Nutrient Enrichment in the Peace, Athabasca and Slave River: Assessment of Present Conditions and Future Trends

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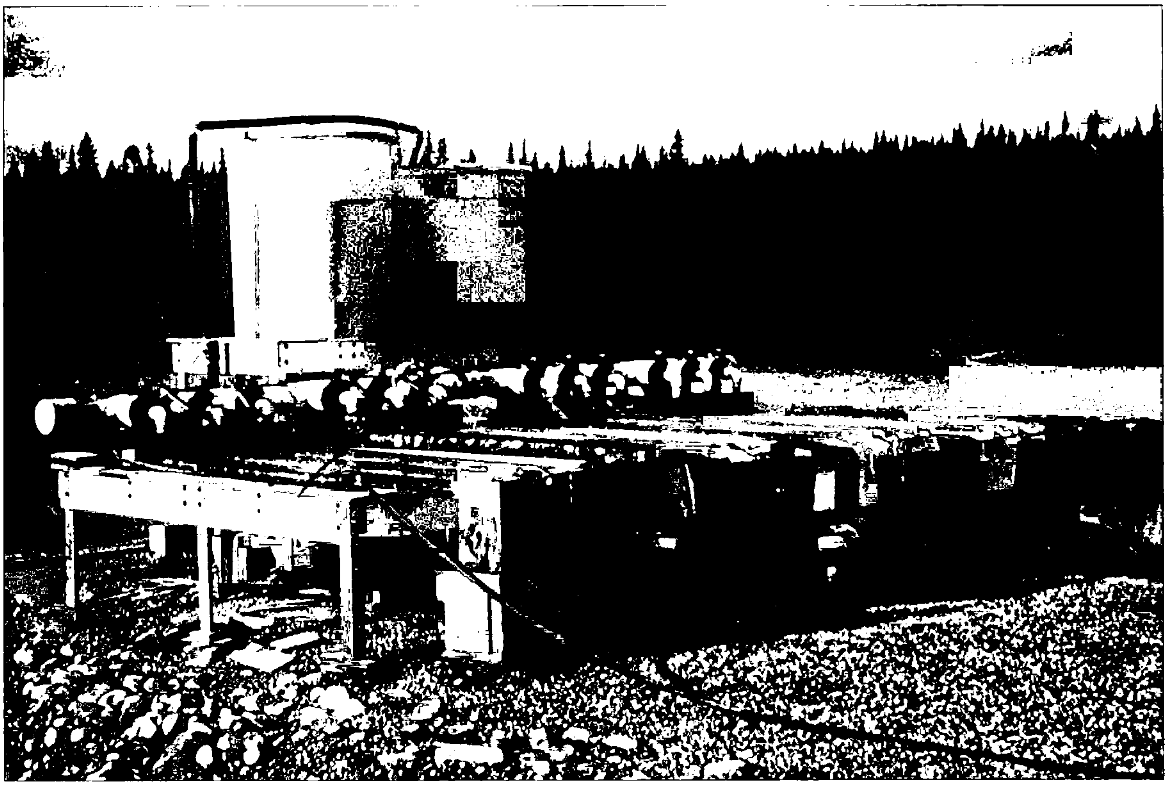

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NORTHERN RIVER BASINS STUDY
SYNTHESIS REPORT NO. 4

NUTRIENT ENRICHMENT IN THE PEACE, ATHABASCA AND SLAVE RIVERS: ASSESSMENT OF PRESENT CONDITIONS AND FUTURE TRENDS

by

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REPORT SUMMARY

The aim of this report was to address the Northern River Basins Study (NRBS) question: "Are the substances added to the rivers by natural and manmade discharges likely to cause deterioration of the water quality?" In this report, the word "substances" was taken to mean nutrients or, more specifically, nitrogen and phosphorus. Other NRBS reports have addressed the impact of effluent loading from the perspective of contaminants. This report synthesizes results from research and monitoring studies undertaken as part of the NRBS to characterize nutrient loading from all point and diffuse sources in the Northern River basins, evaluate the impacts of nutrient loading on river chemistry, assess the response of riverine biota to nutrient loading from pulp mill and municipal effluents *in situ*, quantify nutrient responses of benthic biota, and investigate interactions between nutrients and contaminants in pulp mill effluent on food webs. These findings are used to assess the state of aquatic ecosystem health, and develop scientific and management recommendations for the Northern River basins.

During fall, winter and spring, elevated nitrogen and phosphorus concentrations were observed on the Athabasca River downstream of Jasper, Hinton, Whitecourt and Fort McMurray and on the Wapiti River downstream of Grande Prairie. In the Athabasca River, 20% of all TP samples and 2% of all TN samples exceeded the *Alberta Surface Water Quality Objective* of 0.05 mg/L TP as P and 1.0 mg/L TN as N. Most of these exceedances occurred during summer and were likely due to high particulate concentrations. In the Wapiti River, 74% of TP samples and 19% of TN samples collected near the mouth exceeded the *Alberta Surface Water Quality Objectives* compared with exceedances of only 12% for TP and 0% for TN upstream of Grande Prairie. This suggests that nutrients from the City of Grande Prairie and Weyerhaeuser of Canada Ltd. effluents contribute to non-compliance. Annually, continuously-discharging industrial and municipal sources contribute 4 to 10% of the TN load and 6 to 16% of the TP load in the Athabasca River, with the contribution being higher during winter. Likewise, continuously-discharging industrial and municipal sources contribute 20% of the TN and 22% of the TP load in the Wapiti River annually. For the Peace River mainstem there is no evidence of nutrient impacts and the same is likely true for the Slave River, although there are only limited nutrient data for this river.

Elevated nutrient concentrations in the Athabasca and Wapiti rivers have increased periphyton biomass and benthic invertebrate densities and, for the Athabasca River downstream of Hinton, increased the length and body weight of spoonhead sculpin (*Cottus ricei*), a small insectivorous fish species. Enrichment studies conducted with nutrient diffusing substrata in fall 1994 showed that periphyton growth was nutrient saturated for at least 2.5-4 km downstream of Jasper, from downstream of Hinton to upstream of Whitecourt, for at least 3 km and possibly up to 48 km downstream of Fort McMurray, and for at least 2 km downstream of the Grande Prairie bleached kraft pulp mill. Phosphorus concentrations at sites immediately upstream of the outfalls to these nutrient-saturated reaches were usually < 2 g/L SRP in the Athabasca River and 4-6 g/L SRP in the Wapiti River. These concentrations are similar to the 2-5 g/L SRP that was determined to be the concentration above which the growth of individual cells and thin periphyton films in

artificial streams are phosphorus saturated. Periphyton growth was nitrogen limited from downstream of the Alberta Newsprint Co. to the confluence of Lesser Slave River and in the Smoky River. The increase in periphyton biomass and benthic invertebrate densities downstream of effluent outfalls and, in the case of the benthic invertebrates, no loss of species suggests that the response to effluents is one of nutrient enrichment not toxicity. Studies conducted in artificial streams further showed that periphyton biomass and growth of several mayflies, stoneflies and caddisflies increased in response to nutrient or 1% effluent addition, with no significant difference between the two treatments. These results further verify that the response to the current level of effluent loading is one of nutrient enrichment. There is no evidence of adverse effects to the ecosystem (e.g., no benthic invertebrate species loss, no problems with dissolved oxygen levels that are directly caused by nutrient addition). While detailed investigations of spawning grounds and early rearing habitat for fish in the Northern Rivers were not undertaken, it does appear not that dissolved oxygen problems caused by nutrient addition are adversely affecting fish populations at present.

The concern with nutrient addition to the Athabasca and Wapiti rivers appears, at present, to be largely one of aesthetics as perceived by increased periphyton growth. Aesthetic criteria for the protection of water bodies are often site specific and developed in consensus with the users of the lake or river. In the absence of any detectable deleterious effects of nutrient loading on the Athabasca and Wapiti rivers, the users must determine whether the increase in periphyton growth downstream of outfalls is acceptable or unacceptable. Given our current state of knowledge, setting effluent permit limits for phosphorus to control periphyton biomass at a specific level is not possible since there is as yet no quantitative relationship between river phosphorus concentrations and periphyton biomass for a given site. For example, periphyton biomass 1 km downstream of Hinton was found to range from 25 to 242 mg chl*a*/m^2 for October 1990, 1992, 1993 and 1994 despite relatively constant TP loads from Weldwood of Canada Ltd. and relatively constant river flows (111, 134, 97 and 118 m^3/s for October 1990, 1992, 1993 and 1994, respectively). Yet despite the lack of site-specific quantitative relationships between periphyton biomass and phosphorus concentration, experiments and *in situ* observations undertaken by the NRBS and other agencies have clearly shown that phosphorus (and, in some locations, nitrogen) are controlling factors for periphyton abundance in the Athabasca, Wapiti and Smoky rivers.

Based on findings from studies reviewed in this synthesis report, the following key recommendations are proposed:

- regular monitoring and reporting of nutrients from sewage treatment plants. This should be a license requirement. In addition, provision is needed for ensuring compliance with sampling and analytical procedures for all licensed dischargers (industrial and municipal) and to ensure training of certified operators to measure (and record) flow rates and discharge volumes and for enforcement of reporting requirements. Standard reporting requirements for water quality parameters should be established and reporting proper data should be a license requirement.

- development of effluent permit limits based on environmental effects rather than on technology design limits. All industries and municipalities should be licensed on the basis of environmental effects. In the case of no perceptible environmental effects, designated technology standards should prevail.

- *in situ* experiments to confirm nitrogen limitation of periphyton growth in the 230 km reach of the Athabasca River from downstream of the Alberta Newsprint Co. to the Lesser Slave River and in the Smoky River downstream of the Wapiti River confluence.

- collection of environmental effects monitoring data during fall as it is the time of maximum biological productivity. At present, limited data are collected on nutrient concentrations during fall. For the Athabasca River, environmental monitoring should be coordinated such that a comprehensive longitudinal survey of the river is obtained each fall.

- assessment of the impacts of changing landuse on nutrient loading. Data are almost entirely lacking on the contribution of non-point sources to nutrient loads in the Northern Rivers. While contributions can be estimated from the limited data for Alberta and other parts of the world, the large changes in landuse patterns that have taken place and continue to occur (e.g., agricultural land clearing, timber harvesting, oil and gas activities) may cause substantial impacts in nutrient loading particularly to tributaries.artificial streams and nutrient diffusing substrata developed for NRBS should beconsidered as a promising tool for environmental effects monitoring by the pulp and paper industry.

- artificial streams allow investigation of cause and effect scenarios and development of ecological indicators for riverine biota under experimentally controlled dose-response regimes. Nutrient diffusing substrata permit *in situ* assessment of the effluents on river nutrient status. These approaches would assist in defining the effects of pulp mill effluent on benthic biota.

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INTRODUCTION

1.0 INTRODUCTION

The aim of this report is to address the Northern River Basins Study (NRBS) question: "Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality?" In this report, the word "substances" is taken to mean nutrients or, more specifically, nitrogen and phosphorus.

The impact of added nutrients on aquatic ecosystems is a major concern since added nutrients can increase the growth of the primary producers (algae and aquatic weeds) to levels that result in impairment of the ecosystem (e.g., changes in benthic invertebrate and fish species composition, fish kills, or impaired recreational use). The critical role of nutrients (nitrogen and phosphorus) in regulating the productivity and trophic status of aquatic systems is well known and has been widely studied (Schindler *et al.* 1971; Dillon and Rigler 1974). In lakes, nutrient addition from sewage, industrial, or agricultural inputs has been shown to increase primary, benthic invertebrate and fish production whereas nutrient abatement can reverse these effects (e.g., Beeton 1965; Edmondson and Lehman 1981; Stockner and Shortreed 1985). Likewise, nutrient addition to streams and rivers can increase periphyton standing crop and benthic invertebrate growth rates (Cole 1973; Peterson *et al.* 1985; Perrin *et al.* 1987; Johnston *et al.* 1990). Fish standing crop for rivers in North America has also been positively correlated with total phosphorus concentrations (Hoyer and Canfield 1991). However, while moderate nutrient additions to unproductive lakes and rivers can enhance productivity, nutrient additions to productive systems can cause environmental degradation. For example, nutrient enrichment from discharge of bleached kraft pulp mill and sewage treatment plant effluents to the Thompson River, British Columbia resulted in a massive increase in algal biomass downstream of the City of Kamloops (Bothwell 1992). Similarly, Marcus (1980) found that nitrogen loading from a reservoir discharge increased the biomass and changed the species composition of periphyton communities in Hyalite Creek, Montana. Nitrification can also affect the dissolved oxygen regime of enriched rivers such that the nitrification of ammonium to nitrite (NO_2) and nitrate (NO_3) has been shown to depress dissolved oxygen concentrations in the Willamette River, Oregon (Dunnette and Avedovech 1983) and the Passaic River, New Jersey (Cirello *et al.* 1979). The aim of this report was to assess nutrient loading from pulp mills, municipalities, other industries and diffuse sources on the Athabasca, Wapiti, Smoky, Peace and Slave rivers and evaluate the impacts of these loads on riverine biota. Residents in the Northern River basins are concerned about water quality, and household surveys undertaken by NRBS (Bill and Flett 1996; Thompson and MacLock 1996) indicate that residents view the rivers as having more algae and vegetation, being more polluted, and having fewer or smaller fish than previously. During the past four years, studies have been undertaken as part of the NRBS to characterize nutrient loading from point and diffuse sources in the Northern River basins, evaluate the impacts of nutrient loading on river chemistry, assess the response of riverine biota to pulp mill and municipal effluents *in situ*, quantify nutrient responses of benthic biota, and investigate interactions between nutrients and contaminants in pulp mill effluent on food webs. In this report, the current state of knowledge with respect to nutrient addition on river ecosystems will be reviewed (Chapter 1) and results from research and monitoring studies on the impacts of nutrient addition will be synthesized for work undertaken by the NRBS and other agencies operating in the Northern River basins (Chapters 2-6). This information will be used to provide an assessment of the state of aquatic ecosystem health and develop scientific and management recommendations for the Northern River basins (Chapters 7 and 8).

1.1 NUTRIENTS AND NUTRIENT ENRICHMENT

Nitrogen (**N**) and **phosphorus** (**P**) are essential nutrients for all organisms including aquatic plants (the free-floating algae or **phytoplankton**, the attached algae on rocks and sediments or **periphyton**, and the large aquatic weeds or **aquatic macrophytes**). Because N and P are relatively scarce in freshwater compared with other essential nutrients and since plants require large amounts of these nutrients, N, P or both may limit aquatic plant growth. In most fresh waters, P is the nutrient that is in shortest supply; therefore, its availability usually controls aquatic plant growth. Thus, it is referred to as the **limiting nutrient**. In lakes and rivers where P is the limiting nutrient, addition of P will increase phytoplankton and periphyton abundance or **biomass** until their growth is again limited by another nutrient or other factor. Nitrogen tends to be the limiting nutrient in the oceans and a few inland waters (e.g., Grimm 1987). In these systems, addition of N will increase aquatic plant biomass. In some lakes and rivers, both N and P are in short supply (Hershey *et al.*1988; Dodds *et al.* 1989; Hullar and Vestal 1989) . In these systems, plant growth is controlled by both nutrients such that when one nutrient is added the second nutrient becomes limiting. These systems are said to be **co-limited** by N and P. Still other systems have N and P concentrations that are greater than that required for maximum growth. Plants in these systems are said to be **nutrient saturated**. Aquatic macrophytes may not respond directly to P or N addition as many of these large plants obtain their nutrients from the bottom sediments through their roots, rather than from the surface water.

Phosphorus is usually measured as one of three forms: (1) **total phosphorus** (**TP**) which includes all forms of P in the water, (2) **total dissolved phosphorus** (**TDP**) which includes only the forms of P dissolved in the water (i.e., the P forms that will pass through a 0.045 mm sieve), and (3) **soluble reactive phosphorus** (**SRP**) which includes the forms of dissolved P that are largely able to be taken up by aquatic plants. These measures of P are reported as milligrams of phosphorus per litre (**mg/L P**) or micrograms of phosphorus per litre (**µg/L P**) with 1 mg/L being 1000 times greater than 1 µg/L.

While some species of blue-green algae can use nitrogen gas directly and incorporate it into organic compounds, most plants require inorganic forms of nitrogen dissolved in water: **nitrate** (**NO_3**), **nitrite** (**NO_2**) and **ammonium** (**NH_4**). Nitrite and nitrate are usually analysed together and the results reported as µg/L or mg/L N as NO_2+NO_3. The concentrations of the three forms of nitrogen used by plants (i.e., nitrate, nitrite and ammonium) are often added to give **dissolved inorganic nitrogen** (**DIN**). Besides these forms of N, **total Kjeldahl nitrogen** (**TKN**), which includes ammonium and organic nitrogen, and **total nitrogen** (**TN**), which includes all forms of N in the water, are often measured.

Plants require more N than P for growth such that the atomic mass or weight of N compared to that of P (i.e., **N:P**) in the tissues of plants exposed to unlimited quantities of nutrients is approximately 9:1. Studies of river periphyton have shown that when the ratio of NO_3-N to SRP is less than 10, N is the limiting nutrient whereas when NO_3-N:SRP is greater than 20, P is the limiting nutrient (Shanz and Juon 1983). For NO_3-N:SRP ratios between 10 and 20, neither nutrient can be assumed to be limiting periphyton growth. However, it is important to remember that periphyton communities consist of many different algal species, each with different optimal N:P requirements, and that even if an N:P ratio suggests nutrient limitation, other factors (such as light, temperature or current speed) can be more important in controlling aquatic plant growth.

Nutrients in freshwater are derived from natural and man-made sources (Figure 1.1). Natural sources of nutrients include external inputs (called **external loads** and usually expressed as kilograms per year (kg/y) of N or P) and internal inputs (i.e., **internal loads**). Natural sources of external loading include runoff from undeveloped land, precipitation and dust (i.e., atmospheric deposition) falling directly on the lake or river, and groundwater and tributary inputs, although the latter can have elevated nutrient concentrations due to human activity. Internal loads are derived from P or N release from the bottom sediments or decaying plant or animal material. Man-made (or **anthropogenic**) sources are classed as **point sources** and **non-point or diffuse sources**. Point sources are inputs from a discrete source, such as a pipe or drainage canal, and include sewage, stormwater and industrial outfalls. Non-point sources are difficult to measure as they do not enter the lake or river at a single point. They include runoff from agricultural fields and municipalities.

The addition of nutrients to a lake or river in which nutrients are limiting will increase aquatic plant growth. This, in turn, may cause changes in the abundance and taxonomic composition of the aquatic herbivores that feed on aquatic plants (e.g., herbivorous aquatic insects such mayflies (Ephemeroptera) and chironomids (Diptera)) which may then result in changes in the abundance and composition of aquatic carnivores (e.g., carnivorous aquatic insects such as stoneflies (Plecoptera) and carnivorous fish such as walleye, pike and whitefish). The concentration of P or N that changes a lake or river from acceptable to unacceptable conditions is difficult to define because it depends on the goals of the users of that aquatic system. N and P are required in moderate amounts to support aquatic plant growth which, in turn, supports aquatic insects and fish (Figure 1.2). However, once this baseline concentration of nutrients is present, there is a wide range of acceptable concentrations (and, consequently, acceptable abundances and types of aquatic insects and fish) before excessive nutrient concentrations result in clear degradation of the lake or river. Many agencies throughout the world that are responsible for environmental protection are now meeting with the users of lakes and rivers to help define what are acceptable conditions for their particular lake or river.

Besides the amount of nutrients added, the duration of nutrient loading is also important, particularly for rivers. Pulse events, in which nutrient addition is of a limited and definable duration (e.g., a wastewater spill from an industry or municipality) often have little affect the aquatic ecosystem and recovery is generally rapid. In contrast, sustained events (e.g., resulting from the addition of another source of continuous effluent discharge) are of longer duration and, depending upon the river nutrient concentrations resulting from the sustained event, can cause habitat alteration and changes in the structure of the aquatic **food web** (i.e., the transfer of food energy from plants through a network of organisms that are eating and being eaten).

1.2 EFFECTS OF NUTRIENT LOADING ON RIVERS

Until recently, studies on the effects of nutrient addition to aquatic systems focused largely on lakes and reservoirs with comparatively little work conducted on streams and rivers. However, food web responses to nutrient addition can differ markedly between running and standing water systems, particularly since the biota are usually very distinct from one another (Welch 1992). For example, primary producers in rivers and streams are usually periphyton as opposed to planktonic algae in lakes. The relatively little attention originally directed at assessing the impact of nutrient addition on riverine biota likely relates to early beliefs that rivers were conduits for pollutants and could assimilate any loading of organic waste. This may have been true before the rapid industrialization and acceleration in population growth of this century which resulted in severe degradation of many large rivers (e.g., Thames, England; Rhine, Europe; Elbe River, Czechoslovakia/Germany; Cuyahoga, Ohio, U.S.A.). As a result of these observations of gross pollution as well as other observations of increased productivity and/or changes in diversity downstream of point or diffuse sources of nutrient loading, many investigators have examined nutrient dynamics and the response of river communities to nutrient inputs.

The River Thames in England is a good example of a system that was grossly polluted by industrial and sewage waste. The Thames has received waste from the City of London for almost two thousand years. The river was once known for its large salmon runs; however, by 1850 the fishery was destroyed largely due to the expansion of the population of London to over two million and the introduction of indoor plumbing which increased household sewage to the river (Gameson and Wheeler 1977). Prior to this, sewage was collected in individual or communal cesspits which were periodically emptied to fertilize farmland. To reduce pollution, outbreaks of cholera and noxious odours, a system was devised in 1865 to pipe the waste 10 miles downstream and discharge it on the ebb tide. The extra dilution resulting from this diversion along with a precipitation treatment for suspended solids resulted in an improvement in water quality between 1881-1910. Migratory marine fish (e.g., smelt and flounder) were once again caught in the river and dissolved oxygen conditions improved. However, as the population and industrialization increased, the fishery again declined until by 1950 only eels were found in a few reaches. With the introduction of secondary treatment plus nitrification in the late 1960's and 1970's, dissolved oxygen concentrations in the river increased, fish have increased from one species in 1950 to at least 80 by 1974, and smelt and flounder are again present. Salmon have been stocked into the river and it is hoped that the locks and weirs on the river will not block their migrations.

While many rivers that have been sites of intensive human settlement for hundreds of years became grossly polluted following centuries of nutrient loading, rivers receiving moderate additions of nutrients from sewage or agricultural waste (i.e., the pollutant loading is not so severe as to cause de-oxygenation) have shown increased biological productivity. For example, nutrient addition from a kraft pulp mill increased periphyton biomass in the Thompson River, British Columbia and the McKenzie River, Oregon (Bothwell 1992). Nutrient addition from sewage disposal has also increased aquatic macrophyte biomass in the Bow River, Alberta (Culp *et al.* 1992), while in Hyalite Creek, Montana, loading from the N rich deep-water discharge of the Hyalite reservoir has stimulated periphyton productivity and biomass, and increased diatom species diversity and evenness for communities grown on artificial substrata in the creek downstream of the reservoir (Marcus 1980). This increase in primary productivity as a result of nutrient loading has, in turn, been found to increase the growth and abundance of higher trophic levels. In the Kuparuk River, Alaska Peterson *et al.* (1993b) found that the large increase in periphyton biomass due to P addition increased the growth rate of the four most abundant large insects in the enriched section of the stream. Along with the stimulation of invertebrate growth rates, growth of both young-of-the-year and adult grayling (*Thymallus arcticus*) increased.

The effect of nutrient addition on river periphyton is generally one of increasing productivity and biomass. Studies conducted in artificial streams to assess the effect of nutrient addition showed that periphyton growth in the Thompson River, British Columbia was controlled by P availability and that added P from the pulp mill at Kamloops, British Columbia was responsible for increased periphyton growth downstream of the effluent outfall (Bothwell 1985, 1988, 1989, 1992; Bothwell *et al.* 1989). Peterson *et al.* (1983, 1985) observed a 10-fold increase in both periphyton photosynthesis and biomass in response to phosphate (10 μg/L) addition to the Kuparuk River., Alaska. Johnston *et al.* (1990) also showed that fertilization of the Keogh River, British Columbia resulted in five to ten-fold increases in periphyton biomass. While many studies of periphyton response to nutrient addition have focused on changes in algal biomass, Grimm and Fisher (1986) noted that both biomass (i.e., a measure of the standing crop) and primary production (i.e., a measure of the rate of biomass accrual) should be examined as response variables of nutrient enrichment. In temperate streams that are often 'reset' by annual freshet (Fisher *et al.* 1982), increased productivity due to nutrient addition could result in the maximum biomass being reached at a different time of year. For example, in a nutrient-limited stream, periphyton biomass may be minimal before annual freshet. However, if that stream is then enriched with nutrients, increased productivity may lead to greater biomass being reached before freshet. Similarly, if maximum periphyton biomass in nutrient-limited streams is never attained in fall due to the onset of shorter day lengths, colder temperatures and ice cover, increased productivity due to nutrient addition may result in greater biomass at the onset of winter. This, in turn, could lead to a larger under-ice oxygen demand.

Some researchers have examined the effects of P addition on river bacterial communities or **biofilms** (the heterogeneous assemblages of benthic bacteria, fungi, algae, macroinvertebrates, and microinvertebrates contained within a polysaccharide matrix (Lock *et al.* 1984)). Hepinstall and Fuller (1994) reported that P addition to Bradley Brook, a second order stream located near Hamilton, New York, increased both periphyton and bacterial biomass and suggested that the bacteria were receiving both energy and nutrients from the algae. The addition of P to a woodland stream in Tennessee increased the abundance of the N-fixing algae *Nostoc* in leaf detritus, and thus increased the N content of the detritus and its consumption by detritivores (Elwood *et al.* 1981). Grimm and Fisher (1989) noted that in N-limited Sycamore Creek, Arizona, sustained high feeding rates of macroinvertebrate detritivores were possible only if bacteria increased the N content of faecal material through microbial conditioning or immobilization of N. This conditioning of faecal material before re-ingestion by detritivores appeared to be controlled by N availability. Thus, in addition to showing effects of nutrient addition on benthic bacteria, these studies also indicated that nutrient-limited responses of both bacteria and periphyton can influence the productivity of higher trophic levels.
Biofilms also contribute to nutrient cycling in rivers. This cycling involves the biological uptake

Figure 1.1 Sources of nitrogen and phosphorus to a river can be from outside the river (external sources such as precipitation, agricultural runoff or effluents) or within a river (internal sources such as release from the bottom sediments or decaying plant and animal material).

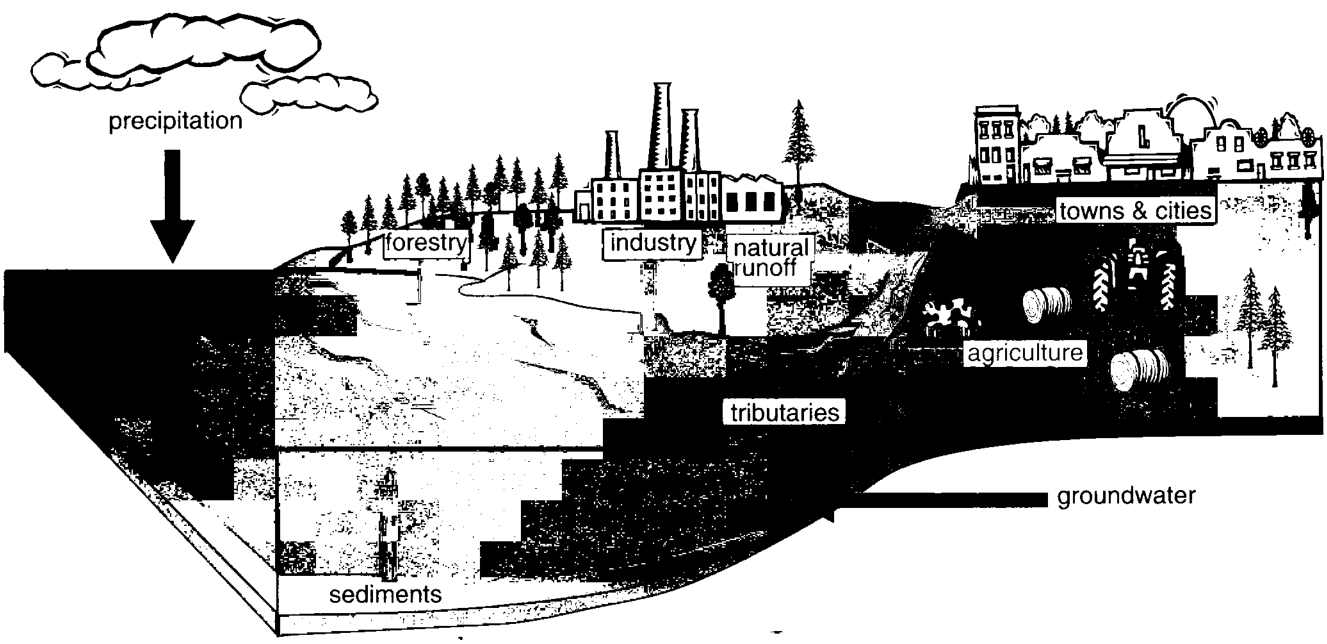
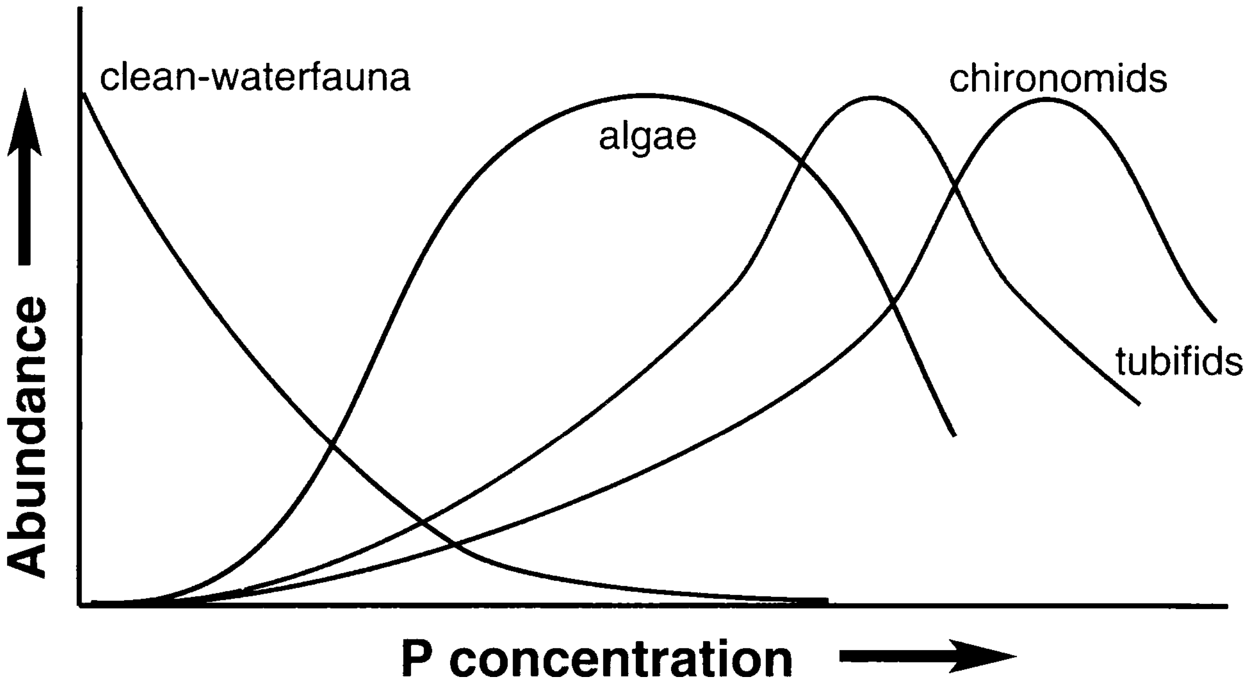


Figure 1.2 Diagrammatic presentation of the effects of phosphorus addition on water chemistry and biota in a river that is limited by the nutrient phosphorus.



of N and P during cellular processes and their release during tissue decomposition and subsequent re-uptake by organisms further downstream. This continuous uptake, release and translocation of nutrients downstream is referred to as 'nutrient spiralling' (Newbold *et al.* 1981; Paul and Duthie 1988; Mulholland *et al.* 1990). The ecological importance of nutrient spiralling is evident when considering nutrient-limited systems in which periphyton biomass often exceeds that predicted from empirical P-biomass relationships. For example, Paul and Duthie (1988) found that for the P-limited Matamek River, Quebec, the intensity at which nutrients were re-utilized was directly proportional to their degree of limitation in the periphyton (i.e., the lower the ambient nutrient concentration, the higher the rate of recycling). Further research by Paul *et al.* (1991) on two rivers of differing bioavailable P concentrations in Algonquin Park, Ontario showed that periphyton in the more P-limited river re-assimilated P more quickly. Mulholland *et al.* (1994) also found that a greater fraction of the P-demand was met by P recycling from higher biomass communities. These results indicate that P supply shifts from ambient sources in early low biomass communities to internal recycling of P in later, higher biomass communities. Bothwell (1985, 1989; Bothwell *et al.* 1989) also found that the concentrations of phosphate required to saturate peak biomass were two orders of magnitude greater than those required to saturate specific growth rates in thin periphyton communities of similar taxonomy, indicating that denser algal accumulations require higher absolute concentrations of P to saturate and maintain growth of the whole community.

Increases in periphyton productivity due to nutrient addition have, in turn, been found to affect productivity of higher trophic levels. Hart and Robinson (1990) showed that P addition to replicate flumes beside Augusta Creek, Michigan increased periphyton biomass 1.8 times and, in turn, body size, development rates, and population densities of larvae of two species of grazing caddisflies. Using stable isotope procedures, Peterson *et al.* (1993a) showed tight coupling between increased algal production due to P addition and increased growth rates of grazing insects in the Kuparuk River, Alaska. However, increased benthic invertebrate densities can, in turn, reduce periphyton biomass. Using nutrient (N, P and N+P) diffusing substrates in the Kakanui River, New Zealand, Biggs and Lowe (1994) found that increases in P increased macro-grazer production but did not increase periphyton biomass. However, removal of the grazers resulted in a 5-fold increase in chl*a* concentrations, indicating that the increased periphyton production was being assimilated by a correspondingly more productive macroinvertebrate community. Similar results have been reported by Elwood *et al.* (1981) for a woodland stream, by Winterbourn (1990) using nutrient diffusing substrata in a small mountain stream and spring in New Zealand, and by Yangdong and Lowe (1995) using nutrient diffusing substrata in a small northern Michigan stream.

The increase in periphyton and benthic invertebrate production in response to nutrient addition can, in turn, increase fish production. In British Columbia, addition of N and P to several oligotrophic coastal lakes resulted in increased algal production, larger standing stocks of zooplankton, and increased in-lake growth of juvenile sockeye salmon (*Oncorhynchus nerka*) and larger out-migrant smolts (Hyatt and Stockner 1985; Stockner and Shortreed 1985). This research on lake enrichment lead to whole-river experiments in British Columbia to determine the enhancement effects of fertilizers on salmonid production. Initial experiments by Perrin *et al.* (1987) in which grain or inorganic fertilizer was added to the Keogh River, British Columbia during spring and summer 1981 showed that N and P additions increased periphyton accrual by an order of magnitude, while grain addition (a direct food source) increased insect standing crop. Increased periphyton production by N and P addition resulted in a potentially greater benefit for growth of salmonids in the nutrient-deficient stream. Further research on the Keogh River, British Columbia during 1983-1986 showed a 5 to 10-fold increase in periphyton biomass which translated to a 1.4 to 2.0-fold increase in salmonid fry weights with whole river fertilization (Johnston *et al.* 1990). In the Bow River, Alberta, nutrients from sewage treatment plant discharges sustain an internationally known trout sport fishery in the 50 km reach downstream of Calgary (Culp *et al.* 1992). Hoyer and Canfield (1991) further showed that total fish standing crop was significantly correlated to TP concentrations ($r = 0.79$) for 79 rivers throughout North America.

To examine the long-term effects of nutrient addition on an entire aquatic ecosystem, a whole-river enrichment experiment was initiated in 1983 on a pristine Alaskan tundra river (the Kuparuk River). The study was initiated after *in situ* bioassay experiments showed that both periphyton photosynthesis and biomass increased 10-fold in response to 10 µg/L phosphate addition (Peterson *et al.* 1983; 1985). The increase in periphyton growth was also accompanied by an increase in bacterial activity in the benthic biofilm, which is consistent with the findings of others (e.g., Hepinstall and Fuller 1994) who observed increased bacterial activity and increased algal production in response to nutrient addition. Peterson *et al.* (1985) concluded that after P addition, the major source of energy in the stream became the photosynthetic carbon fixed in the stream rather than the organic material entering the stream. This conclusion is consistent with the findings of Paul and Duthie (1988) and Mulholland *et al.* (1994) who found that increased nutrients lead to increased nutrient cycling and a switch from carbon sources produced outside the stream channel to carbon fixed in the stream. In contrast, Lock *et al.* (1990) concluded that increased biofilm accrual due to P-enrichment may be due to both increased algal production and increased rates of capture and/or assimilation of organic material derived from outside the stream channel. However, further studies with stable N and carbon isotopic ratios showed a tight coupling between algal production enhanced by P addition and increases in growth of invertebrates and fish (Peterson *et al.* 1993a). This reliance on carbon sources produced within the stream channel occurred despite large inputs of peat and dissolved organic matter from the tundra which, on the basis of mass, strongly dominated the carbon cycle (Peterson *et al.* 1993b).

The large increase in periphyton biomass in the Kuparuk River following P addition was sustained for two summers but decreased in following summers (Peterson *et al.* 1983). This reduction in algal biomass after the first two summers of P addition was due to increased grazing associated with the increased growth of the four most abundant large insects in the enriched section of the stream (Peterson *et al.* 1985; Hershey *et al.* 1988; Miller *et al.* 1992). Thus, the Kuparuk system was transformed from a nutrient-limited, bottom-up control to a herbivore, top-down controlled system. Along with the stimulation of invertebrate growth rates, growth of both young-of-the-year and adult grayling (*Thymallus arcticus*) was stimulated by P-addition in years 3 and 4 of the study, with the size of 0+ fish increasing by 1.4 to 1.9-fold and a weight gain of 1.5 to 2.4-fold in adults (Deegan and Peterson 1992). Neutral lipid storage in adults also increased 1.3 to 3.4-fold in the enriched sections of the stream; however, there were no detectable differences between enriched and control zones in gonad mass, percent lipid in eggs or egg size. Shifts in stable isotopic ratios showed that the accelerated growth of both the insects and grayling was due to increased periphyton productivity (Peterson *et al.* 1993a). These results are consistent with those of others who have shown that increased primary production through nutrient enrichment can enhance fish production (Hyatt and Stockner 1985; Stockner and Shortreed 1985; Johnston *et al.* 1990). More recent studies on the Kuparuk River have shown that seven years after the start-up of P addition, a community shift has occurred from periphyton to bryophytes (mosses) as the dominant primary producers in the enriched reach (Bowden *et al.* 1994). The moss *Hygrohypnum* spp. alone appears to remove two-thirds of the P added and has become a dominant sink for P in the river. This switch was very slow to occur (seven years) and may have been facilitated by the reduction in epiphytes by grazing invertebrates (Finlay and Bowden 1994).

