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Spatial and Temporal Patterns in Nutrients and Algal Abundance in Alberta Rivers

Final Report

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By

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EXECUTIVE SUMMARY

The aim of this investigation was to review plant biomass and nutrient relationships in Alberta rivers over time and space and to propose preliminary guideline values for management of plant abundance and nutrients in prairie rivers. In this report, we analysed data collected for Alberta rivers from 1980 to 1995 and tested for trends over time and with downstream distance for each river. Multiple regression models were constructed relating benthic and planktonic chlorophyll *a* in the rivers to the nutrients nitrogen (N) and phosphorus (P), river discharge, and surrogate variables for light availability (turbidity and non-filterable residue). By comparing our model results to similar studies for other river systems and interpreting trends observed within and among Alberta's rivers, we proposed preliminary guidelines for the management of periphyton biomass and P and N in Alberta rivers.

Nutrient concentrations and algal abundance (measured as benthic and planktonic chlorophyll *a*) in the Milk, Oldman, Bow, Elbow, Highwood, Sheep, Red Deer, North Saskatchewan, Athabasca and Peace river systems ranged from below detection limits to greater than 3 mg l^{-1} total phosphorus (TP), greater than 15 mg l^{-1} total nitrogen (TN), near 1000 mg m^{-2} benthic chlorophyll *a* and near 900 mg m^{-3} planktonic chlorophyll *a*. Despite the broad range of nutrient and chlorophyll *a* concentrations measured in Alberta rivers, the mean concentrations for each river fell within expected ranges for similar rivers in North America and abroad.

There was no consistent pattern in nutrients and chlorophyll *a* in Alberta rivers over time. Improvements in water quality (characterized by declines in algal abundance and P and N concentrations) were observed in some rivers (most notably the Bow River, but also modest improvements in the Highwood-Sheep, Elbow, Oldman, and South Saskatchewan rivers). In other rivers (*e.g.,* the Red Deer, North Saskatchewan and Athabasca rivers), water quality remained the same or deteriorated slightly over the monitoring period. The influence of the cities of Lethbridge, Calgary, Medicine Hat, Red Deer, Edmonton and the town of Hinton on water quality was observed immediately downstream of the municipal boundaries in the form of increased concentrations of P and N and elevated levels benthic and planktonic algae. These increases were most noticeable in the spring and fall when river discharge was low; most systems recovered to near upstream concentrations within 100-200 kilometres downstream of the municipal inputs.

Regression models relating instantaneous samples of chlorophyll *a* (benthic and planktonic) to corresponding concentrations of P and N, discharge and surrogate variables for light availability for all Alberta rivers collectively showed that instantaneous nutrient concentrations were poor predictors of algal biomass for all Alberta rivers (benthic algae: $0.19 \leq r^2 \leq 0.21$; planktonic algae: $0.13 \leq r^2 \leq 0.16$). Instantaneous models for benthic chlorophyll *a* were moderately improved when the data were grouped by major drainage basin (Peace-Athabasca: $r^2 = 0.34$; Saskatchewan River: $r^2 = 0.23$) and sub-basins of the Saskatchewan River drainage (North basin: $r^2 = 0.41$; South basin: $r^2 = 0.41$). Similarly, planktonic chlorophyll *a* models were improved in drainage basin nutrient models (Peace-

Athabasca: $r^2 = 0.49$; Milk River: $r^2 = 0.84$; Saskatchewan River: $r^2 = 0.17$) and sub-basin models for the Saskatchewan River drainage (North basin: $r^2 = 0.18$; South basin: $r^2 = 0.40$).

In addition to models relating instantaneous chlorophyll *a* to instream nutrient concentrations, mean seasonal (spring, summer and fall) concentrations of chlorophyll *a* were related to water chemistry and flow from the season in which the algae were collected and to the seasons preceding chlorophyll *a* sampling. With the exception of benthic chlorophyll collected in the summer, mean seasonal chlorophyll *a* was best modelled by water chemistry from the season in which it was collected (*i.e.*, mean fall chlorophyll *a* was best modelled by mean fall chemistry). Spring concentrations of total dissolved P (TDP), nitrite plus nitrate (NO_2+NO_3), non-filterable residue (NFR) and flow were the best predictors of spring epilithic chlorophyll *a* ($r^2 = 0.36$), whereas spring TN and flow were the best predictors of spring planktonic chlorophyll *a* ($r^2 = 0.41$). Spring TDP, NO_2+NO_3 and maximum annual flow were the best predictors of summer periphyton abundance ($r^2 = 0.33$) whereas summer TN and TP explained most variation in summer planktonic algae (50%). Thirty-five percent of fall periphyton variability was explained by fall concentrations of NO_2+NO_3, turbidity and TP, whereas 49% of fall planktonic variability was explained by fall TP, annual maximum flow, NO_2+NO_3 and NFR. Finally, we examined the relationship between nutrients and chlorophyll *a* for all seasons combined: 31% of the variability in epilithic algal abundance was explained by TDP, NFR, NO_2+NO_3 and total Kjeldahl N (TKN) whereas 42% of planktonic chlorophyll *a* variability was explained by TN, TDP, and annual mean flow.

Assessment of periphyton chlorophyll *a* concentrations from river sites throughout Alberta showed that 95% of all reference sites (*i.e.*, sites upstream of any major point sources) had periphyton chlorophyll concentrations ranging from 37 to 51 mg m^{-2}. Results from our regression models as well as periphyton-nutrient frequency distributions showed that, in general, TP (or TDP, depending on the metric used to predict chlorophyll concentrations) concentrations less than 0.012 mg l^{-1} will result in periphyton growth of less than 50 mg m^{-2} chlorophyll *a*. Similarly, dissolved inorganic N (DIN) concentrations less than between 0.058 and 0.187 mg l^{-1} or NO_2+NO_3 concentrations less than 0.050 mg l^{-1} will yield the same benthic chlorophyll *a* levels as those for P. Further research is recommended to validate approaches for establishing guidelines and to assess the most sensitive variable for measuring the response of periphyton to enrichment.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

Anthropogenic loading of the nutrients nitrogen (N) and phosphorus (P) from industrial, municipal and agricultural sources has increased nutrient concentrations of many lakes and rivers worldwide and enhanced production of phytoplankton (suspended algae), periphyton (benthic algae) and rooted vascular plants (macrophytes). The role of nutrients in regulating phytoplankton biomass in lakes has long been established and reductions of P and N inputs to lakes have been successful in reducing phytoplankton abundance (*e.g.*, Dillon and Rigler 1974; Edmonson and Lehman 1981). However, the relationship between nutrient concentrations and plant biomass in rivers, where the dominant primary producers are the periphyton, is less clear. Consequently, it has been difficult to establish nutrient guidelines that effectively control plant growth (Welch et al. 1989).

The aim of this study was to evaluate the relationship between plant biomass (periphyton and phytoplankton, measured as chlorophyll *a* per unit area or volume) and P and N concentrations in Alberta rivers. Rivers in Alberta receive nutrient inputs from municipal sewage effluent, agricultural activities, and industrial effluents. For example, a recent report investigating agricultural impacts on water quality in Alberta showed that between 65 and 99% of water samples collected from streams draining moderate to high agricultural intensity regions (most notably in the southern half of the province) had total P and N concentrations that exceeded Alberta Surface Water Quality Interim Guidelines (CAESA 1998). In northern Alberta on the Athabasca River system, 20% of water samples exceeded Alberta guidelines for total P between 1980 and 1993; during low flows, between 37 and 90% of this total P load was from anthropogenic sources (Chambers 1996). Sewage effluent from the city of Grande Prairie has also been linked to exceedances in total P and N along the Wapiti-Smoky river system (Chambers 1996) and sewage effluent from Calgary has been linked with increased P and N and subsequent plant growth in the Bow River (Sosiak 1990). In this report we: (1) examine temporal and spatial trends in nutrient concentrations (P and N) and plant biomass (periphyton and phytoplankton) in Alberta rivers, (2) quantify the relationship between plant biomass, nutrients and flow in Alberta rivers, (3) relate plant biomass to nutrient levels in prairie rivers for three plant biomass scenarios, and (4) recommend any necessary improvements in eutrophication monitoring strategies for Alberta rivers.

1.1 Background

Many studies have demonstrated that growth and abundance of benthic and planktonic algae in rivers are related to instream nutrient concentrations. For example, Stockner and Shortreed (1978), Bothwell (1985), and Mundie et al. (1991) demonstrated through the use of artificial streams that benthic algal growth in oligotrophic rivers in British Columbia was P-limited. Periphyton growth in Australian streams draining sub-alpine, forested, agricultural or urban catchments was either N or P-limited, depending on instream N to P ratios (Chessman et al. 1992). In Denmark, P was an important regulator of benthic algal biomass in small lowland streams with fine-grained sediments (Kjeldsen 1994). Basu and Pick (1996, 1997) showed that planktonic chlorophyll *a* concentration was predicted by total P in the Rideau River, Ontario ($r^2 = 0.43$) and in 31 rivers in eastern Canada ($r^2 = 0.76$). Similarly, Jones et al. (1984) demonstrated that planktonic chlorophyll *a* was positively related to both total P and total N concentration in eight Missouri Ozark streams.

Despite the importance of nutrients in regulating lotic algal growth, a number of other physical, chemical and biological factors confound these relationships. Biggs (1988) recognized the importance of flood events, sediment stability, and water velocity in influencing benthic algal growth and developed a model that incorporated these factors to predict algal growth potential in New Zealand streams. Biggs and Close (1989) further concluded from a study of periphyton biomass in nine New Zealand rivers that hydrological factors contribute equally with nutrients to determine periphyton growth. Horner et al. (1990) demonstrated that periphyton uptake of P increased with increasing concentration and water velocity, up to approximately 60 cm s^{-1}, beyond which biomass was reduced by scouring. In addition to nutrients and water flow, the roles of grazing organisms light have been recognized as determinants of periphyton biomass in rivers. For example, Hill et al. (1992) showed by means of experiments conducted in artificial streams that primary production in a Tennessee stream was simultaneously limited by nutrient availability and grazing by snails. Winterbourn (1990) studied the role of grazers in influencing algal growth and found that a reduction in herbivory resulted in an increase in algal standing crop in a New Zealand mountain stream. Hansson (1992) found a curvilinear response between periphytic algal biomass and nutrient availability and light in Swedish and Antarctic lakes.

Large, long-term databases are uniquely suited for determining both temporal and spatial trends in water quality in rivers. The ability to detect such trends facilitates the development of management strategies and makes it possible to target management practices on sites or regions of particular concern (Stow et al. 1998). For example, Cun et al. (1997) quantified trends in water quality in the Seine and Marne rivers, France, from 1910 to 1993 and reported that ammonia and dissolved oxygen concentrations in the Paris area were problematic and should be targeted for improved management practices. Momen et al. (1997) evaluated trends in water quality in Lake George, New York, and found few significant changes from 1981 to 1993, despite previous reports suggesting increases in primary productivity in the lake caused by increased urbanization. Lettenmaier et al. (1991) evaluated trends in stream water quality in the United States and reported that common ions and nutrient concentrations had generally increased, while phosphorus had for the most part declined over the period 1978 to 1987. In a similar study, Smith et al. (1987) reported that faecal bacteria and lead concentrations had generally declined, whereas concentrations of nitrate, chloride, arsenic, and cadmium had increased in streams of the United States over the period 1974 to 1981.

This report summarizes results from statistical analyses of the relationship between algal biomass, nutrients and flow in Alberta rivers and discusses dominant trends in plant biomass and nutrients within rivers over time. We relate patterns observed in this report to findings in the current literature and we relate benthic chlorophyll *a* to phosphorus and nitrogen concentrations for three biomass scenarios. We also make recommendations on how to improve monitoring of chlorophyll *a* and nutrients within Alberta rivers to most effectively detect trends into the future.

2.0 METHODS

2.1 Study Area

Water quality in Alberta rivers has been monitored by Alberta Environmental Protection for more than 20 years. Some regions have been more intensively studied than others, and these are usually in the more highly populated parts of the province. We examined patterns in algal abundance and nutrients in most of the major mountain-fed rivers in the province, including the Milk, Oldman, Bow, Highwood, Sheep, South Saskatchewan, Red Deer, North Saskatchewan, Athabasca, Wapiti, Smoky and Peace rivers (Fig. 1).

The Milk River arises in the Rocky Mountain foothills of Montana and flows through the most southern portion of Alberta. It drains a small area consisting mostly of grasslands with a population of less than 2000 in 1988 (Mitchell and Prepas 1990). The Milk River and its major tributary, the North Milk River, were sampled for epilithic and planktonic chlorophyll *a* by Alberta Environmental Protection in 1986 and 1987.

The Oldman River arises in the Rocky Mountains west of Pincher Creek and flows across Alberta's foothill regions, through the prairie grassland ecoregion. The river flows through the City of Lethbridge (1994 population: 64,938; Canadian Almanac and Directory 1997 (CAD1997)) and eventually converges with the Bow River approximately 330 river kilometres downstream of its headwaters. Much of the Oldman River drainage basin is used for agricultural activities. Flows in the Oldman River are regulated by one dam, the Oldman Dam, located approximately 100 river

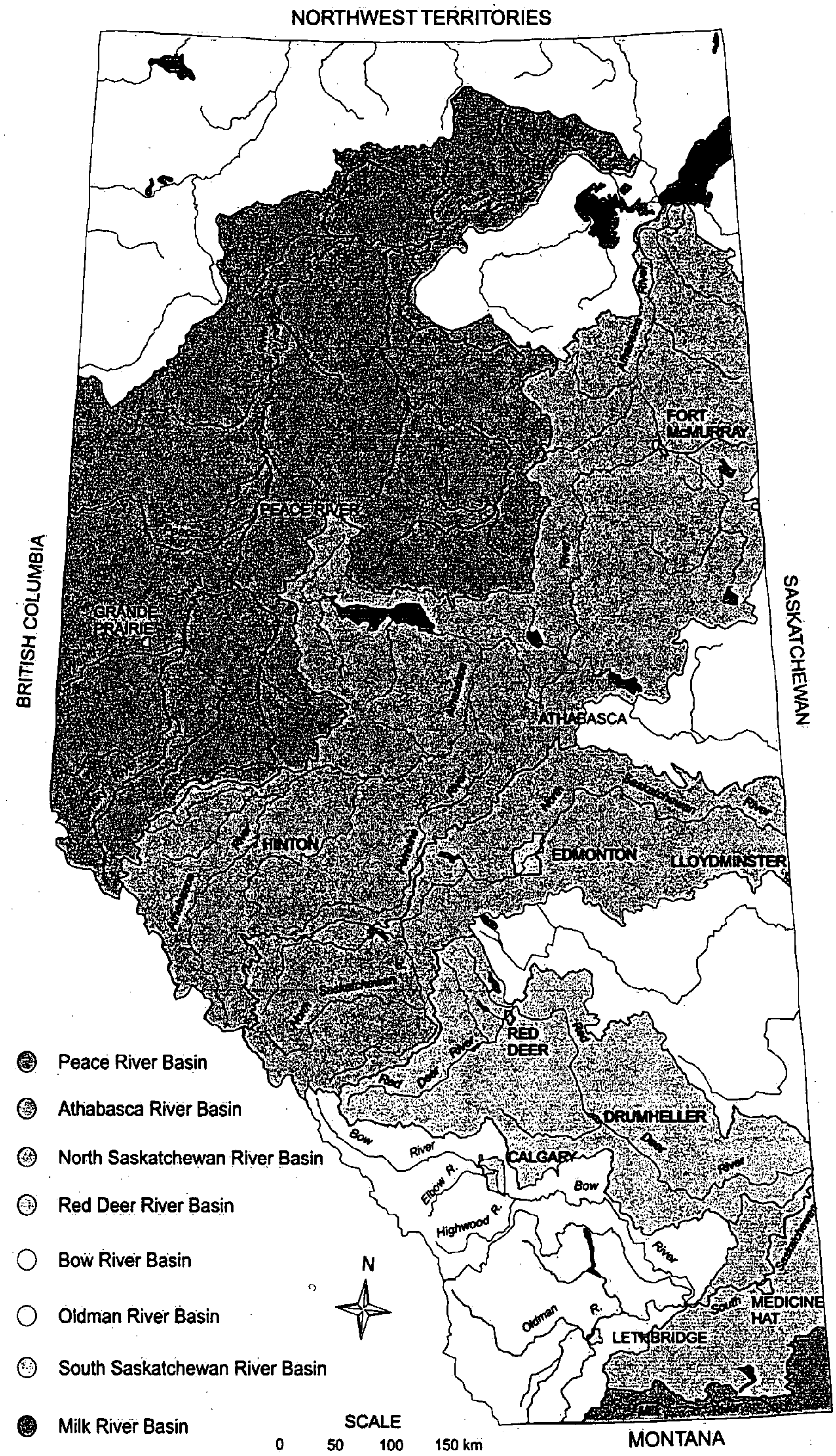

Figure 1. Drainage basins and major Alberta rivers investigated in this study. Adapted from Mitchell and Prepas (1990).

kilometres upstream of Lethbridge. One fifth of the entire flow of the South Saskatchewan River basin (which includes the Bow, Oldman and Red Deer rivers) comes from the Oldman River, and this amounts to approximately 1.5 billion m^3 of water annually (Mitchell and Prepas 1990). Planktonic and epilithic algal abundance were monitored in the Oldman River and its tributaries by Alberta Environmental Protection in 1980, 1981, 1984 to 1986, and from 1990 to 1995.

