Number of coldwater species
	Number of benthic species
	Number of minnow species
	Percent coldwater individuals
Indicator Species	Percent intolerant individuals
	Percent tolerant individuals
	Percent salmonids that are brook trout
	Percent white sucker
	Percent top carnivores
Abundance & Condition	Number of coldwater individuals
	Number of warmwater individuals

Source:Mundahl and Simon (1999)

TABLE 5-2:
Metrics for a Benthic Index Of Biotic Integrity (B-IBI) for Benthic Invertebrates in Pacific Northwest Streams

Characteristic	Metric	Predicted Response to Stress
Taxa Richness & Composition	Total number of taxa	Decrease
	Number of Ephemeroptera taxa	Decrease
	Number of Plecoptera taxa	Decrease
	Number of Trichoptera taxa	Decrease
	Number of long-lived taxa	Decrease
Tolerance	Number of intolerant taxa	Decrease
	Percent of individuals in tolerant taxa	Increase
Feeding Ecology	Percent of predator individuals	Decrease
	Number of clinger taxa	Decrease
Population Attributes	Percent dominance (2 or 3 taxa)	Increase

Source: Karr (1998)

Watershed Report Card

A watershed report card that focuses on existing management processes and responses to environmental issues and identifies action items may be considered. It can be a series of questions (e.g., is there a spill reporting process, how common are spills and how great are their impacts; are water quality objectives being met routinely; are ecologically sensitive areas identified and considered in land development proposals; are fish safe to eat, rivers safe for swimming, etc.). The list of questions can be expanded as desired, and can also address the "good or bad" (societal) interpretation of river health. An example is presented in Appendix 2. This aspect of integration is particularly suited to communicating results to a wider audience (e.g., public).

Links Between River & Watershed Activities

There are several review processes for land development, some of which refer to river health or environmental impacts on the Columbia River. These include Official Community Plans (OCP), required through the Municipal Act for communities such as Castlegar, Trail and Nelson. Many municipalities recognize, map and protect ecologically sensitive areas (ESA). Land and Resource Management Plans (LRMP) are developed for long range planning of forestry and other activities. Since all activities on land eventually affect the river, potential aquatic impacts are or should be considered in planning. A watershed report card may ask whether these issues are addressed in OCPs and LRMPs.

5.4 Communication Tools

A large amount of data has been collected regarding the Columbia River and more will be generated in ongoing and future studies. Some is available in formal reports and much more is contained in government and private or restricted-access databases. Collecting this data and making it accessible to a wider audience (CRIEMP members, scientists, perhaps even the public) is an important and necessary aspect of the integrated river health assessment. In addition, reporting and reviewing the data, evaluating its validity (QA/QC), and incorporating it into assessments is and should remain an ongoing process. Communication issues and bottlenecks have been identified in the current data gap analysis and study design preparation. Ongoing CRIEMP initiatives and special studies will benefit from improved communication tools, which lead to efficiency, timeliness and improved data quality, all of which contribute to the integrated purpose of CRIEMP.

Some basic communication tools exist within CRIEMP and must be expanded to meet committee and program needs. The act of collecting information for this current document identified a wide range of possibilities for storing reports, data, and supporting information (websites, printed documents from many sources, databases), as well as difficulties quickly accessing information. Interest in developing and maintaining more permanent information storage systems, such as a library, database, GIS system and website was assessed in the questionnaire distributed to CRIEMP members as part of the current project. Individual members affirmed the value of these communication tools, although there has been limited discussion of priorities.

Databases

The EMS database, organized and managed by MWLAP with input from permittees, is currently accessible to Ministry staff only. Information is available to others following a *Freedom of Information* request. This database includes information on water quality monitoring, sediment and fish analyses, with a time lag between sampling and reporting. The database is designed for physicochemical monitoring data, but does not include information of a more general or specific (biological) nature. Likewise, federal databases (ENVIRODAT, ERS for EEM) are not designed or intended for public access.

Depending on needs of CRIEMP committee members, additional database capability may be desirable and can be modelled on existing databases such as that currently used for EEM data. For example, an Application Service Provider (ASP) can be used as a cost-effective alternative to a specially designed database. An ASP can be accessed through existing internet connections, so can be accessed from anywhere in the world. This approach requires little or no hardware, little new software, and basic web-based training, enabling sharing of data, secure access and posting of data and reports by clients. Details regarding ASPs are included in Section 5.2 of the companion study design document.

Geographical Information Systems (GIS)

Parameters and spatial data are related in concise ways in GIS systems. Teck Cominco has developed a GIS system and other stakeholders (e.g., municipalities, MWLAP) may have systems in place or a desire to develop one. Such systems are accessible to a variety of users and store information in an easily retrieved and updated manner. The benefits of handling and communicating large quantities of data from routine monitoring or from a CRIEMP II study using GIS can be considered.

Web Sites

Web sites can be developed in many ways, from simple to complex. Currently there are websites for government agencies, Trail, Castlegar, Teck Cominco, Pope and Talbot, BC Hydro, Columbia Power Corp., UtiliCorp and Columbia Basin Trust. CRIEMP may decide that a simple website, posting information about goals and objectives, history, current activities, contact people and links to other websites is useful for public communication. A more fully functioning website could be developed to allow posting and retrieving of information by stakeholders in a secure environment. Considerations of type and extent of content and linkages should be discussed by CRIEMP members prior to developing a system.

5.5 Public Involvement

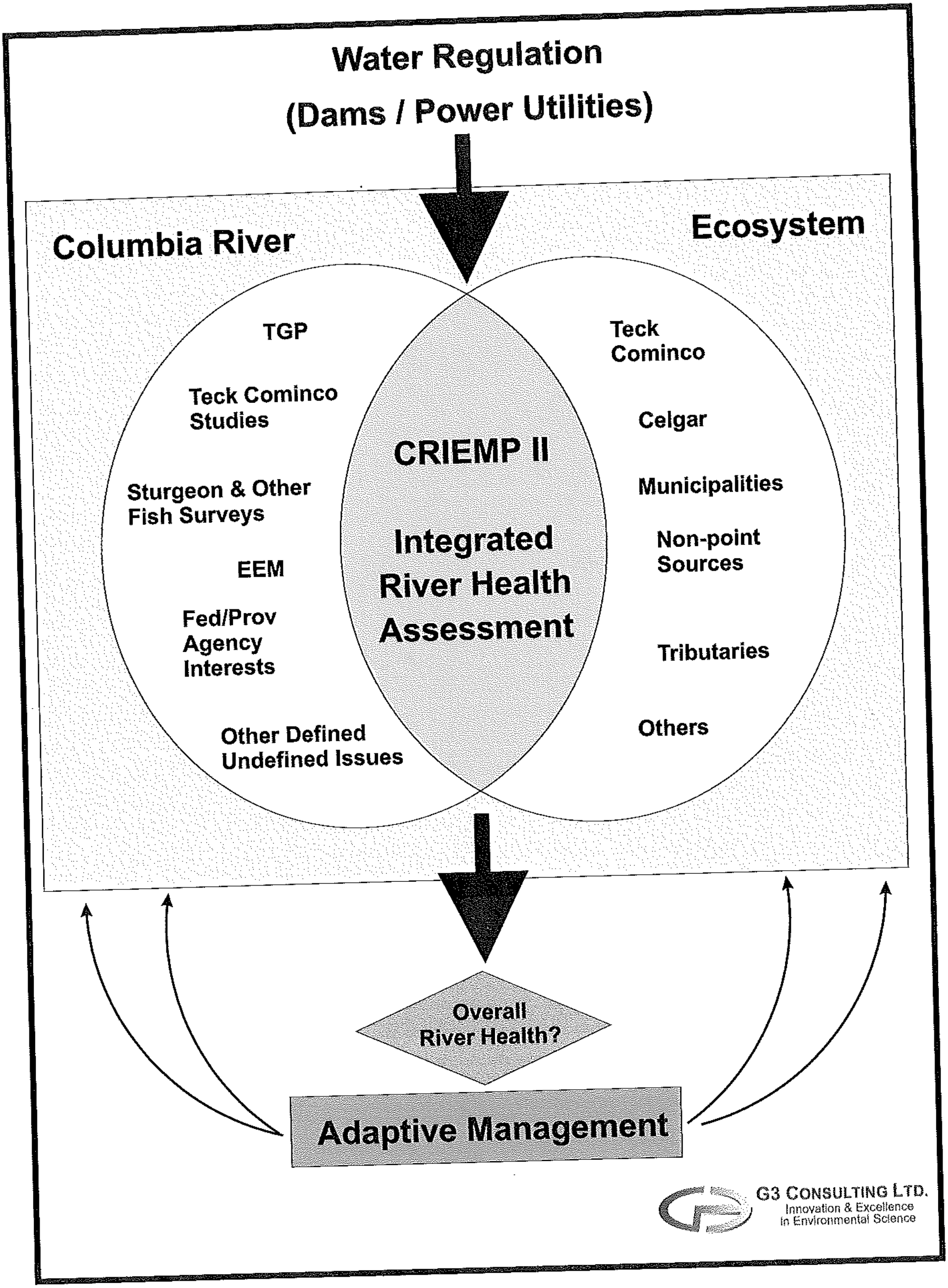
Improving communication raises questions of who will have access to information and how, the intended audience, and, ultimately, which segments of society are involved in decision-making and establishing standards used to assess river health. Currently, staff from federal and provincial agencies, municipalities, First Nations and Columbia Basin Trust represent public interests on CRIEMP. Consideration of direct involvement of various communities may become of interest. Although less likely to occur in relation to scientific aspects of the CRIEMP II study, public input to other CRIEMP activities may be relevant. These include consideration of criteria and standards used to evaluate river health, as consideration of "good and bad" includes a societal evaluation. A public awareness component is highly relevant for protecting the river from non-point sources and fostering a stewardship ethic. Committee members expressed a range of opinions in the questionnaire regarding public involvement. Responses ranged from "always appropriate," through yes with caveats (clearly defined role, participation in setting of broad priorities but not in scientific reviews, review of final drafts of monitoring reports) to no public involvement at this time. Consideration of public involvement in CRIEMP adds another potential layer of integration. In the long term, this aspect has much to do with an assessment of river health and successful implementation of recommendations from an integrated environmental study.

6.0 ADAPTIVE MANAGEMENT STRATEGIES

Components of a Columbia River health assessment include an integrated river study, data from the BC Hydro fish population abundance index study and other sources. Figure 6-1 shows the conceptual framework, with flow regulation of the Columbia River ecosystem as an overriding factor and a range of watershed influences and study initiatives to be considered in river health. These provide information for management strategies, with feedback loops between future monitoring and management decisions. The design for an integrated river study, presented separately in the companion document, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Study Design*, incorporates ongoing monitoring and assessment programs of MWLAP, EC, BC Hydro, Columbia Power Corp., UtiliCorp, Celgar, Teck Cominco and communities, along with use of additional sites and parameters for a more complete river health assessment. With such a complex river study and so many organizations involved, coordination of efforts and communication of plans and data among entities is essential.

Incorporation of river health assessments and other watershed initiatives and planning processes into the daily decision-making and planning processes is important for meaningful results to be obtained. This will require an ongoing commitment on the part of CRIEMP members to maintain clear goals, objectives and communication. Integration with initiatives in the US is also considered to be an important aspect of a truly integrated and overall assessment of ecosystem health. Many aspects relevant to integrating science with strategic and planning and adaptive management have already been discussed in this report. Developing a strategy for their implementation is an ongoing project of the CRIEMP committee.

FIGURE 6-1:
Integration of River Study and Overall River Health Assessment



7.0 RECOMMENDATIONS

Several recommendations for developing an integrated river health assessment emerge from the data gap analysis. The integrated CRIEMP II river health assessment involves coordination of various stakeholder's study plans, development of additional aspects to maintain a whole river approach and provide ecological integration, communication of data among stakeholders, and integration of study findings and recommendations into resource management decisions.

The following recommendations are addressed in the accompanying study design document.

1. Acknowledge shared responsibility for health of the Columbia River and develop an effective integrative process that reflects responsibilities. Industrial point sources are already recognized and assessed; however, other point and non-point sources (e.g., municipal emissions and discharges, other land use activities), often less emphasized as these influences are smaller in size and more difficult to measure, may exert significant cumulative effects.
2. Widen the scope of CRIEMP by establishing more formal links with other municipalities and organizations beyond the traditional study area. In addition to sampling stations in the study area, include sites in Arrow Lake, Kootenay River below Brilliant Dam and Pend d'Oreille River upstream of Waneta Dam, to assess conditions relevant to the study area. This perspective also should extend downstream of the Canada-US border through partnership with American entities involved in Columbia River health assessment, to address downstream concerns with river health.
3. Establish an integrated process that maintains the overall program perspective. This process should be flexible and adaptable in terms of responsiveness to issues and management decisions.
4. Coordinate ongoing and planned studies and additional critical health aspects into an integrated river health assessment, avoiding a piece-meal approach with its incurred costs and reduced efficiency. This involves:
   - recognizing regulated flow resulting from dam operations as an overriding factor that determines ambient river conditions;
   - addressing replication to understand system variability and provide statistical relevance;
   - addressing quality assurance/quality control issues to ensure that defensible data from a variety of sources can be integrated into a river health assessment, particularly important when data are incorporated from numerous types of studies and analytical laboratories;
   - developing an environmentally relevant sampling regime in terms of timing;
   - including adequate spatial representation of habitat types, to assess ambient conditions and exposure to specific discharges and disturbances (location and sufficient number of sites), as well as assessing cumulative impacts of a range of influences. This involves using sites traditionally and currently used for monitoring, as well as new sites to reflect a watershed health approach;
   - choosing appropriate components, parameters, endpoints and detection limits for measurement;

- including biological indicators that integrate environmental influences and provide ecological linkages and evidence of ecological integrity;
- maintaining consistent and established methodologies and appropriate documentation; and,
- assimilating results from ongoing programs and additional, specially designed studies to address gaps as part of an overall river health assessment.

5. Develop improved communication tools to facilitate data sharing (accessible database, GIS, web site) among CRIEMP members.
6. Consider increased public involvement or communication to maintain a watershed perspective regarding river health.
7. Integrate results of the scientific study with ongoing management processes, strategic planning and decision-making.
8. Adopt the proposed study design, which incorporates the above-identified issues of replication, sampling location, ecological relevance, timing, biological assessments that integrate environmental effects and recognize cumulative effects.

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APPENDICES

1.0 Summary of Questionnaire Feedback

2.0 CRIEMP II – Integrated River Study
Watershed Report Card (Example)

APPENDIX 1.0: Summary of Questionnaire Feedback

Topic	Feedback
New issues since CRIEMP I	total gas pressure (TGP) and temperature, contaminants endocrine disrupting compounds in waste treatment facility discharges reports of excess algal growth (*Didymosphenia* mats) transboundary concerns (downstream movement of contaminants, TGP) spill procedures for industries white sturgeon status and recovery Ecological Risk Assessment, Trail Lead Task Force Assessment (Teck Cominco)
Updates and initiatives since CRIEMP I, reported by CRIEMP members	evolution of watershed approaches to monitoring evolution of EEM procedures, tools and guidance Cycle 1 (1992-1996), Cycle 2 (1997-2000), Cycle 3 (2001-2004) Celgar Pulpmill upgrades, conversion from Cl_2 to ClO_2 (1993) lifting of fish consumption advisories in 1995 (mercury in walleye) and 1997 (dioxins in lake whitefish, mountain whitefish) automated water monitoring at Waneta Teck Cominco upgrades to lead smelter, effluent treatment facilities, cessation of slag discharge (1995 through 1999) publishing of water quality objectives and monitoring program, Birchbank to Waneta, along with objectives for sediment and fish tissue (2000) many studies of temperature and TGP levels in relation to Keenleyside, Brilliant, and Waneta Dams (Columbia Power Corp., BC Hydro) Brilliant Dam Upgrade of hydroelectric facilities underway (Columbia Power Corp.) Arrow Lake Generating Station (Columbia Power Corp.) expected on line in 2002 proposed Brilliant Expansion Project (Columbia Power Corp.) development of White Sturgeon recovery plan application to expand Castlegar waste treatment plant (current)
Updates and initiatives since CRIEMP I, reported by G3	creation of Columbia Power Corp., Columbia Basin Trust, Columbia Basin Fish and Wildlife Conservation Program development of *Water Use Plan* for Keenleyside Dam by BC Hydro (2001) development of a large river fish community indexing procedure by RL&L for BC Hydro (2001 onward) development of websites for many CRIEMP stakeholders inception of Arrow Reservoir Fertilization Program (1998) formation of Transboundary Gas Group (1998)
Desire for common library or database?	many members see value of a common information source for members some information is held in provincial EMS and federal databases (with limited access) and with individual organizations (e.g. Celgar, BC Hydro, Cominco, Columbia Power Corp., consultants) until released publicly could link continuous flow, TGP, temperature data to the EMS database