In summary, studies of the effects of nutrient addition on river systems have generally found that in the case of moderate enrichment (i.e., the pollutant loading is not so severe as to cause de-oxygenation), the productivity of river biota is increased, often without loss of species. Gross pollution involving de-oxygenation of the water, results in reduced productivity by periphyton, benthic invertebrates and fish, and loss of species.

1.3 ENRICHMENT RESPONSES TO PULP MILL EFFLUENT

The environmental impacts of pulp mill effluents (in particular bleached kraft mills) on the aquatic environment have been studied intensely since the 1960's and are associated with four characteristics of the effluents: (a) organic inputs, (b) colour and turbidity, (c) toxic effects, and (d) nutrient addition (see reviews by Kovacs 1986; McLeay 1987; Owens 1991; Smith and Sprague 1992; Carey *et al.* 1993; Kovacs *et al.* 1995). During the last few decades the main concerns regarding environmental impacts of pulp mill effluents on receiving waters have shifted as new technologies have been employed by the pulping industry to address the most demanding issues. During the 1960's and 1970's, the main environmental issue regarding pulp mills was the high colour, turbidity and organic content of the effluents and the associated high biological oxygen demand (BOD)(Owens 1991). With the implementation of biological oxidation systems (e.g., aerated stabilization basins and activated sludge treatment) and improved circulation of waste water in the 1960's, the threat of high BOD was greatly reduced. Wartiovaara and Heinonen (1991) noted that for Finnish mills organic matter has been reduced in pulping effluents by nearly 70% since 1972. A decrease in colour and turbidity has also been associated with the implementation of biological oxidation systems through settling. With the reduction of the colour, turbidity, and BOD problems, recent attention has focused on the toxic effects associated with pulping effluents, especially organochlorines (Heimburger *et al.* 1988; McKague *et al.* 1990; Owens 1991; Voss *et al.* 1988). However, the introduction of chlorine-dioxide substitution and the associated reduction in organochlorine production (Berry *et al.* 1989; Shimp and Owens 1993) is reducing this hazard to the environment as well. Presently, one of the last remaining environmental issues concerning pulp mill effluents is eutrophication due to the nutrient content of the effluents (Bothwell 1992).

The nutrient content in pulp mill effluent is primarily derived from the wood itself, although the addition of nutrients to biological oxidation systems for bacterial-mediated breakdown of organic material also plays an important role. The nutrient content of Finnish pulp mill effluents is normally in the range of 1-3 mg/L TP and 5-10 mg/L TN (Meloni 1991). Not all of these nutrients end up in the effluents, although approximately 100-150 g P and 400-600 g N per tonne of product are discharged into receiving waters (Meloni 1991). Moreover, the proportion of dissolved P relative to TP in pulp effluents is high, averaging 80% dissolved P, and of this approximately 80-90% is reactive P in Finnish pulp mill effluents (Priha 1994). Thus, approximately 80% of TP in activated sludge treated BKME is biologically available for algae, either immediately or after inherent degradation (Priha 1994).

Some of the early studies into the effects of pulp mill effluents showed slight eutrophication effects in receiving waters. Stockner and Cliff (1976) stated that prolific benthic algal growth at the head of Neroutos Inlet on Vancouver Island, British Columbia was likely caused by N addition from the Port Alice sulphite pulp mill. Stockner and Costella (1976) also observed greater growth of test algae in 80% mill effluent than in controls with 80% filtered sea water. However, there are problems discerning effects of nutrients in pulp mill effluents due to interference by other factors (e.g., increased turbidity and colour or increased toxicity). For instance, Stockner and Cliff (1976) noted that eutrophication caused by effluent from two kraft mills in Howe Sound, British Columbia may be a positive attribute, balancing the negative effects of light reduction and toxicity. Davis *et al.* (1988) using *in situ* ^{14}C incubation studies on the Sulphur River, Texas, showed that periphyton productivity did not decrease significantly downstream of a mill discharge but that phytoplankton productivity significantly decreased. They hypothesized that these differences were due to the ability of the periphyton community to adapt to the light limitation caused by the effluent. Amblard *et al.* (1990), using artificial streams on the Malbaie River, Quebec, showed an increase in Chlorophyceae as well as a decrease in species richness and diversity with increasing effluent concentrations, but noted the difficulty of establishing the main factor influencing the change at the level of the algal community.

Despite conflicting responses to factors associated with pulp mill effluents, other research has shown clear eutrophication effects in receiving waters. Byrd *et al.* (1986) noted that increased primary productivity and algal biomass in the Flint River, Georgia immediately downstream of a pulp mill outfall was likely caused by nutrients in the effluent. Similarly, the increase in periphyton growth in the Thompson River downstream of Kamloops, British Columbia has been attributed to nutrient addition from the pulp mill and the city sewage (Bothwell 1992 after Federal-Provincial Task Force Report 1976). Moreover, Bothwell (1992) showed from artificial stream studies that the increase in periphyton growth downstream of the Kamloops mill on the Thompson River, British Columbia and a mill on the McKenzie River, Oregon was due to nutrient addition, specifically P addition to the Thompson River and N addition to the McKenzie River. Both these studies showed that very small increases in the nutrient concentration of the receiving waters could increase algal productivity. For instance, an increase in SRP concentration of only 1 µg/L in the Thompson River could substantially increase algal growth rates while in the McKenzie River, the dissolved inorganic nitrogen in the effluent increased algal specific growth rates by two-fold during summer months, even with full dilution in the river (0.5% v/v).

1.4 OBJECTIVES OF THIS REPORT

This report presents a synthesis of results from studies on the impacts of nutrient addition on the Athabasca, Wapiti, Smoky, Peace and Slave rivers as undertaken by the NRBS and other agencies operating in the Northern River basins. The report addresses:

- the identification and regulation of point and non-point sources of nutrient loading (Chapter 2)
- changes in river chemistry in response to nutrient loading (Chapter 3)
- the contribution of anthropogenic and natural sources to nutrient loads (Chapter 4)
- the responses of the biota to nutrients as assessed *in situ* (Chapter 5)
- the effects of nutrients and contaminants on biota (Chapter 6).

The information obtained from these studies was then integrated to provide an assessment of the state of aquatic ecosystem health (Chapter 7) with respect to nutrients and develop scientific and management recommendation for the Northern River basins (Chapter 8).

CHAPTER 2.0
IDENTIFICATION AND REGULATION OF POINT AND NON-POINT SOURCES OF NUTRIENT LOADING

2.0 IDENTIFICATION AND REGULATION OF POINT AND NON POINTSOURCES OF NUTRIENT LOADING

The NRBS area encompasses the Athabasca, Peace and Slave river drainage basins that lie within Alberta and the North West Territories. The Athabasca River receives effluent from 15 continuous-discharge point sources (five pulp mills, one oil sands project and ten municipalities; one mill and one municipality have a combined discharge). The Wapiti River receives effluent from two continuous-discharge point sources (a pulp mill and a municipality) while the Smoky River receives continuous-discharge effluent from the Wapiti River sources as well as from one additional municipality. The Peace River receives effluent from five pulp mills (two in the NRBS area) and four sources of continuous-discharge sewage within the NRBS area, in addition to the sources on the Wapiti-Smoky rivers. The Slave River receives effluent from all the Peace and Athabasca sources as well as from one continuously-discharging sewage treatment plant (STP).

The purpose of this chapter is to: (1) characterize the sources of nutrient loading on each river within the NRBS area, and (2) summarize regulations, effluent permit limits and monitoring requirements with respect to nutrients. Daily discharge and weekly measurements of nutrient concentrations are collected by all pulp mills as part of their licensing requirements. These data have been compiled in the NRBS database *Northdat* (McCubbin and AGRA Earth and Environmental 1995) and summarized in McCubbin and Folke (1993). Municipalities in the Alberta and Northwest Territories portion of the NRBS area measure daily discharge but are not required to monitor nutrient concentrations. The municipal data have been compiled in the NRBS *Municipal and Non-Pulp Mill Industrial Effluents* database (Sentar Consultants Ltd. 1995c).

2.1 IDENTIFICATION OF POINT AND NON-POINT SOURCES OF NUTRIENT LOADING

2.1.1 The Athabasca River

The Athabasca River originates in the Rocky Mountains of west-central Alberta in Jasper National Park. It then flows northeast across the boreal foothills and boreal mixed-wood ecoregions of Alberta to Lake Athabasca where it joins with the Peace River to form the Slave River (Figure 2.1). The Athabasca River is not regulated. Mean daily flows at the Town of Athabasca average 407 m^3/s (1980-1993) with peak flows occurring in July after mountain snow-pack melt (1016 m^3/s July monthly mean, 1980-1993) and lowest flows in February (62m^3/s February monthly mean, 1980-1993) (Environment Canada 1994).

Concern about water quality in the Athabasca River dates from the 1950's when the first pulpmill became operational. Currently, nine municipalities discharge continuously to the AthabascaRiver or its tributaries (Table 2.1) as well as the Town of Hinton which discharges with the Weldwood of Canada Ltd. effluent.In addition, 40 municipalities and two oil sands extraction plants discharge sewage lagoons once or twice per year (fall and sometimes spring)to rivers, creeks and

Figure 2.1 The Athabasca, Peace and Slave river systems showing locations of municipal, pulp mill and industrial discharges.

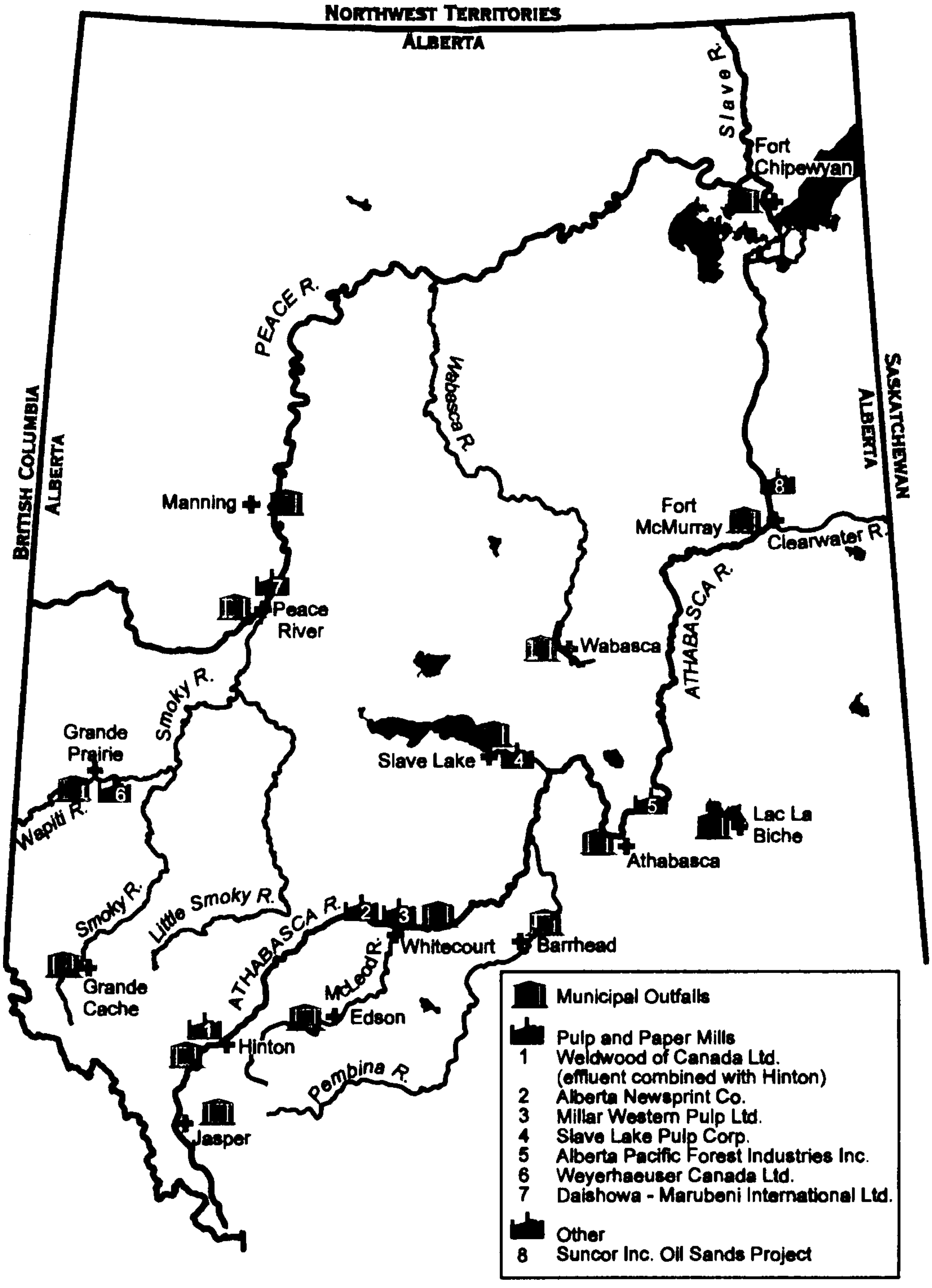


Table 2.1 **Effluent discharge and loads of total phosphorus (TP) and total nitrogen (TN) for municipalities with continuous discharge in the NRBS area. Discharge data from the NRBS *Municipal and Non-Pulp Mill Industrial Effluents Database* (Sentar Consultants Ltd. 1995c). Nutrient concentrations for all towns (except Fort Smith) from Alberta Environmental Protection winter water quality surveys (1989-1993) and database of D. Prince and S. Stanley (University of Alberta, Department of Civil Engineering). (Data detailed in Chambers and Dale (1996, Appendix B)). Nutrient concentrations were multiplied by mean discharge to give loads. Fort Smith TP data based on two measurements in 1995 (B. Collins, Water Resources Division, Government of the Northwest Territories). Note: Hinton municipal effluent is discharged with Weldwood of Canada Ltd. effluent; N/A is not available. Population data from Statistics Canada (1992).**

[redacted]	Population (in 1991)	Effluent Treatment	Receiving Water	TP (kg/d)	TN (kg/d)	Discharge (m^3/d)
Athabasca River						
Jasper	3619	aerated stabilization basin	Athabasca River	16.8	78.6	3948
Edson	7323	aerated stabilization basin	McLeod River	16.2	60.6	3954
Whitecourt	6938	extended aeration activated sludge	Athabasca River	12.4	60.7	3417
Barrhead[1]	4160	aerated stabilization basin	Paddle River	N/A	N/A	N/A
Slave Lake	5607	aerated stabilization basin	Lesser Slave River	9.4	62.1	2730
Athabasca	1965	aerated stabilization basin	Athabasca River	4.6	24.7	952
Lac La Biche	2549	aerated stabilization basin	Field Lake	5.9	32.6	1425
Fort McMurray	34706	aerated stabilization basin	Athabasca River	26.6	344	14000
Fort Chipewyan	537	facultative lagoons	Riviere des Rochers	N/A	N/A	N/A
Peace River						
Grande Cache	3842	extended aeration activated sludge	Smoky River	8.1	32.3	2032
Grande Prairie	28,271	rotating biological contactor	Wapiti River	53.3	249	10728
Peace River Correc. Inst.	N/A	oxidation ditch, disinfection	Peace River	N/A	N/A	286
Peace River	6717	anaerobic lagoon	Peace River	N/A	N/A	N/A
Manning	1139	aerated stabilization basin	Notikewin River	2.1	11.7	464
Wabasca	890	aerated stabilization basin, disinfection	North Wabasca Lake	0.2	2.9	245
Slave River						
Fort Smith	2480	facultative lagoons	Slave River	1.35	N/A	480

[1] Barrhead sewage is discharged for five months over the summer and is held back for the remaining seven months of the year.

lakes in the Athabasca drainage basin. One community (Lac la Biche) has continuous discharge of primary-treated effluent to a small lake (Field Lake) in the watershed.

In 1957, North Western Pulp and Power Ltd. (now owned by Weldwood of Canada Ltd.) commenced operations in Hinton (Table 2.2). The mill is a bleached kraft plant and up to 1966, discharged minimally-treated effluent (i.e., from a facultative settling pond). Changes in operating licenses and mill technology have reduced effluent loading from the mill. In 1967, a primary clarifier (for removing solids) and aerated lagoons (five-day retention time) were installed to provide secondary treatment, with the latter expanded in 1975. The largest change occurred in 1990 when oxygen delignification and chlorine dioxide substitution were introduced and the effluent clarifier and aerated lagoons upgraded; 100% chlorine dioxide substitution was achieved in June 1993. Between August 1988 and late 1990, three chemi-thermomechanical mills started operations in the basin (Table 2.2); another kraft mill (Alberta-Pacific Forest Industries Inc., AlPac) became operational in September 1993. TP and TN loads to the river from all mills totalled 331 and 1033 kg/d (Table 2.2). There are also two oil sands projects in the basin but only one (Suncor Inc. Oil Sands Group) with continuous discharge of utility wastewater (from settling and retention basins plus American Petroleum Institute (API) separation system for oily wastewater) (Table 2.3). Other activities in the basin include four active coal mines, 67 gas plants, another oil sands project and 12 gravel-washing enterprises; however, all have little or no discharge (Alberta Environmental Protection 1995b).

2.1.2 Wapiti-Smoky Rivers

The Wapiti River arises in the Rocky Mountains of east-central British Columbia, south of Dawson Creek (Figure 2.1). It then flows east across the boreal uplands, boreal foothills and boreal mixed-wood ecoregions of Alberta and converges with the Smoky River 42 km downstream of Grande Prairie. The Wapiti River is not regulated. Mean daily flows at Grande Prairie average 88 m^3/s (1980-1993) with peak flows occurring in June after mountain snow-pack melt (297 m^3/s June monthly mean, 1980-1993) and lowest flows in February (12 m^3/s February monthly mean, 1980-1993) (Environment Canada 1994).

The Smoky River originates in the Rocky Mountains of west-central Alberta, northwest of the Town of Jasper (Figure 2.1). It then flows northeast across the boreal uplands, boreal foothills and boreal mixed-wood ecoregions of Alberta and is joined by the Wapiti River. The Smoky River continues north and drains into the Peace River near the Town of Peace River. The Smoky River is not regulated. Mean daily flows near Watino average 315 m^3/s (1980-1993) with peak flows occurring in June after mountain snow-pack melt (921 m^3/s June monthly mean, 1980-1993) and lowest flows in February (43 m^3/s February monthly mean, 1980-1993) (Environment Canada 1994).

The only source of continuous industrial discharge on the Wapiti River is the Weyerhaeuser Canada Ltd. (formerly Procter and Gamble Cellulose Ltd.) bleached kraft pulp mill at Grande Prairie (Table 2.2). The mill began operations in 1973 and discharged effluent treated in a primary clarifier and aerated lagoons. Upgrades to the mill included a switch from 25% to 70%

Table 2.2 **Total phosphorus (TP) and total nitrogen (TN) loads from pulp mills in the Athabasca and Peace drainage basins. TP and TN loads were obtained for 1990-1993 from the Northern River Basins Study database *Northdat* (McCubbin and AGRA Earth and Environmental 1995) with the exception of TP and TN concentrations for Alberta Pacific Forest Industries Inc. which were obtained directly from AlPac (for 1994). TP and TN loads for pulp mills were corrected by substracting the estimated concentration of the influent water from the effluent concentration.**

Pulp [redacted]	Location	Type	Start Up	Effluent Treatment	TP kg/d)	TN (kg/d)
Weldwood of Canada Ltd.	Hinton	Kraft Pulp	1957, expansion in 1990	Aerated stabilization basin	79±3(203)[3]	535±15(138
Alberta Newsprint Company	Whitecourt	CTMP[4] and paper	Aug. 1990	Extended aeration, activated sludgetreatment	92±5(176)	94±14(56)
Millar Western Pulp Ltd.	Whitecourt	CTMP	Aug. 1988	Extended aeration, activated sludge treatment	34±2(213)	124±9(126)
Slave Lake Pulp Corp.	Slave Lake	CTMP	late 1990	Activated sludge treatment	54±5(207)	103±8 (40)
Alberta Pacific Forest Industries Inc.	Athabasca	Kraft Pulp	Sept. 1993	Activated sludge treatment	72±4(53)	177±20 (52)
Weyerhaeuser Canada Ltd.	Grande Prairie	Kraft Pulp	1973	Aerated stabilization basin	72±3(214)	469±26(50)
Daishowa - Marubeni International Ltd., Peace River Pulp Division	Peace River	Kraft Pulp	July 1990	Aerated stabilization basin	101±3 (252)	369±17 (137)

[2]Further description of the pulp mills is provided in McCubbin and Folke (1993).

[3]Hinton municipal sewage is combined and discharged with Weldwood effluent

[4]Chemi-thermomechanical pulp

Table 2.3 **Effluent discharge and loads of total phosphorus (TP) and total nitrogen (TN) for non-pulp mill industries with continuous discharge in the NRBS area.**

[redacted]	Start Up	Effluent Treatment	Receiving Water	TP	TN ([redacted]/d)	Discharge ([redacted]/d)	Reference (m^3/d)
Athabasca River Suncor Inc. Oil Sands Group	1967	retention basin + American Petroleum Institute (API) separation system for oily wastewater	Athabasca River	6.86	42.4	38863	Discharge from NRBS *Municipal and Non-Pulpmill Effluent Database* (Sentar Consultants Ltd. 1995c) and TP and TN concentrations from Alberta Environment winter water quality surveys (1988-1994)
Alberta Power Ltd. H.R. Milner station	N/A	process wastewater	Smoky River	0.18	1.04 (TKN)	1469	Discharge from Shaw *et al.* (1990) after Nagendran *et al.* (1989) and TP and TKN concentrations from Sentar Consultants Ltd. (1994b).
Peace River Oils #1	1916[5]	flowing well (TKN)	Peace River	0.03	102	3456 (May88-Mar89; n=4)	Alberta Environment (1989)

[1]Peace River Oils #1 abandoned in the mid-1950's (Alberta Environment 1989).

chlorine dioxide substitution in fall 1990 and then to 100% substitution in July 1992. In addition to the pulp mill, there are two municipalities with continuous discharge to the basin: Grande Prairie to the Wapiti River (the town discharges for a two week period followed by a two week hold-back) and Grande Cache to the Smoky River (Table 2.1). There are also 28 other communities in the Wapiti-Smoky drainage basin which discharge sewage lagoons once or twice yearly to the rivers and their tributaries. The Alberta Power Ltd. H.R. Milner thermal electric power station near Grande Cache discharges process wastewater to the Smoky River (Table 2.3). There are also 20 natural gas processing plants in the Wapiti-Smoky drainage (Alberta Environmental Protection 1995b).

2.1.3 Peace River Mainstem

The Peace River originates in northeastern British Columbia, flows through Williston Reservoir and the Bennett Dam, and enters Alberta west of the Town of Peace River. From there, the river flows northeasterly across Alberta and drains into the Slave River north of Fort Chipewyan (Figure 2.1). Mean daily flows at Peace Point average 2090 m^3/s (1970-1993) with peak flows occurring in June (3608 m^3/s June monthly mean, 1970-1993) and lowest monthly flows in March (1426 m^3/s March monthly mean, 1970-1993) (Environment Canada 1994). Flows are maintained at high levels during winter (1531 m^3/s November-March, 1970-1993) for power generation.

The entire Peace River basin is sparsely populated and largely undeveloped. In addition to Grande Prairie and Grande Cache on the Wapiti-Smoky rivers, the other sources of continuous sewage discharge within the NRBS area are the Town of Peace River and Peace River Correctional Institute (which discharge to the Peace River), Manning (which discharges to the Notikewin River) and Wabasca (which discharges to North Wabasca Lake) (Table 2.1). As well, there are 29 other small communities which discharge sewage periodically (fall and sometimes spring) to rivers, creeks and lakes in the Peace River drainage basin (Alberta Environmental Protection 1995b). The sources of industrial wastewater to the Alberta portion of the Peace River are Daishowa - Marubeni International Ltd.'s Peace River Pulp Division mill, the Weyerhaeuser Canada Ltd. pulp mill in Grande Prairie, and the Alberta Power Ltd. H.R. Milner station near Grande Cache (Tables 2.2 and 2.3). The Daishowa mill is a bleached kraft mill. It began operations in July 1990 and discharges effluent treated in aerated stabilization basins to the Peace River approximately 19 km downstream of the Town of Peace River. In addition, water from flowing abandoned oil wells may affect surface water quality. Alberta Environment (1989) noted that discharge from Peace River Oils #1 adversely affected water quality (notably salinity) in the mainstem of the Peace River, immediately downstream of the outflow. Agriculture is also a major economic activity in the Peace River basin particularly around Grande Prairie, Valleyview, High Prairie, Fairview, the Town of Peace River and, to a lesser extent, in the High Level-Fort Vermilion district (PRRPC 1982). There are also 40 natural gas processing plants in the Peace drainage (Alberta Environmental Protection 1995b).

2.1.4 Slave River

The Slave River originates in northeastern Alberta from the confluence of the Peace and Athabasca Rivers (Figure 2.1). It flows northwest approximately 340 km where it drains into Great Slave Lake. The Slave River is not regulated although its major tributary, the Peace River, is regulated. The Slave River basin is scarcely populated. The only source of continuous discharge to the river is the Town of Fort Smith in the Northwest Territories (Table 2.1).

2.2 REGULATION OF NUTRIENTS IN INDUSTRIAL AND MUNICIPAL EFFLUENTS

2.2.1 Ambient Waters

As part of the NRBS, regulatory requirements for nutrient effluent discharges have been reviewed for jurisdictions throughout the world (Sentar Consultants Ltd. 1994a). Nutrients are considered more difficult to regulate than other water quality variables since an increase in either P or N can have a beneficial impact, a negative impact or no impact depending upon the factor(s) limiting aquatic plant growth in the river and the use of the receiving water. Moreover, water uses may conflict in their nutrient requirements. Thus, coastal streams in British Columbia are routinely fertilized to enhance periphyton growth and increase salmon production while some would argue that the systems should remain natural.

Currently the *Canadian Water Quality Guidelines* (CCREM 1987) do not contain a guideline for nutrients as related to eutrophication. The *Canadian Water Quality Guidelines* for ammonia is based on toxicity of un-ionized ammonia for freshwater organisms and depends upon pH and temperature such that the guideline for total ammonia is 1.53 mg/L for conditions typical of the Athabasca River in winter (0^{o}C and pH of 8) and 1.33 mg/L for summer conditions (15^{o}C and pH of 8). The *Canadian Water Quality Guideline* for nitrite is also based on toxicity to freshwater organisms and recommends concentrations not exceed 0.06 mg/L. There is not a numeric guideline for nitrate but excessive concentrations are to be avoided as they may cause prolific weed growth. A draft guideline for nutrients as related to eutrophication is currently being developed and it will likely emphasize nutrient effects, namely a numerical limit for periphyton biomass, rather than nutrient concentrations.

The *Guidelines for Canadian Recreational Water Quality* (Health and Welfare Canada 1992) recommend that a bathing area be as free as possible from nuisance organisms that could affect swimmers; however, they also point out that it is impossible to have natural areas free from nuisance organisms. Regarding aesthetics, the guidelines state that "all water should be free from substances attributable to wastewater or other discharges in the amounts that would interfere with the existence of life forms for aesthetic value".

The *Alberta Environmental Protection and Enhancement Act* provides for the development of guidelines and ambient environmental quality objectives for Alberta. Prior to the Environmental Protection and Enhancement Act, the *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) were established with the aim of protecting the most sensitive water use. Possible uses include raw water supply for treated drinking water, propagation of fish and other aquatic life, contact and non-contact recreational activities, and agriculture. The *Alberta Surface Water Quality Objectives* are also used to set wastewater emission standards so as to protect receiving waterbodies. With the establishment of the *Environmental Protection and Enhancement Act* in 1993, all *Alberta Surface Water Quality Objectives* were carried forward under the new Act. The *Alberta Surface Water Quality Objectives* for TP and TN are 0.05 mg/L TP (as P) and 1.0 mg/L TN (as N). There are no *Alberta Surface Water Quality Objectives* for TDP, SRP, nitrate, nitrite, or ammonium. It should be noted that the *Alberta Surface Water Quality Objectives*: (1) "apply to surface water except in areas of close proximity to outfalls", (2) do not apply "where the natural water quality of a lake or river does not meet some of the suggested limits", and (3) are not legal statutes (only limits as given in effluent discharge licenses are recognized as enforceable environmental control laws by the provincial government). Moreover, while the *Alberta Surface Water Quality Objectives* are provincial in scope, reach-specific guidelines are also set on a case-by-case basis from an assessment of instream flow needs.

The government of the Northwest Territories has narrative objectives for nutrients. In receiving waters, nutrients must be sufficiently low to prevent nuisance conditions. In rivers and streams, this is interpreted as massive growths of attached green algae, filamentous diatoms and/or rooted aquatic plants, slime-forming bacteria, sludge worms or chironomids. Specific numeric guidelines exist for P concentrations in streams, rivers or estuaries where the dilution factor ranges between 10:1 and 100:1 (river water:effluent on a volumetric basis).

Guidelines/objectives for N and P vary widely throughout the world. In the U.S.A., the Environmental Protection Agency does not provide guidelines/objectives for P with respect to eutrophication. A Task Force recently assembled to examine eutrophication issues will be examining nutrient effects, rather than P criteria, for control of eutrophication. In Europe, P guidelines are 0.07 mg/L TP for salmonid waters (including salmon, trout, grayling and whitefish) and 0.13 mg/L TP for cyprinid waters (including cyprinids, pike, perch and eel). The U.S.A. and European guidelines for N address toxicity not eutrophication.

2.2.2 Effluent Permit Limits and Monitoring Requirements

The federal Department of Fisheries and Oceans Canada is responsible for the *Pulp and Paper Effluent Regulations* under the *Fisheries Act*. The regulations allow pulp mills to release "deleterious substances" to waterbodies if the quantity does not exceed the maximums specified in the regulations. Monitoring of nutrients is not required under the regulations directly, but the regulations do require environmental effects monitoring (EEM) studies. The requirements for

EEM are defined by Environment Canada and Department of Fisheries and Oceans (1992). They include monitoring for nutrients, specifically ammonia, nitrate+nitrite, total Kjeldahl nitrogen and total phosphorus in effluent and receiving waters.

In Alberta, all pulp mills must monitor nutrients (usually once per week on grab samples of effluent before it enters the receiving waterbody) as a licence requirement. With respect to nutrients, the parameters include ammonia, nitrate, nitrite, total Kjeldahl nitrogen, TDP and TP. At present, the concentrations of P or N (as nutrients) in pulp mill effluents are not limited by licence or regulation. However, all licenses contain a clause in which the Director, Standards and Approvals Division, Alberta Environmental Protection reserves the right to add or delete parameters in the Table of Effluent Limits. All pulp mills have also been advised that effluent limits for nutrients are a distinct possibility. Other industries in the Northern River basins that have monitoring requirements and/or permit limits for nutrients are the Athabasca River Suncor Inc. Oil Sands Group (weekly monitoring of ammonia at the outfall weir with a permit limit of 25 kg/d monthly average and 70 kg/d maximum daily), the H.R. Milner Thermal Electric Generating Station (TP limitation of 2 mg/L P and 6 kg/d monthly average or 12 kg/d daily maximum with composite samples for weekly TP and monthly TN monitoring), all coal processing facilities (monthly nitrite and nitrate and annual nutrient monitoring; no permit limits), and all gas processing plants (measurement of ammonia prior to and during pond discharge periods; 5 mg/L NH_4 as N limit).

The Northwest Territories has no general regulations that pertain to nutrients in industrial effluents. Fort Smith discharges sewage continuously to the Slave River from a three celled lagoon. There are no permit limits or monitoring requirements for nutrients.

Currently, P or N (as nutrients) in pulp mill effluents are not limited by license or regulation anywhere in Canada. However, a technology-based loading limit for TP in pulp and paper mill effluent began in Ontario at the end of 1995. Daily loading limits have been calculated for each mill based on an effluent concentration of 2 mg/L TP which, in turn, translates into 280 g/t TP for sulphate (kraft) and sulphite-mechanical mills and 163 g/t TP for corrugating, de-inking, board, fine papers and tissue mills.

In the U.S.A., the Environmental Protection Agency recently released new technology-based effluent guidelines for pulp and paper mills, but these do not limit nutrients. However, some states have added nutrient limits to pulp mill permits to address site-specific water quality concerns. Finland has a national technology-based P loading target for pulp mills of 60 g/t which is reduced to 40-50 g P/t for new mills with biologically-treated effluent.

With respect to sewage discharge, municipalities within the Alberta portion of the NRBS area have neither a monitoring requirement nor a nutrient limit. However, in the event of an sewage treatment plant expansion or upgrade, all municipalities with projected design wastewater flows > 20,000 m^3/d must reduce effluent TP concentrations to < 1.0 mg/L. The need for ammonium and/or TN restrictions on municipal discharges in Alberta are assessed on a site-specific basis.

In the Northwest Territories, Fort Smith discharges sewage to the Slave River; it is not required to monitor N and P (although TP, NH_4 and NO_2+NO_3 concentrations in the effluent are generally monitored twice yearly) and there are no permit limits.

Limits for P are more common in municipal sewage treatment plant effluent permits than industrial permits. In Canada, the municipal sewage limit is often 1 mg/L TP. This appears to be a technology-based limit since tertiary treatment plants can usually achieve P removal to less than 1 mg/L. Application of this limit is usually water-quality based such that it is applied based on assessment of the receiving water and the magnitude of the effluent impact.

CHAPTER 3.0
INSTREAM CHEMISTRY

3.0 INSTREAM CHEMISTRY

The purpose of this chapter is to review longitudinal changes in N and P concentrations in the Athabasca River, Wapiti-Smoky rivers, mainstem of the Peace River, and the Slave River in relation to pulp mill and municipal loadings. Longitudinal changes in N and P concentrations in the Athabasca River were examined by Clayton (1972) for the period 1966-1971, Hamilton *et al.* (1985) for 1970-1985, Anderson (1989) for spring 1984, fall 1985 and winter 1986, and Noton (Noton and Shaw 1989; Noton and Saffran 1995) for winter low flow periods of 1989-1993. Longitudinal changes in nutrient concentrations were also examined in the Wapiti-Smoky (Noton 1992 for the 1987-1991 winters; Noton *et al.* 1989 for 1983) and Peace (Shaw and Noton 1989; Shaw *et al.* 1990) rivers. In addition, Sentar Consultants Ltd. (1994b) summarized data up to 1993 on longitudinal changes, temporal patterns and point sources of nutrient loading while Chambers and Dale (1996), examined longitudinal changes in TP and TN concentrations in the Athabasca and Smoky Rivers during periods of low (December-April) and high (May-November) flow and assessed the relative contribution of anthropogenic point sources to the nutrient load in the rivers.