The Bow River, arising at the Bow Glacier north of Lake Louise, is the most intensively surveyed river in Alberta with respect to algal abundance. The Bow River flows through the Rocky Mountain foothills and across the prairie grassland ecoregion, through the City of Calgary (1996 population: 767,059; CAD 1997), and converges with the Oldman River approximately 630 river kilometres downstream of its headwaters. The Bow River is regulated by a number of dams along its length that are used primarily for hydroelectric power generation and irrigation (Mitchell and Prepas 1990). Algal abundance was monitored in the Bow River along its length from 1980 to 1995. The Elbow River, which drains into the Bow River at Calgary, was sampled for algal abundance in 1988, 1990 to 1992, and 1994 to 1995. The Highwood River, also a major tributary of the Bow, and the Sheep River, which drains into the Highwood, were sampled for algal abundance from 1984 to 1986.

The South Saskatchewan River arises at the confluence of the Bow and Oldman rivers and flows approximately 260 river kilometres, passing through the City of Medicine Hat (1994 population: 45,892; CAD 1997), before reaching the Alberta Saskatchewan border. The region is primarily agricultural and the drainage basin is confined to the shortgrass prairie ecoregion (Mitchell and Prepas 1990). Algal abundance and water quality were sampled at five stations along the length of the river in 1980, 1981 and 1986.

The Red Deer River originates east of Lake Louise, traverses the Rocky Mountain foothills and prairie grassland ecoregion of Alberta, and converges with the Bow River just east of the Alberta-Saskatchewan border (Mitchell and Prepas 1990). The Red Deer River is regulated by the Dickson

Dam upstream of Red Deer and flows through the cities of Red Deer (1996 population: 59,834; CAD 1997) and Drumheller (1994 population: 6,277; CAD 1997), extending approximately 640 river kilometres across the province. Algal abundance and water quality in the Red Deer River were monitored from 1983 to 1988 and in 1991 and 1995.

The North Saskatchewan River, which drains a total area of approximately 56,700 km^2 within Alberta, arises in the Rocky Mountains and flows through a number of ecoregions, including the boreal northlands, boreal uplands, boreal foothills and ultimately the boreal mixedwood forest (Mitchell and Prepas 1990). The river flows through the towns of Rocky Mountain House (1994 population: 5,684; CAD 1997), and Drayton Valley (1994 population: 5,983; CAD 1997), and the cities of Edmonton (1995 population: 637,442; CAD 1997) and Fort Saskatchewan (1994 population: 12,313; CAD 1997). The river drains eastward into Saskatchewan north of the city of Lloydminster and eventually converges with the South Saskatchewan River in east-central Saskatchewan to form the Saskatchewan River. Algal abundance and water quality in the North Saskatchewan River were monitored in 1983, 1984, 1985, 1988, and 1994 by Alberta Environmental Protection.

The Peace-Athabasca drainage basin covers approximately 346,530 km^2 and is the largest watershed in Alberta. The Athabasca River arises in Jasper National Park and flows north and east across the province through the boreal foothills and boreal mixedwood ecoregions, ultimately draining into Lake Athabasca (Mitchell and Prepas 1990). The Athabasca River flows through the towns of Hinton (1994 population: 9,341; CAD 1997), Whitecourt (1994 population: 7,056; CAD 1997)and the city of Fort McMurray (1991 population: 34,706; Chambers 1996). Epilithic and planktonic chlorophyll *a* and water quality were monitored in the Athabasca River and its tributaries from 1984 to 1989 and in 1992 and 1994 by Alberta Environmental Protection, and in 1990 through 1995 by independent consultants (TAEM 1991a, 1991b and1992; Sentar 1994 and 1995).

The Peace River arises in British Columbia and enters Alberta east of Fort St. John, BC, flowing east and north across the province through the town of Peace River (1994 population: 6,696; CAD 1997) and Wood Buffalo National Park. The river converges with the Athabasca River to form the Peace-Athabasca delta on the west end of Lake Athabasca. Flow exits Lake Athabasca via the Slave River, which is the largest river in Alberta and drains north into the Northwest Territories. The Wapiti River flows through the city of Grande Prairie (1994 population: 29,242; CAD 1997) and is a tributary of the Smoky River that drains into the Peace River at the town of Peace River. Much of the Peace River drainage basin lies within the boreal mixedwood ecoregion in Alberta. The Peace River is regulated in British Columbia by the W.A.C. Bennett Dam (Mitchell and Prepas 1990). Water quality and algal abundance in the Peace, Wapiti and Smoky rivers were monitored in 1988, 1989 and 1991 by Alberta Environmental Protection and in 1990 and 1991 by independent consultants (TAEM 1991c).

2.2 Data Assembly and Manipulation

Planktonic and epilithic chlorophyll *a* and water quality data were retrieved from the Alberta Environmental Protection (AEP) surface water quality electronic database (Edmonton, AB) for the Milk, Oldman, Bow, Highwood, Sheep, Elbow, Red Deer, South Saskatchewan, North Saskatchewan, Athabasca, Peace, Wapiti and Smoky rivers and some of their tributaries. Chlorophyll *a* was not always sampled during routine water quality analyses; the water quality data used in this study was therefore limited to all sampling dates for any year in which chlorophyll *a* was sampled by AEP. Thus, our examination of trends in water quality is only for those years in which chlorophyll *a* was sampled.

Epilithic chlorophyll *a*, nutrient and non-filterable residue data from 1980 to 1988 for the Milk, Oldman, Bow, Highwood, South Saskatchewan, Red Deer, North Saskatchewan, and Athabasca rivers are reported in Yonge (1988). Athabasca River data from 1980 to 1985 and 1990 to 1993 can be found in Hamilton et al. (1985) and Noton and Saffran (1995), respectively. Peace, Wapiti and Smoky River data from 1988 and 1989 are reported in Shaw et al. (1990) and from 1987 to1991 in Noton (1992). Cross et al. (1986) compiled nutrient and water chemistry data in a report on the limnological characteristics of the Bow, Oldman and South Saskatchewan rivers for 1979 to 1982. Sosiak (1990 and 1996) evaluated Bow River data from 1986 to1988 and 1994 to 1995. The AEP data were supplemented with chlorophyll *a* and nutrient data collected by independent consultants for the Athabasca and Wapiti rivers (Sentar 1994 and 1995; TAEM 1991a, 1991b, 1991c, 1992, and 1993).

The influence of flow on chlorophyll-nutrient relationships was investigated by combining the AEP water quality database with Environment Canada's HYDAT Surface Water and Sediment Database (Version 4.95; Atmospheric Environment Service, Water Survey of Canada 1997). Water quality sampling stations were paired with discharge monitoring stations on a 1:750,000 topographic map of Alberta. The majority of the water quality stations did not coincide with discharge monitoring stations along Alberta's rivers (Fig. 2). Thus, discharge at AEP stations was assumed to be the discharge measured at the nearest upstream or downstream flow monitoring station providing there were no major tributaries (*i.e.,* those present on a 1:750,000 topographic map) entering the river between the two stations. In cases where one or more tributaries entered the river between discharge and water quality stations, the flow of these tributaries, when available, was added to the flow of the nearest upstream or subtracted from the nearest downstream Environment Canada discharge station to give an estimate of flow at the AEP station. When flow data were not available for the major tributaries, the flow at the AEP station was estimated without accounting for the influence of the tributary flow and these sites were flagged in the database. We retrieved information from the database on annual peak discharge for a single date, annual average monthly discharge and annual average discharge for each flow station investigated. We did not estimate annual peak discharge for sites that had flow estimates derived from two or more Environment

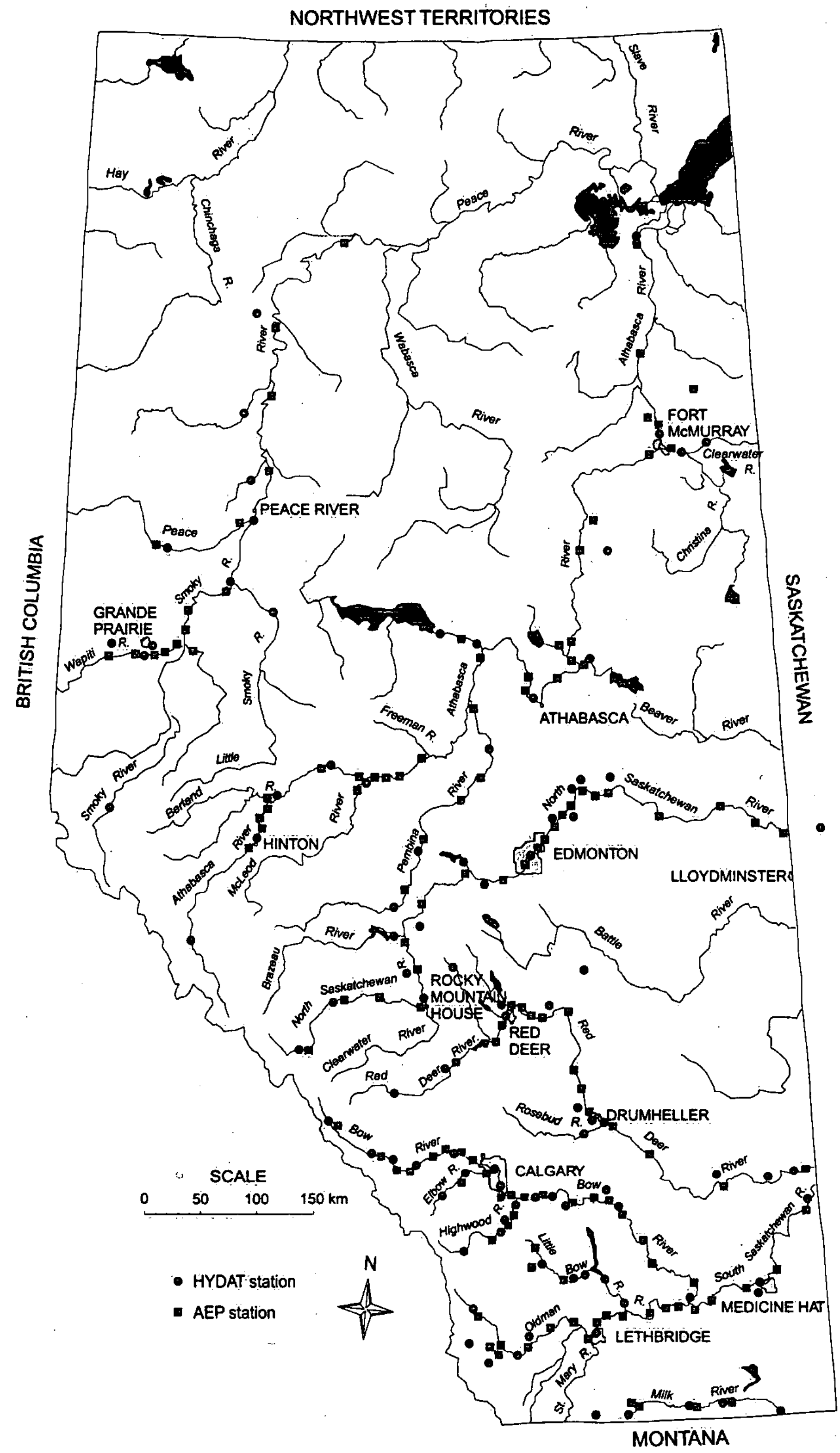

Figure 2. Alberta Environmental Protection (AEP) water quality and Environment Canada (HYDAT) discharge stations along major Alberta rivers. Not all stations shown due to overlap.

Canada stations. Alberta Environment water quality sampling sites and their corresponding discharge stations are found in Appendix A.

Epilithic and planktonic chlorophyll *a* (epichl*a* and phytchl*a*, respectively) concentrations were used to represent benthic and suspended algal biomass, respectively. Charlton et al. (1986) reported that algal material collected from the water column of the Bow River (*i.e.*, planktonic chlorophyll *a*) is mainly scoured forms of benthic algae rather than true river phytoplankton and thus it is possible that concentrations of planktonic chlorophyll *a* used in this study do not represent true river plankton. However, there was almost no relationship between planktonic and epilithic chlorophyll *a* when examined across all rivers ($r^2 = 0.04$, $n = 1755$, linear regression on ln-transformed variables) suggesting that the river plankton is probably a community composed of scoured forms of benthic algae, phytoplankton washed in from connecting lakes and reservoirs, and true potamoplankton. Because of the lack of relationship between benthic and suspended algal biomass, we deemed that an investigation of planktonic chlorophyll *a* separate from benthic chlorophyll may provide insight into patterns of algal growth in Alberta rivers.

Phosphorus variables examined included total P (TP) and total dissolved P (TDP). Dissolved orthophosphate (DOP), also known as soluble reactive P (SRP), was seldom reported and consequently not included in our analysis. Nitrogen variables examined included total Kjeldahl N (TKN), dissolved nitrite plus nitrate (NO_2+NO_3), total ammonia (NH_3tot), and dissolved ammonia (NH_3diss). NO_2+NO_3 and NH_3diss were combined to represent dissolved inorganic N (DIN) and NO_2+NO_3 and TKN were combined to represent total N (TN). Photosynthetically active radiation was not monitored at sampling stations, and we therefore examined the effect of surrogate variables for light availability, including nonfilterable residue (NFR) and turbidity (Turb), on plant abundance in Alberta rivers. In some cases, analytical methods for a variable changed over time resulting in a change in the analytical limit of detection. We combined all values for a given variable, regardless of analysis method, to enable longer term analysis of trends. A complete list of variables examined and their associated Alberta Environmental Protection Water Quality codes, analytical detection limits, reporting units, and analytical methods are found in Table 1.

The data were condensed by calculating the mean of any variable for which replicates were reported on a given sampling day. In some instances, chlorophyll *a* and nutrient sampling did not take place on the same day. In these cases, chlorophyll *a* concentrations were paired with water quality concentrations collected up to seven days before or after the date of chlorophyll sampling.

To examine temporal patterns in the relationship between plant abundance and nutrient concentrations, the data were subdivided into seasons based upon the dominant patterns in mean monthly discharge and biological productivity in the rivers. Thus, April and May data were averaged to correspond to spring low flow periods and times of potential algal accumulation. June, July and August were combined to correspond to periods of summer peak flows and high scour. September and October were averaged to correspond to fall low flow periods and the approximate period of peak algal abundance in Alberta rivers. November through March of the following year were grouped to correspond to winter base flow. These divisions are approximately the same as those used in Anderson et al. (1998) in a provincial survey of the impacts of agriculture on surface water quality in Alberta. Mean annual hydrographs for sites along the river mainstems are shown in Appendix B.