APPENDIX 1.0: Continued

Topic	Feedback
Desire for GIS?	most members see the value of using a GIS-based system, perhaps linked to the database Teck Cominco has developed GIS for Ecological Risk Assessment program and other purposes
Desire for a CRIEMP website?	opinions vary from low priority, through secure access for CRIEMP members only, to full accessibility concerns about funding and maintaining a website a simple CRIEMP website could include links to existing stakeholder websites and other useful sites
Desire for public input?	opinions vary from "always appropriate," through yes with caveats (clearly defined role, participation in setting of broad priorities but not in scientific reviews, review of final drafts of monitoring reports), to no public involvement at this time
Strengths of CRIEMP I	established a temporal and spatial baseline coordinated and organized resources and skills needed to determine river health, was a coordinated basin approach improved cooperation and communication eliminated duplication of effort
Weaknesses of CRIEMP I	some stakeholders had little or no involvement possible weaknesses in details of sampling program identified fuzzy goals, difficult to monitor the study and ensure appropriate results did not continue or use lessons learned to improve process difficult getting consensus on published results concurrent sampling was lacking for some components, making it difficult to link measured contaminant levels to impacts did not integrate impacts of flow regulation into overall impact assessments
Hopes for CRIEMP II	develop integrated monitoring program to answer specific questions, identify cumulative effects, point and non-point sources of pollution, integrate data eliminate permit-based piecemeal monitoring programs, supplement programs with broader based population wide monitoring activities unless a specific local need is identified provide a broader picture of what is happening on the river help identify and focus resources on environmental impacts maintain communication and cooperation among agencies and corporations use limited financial resources efficiently create a template for other big river environmental impact assessments demonstrate how stakeholders can join, address issues in timely economic manner ultimately hope for ability to assess results and make changes to industrial processes, if necessary

APPENDIX 2.0:
CRIEMP II – Integrated River Study Watershed Report Card (Example)

Question	Issue	Response	Action Needed
Is there a procedure for reporting industrial spills			
Is there an action plan for industrial spills			
What is the frequency of spills and their environmental or human health consequences			
Are water quality objectives monitored fully			
Are measured levels in compliance with water quality objectives			
Are fish safe to eat (health advisories)			
Are coliform levels low enough to permit recreational use in the river (all areas? some?)			
Are regulated flow issues on the river protecting aquatic life			
Are there fish strandings or deaths reported resulting from flow reductions			
Are TGP objectives met			
Are TGP impacts on fish measured or reported			
Are fish populations stable, increasing or decreasing (anecdotal and scientific studies)			
Land Use Planning – does the current OCP or LRMP reflect current and anticipated community plans			
When will OCPs or LRMPs be re-evaluated			
Does the OCP or LRMP identify protection of river or tributary habitat and quality as an objective			
Does the review process for development applications adequately protect river quality			

CRIEMP II

COLUMBIA RIVER INTEGRATED ENVIRONMENTAL MONITORING PROGRAM

Study Design

Final Report

Submitted to:

CRIEMP Committee

By:

G3 Consulting Ltd.
4508 Beedie Street
Burnaby, BC
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May 2002

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1.0 INTRODUCTION

This document discusses an overall river health study design for the Columbia River Integrated Environmental Monitoring Program (CRIEMP). The need for a coordinated, integrated approach to assessing Columbia River health was recognized in the early 1990's, in part to overcome duplication of efforts and increase communication among stakeholders, and in part to recognize the complex and dynamic nature of the river. The CRIEMP committee was established in 1991 to identify, monitor and address environmental impacts of the many human activities in the lower Columbia River watershed and a broad-based study plan implemented in 1992/1993 (Aquametrix, 1994). Since that time, major initiatives to improve environmental performance of industries and dams have occurred, accompanied by a substantial commitment of resources. Consumption advisories for sportfish, issued in 1989, were lifted in 1995 for mercury levels in walleye and 1996 for organochlorine levels in mountain whitefish and lake whitefish, reflecting considerable improvement in levels of these compounds discharged to the river. Water quality monitoring programs and objectives have been developed and implemented (MELP, 2000). The CRIEMP committee convenes regularly to share information and discuss issues related to Columbia River health.

An integrated river health assessment has been proposed by CRIEMP, given substantial industrial upgrades and changes in environmental standards. As a result, current information and issue-specific study plans are being examined to identify data gaps and recommend a rejuvenated framework for integrated environmental monitoring. G3 Consulting Ltd. (G3) was retained by CRIEMP to identify current data gaps (companion report) and recommend an integrated study design to assess overall river health within the defined study area (this report). The companion report, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Data Gap Analysis and Study Design Considerations*, provides a synopsis of issues, industrial initiatives and upgrades, current and ongoing studies, and assessment of study components and design elements necessary for developing an effective study design. Many practical and philosophical perspectives of developing an integrated river health assessment are included, particularly those establishing links to ecological risk, activities on the land, and ongoing planning and decision-making by environmental managers.

There are many benefits to developing an integrated approach, from efficient use of resources through establishment of ecological relevance, communication of findings and establishment of feedback loops between scientific assessments, management strategies and decision-making. Assessing the state of the river from a broader ecological health perspective rather than a traditional upstream-downstream assessment of specific point sources enables many questions to be addressed. These include cumulative effects and interactions, land-use practices, long distance transport and fate of chemicals of concern, biological responses to physicochemical changes, environmental risks and other issues. This approach is highly relevant for large, regulated rivers such as the Columbia, with many potential impacts in the watershed, and includes numerous stakeholders, not just recognized point sources. Ongoing programs are coordinated into an integrated approach and specific components and stations incorporated to obtain a more realistic assessment of environmental conditions. Existing programs and objectives can be evaluated relative to the goal of adequate protection of the environment and adapted, if deemed necessary. Information and input from individual members and entities can be integrated, interpreted and communicated more readily, and, ultimately, connections or feedback loops with ongoing management, decision-making and planning processes maintained.

This design develops program integration and implementation aspects. Proposed and ongoing studies for 2002/2003 include routine water quality objective monitoring (Ministry of Water, Land and Air Protection; Environment Canada), Environmental Effects Monitoring, Cycle 3 (Celgar Pulp Company), environmental assessment and applicable ecological risk assessment (Teck Cominco Metals Ltd.), and monitoring, fish and habitat assessment (BC Hydro, Columbia Power Corp.). Many aspects of these programs already contribute valuable information to a river health assessment. As a result, these studies are coordinated to produce a design for an integrated river study with incorporation of some additional stations and components to yield a usable river health assessment. Practical aspects of the CRIEMP II study design are discussed in this document. Stakeholder initiatives and responsibilities have been considered carefully when recommending assignments for various study aspects.

This design has been provided in sections, using a river-health and science perspective (i.e., scientific rationale, components, parameters), rather than a specific stakeholder perspective. Stakeholders wishing to ascertain individual roles in the integrated assessment are directed to Sections 2.0 through 4.0, where suggested responsibilities are recommended under each design aspect. Section 2.0 presents the rationale, i.e., a whole-river approach with use of a gradient design and multiple reference sites to define ambient and perturbed conditions. Section 3.0 discusses locations and reasons for selecting reference and exposure stations, as well as timing (late summer, spring). Integration of both timing and station locations used in ongoing studies by stakeholders and additional work proposed to yield an integrated river study are also discussed here. Section 4.0 describes design elements, including components to be assessed (physical, chemical, biological), parameters to be used and endpoints to be measured. Integration of these components with ongoing studies by stakeholders is also discussed. Section 5.0 presents the integrated river study, with recommended schedules and responsibilities for field and analytical work. Recommendations for data acquisition, sharing and handling procedures are presented in this section as well. Section 6.0 discusses quality assurance and control (QA/QC) considerations from an overall perspective, although details related to individual components are discussed in Section 4.0. The approach to recognizing ecologically and statistically significant differences at various stations, beyond ambient, is presented in Section 7.0. The proposed design approach is summarized in Section 8.0. Report preparation and information release are also discussed, given their relevance to effective integration.

The proposed study design described here has been developed in consultation with, and partial funding by, the CRIEMP committee. Information and design theory presented should be considered proprietary and has been supplied for the express purpose of review and discussion by CRIEMP.

2.0 RATIONALE & APPROACH

Integrated environmental monitoring and assessment requires a coordinated effort among stakeholders, researchers and managers (Sections 1.0 and 5.0 of companion document). Successful integration requires clearly defined scope, objectives and approach. The study area comprises the Columbia River from Hugh Keenleyside Dam to the international border. For such sections of regulated rivers, maintaining a whole-river approach and considering the river basin as a fundamental unit (Sundborg, 1984), provides a framework that links ecological relevance with management. Adopting a whole-river perspective is in keeping with a flexible management process, relating science to decision-making, as discussed more fully in the companion report, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Data Gap Analysis and Study Design Considerations.* The ultimate objective for CRIEMP II is to assess overall health of the Columbia River, which requires agreement regarding standards, endpoints and river health definition. Long term goals, processes and responsibilities of CRIEMP are currently circumscribed by agency jurisdictions and recognized "effect" areas from identified stakeholders.

It is necessary to agree upon a baseline for ambient conditions, from which temporal or spatial changes can be evaluated. Precise definitions of "ambient" and "healthy" (as opposed to "normal" or "natural") are essential and should incorporate temporal (current vs. historical), regional (e.g., limitations of the study area, jurisdictions) and socio-economic (e.g., watershed use and planning) perspectives. The ambient condition is the regulated nature of the river, the effects of which must be considered in any effort to monitor Columbia River health. Regulation controls, directly and indirectly, many environmental variables essential to river organisms, through both release depth and discharge volume. It modifies thermal regimes, which in turn alter chemical and physical processes that affect structure, behaviour and function of biota (e.g., colonization, species diversity and interaction, ecological and seasonal succession). Superimposed on regulation are effects of point and non-point discharges from industries and other anthropogenic and natural sources.

Serious limitations are imposed on a study when ambient is not well defined, particularly for rivers, with their great longitudinal and temporal variation. A common approach is to identify industry-specific contaminants, then measure levels upstream and downstream of sources (Before-After Control-Impact or BACI). Although sufficient for a study of specific parameters or industries within a defined area, difficulties become apparent when attempting to use results to assess overall river health. BACI study designs do not resolve issues of persistence, accumulation, bioaccumulation, exposure, burial and re-exposure, adding to difficulties understanding the extent of effects of specific operations, non-point discharges, ecological risk or recovery resulting from improvements. It is difficult to apply such data to risk assessment models, management plans and mitigation procedures, as problems related to underlying inadequate definitions of ambient and health confound the issue. Extending program-specific results to make more meaningful evaluations based on comparisons of locations, parameters or time frames is also a challenge. These problems invariably relate back to the need for a properly defined study and clear understanding of ecosystem functionality and characteristics.

2.1 Whole-river Approach

The study area is the approximately 60 km stretch of regulated river extending from just above Hugh Keenleyside Dam to the international boundary, described in detail in the companion data gap report. A whole-river approach to integrated health assessment is proposed, considering flow regulation as the dominant system effect. This approach investigates the river ecosystem as a whole within the study area, treating it as a fundamental experimental unit (Ward & Stanford, 1984), rather than using a piece-meal, component- or issue-based approach. The ambient aquatic ecosystem is affected by climate, watershed inputs (e.g., precipitation, dry fall, groundwater, surface runoff) and interactions between physical, chemical and biological components of the ecosystem itself, all of which vary considerably along its length.

Within the framework of a flowing ecosystem undergoing spatial and temporal succession, it is useful to consider several characteristics of rivers in general and the Columbia in particular. The river continuum concept acknowledges that a river changes along its length in morphology, habitat, aquatic environment and biotic communities (Vannote *et al.*, 1980). Perturbations are alterations that act as reset mechanisms, i.e., that affect temporal and spatial succession (Vannote *et al.*, 1980; Ward and Stanford, 1984). These perturbations shift the overall continuum response toward headwater or downstream characteristics, depending on type of disturbance (e.g., impoundment, sediment, nutrients, organic or inorganic inputs) and location.

Seven major habitat types or reaches have been defined in the Columbia River study area (BC Hydro *et al.*, 1995), which change over time, eroding and depositing to change yet again. Watershed influences and interactions occur throughout the area, with non-point influences often neglected, misunderstood and underestimated. Spatial and temporal cycles operate throughout the river, particularly related to regulation. Defining ambient or baseline conditions in this regulated system is essential to defining acceptable and unacceptable change and ambient conditions can only be defined by looking at the overall study area.

Whole-river study begins by defining ambient conditions, including effects of climate, morphology, hydrology, edaphic interactions and spatial and temporal succession patterns (e.g., drift, colonization, life-cycle behaviour, competition, predation) within the study area. This is accomplished by treating reference stations collectively along the river, relative to one another rather than in isolation, with appropriate analysis of several components and endpoints. Design tools and considerations include type of spatial design, definition and use of reference stations, indicators of ecosystem health, structural and relationship endpoints and weight-of-evidence analysis. Spatial designs range from gradient to before-after control-impact.

A gradient design is recommended for CRIEMP II, as it accounts for anticipated spatial patterns and avoids misleading conclusions associated with recognized differences. Within a gradient, reference stations define system or predicted variability and form the basis for assessing perturbations (i.e., variability greater than predicted), so are not regarded simply as upstream of perceived point sources. Suitable components (water, sediments, periphtyon, benthic invertebrates, fish) are selected to reflect health. How the component is measured (the endpoint) determines its usefulness as an indicator of river "health" and aquatic "fitness". Although structural endpoints (e.g., total abundance, composition) are most commonly used, many researchers suggest that relationship endpoints (e.g., feeding behaviour) better define community and ecosystem fitness (Schindler, 1987). Relationship endpoints are typically derived from interpretation of structural endpoint data. A weight-of-evidence approach is useful for analyzing and interpreting the large amounts and types of data generated and it provides crucial linking between components, their various measures and other environmental variables to define aquatic fitness and river health.

The study design described here challenges traditional control-impact approaches, as it has been developed to assess overall river health and recognize cumulative effects. The design uses an integrated ecosystem-based approach, with traditional and alternative endpoints. It recommends a gradient design with multiple reference stations, structural and relationship endpoints, weight-of-evidence analysis and relationship linking models.

2.2 Accounting for System Variability

Understanding, defining and accounting for system variability is crucial to identifying perturbations and assessing whole-river health. High system variability, recognized in previous studies, has not always been addressed successfully, particularly when the entire study area is considered. Insufficient number of stations, low replication and unclear methodologies and quality control have hampered any overall health assessment. Variability can be either reduced or incorporated into the design. The latter is preferred, given that it provides a more realistic reflection of the ecosystem and a more reliable prediction of significance of effects. Variability should be accounted for by consistent sampling and diversification, achievable in several ways: selection of sufficient and appropriate reference stations, with attention to habitat and location on the river, concurrent component sampling and standardized sampling positions (e.g., depth). Sufficient sample replication is critical to increasing accuracy and precision and reducing uncertainty, while providing statistical validity and quality assurance to subsequent trend analysis. Replication required to estimate statistical power and discern optimum sample size for reliable comparisons and relevant conclusions is discussed in Section 7.2.

2.3 Design Hypotheses & Statistical Treatment

The overall sampling program design incorporates a gradient of stations relative to the dams, given the need to understand background effects of water regulation on biotic community structure and overlying spatial effects of point-source discharges along the river. As a result, this design is a spatial gradient relative to the dams, overlain by a series of control-impact designs, similar to the design described in the Pulp and Paper EEM Technical Guidance Document (EC, 1998). Each station forms part of the gradient, and may serve as an upstream or downstream impact location. The proposed design uses multiple references within a spatial gradient. Collectively, reference stations located throughout a study area act as spatial and temporal references, provided they are strategically placed and data interpreted judiciously, recognizing limitations imposed by study design and types of data collected.

Given that no one design can answer every question, it is important to limit interpretation to hypotheses proposed in the design. Limitations to be considered include those associated with Type I and Type II errors (concluding that there is no effect when there is one or that there is an effect when there is none), comparative level of effort and ecological relevance.

Control-impact designs for individual discharges would use ANOVA hypothesis and power tests to determine differences between means of test factors upstream and downstream of discharges, based on 95% confidence intervals.

Ho: There are no differences in biotic or other test factors upstream and downstream of specific discharges.

Ha: There are differences in these factors upstream and downstream of specific discharges.

Data from the overall sampling gradient would be used for regression analysis to test hypotheses about relationships between biotic factors and physical factors such as distance from the dam, habitat type, etc. Including a 95% confidence interval around the regression will provide an indication of power determined simply by the variance of data (see Cohen, 1988).

Ho: There is no relationship between biotic and physical/chemical factors along the sampling gradient, as shown by regression analysis.

Ha: There is a relationship between biotic and physical/chemical factors along the sampling gradient, as shown by regression analysis.

Cluster analysis of overall biotic composition (abundance and biomass) would be done in association with statistical hypothesis testing and power analysis (Nemec, 2000) to determine significant groupings of biotic communities. This type of analysis allows statistical separation of "affected" and "unaffected" stations, and shows where "breaks" in a biotic continuum occur because of changes in the community due to some external source.

Ho: The biotic assemblages are the same at any given linkage level.

Ha: The biotic assemblages are different at predetermined linkages.

The faunal or floral similarity data used in clusters could then be plotted along environmental gradients to show how biotic communities change with changing natural or anthropogenic conditions. A similarity gradient is sometimes used for this purpose. The pattern of the gradient helps to determine the "health" of the system, as G3 has shown successfully in other studies. Also, ANCOVA could be used to compare biotic gradients statistically, to determine if the continuum in community patterns stays the same (null hypothesis) in the absence or presence of an extraordinary discharge source. An assessment of the overlap in 95% confidence intervals of two relationships being compared would give an indication of power determined simply by the variance of data (see also Cohen, 1988).

Ho: The relationship between a biotic/physical factor in one part of the river is the same as in another part of the river.

Ha: The relationship between a biotic/physical factor in one part of the river differs from another part of the river.