3.1 LONG-TERM DATA

Analysis of long-term (1980-1993) median values of TP and TN from 10 sites showed that nutrient concentrations varied along the length of the Athabasca River with TP and TN concentrations lowest in Jasper National Park and increasing from downstream of Jasper to downstream of Hinton (Figure 3.1) (Chambers and Dale 1996). On an annual basis, there was little change in median annual TP and TN concentrations from upstream (at Athabasca Falls) to downstream (below Snaring River) of Jasper (from 0.006 to 0.010 mg/L TP and 0.113 to 0.120 mg/L TN), despite loads of 17 and 79 kg/d TP and TN, respectively, from the Jasper sewage system. Concentrations of TN and TP doubled between the Snaring River and upstream of Hinton sites although there were no point-sources of nutrient loading in this reach. Nutrient loads from the combined Weldwood of Canada Ltd. and Town of Hinton outfall (79 and 535 kg/d TP and TN, respectively) caused a 33 and 58 % increase in TP and TN concentrations, respectively, from upstream of Hinton to 37 km downstream (Obed Coal bridge). Thereafter, TN concentrations increased steadily along the river to Fort McMurray. In contrast, TP concentrations returned to background levels by 170 km downstream of Hinton, increased downstream of Whitecourt in response to the 138 kg/d load from the Alberta Newsprint Co., Millar Western Pulp Ltd. and the Town of Whitecourt, and then remained relatively constant along the remainder of the river. Of the 721 TP measurements from Athabasca River between 1980-93, 146 measurements or 20% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) guideline for TP of 0.05 mg/L P (Table 3.1). The majority of these exceedances (79%) occurred during the higher-flow period between May and November with only 21% between the lower-flow period of December-April. The fact that fewer exceedances occurred during low flows when effluent dilution would be lowest, that most exceedances occurred at or below the Town of Athabasca (where, for these pre-1993 data, there were no pulp mills) and that the percent of exceedances is similar upstream and downstream of Hinton suggests that effluent inputs are not the major cause of TP exceedances. TP exceedances are likely due to transport of particulate

Figure 3.1 Total nitrogen (TN) and total phosphorus (TP) concentrations (median, 25th and 75th percentiles) in the Athabasca River, Alberta in relation to distance downstream of the uppermost site (i.e., 2 km upstream of the confluence with the Sunwapta River) (Chambers and Dale 1996). (Data from Table 3.1)

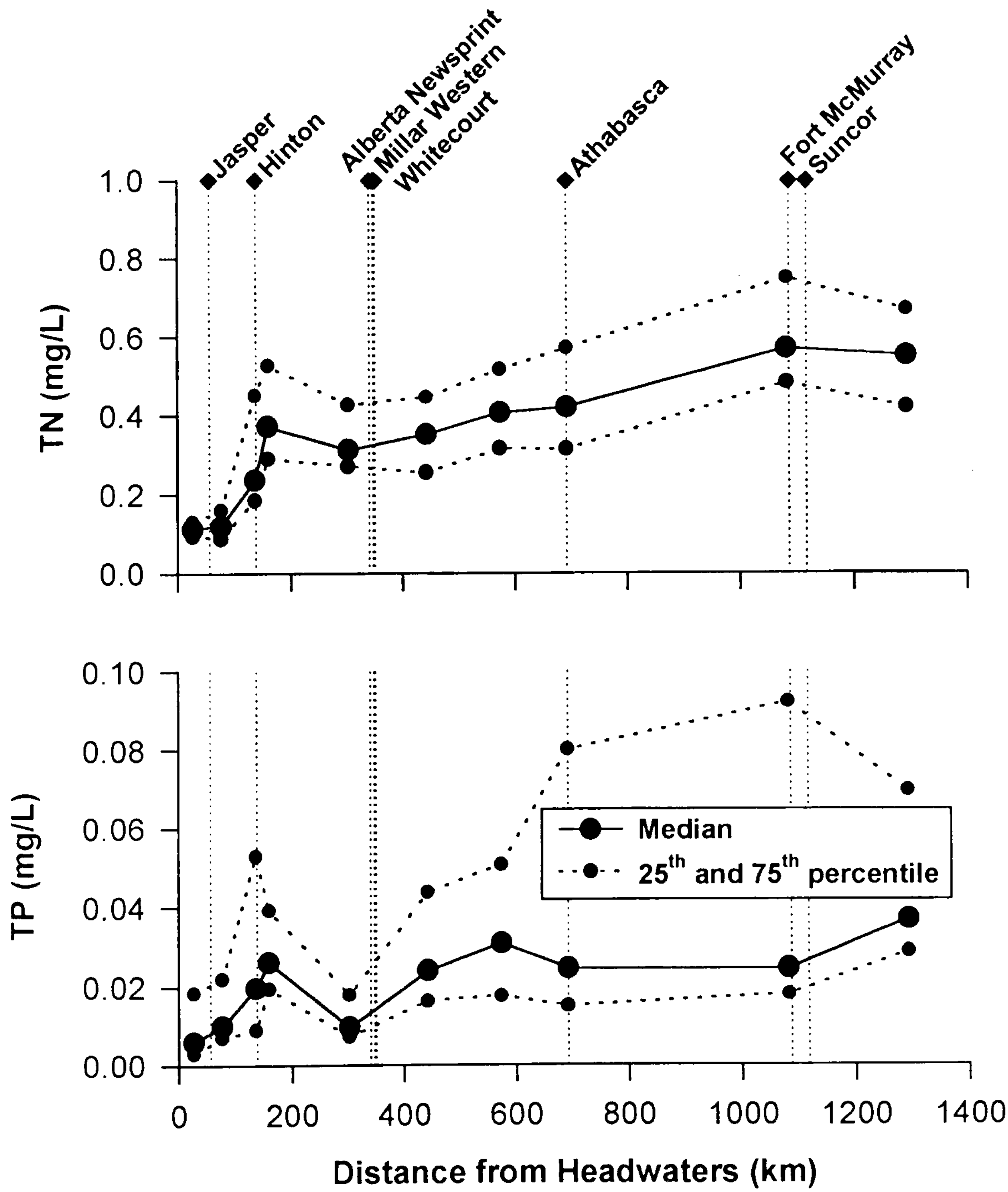


Table 3.1 **Summary statistics for total nitrogen (TN) and total phosphorus (TP) concentrations from longer-term monitoring sites on the Athabasca, Wapiti and Smoky rivers and number of values exceeding the *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) of 0.05 mg/L TP as P and 1.0 mg/L TN as N.**

[redacted]	Years	TN (mg/L)				#	TP (mg/L)				#
		Median	Max	Min	n	exceedances	Median	Max	Min	n	exceedances
Athabasca below Snaring R.	1980-93	0.12	0.42	0.055	165	0	0.01	0.256	0.002	166	14
Athabasca u/s of Hinton	1989-93	0.236	0.99	0.122	22	0	0.0197	0.25	0.0049	24	6
Athabasca @ Obed Coal Br.	1989-93	0.373	1.384	0.184	29	1	0.0262	0.323	0.007	30	6
Athabasca @ Windfall Br.	1991-93	0.3125	0.61	0.145	18	0	0.0097	0.312	0.005	19	1
Athabasca near Ft. Assiniboine	1989-93	0.353	0.686	0.164	25	0	0.024	0.405	0.007	32	7
Athabasca @ Hwy. 2 Br.	1991-93	0.4075	0.964	0.1	30	0	0.0308	0.114	0.009	33	8
Athabasca @ Athabasca	1980-93 (TP) 1987-93 (TN)	0.422	1.444	0.183	71	5	0.0245	0.682	0.004	163	56
Athabasca 0.1 km u/s Horse R.	1989-92	0.571	1.124	0.203	27	3	0.0244	0.304	0.01	32	11
Athabasca @ Old Fort	1988-92	0.553	1.295	0.09	39	3	0.0368	0.332	0.004	56	19
Smoky R. @ Watino	1980-92 (TP) 1987-92 (TN)	0.48	2.134	0.124	53	7	0.0415	1.05	0.0053	150	67
Wapiti R. @ Hwy. 40	1991-93	0.289	0.69	0.141	21	0	0.0098	0.138	0.0028	25	3
Wapiti R. @ mouth	1991-93	0.7465	1.454	0.049	26	5	0.0689	0.21	0.0222	27	20

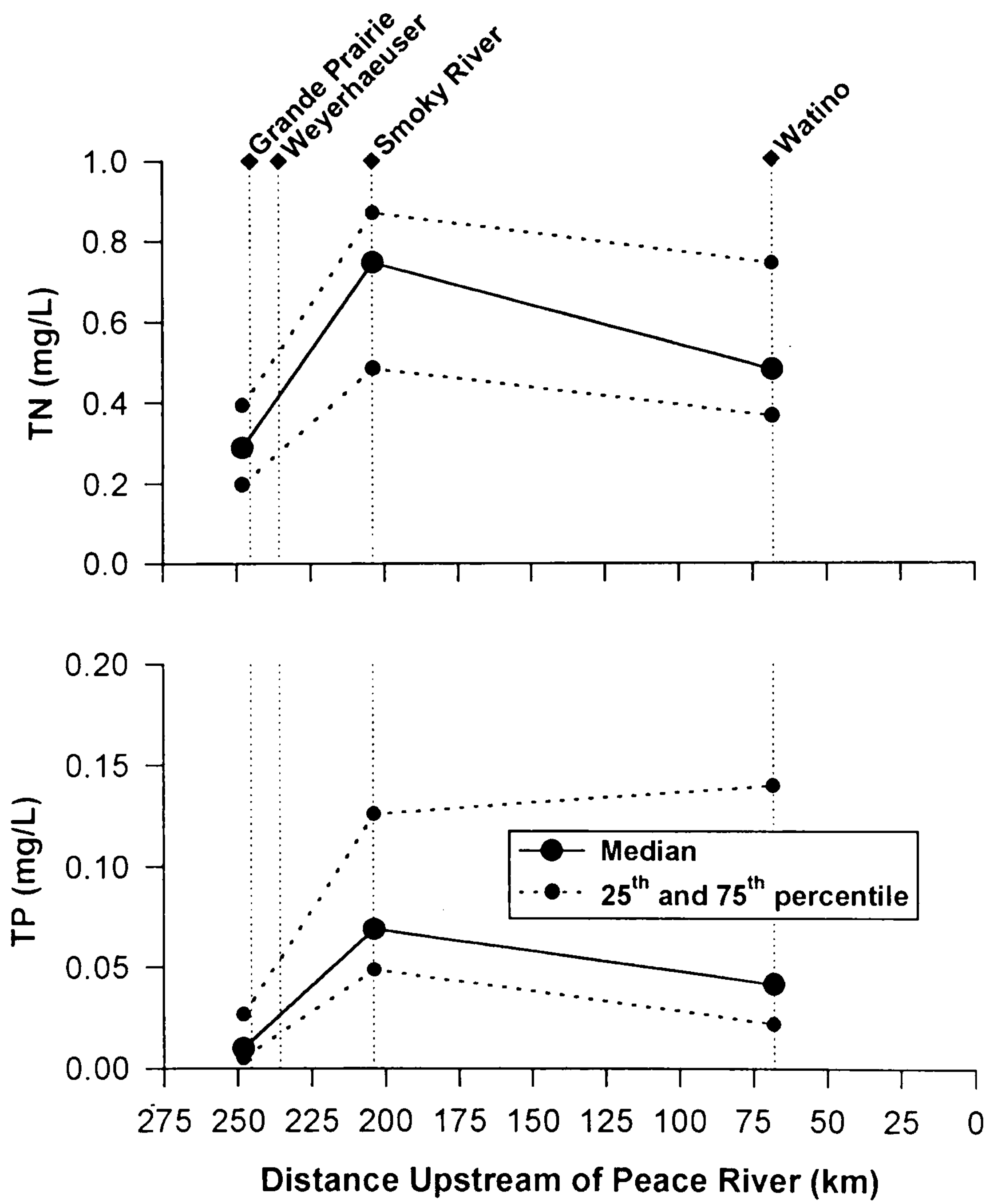
P during periods of high discharge. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by only 2% of the samples (Table 3.1). In contrast to the Athabasca River, there are only three long-term monitoring sites on the Wapiti-Smoky system. Analysis of these data showed that, on an annual basis, TN and TP concentrations increased along the Wapiti River from upstream of Grande Prairie to the river mouth; concentrations were lower in the Smoky River at Watino than at the mouth of the Wapiti River (Figure 3.2). Of the 202 TP measurements for the Wapiti-Smoky system, 90 measurements or 45% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TP of 0.05 mg/L P, with the site of greatest number of exceedance being the Wapiti River at the mouth (Table 3.1). The fact that the percent exceedances increased from 12 to 74% from upstream of Grande Prairie to the mouth of the Wapiti River indicates that P from the City of Grande Prairie and Weyerhaeuser of Canada Ltd. effluents contributed to non-compliance with the TP objective. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by 12% of the samples and the observation that all samples from upstream of Grande Prairie were below the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN while 5 of 26 samples from the Wapiti River at the mouth exceeded the objective indicates, again that the Grande Prairie pulp mill and, to a lesser extent, sewage discharge contribute to exceedances.

Longitudinal patterns in long-term data have not been examined for the Peace and Slave Rivers. In the case of the Slave River, there is only one site with long-term data (the Slave River at Fitzgerald, the joint federal/provincial/territorial site at the Alberta-Northwest Territories border which has been monitored since the 1970's). Long-term sampling has been undertaken at three sites on the mainstem of the Peace River: British Columbia/Alberta border (by Environment Canada and British Columbia since 1980's), Dunvegan (by Environment Canada since 1960's) and Fort Vermilion (by Alberta Environment since 1980's). While the Dunvegan data has been examined for changes over time (Shaw *et al.* 1990), longitudinal changes have not been examined for the long-term data from the Peace River.

3.2 SEASONAL VARIATION

While examination of long-term nutrient data shows general patterns of changing concentrations with river distance, interpretation of the effects of anthropogenic point-sources on water chemistry is limited due to variability introduced by averaging values collected over many years and all seasons and the fact that for most sites, long-term data are only available for TP and TN. Winter water quality surveys have been undertaken by Alberta Environmental Protection during February-March 1988-1995 for the Athabasca River (Noton and Shaw 1989; Noton and Saffran 1995) and February-March 1989-1991 for the Wapiti-Smoky system (Noton 1992). These surveys sampled approximately 30-90 mainstem, tributary and effluent stations on the Athabasca River and approximately 16-25 similar stations on the Wapiti-Smoky rivers. In addition, nutrient concentrations were measured at 28 sites in the Athabasca River and five sites in the Wapiti-Smoky rivers during fall 1993 as part of an NRBS study (Scrimgeour and Chambers 1996) while all the pulp mills have also collected data on river nutrient concentrations as part of their licenses to operate.

Figure 3.2 **Total nitrogen (TN) and total phosphorus (TP) concentrations (median, 25th and 75th percentiles) in the Wapiti-Smoky rivers, Alberta in relation to distance upstream of the Peace River confluence (Chambers and Dale 1996). (Data from Table 3.1)**



For the Athabasca River during winter, TP and TDP concentrations typically increase downstream of Hinton due to loading from the Town of Hinton and Weldwood of Canada Ltd. pulp mill, return to background levels within another 150 km downstream, and then increase upstream of Whitecourt as a result of effluent loading for the Alberta Newsprint Co. (Noton and Shaw 1989; Noton and Saffran 1995) (Figure 3.3). Effluent loading from Millar Western Pulp Ltd. increased P concentrations downstream of Whitecourt in its start-up year (1989) but, thereafter, caused little change in downstream P concentrations. P concentrations typically increase slightly between Smith and Athabasca, particularly since 1991 when Slave Lake Pulp Corp. started operating. P concentrations also increase at Fort McMurray due to inputs from the Clearwater River.

Nitrogen measurements from the Alberta winter water quality surveys for the Athabasca River showed that $NO_2 + NO_3$ concentrations tend to increase with distance downstream, from 0.11 mg/L upstream of Hinton to maximum values of 0.15 to 0.2 mg/L downstream of Fort McMurray (Noton and Shaw 1989; Noton and Saffran 1995) (Figure 3.4). While some point-sources have high $NO_2 + NO_3$ concentrations (e.g., Whitecourt STP), most of the increase in $NO_2 + NO_3$ concentrations in the Athabasca River is due to tributary inputs, in particular the McLeod and Clearwater Rivers. Ammonium concentrations in the Athabasca River during winter usually range from 0.01 to 0.13 mg/L and are highest downstream of municipal outfalls (Hinton, Whitecourt and Fort McMurray) due to sewage inputs and loading from the McLeod and Clearwater Rivers. Total N concentrations during winter usually range from 0.1 to 0.6 mg/L and increase as a result of inputs from the Hinton combined effluent, Millar Western Pulp Ltd., McLeod River, Lesser Slave River and Clearwater River.

In addition to the winter surveys conducted by Alberta Environmental Protection, seasonal data on water quality in the Athabasca River have been collected as part of provincial, industrial and NRBS programs. For example, nutrient data collected as part of an NRBS study in fall 1994 showed elevated P and/or N concentrations downstream of Jasper, Hinton, Whitecourt and Fort McMurray (Scrimgeour and Chambers 1996) (Figure 3.5). Likewise, surveys conducted on behalf of Alberta Newsprint Co. and Millar Western Pulp Ltd. showed increases in TP concentrations downstream of each of these mills (Sentar Consultants Ltd. 1992a, 1993c, 1995b).

For the Wapiti-Smoky rivers, winter water quality surveys have shown that TP and TN concentrations range from 0.003-0.009 and 0.096- 0.289 mg/L, respectively, upstream of Grande Prairie compared to 0.91-0.224 and 0.590-1.6 mg/L, respectively, downstream (Noton 1992). This large increase in TP and TN is due to effluent loading from both the Grande Prairie STP and Weyerhaeuser Canada Ltd. pulp mill (Figures 3.6 and 3.7). These higher nutrient concentrations in the Wapiti River as a result of effluent inputs also elevated N and P concentrations in the Smoky River. Fall water quality surveys undertaken in October 1990 on behalf of Procter and Gamble Cellulose Ltd. (Terrestrial and Aquatic Environmental Managers Ltd. 1991b) and October 1994 by NRBS (Scrimgeour and Chambers 1996) also showed a slight increase in SRP below the STP outfall and large increases in TP and SRP downstream of the mill outfall (Figure 3.8). An April 1991 survey undertaken on behalf of Procter and Gamble Cellulose Ltd. (Terrestrial and Aquatic Environmental Managers Ltd. 1991b) also showed increases in TP and TKN downstream of both the Grande Prairie STP and mill with the increase in TP being larger below the STP.

Figure 3.3 Total phosphorus (TP) and total dissolved phosphorus (TDP) concentrations in the Athabasca River during winter 1993 in relation to distance downstream of the uppermost site (i.e., 2 km upstream of the confluence with the Sunwapta River) (Noton and Saffran 1995).

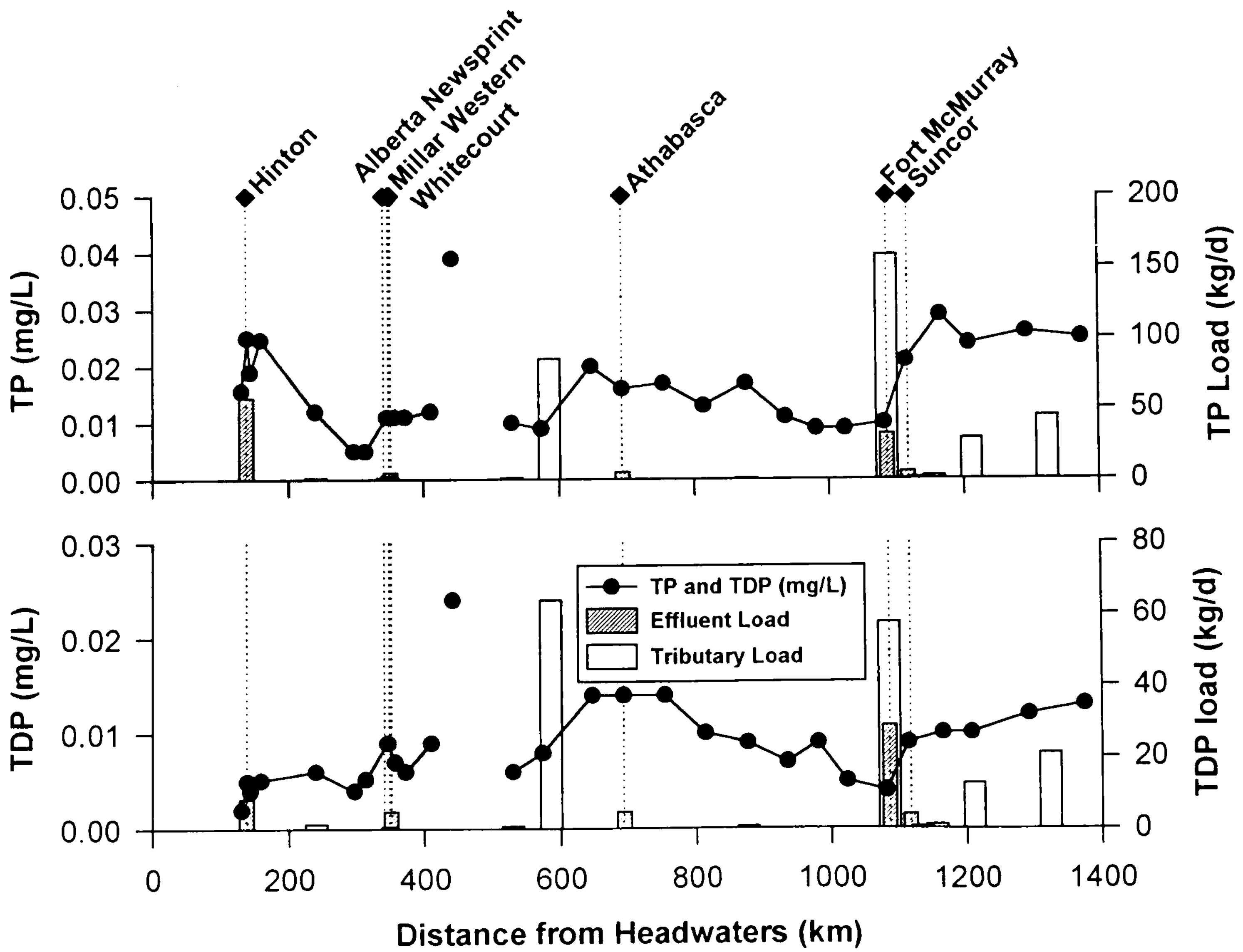


Figure 3.4 Nitrate + nitrite (NO_2+NO_3), ammonium (NH_4) and total nitrogen (TN) concentrations in the Athabasca River during winter 1993 in relation to distance downstream of the uppermost site (i.e., 2 km upstream of the confluence with the Sunwapta River) (Noton and Saffran 1995).

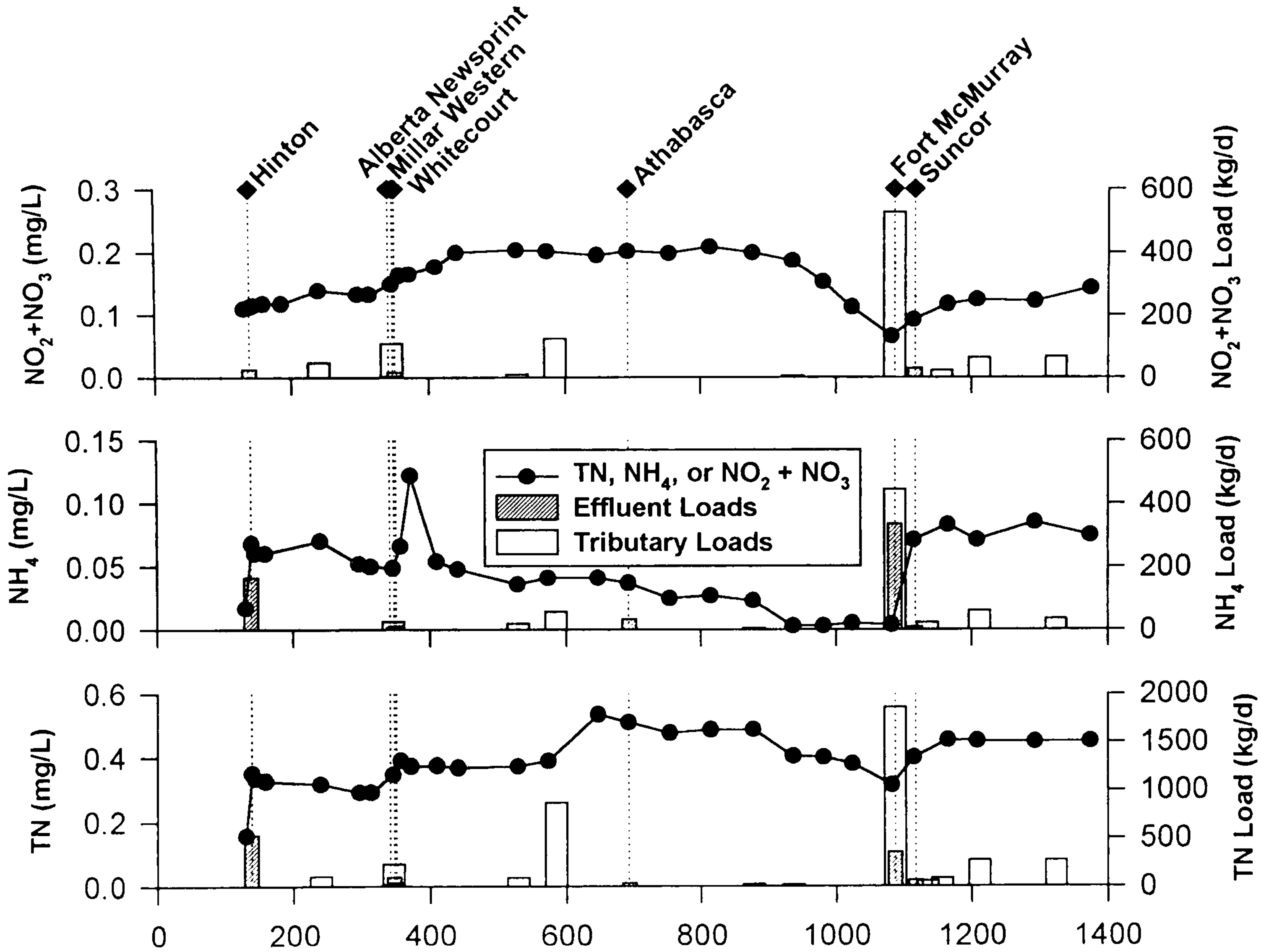


Figure 3.5 Total phosphorus (TP) and total dissolved nitrogen (TDN) concentrations in the Athabasca River from fall 1994 in relation to distance downstream of the uppermost site (after Scrimgeour and Chambers 1996) (i.e., 2 km upstream of the confluence with the Sunwapta River). Note changes in scale of Y-axis between reaches.

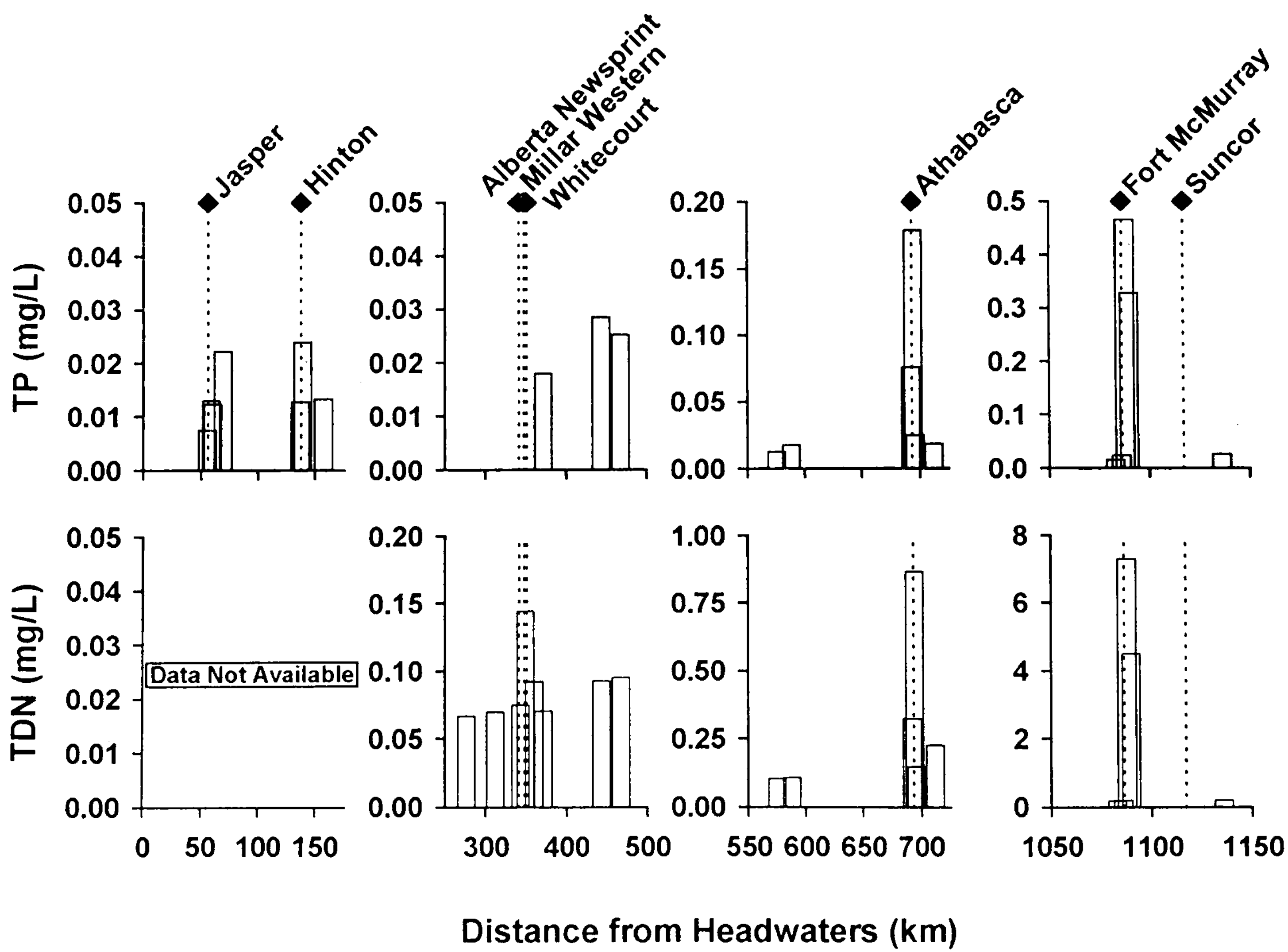


Figure 3.6 Total phosphorus (TP) and total dissolved phosphorus (TDP) concentrations in the Wapiti-Smoky rivers, Alberta during winter 1991 in relation to distance upstream of the Peace River confluence (Noton 1992).

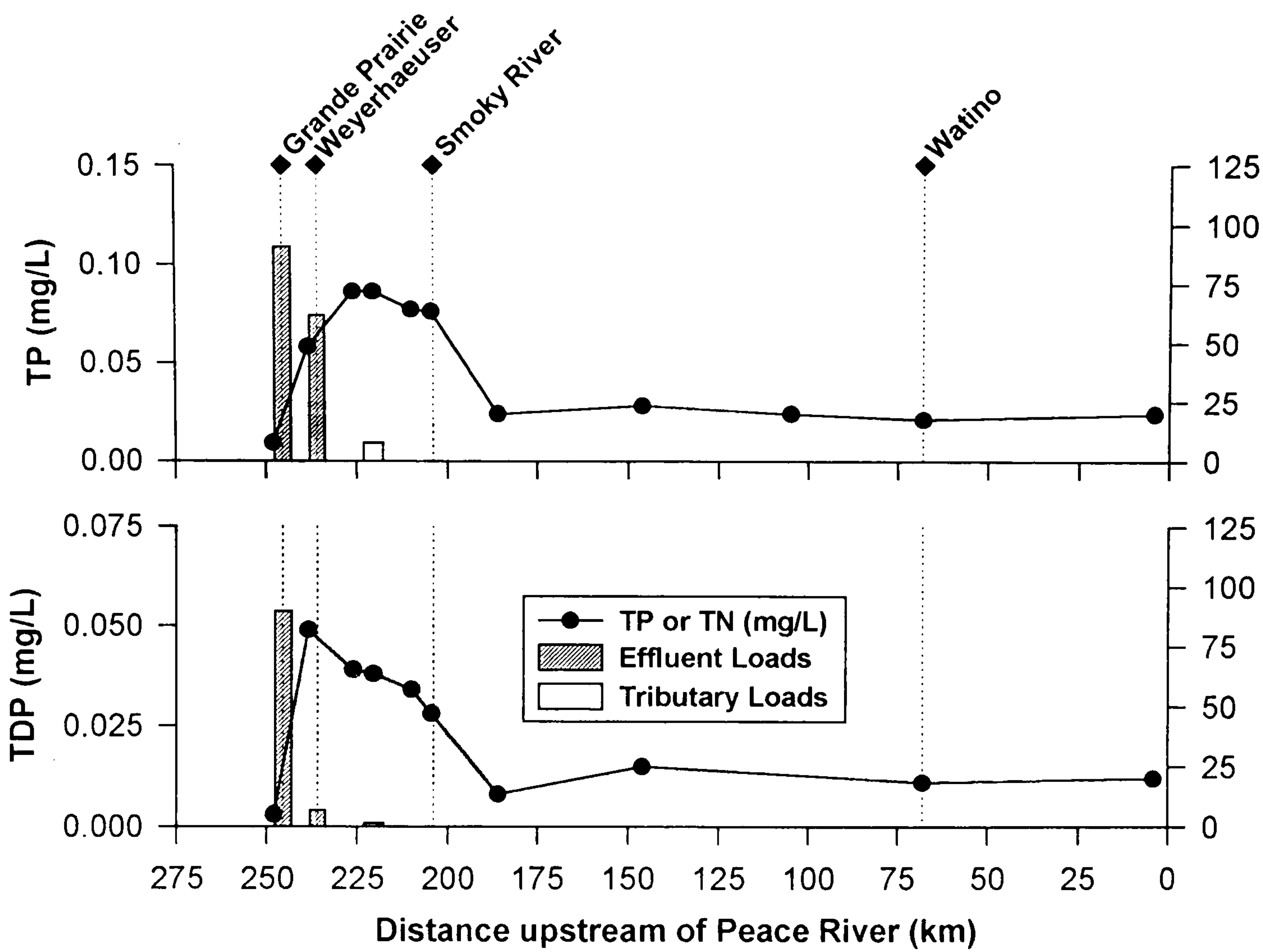


Figure 3.7 Nitrate + nitrite (NO_2+NO_3), ammonium (NH_4) and total nitrogen (TN) concentrations in the Wapiti-Smoky rivers, Alberta during winter 1991 in relation to distance upstream of the Peace River confluence (Noton 1992).

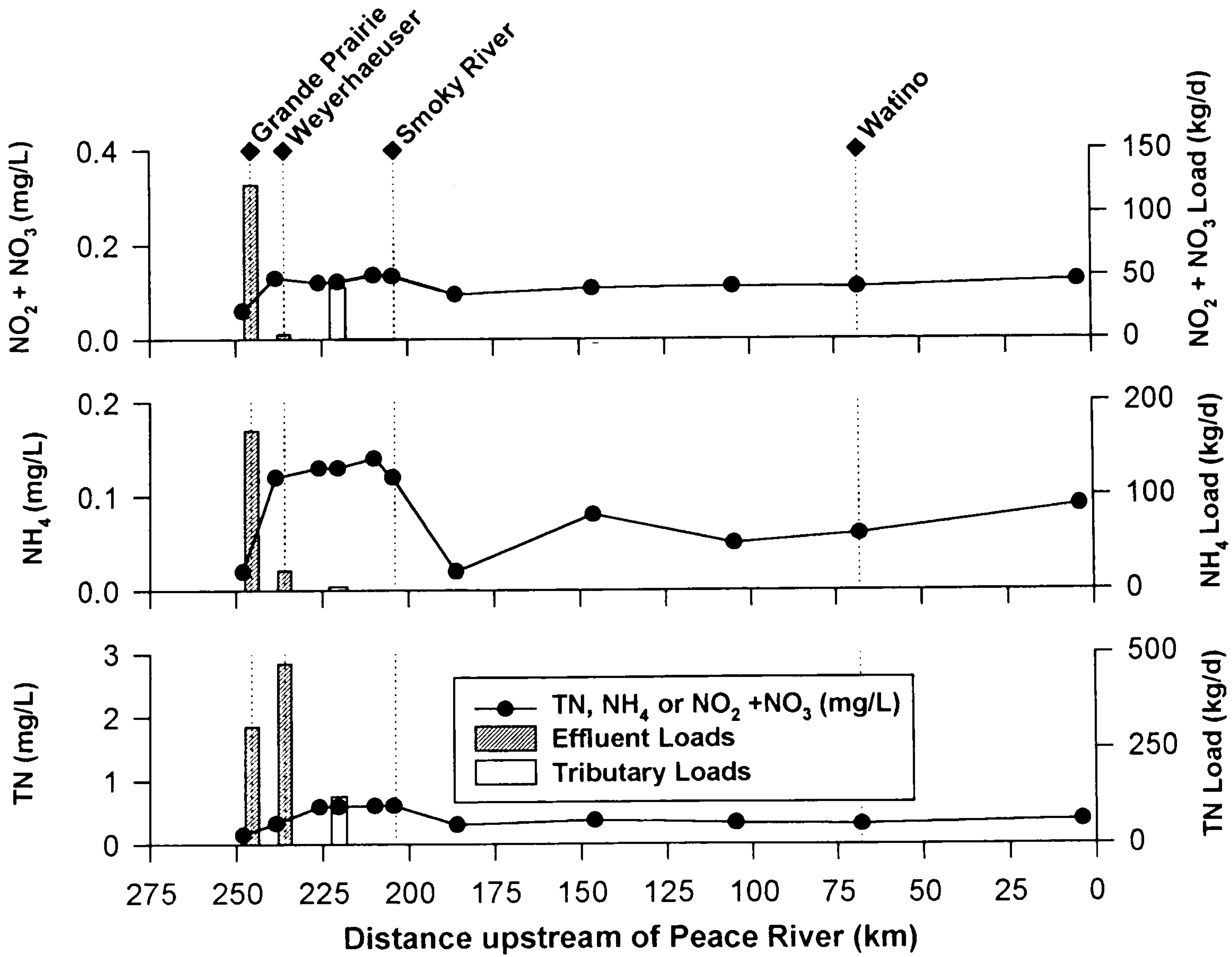
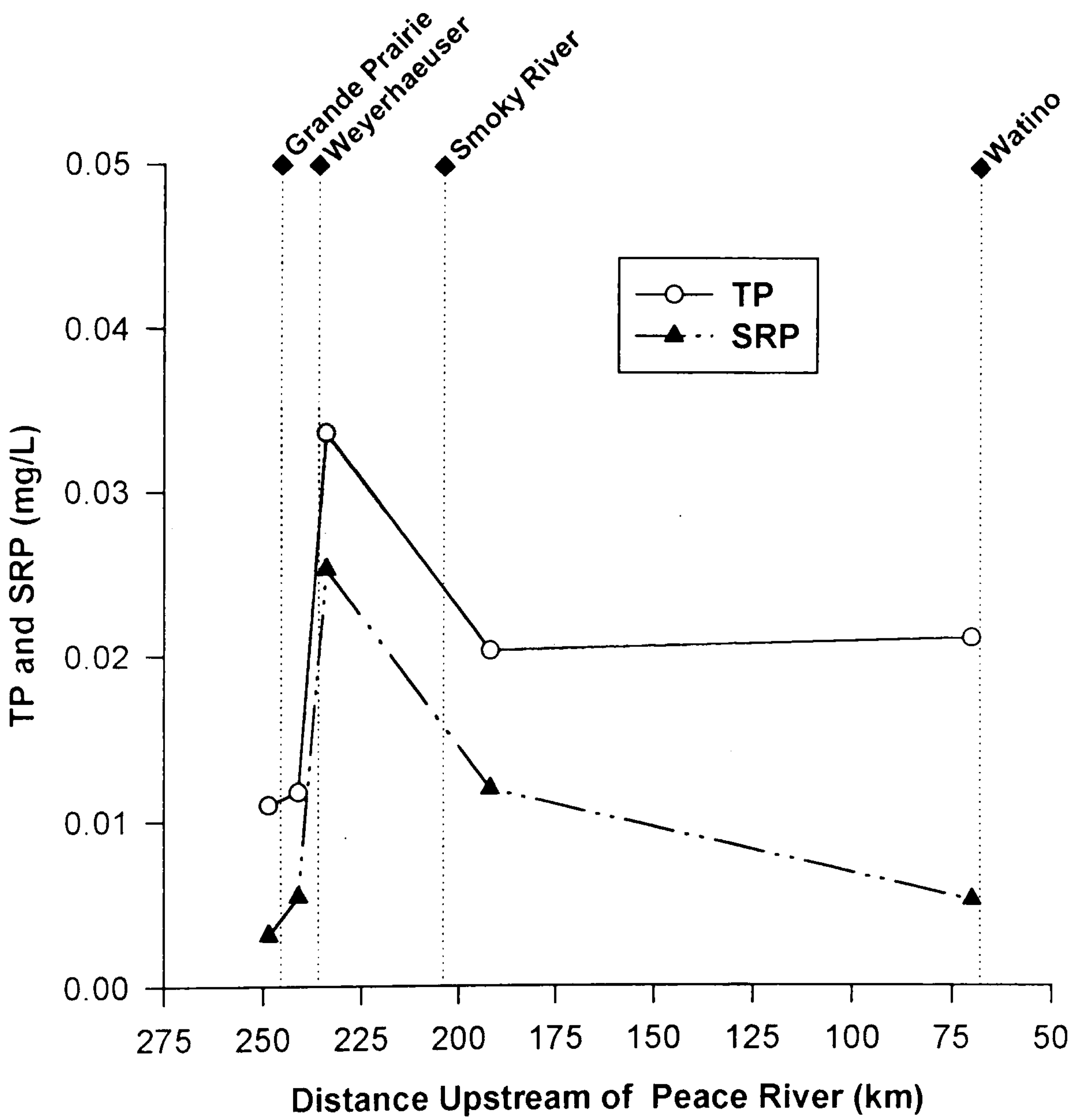


Figure 3.8 Total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations in the Wapiti-Smoky rivers from fall 1994 in relation to distance upstream of the Peace River confluence (after Scrimgeour and Chambers 1996).