It is not uncommon that water quality databases contain values for variables that fall below analytical detection limits (Helsel 1990; Porter et al. 1988). These numbers are difficult to treat statistically and often are replaced with the value of the detection limit, one half this value, or zero. However, this introduces bias into the data when estimating means and standard deviations for these numbers (Gilliom et al. 1984; McBride and Smith 1997). A number of techniques have been recommended for dealing with values below detection limits. We used a computer program, UnCensor (Newman, Greene and Dixon 1995), to obtain unbiased estimates of means for data sets

Table 1. Water quality variables assembled from Alberta Environmental Protection (AEP) water quality database. All similar AEP variables were combined into one variable for our analyses. Detection limit was not reported for all variables and is represented as "n/a" (not available).

Variable	AEP Code	Units	Detection Limit	Analytical Method
Epilithic chlorophyll *a*	101942 Chlorophyll a epilithon	mg m^{-2}	0.001	Known areas of individual rocks are scraped and filtered through a GF/C filter. Samples extracted in 90% acetone and frozen at -4 °C for 24 hours. Absorbance determined spectrophotometrically at 750, 665, 480, 430, and 410 nm.
	6721 Chlorophyll a epilithon	mg m^{-2}	n/a	Entire rocks are brushed and rock area is determined by planimetry. Samples filtered through a Gelman A-E filter, extracted in 90% acetone and frozen at -4 °C for 24 hours. Chlorophyll determined by colorimetry following Lorenzen method.
	6722 Chlorophyll a epilithon	mg m^{-2}	n/a	Samples filtered through glass fibre filters, extracted for 20 hours in methanol. Chlorophyll determined by fluorometry and is uncorrected for phaeophytins.
Planktonic chlorophyll *a*	6715 Chlorophyll a	mg m^{-3}	0.1	Samples filtered through 0.8 µm membrane filter and extracted in 90% acetone. Chlorophyll determined by fluorometry.
	6720 Chlorophyll a phytoplankton	mg m^{-3}	0.001	Samples filtered through Gelman A-E filter, extracted in 90% acetone and frozen at -4 °C for 24 hours, then centrifuged. Chlorophyll determined by colorimetry following Lorenzen method.
Total phosphorus (TP)	15405 Phosphorous total (P)	mg l^{-1}	0.002	H_2SO_4 & $K_2S_2O_8$ added to unfiltered sample aliquot. Aliquot boiled 90 minutes. Moybdenum blue colour determined at 660 nm on an autoanalyzer following addition of ammonium molybdate and $SNCl_2$.
	15406 Phosphorous total (P)	mg l^{-1}	0.002	H_2SO_4 & $K_2S_2O_8$ added to unfiltered sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid and potassium antimonyl tartrate.
	15421 Phosphorous total (P)	mg l^{-1}	0.006	Unfiltered sample is digested in a block digester during a 2-stage heading cycle following addition of H_2SO_4, K_2SO_4 & HgO. TP is determined by an automated phosphomolybdate colorimetry using antimony followed by reduction with ascorbic acid and read at 880 nm.
	15422 Phosphorous total (P)	mg l^{-1}	0.001	Unfiltered sample is digested on a continuous digester at 300 °C following addition of $HClO_4$ and H_2SO_4. Ammonium molybdate, potassium antimony tartrate and hydrazine are then added to sample and absorbance is determined on an autoanalyser at 880 nm.
Total dissolved phosphorus (TDP)	15102 Phosphorous total dissolved	mg l^{-1}	0.002	Sample is passed through a 0.45 µm membrane filter. H_2SO_4 & $K_2S_2O_8$ added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid and potassium antimonyl tartrate.

Table 1 *(continued)*

Variable	AEP Code	Units	Detection Limit	Analytical Method
	15103 Phosphorous total dissolved	mg l^{-1}	0.003	Sample is passed through a 0.45 µm membrane filter. H_2SO_4 & $K_2S_2O_8$ added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid and potassium antimonyl tartrate.
	15105 Phosphorous total dissolved	mg l^{-1}	0.04	Sample is passed through a 0.45 µm filter and digested on a continuous digester at 300 °C following addition of $HClO_4$ and H_2SO_4. Ammonium molybdate, potassium antimony tartrate and hydrazine are then added to sample and absorbance is determined on an autoanalyser at 880 nm.
	15113 Phosphorous total dissolved	mg l^{-1}	n/a	Sample is passed through a 0.45 µm membrane filter. H_2SO_4 & $K_2S_2O_8$ added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid, sulfuric acid and potassium antimonyl tartrate.
	15114 Phosphorous total dissolved	mg l^{-1}	0.002	Sample is passed through a 0.45 µm filter and digested on a continuous digester at 300 °C following addition of $HClO_4$ and H_2SO_4. Ammonium molybdate, potassium antimony tartrate and hydrazine are then added to sample and absorbance is determined on an autoanalyser at 880 nm.
	15423 Phosphorous total dissolved	mg l^{-1}	0.002	Filtered sample is digested in an autoclave in a sulfuric acid-persulfate mixture. Ammonium molybdate, stannous chloride and hydrazine are added and absorbance determined at 660 nm on an autoanalyzer.
Dissolved orthophosphate (DOP)	15256 Phosphate dissolved ortho	mg l^{-1}	0.003	Sample is passed through a 0.45 µm membrane filter. H_2SO_4 & $K_2S_2O_8$ added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid, sulfuric acid and potassium antimonyl tartrate.
	15266 Phosphate dissolved ortho	mg l^{-1}	n/a	Sample is passed through a 0.45 µm membrane filter. H_2SO_4 & $K_2S_2O_8$ added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid, sulfuric acid and potassium antimonyl tartrate.
Dissolved inorganic phosphorus (DIP)	15346 Phosphorous dissolved inorganic	mg l^{-1}	n/a	Sample is passed through a 0.8 µm filter in the field. H_2SO_4 added to sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid, sulfuric acid and potassium antimonyl tartrate.
	15356 Phosphate dissolved inorganic	mg l^{-1}	0.002	H_2SO_4 added to filtered sample which is then autoclaved 30 minutes at 121 °C. Absorbance determined at 880 nm on an autoanalyzer following addition of ammonium molybdate, ascorbic acid, sulfuric acid and potassium antimonyl tartrate.

Table 1 *(continued)*

Variable	AEP Code	Units	Detection Limit	Analytical Method
Total Kjeldahl nitrogen (TKN)	7015 Nitrogen total Kjeldahl (TKN)	mg l^{-1}	0.05	Sample is digested with H_2SO_4, in the presence of $K_2S_2O_8$ or disodium EDTA, or dipotassium EDTA. Resultant NH_3 is determined colorimetrically on an autoanalyzer with alkaline phenol, potassium sodium tartrate and and sodium hypochlorite at 630 nm (Berthelot method).
	7021 Nitrogen total Kjeldahl (TKN)	mg l^{-1}	0.05	Sample is digested with H_2SO_4, K_2SO_4 and HgO catalyst in a block digester during a 2-stage heating cycle (200 °C and 360 °C). Organic N is converted to NH_3 which is determined colorimetrically on an autoanalyzer following the Berthelot reaction at 660 nm.
Dissolved nitrate + nitrite ($NO_3 + NO_2$)	7105 Nitrogen dissolved NO3 & NO2	mg l^{-1}	0.003	Sample is passed through a 0.45 µm membrane filter and reduced by Cd. Resulting nitrite is determined colorimetrically with sulphanilic acid and 1-naphthylamine on an autoanalyzer.
	7110 Nitrogen dissolved NO3 & NO2	mg l^{-1}	0.005	Sample is passed through a 0.45 µm membrane filter and reduced by Cd. Resulting nitite is determined colorimetrically with sulphanilic acid and 1-naphthylamine on an autoanalyzer.
	7111 Nitrogen dissoved NO3 & NO2	mg l^{-1}	0.002	Filtered sample is mixed with NH_4Cl and passed through a column of amalgamated Cd filings. Sulphanilamide and n-1-naphtylethylenediamine solutions are added to form an azo dye. The intensity of the dye is determined at 543 nm.
	7119 Nitrogen dissolved NO3 & NO2	mg l^{-1}	0.01	Sample is field-filtered through a 0.8 µm glass fibre filter. Analysis is performed following method described under code 7110.
Ammonia, total (NH_3tot)	7505 Ammonia total	mg l^{-1}	0.001	Ammonia determined colorimetrically on an autoanalyzer with alkaline phenol, potassium sodium tartrate and sodium hypochlorite at 630 nm (Berthelot method).
	7506 Ammonia total	mg l^{-1}	0.05	Sample aliquot is adjusted to pH 12 or greater using 10 M NaOH. Ammonia concentration read on an ion selective electrode and corrected to 25 °C.
Ammonia, dissolved (NH_3diss)	7562 Ammonia dissolved	mg l^{-1}	n/a	Sample filtered through 0.45 µm filter. Resultant NH_3 is determined colorimetrically on an autoanalyzer with alkaline phenol, potassium sodium tartrate and and sodium hypochlorite at 630 nm (Berthelot method).
Particulate nitrogen (PN)	7902 Nitrogen particulate	mg l^{-1}	0.002	Sampled passed through pre-ignited Whatman GF/C filter. Residue is washed with diliute H_2SO_4 to remove CO_3^{2-}. Filter is dried, combusted at 905 °C and resulting N_2 is measured by thermal conductivity.
	7904 Nitrogen particulate	mg l^{-1}	n/a	Particulate nitrogen is given by: Total Nitrogen - Dissolved Nitrogen

Table 1 *(continued)*

Variable	AEP Code	Units	Detection Limit	Analytical Method
	7906 Nitrogen particulate total	mg l^{-1}	0.001	Sample passed through pre-ignited Whatman GF/C filter. Filter is dried, put in a tin crucible and introduced in a combustion tube (1050 °C). The oxides of nitrogen are reduced to nitrogen which is measured by thermal conductivity on a CHN analyzer.
Turbidity	2073 Turbidity	JTU	n/a	Light beam passed through the shaken sample on a Hach turbidimeter. The light scattered at 90 ° to the beam-axis is measured by photoelectric cells.
	2074 Turbidity	NTU	n/a	Nephelometric method using a HAC turbidimeter.
Nonfilterable residue (NFR)	10401 Residue nonfiltrable	mg l^{-1}	10	Sample aliquot is passed through a pre-ignited Whatman GF/C filter. Filter is then placed in a porcelain dish, oven-dried at 105 °C for 2.5 hr, cooled 15 minutes in a desiccator and weighed.
	10407 Residue nonfiltrable	mg l^{-1}	2	Sample is homogenized and passed through a 0.45 µm filter. Filter is dried for 0.5 hr at 105 °C and weighed to constant weight.

where less than fifty percent of the cases were below the detection limit. When calculating means for replicates on a given day or means for seasons, we set the mean of the group of data equal to the limit of detection in cases where greater than fifty percent of the data fell below the detection limit. For a few variables (*i.e.*, NO_2+NO_3, NH_3diss and NH_3tot), improved analytical methods resulted in a change in the limit of detection over time. However, multiple detection limits were never encountered within one season, and so we used the method described above to estimate seasonal means for all variables. In the analysis of instantaneous data (rather than seasonal means), we replaced cases with values below detection limits with the value of the detection limit.

2.3 Data Analysis

Data were analysed with SPSS (1993). All variables were natural log (ln) transformed to stabilize variance and normalize residuals. Temporal trends in chlorophyll *a* and nutrients in each river were examined by combining data for all sites along the river and testing the combined data for differences among years with analysis of variance (ANOVA). Following a significant *F* - test, polynomial contrasts, where ANOVA treatment sums of squares (in this case, the sums of squares for the factor 'years') were partitioned into single degree of freedom orthogonal comparisons representing linear, quadratic, cubic and higher order trends, enabled us to determine the direction of trends over time. The technique of polynomial contrasts is useful for detecting patterns between a dependent and quantitative independent variable following a significant ANOVA (Keppel 1991; Sokal and Rohlf 1981). In this study, we used year as the independent variable which allowed us to detect very general temporal patterns in water quality over time. However, this technique does not consider problems of serial correlation among years which is inevitable in a data set such as the one with which we worked. Given that our intent was to study water chemistry as it related to algal abundance and we therefore only examined water chemistry for years in which algae were sampled, the use of polynomial contrasts was suitable for detecting very broad changes in water quality. More exhaustive studies of water quality trends in specific rivers can be found in Alberta

Environmental Protection reports by Hamilton et al. (1981), Noton and Saffran (1995), Noton (1992), Shaw et al. (1990), Cross et al. (1986) and Sosiak (1990 and 1996).

Longitudinal trends in seasonal concentrations (spring, summer and fall) of chlorophyll *a* and nutrients along the mainstem of major Alberta rivers were examined for the most recent sampling years that had relatively complete longitudinal nutrient and chlorophyll *a* profiles: the Bow River for 1993 to 1995; the Oldman River for 1991 and 1992; the South Saskatchewan River for 1980, 1981 and 1986; the Red Deer River for 1983 to1987; the North Saskatchewan River for 1985, 1986, and 1988; and the Athabasca River for 1984. When several sites along a river were sampled repeatedly for two or more years, we examined general longitudinal trends in the river with ANOVA followed by polynomial contrasts. As with the case of our temporal trend analyses, the technique of polynomial contrasts suffers from correlation of spatial data. Thus, we interpreted only very general and highly significant trends from the analyses. We combined sites that were within three kilometres of each other, providing they did not cross an effluent outfall or a tributary to the river. There were insufficient data available as part of this review to evaluate longitudinal trends in the Elbow, Highwood, Sheep, Peace, or Milk rivers.

Instantaneous and seasonal relationships between epilithic and planktonic chlorophyll *a* and nutrient concentrations and flow were explored with stepwise multiple regression. Variables were entered into regression models when $P \leq 0.05$ and removed when $P \geq 0.10$. Chlorophyll *a* concentrations were ln-transformed to normalize their distribution about the independent variables. Water chemistry and flow variables were ln-transformed to meet the regression assumption of linearity. Dependency among nutrient and flow variables was tested by examining the Pearson correlation coefficients, and subsets of variables that were not highly correlated (coefficient $\leq$ 0.60, also used by Meeuwig and Peters 1996) were entered separately into multiple regression models. Correlation coefficients for instantaneous and seasonal databases can be found in Appendix C. Multiple regressions with the instantaneous data were used to identify the best relationships on a province-wide level (*i.e.*, where all rivers are entered into the model), for major drainage basins [*i.e.*, models separated into the Peace-Athabasca drainage, Milk River drainage, and Saskatchewan River drainage (including the North Saskatchewan, Red Deer, South Saskatchewan, Bow, Oldman, Elbow, Highwood and Sheep rivers)], and for individual rivers with sufficient data (the Bow and North Saskatchewan rivers). Multiple regressions with the seasonal data were conducted on a province-wide level only. In the case of seasonal analysis, chlorophyll *a* was examined in relation to nutrients and flow measured during: (1) the season that chlorophyll *a* was sampled, and (2) the seasons preceding the chlorophyll *a* sampling (e.g. spring and summer chemistry for a fall chlorophyll *a* concentration). In addition, all the seasonal averages were combined into one data set and seasonal mean chlorophyll *a* was compared to nutrients and flow measured during the season that chlorophyll *a* was sampled for all seasons simultaneously. Chlorophyll *a* was sampled infrequently during winter months and consequently winter relationships to nutrients and flow were not examined.

3.0 RESULTS

Mean epilithic chlorophyll *a* ranged from 0 to nearly 1000 mg m^{-2} among all rivers in Alberta and was highest in the Bow River (Table 2). Mean planktonic chlorophyll *a* ranged from 0 to nearly 900 mg m^{-3} in Alberta rivers and was highest in the Elbow River. P concentrations in Alberta rivers during years of chlorophyll *a* sampling ranged from analytical detection limits ($\leq$0.003 mg l^{-1}) up to 3.5 mg l^{-1} TP in the Oldman River. For the years in which chlorophyll collections were made, the Peace and Bow rivers had highest mean TP and TDP concentrations, respectively. Similarly, mean total and dissolved inorganic N concentrations were highest in the South Saskatchewan and Bow Rivers, respectively, and instantaneous concentrations ranged from barely detectable levels in many rivers to greater than 15 mg l^{-1} TN in the Athabasca River. The Peace River had the highest mean annual discharge and concentrations of NFR and turbidity among all rivers for the years investigated (Table 2).