The resulting univariate (species richness, abundance, biomass, indicator taxa, etc.) and multivariate (faunal or floral similarity) patterns could then be tested to determine probabilistic relationships between groups of samples and distance from dams, proximity to different types of discharges, etc. This simplistic form of power analysis does not require the limiting assumptions about normal data distribution or the pitfalls of parametric power testing with data not specifically collected for this purpose. This approach and an application are described in Burd (2002).

The sampling strategy and design were constructed to answer some large- and small-scale questions, not to specifically test the power of very rigid and limited hypotheses. For the latter, the design would require careful analysis of the number of samples needed to determine an *a priori* effect level(s) for all parameters in question, simply not feasible with the multitude of factors to be tested. This is the strength of a "weight-of-evidence" approach, but also requires use of a more flexible statistical approach to tease out specific observations, including cause and effect, where applicable.

The statistical approaches described above would be adapted to compare historical and current data where sampling patterns are sufficiently consistent. This is considered a key aspect of the proposed study design.

2.4 Selection of Reference & Exposure Stations

In experimental methodology, a reference is an independent standard. In environmental studies, a reference station is typically an undisturbed, pristine location biophysically similar to an exposure station, without anthropogenic degradation or ameliorative treatment. There are no pristine areas, given that the entire study area is affected by regulation and a variety of anthropogenic influences, so an unconventional approach to regarding reference stations is needed. Traditionally, environmental studies have used references in the context of BACI designs. This view attempts to isolate impacts and is useful only in situations where there is sufficient knowledge of the ecosystem and good definition of ambient conditions and confounding influences, not the case for the Columbia River. Moreover, selecting two environments with similar ecological characteristics, one exposed and the other not, does not guarantee either comparability or an ability to assess cause and effect, as it is common for populations in "two locations to diverge or converge through time" in the absence of an environmental impact (Underwood, 1991). Therefore, it is imperative to make an ecological connection between areas being compared before making valid conclusions.

Columbia River references must serve two purposes: define ambient river continuum from dam to international border and identify perturbations from ambient along its path. References must, therefore, accurately reflect both spatial and temporal variability and longitudinal patterns. This eliminates use of references from similar but unaffected watersheds (Reynoldson *et al.*, 1997) at this time, given the history of flow regulation on the lower Columbia and human development in the watershed. Use of stations in a linear gradient, defined by recognized habitats or reaches, can help elucidate ambient conditions along the river.

Exposure stations are established downstream and, in some cases, upstream of specified discharges to reflect conditions in areas of potential impact. These stations are added to the baseline set of references. Comparison of results from stations along the gradient permits recognition of conditions beyond ambient.

2.5 Integration of Current Studies into Overall Design

The proposed CRIEMP II study design incorporates ongoing monitoring and assessment initiatives by industry and government and addresses specific gaps or limitations to develop an overall assessment of river health. Several aspects are integrated: spatial (station locations), temporal (time, season), matrix (biological, chemical, toxicological, physical) and reasons for testing. These lend themselves to standardized procedures, QA/QC, parameters, methods and locations. Section 3.3 provides details of stakeholder integration with design components, locations and times. As part of the CRIEMP II study, recommendations are made for a standardized core of objectives (field methodologies, endpoint analysis, reporting procedure) and mechanisms for keeping data current and available to stakeholders (e.g., shared database). These elements are considered critical for a fully integrated process for assessing Columbia River health. Finally, a connection is made between scientific assessment of river health and ongoing management and decision-making process, including consideration of societal values.

3.0 STUDY AREA & TIMING

The CRIEMP II study area is the Columbia River from immediately upstream of Hugh Keenleyside Dam to the Canada-USA border (Figure 3-1), similar to that used for CRIEMP I. This covers a distance of approximately 60 km, with an estimated travel time for water of 12 to 16 hours (Aquametrix, 1994). The Kootenay and Pend d'Oreille Rivers are sampled at their confluence with the Columbia. A complete description of influences in the study area is included in Section 1.2 of the companion document, *CRIEMP II: Columbia River Integrated Environmental Monitoring Program, Data Gap Analysis and Study Design Considerations.*

Hugh Keenleyside Dam and other dams upstream combine to regulate flow in the study area, resulting in a very complex system with longitudinal zonation and dynamic, ever-changing characteristics. The natural flow regime has been altered considerably, resulting in higher winter flows, lower spring and summer flows and reduced magnitude of seasonal flow fluctuations; however, short-term fluctuations (e.g., daily to weekly) can be much greater than in unregulated systems.

Habitat varies considerably in the study area, with seven habitat reaches defined, based on gradient, velocity, flow characteristics, basin physiography and fluvial morphology (Figure 3-2 and Table 3-1; BC Hydro *et al.*, 1995). For example, the river is very deep and slow flowing upstream of Tin Cup Rapids (Castlegar) and more riverine downstream. In addition to habitat changes between the dam and the border, there are specific and diffuse anthropogenic activities that influence river quality.

3.1 Sampling Stations

Locations of sampling stations proposed for CRIEMP II are shown in Figure 3-3. Reference and exposure stations were selected based on identified habitat types and anthropogenic activities. Fluctuating discharges from the dams make establishing comparable sampling stations and interpreting data a challenge. Discharge rates determine depositional characteristics of a sampling station and its physical, chemical and biological characteristics. Change in discharge, which can fluctuate daily, is a significant variable when assessing environmental impacts. Natural influences include habitat, discharge, river morphology, riparian and shore communities and substrate types. Sampling stratification (sampling both depositional and erosional habitat types) can be superimposed on general habitat types, as can identified point sources of potential contamination. Given that both reference and exposure stations comprise a gradient in the study area, it is important to represent varied habitats. This involves careful location of stations and pragmatic use of field replication (stations and samples) to define system variability. Selection of stations also considers practical aspects, such as ability to evaluate components concurrently.

Both erosional and depositional habitats would be sampled for sediment and benthos at sites where both habitats occur. Samples collected from erosional habitat, which comprises the predominant habitat type, would be used to define representative benthic communities and assess overall river health. Samples collected from depositional habitat, reflecting worst-case scenarios for contaminant deposition and concentration, would also be used in sediment triad analysis.

FIGURE 3-1: Lower Columbia River between Arrow Lakes and the Canada - USA Border, Showing Major Anthropogenic Influences

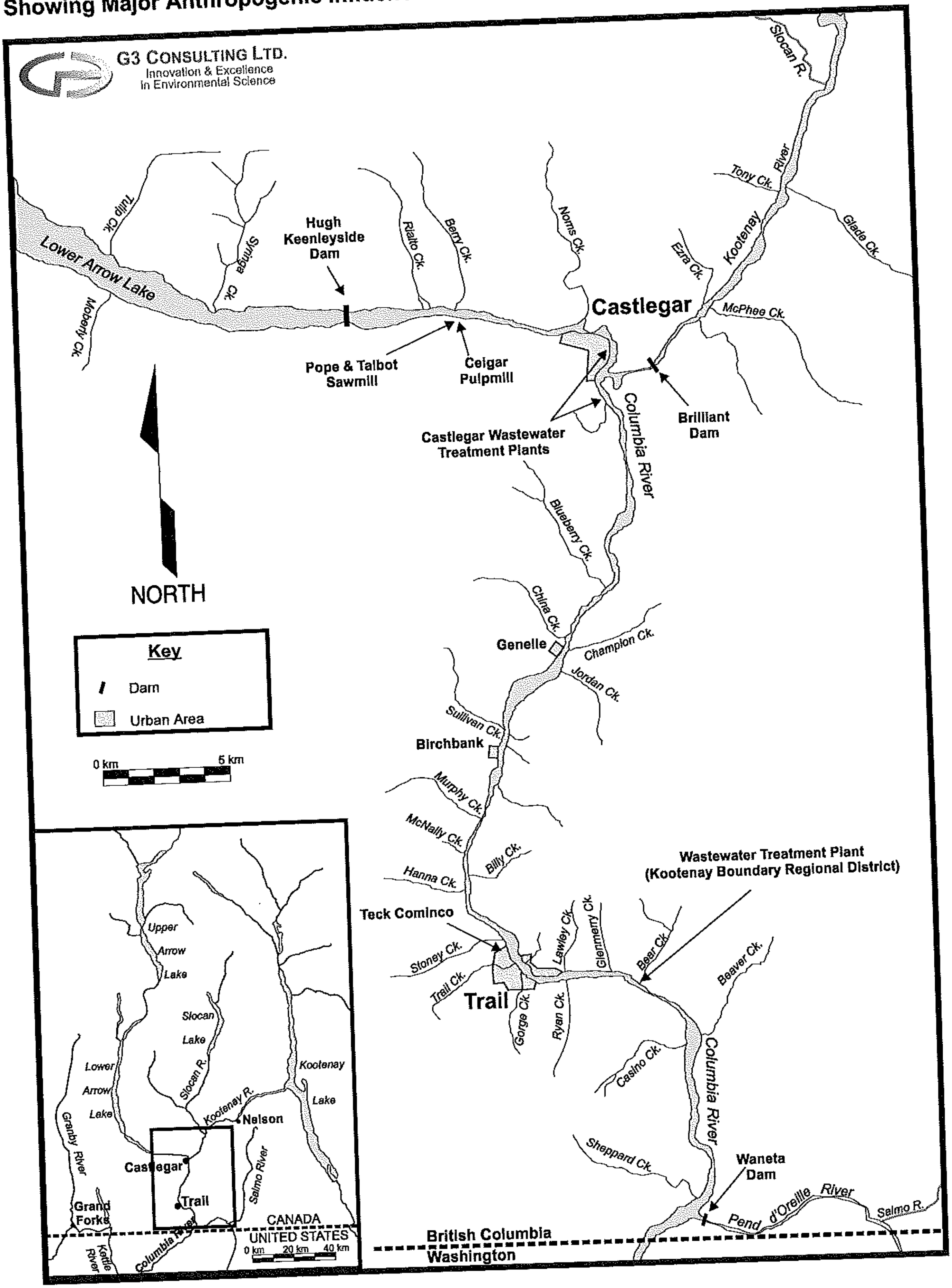

FIGURE 3-2:
CRIEMP II Sampling Sites, Lower Columbia River

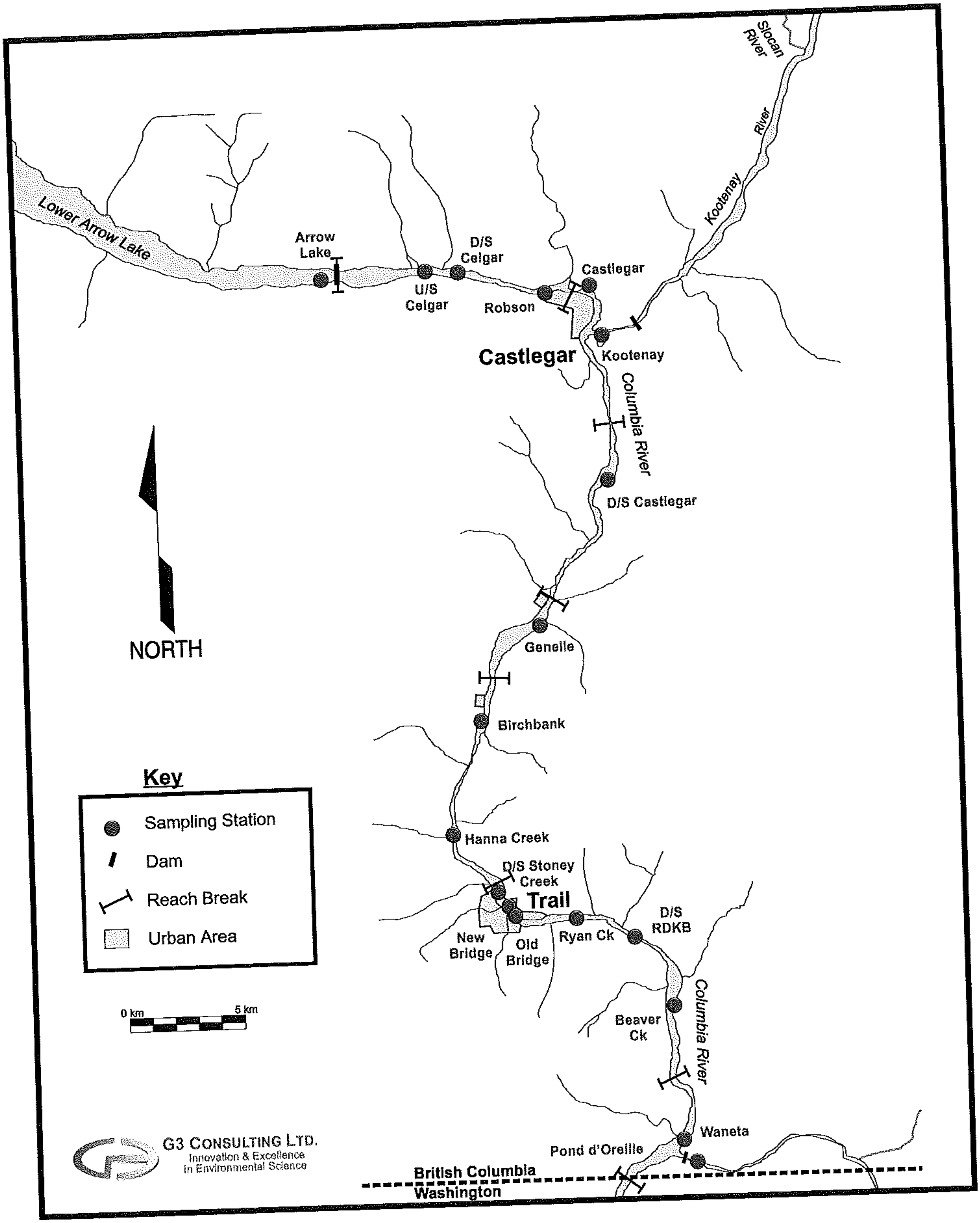

FIGURE 3-3:
Habitat Reaches in the Lower Columbia River, adapted from BC Hydro *et al.* (1995)

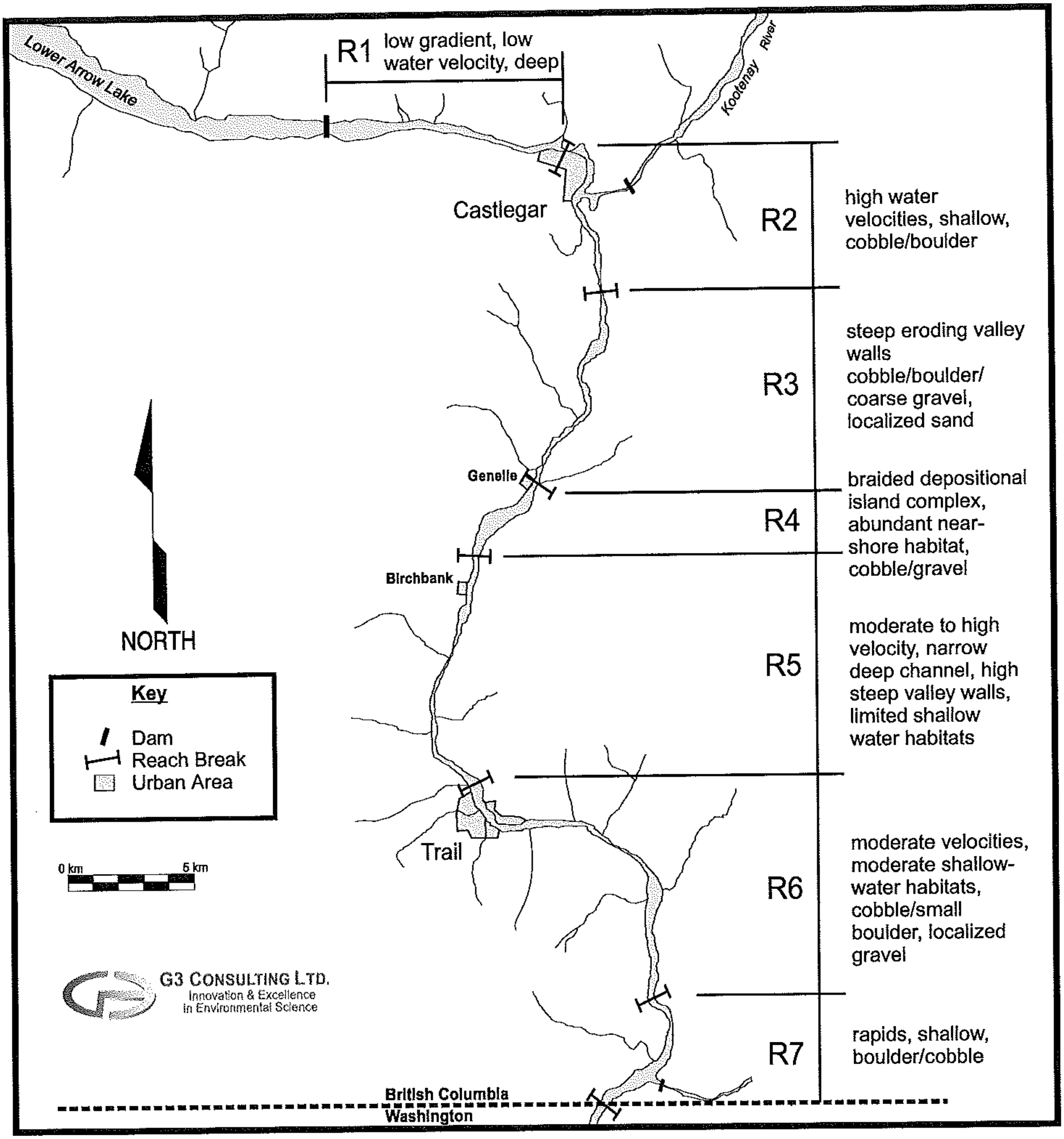

**TABLE 3-1:
Habitat Reaches in the Lower Columbia River**

Reach	Distance	Description
1	km 0 to km 8	Hugh Keenleyside Dam to upstream end of Tin Cup Rapids low gradient, low water velocity, fairly deep (18 to 20 m), lake-like conditions during low discharge sand/silt substrates
2	km 8 to km 14	upstream end of Tin Cup Rapids to downstream of Kinnaird Bridge high water velocities, shallow (2 to 6 m), some channel braiding cobble/boulder substrates
3	km 14 to km 23	downstream of Kinnaird Bridge to Champion Cr. lower flows than Reach 2, moderate depth (6 to 10 m), relatively straight and confined channel between steep, eroding valley walls cobble/boulder/coarse gravel substrates with small localized areas of sand deposition
4	km 23 to km 27	braided depositional island complex downstream of Champion Cr. moderate velocity, shallow (1 to 4 m), abundant near-shore habitat (gently sloping sand bars, many shallow side channels) cobble/gravel substrates
5	km 27 to km 38	downstream of island complex to upstream of Trail moderate to high velocity, narrow, deep channel (6 to 12 m) confined between high steep valley walls, bedrock outcrops along banks, with limited shallow water habitats
6	km 38 to km 51.5	upstream of Trail to upstream of Fort Shepherd Eddy moderate velocities (also areas of low and high velocities), shallow (3 to 8 m), relatively uniform habitat, moderate amount of shallow-water habitat Rock Island (km 43.5) – traverse escarpment of bedrock that produces a localized area of deep turbulent habitat cobble/small boulder substrates with localized areas of gravel
7	km 51.5 to km 56.5	Fort Shepherd Eddy to the Canada/US border high water velocities with rapids, shallow (3 to 6 m), limited nearshore shallow-water habitat Fort Shepherd Eddy (at km 51.5, 50 m deep), low velocity Waneta Eddy (at km 55.0, 20 m deep) boulder/cobble substrates