With respect to the impact of the Grande Prairie STP on water quality in the Wapiti River, it is pertinent to note that the STP operates on a two-week cycle in which effluent is discharged for two weeks followed by no discharge for the next two weeks. However, the status of the Grande Prairie STP is not indicated in any reports documenting conditions in the Wapiti River (e.g., Noton *et al.* 1989; Noton 1992; Terrestrial and Aquatic Environmental Managers Ltd. 1990, 1991b, 1992a, 1993a; Scrimgeour and Chambers 1996).

Surveys of the Peace River during May-September 1988, December 1988 and February 1989 identified three reaches with respect to water quality: (1) an upstream reach (British Columbia-Alberta border to the confluence with the Smoky River) with no effluent inputs, relatively clear water and low nutrient concentrations, (2) a mid reach (Smoky River to near Fort Vermilion) with gradually increasing TN, ammonium and TP concentrations due to tributary inputs, particularly the Smoky River with its pulp mill at Grande Prairie, and (3) a downstream reach (Fort Vermilion to the mouth) where TN, ammonium and TP continued to show a gradual increase (Shaw *et al.* 1990). The authors noted that both historical data from Dunvegan (1978-1988) and 1988/89 survey data from the mainstem and most tributaries were non-compliant with the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) of 1.0 mg/L TN as N and 0.05 mg/L TP as P. Based on significant correlations between discharge and nutrient (total, dissolved and particulate N and P) concentrations for data collected at Dunvegan, Shaw *et al.* (1990) argued that non-compliance with the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) was due to an increase in nutrients associated with suspended solids which were at elevated concentrations during high flows. The authors also noted that effluent discharges have little effect on the Peace River due to the river's large volume relative to effluent inputs. More recent studies conducted by Monenco (1990a,b,c; 1991a,b; 1992) on behalf of the Peace River Pulp Division of Daishowa - Marubeni International Ltd. showed no effect of the mill effluent on TP or TKN concentrations.

3.3 ASSESSMENT

Analysis of long-term data and surveys of nutrients in the Athabasca River have shown that TP concentrations are lowest around Jasper and increase downstream of Jasper, Hinton, Whitecourt and Fort McMurray, during spring, fall and winter. (High flows during summer often mask any impacts of point-source nutrient loading.) Of the 721 TP measurements from the Athabasca River between 1980-93, 146 measurements or 20% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TP of 0.05 mg/L P. Most of these exceedances occurred during summer and were likely due to high particulate P concentrations. TN concentrations in the Athabasca River are lowest around Jasper and typically increase downstream of Hinton and thereafter increase steadily along the remaining length of the river. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by only 2% of the samples.

In the Wapiti-Smoky rivers, TN and TP concentrations increase downstream of the Grande Prairie sewage treatment plant and again, below the Weyerhaeuser of Canada Ltd. outfall. Concentrations remain elevated to the mouth of the Wapiti River mouth and, during periods of low flow, increase concentrations in the Smoky River. Of the 27 TP measurements at the mouth of the Wapiti River, 20 measurements or 74% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TP of 0.05 mg/L P. The fact that the percent of exceedances increased from 12 to 74% from upstream of Grande Prairie to the mouth of the Wapiti River suggests that P from the City of Grande Prairie and Weyerhaeuser of Canada Ltd. effluents contributed to non-compliance with the TP guideline. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by 19% (n=26) of the samples from the Wapiti River near the mouth compared to no TN exceedances (n=21) for samples from upstream of Grande Prairie, again suggesting that exceedances are related to nutrient loading from the Grande Prairie STP and mill.

Water quality in the mainstem of the Peace River appears little affected by effluent discharges, undoubtedly due to the river's large volume relative to effluent inputs. Historical data from Dunvegan (1978-1988) and 1988-1989 survey data showed that samples were often non-compliant with the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) of 1.0 mg/L TN and 0.05 mg/L TP due to high particulate loads associated with high flows (Shaw *et al.* 1990).

Exceedances of *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) have also been routinely observed in other rivers in the province. From 1970-1980, TP and TN concentrations were consistenly low in the Bow River upstream of Calgary but regularly exceeded guidelines for over 300 km downstream of Calgary in the case of TP and over 80 km downstream for TN (Hamilton and North 1986). These exceedances of nutrient guidelines served in part for the decision to upgrade the Calgary's two STP's in 1982-83. While TP and TN concentrations have decreased downstream of Calgary since the STP upgrades, concentrations still frequently exceed the *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) (Sosiak 1990). In the North Saskatchewan River between 1982-1984, 20 to 30% of samples from upstream and > 85% of samples from downstream of Edmonton exceeded the *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) for TP (Anderson *et al.* 1986). Most of the TP was particulate and unlikely to be biologically available (Anderson *et al.* 1986 after McNeely *et al.* 1979). TN exceedances in the North Saskatchewan River occurred less frequently and were usually limited to downstream of major effluent outfalls (Anderson *et al.* 1986). It should be noted that *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) are not legal statutes; only limits as given in effluent discharge licenses are recognized as enforceable environmental control laws by the provincial government.

There are too few data to assess longitudinal changes in nutrient concentrations in the Slave River. Nutrient data are limited to samples collected at Fort Smith since May 1990 as part of the Slave River Environmental Quality Monitoring Program and at Fitzgerald, Alberta as part of the joint federal, provincial and territorial monitoring program.

CHAPTER 4.0
CONTRIBUTIONS OF ANTHROPOGENIC AND NATURAL SOURCES TO NUTRIENT LOADS

4.0 CONTRIBUTIONS OF ANTHROPOGENIC AND NATURAL SOURCES TO NUTRIENT LOADS

Studies of annual and seasonal patterns in nutrient concentrations in the Athabasca and Wapiti-Smoky river systems have shown that nutrient loading from pulp mills and, to a lesser extent, municipalities can affect instream concentrations, particularly during periods of low flow (Chapter 3). In the Athabasca River, elevated N and P concentrations were observed below Jasper, Hinton, Whitecourt and Fort McMurray during spring, fall and winter while in the Wapiti River, nutrient concentration are elevated year-round downstream of the Grande Prairie sewage and Weyerhaeuser of Canada Ltd. outfalls. In contrast, effluent discharges have little effect on the Peace and Slave rivers due to the rivers' large volumes relative to effluent inputs.

The purpose of this chapter is to quantify the contribution of non-point and anthropogenic point-sources to the nutrient load in the Athabasca, Peace and Slave river systems. As part of the NRBS, Sentar Consultants Ltd. (1994b) assessed the contribution of anthropogenic point sources to TN and TP loads in the Athabasca, Wapiti-Smoky and Peace river mainstems. More recently, Chambers and Dale (1996) and Alberta Environmental Protection (1995a) examined the contribution of pulp mills, other industrial and municipal sources to P and N loads in the Athabasca and Wapiti-Smoky rivers.

4.1 POINT-SOURCE CONTRIBUTIONS

To quantify the contribution of pulp mill and other effluents to the nutrient load in the Athabasca and Wapiti-Smoky river systems, Chambers and Dale (1996) calculated annual, high-flow (May-November) and low-flow (November-April) loads of N and P for all sites on the Athabasca and Wapiti-Smoky rivers with discharge data and > 3 years of nutrient data: Athabasca River 20 km downstream of Jasper at Snaring River (1980-1993), Athabasca River 37 km downstream of Hinton at Obed Coal (1989-1993 for TP, 1989-1992 for TN), Athabasca River at Athabasca (1980-1992 for TP, 1987-1992 for TN), Athabasca River 3 km upstream of Fort McMurray near the Horse River (1989-1992), Athabasca River at Old Fort (1988-1992), Wapiti River 2 km upstream of the Grande Prairie STP near Highway 40 (1991-1993), Wapiti River at mouth (1991-1993), and Smoky River at Watino 68 km upstream of the Peace River confluence (1980-1992 for TP, 1987-1992 for TN) (Figure 4.1). From this information and data on pulp mill, municipal and other industrial nutrient loads (Tables 2.1, 2.2 and 2.3), they estimated the contribution of continuously-discharging industrial and municipal sources to TP and TN loads in the Athabasca and Wapiti-Smoky rivers.

On an annual basis, anthropogenic point-sources were found to contribute 6 to 16% of the TP load in the Athabasca River (Chambers and Dale 1996) (Figure 4.2). With the exception of Jasper, most of these loadings were from pulp mills. However, during low flows, 37% of the TP load at Old Fort was from continuously-discharging industrial and municipal sources (27% from pulp mill sources and 9.5% from municipal sources) while downstream of Hinton at the Obed Coal bridge, the combined Hinton discharge contributed 61% of the TP load during low flow seasons. The only significant municipal contributor to TP loads in the Athabasca River was the Town of Jasper which contributed 90% of the TP load at the

Figure 4.1 Discharge and water quality monitoring sites used to calculate nutrient loads for the Athabasca and Wapiti/Smoky Rivers (Chambers and Dale 1996).

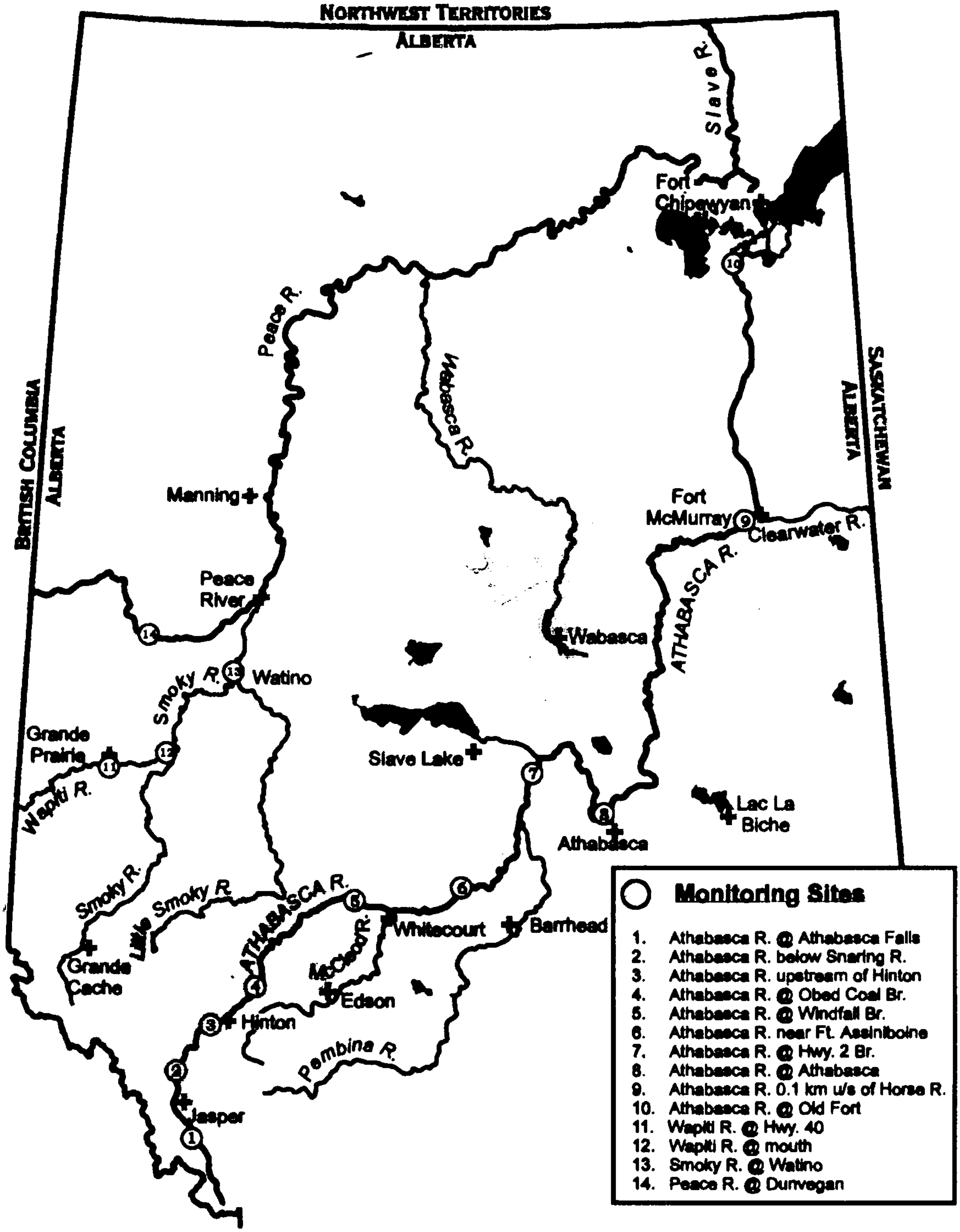
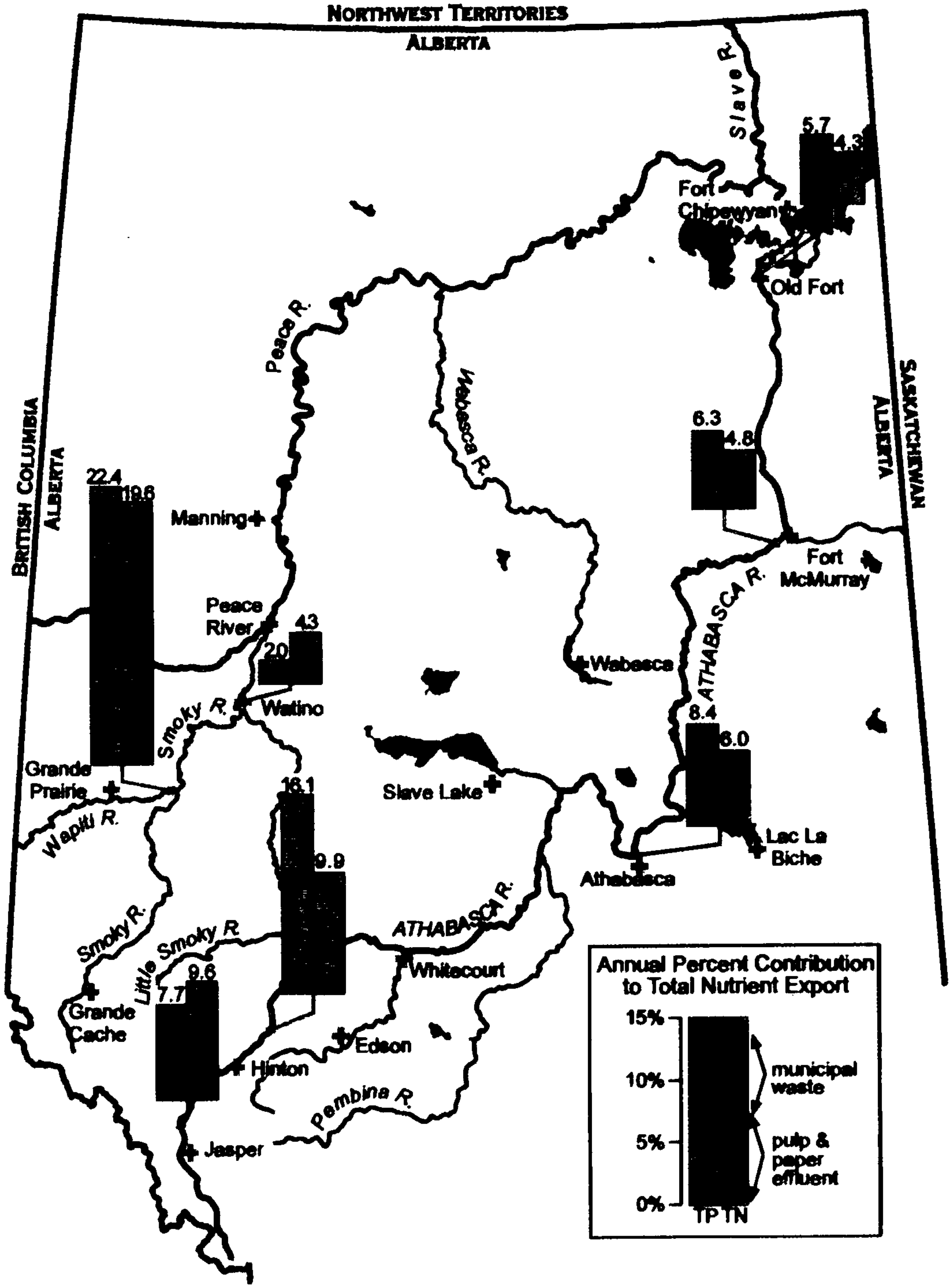


Figure 4.2 Municipal and industrial contributions to total phosphorus (TP) and total nitrogen (TN) export for the Athabasca and Wapiti rivers, Alberta (Chambers and Dale 1996) (Contributions calculated from river water chemistry for selected sites in Table 3.1 and from municipal and industrial data in Tables 2.1, 2.2 and 2.3).



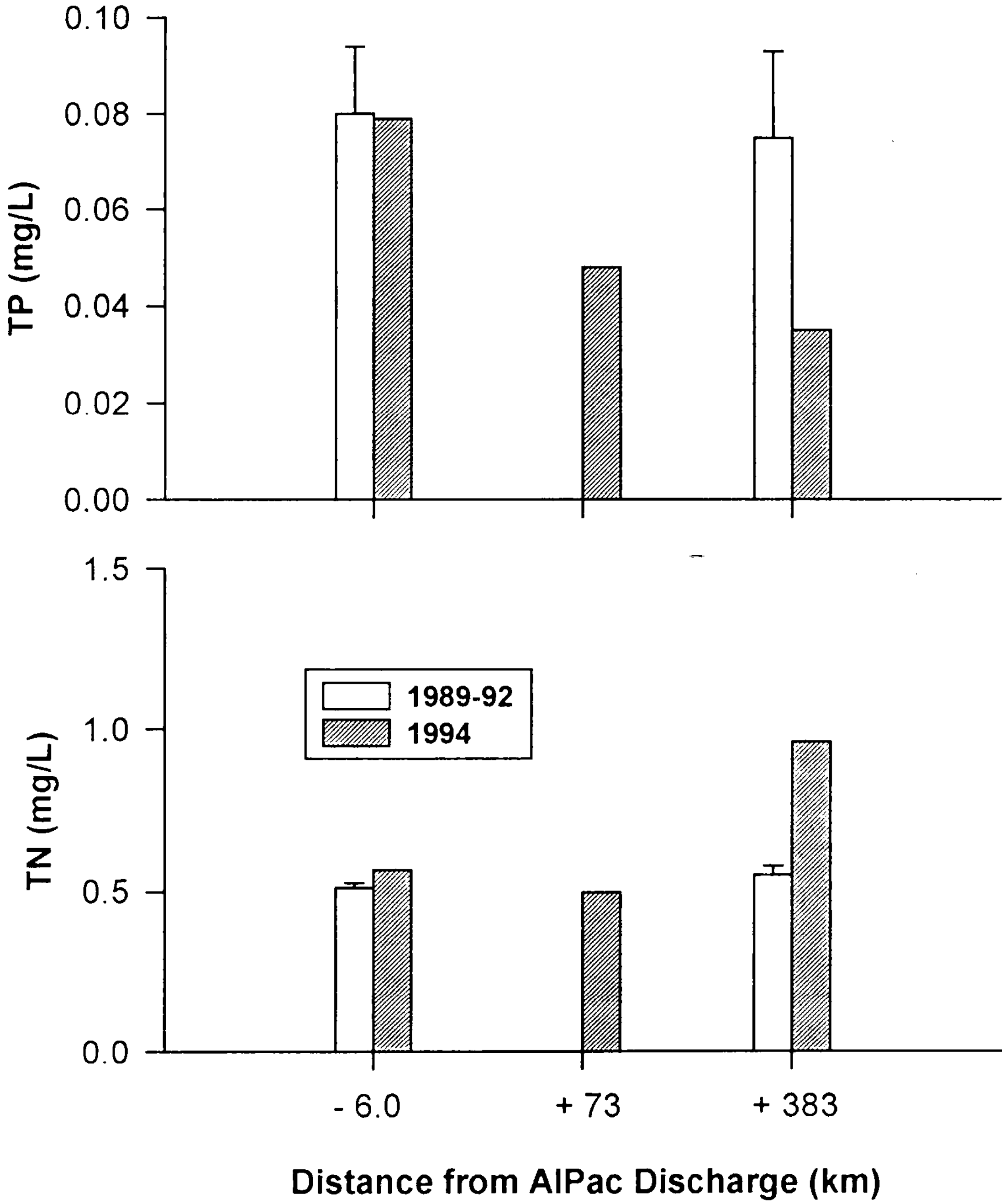
Snaring River site during low flow. While the TP load from Jasper sewage is similar to that of other towns on the Athabasca River (Table 2.1), it represents a substantial contribution because of the very low TP concentrations upstream of Jasper (0.006 mg/L TP median value). With respect to TN, continuously-discharging industrial and municipal sources contributed 4 to 10% of the TN load in the Athabasca River on an annual basis, with < 2% attributable to municipalities except Jasper which contributed approximately 10% of the TN load at the Snaring River site (Figure 4.2). However, during low flows, 42 % of the TN load downstream of Jasper was due to sewage while 39% of the TN load at the Obed Coal bridge was due to the combined Weldwood of Canada Ltd. and Hinton effluent.

The above assessments of nutrient loading in the Athabasca River do not consider the effect of the AlPac pulp mill which started operations in September 1993. Sufficient data are not available to statistically assess changes in TP and TN loads in the Athabasca River in relation to loading from the AlPac pulp mill. Comparison of 1994 nutrient concentrations for the Athabasca River at Athabasca (6 km upstream of AlPac discharge), Athabasca at Calling River (73 km downstream of the AlPac discharge) and the Athabasca River 0.1 km upstream of the Horse River (383 km downstream of the AlPac discharge) suggests that there have been no perceptible changes in TP and TN concentrations at these near (73 km downstream) and far-field (383 km downstream) sites as a result of the start-up of the AlPac mill (Figure 4.3).

With respect to the Wapiti River, Chambers and Dale (1996) calculated that continuously-discharging industrial and municipal sources contributed 22% of the TP load with 13% of the TP load attributable to the Weyerhaeuser pulp mill (Figure 4.2). However, during low flows, 41% of the TP load of the Wapiti River was from continuously-discharging industrial and municipal sources (24% from pulp mill sources and 18% from municipal sources). The point-source contribution to TP export for the Smoky River at Watino was 2% on an annual basis and less than 7% during the low flow period. TN contributions from continuously-discharging industrial and municipal sources were 20% of the TN load in the Wapiti River on an annual basis (7% from municipal sources and 13% from the pulp mill) (Figure 4.2). However, during low flows, 34% of the TN load of the Wapiti River was due to continuously-discharging industrial and municipal sources (22% from the pulp mill and 12% from municipal sources). TN export for the Smoky River at Watino was 6421 tonnes/y with 3% attributable to Weyerhaeuser Canada Ltd. and 2% to the Grande Prairie and Grande Cache sewage effluents.

Shaw *et al.* (1990) estimated effluent load as a percent of upstream load for the Peace River from 1988-89. They concluded that the Town of Peace River contributed 3 and 2% of the ammonium and the TDP load, respectively, and 0.1% of the TP, nitrate+nitrite, and total nitrogen load in the Peace River. There was no perceptible effect of the Peace River Correctional Institute STP on water quality (< 0.1% contribution of all forms of nutrients) while Peace River Oils #1 contributed 6, 0.2 and 0.2% of the ammonium, total Kjeldahl and total nitrogen loads, respectively, in the Peace River with no perceptible impact (< 0.1%) on other nutrient parameters.

Figure 4.3 Long-term (1989-1992) and 1994 total phosphorus (TP) and total nitrogen (TN) concentrations at sites 6 km upstream (Athabasca River at Athabasca), 73 km downstream (Athabasca River at Calling River) and 383 km downstream (Athabasca River 0.1 km upstream of the Horse River) of the Alberta Pacific Forest Industries Ltd. (AlPac) effluent outfall (Chambers and Dale 1996). (Concentrations calculated from river water chemistry data for selected sites in Table 3.1).



The finding that pulp mills and municipalities contributed 27 and 9.5% of the TP load, respectively, at Old Fort during low flows and 3 and 0.9%, respectively, during high flows compares favourably with results presented by Alberta Environmental Protection (1995a) in their recently published *State of the Environment* report. (Any discrepancies between the Alberta Environmental Protection (1995a) and Chambers and Dale (1996) calculations are solely due to differences in the time period over which the data were integrated (i.e., high and low flows periods for Chambers and Dale (1996) versus summer (May-September) and winter (December-March) for the provincial report as both sets of calculations were based on the same data). Likewise, TN contributions of 7 and 5% from pulp mills and municipalities, respectively, at Old Fort during low flows and 2 and 1%, respectively, during high flows are similar to Alberta Environmental Protection (1995a) calculations. For the Smoky River near Watino, TN contributions of 7 and 4% from pulp mills and municipalities, respectively, during low flows and 2 and 1%, respectively, during high flows were similar to Alberta Environmental Protection (1995a) findings; however, TP contributions differed between the Chambers and Dale (1996) and the provincial report. For the Smoky River at Watino, Chambers and Dale (1996) calculated that 4 and 3% of the TP load was attributable to pulp mills and municipalities, respectively, during low flows compared to 0.7 and 0.6%, respectively, during high flows. This is less than the 20% (11% from pulp mill and 9% from municipal sources) reported by Alberta Environmental Protection (1995a) for the Wapiti-Smoky basin during winter, although our high-flow estimates are similar to the provincial calculations for summer (i.e., 1% each for pulp mill and municipal sources; Alberta Environmental Protection (1995a)).

4.2 NON-POINT SOURCES

To assess the contribution of the various landuses (e.g., pasture, fertilized land and forestry) to non-point loading to the Athabasca and Wapiti Rivers, Chambers and Dale (1996) estimated the nutrient load from these river systems based on export coefficients (i.e., the nutrient loss expressed as mass per unit area of the drainage basin) for each of the major landuses and the area of each landuse within the river basin. Using this approach, they estimated a total export of 2049 and 242 tonnes/y TP from the Athabasca and Wapiti rivers, respectively (Table 4.1). This approach gave estimates that were similar to values calculated from TP concentrations and discharge, namely 2311±701 tonnes/y (mean±95% confidence limit) for the Athabasca River and 204±174 tonnes/y (mean±95% confidence limit) for the Wapiti River. This indicates that use of export coefficients and land use patterns provide a reasonable estimate of TP export for the Athabasca and Wapiti Rivers, and gives confidence in proceeding with partitioning the non-point load between the various landuses.

Of the total export of TP from the Athabasca River, most (94%) was from non-point sources (Table 4.1). Forested land contributed 69% of the total TP export while agricultural land (fertilized cropland and unfertilized pasture land) contributed only 17% of the total TP export, although this contribution is disproportionately high given that agricultural land covers only 3% of the basin (Chambers and Dale 1996). Similar calculations for the Wapiti River indicated that 45% of the TP export was from forested land with agricultural land contributing another 33%.

Table 4.1 Non-point and point source loads of total phosphorus (TP) to the Athabasca and Wapiti rivers (Chambers and Dale 1996).

Sources	Athabasca		Wapiti	
	Load (tonnes/y)	% of Total Load	Load (tonnes/y)	% of Total Load
Non-Point Sources				
Forested land	1410	68.7	109	45.0
Cropland	116	5.7	79	32.6
Pasture land	234	11.4	0	0
Atmospheric	160	7.8	8	3.3
Total	1920	93.6	196	81.0
Point Sources[6]				
Pulp mills	95	4.6	26	10.7
Other	36	1.8	20	8.3
Total	131	6.4	46	19.0
Total Load	**2051**	**100**	**242**	**100**

[6]includes all municipalities and pulp mills (except Alberta Pacific Forest Industries Inc.) in Tables 2.1 and 2.2 as well as Athabasca River Suncor Oil Sands Group (Table 2.3). Loadings from Alberta Pacific Forest Industries Inc. not included to allow comparison with measured loads available only up to 1993.

4.3 COMPARISONS OF NUTRIENT EXPORT AMONG WORLD RIVERS

Pulp mill contributions to nutrient export have been evaluated for other watersheds in Canada and throughout the world (Table 4.2). For the Fraser River, British Columbia, 13% of the TP export at Marguerite during the low flow season is from anthropogenic point sources (11% from pulp mill and 2% from municipal sources) as compared to 5% (4% from pulp mill and 1% from municipal sources) during high flows (French and Chambers 1995). Byrd *et al.* (1986) noted that the Flint River pulp mill near Oglethorpe, Georgia, USA contributed 5% of the N and P in the Flint River while in Scandinavia, 10% of the TP load and 4% of the TN load to the Gulf of Bothnia was from the pulp and paper industry with the major contributor being sewage (14% of the TP and 7% of the TN load) (Enell and Haglind 1994). Wartiovaara and Heinonen (1991) noted that in Finland, the relative contribution to nutrient loading from sewage versus the pulp and paper industry has changed over the period between 1972 and 1988: total loading from domestic waste decreased by almost 92% for TP (from 15.6 to 1.3 tonnes/day) and 44% for TN (from 72 to 40 tonnes/day) due to improved technologies while pulp mill loading showed little change (from 2.0 to 2.3 tonnes TP/day and from 15 to 13 tonnes TN/day) despite great increases in mill production. The result was a shift from domestic sewage to pulp mill effluent as the major anthropogenic point source of TP in Finland.

In contrast to western Canada and Scandinavia, point sources are greater contributors of nutrients in heavily-developed European basins. Thus, point-source contributions near the mouths of the Rhine, Neckar, Main and Mosel rivers average 64, 74, 52 and 29%, respectively, of the TP load and 47, 62, 48 and 21%, respectively, of the dissolved inorganic N load (1973-1987; Behrendt 1993). Point-sources discharges totalled 850-950, 80-100, 80-100 and 50-100 m^3/s to the Rhine, Neckar, Main and Mosel rivers, respectively. In the Vistula River, Poland, point-source discharges were 70 m^3/s and contributed about 30% of the N and P load (Sundblad *et al.* 1994 from Rybinski *et al.* 1990) while in the Girou River, France, point sources were estimated to account for about 61% of the TP load (Probst 1985).

4.4 ASSESSMENT

The observation that pulp and paper mills contribute <5 and <2% of the TP load in the Athabasca River at Old Fort and the Smoky River near Watino, respectively, on an annual basis suggests that this industry has only small impacts on TP export. However, pulp mills and, in the case of Grande Prairie, sewage discharges can have a substantial impact on nutrient loading during low flows. In addition, the available forms of N and P (i.e., SRP, ammonium and nitrate+nitrite) are generally proportionately more abundant in pulp mill and municipal effluents. For example, the ratio of SRP to TP for Weldwood of Canada Ltd. effluent is 0.62 (n=5, fall 1994; Podemski and Culp, unpubl. data) compared to values usually < 0.5 for non-point sources of P (e.g., 0.24 in lakes and rivers with < 30 g/L TP and 0.34 for rivers with TP > 30 g/L (Bradford and Peters 1987)). This means that despite relatively low contributions to nutrient loading in the Athabasca and Smoky rivers on an annual basis, effluent discharge from pulp mills may still have ecological consequences. Chapter 5 examines the ecological significance of effluent loading from pulp mills on the biota of the Athabasca and Wapiti-Smoky rivers.

Table 4.2 **Total phosphorus (TP) and total nitrogen (TN) export from rivers throughout the world and the percent contribution from point sources to these exports.**

River and Site	Drainage Area (km^2)	Mean Annual Discharge (m3/2)	TP % Point	TP Export	TP % Point	TP Export	References
Athabasca, Canada							
at Snaring River	3880	86	80	7.7	298	9.6	Chambers and Dale (1996); drainage areas for Snaring River, Obed Coal, Horse River and Old Fort are for nearest gauging station (Jasper, Hinton, Fort McMurray, Athabasca and Embarras, respectively)
at Obed Coal	9780	186	219	16.1	2254	9.9	
at Athabasca	74600	417	1361	8.4	6816	6.0	
at Horse River	13300	503	1866	6.3	8980	4.8	
at Old Fort	155000	650	2311	5.2	13670	4.2	
Fraser, Canada							
at Red Pass	1700	14	7	0.0	n/a	n/a	French and Chambers (1995)
at Hansard	18000	444	1076	0.0	n/a	n/a	
at Marguerite	114000	1315	5772	6.6	n/a	n/a	
at Hope	217000	2684	10337	4.4	n/a	n/a	
Flint, Ga, USA	n/a	n/a	n/a	< 5	n/a	< 5	Byrd *et al.* (1986)
Girou, France	520	< 5	11.5	60.8	n/a	n/a	Probst (1985)
Main, Germany							
at Kostheim	21505[1]	212[2]	5800	51.7	54000	48.1	chemistry data from Behrendt (1993); [1]Van der Leeden (1975) at Kleinhaubach; [2]Van der Weijden and
Mosel, Germany							
at Koblenz	27100[1]	367[2]	5300	34.0	56000	21.4	chemistry data from Behrendt (1993); [1]Van der Leeden (1975) at Cochem; [2]Van der Weijden and Middleburg (1989)
Neckar, Germany							
at Mannheim	n/a	161[1]	3100	74.2	34000	61.8	chemistry data from Behrendt (1993); [1]Van der Weijden and Middleburg (1989)
Rhine, Germany							
at Koblenz	103730[1]	1560[1]	24500	56.3	216000	42.1	chemistry data from Behrendt (1993); [1]Van der Leeden (1975); [2]Van der Weijden and Middleburg (1989)
at Lobith	160000[1]	2200[2]	35400	63.6	505000	51.9	
Smoky, Canada							
at Watino	50352	323	2442	2.0	6421	4.3	Chambers and Dale (1996)
Vistula, Poland							
at Kiezmark	194414[1]	1010[2]	2323 (for 6 mon.)[1]	30[3]	29904 (for 6 mon.)[1]	30[3]	[1]Sundblad *et al.* (1994); [2]Van der Leeden (1975); [3]Sundblad *et al.* (1994 after Rybinski *et al.* 1990)
Wapiti, Canada							
at mouth	14468	74	204	22.4	1335	19.6	Chambers and Dale (1996)

CHAPTER 5.0
EFFECTS OF NUTRIENTS ON BIOTA: *IN SITU* STUDIES

5.0 EFFECTS OF NUTRIENTS ON BIOTA: *IN SITU* STUDIES

Studies of the impact of effluents on the biota of the Athabasca and Wapiti rivers have been undertaken for at least 20 years by both provincial agencies and private consultants working on behalf of the pulp mill and oil industries. As part of the NRBS, surveys of benthic invertebrate densities and taxonomic composition were undertaken in the Upper Athabasca in April-May 1992 and February-March, May and September 1993 (R.L. and L. Environmental Services Ltd. 1993a,b,c,d; Saunders and Dratnal 1994; Westworth and Associates Ltd. 1995). In addition, Scrimgeour *et al.* (1995b) collated benthic invertebrate data for the Wapiti and Athabasca Rivers for 1960-1992 and analysed changes in benthic invertebrate community composition for the Athabasca River near Hinton (1983-1992) and Whitecourt (1987-1992), and the Wapiti River near Grande Prairie (1987-1992).

Periphyton sampling of the Athabasca and Wapiti-Smoky rivers commenced more recently. Hamilton *et al.* (1985) and Anderson (1989) reviewed seasonal data collected in 1984 for the Athabasca River while Yonge (1988) summarized the existing periphyton biomass data. Periphyton sampling was conducted in the Wapiti River in 1983 (Noton *et al.* 1989). As part of the NRBS study, under-ice periphyton biomass was measured on the Athabasca River in February-March 1993 (R.L. and L. Environmental Services Ltd. 1993d) and longitudinal surveys of the Athabasca and Wapiti rivers were undertaken in fall 1994 (Scrimgeour and Chambers 1996).

The purpose of this chapter is to assess the *in situ* impacts of effluent loading from pulp mills and sewage treatment plants in the NRBS area on periphyton and invertebrate communities. Biotic responses to effluent loading in this and subsequent chapters will focus on the Athabasca and Wapiti rivers. Previous assessments of biotic responses to effluents in the Peace River found no detectable difference in periphyton biomass and benthic invertebrate densities and diversity upstream and downstream of outfalls, likely due to the high dilution of the effluent in the river (Shaw *et al.* 1990). However, recent household surveys conducted as part of the NRBS with First Nations people in Fox Lake and Tall Cree reported increased occurrences of algae in certain reaches of the Peace River and its tributaries (Bill and Flett 1996). Data on benthic invertebrate abundance and community structure for the Slave River are not currently available but are being collected as part of the joint Department of Indian Affairs and Northern Development and Government of the Northwest Territories Slave River Environmental Quality Monitoring Program. Household surveys conducted as part of the NRBS with First Nations people in Fort Smith reported increased occurrences of algae in the Slave River during the past five years, both on the river banks in fishing nets (Bill and Flett 1996).