Table 2. Summary statistics of chlorophyll *a*, water chemistry and discharge for the major Alberta rivers investigated in this study for the years in which benthic or planktonic algal sampling took place. "n/a" denotes data that were not collected for a particular river.

	Milk	Oldman	Bow	Elbow	Highwood -Sheep	South Saskatchewan	Red Deer	North Saskatchewan	Athabasca	Peace
Years of data										
	'86-'87	'80-'81, '84-'86, '90-'95	'80-'95	'88, '90-'95	'84-'86	'80-'81, '86	'83-'88, '91, '95	'83, '85-'86, '88, '94	'84-'89, '91, '93, '95	'88-'89, '91
Epichl*a* (mg m^{-2})										
$\bar{x}$±1SE	3.75±0.78	75.2±4.8	128±4	52.3±5.9	111±9	29.1±4.0	88.0±7.1	65.8±5.7	35.9±3.4	16.5±3.5
min	0	0	0	0.3	1.8	0	0	0	0	0.6
max	22.9	531	988	262	389	198	899	530	382	91.3
n	39	392	1081	112	117	79	342	254	318	54
Phytchl*a* (mg m^{-3})										
$\bar{x}$±1SE	20.6±8.2	10.3±1.3	24.1±2.6	171±40	1.62±0.13	15.9±3.1	5.58±0.54	6.30±0.57	3.51±0.35	6.72±3.55
min	0	0	0	2	0	0.3	0	0	0	0.1
max	206.5	176	682	881	8.6	152	103	63.9	56	114.3
n	39	385	839	26	147	87	435	298	242	37
TP (mg l^{-1})										
$\bar{x}$±1SE	0.067±0.019	0.061±0.008	0.056±0.003	0.008±0.001	0.040±0.011	0.104±0.017	0.061±0.007	0.091±0.008	0.040±0.004	0.135±0.030
min	0.003	0.003	0.001	0.002	0.003	0.007	0.002	0.003	0.003	0.004
max	0.650	3.50	1.50	0.062	1.25	0.920	1.65	1.65	0.900	0.780
n	55	519	1075	97	128	83	466	282	370	45
TDP (mg l^{-1})										
$\bar{x}$±1SE	0.007±0.001	0.027±0.003	0.042±0.003	0.003±0.001	0.014±0.007	0.028±0.006	0.017±0.001	0.027±0.003	0.021±0.006	0.015±0.003
min	0.003	0.001	0.001	0.001	0.003	0.003	0.001	0.002	0.001	0.002
max	0.029	0.590	1.40	0.007	0.040	0.340	0.150	0.192	0.900	0.085
n	55	503	1213	97	5	83	447	159	232	45
TN (mg l^{-1})										
$\bar{x}$±1SE	0.61±0.08	0.46±0.02	0.95±0.03	0.23±0.01	0.46±0.03	1.02±0.09	0.52±0.02	0.62±0.04	0.49±0.05	0.61±0.07
min	0.27	0.03	0.03	0.03	0.16	0.39	0.05	0.07	0.05	0.15

Table 2 *(continued)*

	Milk	Oldman	Bow	Elbow	Highwood Sheep	South Saskatchewan	Red Deer	North Saskatchewan	Athabasca	Peace
max	4.1	4	7.81	0.98	2.44	2.88	5.15	5.57	15.1	2.07
n	55	462	713	97	97	40	470	270	353	44
DIN (mg l^{-1})										
$\bar{x}$±1SE	0.077±0.016	0.097±0.016	0.762±0.045	0.087±0.011	n/a	0.357±0.079	0.107±0.013	0.311±0.031	0.179±0.047	0.098±0.035
min	0.013	0.005	0.003	0.013	n/a	0.013	0.003	0.003	0.002	0.013
max	0.250	1.30	2.38	0.270	n/a	1.10	1.05	4.27	14.1	0.333
n	27	129	180	40	n/a	21	207	235	343	8
TKN (mg l^{-1})										
$\bar{x}$±1SE	0.5	0.39±0.02	0.46±0.02	0.17±0.01	0.38±0.02	0.68±0.08	0.45±0.02	0.45±0.03	0.33±0.02	0.55±0.06
min	0.2	0	0	0	0.2	0.3	0.1	0.1	0.1	0.1
max	4	4	7.8	0.8	2.4	2.9	5	5.3	1.6	2
n	55	465	715	97	127	40	470	299	353	44
NO_2+NO_3 (mg l^{-1})										
$\bar{x}$±1SE	0.114±0.030	0.069±0.005	0.516±0.014	0.066±0.008	0.046±0.008	0.303±0.039	0.076±0.006	0.155±0.011	0.159±0.045	0.054±0.009
min	0.003	0.001	0.001	0.002	0.003	0.003	0.001	0.001	0.001	0.003
max	1.17	0.900	2.30	0.399	0.440	1.47	1.13	1.06	14.1	0.290
n	55	519	1261	97	98	83	471	270	354	44
NH_3 (total) (mg l^{-1})										
$\bar{x}$±1SE	0.021±0.003	0.031±0.002	0.181±0.019	0.011±0.001	0.028±0.004	0.090±0.011	0.034±0.005	0.061±0.024	0.042±0.009	0.034±0.007
min	0.010	0.002	0.004	0.002	0.010	0.010	0.002	0.002	0.010	0.010
max	0.070	0.440	15.0	0.030	0.300	0.500	1.00	1.40	0.070	0.160
n	28	392	924	57	133	62	267	63	6	39
NH_3 (dissolved) (mg l^{-1})										
$\bar{x}$±1SE	0.016±0.003	0.039±0.006	0.134±0.014	0.015±0.002	n/a	0.081±0.018	0.032±0.004	0.147±0.025	0.017±0.002	0.029±0.007
min	0.010	0.002	0.001	0.004	n/a	0.010	0.002	0.002	0.001	0.010
max	0.070	0.530	0.930	0.051	n/a	0.400	0.300	4.00	0.348	0.050

Table 2 *(continued)*

	Milk	Oldman	Bow	Elbow	Highwood Sheep	South Saskatchewan	Red Deer	North Saskatchewan	Athabasca	Peace
n	27	129	180	40	n/a	21	207	236	343	8
NFR (mg l^{-1})										
$\bar{x}\pm1$SE	64.1±22.5	37.2±12.2	17.7±1.9	5.6±1.4	6.43±1.03	124±37	63.6±14.9	27.8±2.2	39.1±5.6	128±38
min	0.4	0.4	0.4	0.4	0.4	0.8	0.4	0.4	0.3	0.4
max	1100	5840	966	76.4	68.8	1990	5285	251	966	1058
n	55	517	668	72	96	83	467	298	351	42
Turb (NTU)										
$\bar{x}\pm1$SE	53.9±18.4	18.2±4.4	11.1±1.1	4.2±1.3	3.94±0.74	66.3±21.5	21.5±3.3	13.5±1.5	13.1±1.6	74.1±21.6
min	0.6	0.1	0.2	0.3	0.4	1.2	0.1	0.7	0.1	1.4
max	670	2025	520	60	42	1660	800	125	275	620
n	55	501	703	72	97	83	465	130	288	36
Mean annual discharge (m^3 s^{-1})										
$\bar{x}\pm1$SE	14.5±6.1	52.9±4.9	84.4±2.8	9.58±0.85	8.67±0.73	185±8	34.4±1.7	169±6	185±12	411±82
min	1.48	0.37	2.9	2.91	5.63	141	16.4	47	0.9	100
max	52.5	136	185	15.7	14.3	220	66.9	283	599	1931
n	8	100	179	20	14	17	59	80	166	60

3.1 Temporal trends in chlorophyll *a* and nutrients

General temporal trends in epilithic and planktonic chlorophyll *a*, phosphorus (TP and TDP) and nitrogen (NO_2+NO_3, total NH_3, TKN) were examined for the Bow, Oldman, South Saskatchewan, Elbow, Highwood and Sheep, Red Deer, North Saskatchewan, and Athabasca river systems for the years in which algae were collected. Temporal trends in the Milk and Peace, Wapiti and Smoky systems were not examined because these systems were not sampled for algal abundance in more than two years.

In the Bow River, plant abundance and nutrients were sampled regularly from 1980 to 1995. Decreases in mean annual epilithic and planktonic chlorophyll *a* concentrations coincided with general declines in phosphorus (TP and TDP) and nitrogen (NO_2+NO_3, total NH_3, TKN) concentrations (Fig. 3). Declines in epilithic chlorophyll *a* were dramatic, with mean values near 150 mg m^{-2} in the early 1980s decreasing to concentrations near 50 mg m^{-2} in the 1990s. Declines in planktonic chlorophyll *a* were less obvious over time and variability about the mean appeared to increase after 1987. P concentrations dropped in 1983 and remained low (< 0.05 mg l^{-1}) throughout the study period. Although NO_2+NO_3 and TKN decreased significantly ($P < 0.001$) over time, the declines were small compared to total NH_3 which declined from mean concentrations near 0.3 mg l^{-1} in the early 1980's to concentrations less than 0.1 mg l^{-1} in the 1990's.

Trends in water quality in the Elbow and Highwood-Sheep river systems, two systems that drain into the Bow River, were similar to those observed for the Bow (Fig. 4). However, these systems were sampled infrequently over the period from 1980 to 1995, making it difficult to confidently detect trends. Mean annual epilithic chlorophyll *a* in both systems declined significantly and planktonic chlorophyll *a* declined in the Highwood and Sheep river system ($P < 0.001$). In the Highwood-Sheep system, TP and TKN also declined over the yeras in which chlorophyll *a* was measured (1984 to 1986), but NO_2+NO_3 increased significantly over the same period. Ammonia in the Highwood-

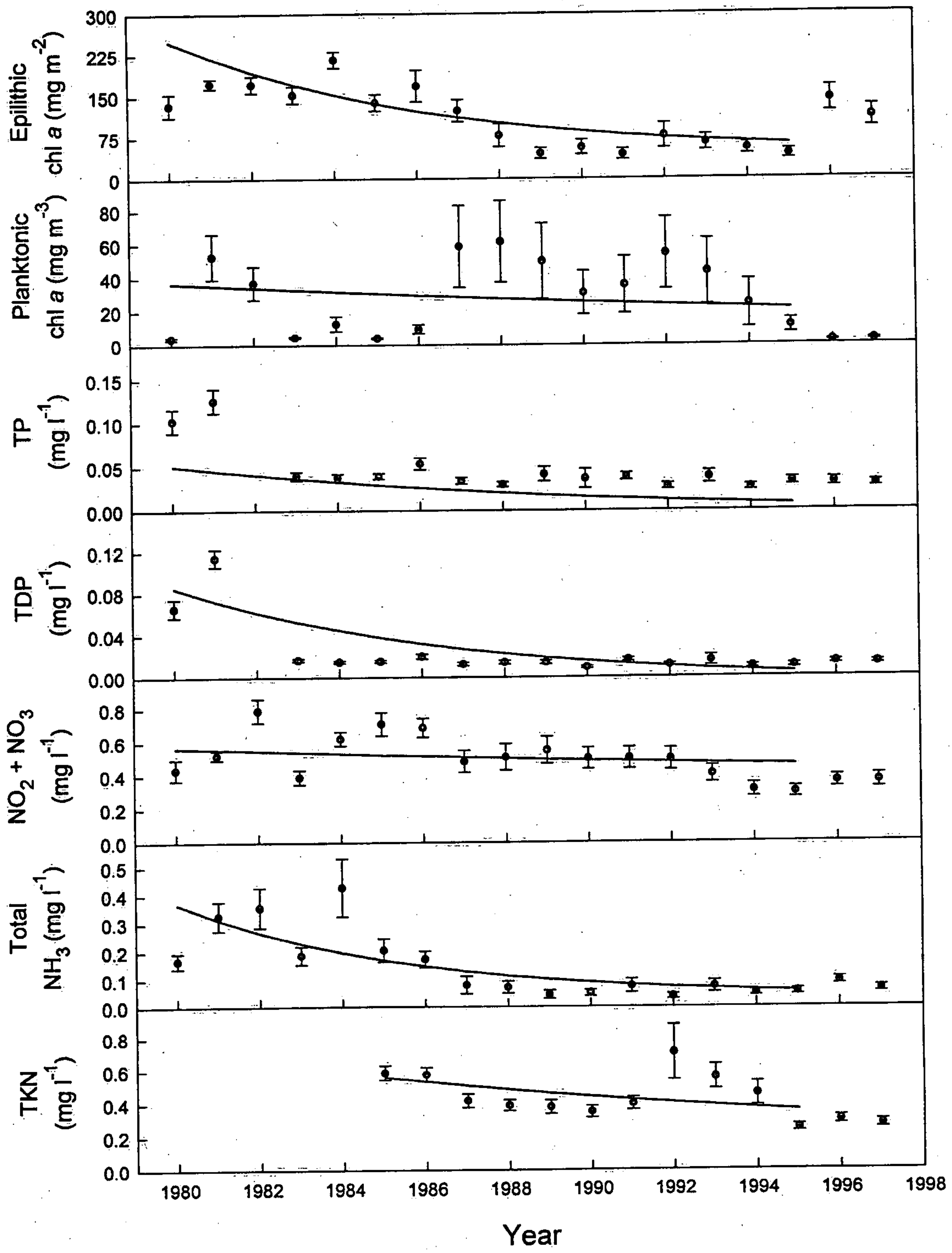

Figure 3. Mean annual chlorophyll *a* and nutrient concentrations in the Bow River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$. Data are mean ± 1 SE for all sites and dates sampled along the river.