Source: BC Hydro *et al*, 1995

Reference Stations

Columbia River references were selected to characterize the ambient river continuum from dam to international border and identify perturbations from ambient along its path. Reference stations were placed in all identified habitat reaches (Figure 3-2) to define ambient, recognizing that ambient refers to conditions not immediately affected by point discharges, rather than pristine conditions. As a result, references would reflect effects of non-point runoff in addition to flow regulation. Most of the stations are currently used for federal and provincial monitoring programs and Celgar and Teck Cominco studies (Table 3-2). Additional stations are required to fully address system variability as part of the CRIEMP II study.

Exposure Stations

Exposure stations are established downstream and, in some cases, upstream of specified discharges to reflect conditions in areas of potential impact. These stations are added to the baseline set of references. Many exposure stations already exist as part of ongoing studies and comprise Near-Field areas or stations within initial discharge zones (IDZ) of effluent discharges for Celgar and Teck Cominco (Table 3-2, Figures 3-1 and 3-3). Additional stations downstream of municipal wastewater discharges are included. Some stations are already assigned as reference stations, including those near areas of suspected or known non-point discharge (e.g., Pope & Talbot sawmill, leachate from landfill sites, stormwater discharge, runoff from roads and agricultural lands, air emissions). Section 3.3 discusses integration with ongoing and proposed studies of CRIEMP members.

Studies to date have focused primarily on environmental issues related to specific industries, discharges and components, rather than overall river health. This is understandable, given mandate and scope of these studies. The integration necessary for river health assessment will establish links with relevant references and river health indicators.

Reference & Exposure Station Locations

Table 3-2 describes stations proposed for sampling, with rationale for selected locations. Figure 3-1 shows station locations. In total, 19 sampling stations are proposed, encompassing the study area defined by CRIEMP members (January 21, 2002 meeting). Study scope was broadened to include stations on the Kootenay River (downstream of the City of Nelson), Arrow Lake (above Hugh Keenleyside dam), the Pend d'Oreille River (upstream of Waneta Dam) and a potential site downstream of the Canada-US border (Kettle Falls area). All but three (exposure stations for Celgar and Teck Cominco) could be considered reference stations for the purpose of defining system variability and baseline conditions in the Columbia River or for providing spatial and temporal references to more issue-specific phenomena. Hence, each station serves as a reference to all others along the river. Remaining stations are considered exposure stations, addressing issue-specific exposure from particular point sources. Some stations serve as both exposure and reference, given that they provide references for the river as a whole, in addition to information about exposure to a particular point or non-point source. Integration of current studies with locations is discussed in Section 3.3.

3.2 Study Timing & Frequency

Ideal sampling frequency includes consideration of season and flow (both low and high flow periods) to assess the full range of river dynamics and river health. Practical considerations include dam operations and planned or ongoing field efforts. Although details are not finalized for some studies proposed to be integrated with CRIEMP II (e.g., Teck Cominco), standardization of study periods, stations and components are recommended.

TABLE 3-2: CRIEMP II – Integrated River Health Study, Station Locations & Rationale

Study Station	Reach # and Location	Matrix[1]	Rationale
Keenleyside	Arrow Lake near dam	Ssb	UPSTREAM REFERENCE: temporal reference with CRIEMP I, changes in watershed, help evaluate QA/QC
U/S Celgar EMS 200183	R1: 400 m u/s of Celgar	WSsb PB	UPSTREAM REFERENCE: for Celgar; historic data from CRIEMP I, MWLAP monitoring, Celgar EEM
D/S Celgar EMS 213039	R1: 100 m d/s of Celgar diffuser	WSsb PBFCF	EXPOSURE STATION: Celgar near-field; historic data from CRIEMP I, MWLAP monitoring, Celgar EEM
Robson	R1: EEM station	WS PB	AMBIENT REFERENCE/EXPOSURE STATION: u/s reference for Castlegar; Celgar near-field, historic data from CRIEMP I, MWLAP monitoring, Celgar
Castlegar EMS 0200200	R2: u/s of Kootenay River	WS PB	AMBIENT REFERENCE/EXPOSURE STATION: u/s of Castlegar waste treatment discharges, high fish use area; Celgar EEM station; historic data from CRIEMP I, MWLAP monitoring
Kootenay R.	Kootenay River	WSsb PB	AMBIENT REFERENCE: New station downstream of Brilliant Dam, to assess upstream influences of Nelson, etc.
D/S Castlegar	R3: u/s of Waterloo Eddy	WS PBC	AMBIENT REFERENCE: New station d/s of Castlegar, Kootenay R.; characterize conditions in Reach 3
Genelle	R3/4: erosional, depositional	WS PBF	AMBIENT REFERENCE: New station for periphyton & water, high fish use area; MWLAP & DFO fish sampling, Celgar EEM far field, CRIEMP I sediment assessment
Birchbank EMS 0200003	R5: erosional, depositional	WSsb PBC	AMBIENT REFERENCE: Long term monitoring station (MWLAP, EC); historic water, sediment & biota data for CRIEMP I, Celgar EEM, Teck Cominco studies
Hanna Cr.	R5: New station near Hanna Cr.	WPB	AMBIENT REFERENCE: To assess conditions between Birchbank and Trail (long reach); Trail water intake at Oasis
D/S Stoney Cr. EMS 223892	R6: Trail, 100 m d/s of Stoney Cr.	WP	REFERENCE/EXPOSURE STATION: Influenced by Stoney Cr. watershed, historic Teck Cominco activities, Outfall IV; MWLAP monitoring, Teck Cominco & historic data
New Bridge EMS 200558	R6: Trail, New Bridge	WP	EXPOSURE STATION: d/s of Teck Cominco discharges; MWLAP monitoring, Teck Cominco, historic data
Old Bridge EMS 216137	R6: Trail, Old Bridge	WP	EXPOSURE STATION: 1 km d/s of Teck Cominco; MWLAP monitoring, Teck Cominco, historic data
Ryan Cr.	R6: New station d/s of Trail	WSsb PBC	REFERENCE/EXPOSURE STATION: 1 km d/s of Old Bridge, for benthos sampling (difficult to do in Trail); historic data from CRIEMP I (benthos and sediment sampling)
D/S RDKB EMS 223893	R6: 100 m d/s RDKB	WP	REFERENCE/EXPOSURE STATION: MWLAP monitoring station d/s of wastewater treatment plant
Beaver Cr.	R6: New station d/s of Beaver Cr.	WS PBF	AMBIENT REFERENCE: assess conditions between Trail and Waneta (long reach, Beaver Cr. influence); MWLAP and DFO fish sampling area, historic data from CRIEMP I
Waneta EMS 0200559	R7: u/s of Pend d'Oreille R.	WSsb PBC	DOWNSTREAM/AMBIENT REFERENCE: First major depositional area d/s of Birchbank, last station before US border, sturgeon issues; monitoring station for MWLAP, EC, Teck Cominco, CRIEMP I
Pend d'Oreille R.	New station in Pend d'Oreille R.	WSsb	AMBIENT REFERENCE: New station above dam on Pend d'Oreille, to assess potential influence on Columbia
Kettle Falls area, WA	D/s of US border	WSsb PBC	DOWNSTREAM REFERENCE: Long range transport & deposition; integration with U.S. studies

1. W=water S=sediments sb=sediment bioassay P=periphyton B=benthos F=fish C=caddisfly bioaccumulation

A minimum of two sampling periods is recommended, based on flow conditions, characteristics of the biological community and accessibility to stable substrates. These are late summer (August/September), when flow is abating and diverse periphyton and benthic invertebrate communities are found, and spring (March/April), when flows are low and primary producers such as periphyton are in an optimimum growth period. Recommendations arising from CRIEMP I were that sampling in August would satisfy biological and physical requirements (Aquametrix, 1994). Late August/September 2002 would coincide with EEM Cycle 3 for Celgar. The spring period (March/April) corresponds with MWLAP water quality objective monitoring and studies previously conducted by Teck Cominco. Integration of current studies with design timing is further discussed in Section 3.3.

Late summer and spring sampling would be conducted within 30-day periods, as defined by MWLAP water quality objectives. Water samples would be collected five times during the 30-day period. Periphyton samplers would be placed at the start and retrieved at the end of the late summer and spring periods. Benthic invertebrate sampling would occur during the late summer sampling period (preferably toward the end, when flows have further decreased). Sediment samples for chemical analysis and bioassay would be taken in late summer, concurrent with benthos sampling. Emerging adult caddisflies would be collected in mid-summer. Ideally, fish would be collected during late summer, at the time of Celgar EEM studies. This approach would provide relevant physicochemical data concurrent with biota sampling.

3.3 Integration of Ongoing Studies in Location & Timing

The sampling program describes components relevant to overall river health assessment. In order to integrate work already planned by CRIEMP members, established locations, timing, components, parameters and endpoints have been considered and adapted to the overall design. Underlying rationale for assigning responsibility for sampling regions and components, based on historically and currently recognized areas of environmental impacts, is discussed in the companion data gap analysis. Ongoing programs include MWLAP objective monitoring, EC trend monitoring at Birchbank and Waneta, Celgar's EEM study and aquatic work considered under Teck Cominco's ongoing ecological risk assessment. Other stakeholders include the municipalities of Castlegar, Trail and Nelson, BC Hydro, Columbia Power Corp., UtiliCorp and Pope and Talbot Sawmill. Additional stations (Table 3-2) and components are added to develop an overall river health perspective. Suggestions have been made to assign various responsibilities to specific stakeholders or CRIEMP in general based on practical and logistical considerations (e.g., adding tests to an existing set; responsibility based on geographic or component considerations), as well as perceived and agreed upon river responsibilities.

To avoid overlap and maintain consistency and efficiency, recommendations are made for some entities to sample beyond their perceived sphere of influence, as inkind contributions to CRIEMP. For example, it is recommended that Celgar be responsible for benthos, Teck Cominco for periphyton, and MWLAP for water sampling and analysis. Given that considerable interpretive work is required beyond the sampling and analysis phase, this aspect would become balanced in the overall picture. Partitioning of work was based on spatial considerations, timing and components to produce an efficient design. A brief description of spatial and temporal integration is included here and a comprehensive discussion of full integration provided in Section 5.0.

Ministry of Water, Land, and Air Protection

The Ministry currently conducts water quality objective monitoring at several stations between Birchbank and Waneta. Water is sampled five times in one month in spring, fall, and winter; sediments are sampled in November at Birchbank and Waneta for toxicity bioassays and chemical analyses; and fish are sampled at Genelle and Beaver Cr. in November. Several modifications are proposed to integrate with CRIEMP II. The MWLAP spring sampling period coincides with that proposed for CRIEMP II, but the fall sampling is typically October and November. It is recommended that MWLAP move forward water, sediment and fish sampling in 2002 to August and September to provide sampling concurrent with biota collection. As there are no biological components associated with the winter water monitoring program, the CRIEMP II study design recommends routine sampling by MWLAP at that time, with results integrated in subsequent river health assessment.

Stations upstream of Birchbank are no longer sampled by MWLAP, as water quality objectives have been met since the early 1990s. Given that water quality data concurrent with biota sampling is important to river health assessment, these stations should be sampled for CRIEMP II. It is recommended that MWLAP be responsible for collection and analysis of water samples taken during late summer and spring study periods at all stations. Parameters recommended for CRIEMP II but not currently measured at all stations, such as nutrients and metals, should also be included. Details of parameters are discussed in Section 4.2. Overall integration with other design elements is discussed in Section 5.1. As field staff for Celgar and Teck Cominco would visit most relevant stations once or twice during each sampling period, it is feasible to coordinate collection of water samples with them. Celgar and Teck Cominco would collect sediment samples for chemical analysis and bioassay/bioaccumulation tests at depositional areas, including Birchbank and Waneta in late summer. MWLAP would continue to sample fish for tissue analysis, with timing moved forward to September. An additional station would be sampled near Celgar for fish as part of the EEM study.

Environment Canada Trend Monitoring

River water is sampled biweekly at Birchbank and Waneta by EC for several parameters of interest to the CRIEMP II study. In terms of an integrated study, this might lead to duplication of efforts; however, overlap with CRIEMP II sampling would occur at only two stations on two or three dates per sampling period. Rather than trying to merge this process for only a few samples, it would be more efficient to maintain EC sampling, then integrate data into CRIEMP II. Results would also serve as important checks for quality assurance and variability. Access to data from continuous monitoring at Waneta (total gas pressure, conductivity, temperature) would be desirable for assessment of trends between discrete weekly samplings.

Celgar EEM Cycle 3

Several stations incorporated in the study design (Figure 3-3 and Table 3-2) were used for Celgar's earlier EEM work and would be used for Cycle 3 in late summer 2002 (Hatfield, 2002). Water, sediment, benthos, and fish tissue sampling and analyses planned for EEM would be directly relevant in river health assessments. Aspects not covered by EEM, but essential to understanding river health include additional stations downstream of Birchbank (chlorinated phenolics), components (e.g., periphyton) and endpoints (e.g., fitness parameters for biota). For example, a tracer for pulpmill effluent would be useful for delineating long range transport.

Measuring levels of chlorinated phenolic compounds (guaiacols, catechols, phenols) in sediment is suggested at several stations as a cost-effective alternative, with dioxin/furan measurements, which have been very low in recent years, made at select stations.

Studies done for EEM Cycle 1 and Cycle 2 identified many improvements related to Celgar's modernization, although some issues of potential long-range transport, deposition and fate of certain compounds have not been resolved. To help address issues relevant to river health, it is recommended that Celgar's involvement be extended to include other stations and components of benefit to both CRIEMP and EEM. Specifically, it is proposed that Celgar sample and analyze benthos at all specified CRIEMP stations and sediment (chemistry, bioassay, bioaccumulation) at stations upstream of Birchbank. EEM studies included benthos samples from both depositional and erosional habitat in Cycle 1 and erosional and fibre mat habitats in Cycle 2 (Hatfield, 2000). Plans for Cycle 3 include sampling of depositional and fibre mat habitats (Hatfield, 2002), so CRIEMP contributions would include extending sampling to erosional habitats at all stations. Detailed discussions of components and endpoints are included in Section 4.0 and the fully integrated study design is discussed in Section 5.0.

Teck Cominco Risk Assessment & Other River Work

The geographic scope of Teck Cominco's previous and recommended programs in water quality and risk assessment spans from Birchbank to Waneta. Given the direct and relevant association of its discharges with river health, it is recommended that Teck Cominco generally be responsible for work in this part of the river. This responsibility is based on its benefit and contribution to CRIEMP, direct applicability to ongoing river health, ability to establish linkages to aquatic and terrestrial ecological risk assessments and ability to address historic and current issues. For example, an understanding of fate (burial, exposure, transport) and biolgocial activity (toxicity, bioccumulation, biomagnification) is required to assess current impacts of historically discharged slag. It is recommended that Teck Cominco be responsible for collecting and analyzing periphyton data at all sites, given their knowledge and previous success with this approach. Successful data interpretation requires a high degree of familiarity with periphyton ecology. The design includes collection of periphyton in both late summer and spring, using artificial substrates set at most stations over a four-week period. Other components recommended to be sampled by Teck Cominco include sediment (chemistry, bioassay, bioaccumulation) from Birchbank downstream and bioaccumulation in emergent caddisflies. Section 4.0 details design requirements for component and endpoint measurement and Section 5.0 discusses full integration of design elements for all stakeholders.