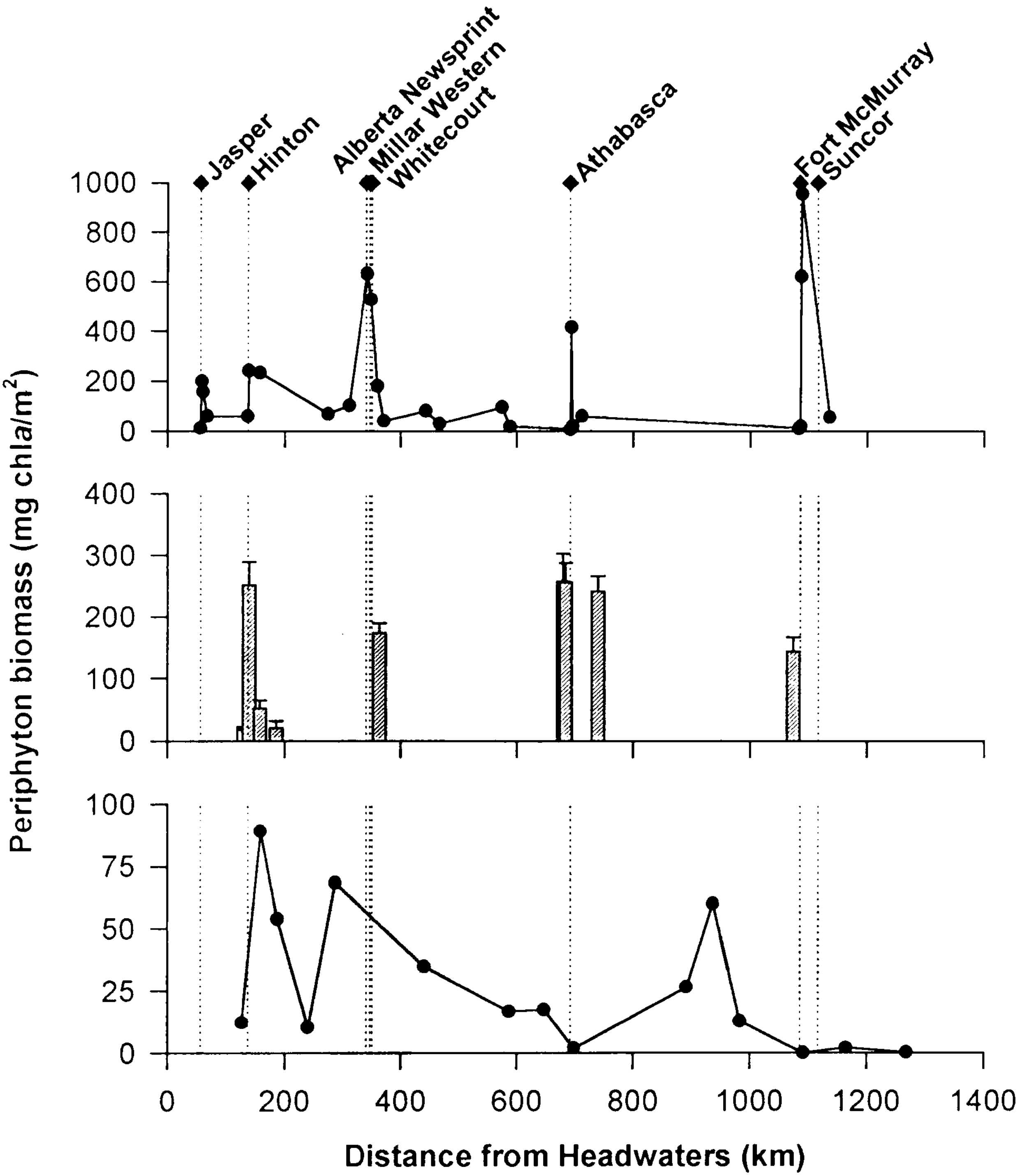
In this chapter, the responses of periphyton, benthic invertebrates and small fish species in the Athabasca and Wapiti rivers to pulp mill and municipal effluents are examined. Most of these studies have focused on fall collections. In the case of periphyton, cold temperatures and low under-ice irradiance levels during winter and high turbidity and scouring flows in spring and summer limit the window for primary production to late summer and fall (see Hamilton *et al.* (1985) for an examination of seasonal patterns in periphyton biomass in the Athabasca River). In the case of benthic invertebrates, spring and fall is a biologically preferable time to sample because many taxa consist of early or late instars which may be more vulnerable to the chemical stresses that occur during lower flows. Sampling at these times is also preferable because of relatively low or stable flow conditions that increase the accuracy or precision of sampling protocols. In addition to monitoring of benthic communities, zones of nutrient saturation (i.e., where additional nutrients will not enhance periphyton growth) and nutrient limitation (i.e., where additional nutrients will increase periphyton biomass) are described from *in situ* experiments with nutrient diffusing substrata.

5.1 IMPACTS OF EFFLUENT ON PERIPHYTON: *IN SITU* STUDIES

The biomass of periphyton is commonly expressed as the concentration of the photosynthetic pigment chlorophyll *a* (chl*a*, expressed as mg/m^2) (Jones 1978; Mulholland *et al.* 1986; LaPerriere *et al.* 1989; Winterbourn *et al.* 1992; Barnese and Schelske 1994). Periphyton samples are collected by scraping (with a scalpel or stout brush) defined areas on the surface of rocks; the samples are then extracted for their chl*a* content. All periphyton samples collected by Alberta Environmental Protection and the NRBS have been analysed for chl*a* content (Hamilton *et al.* 1985; Yonge 1988; Anderson 1989; Noton *et al.* 1989; R.L. and L. Environmental Services Ltd. 1993d; Scrimgeour *et al.* 1995a; Scrimgeour and Chambers 1996). In addition, Weldwood of Canada Ltd., Alberta Newsprint Co., Millar Western Pulp Ltd. and Slave Lake Pulp Corp. measure periphyton biomass as part of their environmental effects monitoring program.

The October 1994 periphyton survey by Scrimgeour and Chambers (1996) of 28 sites on the Athabasca River showed that periphyton biomass increased by 16-fold immediately downstream of Jasper, approached upstream concentrations by 12 km downstream of Jasper, and then increased by four-fold 1 km downstream of Hinton (Figure 5.1a). Algal biomass upstream of the Whitecourt outfalls was similar to levels found below Jasper but increased downstream of the Alberta Newsprint Co. and Millar Western Pulp Ltd. By 20 km downstream of the Whitecourt STP, algal biomass had returned to levels similar to those found above Whitecourt. Algal biomass remained low until 1 km downstream of the Town of Athabasca STP. Thereafter, concentrations remained low until 1-3 km below the Fort McMurray STP. While few sites were sampled in March 1993, the data showed a similar pattern with low chl*a* concentrations immediately upstream of Hinton, and high concentrations downstream of Hinton, Whitecourt, and near the Town of Athabasca (Figure 5.1b). The high chl*a* values observed in March 1993 when all sites except for immediately below Hinton were ice-covered is consistent with Noton and Allan's (1994) observation of thinning ice cover and periphyton photosynthesis (as indicated by diurnal fluctuations of up to 2 mg/L in dissolved oxygen). Data from Hamilton *et al.* (1985) and Anderson (1989) for October 1984 also showed elevated chl*a* concentrations downstream of Hinton; however, concentrations were also high upstream of Whitecourt and upstream of Fort McMurray (Figure 5.1c). There was no evidence of elevated concentrations of periphyton chl*a* downstream of Fort McMurray. In contrast, Scrimgeour and Chambers (1996) reported significantly higher concentrations of periphyton chl*a* downstream of the Fort McMurray STP. This discrepancy between Hamilton *et al.* (1985) and Scrimgeour and Chambers (1996) in periphyton chl*a* concentrations downstream of Fort McMurray may be due to the infrequent occurrence of rocks in this largely sandy-bottom river reach and thus the difficulty in obtaining a random periphyton sample.

Figure 5.1 Periphyton biomass (expressed as chlorophyll *a* concentration) for the Athabasca River in: (a) fall 1994 (Scrimgeour and Chambers 1996), (b) March 1993 (collected by R. L. and L. Environmental Services Ltd. 1993d), and (c) October 1984 (Hamilton *et al.* 1985).



In addition to longitudinal surveys of periphyton biomass for the entire Athabasca River, localized studies have recently been undertaken near Hinton by Terrestrial and Aquatic Environmental Managers Ltd. (1991a,c; 1992b,c; 1993b) for Weldwood of Canada Ltd. and near Whitecourt by Sentar Consultants Ltd. (1994c, 1995a) for Alberta Newsprint Co. These studies likewise showed increased periphyton biomass downstream of Hinton and the Alberta Newsprint Co. outfall, but no or only a slight increase downstream of the Millar Western Pulp Mill outfall. Surveys of periphyton biomass in the Wapiti River were undertaken in October 1989, October 1990, February 1991, April 1991 and October 1994 (Terrestrial and Aquatic Environmental Managers Ltd. 1991b; Noton 1992; Scrimgeour and Chambers 1996). These studies showed that periphyton chl*a* concentrations increased downstream of the Grande Prairie STP outfall and, with the exception of October 1990, showed no further increase downstream of the mill outfall (Figure 5.2).

Scrimgeour and Chambers (1996) also found from their fall 1994 survey of the Athabasca, Wapiti and Smoky rivers that periphyton biomass was significantly related to bioavailable N and P concentrations such that:

in early fall: $\text{Chl}a = 3.395 + 0.809\text{P} + 0.005\text{N}$ (r^2=0.38, $P < 0.001$)

in late fall: $\text{Chl}a = 10.38 + 0.256\text{P} + 0.10\text{N}$ (r^2=0.57, $P < 0.0001$)

where Chl*a* is periphyton biomass (expressed as chl*a* concentration, g/cm^2), P is SRP (g/L) and N is dissolved inorganic N (g/L).

The *Alberta Surface Water Quality Objectives* (Alberta Environment 1977) do not have a water quality objective that relates to periphyton abundance. The *Canadian Water Quality Guidelines* (CCREM 1987) currently recommend that biota, such as filamentous algal mats, phytoplankton scums, etc., be absent from areas intended for development as beaches. Numeric guidelines for periphyton biomass are currently under review. The British Columbia Ministry of Environment, Lands and Parks has a periphyton chl*a* criteria of 100 mg/m^2 to protect aquatic life (particularly for streams containing salmonids) and 50 mg/m^2 for aesthetics and recreation (Nordin 1985). While data on periphyton biomass during fall are limited, assessment of all periphyton data collected in October for the Wapiti-Smoky river and for sites sampled in at least two years for the Athabasca River showed that periphyton chl*a* concentrations often exceeded the British Columbia criteria downstream of Hinton and Grande Prairie (Tables 5.1 and 5.2). The periphyton chl*a* concentrations observed in the Athabasca and Wapiti-Smoky rivers are comparable to values recorded for other Alberta rivers. Yonge (1988), in a review of Alberta Environment periphyton chl*a* data, noted median concentrations of <1 to 48 mg/m^2 above outfalls and 6 to 394 mg/m^2 below outfalls for rivers in southern and central Alberta. Values as high as 800 mg/m^2 have been reported for the Bow River (Charlton *et al.* 1986).

Figure 5.2 **Periphyton biomass (expressed as chlorophyll *a* concentration) in the Wapiti-Smoky rivers (after Terrestrial and Aquatic Managers Ltd. 1991b; Noton 1992; Scrimgeour and Chambers 1996).**

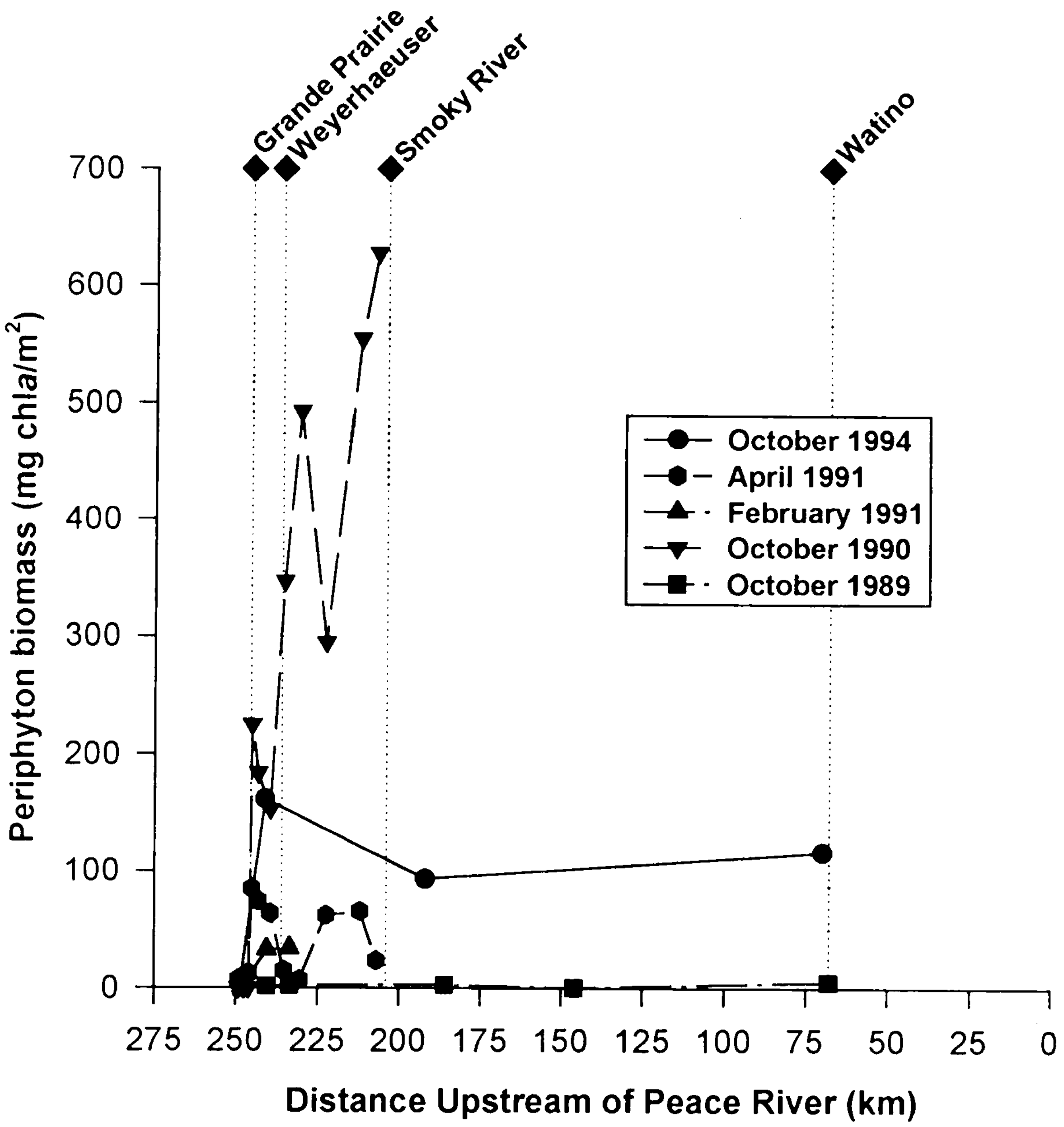


Table 5.1 **Summary of October periphyton biomass in the Athabasca River for sites with >2 years of data. Distance is the distance downstream of the uppermost sampling site (i.e., 2 km upstream of the confluence with the Sunwapta River). ANC is Alberta Newsprint Co.; MWPL is Millar Western Pulp Ltd.; STP is sewage treatment plant.**

Site	Distance	October Periphyton Biomass (mg/m^2) 1988	1989	1990	1992	1993	1994	1995	Meanl	Data Sources
5.8 km u/s Hinton	132.0			80	14.4				47.2	Sentar Consultants Ltd. (1994b)
2.1 km u/s Hinton	135.7			74	17.8				45.9	Sentar Consultants Ltd. (1994b)
1 km u/s Hinton	136.8			81	30.5	4.98	60.67		44.3	Scrimgeour *et al.* (1995a),Scrimgeour and Chambers (1996)
1 km d/s Hinton	138.7			182	191	24.95	241.9		160.0	Sentar Consultants Ltd. (1994), Scrimgeour *et al.* (1995a), Scrimgeour and Chambers (1996)
3.6 km d/s Hinton	141.4			150	163.4				156.7	Sentar Consultants Ltd. (1994b)
9 km d/s Hinton	146.8			222	63.1				142.6	Sentar Consultants Ltd. (1994b)
22 km d/s Hinton	159.8			368	140.7				254.4	Sentar Consultants Ltd. (1994b)
44 km d/s Hinton	181.8			320	27				173.5	Sentar Consultants Ltd. (1994b)
200.3 km d/s Hinton	338.1					137.5	37.9		87.7	Sentar Consultants Ltd. (1993b, 1994b)
201.3 km d/s Hinton	339.1					143.4	65		104.2	Sentar Consultants Ltd. (1993b, 1994b)
203.6 km d/s Hinton	341.4					544.2	75.4		309.8	Sentar Consultants Ltd. (1993b, 1994b)
210 km d/s Hinton, 7.1 km d/s ANC, 0.6d/s MWPL	347.8	32.2	25.66			218.4	176.7	157.8	122.15	Alberta water quality surveys of 1988 and Sentar Consultants Ltd. (1993b, 1994b), Noton (1995)
214.7 km d/s Hinton, 1994b) 11.9 km d/s ANC, 4.7 km d/s MWPL	352.5						293.8	62.5		178.15 Sentar Consultants Ltd. (1993b,
234 km d/s Hinton, 31.2 km d/s ANC, 24.4 km d/s MWPL	371.8	31.9				349.2	90.4	48.1	129.9	Alberta water quality survey of 1988, Sentar Consultants Ltd. (1993b, 1994b), Noton (1995)
3 km d/s Athabasca STP	695					1.16	19.69		10.43	Scrimgeour *et al.* (1995a), Scrimgeour and Chambers (1996)
11 km d/s Athabasca STP, 4 km d/s AlPac	703					0.75	59.58		30.17	Scrimgeour *et al.* (1995a), Scrimgeour and Chambers (1996)

Table 5.2 **Summary of October periphyton biomass on the Wapiti-Smoky rivers. Distance is the distance upstream of the confluence of the Smoky and Peace rivers. Data from Terrestrial and Aquatic Managers Ltd. (1991b), Scrimgeour and Chambers (1996) and Sentar Consultants Ltd. (1994b).**

Site	Distance (km)	Year	Biomass (mg/m^2)
3 km u/s Grande Prairie STP	250	1994	4.3
2 km u/s Grande Prairie STP	249	1990	Below Detection
1 km u/s Grande Prairie STP	248	1989	0.5
0.5 km u/s Grande Prairie STP	247.5	1990	Below Detection
1 km d/s Grande Prairie STP	246	1990	Below Detection
1.9 km d/s Grande Prairie STP	245.1	1990	225
3.8 km d/s Grande Prairie STP	243.2	1990	184
4.5 km d/s Grande Prairie STP	242.5	1994	162
6.5 km d/s Grande Prairie STP	240.5	1989	1.8
8.5 km d/s Grande Prairie STP	239.5	1990	153
11.5 km d/s Grande Prairie STP; 1.5 km d/sWeyerhaeuser	235.5	1994	188
11.7 km d/s Grande Prairie STP; 1.7 km d/s Weyerhaeuser	235.3	1990	347
13.5 km d/s Grande Prairie STP; 3.5 km d/s Weyerhaeuser	233.5	1989	2.6
16.5 km d/s Grande Prairie STP; 6.5 km d/s Weyerhaeuser	230.5	1990	493
24.5 km d/s Grande Prairie STP; 14.5 km d/s Weyerhaeuser	222.5	1990	295
35 km d/s Grande Prairie STP; 25 km d/s Weyerhaeuser	212	1990	555
40 km d/s Grande Prairie STP; 30 km d/s Weyerhaeuser	207	1990 1994	628 93.5
20 km d/s Smoky confluence	186	1989	2.9
60 km d/s Smoky confluence	146	1989	0.5
94 km d/s Smoky confluence	112	1994	117
138 km d/s Smoky confluence	68	1989	5.3

5.2 IMPACTS OF EFFLUENT ON BENTHIC INVERTEBRATES: *IN SITU* STUDIES

Benthic macroinvertebrate density and taxonomic composition are often used as biological indicators of the impact of pollution on river ecosystems (Rosenberg and Resh 1993). In the Athabasca, Lesser Slave, Wapiti and Smoky rivers, the NRBS, Alberta Environmental Protection, Weldwood of Canada Ltd., Alberta Newsprint Co., Millar Western Pulp Ltd., Slave Lake Pulp Corp., and Weyerhaeuser Canada Ltd. (formerly Procter and Gamble Cellulose Ltd.) have all monitored the benthic invertebrate community (Beak 1960; Beak Consultants Ltd. 1973, 1975a, 1975b, 1976, 1977, 1978, 1979, 1980, 1981; Sergy and Ruggles 1975; Exner and Reynoldson 1976; Integrated Environmental Sciences Inc. 1982, 1983, 1984a, 1984b, 1986a, 1986b; Gregoire and Anderson 1987; Beak Associates 1988, 1989, 1990a, 1990b, 1991a, 1991b; Terrestrial and Aquatic Environmental Managers Ltd. 1988, 1989a, 1989b, 1990, 1991a, 1991b, 1991c, 1992a, 1992b, 1992c, 1993a, 1993b, 1993c; Anderson 1989, 1991; Noton 1989; Sentar Consultants Ltd. 1992a, 1992b, 1992c, 1993a, 1993b, 1993c, 1994c, 1995a, 1995b; R. L. and L. Environmental Services Ltd. 1993a, 1993b, 1993c, 1993d; Saunders and Dratnal 1994; Westworth and Associates Ltd. 1995). Not all data are comparable, however, due to differences in sampling protocol and levels of taxonomic identification. Scrimgeour *et al.* (1995b) noted that sampling methods ranged from semi-quantitative net sweeps to artificial substrata and, more recently, quantitative area-restricted sampling methods (e.g., Neil and Hess samplers). In addition, sampling procedures also varied with respect to net mesh size. Data collected on the mainstem of the Athabasca River since 1983 and the Wapiti River since 1987 are comparable with respect to sample collection and processing protocols. In fact, for these years sampling protocols within each habitat type are highly consistent in terms of sampler type (i.e., Neil or Hess samplers), replication, and sample processing techniques including the level of taxonomic resolution. However, the Lesser Slave River data are not comparable due to differences in substratum characteristics (fine sediments in upper reaches; cobble in lower reaches) and methodology (Ponar dredge for fine sediments and Hess sampler for cobbles).

Analysis of spring and fall samples from 1983-1986 inclusive (Anderson 1991) and May 1984 and October 1985 (Anderson 1989) showed that 1 km below the Hinton outfall, benthic invertebrate densities increased significantly ($P < 0.0001$) with both pollution tolerant and intolerant taxa increasing in numbers (Figure 5.3). Further downstream (20-50 km), densities decreased and there was a shift in species composition wherein taxa such as midges (notably Chironomidae) or worms (Oligochaeta) became more abundant and taxa such as mayflies (Ephemeroptera) somewhat less abundant. Spring surveys by Weldwood of Canada Ltd. in 1984, 1986, 1989, 1991 and 1992 showed similar patterns with densities increasing by an order of magnitude 0.8-9 km downstream of the outfall and then returning to background at 44 km downstream (Terrestrial and Aquatic Environmental Managers 1992b). In addition, these surveys found that Ephemeroptera and Chironomidae numerically dominated the benthic invertebrate community at upstream control stations while Chironomidae were dominant below the outfall. This shift in abundance was due to an increase in the number of Chironomidae and not a decrease in Ephemeroptera densities; therefore, there was an overall increase in number of organisms. Likewise, an under-ice survey conducted for the NRBS in March 1993 by R.L. and L. Environmental Services Ltd. (1993d) showed that benthic invertebrate densities increased downstream of Hinton, largely due to increased numbers of Orthocladinae and *Baetis* sp, with

Figure 5.3 Benthic invertebrate densities in the Athabasca River near Hinton in spring 1984 and fall 1985 (after Anderson 1989).

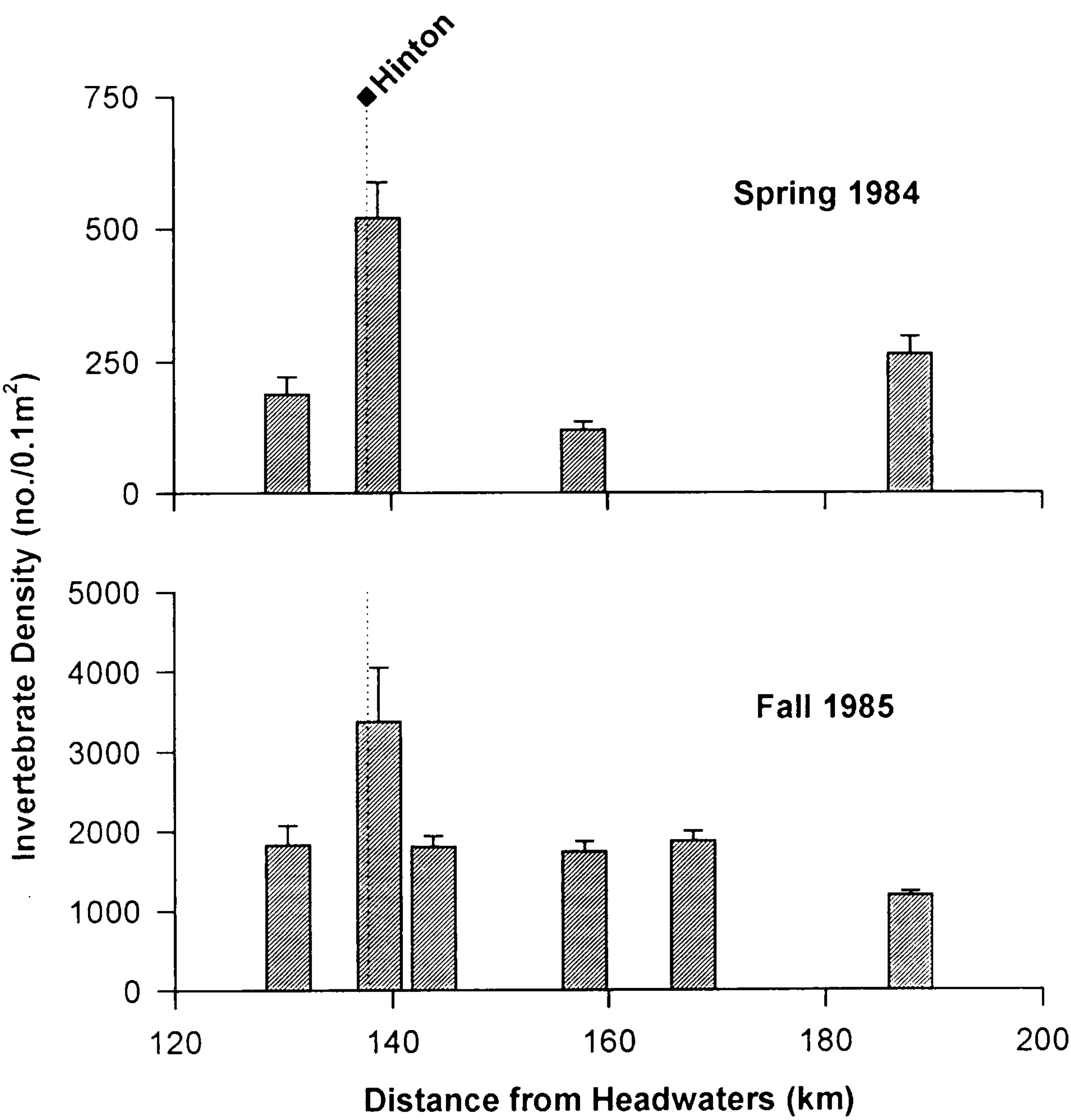
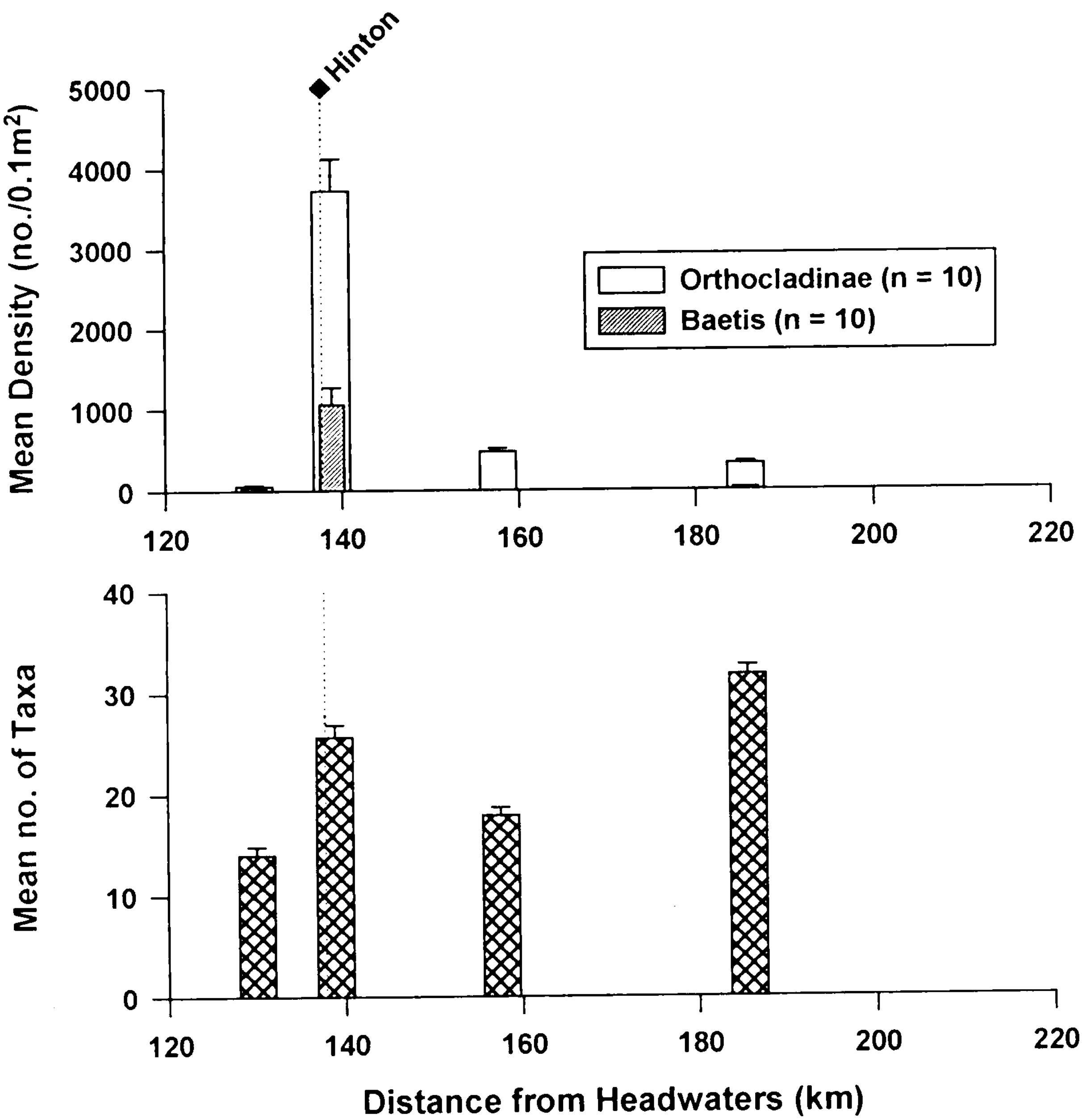


Figure 5.4 Benthic invertebrate densities in the Athabasca River near Hinton in March 1993 (R.L. and L. Environmental Services Ltd. 1993d; Saunders and Dratnal 1994).



little change in the number of taxa (Saunders and Dratnal 1994; Figure 5.4). These results suggest nutrient enrichment in the absence of contaminant toxicity. Principal component analysis by Anderson (1989) also showed that the increase in densities downstream of the outfall was associated with water quality variables relating to enrichment. Benthic invertebrate studies conducted by Sentar Consultants Ltd. (1992b; formerly Beak Associates 1990b, 1991a,b) and EVS Consultants (1992) for the Alberta Newsprint Co. near Whitecourt also concluded that effluent loading increased densities immediately downstream of the outfall without eliminating any taxa (Figure 5.5). Thus, mean numbers of organisms within both tolerant taxa such as Chironomidae and less tolerant taxa such as Ephemeroptera and Plecoptera increased downstream of the Alberta Newsprint Co. in response to organic enrichment. Surveys of benthic invertebrate communities downstream of the Millar Western Pulp Ltd. outfall also suggested an enrichment response in which the densities of both certain tolerant (mainly Oligochaeta) as well as intolerant taxa (Ephemeroptera and Plecoptera) taxa increased, with increasing proportions of tolerant taxa at downstream sites (Sentar Consultants Ltd. 1992b) (Figure 5.5).

The lower Athabasca River has been surveyed less frequently for benthic invertebrates. Early studies were conducted as part of the Alberta Oil Sands Environmental Research Program (AOSERP) from 1975-1979 (McCart *et al.* 1977, 1978; Hartland-Rowe *et al.* 1979; Barton and Wallace 1980; Crowther and Lade 1981; Corkum 1985) and in 1981-1987 by Alberta Environment (Boerger 1983; Walder and Mayhood 1985; Anderson 1991). The invertebrate communities at the two long-term Alberta Environment sites (upstream of Fort McMurray and at Embarras) were typical of a larger, slower-moving river with depositional sediments in that population diversity and community diversity tended to be lower than in the Hinton area and the community was dominated by Chironomidae, Oligochaeta and Nematoda.

In the Wapiti River, early studies from the mid-1970's indicated little effect of the mill effluent on the benthic macroinvertebrate community (Noton *et al.* 1989). However, a considerable reduction in benthic invertebrate densities was observed in 1980 following low river flows (Noton *et al.* 1989). By 1983, benthic invertebrate densities and, to a lesser extent, number of taxa had increased in the lower Wapiti River and the Smoky River as far downstream as Watino (Noton *et al.* 1989). More recent surveys by Noton (1992) in October 1989 and February 1991 also showed higher densities and similar number of taxa upstream and downstream (for about 20 km) of the Grande Prairie municipal and pulp mill outfalls (Figure 5.6a). Surveys undertaken by Terrestrial and Aquatic Environmental Managers Ltd. (1990, 1991b, 1992a, 1993a) for Weyerhaeuser Canada Ltd. (formerly Procter and Gamble Cellulose Ltd.) in October 1990 and 1992, April 1991 and January 1992 also showed increased benthic invertebrate densities downstream of the municipal and pulp mill outfalls (Figure 5.6b). The treated municipal and pulp mill effluents had either a positive influence or no effect on the number of taxa. However, on some dates, there was a shift in the proportional representation of different taxa such that in October 1990, Chironomidae increased in density below the sewage and pulp mill outfalls whereas in April 1991, Chironomidae densities decreased while Naididae densities increased below the sewage outfall. Overall, there was increased densities of some species but no loss of taxa. These results indicate that, except for the low flow period in 1980, the response of the benthic invertebrate community in the Wapiti River to municipal and pulp mill loading is one of enrichment and there is no evidence of toxicity.

Figure 5.5 Benthic invertebrate densities in the Athabasca River near Whitecourt in October 1991 (Sentar Consultants Ltd. 1992b, c).

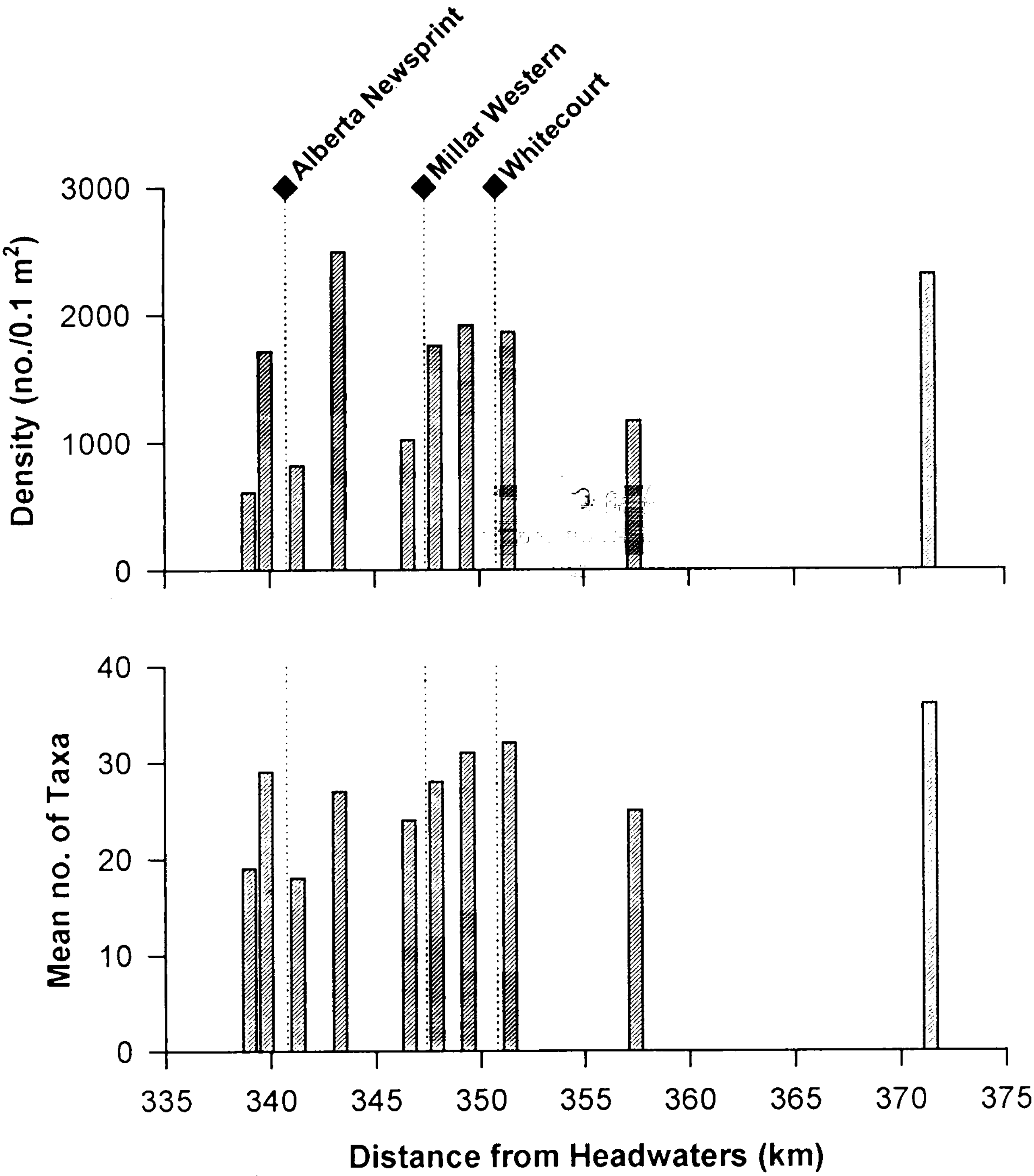
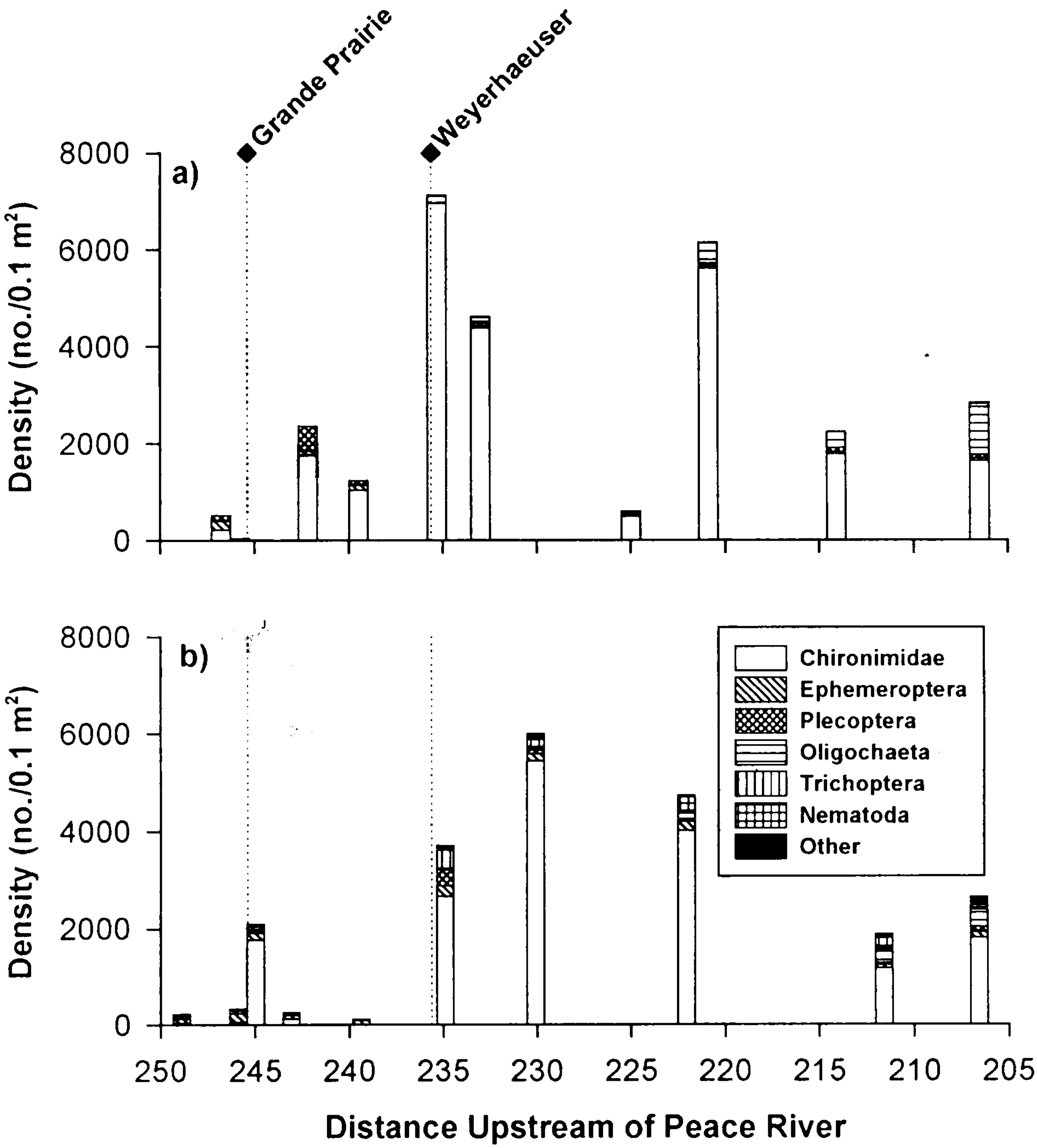


Figure 5.6 Benthic invertebrate densities in the Wapiti River in: (a) February 1991 (after Noton 1992), and (b) January 1992 (Terrestrial and Aquatic Managers Ltd. 1992a).