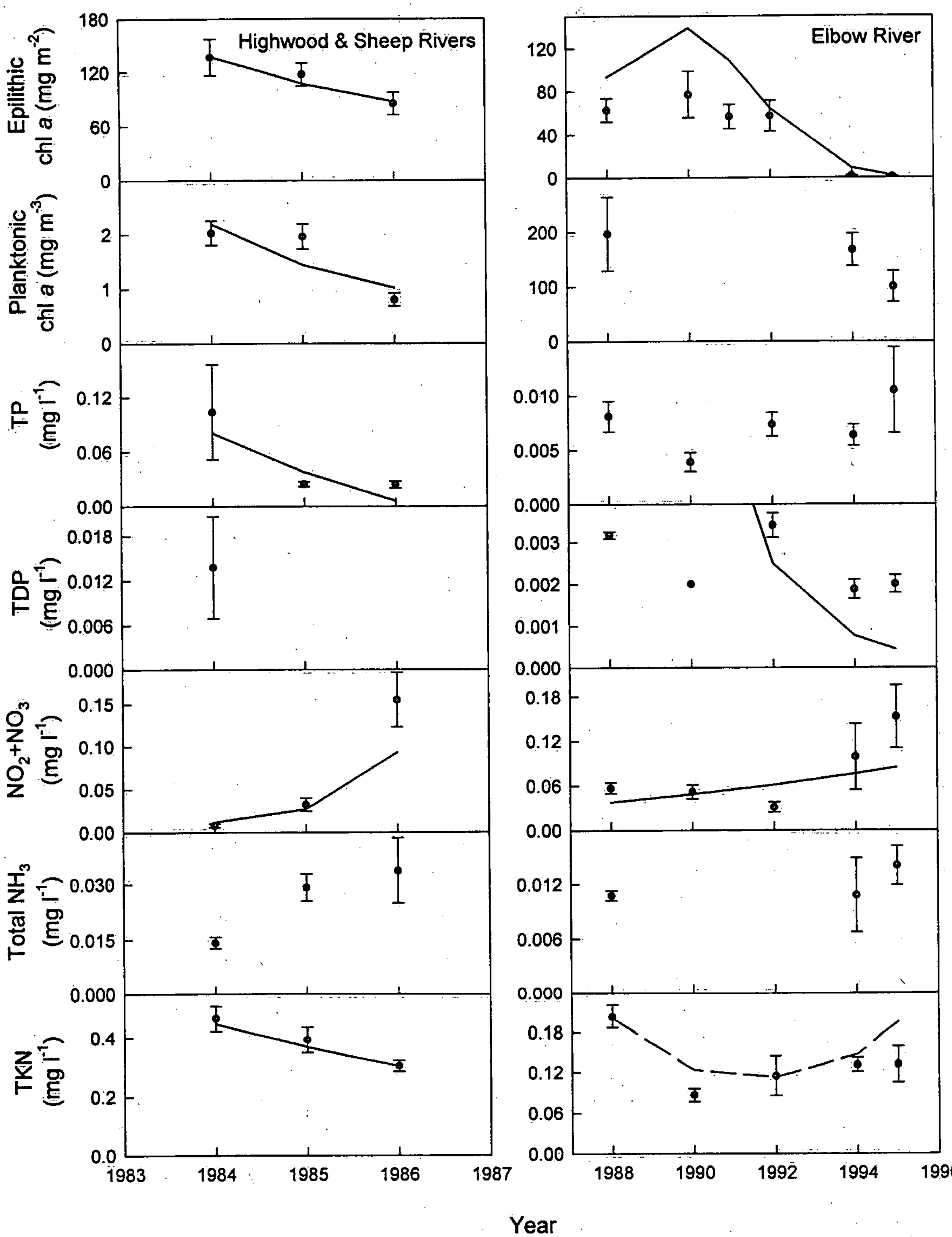

Figure 4. Mean annual chlorophyll *a* and nutrient concentrations in the Highwood-Sheep and Elbow river systems. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$ (solid lines) or $P \leq 0.10$ (dashed lines). Data are mean ± 1 SE for all sites and dates sampled along the river. Note the difference in scales on the X and Y axes.

Sheep system differed among years ($P = 0.044$) but a significant trend was not present. In the Elbow River, water quality was sampled irregularly from 1988 to 1995 and significant declines in TDP were observed during the years that chlorophyll *a* was measured. However, NO_2+NO_3 increased significantly over the same period and a slight increase in TKN was also observed. Planktonic chlorophyll *a* and TP did not differ among years in the Elbow ($P \geq 0.175$). Total NH_3 in the Elbow differed for the three years it was sampled (1988, 1994 and 1995), but no trend was evident (Fig. 4).

Epilithic chlorophyll *a* in the Oldman River increased significantly from 1980 to 1995, whereas planktonic chlorophyll *a* showed a general decline over the same period. TP and TDP also declined significantly over this period and no trend could be discerned in NO_2+NO_3 or TKN concentrations in the river. Total NH_3 also declined from 1980 to 1995 (Fig. 5).

The South Saskatchewan River, which arises from the confluence of the Bow and Oldman rivers, was sampled for plant abundance in 1980, 1981 and 1986. Very few trends could be discerned from the limited data available. There were declines in epilithic chlorophyll *a* and total NH_3 in the river over the sampling period and TP concentrations differed among years with no discernable trend in the concentrations. There were no differences in planktonic chlorophyll *a*, TDP or NO_2+NO_3 concentrations over time ($P \geq 0.169$) (Fig. 6).

The Red Deer River was sampled for plant abundance from 1983 to 1991, but only weak trends were evident in the data (Fig. 7). Epilithic chlorophyll *a*, TP and TDP differed among years ($P \leq 0.023$). There were significant positive quadratic trends in the data for these variables, indicating an initial decline followed by an increase in concentration toward the end of the sampling period. NO_2+NO_3 also differed among years ($P < 0.001$) and a weak trend was evident suggesting that concentrations were declining towards the end of the sampling period. TKN concentrations were

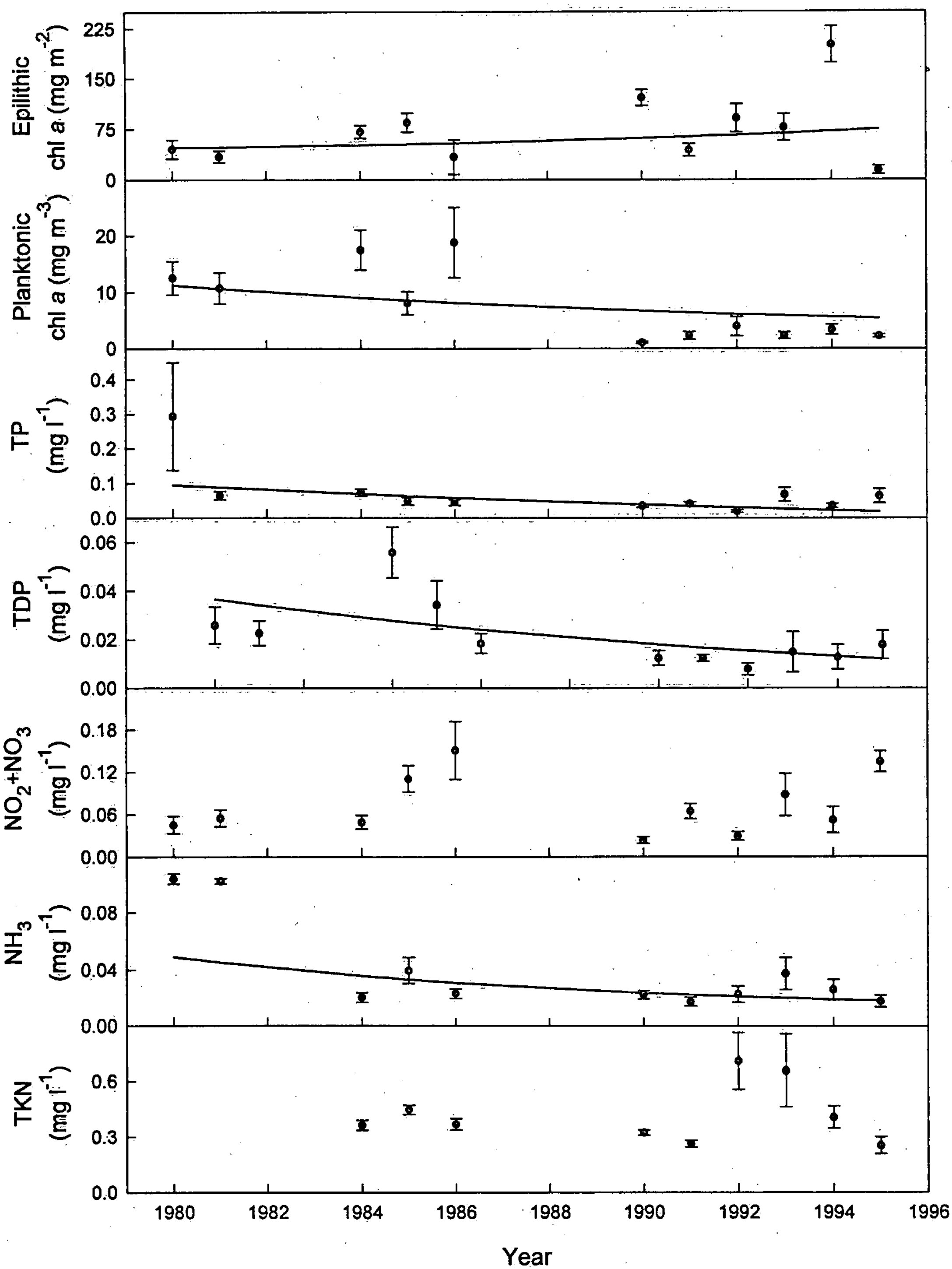

Figure 5. Mean annual chlorophyll *a* and nutrient concentrations in the Oldman River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$. Data are mean ± 1 SE for all sites and dates sampled along the river.

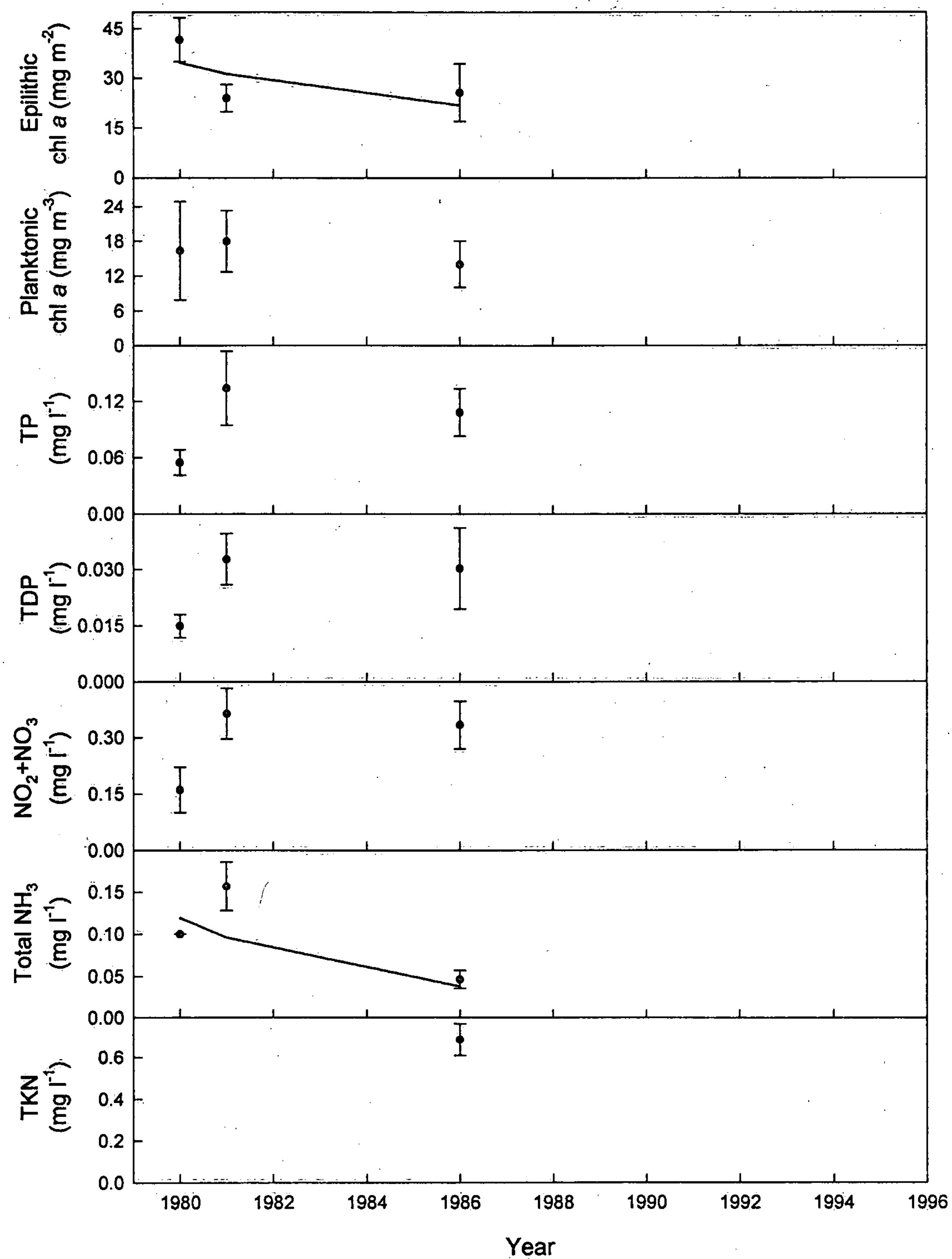

Figure 6. Mean annual chlorophyll *a* and nutrient concentrations in the South Saskatchewan River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$. Data are mean ± 1 SE for all sites and dates sampled along the river.

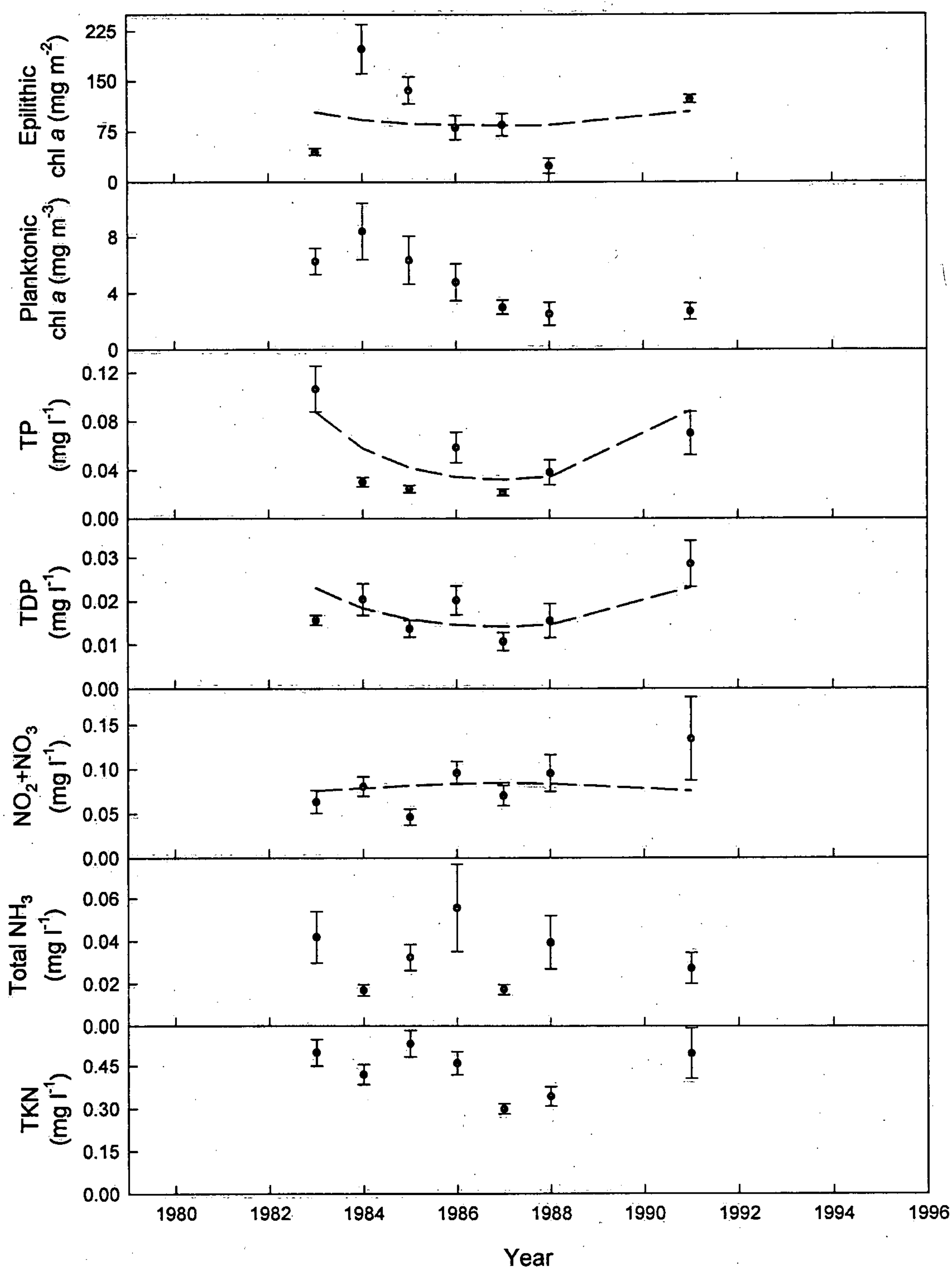

Figure 7. Mean annual chlorophyll *a* and nutrient concentrations in the Red Deer River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$ (solid lines) or $P \leq 0.10$ (dashed lines). Data are mean ± 1 SE for all sites and dates sampled along the river.

different among years ($P = 0.003$) but there was no trend in the pattern of change. Finally, NH_3 and planktonic chlorophyll *a* concentrations did not differ among the years sampled.