Castlegar, Nelson & Trail

The three municipalities represented in CRIEMP have concerns and responsibilities for health of the Columbia River in terms of point and non-point sources (wastewater treatment plant discharges, runoff, stormwater associated with land use). Based on their interest in river health and commitment to CRIEMP, municipalities could consider coordinating with MWLAP to provide staff or other resources for water sampling at relevant stations (sampling five times in 30 days, late summer and spring). Trail has a direct interest in data from Hanna Cr. (situated to assess river water upstream of the Trail waterworks intake) and d/s RDKB (downstream of wastewater treatment plant discharge at Bear Cr.) stations. Nelson has an interest in results from the Kootenay station (upstream of confluence with the Columbia River). Castlegar has a interest in data from several stations in Castlegar (including upstream of wastewater treatment plant discharges and the d/s Castlegar station, downstream of most urban influences).

BC Hydro, Columbia Power Corp., UtiliCorp

Agencies responsible for dam operation have monitored total gas pressure (TGP) in the past. Information about TGP studies currently planned for 2002 or 2003 is not available. BC Hydro is conducting a fish study to develop population abundance indices for various species (Dana Schmidt, Golder, pers. comm.). The study is expected to yield information useful to river health assessments and data should be integrated into the CRIEMP II study, as discussed in Section 4.2. Incorporation of performance measures into water quality objectives has been discussed as a way to address potential habitat issues related to dam operation (Gary Birch, BC Hydro, Julia Beatty, MWLAP, pers. comm.), but details about data collection and reporting have not been made available. Integrating this information into river health assessments would be most useful.

Columbia Basin Trust

Involvement of the Columbia Basin Trust is highly desirable, given its connections in the broader watershed and its mission to support "efforts by the people of the Basin to create a legacy of social, economic and environmental well-being and to achieve greater self-sufficiency for present and future generations". Data integration and interpretation, communication and information sharing aspects of CRIEMP II are particularly applicable to the Columbia Basin Trust mandate.

Lake Roosevelt Water Quality Council

Representation of the Lake Roosevelt Water Quality Council on CRIEMP provides several benefits, including highlighting transboundary concerns regarding environmental issues and maintaining communication. In particular, integrating the CRIEMP II river health study with initiatives south of the US border would be cost-effective and ecologically relevant. The study design specifically proposes one station in the Kettle Falls area of Washington State, where river flows decrease in response to Lake Roosevelt impoundment. In addition, concurrent studies at other downstream stations would provide wider relevance to the river health assessment and address concerns of stakeholders in both countries. As a result, seeking either inkind or direct financial contributions for a study on the US side of the border is recommended.

4.0 STUDY ELEMENTS

Table 4-1 summarizes environmental issues on the Columbia River and associated stakeholders. Although point discharges are largely addressed through ongoing studies, with some limitations when applied to river health assessments, non-point sources and cumulative effects on river health are not addressed. This table also suggests relevant components, environmental indicators and parameters that would best apply, considering issues for the Columbia River.

**TABLE 4-1:
CRIEMP II – Integrated River Health Study,
Issues & Stakeholder Responsibility**

Issue	Stakeholder/ Study	Issue Details	Where
River Regulation	BC Hydro, Columbia Power Corp., UtiliCorp (fish population studies, White Sturgeon Recovery Program)	hydrology, total gas pressure habitat disturbance, fish stranding, performance measures and habitat evaluation oligotrophication, fertilization program	throughout the river
Point Discharges	Celgar Pulp Company (EEM)	chlorinated organics, resin acids, nutrients; local fibre mat sediment toxicity, water quality, biotic integrity	downstream of Celgar to Birchbank; upstream reference
	Teck Cominco Metals Ltd. (Impact and EcoRisk Assessments)	metals in water and air, nutrients sediment toxicity, water quality, biotic integrity	downstream of Teck Cominco outfalls to Waneta; upstream reference
	Castlegar, Trail, Nelson (wastewater treatment plant discharges)	nutrients, BOD, coliforms, metals, EDCs, other chemicals of concern sediment toxicity, water quality, biotic integrity	downstream of municipal discharges
Non-Point Discharges	municipal, road, industrial and agricultural runoff in watershed; airshed	metals, nutrients, PAHs, pesticides, herbicides, oil & grease, residues, etc. sediment toxicity, water quality, biotic integrity	throughout the river
Cumulative Effects	all stakeholders, including ED, DFO and MWLAP	water & sediment quality objectives; Fisheries Act & other regulations	throughout the river

4.1 Flow Regulation

Flow regulation is a pervasive influence on the Columbia River ecosystem. Consequently, several factors need to be considered when assessing river health. These include spatial and temporal habitat disturbance; hydrology and discharge characteristics; velocity, direction and type of flow (e.g., laminar, turbulent, chaotic); stream morphology and channel characteristics; and riparian characteristics and function. Physical characteristics of flow, such as velocity, direction and type of flow, are also important considerations where periphyton or benthos are sampled. For CRIEMP II, habitat alteration will be addressed through field assessments associated with benthos and sediment sampling and by incorporating information from BC Hydro fish population studies, performance measure evaluations and other assessments. Total gas pressure data will either be collected *in situ* at times of water sampling or integrated from other programs (BC Hydro, Columbia Power Corp., Utilicorp monitoring).

4.2 Study Components, Parameters & Endpoints

Of components assessed in previous studies, including CRIEMP I, it is recommended that water, effluent, sediment, periphyton, benthic invertebrates, terrestrial insects (emerging caddisflies) and fish be further investigated in CRIEMP II. The integrated river health assessment will examine ecological integrity of the river as represented by these components, in response to sources of potential perturbation (toxicity, river regulation, point and non-point discharges) and cumulative effects. Where proven defensible, recommended methods correspond to those used by stakeholders in previous programs, to maintain consistency and comparability. Parameters and endpoints to be measured are listed in Table 4-2.

Water & Effluent

Water testing is essential to defining ambient conditions and longitudinal and temporal trends, both natural and induced, along the river. Comparisons with water quality objectives (Butcher, 1992; MELP, 2000) and historic data would be made. Sampling methods consistent with MWLAP water quality objective monitoring should be followed. Consistent methods and QA/QC are essential. Broadening the list of parameters used to include nutrients and metals at all stations is necessary for understanding ambient conditions and river health. From a river health perspective, there are no recommendations to sample for organochlorines, resin acids or coliforms (total coliforms, *E. coli*, Enterococci), as water quality objectives have been met for these parameters for several years. Testing concurrent with biota and sediment sampling provides required information about health of the receiving environment. Data for effluents sampled by specific industries in conjunction with monitoring for permits would be used during final integrative aspects of the assessment.

Use of trip and field blanks and 10% replication for field and laboratory duplicates are included for QA/QC, along with comparisons of results for Certified Reference Materials. Temperature, conductivity, pH and dissolved oxygen would be measured in the field (e.g., Hydrolab). Total gas pressure (TGP) would be measured in the field using equipment consistent with MWLAP sampling. Further coordination with BC Hydro or Columbia Power Corp. would be required for TGP monitoring. Table 4-2 contains a complete list of parameters and endpoints to be analyzed.

Sediments

Important considerations in collecting and analyzing sediments for health assessment include erosional vs. depositional substrates, fibre mats, other introduced surfaces and MELP water quality objectives. In addition to general composition (percent sand/silt/clay), *in situ* indicators of sediment dynamics (i.e., field assessment of gross sediment characteristics), which help determine some physical and chemical dynamics, could be examined using established protocols (e.g., Expert Working Groups associated with federal EEM programs). Visual assessments (e.g., diving, underwater video) could also be considered for little additional cost.

TABLE 4-2:
CRIEMP II – Integrated River Health Study, Components & Parameters

Component	Parameters & endpoints
Water	*In situ* (temperature, dissolved oxygen, pH, conductivity) *In situ* total gas pressure General (pH, hardness, nonfilterable residue, turbidity, Cl^-, SO_4^{-2}) Nutrients (NH_3, NO_3^-, NO_2^-, total organic N, total P, total dissolved P, o-PO_4^{-3}) Metals (full spectrum including As, Cd, Cr, Cu, Pb, Tl, Zn)
Sediment	Total Organic Carbon (TOC) Acid Volatile Sulphide (AVS) Particle size (% sand, silt, clay), % moisture Metals (full spectrum, cold vapour for Hg, SEM) Organochlorine (chlorinated phenolics, resin & chlorinated resin acids) Organochlorine (EOX [extractable organic halides], includes pesticides, PCB, etc.) Organochlorine (provincial testing of dioxin/furans at Birchbank and Waneta only)
Sediment Bioassay	*Hyalella azteca* 14-day and 28-day bioassay Bioaccumulation of metals and chlorinated organics following 28-day bioassay
Benthic Invertebrates (depositional and erosional habitat)	Abundance and taxonomy Biomass Substrate characterization (% embeddedness, boulder/cobble/sand) Fitness parameters (deformities, fluctuating asymmetry) Adult caddisfly bioaccumulation for metals and chlorinated organic compounds
Periphyton	Chlorophyll *a*, phaeopigment Ash-free Dry Weight Abundance and taxonomy Fitness parameters (deformities, fluctuating asymmetry)
Fish	General health (age, sex, weight, fork length, gross pathology) Metals in liver tissue (full spectrum including As, Cd, Cr, Cu, Hg, Pb, Tl, Zn) Organochlorines in liver tissue (dioxins and furans) % lipids

Sediment sampling methods used for Celgar EEM Cycle 3 studies are suggested for CRIEMP II. Proposed CRIEMP sampling sites include Keenleyside, u/s Celgar, d/s Celgar, Robson, Castlegar, Kootenay R., d/s Castlegar, Genelle, Birchbank, Ryan Cr., Beaver Cr., Waneta and Pend d'Oreille R. The EEM study design includes several other stations, including the fibre mat downstream of Celgar. Samples would be collected with a 23 cm stainless steel Ponar grab, with the top 2 cm of sediment removed for analysis. Composites would be made from two replicates at each station, except at Waneta, where more extensive sampling is recommended. Although it is suggested that analyses be done on composited samples, it is recommended that individual samples be archived, and analyzed should follow-up be warranted.

For CRIEMP II river health assessment, it is recommended that total organic carbon (TOC), acid volatile sulphide (AVS), percent particle size, metals (full spectrum and simultaneously extracted metals [SEM]), resin and fatty acids, chlorinated phenolics and extractable organic halides (EOX) be examined at stations identified for sediment analysis (Table 4-2). The EOX analysis would provide a general screen for chlorinated organic compounds (pesticides, PCBs, dioxins, furans, etc). Chlorinated phenolics analysis would provide a general tracer for pulpmill compounds. QA/QC for chemical analyses would consist of 10% replication for field and laboratory duplicates, with results compared with Certified Reference Materials values.

For dioxins and furans, a combination of replication methods used for EEM and MWLAP are suggested. As Celgar no longer discharges measurable quantities of dioxins and furans, potential concerns relate to historic depositional areas such as the fibre mat. For EEM Cycle 3, composites of three replicates are proposed at four MWLAP stations (u/s Celgar, 400 m d/s Celgar, Castlegar, Birchbank) and three locations within the fibre mat; however, for consistency with MWLAP annual water quality objective monitoring and historic data, analysis of three replicates from Birchbank and Waneta is suggested. The CRIEMP committee should consider costs and benefits of increased replication, the main benefit being increased understanding of resuspension and transport of dioxins and furans from historic deposition areas.

Additional sampling at Waneta is recommended to provide a more accurate spatial representation, as this is one of only a few depositional areas and the last before the Canada-US border. At Waneta, long term consequences of slag deposition, burial, re-exposure, toxicity and bioaccumulation and elevated metal levels from smelter effluent discharges are primary concerns. Some issues with organochlorine deposition may remain. An increased number of samples is recommended for metal and AVS analyses (twelve in total, including three from nearshore areas). Given that organochlorines are typically associated with organic deposits and that Waneta sediments tend to have low organic content, sampling specifically in organically rich areas (composite samples from three nearshore areas) is recommended to reflect a potential worst-case scenario in addition to objectives monitoring. A field assessment for evidence of slag deposition patterns is also proposed, involving taking a number of cores, visual examination for black slag (layers, dispersal) and creating a photographic record.

Sediment sampling downstream in the US for chemicals of concern is highly recommended, with cooperation from US agencies. Areas in Lake Roosevelt and upstream to the border (e.g., Kettle Falls area) should be considered.

Sediment Bioassay & Bioaccumulation

Sediment bioassays using the amphipod *Hyalella azteca* (14-day and 28-day survival and growth tests) are done by MWLAP at Birchbank and Waneta and are recommended at six additional stations for river health assessment (Keenleyside, u/s Celgar, d/s Celgar, Kootenay R., Ryan Cr., Pend d'Oreille R.). In addition, Celgar EEM proposes toxicity testing (28-day bioassays) for two stations within the fibre mat (n=1, composite). *Hyalella* occurs in Columbia River sediments and has known sensitivity to and bioaccumulation of various toxicants (Day *et al.*, 1995; Borgmann *et al.*, 2001). Sediment samples for toxicity bioassays are treated separately from those for chemical analysis. It is recommended that three replicates per station be analyzed; however, cost savings could be achieved by creating composite samples for bioassay analyses, with original samples retained for further analysis, if warranted.

It is recommended that bioaccumulation of metals and organochlorines be measured on one replicate from each station following the 28-day test to identify relationships among sediment, toxicity and bioaccumulation. Levels of tracer compounds would be measured in washed and digested test organisms.

Benthic Invertebrates

Benthic invertebrate communities reflect many environmental influences and are important components of the food web, making study of these organisms an important aspect of integrated river health assessment. Historic data from CRIEMP I, EEM and Teck Cominco studies are available for comparison. Some functional groups (e.g., Ephemeroptera, Plecoptera, Trichoptera, EPT) were not well represented in natural substrate samples taken for CRIEMP I and EEM, likely due to difficulty sampling the deep, stable habitats where these organisms reside. Teck Cominco has used artificial substrates (Hester-Dendy substrates suspended in the water column); however, results had limited applicability, given that samples were more representative of drift than benthic communities (interestingly, EPT organisms were more common than in natural substrate samples). Collection of benthos from natural substrates is recommended as providing better representation of the entire community, although limitations regarding habitat accessibility remain. Late summer (mid-September) sampling is recommended, concurrent with Celgar EEM investigations. Methods previously used for EEM should be followed at all stations, with consistent efforts made to sample similar habitat types. Sample collection is expected to be a challenge, given flow fluctuations, variety of reaches and habitat types and difficulty accessing stable, deep-water habitat. As stations in Trail may not have suitable access for benthos sampling, Ryan Cr. is proposed for assessing conditions downstream of smelter operations.

Given Celgar's previous experience with benthos sampling for EEM and plans for Cycle 3 studies, it is recommended that Celgar collect and analyze samples at all stations, whether for EEM (dam to Birchbank) or CRIEMP II river health assessment (downstream to Waneta). At each station, it is recommended that samples be taken in both erosional habitat (representative of predominant river habitat, river health) and depositional habitat (representative of worst-case scenarios, potential contaminant deposition). It may be difficult to find depositional habitat in areas between Birchbank and Waneta. Power analysis done in previous and current EEM studies for Celgar (Hatfield, 2002) indicated that three replicates would be sufficient for statistical purposes. However, it is recommended that the standard EEM protocol of taking five replicates, analyzing three and archiving two, be followed (Brenda Burd, pers. comm.).

For erosional areas, methods used in EEM Cycle 2 would be followed: collection of five replicates at each station (three to be examined, two to be archived) in nearshore areas with 25 to 30 cm of water, using a modified Hess sampler (0.1 m^2 area sampled, 202 μm mesh size) and preservation with buffered formalin (Hatfield, 2000). Samples would be sieved in the laboratory through 1 mm, 500 μm and 240 μm screens. Organisms in the 240 μm fraction would be examined, with subsamples (1/5 or 1/10) used when high numbers of organisms are present. Current EEM standards for taxonomy would be followed (genus for many organisms, family for oligochaetes, order for damaged or very juvenile organisms, class for nematodes). Biomass estimates (total weight of organisms in the sample) are recommended, as this information is useful for ecological interpretations (SAB; species, abundance, biomass; Pearson and Rosenberg, 1978). QA/QC would conform with past EEM efforts (i.e., repeat counts on 10% of samples by an independent taxonomist). Substrate would be characterized in terms of general composition (boulder, cobble, sand) and embeddedness at each station.

For depositional areas, methods proposed for EEM Cycle 3 would be followed: collection of five replicates per station (three to be examined, two to be archived), in deepwater, using a 23 cm Ponar. Samples would be sieved in the field at 200 μm and preserved with buffered formalin (Hatfield, 2002). In the laboratory, samples would be sieved through 200 and 500 μm screens, with organisms in the 500 μm fraction examined and those in the 200 to 500 μm fraction archived. Current EEM standards for taxonomy would be used (genus for many organisms, family for oligochaetes, order for damaged or very juvenile organisms, class for nematodes).