As part of the NRBS, Scrimgeour *et al.* (1995b) assessed long-term trends in benthic macroinvertebrate community structure in the Athabasca River upstream and downstream of: (1) the Weldwood of Canada Ltd. pulp mill at Hinton, (2) the Alberta Newsprint Co. and Millar Western Pulp Ltd. mills near Whitecourt, and (3) the Weyerhaeuser Canada Ltd. mill at Grande Prairie. Cluster analysis of nine, six and five years of data for the Hinton, Whitecourt and Grande Prairie areas, respectively, showed that benthic macroinvertebrate community structure did not differ between sites located upstream and downstream of pulp mill outfalls. In many cases, upstream sites formed strong clusters with sites located immediately downstream of outfalls. These results indicate that, while changes in taxonomic composition were observed below some outfalls in certain years (e.g., Terrestrial and Aquatic Environmental Managers 1991b, 1992b), there was no consistent long-term effect of pulp mill effluent and that taxonomic variability was greater between years than between sites located upstream and downstream of an outfall. While other factors (e.g., high variation in community structure, confounding responses to complex effluents) could mask effects of the outfalls on benthic communities, it is most likely that the <1-4% dilution of pulp mill effluent in the Athabasca and Wapiti rivers resulted in effluent concentrations that are below threshold levels for a long-term shift in community structure.

5.3 IMPACTS OF EFFLUENT ON SMALL FISH SPECIES: *IN SITU* STUDIES

As part of a NRBS program to evaluate the suitability of small fish species as biomonitors of pulp mill effluents in receiving waters, spoonhead sculpin (*Cottus ricei*) and lake chub (*Couesius plumbeus*) were collected from upstream and downstream of Hinton and Whitecourt, respectively (Gibbons *et al.* 1996). Smaller fish species, such as cyprinids and cottids, have been advocated as possible *in situ* biomonitors of environmental stress since they typically occupy a smaller home range relative to larger species (Gibbons *et al.* 1996). Spoonhead sculpin collected 1 km downstream of the Hinton outfall were found to be heavier, longer, fatter and had larger gonad and liver weights than reference fish collected upstream of the outfall (Figure 5.7). The increased size in the downstream fish likely represents a response to increased food supply (i.e., a nutrient enrichment response). The fact that spoonhead sculpin (as well as lake chub) are insectivores (Scott and Crossman 1985) and that benthic invertebrate densities are greater downstream of Hinton (Section 5.3) supports this hypothesis of enrichment. In contrast, there were no significant differences ($P>0.15$) in length or weight of male or female lake chub collected approximately 2 km upstream of the Alberta Newsprint Co., 3.5 km downstream of the Alberta Newsprint Co., and 2.25 km downstream of Millar Western Pulp Ltd. (Figure 5.8). Gonad and live weight were also similar for male and female fish from the reference and impacted reaches near Whitecourt, except for larger livers ($P=0.02$) in males downstream of the Alberta Newsprint Co.

The similarity in body size of fish from upstream and downstream of the Whitecourt mills and the increase in body size downstream of the Hinton outfall contrasts with studies of fish populations in receiving waters from bleached kraft mills in eastern Canada (e.g., McMaster *et al.* 1991, 1992; Munkittrick *et al.* 1991). They found that fish collected downstream of bleached kraft mill effluents usually had reduced body size, smaller gonads, and larger livers and attributed this response to some form of metabolic disruption. In contrast, fish in the Athabasca River appeared to show an enrichment response (i.e., increased body size) downstream of

Figure 5.7 Body weight and length and gonad and liver weight of male and female spoonhead sculpin (*Cottus ricei*) collected from the Athabasca River during spring 1994 upstream and downstream of the Weldwood of Canada Ltd. effluent outfall at Hinton, Alberta (after Gibbons *et al.* 1996).

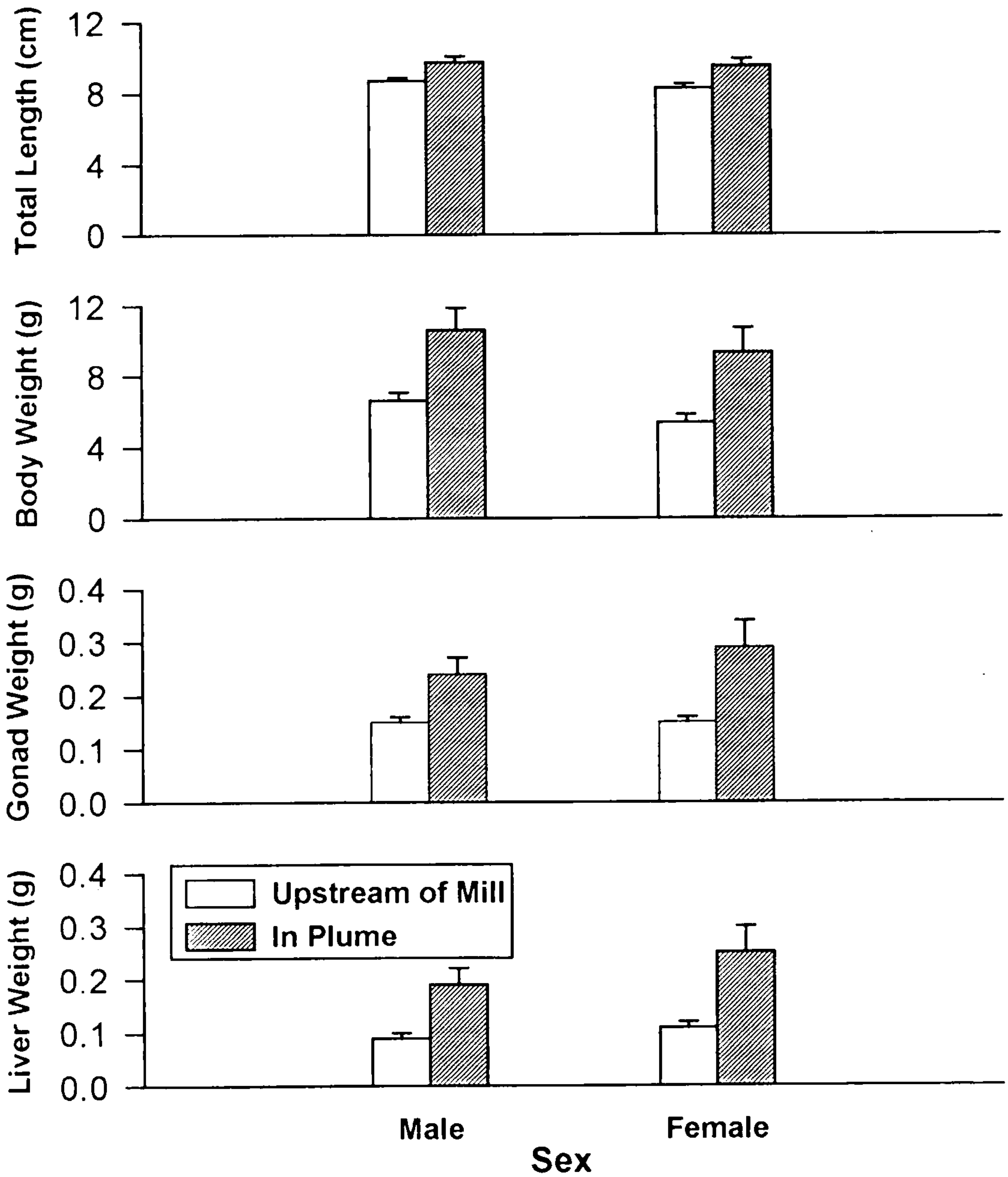
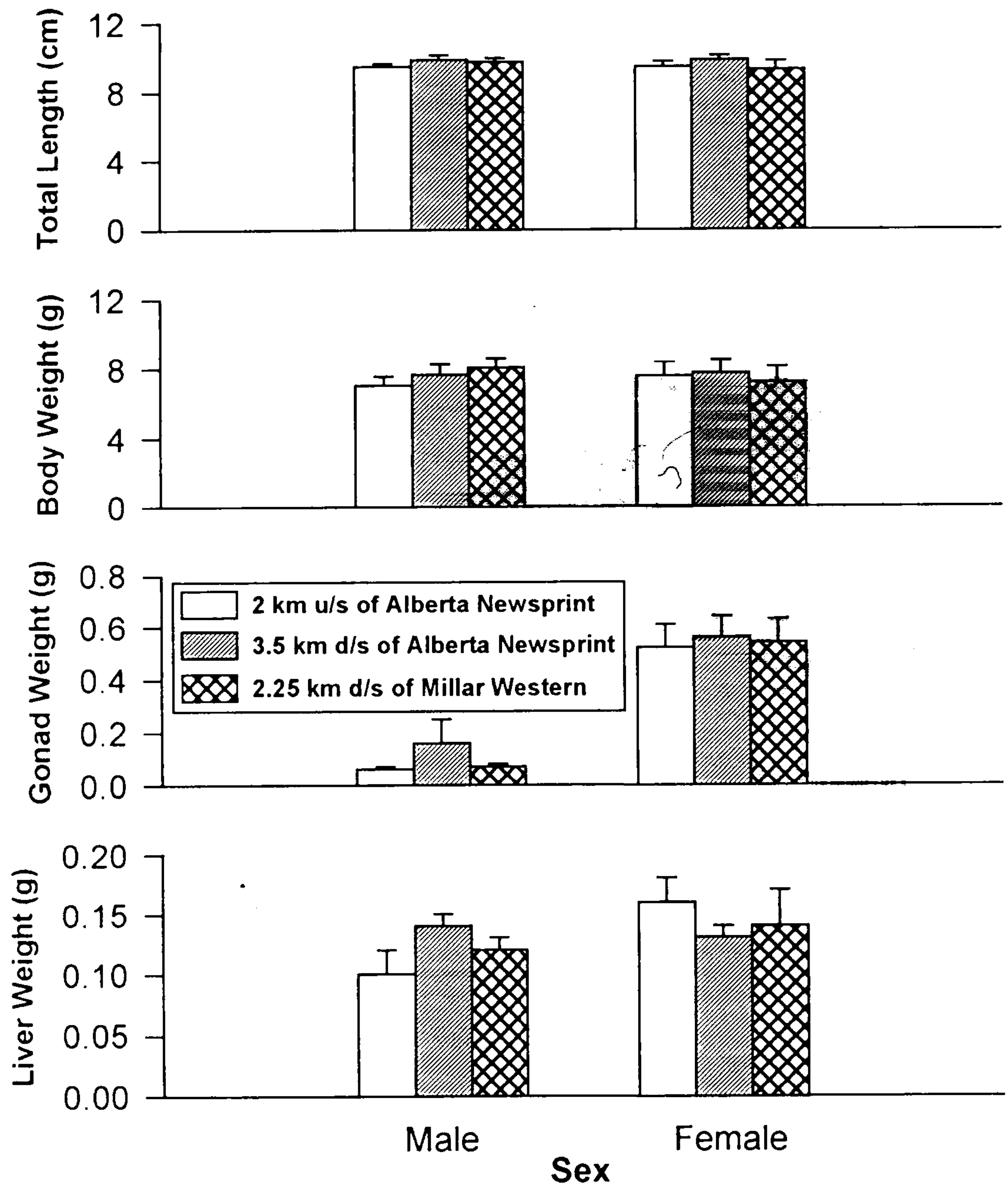


Figure 5.8 Body weight and length and gonad and liver weight of male and female lake chub (*Couesius plumbeus*) collected from the Athabasca River during fall 1994 upstream and downstream of the Alberta Newsprint Co. and Millar Western Pulp Ltd. effluent outfalls at Whitecourt, Alberta (after Gibbons *et al.* 1996).



Hinton or no response with respect to body metrics downstream of the Whitecourt mills. The enrichment response seen in the sculpins downstream of Hinton is consistent with studies by Peterson *et al.* (1985) which showed an increase in body size of Arctic grayling downstream of the point of nutrient enrichment in the Kuparuk River, Alaska. The lack of an enrichment response in the lake chub population despite increases in periphyton biomass and benthic invertebrate densities downstream of the Whitecourt outfalls (Sections 5.2 and 5.3) may relate to the fact that chub are more mobile than sculpins and are pelagic feeders (McPhail and Lindsey 1970) and, thus, rely less on benthic invertebrates as the primary food source .

5.4 *IN SITU* ASSESSMENT OF NUTRIENT LIMITATION

Spatial patterns in nutrient limitation in the Athabasca and Wapiti-Smoky rivers were investigated using nutrient diffusing substrata (Scrimgeour *et al.* 1995a; Scrimgeour and Chambers 1996). The nutrient diffusing substrata consisted of porous clay flower-pots that were filled with agar prepared with deionized distilled water alone (controls) or deionized distilled water and the test compound (i.e., P as PO_4^{3-}, N as NO_3-, or N+P), and then sealed on the bottom with a polypropylene base (Figure 5.9a). The nutrient diffusing substrata were then attached to the riverbed with plastic pegs (Figure 5.9b). Trial experiments conducted between October-December 1993 showed that upstream of Hinton, periphyton biomass and invertebrate densities were higher on substrata enriched with P and P+N compared to control and N-enriched substrata (Figure 5.10). In contrast, neither periphyton biomass nor invertebrate densities were affected by nutrient addition downstream of the Hinton outfall. These results showed that downstream of Hinton, nutrient availability exceeds periphyton requirements for maximum growth whereas upstream of Hinton, periphyton abundance is constrained by insufficient P.

The finding that nutrient diffusing substrata could be used successfully in the Athabasca River to identify river reaches that are nutrient-limited led to the expansion of the study in fall 1994 to 28 sites in the Athabasca River and five sites in the Wapiti-Smoky river system (Table 5.3; Scrimgeour and Chambers 1996). Comparison of periphyton biomass on nutrient diffusing substrata enriched with P, N or N+P and unamended controls showed that periphyton biomass at 15 of 28 sites in the Athabasca river system was limited by P, N or a combination of N+P (Table 5.3). Thus, periphyton growth was constrained by insufficient P upstream of Jasper, 12 km downstream of Jasper, and 1 km upstream of Hinton; by insufficient N in the reach from 1.5 km downstream of the Alberta Newsprint Co. to 10 km upstream of the confluence with the Lesser Slave River; and by insufficient N+P 4 km downstream of Jasper, 4 km downstream of AlPac and 4 km upstream of Fort McMurray (Figure 5.11). Periphyton biomass was nutrient saturated for at least 2.5 km downstream of Jasper, 156 km downstream of Hinton and 3 and possibly up to 48 km downstream of Fort McMurray (i.e., to Fort MacKay). In the Wapiti-Smoky rivers, periphyton growth was limited by N+P upstream of Grande Prairie and downstream of the Grande Prairie sewage outfall but upstream of the Weyerhaeuser outfall, and by N in the Smoky River (Figure 5.11). Immediately downstream of the Weyerhaeuser outfall, periphyton biomass was nutrient saturated.

The observation that the Athabasca River is P limited upstream of Jasper, Hinton and Fort McMurray and not nutrient limited downstream of these sources of municipal and/or pulp mill effluent is not surprising and has been suggested by others (Noton 1990). However, the finding that reaches of the Athabasca and Wapiti-Smoky rivers are N limited is contrary to the accepted belief that these systems are P limited throughout their length except immediately below effluent outfalls (Noton 1990). The *in situ* experiments by Scrimgeour and Chambers (1996) showed that in fall 1994, periphyton growth was N limited in the Athabasca River from 1.5 km downstream of the Alberta Newsprint Co. to 10 km upstream of the confluence with the Lesser Slave River and in the Smoky River from Bezanson to Watino. In addition, N+P limitation of periphyton biomass occurred in the Athabasca River 4 km downstream of AlPac and 4 km upstream of Fort McMurray, and in the Wapiti River upstream of the Weyerhaeuser outfall. The observation that seven of the ten N-limited sites had DIN:SRP mass ratios < 9 on at least one of the two sampling dates substantiates the experimental finding of N limitation. Of the five P-limited sites, three had DIN:SRP mass ratios > 11. The onset of N limitation immediately downstream of the Alberta Newsprint Co. outfall and its continuance for approximately 230 km downstream likely relates to the low N relative to P concentrations in the Alberta Newsprint Co., Millar Western Pulp Ltd. and Whitecourt sewage effluents. While DIN and SRP data are not available, TN:TP mass ratios for these effluents averaged 0.8, 2.9 and 2.3, respectively, compared to ratios of 7.2 and 7.6 for Weldwood of Canada Ltd. and Weyerhaeuser Canada Ltd., respectively (McCubbin and AGRA Earth and Environmental 1989). In the case of the Smoky River, the river may be naturally N limited or its headwaters may be N+P co-limited (like the headwaters of the Wapiti River) and input of the Weyerhaeuser of Canada Ltd. effluent (which is disproportionately higher in phosphorus, TN:TP = 7.6) may switch the river to N limitation.

5.5 ASSESSMENT

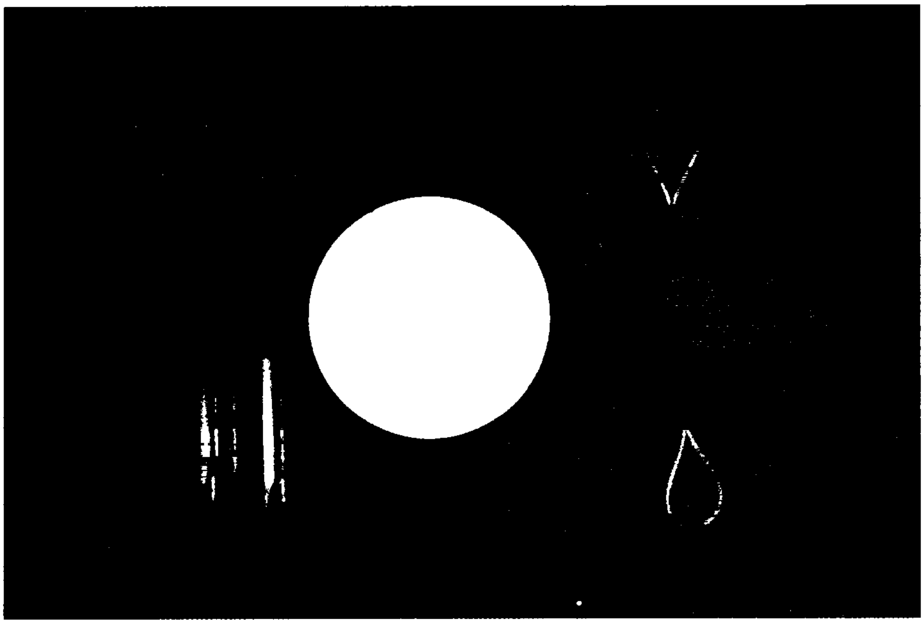
Periphyton growth in the Athabasca and Wapiti-Smoky rivers is greatest in fall after the high summer flows and turbidity have subsided. At this time, high (> 100 mg/m^2) biomasses of periphyton are often observed downstream of Jasper, Hinton, Whitecourt and Fort McMurray in the Athabasca River and downstream of the Grande Prairie STP and Weyerhaeuser Canada Ltd. bleached kraft pulp mill in the Wapiti River. The occurrence of high periphyton biomasses downstream of Fort McMurray is consistent with the observation of increased algal growth by 86% of 35 interviewees in the Fort McMurray area (Bill and Flett 1996). Enrichment studies conducted with nutrient diffusing substrata in fall 1994 showed that periphyton growth was nutrient saturated on the Athabasca River for at least 2.5-4 km downstream of Jasper, from downstream of Hinton to upstream of Whitecourt and for at least 3 km and possibly up to 48 km downstream of Fort McMurray and, on the Wapiti River, for at least 11.5 km downstream of the Weyerhaeuser mill. Phosphorus concentrations at sites immediately upstream of the outfalls to these nutrient-saturated reaches were usually less than 2 g/L SRP for the Athabasca River and 4-6 g/L SRP for the Wapiti River. Within the reaches of nutrient saturation, SRP concentrations were 3 to 7 and, at one site, 40 g/L in the Athabasca River and 21 g/L in the Wapiti River. Nitrogen limitation was observed in the Athabasca River from downstream of the Alberta

Newsprint Co. outfall to the Lesser Slave River and in the Smoky River. DIN concentrations were 14-48 g/L in the N-limited reach of the Athabasca River and 25 g/L in the N-limited Smoky River. In the Athabasca River, most reaches showing no N limitation had DIN concentrations that were usually > 30-40 g/L. However, the N limitation in the Smoky River is surprising given that DIN concentrations are comparable to those of N+P saturated sites (i.e., 19 g/L downstream of the Weyerhaeuser mill in the Wapiti River).

The effect of enhanced periphyton production due to effluent loading has transferred to higher trophic levels in the food web. Benthic invertebrate communities downstream of pulp mill discharges showed increased densities and diversity. There were also no changes in taxonomic composition over the long term (i.e., > 5 yr) (Scrimgeour *et al.* 1995b), with variability in taxonomic composition being greater between years than between sites located upstream and downstream of outfalls. In addition, the insectivorous small fish species *Cottus ricei* (spoonhead sculpin) was found to be heavier, longer, fatter and have larger gonad and liver weights downstream than upstream of a the bleached kraft mill discharge at Hinton (Gibbons *et al.* 1996). These studies all show that the response to effluent addition is one of nutrient enrichment and not a toxicity response such as reduced feeding rate, growth, fecundity or death which would be caused by elevated concentrations of terpenes (Rosenthal and Janzen 1979; Harborne 1990), chlorinated lignin residuals (Petersen and Petersen 1984) or other deleterious compounds in bleached kraft mill effluent.

The observation of N-limited conditions in the 230 km reach of the Athabasca River between the Alberta Newsprint Co. and the Lesser Slave River and the approximately 120 km reach of the Smoky River (from Bezanson to Watino) raises concerns about potential chlorate (ClO_3-) toxicity. Weldwood of Canada Ltd. and Weyerhaeuser Canada Ltd. converted from molecular chlorine to chlorine dioxide bleaching between 1990-1992. Chlorate ions formed during bleaching with chlorine dioxide have been found to be toxic to some marine algae under conditions of N limitation. For example, the die-off of the brown macro-algae *Fucus vesiculosus* along the Swedish coast and the resulting shift from a herbivore/omnivore system to one of lower productivity dominated by detritivores has been linked to chlorate (Rosemarin *et al.* 1986; Lehtinen *et al.* 1988). However, the replacement of *F. vesiculosus* by red algae and diatoms (notably *Melosira* sp.), cyanophytes and chlorophytes also indicated differences in sensitivity to chlorate exposure between taxa (Lehtinen *et al.* 1988). The toxicity of chlorate only under N-limited conditions results from competition by both chlorate and nitrate for transport sites (Balch 1987). Nitrate uptake rates are about 1000 times greater than uptake of chlorate. Thus, uptake of chlorate by plants typically occurs only under conditions of N limitation. In the case of marine algae, toxic effects have only been observed when nitrate concentrations were < 5 g/L N (Balch 1985, 1987; Lehtinen *et al.* 1988). The presence of ammonium also appears to inhibit chlorate transport, possibly by blocking the enzymes responsible for nitrate and, thus, chlorate uptake (Conway 1977). Little information is available about chlorate toxicity in freshwaters; however, Perrin and Bothwell (1992) found that additions of up to 500 g/L chlorate had no effect on growth rates or biomass accumulation of periphyton diatom communities grown in artificial

Figure 5.9 Nutrient diffusing substrata: (a) being assembled in the laboratory, and (b) deployed in the river (Scrimgeour *et al.* 1995a).



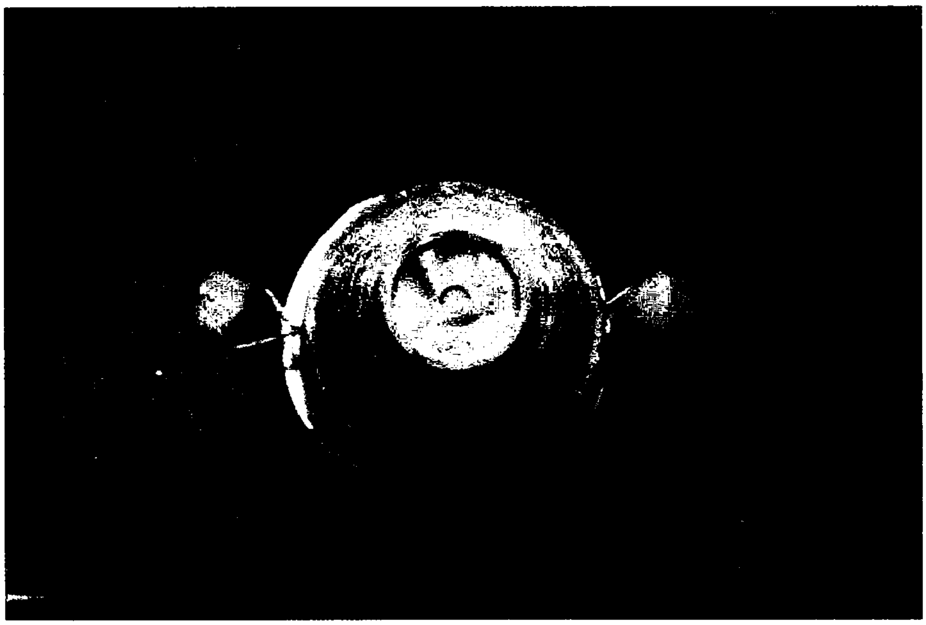


Figure 5.10 **Periphyton biomass (expressed as chlorophyll a concentration) from nutrient diffusing substrata enriched with phosphorus (P), nitrogen (N), N+P or unamended controls: (a) upstream, and (b) downstream of the Weldwood of Canada Ltd. effluent outfall at Hinton, Alberta in fall 1993 (Scrimgeour *et al.* 1995a).**

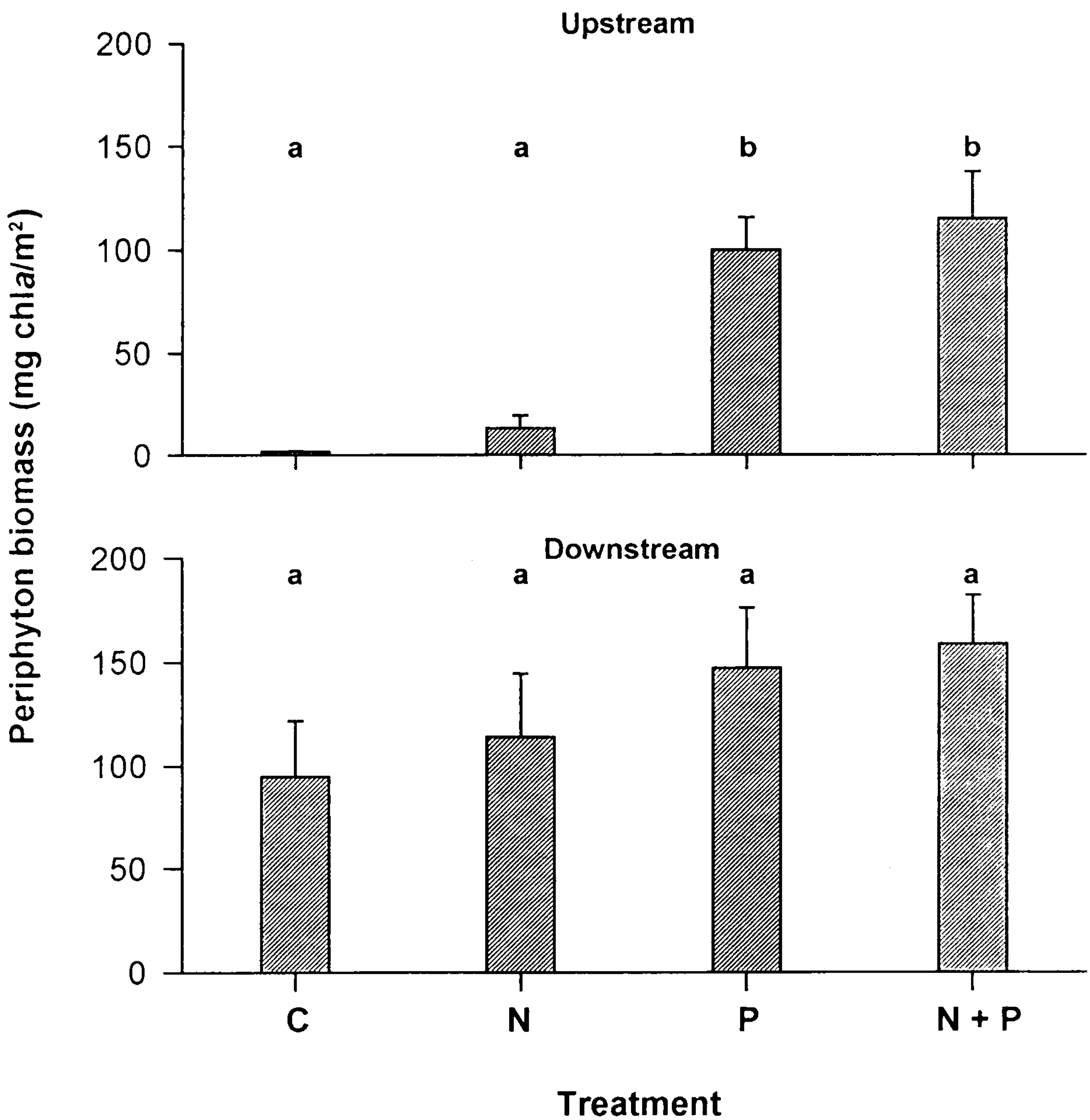
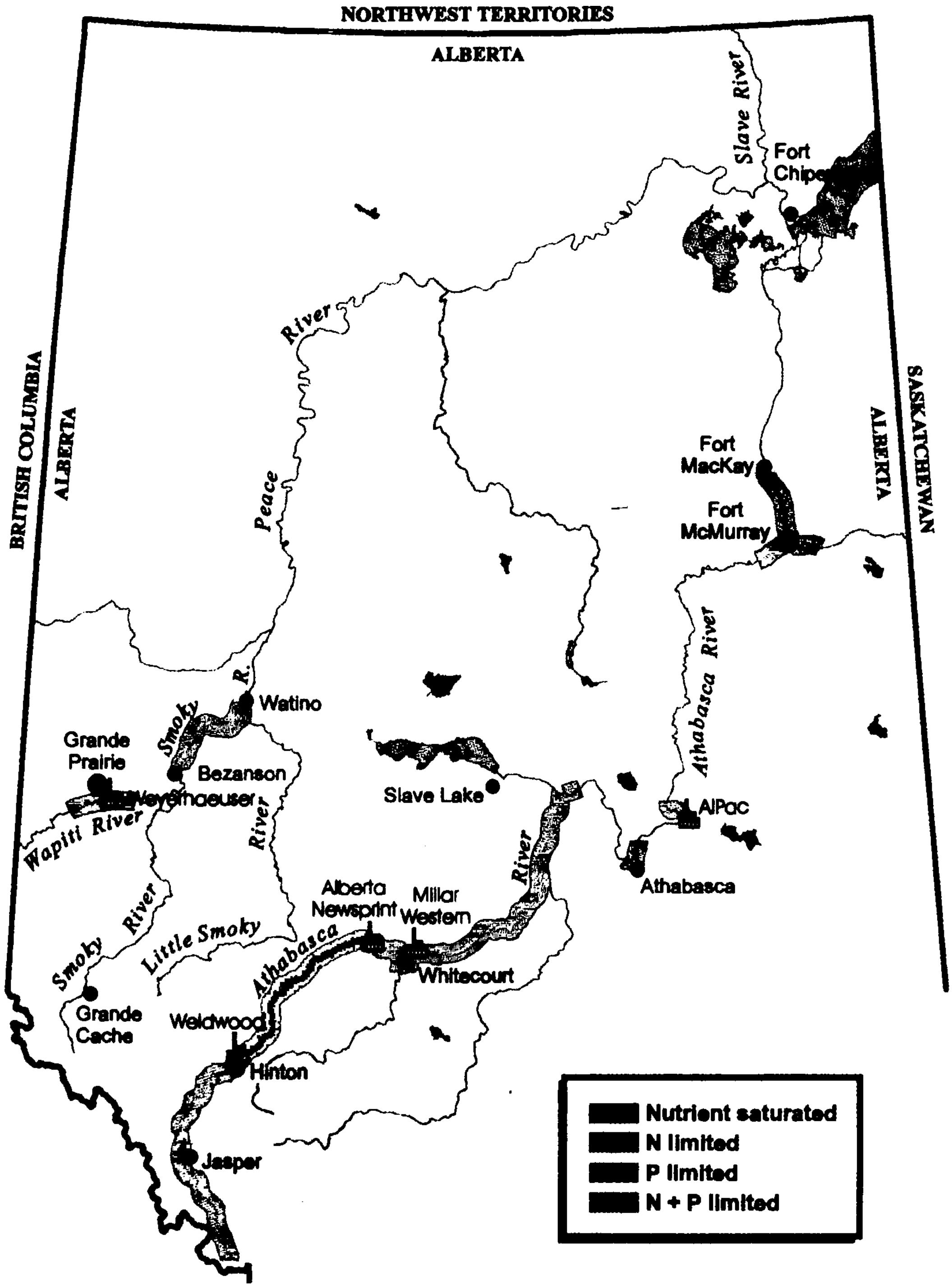


Table 5.3 **Nutrient status as determined from deployment of nutrient diffusing substrata at 28 sites on the Athabasca and five sites on the Wapiti-Smoky river systems (Scrimgeour and Chambers 1996). (Distance is the distance downstream of the uppermost sampling site on the Athabasca (i.e., approximately 2 km upstream of the confluence with the Sunwapta River) or upstream of the Peace River for the Wapiti-Smoky rivers). Open-water DIN:SRP are shown for water samples collected when the diffusing substrata were installed and removed. A DIN:SRP ratio of E means SRP 30 g/L and DIN 190 g/L and signifies that SRP and DIN concentrations likely exceed saturating concentrations for the periphyton mat (after Bothwell 1989). N/A indicates data not available; ANC is Alberta Newsprint Co.; MWPL is Millar Western Pulp Ltd.; STP is sewage treatment plant.**

Site	Distance (km)	Nutrient Diffusing Substrata		Open-Water DIN:SRP
		Pairwise Comparison	Interpretation	
Athabasca River				
0.7 km u/s Jasper STP	55.3	C=N<P=N+P	P limited	70.1, 41.6
2.5 km d/s Jasper STP	58.5	C=N=P=N+P	N & P saturated	38.9, 18.1
4 km d/s Jasper STP	60	C<P=N=N+P	N+ P limited	43.4, 11.4
12 km d/s Jasper STP	68	C=N<P=N+P	P limited	34.4, 5.5
1 km u/s Hinton	136.8	C=N<P=N+P	P limited	>17, 30.3
1 km d/s Hinton	138.8	C=N=P=N+P	N & P saturated	N/A, 7.0
20 km d/s Hinton	157.8	C=N=P=N+P	N & P saturated	N/A, 9.5
120 km d/s Hinton	274.6	N<C=P=N+P	N & P saturated	2.8, 35.5
156 km d/s Hinton; 30 km u/s ANC	310.6	C=N=P=N+P	N & P saturated	20.3, 29.0
1.5 km d/s ANC; 8.3 km u/s MWPL	342.1	C=P<N=N+P	N limited	15.5, 10.4
2 km d/s MWPL; 2 km u/s Whitecourt STP	348.8	C=P<N=N+P	N limited	15.3, 8.6
9 km d/s Whitecourt STP	359.8	C=P<N=N+P	N limited	20.2, N/A
20 km d/s Whitecourt STP	370.8	C=P<N=N+P	N limited	21.0, 0.63
1 km d/s Fort Assiniboine	443	C=P<N=N+P	N limited	6.1, 1.2
25 km d/s Fort Assiniboine	467	C=P<N=N+P	N limited	9.2, 2.7
10 km u/s Lesser Slave River	575	C=P<N=N+P	N limited	2.6, 14.5
3 km d/s Lesser Slave River	588	C=N<P=N+P	P limited	N/A, 2.4
1 km u/s Athabasca STP	692	C=N=P=N+P	N & P saturated	6.7, 7.3
1 km d/s Athabasca STP	694	C=N=P=N+P	N & P saturated	E, E
3 km d/s Athabasca STP; u/s AlPac	696	C=N=P=N+P	N& P saturated	8.2, 2.6

4 km d/s AlPac	712	C=N=P<N+P	N + P limited	N/A, N/A
4 km u/s Fort McMurray STP	1083	C<N=P<N+P	N + P limited	N/A, 16.4
1 km u/s Fort McMurray STP	1086	C<N<P=N+P	P limited	N/A, 7.3
1 km d/s Fort McMurray STP	1088	C=N=P=N+P	N& P saturated	N/A, E
3 km d/s Fort McMurray STP	1090	C=N=P=N+P	N& P saturated	74.8, E
1 km d/s Fort MacKay	1136	C=N=P=N+P	N& P saturated	3.3, 8.5
McLeod River				
2.5 km u/s of confluence with Athabasca R.	346.9	C=P<N=N+P	N limited	6.2, 5.5
Clearwater River				
7 km u/s of confluence with Athabasca R.	1086.5	C=N=P=N+P	N& P saturated	N/A, 4.8
Wapiti-Smoky River				
3 km u/s Grande Prairie STP	248.5	C=P<N=N+P	N + P limited	2.4, 1.7
4.5 km d/s Grande Prairie STP; u/s Weyerhaeuser	241	C<P<N<N+P	N + P limited	4.1, 2.3
11.5 km d/s Grande Prairie STP; 2 km d/s Weyerhaeuser	234	C=N=P=N+P	N& P saturated	1.1, N/A
35 km d/s Weyerhaeuser; 12 km d/s Wapiti-Smoky confluence (upstream of Bezanson)	192	C=P;C=N+P; N=N+P	N limited	4.3, 1.8
157 km d/s Weyerhaeuser; 135 km d/s Wapiti-Smoky confluence (upstream of Bezanson)	70	C=P<N=N+P	N limited	10.0, N/A

Figure 5.11 Map of the Peace-Athabasca river system showing zones of nutrient limitation or saturation for the Athabasca, Wapiti and Smoky rivers as assessed in fall 1994 using nutrient diffusing substrata (after Scrimgeour and Chambers 1996).



streams located along the South Thompson River at Chase, British Columbia. The lack of a chlorate effect may be due to: (1) insensitivity of diatoms to chlorate (either chlorate is not recognized as a nitrate analogue or chlorate is not reduced to the toxic chlorite), or (2) river-water nitrate concentrations were sufficiently high (5.8-11.5 g/L N) to inhibit chlorate uptake (although N addition showed that the diatom community was strongly N limited). Chlorate concentrations in the effluent of the Weldwood of Canada Ltd. and Weyerhaeuser Canada Ltd. pulp mills averaged 2.6 mg/L (range 1-14 mg/L, *n*=11 for 1994) and 29 mg/L (range 1-73 mg/L, *n*=53 for 1994), respectively (Alberta Environmental Protection Industrial Water Quality Database). Based on an average effluent discharge of 1.23 m^3/s for Weldwood and an average fall (September-October) discharge of 236 m^3/s at Windfall (1960-1988, Environment Canada 1989), then chlorate concentrations downstream of Windfall in autumn would average 14 g/L. Similar calculations for the Weyerhaeuser mill based on an average effluent discharge of 0.68 m^3/s and fall discharges of 76 m^3/s for the Wapiti River at Grande Prairie (1961-1988; Environment Canada 1989) and 260 m^3/s for the Smoky River at Watino (1915-1988; Environment Canada 1989) give average chlorate concentrations of 255 and 75 g/L in the Wapiti and Smoky rivers, respectively. More recent data from Weyerhaeuser Canada Ltd. show a reduction in chlorate concentrations in the effluent to 5.5 mg/L (ranging from below detection to 14 mg/L; *n*=32 for January - October 4, 1995). Based on this average, chlorate concentrations in the Wapiti and Smoky rivers would be 49 and 14 g/L, respectively. Comparison of these calculations for the Athabasca and Smoky rivers with the findings of Perrin and Bothwell (1992) indicate that chlorate toxicity is unlikely to be a problem in N-limited reaches of the Athabasca and Smoky rivers.