Plant abundance and nutrients in the North Saskatchewan River were sampled in 1983, 1985, 1986 and 1988 and all variables with the exception of planktonic chlorophyll *a* differed significantly among years ($P \leq 0.002$). Epilithic chlorophyll *a* showed an initial decline in concentration followed by an increase in 1988, as described by a quadratic trend in the data (Fig. 8). TP declined over the sampling period, whereas TDP increased over the same period. NO_2+NO_3 also declined but total NH_3 increased from 1983 to 1988. TKN declined initially and then increased by 1988.

Data for the Athabasca River and its tributaries were available from 1984 to 1993 and although all variables except NH_3 (dissolved) differed among years ($P \leq 0.001$), significant trends in the data could only be detected for epilithic chlorophyll *a* (a linear increase) and NO_2+NO_3 (a linear decrease) (Fig. 9).

3.2 Longitudinal trends in plant abundance and nutrients

Longitudinal trends in the Bow River were evaluated for the period 1993 to 1995. The influence of the City of Calgary sewage treatment plant (STP) on chlorophyll *a* and nutrients was most evident in the spring (April and May) and fall (September and October) (Fig. 10). Epilithic chlorophyll *a* was low ($\leq$ 100 mg m^{-2}) upstream of the STP, increased to 100 to 300 mg m^{-2} immediately downstream and declined further downstream in all seasons. However, a significant difference among sites could not be detected in the spring due to high variability. By comparison, planktonic chlorophyll *a* differed among sites for all seasons ($P \leq 0.009$), was highest in the spring, and increased linearly along the length of the river. P and N concentrations showed similar trends to epilithic chlorophyll, with increasing concentrations immediately downstream of Calgary's STP followed by gradual declines further downstream. TDP and NH_3 recovered to near upstream concentrations within

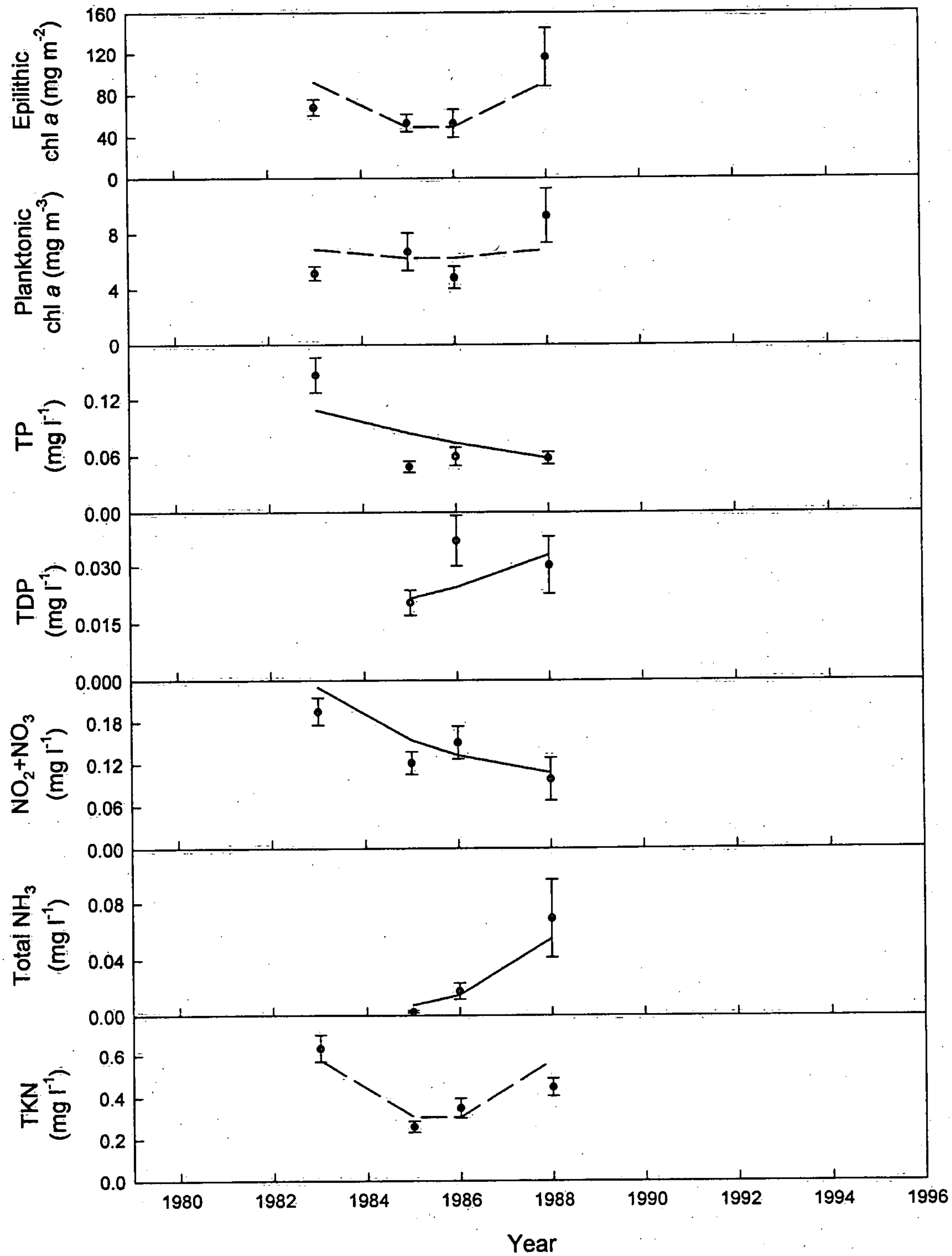

Figure 8. Mean annual chlorophyll *a* and nutrient concentrations in the North Saskatchewan River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$ (solid lines) or $P \leq 0.10$ (dashed lines). Data are mean ± 1 SE for all sites and dates sampled along the river.

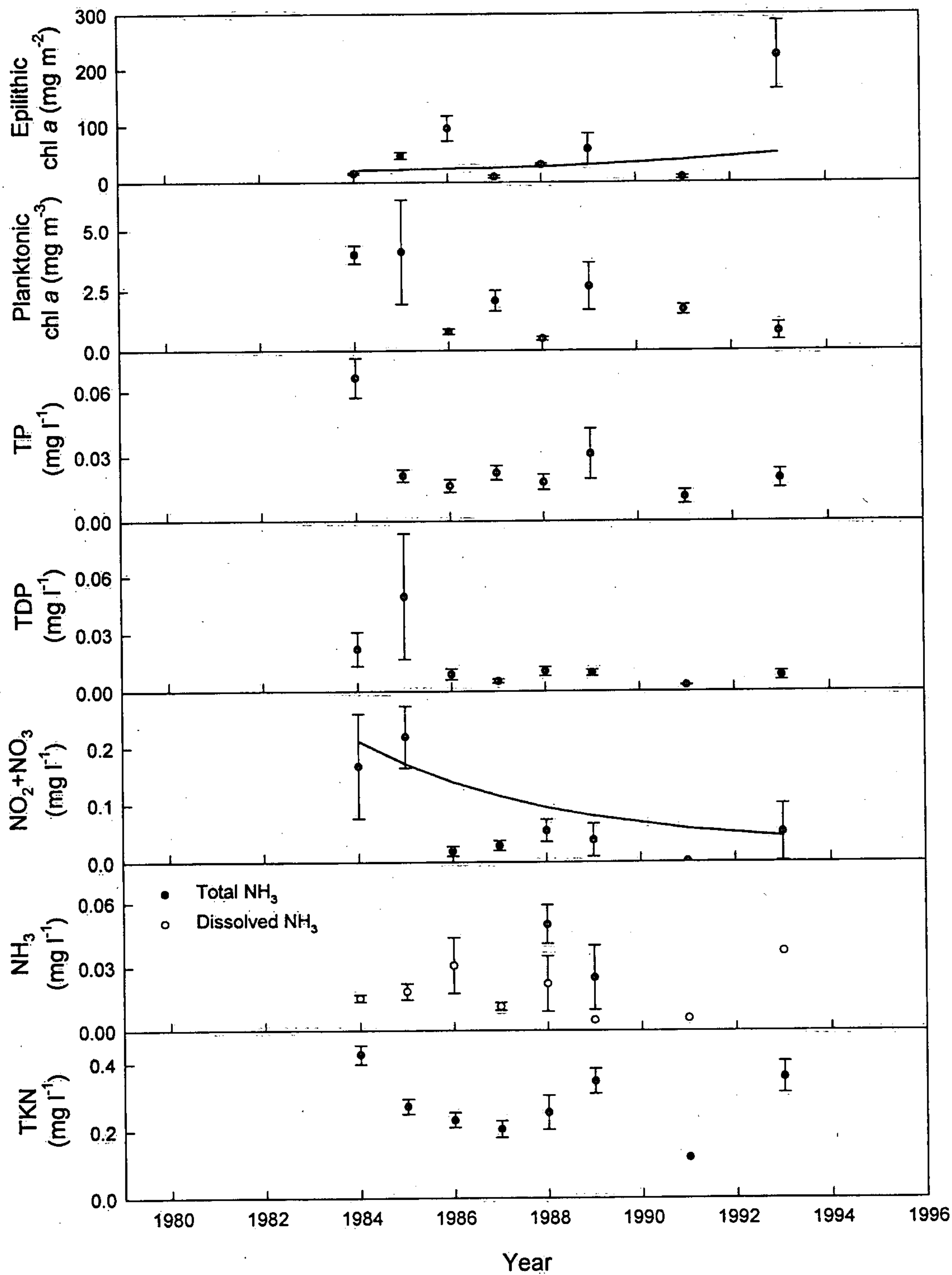

Figure 9. Mean annual chlorophyll *a* and nutrient concentrations in the Athabasca River. Curves fit through data are trends constructed from polynomial contrasts and are significant at $P \leq 0.05$. Data are mean ± 1 SE for all sites and dates sampled along the river.

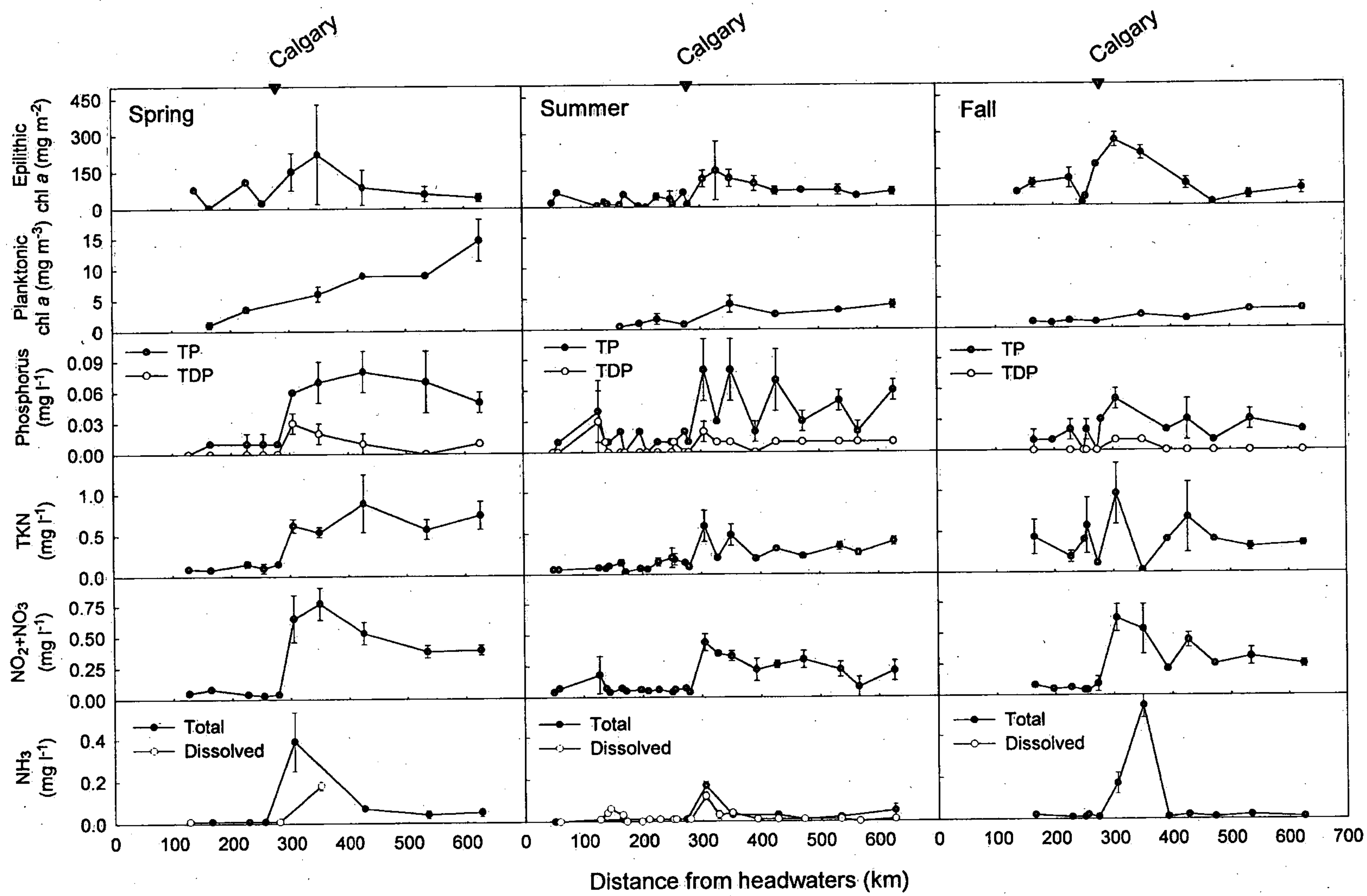

Figure 10. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the Bow River. Data are mean ± 1 SE for seasonal concentrations collected from 1993 to 1995. Sampling stations within three kilometres of each other were combined.

approximately 100 km of the STP, whereas TP, NO_2+NO_3 and TKN declined more gradually downstream of the STP towards the mouth of the river (Fig. 10).

Longitudinal trends were evaluated in the Oldman River for 1991 and 1992, the most recent years in which a suite of stations along the river were sampled repeatedly throughout the year. However, the stations sampled in these years for water chemistry and chlorophyll did not extend over the entire length of the river, and we therefore could only evaluate trends to approximately 215 km downstream of the headwaters, near Waldon's corner (Site AB05AA0050) (Fig. 11). There were no trends in either chlorophyll or nutrient variables and although it appeared that effluent from the City of Lethbridge STP resulted in increased P and epilithic chlorophyll *a*, there were insufficient data to detect a pattern (Fig. 11).

Four sites in the South Saskatchewan River were sampled regularly during the early 1980s for chlorophyll *a* (1980, 1981 and 1986). Chlorophyll *a* and nutrients did not differ among sites along the length of the river and no trends were detected among these sites (Fig. 12). There was no apparent influence of the City of Medicine Hat on water quality in the South Saskatchewan River.

Very few sites in the Red Deer River were sampled regularly for chlorophyll *a* for any consecutive length of time; consequently, it was difficult to evaluate statistically trends in water quality along the river. Data from 1983 to 1987 showed that epilithic and planktonic chlorophyll *a* increased immediately downstream of the City of Red Deer STP in spring, summer and fall but recovered to upstream concentrations within less than 100 km. Nutrients did not appear to increase dramatically downstream of Red Deer, but there was a noticeable increase downstream of Drumheller after which there was no evidence of recovery to upstream conditions (Fig. 13).