River health analysis should assess structural and relationship aspects of population, community and ecosystem endpoints. Population endpoints include fitness parameters (e.g., size, condition, fluctuating asymmetry, morphological deformities). Community endpoints include structural (e.g., biomass, abundance, species richness, numerical abundance), relationship (e.g., dominance hierarchy, relative abundance, feeding groups, life-cycle stage, indicator species and associations) and linking endpoints (e.g., indexes that integrate structural and relationship endpoints, such as Benthic Index of Biotic Integrity, EPT index, SAB curves, diversity; Barbour *et al.*, 1999). Ecosystem endpoints include ecological succession (temporal and spatial changes along the river, cumulative effects, colonization behaviour, drift, etc.). Many endpoints will be assessed as part of CRIEMP river health assessments using the taxonomic and abundance data provided by Celgar's EEM and additional proposed stations. Separate examinations would be required for analysis and interpretation of fitness parameters. As an option, further investigation of bioaccumulation could be done using native benthos, collected in the field (involving sorting of live specimens on site).

Terrestrial Insects

It is recommended that bioaccumulation of metals and chlorinated organic compounds be assessed in emergent caddisflies, as was done for CRIEMP I. Proposed sampling stations include d/s Celgar, d/s Castlegar, Birchbank, Ryan Cr. and Waneta. This technique is useful in demonstrating links between compounds in river substrates and aquatic and terrestrial food webs, indicating potential for exposure and risk related to chemicals of concern. Endpoints include taxonomy, biomass, numbers and bioaccumulation. Collection methods followed for CRIEMP I are recommended (light traps set over four nights, three replicates per station). Following preservation, composite samples would be analyzed for metals and chlorophenols.

Periphyton

Periphyton respond rapidly to changing river conditions, with growth, accumulation and species composition controlled by a wide range of environmental factors. This responsiveness, coupled with their role as primary producers and food for many benthic invertebates, makes them useful ecological integrators and vital in river health assessments. Natural substrates sampled for CRIEMP I and EEM Cycle 1 did not yield useful results, attributed to fluctuating water levels and difficulty accessing stable deep habitat. Artificial substrates used by Teck Cominco were successful in showing response of the periphyton community (increased abundance and similarity among stations) to reduced metal levels and potential interactions with other factors such as nutrients. A well designed, statistically sound study with concurrent water monitoring is required to discern competing influences. Expertise in sampling, analyzing and interpreting data is essential. Given that periphyton integrate many aspects of the aquatic environment, this component reflects most relevent issues, including flow regulation and point and non-point discharges of metals, nutrients and other compounds.

Periphyton sampling using artificial substrates is recommended for all stations except Arrow Lake and Pend d'Oreille (impoundments), following four-week exposures in spring and late summer, concurrent with water sampling. The arrangement used by Teck Cominco, Wildco artificial substrates suspended from anchored buoys, is proposed (Duncan, 1999; G3 Consulting Ltd., 2001), with five samplers set at each station and three used for analysis (providing for losses and movement to slow-flowing areas). Of the eight microscope slides in a sampler, two would be combined for chlorphyll *a* and phaeopigment, two for ash-free dry weight and four for taxonomy and abundance analyses. This would provide adequate replication (n=3), given that variation among stations and samplers is most relevant. Samples for taxonomic analysis would be preserved in the field using Lugol's solution. Subsamples would be examined in the laboratory, with identification to species or genus and determinations of abundance. Organisms would be examined specifically for fitness parameters (fluctuating asymmetry, morphological deformities). QA/QC would consist of repeat counts on 10% of the samples.

Periphyton endpoints reflect both structural and relationship aspects of community and population. Community endpoints include structural (e.g., chlorophyll *a*, ash-free dry weight, abundance, species richness, standing crop) and relationship endpoints (e.g., dominance hierarchy, relative abundance, indicator species and associations tolerant and intolerant of particular compounds, disturbance indicators). Population endpoints include fitness parameters (e.g., fluctuating asymmetry, other deformities). Deformities are well documented early-warning indicators and are used effectively in some current mining and ecosystem health assessments. Ecosystem endpoints include ecological succession such as temporal and spatial changes along the river, cumulative effects, colonization behaviour and drift.

Fish

Fish studies reflect several important aspects of ecological integration. Information about population health (size, weight, reproductive condition) and community structure (species richness, composition, trophic composition, abundance, condition) provides evidence of overall river health and biotic integrity. Tissue analysis for metals and organochlorines provide information relevant to human, fish and overall river health.

Fish have been sampled annually as part of MWLAP's water quality objective monitoring and Celgar's EEM studies for several years. It is proposed that MWLAP continue to sample and analyze fish from Genelle and Beaver Cr., and that Celgar sample fish within the Near Field area, as proposed for EEM Cycle 3. Moving the MWLAP sampling period forward from fall to late summer, concurrent with EEM and CRIEMP II field work, is recommended. A minimum of eight mountain whitefish and eight rainbow trout would be taken and examined for general health (age, sex, weight, fork length, condition of various organs). Use of eight replicates is recommended, based on both MWLAP sampling methods and EEM protocols (EC, 1998), and would provide for Type 1 and Type 2 errors of 5% and an effect size (for power analysis) of ± 2 standard deviations for simple ANOVA tests. Tissue samples would be taken and submitted to the laboratory for measurements of metals, dioxins and furans, percent moisture and percent lipids. Previously, muscle tissue was examined, primarily to provide data for human health risk assessments. However, it is recommended that liver tissue be analyzed, as this would be more relevant for bioaccumulation. Optional analyses include assessment of reproductive health, related to endocrine disrupting compounds, and biomarker analyses. QA/QC analysis would consist of comparison of results to Certified Reference Materials.

Results of the BC Hydro fish population abundance index study would be integrated into river health assessment. This study is expected to yield more ecosystem-relevant data than previous issue-specific fish studies (Dana Schmidt, Golder, pers. comm.). Merits of adapting an Index of Biotic Integrity (Karr, 1981; Simon, 1999) to the fish community, discussed in Section 5.3 of the CRIEMP II data gap analysis document, would be investigated. Information from habitat assessments conducted for proposed performance measures would also be incorporated.

4.3 Integration of Environmental Indicators

Indicators of river health include measures of structure and function of biotic and physical components. Both 'top-down', holistic approaches that assess structural ecosystem components (Chapman, 1992) and 'bottom up', reductionist approaches (Scrimgeour and Wicklum, 1996) have been recommended for understanding impacts. According to Schindler (1987) and Karr (1991), studies of population dynamics, food-web organization and taxonomic structure of communities have been more successful for gaining an understanding of 'biological integrity' of a system than have structure-based approaches. This suggests that large scale approaches might be most appropriate (Fairweather, 1999). In keeping with this perspective, this design includes use of indicators linked with biological integrity, including a combination of physical, chemical and biological factors to define and understand the overall "riverscape":

- links that relate ecosystem and habitat (e.g., associations, life-cycle behaviour such as r-selected vs. K-selected, sediment quality triad, Waneta sediment quality related to fate of slag and response of biological communities);
- bioaccumulation of chemicals of concern (COCs) in emergent caddisflies, which link aquatic and terrestrial ecosystems;
- sediment toxicity to benthic organisms;
- use of models (e.g., SAB curves) and indices (e.g., diversity, EPT index, index of biotic integrity) that link components and community relationships to ecosystem fitness;
- fitness parameters (e.g., size, condition, fluctuating asymmetry, deformities of organisms), which provide population level analyses and are regarded as early warnings in ecosystem health assessments; and,
- performance and appropriateness of various methodologies (e.g., artificial vs. natural substrates for periphyton and benthos).

Benthos endpoints best suited to studying river health include structure, community balance and functional feeding groups (Barbour *et al.*, 1992). Periphyton may be assessed as individuals and populations (e.g., fitness parameters) and communities (e.g., structure, community balance, richness, diversity). Fish endpoints best suited to studying river health include species richness and composition, trophic composition, abundance and condition (Karr, 1991). Investigations of sediment toxicity to benthos, along with bioaccumulation in bioassay organisms and emergent insects (caddisflies), also provide important links to overall ecosystem integrity.

4.4 Integration of Study Components with Ongoing Studies

There are several options for integrating ongoing monitoring and special studies with an overall assessment of river health. The most efficient arrangements and sources of data are discussed here.

Flow

Information regarding river flow and regulation is essential for study timing and subsequent data interpretation. This information could be obtained from BC Hydro (for Hugh Keenleyside Dam) and Columbia Power Corp. or UtiliCorp (for Brilliant and Waneta Dams). Data from the permanent monitoring gauge at Birchbank would be obtained from EC. Some data (e.g., evidence of habitat disturbance, riparian description, stream morphology and channel characteristics) would be available from previous studies or assessed during field studies.

Water

During late summer, concurrent with Celgar's EEM program, and spring it is recommended that MWLAP collect water samples. Ongoing MWLAP water quality monitoring typically occurs in autumn (October-November) and winter (January). It would be most desirable to omit the fall program in response to proposed sampling in August-September; however, it is suggested that winter sampling (not considered in costing considerations for the integrated river health study) remain the responsibility of MWLAP.

Sediment

Sediment samples are typically taken annually by MWLAP in November at Birchbank and Waneta. However, Celgar and possibly Teck Cominco may conduct studies on the river in late summer, making it appropriate to divide responsibilities for sediment collection and analysis spatially between these two stakeholders. Stations upstream of Birchbank would be sampled by Celgar and stations from Birchbank downstream by Teck Cominco. Samples for chemical analysis and *Hyalella* bioassay (toxicity and bioaccumulation) would be submitted to analytical laboratories used by MWLAP.

Benthic Invertebrates

It is recommended that Celgar conduct benthic invertebrate sampling and taxonomic analysis at all stations for which benthos sampling is proposed, given previous expertise and that sampling of depositional habitat is included in EEM Cycle 3. It is recommended that EEM sampling protocol be used. Requirements for CRIEMP II, beyond EEM standard protocol, of fitness parameter observations could be conducted on voucher specimens submitted to the independent taxonomist for QA/QC (part of EEM protocol). Standard taxonomic analyses would provide information useful for investigating structural and relationship endpoints and other integrative aspects associated with river health assessment.

Emergent Caddisflies

It is recommended that Teck Cominco be responsible for collection, taxonomy and bioaccumulation analysis. Results would then be integrated into overall river health assessment and available for specific assessments conducted by both Teck Cominco and Celgar.

Periphyton

It is proposed that periphyton sampling and taxonomic analysis be the responsibility of Teck Cominco, given the necessary knowledge and experience with this technically demanding method. Taxonomic data would be analyzed in terms of appropriate structural and relationship endpoints and integrated with other components for river health assessment.

Fish

Fish are collected by MWLAP in fall at Genelle and Beaver Cr. as part of water quality objective monitoring and by Celgar downstream of the pulpmill for EEM. It is recommended that MWLAP and Celgar continue to sample fish. Data from ongoing BC Hydro work (developing indices of fish population abundance, performance measures) would be integrated into the river health assessment.

5.0 OVERALL INTEGRATION

The major stages of CRIEMP II assessment are outlined in Table 5-1. Stage 1 was completed by G3 Consulting Ltd. and presented in the companion data gap analysis report. Stage 2, the design for integrating ongoing work into overall river health assessment, is provided in this report. Stages associated with the field program (Stages 3 to 5), would be anticipated to proceed between spring 2002 and fall 2003. Following completion of the field program, data from individual studies would be organized for integration and river health assessment (Stage 6). This stage relies on a sound system for data release, sharing and confirmation (Section 5.2), a data screening process to assess quality assurance and control (Section 6.0) and standard operating procedures. Following screening, data would be interpreted and integrated (Stage 7, Section 7.0). The final report would present and summarize results, interpret data in terms of river health assessment and make recommendations for further assessment, monitoring and actions (Stage 8). This would include state of river health, a watershed report card, suggestions for streamlining and improving the integration process and recommendations on timing, schedules, etc. for any ongoing monitoring.

TABLE 5-1:
CRIEMP II – Integrated River Health Study, Stages of Assessment

Stage	Completed
1. Identify issues & data gaps in ongoing studies	√
2. Design a study integrating ongoing work to assess river health	√
3. Achieve consensus on design elements and associated member responsibility	In progress
4. Obtain funding for the integrated river health study	In progress
5. Execute field program addressing gaps in ongoing studies	
6. Acquire data from ongoing studies, screen and integrate with CRIEMP II data	
7. Interpret collective results and assess overall river health	
8. Provide report on state of river health, including recommendations	

5.1 Integegrated Schedule of Programs in CRIEMP II

Sampling station locations (18 from Arrow Lake to Waneta, additional stations possibly extending into Washington State) were discussed in Section 3.0, along with rationale for station selection and timing (two seasons). Components, parameters and endpoints to be measured and field methods to be used were discussed in Section 4.0, as were specific aspects of program integration. Table 5-2 provides parameter and replication details for each major component and matrix, including those for physical measurements. A scaled-down program would involve composited samples for sediment and sediment bioassay (reduced replication). Costs associated with both full and scaled-down programs are presented in the budget appendix.

TABLE 5-2: CRIEMP II – Integrated River Health Study, Matrix Parameters

Matrix	Parameter	Details	Replication	Total number
Physical	discharge	at Birchbank	in field	na
	velocity	at biota substrates	in field	na
Water	*in situ*	temp, DO, pH, conductivity, TGP	in field	na
	General	pH hardness nonfilterable residue turbidity major anions and cations	1 sample per week, 5 per 30-day period (spring, late summer) QA/QC: 10% for field and laboratory replicates	17 stations x 5 samples x 2 periods + 40 for QA/QC **= 210 samples**
	Nutrients	NH_3, NO_3, NO_2, total organic N total P, total dissolved P, ortho-PO_4		
	Metals	full spectrum		
Sediment	Chemistry	Total Organic Carbon (TOC) Acid Volatile Sulphide (AVS) particle size (%sand, silt, clay) metals (full spectrum, SEM) chlorophenols	3 replicates, late summer QA/QC: 10% for laboratory replicates also dioxin/furans for Celgar (7 sites) & Waneta (3 or 1 rep)	13 stations x 3 reps + 4 for QA/QC **= 43 samples**[1]
	Bioassay	*Hyalella azteca* 14-day and 28-day tests		8 stations x 3 reps **= 24 samples**[2]
	Bioaccum-ulation	following *Hyalella* bioassays		8 stations x 1 rep **= 8 samples**
	Additional at Waneta	extra 9 for metals, 3 for dioxin/furans coring, visual assessment	QA/QC: 10% for laboratory replicates	**9 samples (metals)** **3 samples (dioxin/furans)**
Periphyton	Biomass	chlorophyll *a*, phaeopigment ash-free dry weight	3 replicates, spring and late summer QA/QC: 10% of taxonomy samples	16 stations x 3 reps x 2 periods + 10 for QA/QC **= 106 samples**
	Taxonomy	species abundance		
	Fitness	Fluctuating Asymmetry (FA) morphological deformities		
Benthos (erosion and deposition habitats)	Taxonomy	species abundance biomass	3 replicates, late summer QA/QC: 10% of taxonomy samples	12 stations x 3 reps x 2 habitats + 8 for QA/QC **= 80 samples**
	Fitness	Fluctuating Asymmetry (FA) morphological deformities		
	Substrate	boulder, cobble, sand	in field	na
	Bioaccum-ulation	Emergent adult caddisfly	3 reps taken, only 1 composite analyzed	5 stations **= 5 samples**
Fish	General health liver tissue	mountain whitefish, rainbow trout organochlorines As Cd Cr Cu Hg Pb Tl Zn	minimum n = 8 per species QA/QC: 10% of samples	3 stations x 2 species x 8 reps + 5 for QA/QC **= 53 samples**

1. option to reduce scope (n=1 at most sites, n=3 at Birchbank and Waneta) = 19 samples
2. option to reduce scope (n=1 composite sample at each station) = 8 samples
na = not applicable

The entire integrated CRIEMP II program is presented in Table 5-3a and 5-3b, with organizations assigned responsibility for collecting and, in some cases, analyzing samples. A full page 11' x 17" format is included at the end of the report. It is apparent that MWLAP, Celgar and Teck Cominco would be responsible for much of the data collection, given their major roles and interest in river health and ecological risk. However, other stakeholders would and must be involved in and share responsibility for CRIEMP II assessment, in terms of remaining field work, interpretation and data management. These include BC Hydro (fish studies), municipalities and the CRIEMP committee collectively (analyses, overall funding, report review). Stakeholders contributing directly through integrated field programs would make inkind contributions ranging from provision of technical staff, communications, administration, equipment, supplies, etc., as well as direct and proportionate funding contributions.

5.2 Data Acquisition & Dissemination in CRIEMP II

Data communication is particularly relevant and essential to the current study and ongoing CRIEMP operations, given the number of studies and types of data to be integrated. Data sharing, storing and communication could be approached in many ways, including database sharing, web sites and libraries. Options for selecting an archive and collaboration solution have been explored, using criteria listed in Table 5-4.

Four technological choices meet these criteria, Wide Area Network (WAN), File Transfer Protocol (FTP) site, Website Based Solution and Application Service Provider (ASP) solution. General characteristics are discussed below. Comparative strengths and weakness of these systems are summarized in Table 5-5.

A WAN is either a Private Network, where all sites that need to access a system are linked together by dedicated lines, or a Virtual Private Network (VPN). In a virtual private network, a public network (such as the Internet) is used, with encrypted data exchanged between member sites to prevent non-member access.

An FTP site is a central repository where files can be uploaded or downloaded. Access to the site is either open or restricted by user identification and password. FTP sites usually have a DOS/Windows-like directory structure with folders, sub-folders and files.