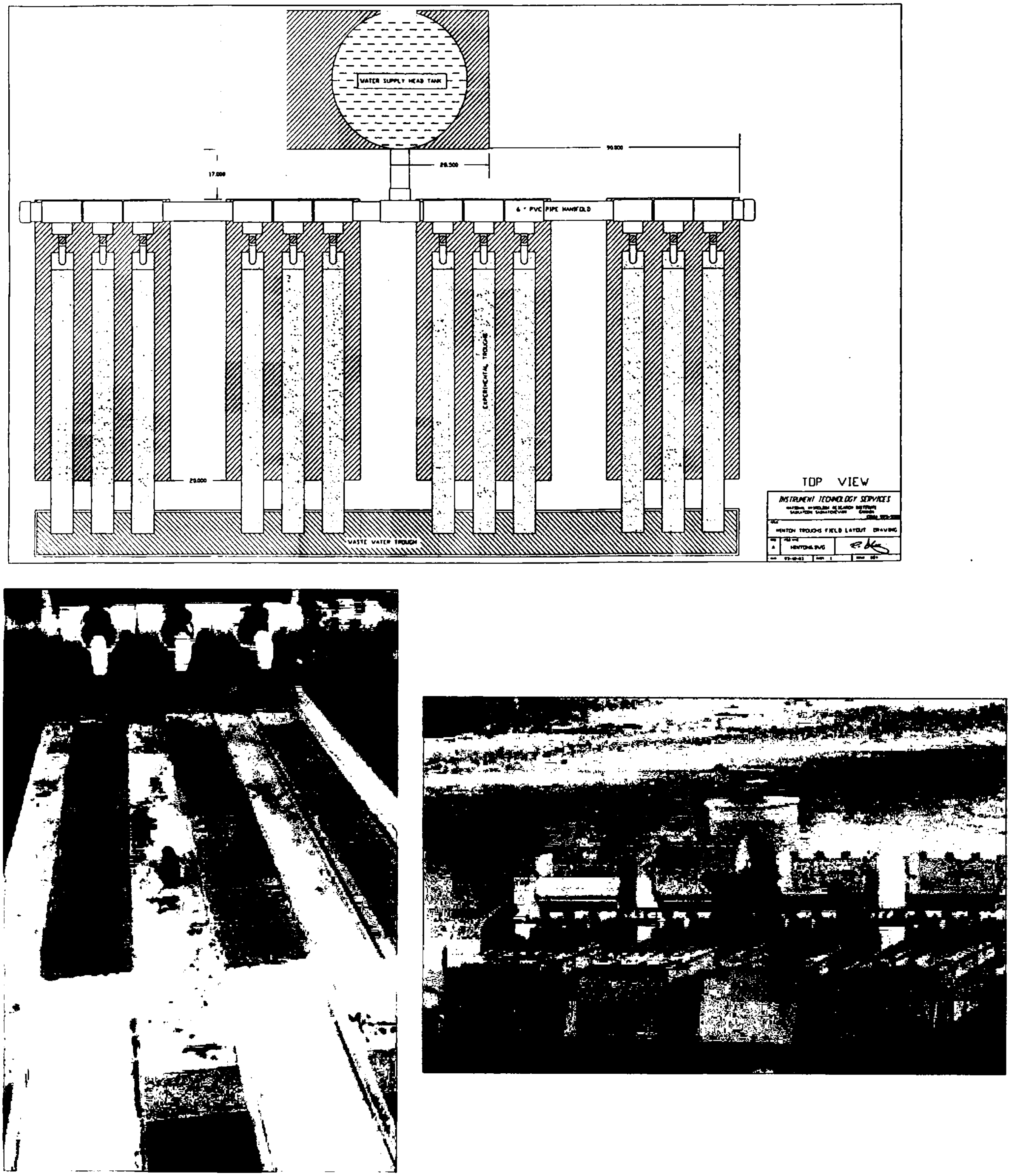
CHAPTER 6.0
EFFECTS OF NUTRIENTS AND CONTAMINANTS ON BIOTA: ARTIFICIAL STREAM STUDIES

6.0 EFFECTS OF NUTRIENTS AND CONTAMINANTS ON BIOTA: ARTIFICIAL STREAM STUDIES

In situ observations and experiments indicated that the main effect of mill effluent on benthic biota (algae, invertebrates and small fish species) was one of enrichment (Chapter 5). The aim of studies presented in this chapter was to quantify responses of periphyton to nutrient enrichment and isolate the effects of enrichment on periphyton and invertebrate communities from contaminant responses. Because both the high degree of spatial heterogeneity in natural environments and the lack of true replicates make it difficult to predict and verify the effects of effluent on riverine biota, artificial streams were employed to simulate key components of the riverine environment. Artificial streams have been used since the 1960's as a tool for examining the effects of augmentation of a limiting nutrient on periphyton growth and biomass and for investigating ecological interactions in running waters (see Lamberti and Steinman 1993 for review). The important advantage of the artificial stream approach lies in its capacity for quantifying benthic biotic responses in model systems that simulate specific conditions in large rivers while allowing for true replication of treatments and controls. By locating the artificial stream system beside the study river, natural river water can be supplied under ambient water temperature and light regimes.

In this chapter, two projects undertaken as part of the NRBS are summarized. The aim of the first project (Section 6.1) was to: (a) quantify periphyton growth in relation to P concentration, and (b) determine if the degree of P limitation varied seasonally in the upper Athabasca River. While *in situ* surveys and experiments indicated that P was the important nutrient regulating periphyton growth in the upper Athabasca River (from the headwaters to approximately Windfall, 170 km downstream of Hinton), the concentration of P causing a switch from acceptable to unacceptable periphytic biomass is unknown. In this study, 12 flow-through artificial streams were supplemented with 0 to 25 or 50 µg/L P to determine P responses of periphyton in the upper Athabasca River during spring and fall (Perrin *et al.* 1995; Dale and Chambers 1995a,b). The aim of the second project (Section 6.2) was to isolate the effects of nutrients and contaminants in bleached kraft mill effluent on complex food webs in the upper Athabasca River. Pulp mill effluents contain a wide variety of compounds that can have inhibitory (chemical toxicity) or stimulatory (through nutrient enrichment) effects on aquatic ecosystems (McLeay 1987; Hall *et al.* 1991; Bothwell 1992). In this study, 15 recirculating artificial streams stocked with a natural community of algae and benthic invertebrates from the upper Athabasca River were exposed to raw river water (control treatment), river water plus 1% bleached kraft mill effluent (from Weldwood of Canada Ltd.; see the NRBS database *Northdat* (McCubbin and AGRA Earth and Environmental 1995) for chemical composition of Weldwood effluent) or river water plus a 1% nutrient solution containing N and P in the concentrations found in the mill effluent (Culp and Podemski 1996a; Podemski and Culp 1996). Both artificial stream projects were conducted in the upper Athabasca River where nutrient concentrations are low and the largest point source of nutrient loading to the Athabasca River (the combined Hinton municipal and Weldwood of Canada Ltd. effluent) is located. Results from these projects quantified the response of periphyton to P enrichment and isolated the effects on nutrients from contaminants in pulp mill effluent on benthic algal and invertebrate communities.

Figure 6.1 Schematic diagram and photographs of the flow-through artificial streams located at Hinton, Alberta (Perrin *et al.* 1995). Note: tile arrangement differs from that in the experimental design.



6.1 RESPONSES OF PERIPHYTON TO NUTRIENT ENRICHMENT

To quantify the growth rate and biomass response of periphyton to P additions and assess the seasonality of nutrient limitation in the upper Athabasca River, P enrichment experiments were conducted during fall 1993 and spring and fall 1994 in flow-through artificial streams (Figure 6.1) located beside the Athabasca River at Hinton, Alberta. The streams were supplied with river water taken from upstream of the combined municipal and Weldwood of Canada Ltd. discharge at Hinton. P additions of 0 (control), 1, 10 and 25 µg/L P as PO_4^{3-}(spring and fall 1994) or 0 (control), 0.1, 0.2, 1, 5, 10, 25 and 50 µg/L P as PO_4^{3-} (fall 1993) were applied continuously by means of peristaltic pumps to 12 randomly selected streams from which Styrofoam (fall 1993) or tile (spring and fall 1994) substrata were sampled for periphyton biomass (expressed as chl*a* concentration) every 5-8 days from 8 to 30 days after start. Water samples were collected from the head tank and the outlet of each trough weekly and analysed for SRP and, for the head tank, $NO_2 + NO_3$, NH_4, TP and TDP concentrations. Specific growth rates were determined for each stream by regression analysis for chl*a* data fit to the exponential growth equation:

$$y=(a)10^{kt}$$

where y is chl*a* concentration (mg/m^2) on day t, a is the initial chl*a* concentration and k is the slope or specific net growth rate. Values of k were divided by log 2 to give the specific growth rate in units of divisions per day. Specific growth rates were then averaged for treatment replicates to give a mean specific growth rate for each treatment. A detailed description of the study site, artificial stream design, experiment protocol and statistical analysis are given in Perrin *et al.* (1995) with subsequent modifications outlined by Dale and Chambers (1995a,b).

The results of these enrichment experiments showed that periphyton growth in the upper Athabasca River was P limited during both spring and fall. For all experiments, periphyton biomass showed exponential growth in the 10 and 25 µg/L SRP treatments while growth in the control and 1 µg/L SRP treatments was approximately linear (Figure 6.2). Growth rates were highest during spring 1994, and progressively lower during fall 1993 and fall 1994 (0.32, 0.24 and 0.18 divisions/day at 10 µg/L P addition for spring 1994, fall 1993 and fall 1994, respectively). This corresponded to a decrease in water temperature and photosynthetically active radiation from spring 1994 (9.1 ^{o}C and 41.7 E/d/m^2) to fall 1993 (7.0 ^{o}C and 17.3 E/d/m^2) and, finally, fall 1994 (0.66 ^{o}C and 14.9 E/d/m^2). However, when the growth rate for each treatment was normalized to the maximum growth rate attained in the experiment, the resulting relative specific growth rates were not significantly different among trials (P = 0.86, ANCOVA; Figure 6.3a). Moreover, the results showed that growth rate saturation occurred at 2-5 µg/L SRP. This is similar to the levels of 3-4 µg/L SRP required to saturate growth rates in experimental streams on the Thompson River (Bothwell 1985; Bothwell *et al.* 1989). However, while growth rates saturated at 2-5 µg/L SRP, phosphorus concentrations required to reach relative peak biomass (i.e., the peak biomass for a given treatment normalized to the maximum biomass attained in the experiment) were much higher (> 14 µg/L SRP; Figure 6.3b), although substantial increases in biomass were still observed with small additions (3-5 µg/L SRP) of phosphorus. There was no change in algal taxonomic dominance in response to P addition for any experiment.

Figure 6.2 Time course accrual of periphyton biomass measured as chlorophyll *a* on tile substrata for fall 1993, spring 1994 and fall 1994 artificial stream experiment (Dale and Chambers 1995a,b).

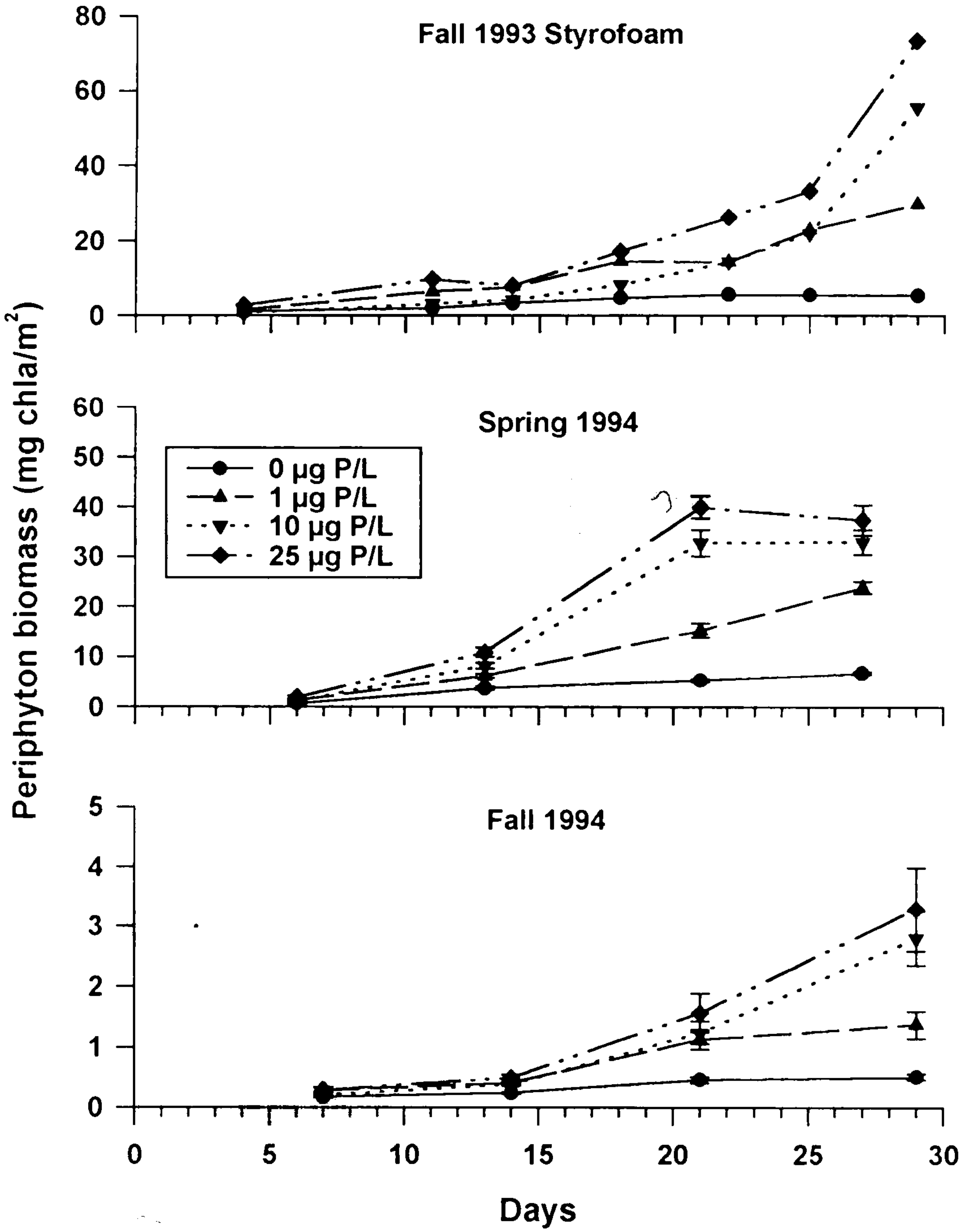


Figure 6.3 Athabasca River fall 1993, spring 1994 and fall 1994 periphyton growth responses to P additions showing: (a) relative specific growth rates, and (b) relative peak biomass (Dale and Chambers 1995a,b).

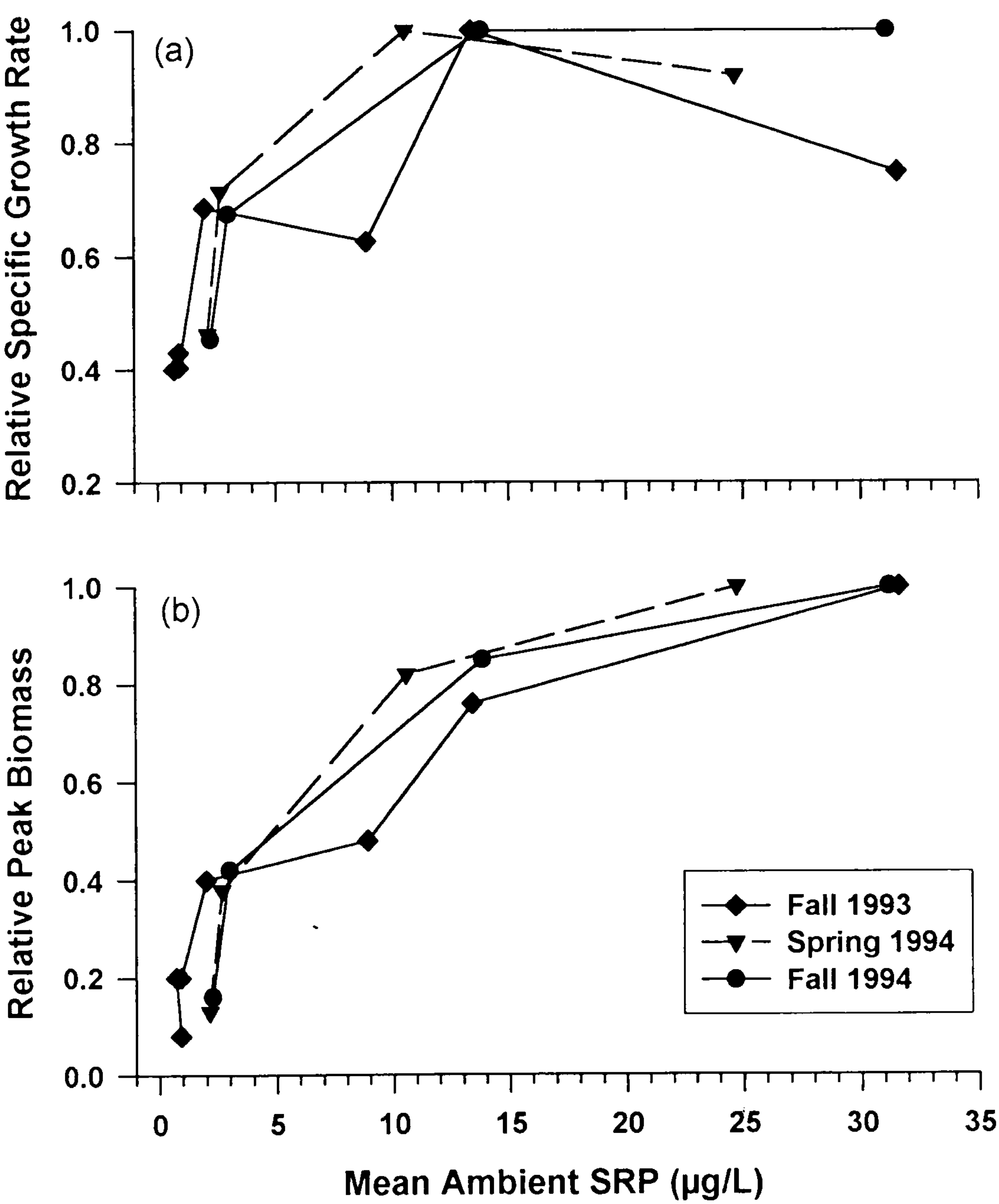


Figure 6.4 Oblique view of the recirculating artificial stream system located at Hinton, Alberta showing circular streams, water delivery and wastewater systems (not drawn exactly to scale), and photographs of streams during operation and collection of benthic invertebrates using sampling bags (Culp *et al.* 1994).

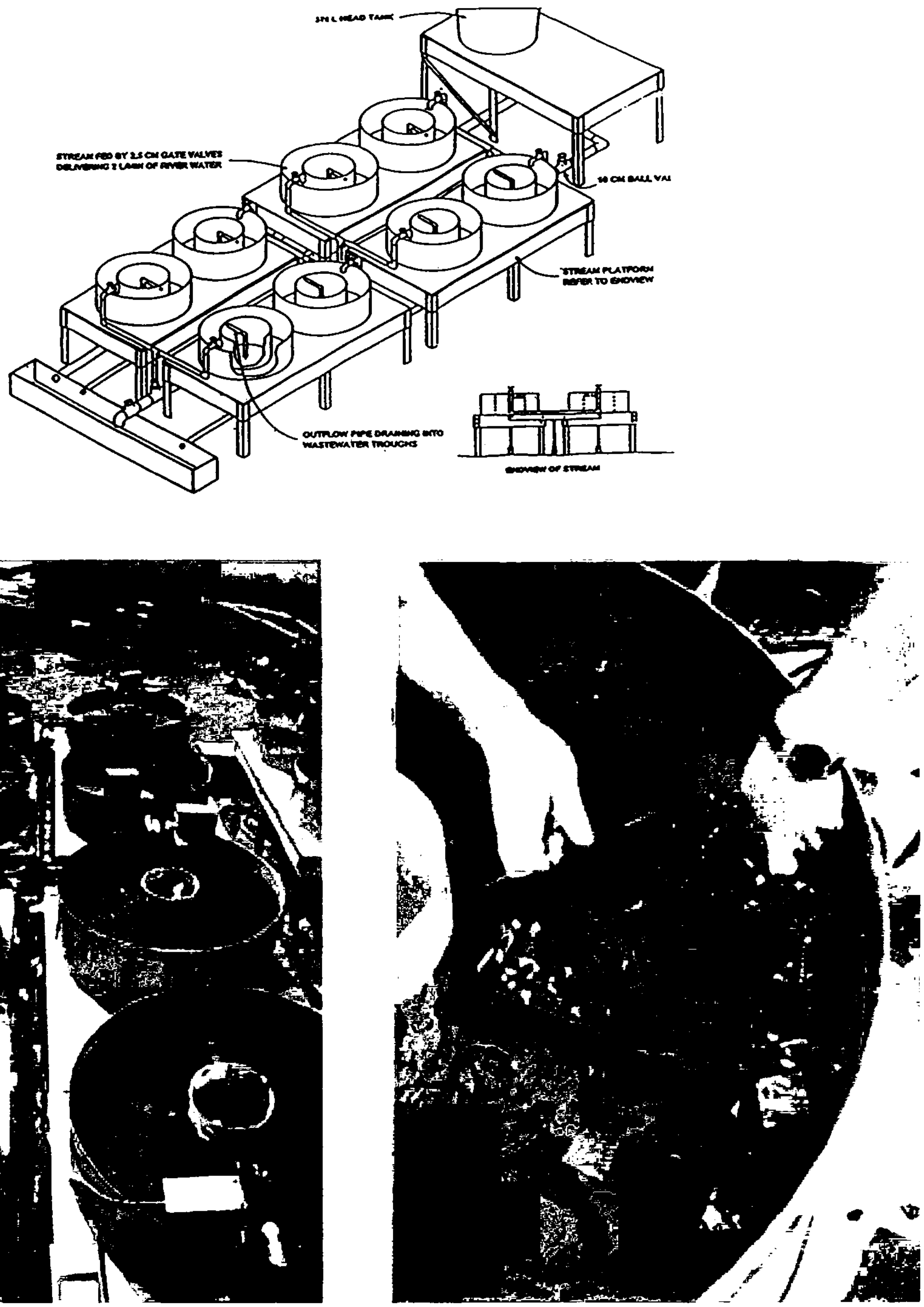
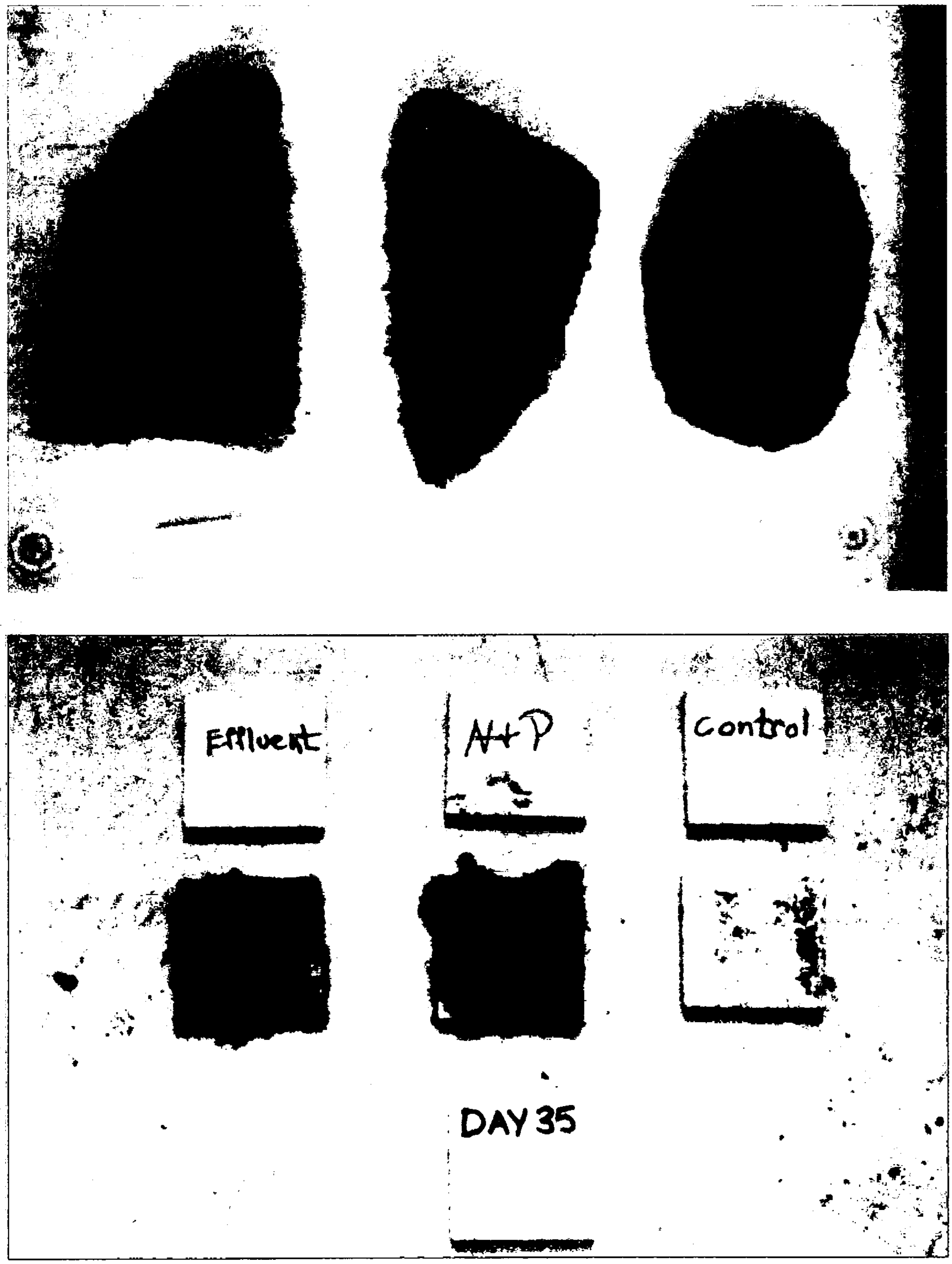


Figure 6.5 **Photograph of rocks and tiles at the end of the fall 1994 experiment illustrating the higher algal biomass on the nutrient (N + P) and effluent treatments relative to the control treatment.**



These experiments showed that despite changes in absolute biomass or growth rate due to abiotic factors (i.e., photosynthetically active radiation and temperature), periphyton growth in the upper Athabasca River is P-limited and the relative response of periphyton to P enrichment does not change seasonally. Periphyton relative specific growth rates saturated in both spring and fall at 2-5 µg/L SRP while relative peak biomass saturated at higher SRP concentrations (> 14 µg/L SRP). This indicates that growth rates of individual cells and thin periphyton films saturate at lower concentrations (i.e., 2-5 µg/L SRP) than does the growth of the community as a whole (which saturates at > 14 µg/L SRP). However, while relatively high P concentrations (15-35 µg/L SRP) are required to reach high biomass, substantial increases in periphytic algae can still occur at low P concentrations (2-5 µg/L SRP) with the magnitude of biomass increases due to P enrichment being related to seasonal changes in abiotic factors such as temperature and PAR.

6.2 NUTRIENT AND CONTAMINANT EFFECTS OF BLEACHED KRAFT MILL EFFLUENT ON BENTHIC ALGAE AND INSECTS

To isolate the effects of nutrients and contaminants from bleached kraft mill effluent on complex foodwebs including both primary (periphyton) and secondary (benthic invertebrates) producers, an experimental stream system was developed to simulate the riverine environment (Culp *et al.* 1994; Culp and Podemski 1996a). This transportable outdoor system consisted of 16 circular 0.9 m^2 streams placed in pairs on tables, required 9 x 5 m area of level ground for set-up and was established beside the study river (the Athabasca River upstream of the Weldwood of Canada Ltd. effluent outfall at Hinton, Alberta) under ambient water temperature and light regimes (Figure 6.4). The streams were recirculating and supplied with river water at a delivery rate of 2 L per minute from a headtank, giving a water residence time for each stream of about 2 h. Water depth in each stream was maintained at 26.9±0.1 cm (mean ± SE) by an overflow drain that returns all wastewater to the river. Water movement in each stream was created by a belt-driven propeller system which produced a mean water velocity of 0.26±0.1 m/s.

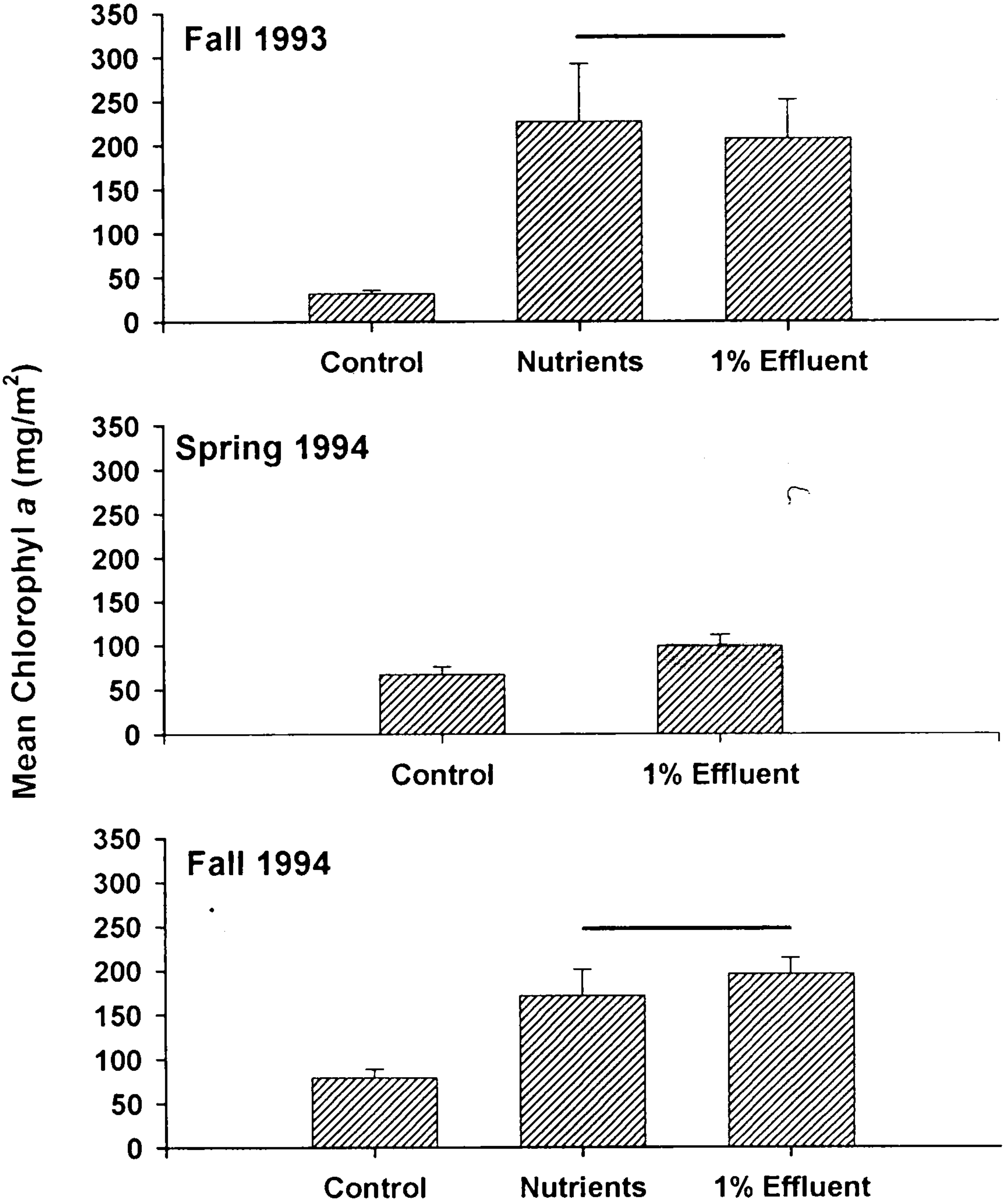
Three experiments were conducted: fall 1993, spring 1994 and fall 1994. At the start of the fall 1993 experiment, the bottom of each stream was covered with a layer of thoroughly washed crushed rock (Figure 6.4). Ten stones (surface area = 53 cm^2) and their associated biota (periphyton and invertebrates) were removed from the Athabasca River and placed on top of the gravel. The stones served to stock the streams with a community of periphyton and invertebrates. In the spring and fall 1994 experiments, gravel and stones (free of invertebrates) were first added to the streams and the periphyton was allowed to develop for 10 days before the addition of invertebrates. Invertebrates for the 1994 experiments were then collected with a U-net sampler and the contents of ten such samples were randomly allocated to each stream. In addition to the stones, unglazed porcelain tiles were placed on the gravel in each stream to provide a standardized substratum for comparison of periphyton development and accumulation.