Longitudinal trends in chlorophyll *a* in the North Saskatchewan River were evaluated for the period 1985, 1986 and 1988. Epilithic chlorophyll *a* increased downstream of Edmonton's STP in summer

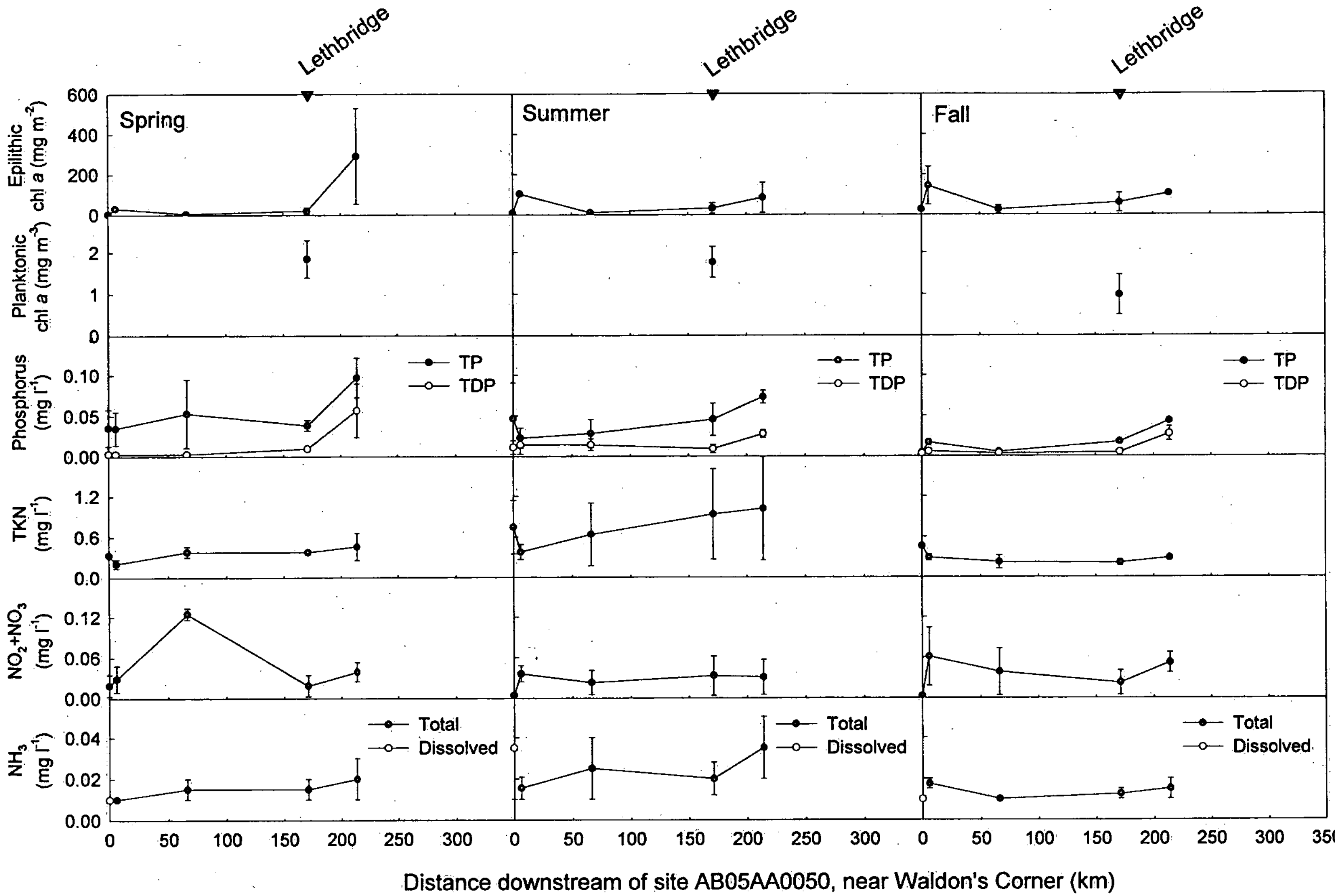

Figure 11. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the Oldman River. Data are mean ± 1 SE for seasonal concentrations collected in 1991 and 1992. Sampling stations within three kilometres of each other were combined.

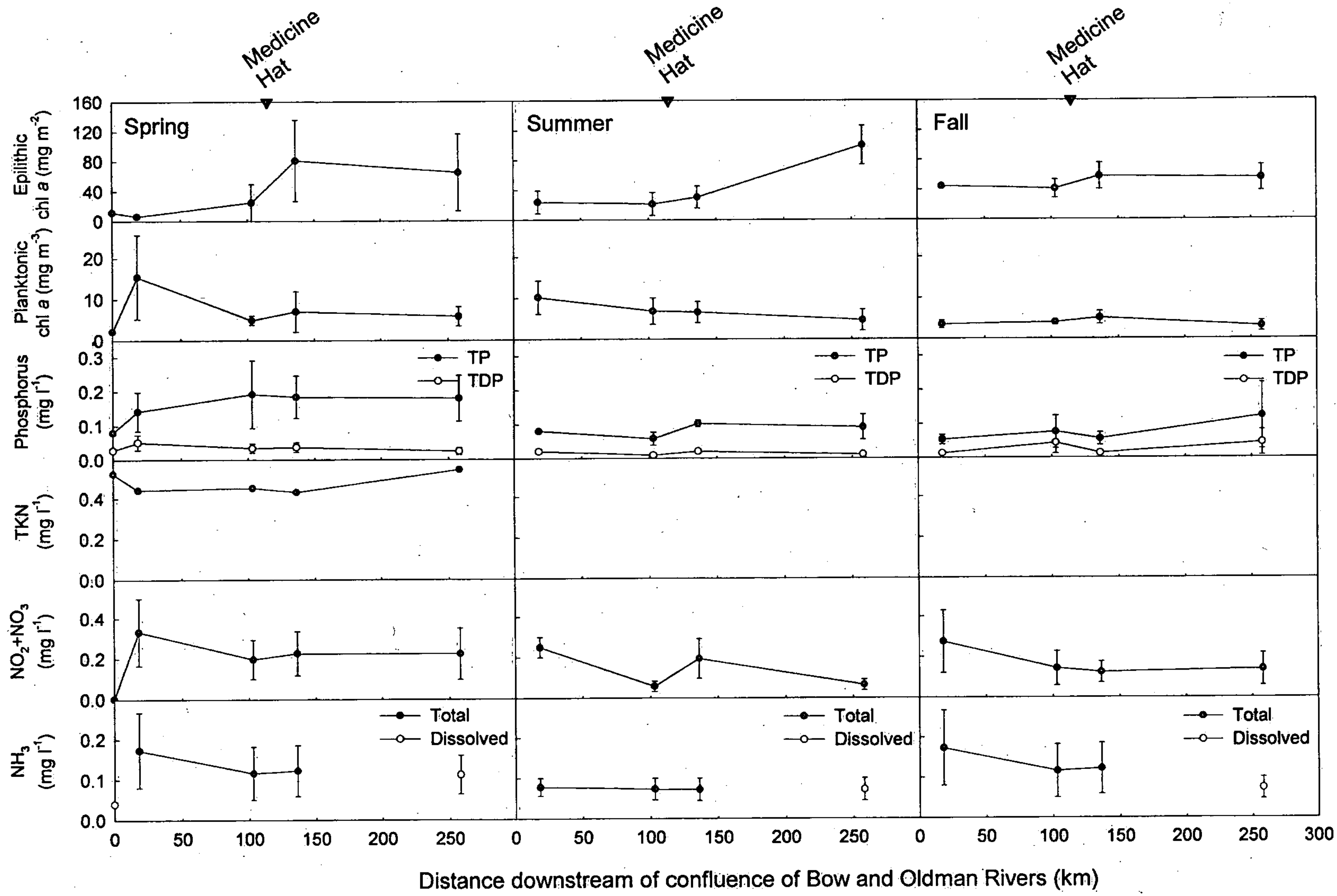

Figure 12. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the South Saskatchewan River. Data are mean ± 1 SE for seasonal concentrations collected in 1980, 1981 and 1986. Sampling stations within three kilometres of each other were combined.

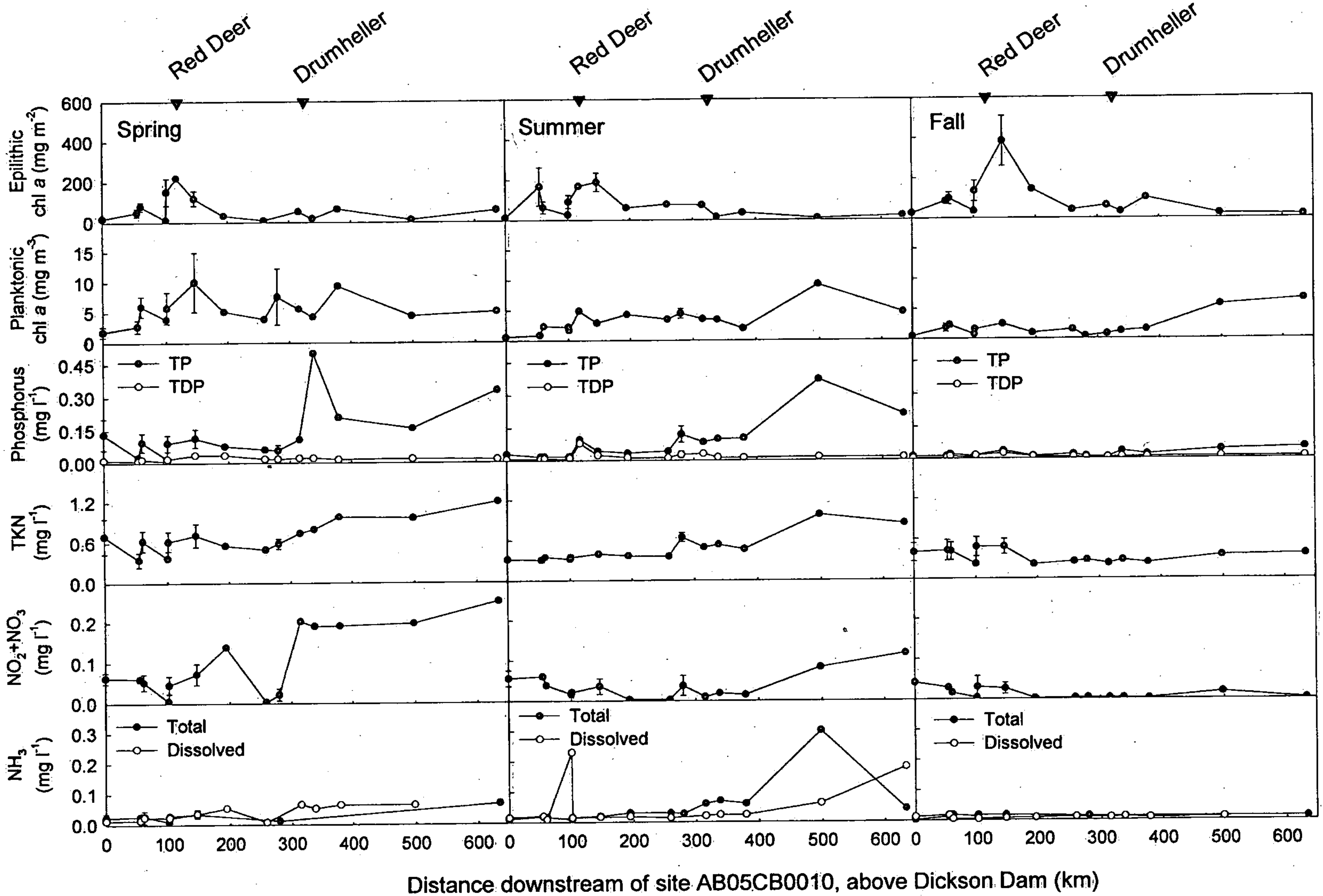

Figure 13. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the Red Deer River. Data are mean ± 1 SE for seasonal concentrations collected from 1983 to 1987. Sampling stations within three kilometres of each other were combined.

and fall, whereas planktonic chlorophyll *a* increased noticeably downstream of the STP in the spring and summer (Fig. 14). N and P increased downstream of the STP in all seasons and declined with distance beyond the STP. TDP and NH_3 recovered to near upstream concentrations within approximately 150 km of the STP whereas TP, TKN and NO_2+NO_3 recovered more gradually with distance downstream of the city (Fig. 14).

It was difficult to evaluate longitudinal trends in the Athabasca River because only a few sites were monitored for chlorophyll *a* more than once over the entire study period. Localized surveys of plant abundance and water quality were conducted in the river upstream and downstream of municipal and pulp mill effluents in the 1990's but these surveys do not provide enough information to make generalizations about the status of the entire river. Thus, we examined data from a survey of the entire river conducted in 1984 and found that epilithic chlorophyll *a* was highest in the fall near the towns of Hinton and Whitecourt, but was much lower in the spring and summer (Fig. 15). Planktonic chlorophyll *a* tended to increase over the entire length of the river and was approximately the same concentration in all seasons. TP and TKN were highest in the summer seasons and tended to increase along the length of the river. NO_2+NO_3 concentrations were highest in the summer and fall seasons and tended to decline along the length of the river in 1984. Dissolved NH_3 concentrations were low along the length of the river and no trends were detected (Fig. 15).

3.3 Relationship between plant abundance, nutrients and flow

3.3.1 Instantaneous data - Province-wide relationships

There was no single variable that was ideal in predicting either instantaneous epilithic or planktonic chlorophyll *a* concentrations on a province-wide scale. The combination of inorganic P (TDP) and N (dissolved NH_3 and NO_2+NO_3 *or* DIN) and a surrogate variable for light availability (NFR or Turb) explained between 19 and 21% of the variability in epilithic chlorophyll *a* (Table 3). No greater than

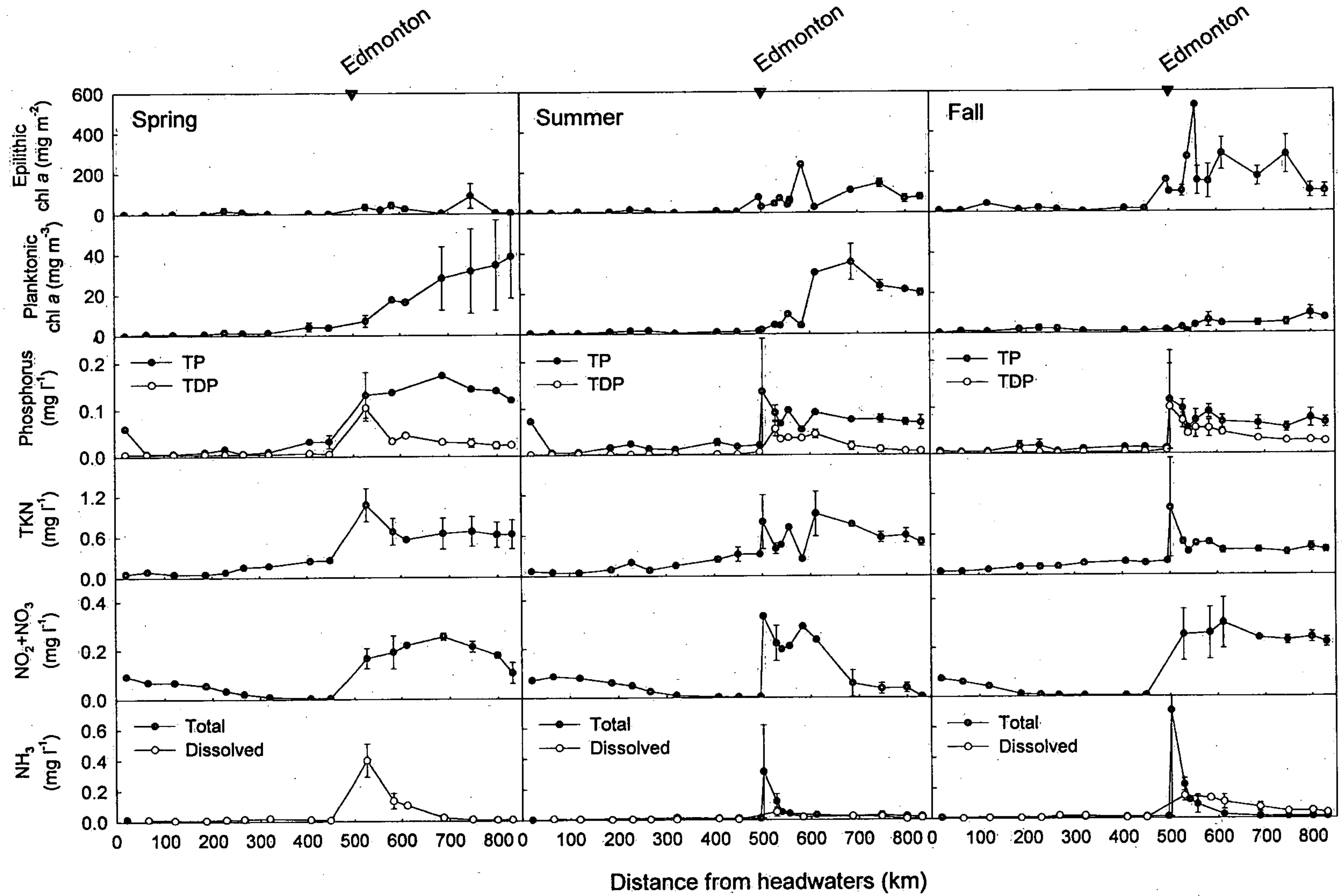

Figure 14. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the North Saskatchewan River. Data are mean ± 1 SE for seasonal concentrations collected in 1985, 1986 and 1988. Sampling stations within three kilometres of each other were combined.