Website Based Solutions involve webpage-based collaboration software (e.g., *Active Project* from *Framework Technologies* and *SiteScape Enterprise* from SiteScape Inc.). These packages reside on a web server and are accessible from any web browser. They offer a wide range of features to enable people to share information effectively.

An ASP solution delivers applications to the end user's desktop over the Internet. In most cases, the application runs on servers in the ASP data centre, with the display being redirected to the remote user and keystokes and mouse movements being accepted from the remote user.

Following evaluation of the collective criteria listed in Table 5-4 and 5-5, an ASP solution was recommended as meeting CRIEMP needs most completely. ASP providers build and maintain computer networks and charge monthly fees to each user. An ASP solution would free end users from concerns about hardware and software acquisition, upgrades, patches, backups, virus scanning, hacker attacks and network administration. ASPs enter into a *Service Level Agreement* (SLA) with their clients, typically three years or longer, defining services to be provided, hours of operation, maximum percentage of downtime, type of backup regimen, etc.

TABLE 5-3a:
CRIEMP II – Columbia River Health Study
Integration of Stations, Timing & Matrices with Stakeholder Responsibility[1]

Reach	Sampling Station	EMS #	Time	Water[1]	Sediment: Chemistry & Particle Size	Sediment: Bioassay & Bioaccumulation
	Arrow Lake		L summer		CRIEMP	CRIEMP
1	U/S Celgar	200183	Spring	MWLAP *Celgar*		
			L summer	MWLAP *Celgar*	Celgar	Celgar
1	D/S Celgar	213039	Spring	MWLAP *Celgar*		
			L summer	MWLAP *Celgar*	Celgar	Celgar
1	Robson		Spring	MWLAP *Celgar*		
			L summer	MWLAP *Celgar*	Celgar	
2	Castlegar	200200	Spring	MWLAP *Castlegar*		
			L summer	MWLAP *Castlegar*	Celgar	
	Kootenay R.	New	Spring	MWLAP *Nelson*		
			L summer	MWLAP *Nelson*	CRIEMP	CRIEMP
3	D/S Castlegar	New	Spring	MWLAP *Castlegar*		
			L summer	MWLAP *Castlegar*	Celgar	
3/4	Genelle	New	Spring	MWLAP *Celgar*		
			L summer	MWLAP *Celgar*	Celgar	
5	Birchbank	200003	Spring	MWLAP *Celgar TC*		
			L summer	MWLAP *Celgar TC*	TC	TC
5	Hanna Cr.	New	Spring	MWLAP *Trail*		
			L summer	MWLAP *Trail*		
6	D/S Stoney Cr.	223892	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*		
6	New Bridge	200558	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*		
6	Old Bridge	216137	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*		
6	Ryan Cr.	New	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*	TC	TC
6	d/S RDKB	223893	Spring	MWLAP *Trail*		
			L summer	MWLAP *Trail*		
6	Beaver Cr.	New	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*	TC	
7	Waneta	200559	Spring	MWLAP *TC*		
			L summer	MWLAP *TC*	TC	TC
	Pend d'Oreille R.	New	Spring	MWLAP *CRIEMP*		
			L summer	MWLAP *CRIEMP*		
	Kettle Falls		L summer	CRIEMP *USA*	CRIEMP *USA*	CRIEMP *USA*

1. stakeholder responsibilities includes cost of collection and analysis in most cases; refer to text for exceptions, MWLAP responsible for water collection and analysis, with other relevant stakeholders identified in italics

MWLAP: BC Ministry of Water, Land, and Air Protection
Celgar: Celgar Pulp Company
CRIEMP or CR: initiative under CRIEMP
BC Hydro
TC: Teck Cominco Metals Ltd.

TABLE 5-3b: Continued

Sampling Station	Time	Periphyton[1]	Benthos: Samples & Substrate	Benthos: Caddisfly Bioaccumulation	Fish liver tissue	Fish Population Studies	Integrate
Arrow L.	L summer						
U/S Celgar	Spring	TC *Celgar*					
	L summer	TC *Celgar*	Celgar				
D/S Celgar	Spring	TC *Celgar*					
	L summer	TC *Celgar*	Celgar	TC *CR*	MWLAP		
Robson	Spring	TC *Celgar*					
	L summer	TC *Celgar*	Celgar				
Castlegar	Spring	TC *CRIEMP*					
	L summer	TC *CRIEMP*	Celgar				
Kootenay R.	Spring	TC *CRIEMP*					
	L summer	TC *CRIEMP*	Celgar *CR*				
D/S Castlegar	Spring	TC *CRIEMP*					
	L summer	TC *CRIEMP*	Celgar *CR*	TC *CR*			Accessible database for information sharing
Genelle	Spring	TC *CRIEMP*					
	L summer	TC *CRIEMP*	Celgar		MWLAP		
Birchbank	Spring	TC *CRIEMP*					
	L summer	TC *CRIEMP*	Celgar *TC*	TC *CR*			
Hanna Cr.	Spring	TC					Data analysis & interpreting
	L summer	TC	Celgar *CR*			BC Hydro	
D/S Stoney Cr.	Spring	TC					
	L summer	TC					Report preparation
New Bridge	Spring	TC					
	L summer	TC					
Old Bridge	Spring	TC					Communi-cation tools
	L summer	TC					
Ryan Cr.	Spring	TC					
	L summer	TC	Celgar *TC*	TC *CR*			
d/S RDKB	Spring	TC					
	L summer	TC					
Beaver Cr.	Spring	TC					
	L summer	TC	Celgar *CR*		MWLAP		
Waneta	Spring	TC					
	L summer	TC	Celgar *CR*	TC *CR*			
Pend d'Oreille	Spring						
	L summer						
KettleFalls	L summer	CR *USA*	CR *USA*	CR *USA*			

1. stakeholder responsibilities includes cost of collection and analysis in most cases; refer to text for exceptions, Celgar responsible for benthos, Teck Cominco for periphtyon, with other relevant stakeholders identified in italics
MWLAP: BC Ministry of Water, Land, and Air Protection BC Hydro
Celgar: Celgar Pulp Company TC: Teck Cominco Metals Ltd.
CRIEMP or CR: initiative under CRIEMP

ASPs often work in conjunction with Application Partners. These are companies that provide installation, training, support and customization for vertical software packages. G3 has prepared this information in conjunction with Stargate Connections Inc. (www.stargate.ca), Burnaby, BC. An application called AutoEDMS from ACS Software (www.acssoftware.com) is the recommended solution to address requirements outilined in a cost-effecive manner.

There are three components to cost: initial setup, on-going monthly cost and database administration. The initial setup varies depending on system complexity and amount of customization required. Stargate estimates that initial setup would be approximately $8,000 to $10,000. The monthly cost would be $185 per user per month for basic ASP service and $28 per user per month for use of AutoEDMS software. The database administration portion would vary based on number of documents added per month and conscientiousness of staff when adding documents to the system. Stargate is willing to set up a pilot project so the committee can verify validity of the solution (approximate cost of $14,000). Typically a pilot project is limited to three users for three months. If full implementation is desired at the end of the pilot period, setup charges mentioned above would be waived. Dollar amounts mentioned here are estimates only, based on currently available information. Changes by CRIEMP in scope or functionality of the proposed solution may result in changes to these estimates.

TABLE 5-4:
Criteria for Selecting a Data Management System for CRIEMP

Criterion	Requirements
Universal Access	• accessible from as wide an area as possible • no need for specialized equipment at the end user's location
Security	• inherent security of a proposed system is a prime concern • some members may have concerns about sharing sensitive information • committee members have the right to determine distribution and access to particular documents or files
Minimal Training Requirement	• proposed solution should be simple enough to learn in 15 min or less, assuming basic computer skills
Low Up-Front Costs	• up-front financial investment less than $15,000 CDN
Large Storage Capacity	• accommodate various data formats commonly used by committee members • accommodate large file sizes (e.g., AutoCAD, ARCInfo, photographs) • provide a minimum of 100 gigabytes of storage
Scalability	• amount of data likely to increase, probably dramatically, over the next decade • potential solutions need to be highly scalable in capacity to store documents and support additional users
Performance	• information sharing and collaboration systems that work over remote links are susceptible to slow performance • attaining acceptable performance over the slowest possible link is a major factor in reducing the cost of a solution

TABLE 5-5:
Comparison of Data Sharing Systems

Criterion	Wide Area Network	File Transfer Protocol	Web Solution	Application Service Provider
Universal Access	Worst of the four private networks require installation of dedicated lines VPN requires encryption/ decryption device at each site or complex client software on each workstation	excellent can be accessed by most web browsers and FTP client software	good can be accessed from any web browser	best in category can be accessed via Internet or by direct dialup. can be accessed by any type of client hardware (PC, MAC, Unix, Linux, Pocket PC) or web browser.
Security	good, although multiple copies of data can result in people working on the wrong copy of a file	mediocre many hacks exist for common FTP servers	worst of the four, most work with Microsoft IIS (Internet Information Server) and Outlook/Outlook Express, very vulnerable to hackers	best data stays safely behind data centre walls, screen image (pixels) goes to user, secure log in and encryption
Minimal Training	good, although some aspects of using a WAN can be obscure	simple operation, given limited functionality	average	easiest to adopt everyday Windows applications, shadowing[1] dramatically reduces training time
Up-front Cost	second highest	lowest	highest	second lowest
Storage Capacity	usable capacity limited by bandwidth and number of users	somewhat limited at most sites	limited	virtually unlimited
Scalability	good, but expensive limited by bandwidth	limited	poor	excellent
Performance	slow - files are moved to the user	slow - files are moved to the user	medium	fastest - data and programs stay in the data center; only "screen scrapings" (pixels) are sent to the user.

1. Shadowing is the ability for one user to see another user's screen and share keyboard and mouse functions. Two or more users can review documents, drawings and photographs together from remote locations. This is an excellent training and support tool, as well as a very effective collaboration tool. Also enables meetings to occur without effort and expense of travel, and draft and final reports to be posted for review, etc.

6.0 QA/QC CONSIDERATIONS

Total Quality Management is one of the aims of QA/QC (EC, 1998) and the largest single factor in determining the successful outcome of any scientific project. Establishment of good communication channels among committee stakeholders sharing data and establishment of an efficient paper trail are of paramount importance. Quality assurance and control is particularly important in an integrated study, where data from a variety of sources conducted by a variety of researchers for different reasons are incorporated. For example, analytical methods, detection limits and error analyses may differ from one project to another. These factors determine reliability and utility of data beyond the originally envisioned scope. In order to minimize exclusion of good data due to an inability to assign appropriate caveats, several QA/QC procedures, standard operating procedures (SOPs) and reporting methods should be adopted by all researchers whose data is integrated into the CRIEMP II river health assessment. At a minimum, a means of recording and reporting deviations from these standards should be adopted to enable comparison and QA assessments to be made.

A comprehensive set of QA/QC procedures and practices ensures program integrity at every level. Careful consideration is given to:

- data collection, management and interpretation;
- a standardized format for data collection forms and electronic data storage;
- protection of sample integrity at each stage of the field program; protocols for sample handling and processing
- project evaluation and review procedures;
- specific and overall program audits;
- evaluation and review of protocols and policies related to the decision process, follow-up actions and revisions to processes;
- use of GPS to verify field location;
- equipment calibration protocols; and,
- use of published government or academic protocols.

The QA/QC procedure starts with study design and follows through field operations, sample collection, laboratory analysis and data interpretation. Consistent station designation (project, station, sample numbers) among study participants is highly desirable. Protocols for packaging, documenting, handling, transporting and receiving samples should be documented and Chain of Custody forms maintained.

For the integrated program, QA/QC procedures include standardized and carefully reported field and laboratory methods, with SOPs for all data submitted for integration. Basic field and laboratory QA/QC in the CRIEMP II integrated study and, ideally, in studies contributing data to CRIEMP II would include Chain of Custody procedure and forms, field and travel blanks, field replicates, laboratory duplicates, blind duplicates, spiked samples, bench record sheets and analysis of Certified Reference Materials (for water, sediment and tissue analyses).

A contingency plan for the field program would deal with modifications of planned collection activities due to weather, equipment or sampling problems (e.g., back-up equipment to ensure that alternate means of obtaining required samples and information are available). A comprehensive audit trail is necessary to protect sample integrity through documentation and verification of all field operations, highly relevant when several entities are supplying data. Field forms (e.g., checklists, photo documentation, station description, sample description) are valuable templates for recording field data on-site. Information pertaining to station position, field surveys and *in situ* water column profiling could be gathered, monitored and stored in electronic format directly from field instruments. Electronic data acquisition would enable unmanipulated data to be recorded directly to disk without potential transcription errors.

Data from chemical analyses are evaluated by screening field and travel blanks for evidence of contamination (especially relevant where concentrations are low and near either analytical detection limits or water quality objectives), comparison of data from field and laboratory replicates, and comparison of measured and reported recovery rates for Certified Reference Materials. It is further recommended that samples spiked with a known concentration of a particular metal be submitted at least once in each sampling period.

For taxonomic analyses of periphyton and benthos, QA/QC procedures followed by subconsultants should be detailed. The minimum requirement is for examination by an independent expert of 10% of the samples.

7.0 DATA ANALYSIS & REPORTING

A variety of tools are used in environmental monitoring to assess impacts, based on empirical, prophetic, statistical and inferential approaches. Given that decisions related to evaluation of environmental impacts have increasingly serious economic, legal and political ramifications, the underlying scientific assessments are scrutinized very closely. Wrongly concluding that an impact has occurred (Type I error) can result in unwarranted changes in regulations, very costly to industry. Wrongly concluding that no impact has occurred (Type II error) can result in no changes to regulations and potentially create ecosystem or human health risks. Both types of errors (not just traditional evaluation of Type I) should be considered equally important. The ability to evaluate acceptable (critical) levels of Type I or II error relies on careful evaluation of the tools, types of tests and decision-making processes used to jointly evaluate these errors.

Given that the study design is based on several ecologically based *a priori* hypotheses, data interpretation would be consistent with an ecosystem approach. Tools include careful application of statistics, ecological knowledge and industrial process knowledge to answer two questions. Are there measurable temporal or spatial effects in the river beyond those changes considered ambient? If so, what are the magnitude, extent and risks associated with these effects, their relevance to the ecosystem and its constituents? The CRIEMP II integrated river health assessment report would present arguments intended to answer these questions using a weight-of-evidence approach to test hypotheses proposed in Section 2.0.

7.1 Definition of Terminology

An assessment of river health in an area with multiple influences of regulated flow and several discharges requires clear definition of terminology. Terms such as "ambient", "background" and "effect" must be carefully defined and these definitions adhered to or their use avoided.

A definition of ambient for the lower Columbia River must include the range of conditions created by a highly regulated river, together with myriad diffuse inputs from the watershed. The receiving environment and communities of the lower Columbia River typically experience disturbance in the form of depth, flow and velocity fluctuations and associated sediment, physiographic and morphometric alterations. This ambient condition provides a baseline from which to assess overall river health. River systems subjected to frequent disturbance may be characterized by distinct biotic communities, which can be identified and recognized as ambient. Background may be defined as ambient, which may include undefinable effects of general watershed use such as groundwater and surface runoff from various land use activities.

A definition of effect is provided in the benthic community section of the revised *Technical Guidance Document for Pulp and Paper EEM* (EC, 1998). For example, an effect of effluent on this community is defined as "the magnitude of the relationship between the benthic community and the effluent that is considered ecologically significant." Implicit in perception of an effect is identification of an effector (factor causing the effect) and the recipient being affected. These must be clearly defined in order to recognize the consequence of an effect, not always straightforward given that effects can proceed in both directions. For many environmental effects, a habitat factor may affect a community and, in turn, be affected by community response.

Given that environmental effects monitoring must rely on clear perception of an effect and its meaning to both industry and regulators, several observations are relevant to clarifying issues. Effects may be perceived differently, depending on whether ecological, sociological, aesthetic or political criteria are used (e.g., an ecological effect may not be perceived at the sociological level if ecological issues are not recognized as important to scientists, managers and the community as a whole). Describing effects as positive or negative is subjective, based on criteria used (e.g., increased community abundance may be considered positive, associated reduction in species richness may be considered negative). Effects can change over time at the source, vector and recipient levels (e.g., changes in effluent quality, method of dispersion, interaction with physical and chemical environment, community receptor response). Because a difference is not necessarily an effect, it is not appropriate to assign effect based simply on differences between exposure and reference stations. A clear link must be established in order to assign an effect by a target source on a target recipient. Effects of a single source are usually complicated by interaction of the target recipient with other natural or anthropogenic factors that may mask or impose effects of their own. These interactions may be antagonistic or synergistic, enhancing or reducing the original effect (e.g., log handling activities alter chemical and physical aspects of habitat, which alter the benthic community and may mask specific effects of discharged effluent; complex currents affect dilution; pH changes the nature and reaction of certain compounds). Effects may be statistically significant (mathematically relevant) without being ecologically significant in a particular receiving environment. Finally, effects may alter the receiving environment in ways not measurable using current techniques.

7.2 *A Priori* Data Assessments

Sample Replication

Sample replication in the field and laboratory is critical to understanding temporal and spatial system variability within a station to make comparative observations and conclusions between stations with confidence. By establishing inherent variability within a sampling area, replication provides statistical confidence in the observation, but does not provide a causal link, which must be accomplished through acknowledgement and, in some cases, reduction of overall system variability. Effects are distinguished from differences in being relating to a cause, accomplished by assigning a relationship to the observed difference through selection of appropriate references and use of concurrent monitoring and standardized methods.