The fall 1993 and 1994 experiments consisted of three treatments: (1) a control receiving raw river water, (2) raw river water plus a 1% dilution of treated effluent from the Weldwood of Canada Ltd. bleached kraft pulp mill (the "effluent" treatment), and (3) raw river water plus a 1% dilution of a nutrient solution with N as (NO_3^- and NH_4^+) and P(as PO_3^-) concentrations equivalent to that of the treated effluent (the "nutrient" treatment. The 1% dilution for the "effluent" treatment was selected as the mean annual dilution of Weldwood effluent in the Athabasca when filly mixed is 1%. The spring experiment consisted of the control and the "effluent" treatment. In each experiment, five replicate streams were randomly assigned to each treatment. Continuous delivery of the treatment solutions (effluent or nutrients) was accomplished with peristaltic pumps. Effluent was collected daily from the mill treatment system just prior to release to the river. Effluent samples were analysed daily for SRP, NO_2+NO_3 and NH_4. The nutrient solution added to the streams in the "nutrient" treatment had NO_3^-, NH_4^+ and SRP concentrations equivalent to the median values of the effluent samples from an 8 d period. The nutrient solution was added to the nutrient-enriched streams for an 8 d period, followed by a 1 d nutrient spike application containing concentrations equivalent to the highest effluent concentrations measured during the previous 8 d period. Periphyton samples in fall 1993 were collected every 5 d from one randomly selected stone and one tile in each replicate stream. In 1994, the sampling frequency was decreased to once per 10 d period, and a composite sample of three rocks per stream was sampled to reduce variability. Rocks were sampled by using a scalpel to remove periphyton from within a 9.6 cm^2 template. Periphyton samples from the river were collected during fall 1993 and 1994, and spring 1994 in a similar manner at sites upstream and downstream of the Hinton discharge. All periphyton samples were analysed for biomass (expressed as chl*a* content and ash free dry mass).

At the end of the autumn 1993 experiment, invertebrates were collected by washing the entire contents of each stream through a 250 μm sieve. In the 1994 experiments, five sampling bags (0.1m^2, 210 μm mesh) were installed under the gravel at the beginning of the experiments. At the end of the experiments, invertebrate samples were collected by simply lifting these bags and washing their contents through a 250 μm sieve. Invertebrates were preserved immediately in 10% formalin. Samples were sorted under 12x magnification, identified to genus whenever possible (large numbers of immature animals precluded identification of many individuals beyond family), and enumerated. Growth of numerically dominant taxa was estimated by measuring thorax length (Ephemeroptera and Plecoptera) or pronotum width (Trichoptera) with the aid of a *camera lucida* and a digitizing pad system and then converting thorax length to biomass based on regression models developed for a sub-sample of animals.

Artificial stream experiments and in-river observations provide strong evidence that the dominant effect of the Weldwood of Canada Ltd. effluent at a 1% dilution to the upper Athabasca River is that of nutrient enrichment and stimulation of food web productivity. In fall 1993 and 1994, both the nutrient and effluent treatments stimulated primary production of the largely diatom algal community relative to the control treatment, which was representative of conditions upstream of the effluent discharge (Figure 6.5). These experimental findings corresponded to in-river trends where periphyton biomass increased at sites downstream of the effluent outfall relative to upstream reference sites. The increased periphyton accumulation in the artificial streams occurred both on rocks with existing algal communities and on tiles (Culp and Podemski 1996b) which experienced rapid accumulation of algae over the duration of the experiment. The effect of effluent on periphyton communities in the upper Athabasca River changed seasonally such that the responses of algal communities, both in the river and artificial streams, were less marked during spring than in fall (Figure 6.6). For example, whereas algal biomass on rocks upstream and downstream of the effluent outfall was similar in the spring, in fall 1993

Figure 6.6 Periphyton biomass (expressed as chlorophyll *a* concentration, mean ± SE) on rocks in the control, nutrient and effluent treatments at the end of the fall 1993, spring 1994 and fall 1994 experiments (Podemski and Culp 1996b). Bars connect means that are not significantly different at $P = 0.05$.



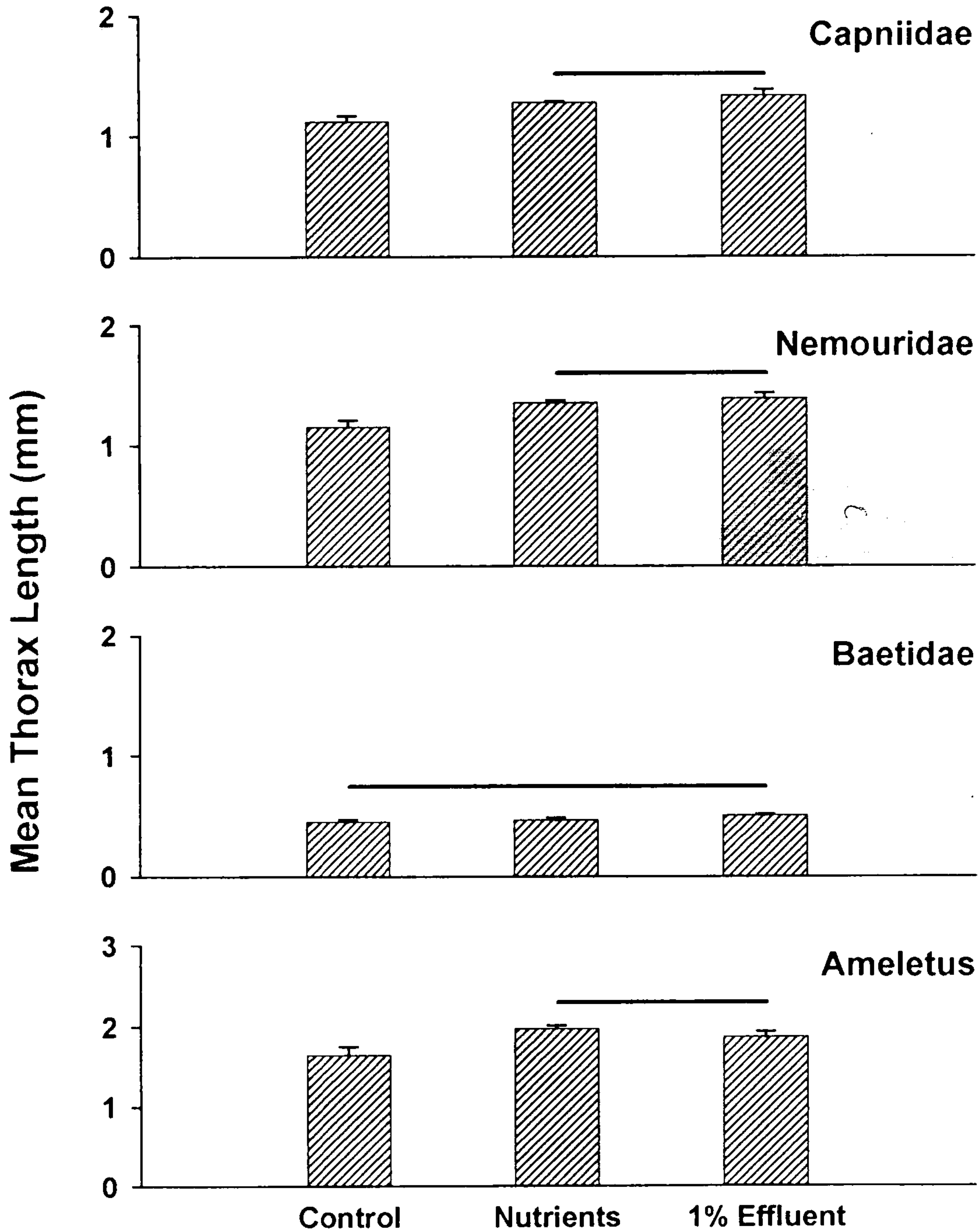
periphyton chl*a* concentrations were 2.5 times higher downstream. The seasonal differences in periphytic algal biomass were due to the much lower concentration of SRP in spring 1994 rather than temperature differences (Culp and Podemski 1996b). In spring, SRP concentrations resulting from 1% effluent addition were 1 µg/L compared to 2-3 µg/L with excursions to 5 µg/L during the fall 1993 and 1994 experiments. On average, in-river SRP concentrations upstream of the effluent outfall were 1.5 µg/L in the spring, and 1 µg/L and 1.7 µg/L in the fall 1993 and 1994, respectively. Thus, prior to biological uptake, the SRP concentrations in the artificial streams averaged 2-3 µg/L in the spring, compared to 2-6 µg/L in fall 1993 and 4-10 µg/L in fall 1994.

The effluent-induced nutrient enrichment, and subsequent increase in periphyton biomass during fall 1993 and 1994, elevated food availability for secondary producers inhabiting the upper Athabasca River (Figure 6.7). Abundances of total insects and several dominant taxa (stoneflies, mayflies and midges) increased in the nutrient and effluent treatments. Moreover, insect communities in the nutrient and effluent treatments were more similar to one another than to the control biota and were dominated by mayflies, stoneflies and midges, suggesting that composition shifts were a response to enrichment rather than toxicity. Communities in the Athabasca River downstream of the Weldwood of Canada Ltd. discharge exhibited a similar shift and were likewise dominated by mayflies, stoneflies and midges (Culp and Podemski 1996b). Although these community shifts are clearly effluent-induced, the effluent-exposed communities included many taxa (mayflies and stoneflies) that are considered to be sensitive to pollution (Rosenberg and Resh 1993). However, because the Athabasca River upstream of the Hinton discharge is P-limited and oligotrophic, the current effluent loads to the upper river provide levels of nutrient enrichment that increase benthic riverine productivity without the biotic changes associated with severe eutrophication. The artificial stream studies of Culp and Podemski (1996b) provide experimental evidence that substantiates speculation from earlier field studies which attributed the increased insect abundance downstream of the Hinton discharge to effluent-induced nutrient enrichment (Anderson 1989; 1991). In addition, these experiments yielded the first evidence that effluent-induced increases of periphyton biomass had growth-enhancing effects on benthic insects (mayfly, stonefly and caddisfly taxa) in the upper Athabasca River (Culp and Podemski 1996b; Podemski and Culp 1996). Interestingly, the growth rates of both herbivores and detritivores were augmented, suggesting the nutrient response is not restricted to algae and their grazers. The fact that growth was similarly increased in the nutrient and effluent treatments indicates that nutrient enrichment effects where not masked by deleterious contaminant effects. Also, effluent exposure produced no measurable effect of contaminants on insects at the community level with the observed changes in community structure largely reflecting the increase in abundance of taxa responding to increased periphytic resources.

6.3 ASSESSMENT

In both artificial stream experiments, nutrient addition in the form of P increased periphyton growth. Addition of approximately 1-3 g/L P increased periphyton chl*a* concentrations to 30 and 74 mg/m^2 in the fall 1993 periphyton and food web experiments, respectively, after 25 and 20 d compared to values of 5.4 and 2.3 mg/m^2 in control streams. These results provide further

Figure 6.7 Mean thorax length (± SE) of baetid and *Ameletus* mayflies, and capniid stoneflies in the control, nutrient and effluent treatments, fall 1993 (Podemski and Culp 1996). Bars connect means that are not significantly different at $P = 0.05$



evidence of P limitation in the Athabasca River upstream of the Hinton effluent outfall. The 32 fold increase in chl*a* concentrations between the control and approximately 3 g/L P-enriched treatments for the food web experiment is greater than the 1.5 and 9-fold differences observed by Scrimgeour *et al.* (1995a) and Podemski and Culp (1996), respectively, in fall 1993 for sites located upstream and 0.8 km downstream of the Hinton effluent outfall. Culp and Podemski (1996b) attributed these differences in the magnitude of the P response to greater grazing pressure in the river than in the artificial streams. This is consistent with observations of greater benthic invertebrate densities downstream compared to upstream of the Hinton pulp mill (Chapter 5) and on P-enriched than control diffusing substrata (Scrimgeour *et al.* 1995a).

The increase in periphyton biomass due to effluent addition was not statistically different from the response due to nutrient addition, suggesting that there were no inhibitory effects of 1% effluent. As Podemski and Culp (1996) note, this conclusion refers, of course, only to a 1% dilution as higher concentrations of effluent could produce chronic toxicity effects (Soniassay *et al.* 1977; Lowell *et al.* 1994) or decrease growth due to colour-related reductions in light penetration (Soniassay *et al.* 1977; NCASI 1985). The effect of effluent on insect growth was taxon-specific with *Ameletus* and capniid nymphs growing larger in the presence of effluent or nutrients. Effluent additions had no impact on insect community structure, suggesting no acute toxicity.

The development of a unique, field-based artificial stream system for NRBS provided the means for obtaining a mechanistic understanding of the effects of effluent-related nutrient and contaminant stressors on the benthic biota of the upper Athabasca River. Causality could be assigned definitively in a field application where inferential hypothesis testing was very limited, such that, for the first time, the nutrient enrichment and contaminant effects of effluent on the riverine biota could be unequivocally determined. By combining artificial stream results with field observations, this mechanistic understanding of stressor effects could be directly linked to *in situ* situations in the upper Athabasca River ecosystem. Future applications of artificial streams to northern rivers could include the linkage of artificial stream experiments with water quality models in order to contribute directly to the development, parameterization, and testing of models for predicting ecosystem-level responses to nutrient and contaminant addition. They would also be valuable tools for assessing the potential for additional mills along the river to raise overall contaminant and nutrient concentrations to levels that could degrade the ecosystem. Artificial stream research is also a promising technique for consideration in aquatic environmental effects monitoring programs for the pulp and paper industry since cause and effect scenarios can be investigated, and ecological indicators for riverine biota developed under experimentally controlled dose-response regimes.

CHAPTER 7.0
OVERALL ASSESSMENT

7.0 OVERALL ASSESSMENT

The aim of this report was to address the Northern River Basins Study (NRBS) question: "Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality?" In this report, the word "substances" was taken to mean nutrients or, more specifically, nitrogen (N) and phosphorus (P). Other NRBS reports have addressed the impact of effluent loading from the perspective of contaminants. During the past four years, studies were undertaken as part of the NRBS to characterize nutrient loading from all point and diffuse sources in the Northern River basins, evaluate the impacts of nutrient loading on river chemistry, assess the response of riverine biota to pulp mill and municipal effluents *in situ*, quantify nutrient responses of benthic biota, and investigate interactions between nutrients and contaminants in pulp mill effluent on food webs. This report synthesizes results from research and monitoring studies on the impacts of nutrient addition to the Northern River basins with the aim of providing an assessment of the state of aquatic ecosystem health, and scientific and management recommendations for the Northern River basins.

7.1 NUTRIENTS IN THE NORTHERN RIVERS

7.1.1 Athabasca River

Analysis of long-term data and surveys of nutrients in the Athabasca River have shown that TP concentrations are lowest around Jasper and increase downstream of Jasper, Hinton, Whitecourt and Fort McMurray during spring, fall and winter. (High flows during summer often mask any impacts of point-source nutrient loading.) Of the 721 TP measurements from Athabasca River between 1980-1993, 146 measurements or 20% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TP of 0.05 mg/L P. Most of these exceedances occurred during summer and were likely due to high particulate P concentrations. On an annual basis, anthropogenic point sources contribute 6 to 16% of the TP load in the Athabasca River. However, during low flows (December-April), 90% of the TP at the Snaring River confluence was from the Town of Jasper, 61% of the TP load at the Obed Coal bridge was from the Hinton combined effluent while 37% of the TP load at Old Fort was from continuously-discharging industrial (27% from pulp mills) and municipal (9.5%) sources. While the TP load from Jasper sewage is similar to that of other towns on the Athabasca River, it represents a substantial contribution because of the very low TP concentrations upstream of Jasper.

TN concentrations in the Athabasca River are lowest around Jasper and typically increase downstream of Hinton and thereafter increase steadily along the remaining length of the river. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by only 2% of the samples. On an annual basis, continuously-discharging industrial and municipal sources contribute 4 to 10% of the TN load in the Athabasca River. However, during low flows, 42% of the TN load downstream of Jasper was due to sewage while 39% of the TN load at the Obed Coal bridge was due to the combined Weldwood of Canada Ltd. and Hinton effluent.

7.1.2 Wapiti-Smoky Rivers

TN and TP concentrations increase downstream of the Grande Prairie sewage treatment plant and again, below the Weyerhaeuser Canada Ltd. outfall. Concentrations remain elevated to the mouth of the Wapiti River and, during periods of low flow, concentrations increase in the Smoky River. Of the 27 TP measurements at the mouth of the Wapiti River, 20 measurements or 74% of the samples exceeded the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TP of 0.05 mg/L P. The fact that the percent exceedances increased from 12 to 74% from upstream of Grande Prairie to the mouth of the Wapiti River suggests that P from the City of Grande Prairie and Weyerhaeuser Canada Ltd. effluents contributed to non-compliance with the TP guideline. The *Alberta Surface Water Quality Objective* (Alberta Environment 1977) for TN of 1.0 mg/L N was exceeded by 19% (n=26) of the samples from the Wapiti River near the mouth compared to no TN exceedances (n=21) for samples from upstream of Grande Prairie, again suggesting that exceedances are related to nutrient loading from the Grande Prairie STP and mill.

7.1.3 Peace River Mainstem

Water quality in the mainstem of the Peace River appears little affected by effluent discharges, undoubtedly due to the river's large volume relative to effluent inputs. Historical data from Dunvegan (1978-1988) and 1988-1989 survey data showed that samples were often non-compliant with the *Alberta Surface Water Quality Objective* (Alberta Environment 1977) of 1.0 mg/L TN and 0.05 mg/L TP due to high particulate loads associated with high flows (Shaw *et al.* 1990).

7.1.4 Slave River

There are too few data to assess longitudinal patterns in nutrient conditions in the Slave River. Nutrient data are limited to samples collected since May 1990 at Fort Smith as part of the Slave River Environmental Quality Monitoring Program and at Fitzgerald, AB as part of the joint federal, provincial and territorial monitoring program.

7.2 BIOLOGICAL RESPONSES TO NUTRIENT ADDITION

While assessments of nutrient loading have shown that man-made sources (industrial, municipal and agricultural) can contribute substantial quantities of N and P to the Athabasca, Wapiti and Smoky rivers, addition of nutrients to a river does not, *per se*, mean a change in water quality. For example, effluent discharges have little impact on periphyton biomass and benthic invertebrate densities and diversity in the Peace River (Shaw *et al.* 1990). Benthic biotic data are not available for the Slave River, but based on the Peace River results, it is very unlikely that the biota in the Slave River are affected by effluents. Therefore, the remainder of this report focuses on the responses of biota (periphyton, benthic invertebrates and small fish species) in the Athabasca and Wapiti-Smoky rivers to nutrient loading from pulp mill and municipal discharges.

7.2.1 <u>Athabasca River</u>

Surveys of the Athabasca River conducted by the NRBS (R. L. and L. Environmental Services Ltd. 1993d; Scrimgeour and Chambers 1996) and Alberta Environmental Protection (e.g., Hamilton *et al.* 1985) showed that there is suitable habitat for periphyton growth along most of the river. High flows and turbidity limit growth in summer while low irradiance and temperatures limit growth in winter. Substantial periphyton biomass can sometimes develop in spring (if sufficient time and appropriate weather conditions occur between ice-out and summer high flows); however, even if this occurs, scouring summer flows remove this biomass. Periphyton are most responsive to nutrient addition in fall when days are still long, flows are reduced and water temperatures are often > $10^{o}C$. As a result, high (> 100 mg/m^2) biomasses of periphyton are often observed during fall downstream of Jasper, Hinton, Whitecourt and Fort McMurray. The occurrence of high periphyton biomass downstream of Fort McMurray is consistent with the observation of increased algal growth by 86% of 35 interviewees in the Fort McMurray area (Bill and Flett 1996). While sampling of periphyton biomass is usually limited to near-shore areas, measurements of light attenuation at 28 sites on the Athabasca River in fall 1994 showed attenuation coefficients ranging from 0.52 to 4.33 m^{-1} (ln units; 1.63±0.12, ±S.E.; Scrimgeour and Chambers 1996) which equates to euphotic depths (based on the 1% light level) ranging from 1.0 to 8.8 m (=2.8 m). Thus, for most of the Athabasca River during fall, periphyton could colonize the entire width of the channel. Enrichment studies conducted with nutrient diffusing substrata in fall 1994 showed that periphyton growth was nutrient saturated for at least 2.5-4 km downstream of Jasper, from downstream of Hinton to upstream of Whitecourt and for at least 3 km and possibly up to 48 km downstream of Fort McMurray (Scrimgeour and Chambers 1996). Phosphorus concentrations at sites immediately upstream of the outfalls to these nutrient-saturated reaches were usually less than 2 g/L SRP which is the concentration above which the growth of individual cells and thin periphyton films saturate (Perrin *et al.* 1995; Dale and Chambers 1995a,b). Within the reaches of nutrient saturation, P concentrations ranged from 3 to 7 and, at one site, 40 g/L SRP, indicating that growth rate of the natural periphyton community had saturated but, with the exception of one site, maximum biomass had not been attained (based on 15-35 g/L SRP required to reach maximum biomass; Perrin *et al.* 1995; Dale and Chambers 1995a,b). While the data are too limited to calculate the P contribution from anthropogenic sources to nutrient-saturated reaches in October (the month of maximum periphyton biomass), 90, 74 and 37% of the TP downstream of Jasper, Hinton and Fort McMurray, respectively, is derived from effluents during winter (November-April) (Chambers and Dale 1996). Since October flows are approximately double the November-April average (312 m^3/s compared to 151 m^3/s 1913-1988 for the Athabasca River at Athabasca; Environment Canada 1989), estimates of effluent contribution to the annual TP load will be less for October. On the other hand, ratios of bioavailable P (expressed as SRP) to TP for municipal and pulp mill effluents (averaging 0.62 for Weldwood of Canada Ltd., *n*=5, fall 1994; Podemski and Culp, unpubl. data) are generally high compared to non-point sources of P (averaging 0.24 in lakes and rivers with < 30 g/L TP and 0.34 for rivers with TP > 30 g/L; Bradford and Peters 1987). Thus, a considerable fraction of the P in the reaches of nutrient saturation appears to be derived from effluents. Indeed, Culp and Podemski's (1996b) artificial stream experiments demonstrated that 1% effluent dilutions from Weldwood of Canada Ltd. significantly stimulated production of the diatom community in the upper Athabasca River at Hinton.

The fall 1994 enrichment experiment also showed that periphyton growth was N limited from downstream of the Alberta Newsprint Co. to the confluence of Lesser Slave River and in the mouth of the McLeod River. No artificial stream data are available to provide good estimates of N concentrations that would saturate growth; however, reaches of Athabasca River showing no N limitation in fall 1994 had dissolved inorganic N concentrations that were usually > 30-40 g/L. Assuming N saturation occurs at dissolved inorganic N concentrations 40 g/L, N limitation of periphyton growth in the Athabasca River downstream of the Alberta Newsprint Co. will persist if dissolved inorganic N concentrations in the Alberta Newsprint Co. do not exceed 40 mg/L (based on the current mill discharge of 0.18 m^3/s and assuming full mixing at an average October discharge of 181 m^3/s at Windfall (1960-1988; Environment Canada 1989)). Dissolved inorganic N concentrations in the Alberta Newsprint Co. effluent are currently 4.3 mg/L (July 1990 - December 1993 average; McCubbin and AGRA Earth and Environmental 1995).

The effect of enhanced periphyton production due to effluent loading has been transferred to higher trophic levels in the food web. Benthic invertebrate communities downstream of pulp mill discharges show increased densities and diversity (see Sentar Consultants Ltd. 1994b for a review) and no changes in taxonomic composition over the long term (i.e., > 5 yr) (Scrimgeour *et al.* 1995b). Studies conducted in artificial streams further showed that abundance and growth of benthic insects was similar in streams containing 1% treated kraft mill effluent or nutrients (N and P) at the same concentrations as occurred in 1% effluent (Culp and Podemski 1996b, Podemski and Culp 1996). Moreover, the insectivorous small fish species *Cottus ricei* (spoonhead sculpin) was found to be heavier, longer, fatter and have larger gonad and liver weights downstream than upstream of the bleached kraft mill discharge at Hinton (Gibbons *et al.* 1996). These studies all show that the response to effluent addition is one of nutrient enrichment and not a toxicity response.

7.2.2 <u>Wapiti-Smoky Rivers</u>

Surveys of the Wapiti-Smoky river conducted by NRBS (Scrimgeour and Chambers 1996), Alberta Environmental Protection (Noton 1992) and by Terrestrial and Aquatic Environmental Managers Ltd. (1991b) for Weyerhaeuser Canada Ltd. (formerly Procter and Gamble Cellulose Ltd.) have shown that there is suitable habitat for periphyton growth along most of these rivers. Periphyton biomass is usually greatest during fall with high (> 100 mg/m^2 chlorophyll *a*) biomasses often observed downstream of the Grande Prairie STP and Weyerhaeuser Canada Ltd. bleached kraft pulp mill. While sampling of periphyton biomass is usually limited to near-shore areas, measurements of light attenuation at five sites on the Wapiti-Smoky river in fall 1994 showed attenuation coefficients ranging from 0.52 to 2.03 m^{-1} (ln units; 1.25±0.19, ±S.E.; Scrimgeour and Chambers 1996) which equates to euphotic depths (based on the 1% light level) ranging from 2.3 to 8.9 m (=3.7 m). Thus, for most of the Wapiti-Smoky river during fall, periphyton could colonize the entire width of the channel. Enrichment studies conducted with nutrient diffusing substrata in fall 1994 showed that periphyton growth was N+P limited upstream of Weyerhaeuser Canada Ltd. (even in the reach receiving Grande Prairie sewage), nutrient saturated for at least 11.5 km downstream of the mill, and N-limited in the Smoky River. Phosphorus and nitrogen concentrations at sites immediately upstream of the pulp mill outfall were usually 4-6 g/L SRP and 10-13 g/L dissolved inorganic N compared to 21 g/L SRP and approximately 20 g/L dissolved inorganic N at the nutrient-saturated site and 25 g/L dissolved inorganic N in the N-limited Smoky River (Scrimgeour and Chambers 1996). The N limitation in the Smoky River is surprising given that DIN concentrations are comparable to those of the N+P saturated site downstream of the Weyerhaeuser Canada Ltd. discharge. While the data are too limited to calculate the P contribution from anthropogenic sources to these nutrient-saturated reaches in October (the month of maximum periphyton biomass), 24 and 18 % of the TP load and 22 and 12% of the TN load in the Wapiti River near the mouth are from the pulp mill and sewage discharge, respectively, during winter (November-April) (Chambers and Dale 1996). Since October flows are more than twice the November-April average (75.4 m^3/s compared to 29.6 m^3/s 1961-1988 for the Wapiti River near Grande Prairie; Environment Canada 1989), these estimates of effluent contribution to the annual TP and TN load will be much less for October. However, as noted previously, municipal and pulp mill effluents contain proportionately more bioavailable N and P than non-point sources (see Section 7.1.1). Thus, a considerable fraction of the N and P in the reaches of nutrient saturation is derived from effluents.

The effect of enhanced periphyton production due to effluent loading has been transferred to higher trophic levels in the food web. Studies of benthic invertebrates have shown increases in densities below both the municipal and pulp mill discharge (Noton *et al.* 1989; Terrestrial and Aquatic Managers Ltd. 1990, 1991b, 1992a, 1993a). While changes in taxonomic composition were observed below some outfalls in certain years (e.g., Terrestrial and Aquatic Environmental Managers 1991b, 1992a), there was no consistent long-term effect of pulp mill effluent, with taxonomic differences being greater between years than between sites located upstream and 500 downstream of the outfall. These results suggest that the response to effluent addition is one of nutrient enrichment and not a toxicity response.

7.3 IMPLICATIONS OF NUTRIENT ADDITION

During fall, winter and spring, elevated N and P concentrations are observed on the Athabasca River downstream of Jasper, Hinton, Whitecourt and Fort McMurray and on the Wapiti River downstream of Grande Prairie. In the case of the Peace River mainstem, there is no evidence of nutrient impacts and the same is likely true for the Slave River. These elevated nutrient concentrations in the Athabasca and Wapiti rivers have increased periphyton biomass and benthic invertebrate densities and, for the Athabasca River downstream of Hinton, increased the length and body weight of spoonhead sculpin (*Cottus ricei*), a small insectivorous fish species. Thus, the response to effluents at a community or population level is one of nutrient enrichment not toxicity. There is no evidence of adverse effects to the ecosystem (e.g., no long-term benthic invertebrate species changes, no problems with dissolved oxygen levels that are directly caused by nutrient addition (Chambers and Mill 1996). In addition, spawning grounds for most fish do not appear to coincide with reaches of nutrient addition (Chambers and Mill 1996). While detailed investigations of spawning grounds and early rearing habitat for fish in the Northern Rivers were not undertaken, it does appear not that dissolved oxygen problems caused by nutrient addition are adversely affecting fish populations at present.

The concern with increased periphyton growth in the Athabasca and Wapiti rivers appears, at present, to be largely one of aesthetics. Aesthetic criteria for the protection of waterbodies are often site-specific and developed in consensus with the users of the lake or river. In the absence of any detectable deleterious effects of nutrient loading on the Athabasca and Wapiti rivers, the users must determine whether the increase in periphyton growth downstream of outfalls is acceptable (because it may increase the productivity of benthic insects and fish or because of socioeconomic reasons) or unacceptable. If the elevated periphyton chl*a* concentrations downstream of outfalls are deemed unacceptable, then guidelines such as the British Columbia benthic chl*a* criteria of 100 mg/m^2 to protect aquatic life (particularly for streams containing salmonids) and 50 mg/m^2 for aesthetics and recreation may be considered. However, a guideline based on a nutrient response will be difficult for an industrial or municipal discharger to apply because there is as yet no quantitative relationship between nutrient concentrations for the Athabasca and Wapiti-Smoky rivers and periphyton biomass for a given site. For example, periphyton biomass 1 km downstream of Hinton varied between 25 and 242 mg chl*a*/m^2 for October 1990, 1992, 1993 and 1994 (Table 5.1) despite relatively constant TP loads from Weldwood of Canada Ltd. and relatively constant river flows (111, 134, 97 and 118 m^3/s for October 1990, 1992, 1993 and 1994, respectively). Because of the lack of quantitative relationships between P concentrations and periphyton abundance for any given site, it is not possible to set effluent permit limits to control periphyton biomass at a specific level. Nevertheless, *in situ* observations and field and artificial stream experiments have clearly shown that phosphorus (and, in some locations, nitrogen) are important factors controlling periphyton abundance in the Athabasca, Wapiti and Smoky rivers.

Finally, the observation of N-limited conditions for periphyton growth in the Smoky River downstream of the Wapiti River raises the question of chlorate toxicity. However, an estimation of chlorate concentrations of approximately 75 g/L in 1994 and 14 µg/L in 1995 for the Smoky River downstream of the Wapiti River during fall indicate that chlorate toxicity is unlikely. The assessment of N limitation in the Wapiti-Smoky rivers needs to be verified for additional years and if N limitation is again observed, then experiments are required to examine the effects of chlorate on benthic communities in N-limited reaches of the Wapiti-Smoky rivers. While N-limiting conditions also occur downstream of the Weldwood of Canada Ltd. discharge (in the reach between the Alberta Newsprint Co. outfall and Lesser Slave River), chlorate concentrations usually appear to be too low to pose a chlorate toxicity problem.

CHAPTER 8.0
SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

8.0 SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

8.1 MONITORING, DATA HANDLING AND REPORTING

Regular monitoring and reporting of nutrients from sewage treatment plants should be license requirements, particularly the larger sewage treatment plants such as Grande Prairie and Fort McMurray. These larger sewage treatment plants have nutrient loads similar to that of pulp mills in the basins. Yet under the 1993 *Alberta Environmental Protection and Enhancement Act*, operators of continuously-discharging sewage treatments plants need only report exceedances (within 24 h) to Alberta Environmental Protection.

Compliance with sampling and analytical procedures should be mandatory for all licensed dischargers. Demonstration of QA/QC for sampling and analytical procedures and adequate detection limits should be a license requirement and conducted at regular intervals. While all licenses stipulate that sample analysis must be done following the latest edition of *Standard Methods for the Examination of Water and Waste Water* (APHA 1995), some samples have been analysed incorrectly. In addition, some laboratories are not analysing to current detection limits (i.e., TP detection limits are reported as 0.05 mg/L).

Standard reporting requirements for water quality parameters should be established. For example, the units of reporting are not consistent (e.g., reporting of nitrite as nitrogen rather than nitrite) or misleading (e.g., nitrite reported as nitrogen but "as N" left off data sheet). Phosphate is reported when the analysis (digestion) would appear to be TP. TDP concentrations are greater than TP concentrations. Provision is needed for ensuring trained personnel to collate laboratory results and prepare data reports. Reporting proper water quality data should be a license requirement

Provisions are needed to ensure training of certified operators to measure (and record) flows and discharge volumes and for enforcement of reporting requirements. At present, sewage treatment plant operators often supply missing, unreliable and/or ambiguous discharge data that then become incorporated in effluent databases (e.g., the Towns of Peace River, Barrhead and Wabasca have not reported reliable flow data). Reporting accurate discharge data should be a license requirement

A properly-maintained central database should be established for: (a) effluent monitoring data (discharge and water quality parameters for all industries and municipalities with licensed monitoring requirements), and (b) environmental data collected by industries. These databases should be linked with the provincial surface-water quality database.

The bioavailability of nutrients in industrial and municipal effluents should be characterized. At present, pulp mill licensing requirements include monitoring of NH_4, NO_3, NO_2, total Kjeldahl N, TDP and TP in weekly grab samples; there is not a monitoring requirement for nutrients by municipal dischargers. Analysis of SRP concentrations and/or algal bioassays for N and P availability in effluents would allow better assessment of instream impacts.

Artificial streams and nutrient diffusing substrata developed for NRBS should be considered as a promising tool for environmental effects monitoring by the pulp and paper industry. Artificial streams allow investigation of cause and effect scenarios and development of ecological indicators for riverine biota under experimentally controlled dose-response regimes. They also facilitate the development, parameterization and testing of water quality models for predicting ecosystem-level responses to nutrient and contaminant addition. Nutrient diffusing substrata permit *in situ* assessment of the effect of effluents on river nutrient status. These approaches would assist in defining the effects of pulp mill effluent on benthic biota.

Limited data are collected on nutrient concentrations during fall, which is the time of maximum biological productivity. Environmental monitoring by industries should be undertaken in fall and, in the case of the Athabasca River, should be coordinated such that a comprehensive longitudinal survey of the river is obtained each fall.

8.2 MODELLING

The scope of nutrient and biotic data collected to date is too limited for simulation modelling. The season of concern is fall and nutrient concentrations are not usually monitored at this time of year. The limitations in the nutrient, periphyton and benthic invertebrate data could likely be addressed if industries coordinated their environmental monitoring. However, there is still no information on rates of nutrient uptake and cycling for the Northern Rivers.

Given the limited database and the problems identified in attempting to model other less complex parameters in the Northern Rivers (Chambers and Mill 1996; McCauley 1996), simulation modelling of nutrient dynamics and associated biological responses is not recommended at this time. At present, predictions of changes in benthic communities can better be made from studies conducted in artificial streams or through empirical modelling.

8.3 RESEARCH

In situ experiments have identified nitrogen limitation of periphyton growth in the 230 km reach of the Athabasca River from downstream of Alberta Newsprint Co. to the Lesser Slave River and in the Smoky River downstream of the Wapiti River confluence. Controlled experiments are required to evaluate the effects of nitrogen addition on biota in these river reaches.

Data are almost entirely lacking on the contribution of non-point sources to nutrient loads in the Northern Rivers. While contributions can be estimated from the limited data for Alberta and other parts of the world, the large changes in landuse patterns that have taken place and continue to occur (e.g., agricultural land clearing, timber harvesting, oil and gas activities) warrant closer examination of the impacts of changing landuse on nutrient loading.

8.4 WATER QUALITY AND EFFLUENT GUIDELINES

Effluent permit limits should be assessed and should be based on environmental effects rather than on technology design standards. The 1 mg/L TP level for most municipal permits is a technology-based limit since tertiary sewage treatment plants can usually achieve P removal to less than 1 mg/L. Similarly, the 3 kg BOD_5/air-dried tonne for most pulp mill permits is a technology-based limit. All industries and municipalities should be licensed on the basis of environmental effects. In the case of no perceptible environmental effects, industries and municipalities should be regulated to a designated technology standard. It should be noted, however, that while phosphorus (and, in some locations, nitrogen) are important factors controlling periphyton abundance in the Athabasca and Wapiti-Smoky rivers, we still lack quantitative relationships between phosphorus concentrations and periphyton biomass for any given site. Thus, it is not possible to set effluent permit limits for phosphorus so as to control periphyton abundance at a specific level.

Alberta Water Surface Quality Objectives (Alberta Environment 1977) are frequently exceeded for TP and occasionally exceeded for TN in the Athabasca, Wapiti, Smoky and Peace rivers. With the exception of the Wapiti River, many of these exceedances are attributable to high particulate loads associated with high flows. In the Wapiti River, many of the exceedances appear attributable to effluent discharge from Weyerhaeuser Canada Ltd. and, in the case of TP, to the Grande Prairie sewage treatment plant. Many regulatory agencies are moving away from numeric guidelines for nutrients but, instead, are evaluating or implementing qualitative or numeric guidelines based on aquatic plant abundance in the receiving water. At present, increased periphyton biomass is observed downstream of all mill and large sewage treatment plant (Fort McMurray and Grande Prairie) discharges. There is no evidence that this increased periphyton biomass has impaired spawning habitats, contributed to DO declines during winter or caused consistent long-term changes in benthic invertebrate taxonomic composition. However, if these reaches are deemed to be of recreational or aesthetic value, then a site-specific guideline for plant biomass may be desired. The British Columbia Ministry of Environment has recommended a criterion based on periphyton biomass of < 50 mg/m^2 chlorophyll *a* to protect uses related to recreation and aesthetics in streams and < 100 mg/m^2 chlorophyll *a* to protect against undesirable changes in aquatic life. However, before adopting a guideline based on a quantitative nutrient response (i.e., a specific level of aquatic plant abundance), a quantitative relationship between periphyton biomass and its environmental controls must be established.

CHAPTER 9.0
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9.0 REFERENCES

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Synthesis Report

The Northern River Basins Study was established to examine the relationship between industrial, municipal, agricultural and other development and the Peace, Athabasca and Slave river basins.

Over four and one half years, about 150 projects, or "mini studies" were contracted by the Study under eight component categories including contaminants, drinking water, nutrients, traditional knowledge, hydrology/hydraulics, synthesis and modelling, food chain and other river uses. The results of these projects, and other work and analyses conducted by the Study are provided in a series of synthesis reports.

This Synthesis Report documents the scientific findings and scientific recommendations of one of these components groups. This Synthesis Report is one of a series of documents which make up the North River Basins Study's final report. A separate document, the Final Report, provides further discussion on a number of scientific and river management issues, and outlines the Study Board's recommendations to the Ministers. Project reports, synthesis reports, the Final Report and other NRBS documents are available to the public and to other interested parties.