The study design summarized in Tables 5-2 and 5-3 proposes use of a minimum of three replicates for periphyton, benthos and sediment sampling. Three replicates would be sufficient for periphyton, given that this includes the use of three samplers per station (eight slides per sampler: two for chlorophyll, two for ash free dry weight, four for identification). Three replicate sediment samples have been analyzed in previous studies and are recommended for CRIEMP II, although an alternative of compositing samples and anlayzing one per station is also considered. For fish, eight replicates per species is recommended, based on MWALP and EEM protocols with underlying statistical rationales. For benthic invertebrates, power analysis conducted for the Celgar's EEM programs (Control-Impact design for Cycle 2; Borenstein *et al.*, 1997 in Hatfield, 2000) 1997) concluded that, for 95% power, use of three replicates (plus one archive sample) per station and 5 stations per area would provide adequate replication. G3 recommends that the EEM-protocol of five replicates per station be employed for CRIEMP II, with two samples archived and used later only if necessary to support results. This is based on the regression-style gradient design of CRIEMP further discussed below. Reducing replication would seriously limit final interpretation and overall health assessments, but may be considered in some areas after careful evaluation.

Variation & Effect Size

Criteria used to define and recognize important changes are key design aspects to be discussed and evaluated carfully prior to confirmation of final program design. In general, a preliminary understanding of expected variation permits better optimization of effect size and reduces the need to assign arbitrary values (e.g., 50% population increase or decrease in a benthos community). Effect size would be determined from review of CRIEMP I data, other Columbia River studies and available literature, together with experience and expertise of scientists developing the design.

7.3 Data Analysis & Statistical Testing

Analyses of biological, physical and chemical data combine several techniques to provide a reliable, accurate portrayal of results, while keeping in mind that statistical significance does not equal ecological relevance (Barnthouse *et al.*, 1989). Methods include univariate analyses, graphic representation, regression and multivariate analyses, critical effects and power analysis, similarity and cluster analyses of biotic communities and sampling precision estimates. Analyses that establish linkages (e.g., indicator species and communities, sediment triad analysis) can be done to recognize ecological relevence, with results brought together in a weight-of-evidence approach, as discussed below. A system of data sharing (e.g., ASP solution discussed in Section 5.2) is particularly necessary to facilitate this stage.

As stated in Section 2.3, the sampling program design is a spatial gradient relative to the dams, overlain by a series of Control-Impact designs along the spatial gradient. Each station forms part of the gradient, serving as upstream or downstream impact locations, to define the background effects of water regulation on biotic community structure and tease out overlying spatial effects of discharges along the river. Thus, data analysis, like sampling strategy, uses a flexible statistical approach, driven by weight-of-evidence integration.

For example, ANOVA hypothesis and power tests would be used in individual Control-Impact designs to test factors upstream and downstream of discharges. Regression analysis with 95% confidence intervals to test hypotheses about relationships between biotic and physical factors, in addiiton to cluster analyses of overall biotic composition, would be conducted in association with statistical hypothesis testing to determine significant biotic groupings. Data would be plotted graphically to demonstrate relationships. Both univariate and multivariate patterns would be tested to determine probable relationships between groups of samples and various causative agents. ANCOVA would provide statistical comparisons among biotic gradients to detemine if the continuum in community patterns remains the same (null hypothesis) in the absence or presence of an extraordinary discharge source.

Univariate Analyses & Graphical Representation

Simple univariate analyses and associated graphical representation of water, sediment, benthos and periphyton data would be used to compare stations. Relationships among key physical and chemical parameters would be identified and evaluated quantitatively and qualitatively, then correlated with biotic data. Abundance, taxa richness and biomass data would be summarized and presented, relative importance of major taxonomic groups assessed, dominant taxa described and associated ecological significance evaluated. These methods also would allow comparison of patterns of survival versus recruitment.

Regression & Multivariate Analyses

Physical, chemical and biological factors in benthos and periphyton would be compared using regression or multiple-regression methods suited to spatial comparative designs. Sediment factors and community patterns would be determined spatially or mapped to show spatial patterns along the study area. Combining univariate analyses and graphical representation with multivariate analyses (e.g., Faunal Similarity Index; see below) facilitates a balanced view of community structure and permits distributions of both large and small taxa to be examined. Comparisons of appropriate reference and exposure stations could then be made.

Critical Effects & Power Analysis

Further statistical evaluations of critical effects would be undertaken (e.g., power analysis) and data presented. Such analyses combined with graphical presentations of key endpoints (e.g., absence, proportion or density of each taxon, species richness, total abundance, biomass) aid in detecting and describing effects of exposure. This information would be intended to provide answers to the principal questions posed by CRIEMP and regulatory agencies.

Benthos & Periphyton Similarity Indices

A variety of indices and ordering techniques can be used to assess and measure differences in community structure, considering the continuum concept (i.e., community structure changes continuously along environmental gradients; Pearson and Rosenberg, 1978). The Faunal Similarity Index or Index of Affinity is a widely used index to assess distribution of individuals among species. This index is the sum of the smaller dominance percentages of each species common to a pair of stations being compared. A traditional similarity measure, this numerical technique permits objective assessment of differences in composition along temporal (Pearson, 1971) and spatial gradients and between different regions affected by discharges (Bagge, 1969; Leppäkoski, 1975; Rosenberg, 1972; Rosenberg *et al.*, 1975; Rades, 1976).

Similarity (multivariate) analyses would be used to characterize community patterns of benthos and periphyton. Among the variety of available indices, Bray-Curtis analysis is favoured as it includes larger sized, less abundant taxa and performs very much like a log transformation of abundance data, with accompanying biological rationale.

Cluster Analyses

Clusters are constructed using three to five replicates from a Bray-Curtis pair-wise similarity or dissimilarity matrix (Bray and Curtis, 1957). A dendrogram showing group membership of stations or samples is constructed using an unweighted pair group mean average sort as described by Sneath and Sokal (1973). Cluster groups are then portrayed on figures of the study area, using symbols to designate members of the same cluster groups. An objective bootstrap hypothesis-testing method is then applied to the cluster groupings to test for homogeneity of group membership at each linkage (Nemec and Brinkhurst, 1988).

Dissimilarity gradients and cumulative frequency distributions would be constructed using paired dissimilarity values from the data matrix calculated for cluster analyses. Dissimilarity between and among reference and exposure stations would then be plotted to show probability of spatial separation (*c.f.*, Burd, 2002, in press) and regularity of expected spatial drift in species composition away from a point source (industrial discharge or reference).

Precision of Sampling

A posteriori analysis of replicate data can be used to examine variance within stations. The mean and variance of each station is plotted using a power function and slope of the regression equation used to determine the degree of assemblage aggregation and number of replicates required to obtain a predetermined precision (standard error of 20% of mean abundance) for the entire sampling region (Downing, 1979). This is also done more simply on a station by station basis (Elliott, 1977) to show measured sampling precision for each location. This form of analysis examines the confidence in sampling replicates at the scale used, since true field replication does not exist effectively (Hurlbert, 1984) and is always considered arbitrary in terms of how far apart replicate samples are collected "within the same station". Further reference to this issue is provided in the federal EEM Technical Guidance Document (EC, 1998).

Biotic Indicators & Opportunists

Use of individual benthic invertebrate and periphyton species or groups of species to characterize the degree of contamination in a water body has extensive application in both freshwater and marine systems (Bagge, 1969; Reish, 1972; Bellan and Bellan-Santini, 1972). For example, benthic invertebrates such as tubificid oligochaetes, in general, and *Tubifex tubifex*, in particular, have long been regarded as indicative of organically enriched sediments. Likewise, the diatom *Achnanthes minutissima* is recognized as an opportunist of physical disturbance (e.g., spates) in river systems and *Gomphonema olivaceum* is generally intolerant of most heavy metals. When assessed as part of a weight-of-evidence approach using a complete data set, including other biotic, community and environmental conditions, indicator species or associations would be used to define either zones or stages of enrichment, physical disturbance and contaminant conditions.

Sediment Quality Triad & Bioaccumulation in Benthos

Data from *Hyalella* toxicity bioassays (growth and survival) and sediment chemistry analyses would be assessed using analysis of variance. Sediments and natural biota from depositional habitat in reference and affected areas would be compared using ANOVA to assess statistical significance of observed differences. Data from bioaccumulation studies (*Hyalella* bioassays) would be handled in a similar fashion. This approach would establish links between chemical analyses, biological effects (toxicity and growth), and uptake (bioaccumulation), highly relevant to establishing exposure and risk in the environment and evaluating river health. These relationships would then be correlated with observed community structure of benthic invertabrates collected in the same depositional area and nearby erosional areas.

Weight-of-Evidence

Relying on any one component to draw conclusions can be highly misleading, given differing fates of various contaminants and differing sensitivities of organisms in various circumstances. Weight-of-evidence integrates components, each providing supportive data weighted with other components or environmental matrices to construct a more accurate depiction of the receiving environment. Use of weight-of-evidence is widely supported by the scientific community and was promulgated at the SETAC World Congress Conference in San Francisco, November, 1997 (Hunt *et al.*, 1997; Taberski, 1997; Wilson *et al.*, 1997). More and more, scientists are coming to rely on weight-of-evidence for complex and complicated environmental studies, which often do not conform to parametric statistics. When statistical analyses are not sufficient to describe relevance of ecological phenomena, very often the case, other means must be used which provide the "so what" to an observation.

Environment Canada describes weight-of-evidence as "considering all lines of evidence, using professional judgement to assess ecological relevance of data, and considering the strengths and weaknesses of the data collected" (EC, 1998).

A weight-of-evidence approach is useful for analyzing and interpreting the large amounts and various types of data generated and it provides crucial linking of data between components, their various measures and other environmental variables to define aquatic fitness and river health. This approach integrates structural components (effluent, bioassays, water, sediments, periphyton, benthos, fish) and functions (underlying ecological relationships and processes such as productivity, ecological tolerances, diversity, recruitment of species) into a spatial analysis of potential effects. Trends in individual characteristics (univariate analysis) and interactions (multivariate analysis) are examined. Qualitative and quantitative aspects of a parameter are compared (e.g., chemical composition, flow, operational activities, dominance hierarchy, rare and indicator species compared with total abundance). Relationships among various endpoints of a single component (e.g., relative abundance hierarchy and species richness) are examined. Relationships among different components, (e.g., periphyton standing crop and nutrient or sediment metal levels) are also explored. Different perspectives of the same components (e.g., standing crop, biomass and total abundance) may also be compared. This enables a more accurate picture of the receiving environment to be constructed and trends identified, essential for understanding ecological consequences resulting from the complex issues that affect the Columbia River (e.g., flow regulation, slag burial or re-exposure, long-range transport of compounds from the pulpmill, smelter and wastewater treatment plants).

A paper presented by G3 at the October 2000 Aquatic Toxicity Workshop Conference in St. John's, Newfoundland, stressed that utility of using weight-of-evidence in environmental assessment relies on the ability of scientists to select appropriate assessment criteria. G3 regards certain criteria inherent to conclusive weight-of-evidence analysis, including:

- avoidance of "component stacking" (e.g., each component assessed in isolation in a multi-component study);
- selection of appropriate and complimentary structure-linked and relationship-linked endpoints to provide functional analyses of the overall ecosystem being studied (e.g., total abundance linked with relative abundance; species hierarchy linked with competition, predation, behaviour/feeding strategies; community structure linked with ecological niches, pollution tolerances and habitat preferences);
- inclusion, where possible, of more than one level of assessment (e.g., individual, population, community);
- use of relationship-linking models (e.g., Pearson and Rosenberg's SAB) over static models of community structure;

- judicious use of indices, with focus on relationship-linked indices (e.g., % *Achnanthes minutissima* may indicate frequent physical disturbance; % motile periphyton such as *Navicula* spp. and *Nitzchia* spp. may indicate siltation, etc.) over community structure indices (e.g., diversity), which may relate to any number of factors;
- integration and comparison of components, endpoints and variables to address how endpoints relate to one another and the receiving environment; and,
- provision for a sufficient understanding of "ambient" and accepted deviation from ambient, regarding variability, ecosystem function and dynamics of change.

7.4 Expected Deliverables

The overall question of river health as it relates to distinguishing effects of effluent discharges (historic or current), flow regulation and non-point sources of pollution will require studies over time within an ongoing and iterative process. However, the present scope of the design proposes to address "ambient" as a flow-regulated river. To expect the present design (mostly an integration of current piecemeal studies aimed at point-source assessments) to fully address the very large and complicated series of potential point and non-point pollution sources is not reasonable. This said, the G3 design integrates ongoing monitoring, incorporates additional sampling and provides a framework for interpretation of results. The overall strength of the study is its ability to integrate data from current and proposed studies into a wider framework for river health (the feedback between monitoring / assessment and management strategies). As such, this design provides a logical first step to answering this large and complicated question and providing an assessment of river health, comparing past with current health and identifying contributions from known discharges.

Multiple sites will be used to define ambient conditions (considering that the river itself changes in the 60 km study area). Ambient will reflect effects of both river regulation and non-point source compounds. Select sites upstream and downstream of point source discharges will define specific impacts of these industries (perturbations from ambient). Hence, it will be possible to demonstrate reduced contaminant loads over time (temporal comparisons) and define biological impacts spatially, distinguishing them from background (flow, non-point source) influences.

The modified sediment triad assessment (chemistry, bioassays, native benthos in depositional areas, bioaccumulation) should identify and better define acute and chronic toxic effects of discharges in near and far-field areas, as will assessments of other natural biotic communities. More intense sediment sampling at Waneta is included to better define conditions at this important site. MWLAP sediment quality studies (bioassay) have indicated problems at Waneta but are not designed to understand underlying causes and implications (e.g., are the reduced growth and survival noted after 28 days but not after 14 days related to the very low TOC through toxicity or starvation; if starvation, why is there so little productivity at Waneta?). Sampling of additional components will help provide explanations.

It will be more difficult to directly define effects of river regulation in this, or any, design as there are no similar undisturbed areas for comparison. Ancillary information from BC Hydro (e.g., fish PAI, studies of dewatering impacts) will provide a framework for assessing impacts on habitat and enable inference and integration with study results. In addition, considerable literature exists on regulated rivers to support interpretations (e.g., caddisfly species distribution in study area, as shown in the Teck Cominco study, agrees with that predicted by literature).

Major stressors related to smelter, pulpmill and wastewater treatment plants will be identifiable. Overall impacts from non-point sources and cumulative impacts should be recognizable; however, it is unlikely that the current study will completely define non-point sources. This said, however, a screening of general classes of chlorinated organics will provide a baseline for future studies, if warranted, inputs from metals in road runoff may be identifiable, and localized effects may be seen (e.g. Beaver Creek confluence). The use of interpretive tools such as the multimetric indices of biotic integrity are also expected provide a reflection of overall river health.

CRIEMP II is intended to study overall river health and there is a cost/benefit analysis to consider. For example, although outside the scope of the current work, a whole watershed land and water use study would benefit CRIEMP. The present emphasis on the river study in the framework of an overall river health assessment (management, long term planning, decision-making, report cards, public awareness) provides an excellent first step in the ongoing process.

7.5 Data Presentation & Public Education

In addition to typical report formats, statistical analyses, spreadsheets and graphics, some information can be summarized in a geographic information system (GIS), which relates parameters and spatial data in concise ways. Teck Cominco has developed a GIS system and other stakeholders (e.g., municipalities, MWLAP) may have systems in place or a desire to develop one. Such systems store information in an easily retrieved and updated manner and are accessible to a variety of users. The benefits of using GIS to handle and communicate large quantities of data from routine monitoring or from a CRIEMP II study can be considered.

Other concurrent and subsequent stages of the CRIEMP process would use the river study data to communicate information to and solicit input from the general public in the watershed and from larger international stakeholder groups. Examples include general educational programs for local communities through schools, community centres and stewardship groups; CRIEMP public release documents; and workshops and training sessions for local interest and stewardship groups.

8.0 SUMMARY

The study design proposed for assessment of Columbia River health integrates ongoing MWLAP and EC water quality monitoring, Celgar's planned EEM Cycle 3 study and Teck Cominco investigations into current river health and ecological risk assessments in the framework of a regulated river. This level of integration is coordination of stakeholder effort. Additional stations and components are added to transform several highly focused studies into a more broadly based ecosystem assessment (involving biological and ecological integration). Information will also be incorporated from BC Hydro fish population and habitat studies. A whole-river approach is recommended, incorporating a gradient design with use of several reference and exposure stations along the length of the study area. This approach enables ambient conditions of the regulated river to be recognized, along with perturbations induced by point and non-point sources and cumulative impacts.

Development of a system for sharing and evaluating data among stakeholders (integration at the communication level) is critical. When brought together into a river health assessment, data will allow questions regarding applicability of current water quality objectives, current environmental effects of point and non-point sources, cumulative effects, transport, deposition, exposure to and potential bioaccumulation of chemicals of concern, links between aquatic and terrestrial ecosystems and ecological relevance to be evaluated. In addition to the integrated river study described in this document, further work will be required to develop recommendations and action plans. This level of integration connects the scientific conclusions with the decision-making and planning processes (adaptive management strategies).

This integrated process and approach should enable evaluation of overall river health in a statistically defensible and ecologically relevant fashion, and be adaptable with changing needs and time.

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