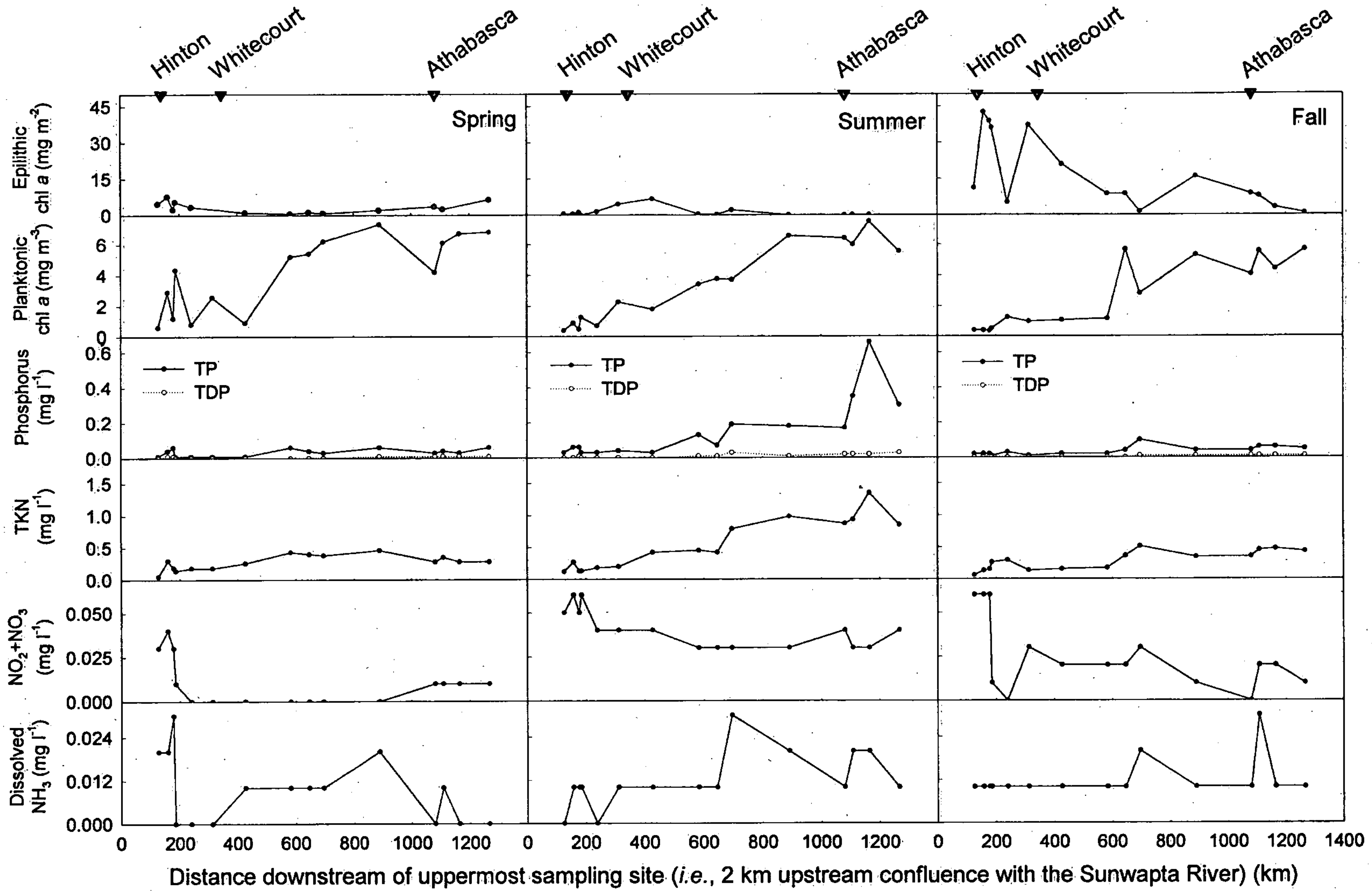

Figure 15. Longitudinal trends in chlorophyll *a* and nutrient concentrations in spring, summer and fall in the Athabasca River. Data are from 1984 surveys. Sampling stations within three kilometres of each other were combined.

Table 3. Regression models predicting instantaneous epilithic and planktonic chlorophyll *a* concentrations in relation to water quality and discharge for all Alberta rivers. Variables are listed in order of importance in the models. Abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed. All regressions are significant at $P \leq 0.0001$.

	Equation	r^2	*n*
Epilithic chlorophyll *a*			
Eqn 1	Epichl*a* = 5.66 + 0.70(TDP) - 0.43(NH_3diss) - 0.30(Turb) + 0.16(NO_2+NO_3)	0.21	921
Eqn 2	Epichl*a* = 6.67 + 0.75(TDP) - 0.36(NFR) - 0.30(DIN)	0.21	920
Eqn 3	Epichl*a* = 6.24 + 0.69(TDP) - 0.34(Turb) - 0.27(DIN)	0.19	920
Planktonic chlorophyll *a*			
Eqn 4	Phytchl*a* = 2.81 + 0.34(TP) + 0.21(DIN)	0.16	881
Eqn 5	Phytchl*a* = 2.38 + 0.28(TP) + 0.39(TN)	0.14	1939
Eqn 6	Phytchl*a* = 2.12 + 0.46(TKN) + 0.08(NO_2+NO_3) + 0.10(TDP)+ 0.07(NFR)	0.13	1997

16% of the variability in planktonic chlorophyll *a* was explained by combinations of P, N and surrogates for irradiance (Table 3). Discharge was never a significant predictor of chlorophyll *a* for instantaneous samples.

3.3.2 Instantaneous data - Drainage basin relationships

Instantaneous relationships between nutrients and chlorophyll *a* were improved slightly when multiple regressions were run for each major drainage basin (Table 4). The combination of turbidity and TP explained 34% of the variability in epilithic cholorophyll *a* in the Peace-Athabasca drainage basin. The best predictors of epilithic chlorophyll *a* in the Saskatchewan River drainage basin, which includes the North Saskatchewan, Red Deer, Bow, Oldman, Highwood, Sheep, Elbow and South Saskatchewan rivers, were TDP, DIN, NFR and flow, explaining 23% of the variability in benthic algal biomass. There were no variables that could model epilithic chlorophyll *a* in the Milk river drainage, probably because of insufficient data. By comparison, 84% of the variability in planktonic chlorophyll *a* in the Milk River was explained by flow, turbidity and dissolved NH_3, but this was based on a very small sample size ($n = 11$) and probably is not reliable. Forty-nine percent of the variability in planktonic chlorophyll *a* in the Peace-Athabasca drainage basin was explained by TP, inorganic N (dissolved NH_3 and NO_2+NO_3), and turbidity. The best predictors of planktonic chlorophyll *a* in the Saskatchewan River drainage were TP and DIN and these explained 17% of the variability (Table 4).

We subdivided the Saskatchewan River drainage into northern and southern components, so that the North Basin consisted of the Red Deer and North Saskatchewan rivers and the South Basin consisted of the Oldman, Bow, Elbow, Highwood, Sheep, and South Saskatchewan rivers. This division further improved relationships between nutrients and epilithic chlorophyll *a*, with the best models explaining 41% of the variability in each basin (Table 4). Phytoplankton relationships were

Table 4. Regression models predicting instantaneous epilithic and planktonic chlorophyll *a* concentrations in relation to water quality and flow divided by drainage basin and individual river. Variables are listed in order of importance in the models. Abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed. All regressions are significant at $P \le 0.0041$.

	Equation	r^2	*n*
Peace-Athabasca drainage			
Eqn 7	Epichla = 2.23 - 0.57(Turb) - 0.29(TP)	0.34	257
Eqn 8	Phytchla = 3.69 + 1.21(TP) - 0.38(NH_3diss) - 0.47(Turb) - 0.15(NO_2+NO_3)	0.49	214
Milk River drainage			
Eqn 9	Phytchla = -19.08 - 4.21(NH_3diss) + 1.37(Turb) - 0.85(Flow)	0.84	11
Saskatchewan River drainage			
Eqn 10	Epichla = 5.96 + 0.78(TDP) - 0.46(DIN) - 0.34(NFR) + 0.17(Flow)	0.23	669
Eqn 11	Phytchla =2.67 + 0.27(DIN) + 0.26(TP)	0.17	648
North Basins (Red Deer and North Saskatchewan Rivers)			
Eqn 12	Epichla = 5.37 + 0.65(TDP) - 0.71(Turb) + 0.90(TKN) - 0.26(NO_2+NO_3) + 0.46(Flow)	0.41	443
Eqn 13	Phytchla =1.10 + 0.50(TN) + 0.19(Turb)	0.18	556
South Basins (Oldman, Bow, Elbow, Highwood, Sheep and South Saskatchewan Rivers)			
Eqn 14	Epichla = 4.70 - 0.92(NH_3diss) + 0.75(TDP) + 0.31(NO_2+NO_3) - 0.15(NFR)	0.41	314
Eqn 15	Phytchla = 2.17 + 0.72(DIN) + 0.31(NFR) - 0.24(Flow) - 0.17(TDP)	0.40	227
Bow River			
Eqn 16	Epichla = 8.90 - 1.37(DIN) + 1.34(TDP) - 0.34(Turb)	0.81	140
Eqn 17	Phytchla = 0.74 + 1.28(DIN) + 0.71(Turb) - 0.80(TP) - 0.47(Flow)	0.74	77
North Saskatchewan River			
Eqn 18	Epichla = 4.23 + 0.74(TDP) - 0.41(NFR) + 0.64(Flow)	0.38	124
Eqn 19	Phytchla = 0.26 + 1.53(TN) - 0.48(TDP)	0.43	130

only marginally improved, with 18 and 40% of the variability explained in the North and South Basins, respectively (Table 4).

When the Bow and North Saskatchewan rivers were examined individually, the relationships between chlorophyll *a* and nutrients remained comparable or were improved as compared to the broader drainage basin relationships. Improvements were most notable in the Bow river, where chlorophyll *a* was best explained by combinations of DIN, TP or TDP, turbidity, and flow (for planktonic chlorophyll *a*) with 81 and 74% of the variability in epilithic and planktonic algal abundance explained, respectively. DIN was always the most important variable in the Bow River models (Table 4). By comparison chlorophyll-nutrient relationships remained comparable to broader drainage basin relationships for the North Saskatchewan river, where TDP, NFR, and flow explained 38% of the variability in periphyton and TN and TDP explained 43% of planktonic variability (Table 4).

3.3.3 Seasonal data - Province-wide relationships

With the exception of summer epilithic algal mass, mean chlorophyll *a* was best predicted by water quality measured during the season in which the algae were collected and not by historical (*i.e.*, preceding seasonal data) nutrient concentrations (Table 5). Spring water chemistry explained 36 and 41% of the variability in spring benthic and planktonic chlorophyll *a*, respectively, but only up to 33% of the variability in summer and fall chlorophyll *a* concentrations. Summer water chemistry explained 28 and 50% of the variability in summer epilithic and planktonic chlorophyll *a*, respectively, and no more than 31 and 41% of fall benthic and suspended algal abundance. Meanwhile, fall water chemistry explained 35 and 49% of the fall benthic and planktonic chlorophyll *a* variability (Table 5).

Table 5. Regression statistics (r^2, n) and model variables from best (*i.e.*, highest r^2) regression models for each combination of seasonal (*i.e.*, spring, summer and fall) chlorophyll *a* and water chemistry. Variables are listed in order of importance in the models. Discharge subscript denotes the type of flow (annual maximum = max). All other abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed. All regressions are significant at $P \leq 0.0001$.

	Water chemistry								
	Spring			Summer			Fall		
	r^2	n	Variables	r^2	n	Variables	r^2	n	Variables
Epilithic chlorophyll *a*									
Spring	0.36	232	TDP, NO_2+NO_3, NFR, Flow						
Summer	0.33	253	TDP, NO_2+NO_3, $Flow_{max}$	0.28	308	TDP, NFR, TN (or TKN)			
Fall	0.33	255	TDP, NO_2+NO_3, NFR	0.31	159	NH_3diss, NFR, TDP	0.35	286	NO_2+NO_3, Turb, TP
Planktonic chlorophyll *a*									
Spring	0.41	206	TN, Flow						
Summer	0.25	193	TN, Flow	0.50	243	TN, TP			
Fall	0.26	207	TDP, $Flow_{max}$, Turb	0.41	216	TN, TDP	0.49	207	TP, $Flow_{max}$, NO_2+NO_3, NFR

When all the seasonal mean data for algal biomass, water chemistry and discharge were pooled into one data set, the best models explained 33 to 36% of the variability in seasonal epilithic chlorophyll *a* and 23 to 50 % of the variability in seasonal planktonic chlorophyll *a* (Table 6). Although the best predictors of chlorophyll *a* varied among models, a form of P and N occurred in all models with the exception of the best spring planktonic chlorophyll *a* model where P was not a significant predictor (Equation 28, Table 6). The importance of either discharge or irradiance in the models differed among seasons such that epilithic chlorophyll *a* in spring and summer was dependent on flow whereas irradiance was important in spring and fall. Planktonic chlorophyll *a* was dependent on flow in all seasons; irradiance was only an important predictor in the fall model (Table 6). When the entire seasonal database was combined for all rivers and not divided according to season, the combination of TDP, NFR, NO_2+NO_3 and either TKN or dissolved NH_3 best modelled benthic algal abundance ($0.30 \leq r^2 \leq 0.31$). By comparison, TN, TDP and mean annual flow were the best predictors of planktonic algal abundance, explaining 42% of the variability (Table 6).

4.0 DISCUSSION

Results from this investigation showed that nutrient and chlorophyll *a* concentrations in Alberta's major mountain-fed rivers fell within expected ranges for similar systems across North America and abroad. Thus, the range of mean TP concentrations in Alberta rivers (0.008-0.135 mg l^{-1}; Table 2) was similar, although at the low end of the P range, to other large North American rivers (0.01-0.20 mg l^{-1} PO_4-P, which can be expected to be much less than TP; UNEP 1995). Similarly, mean NO_2+NO_3 concentrations in Alberta rivers (0.046-0.516 mg l^{-1}; Table 2) fell within the lower half of the concentration range observed in North American rivers (0.03-1.06 NO_3-N; UNEP 1995). Moreover, benthic chlorophyll *a* concentrations in Alberta rivers were within the mid-range of seasonal mean concentrations for more than 200 temperate streams in North America and New Zealand (Dodds et al. 1998).

Table 6. Regression models predicting mean seasonal (spring, summer, fall and all seasons combined) epilithic and planktonic chlorophyll *a* concentrations in relation to water quality and discharge for all Alberta rivers. Variables are listed in order of importance in the models. Variable subscripts denote the season of collection (spring = sp, summer = su, fall = fa) or the type of flow (annual mean = ann, annual maximum = max). All other abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed. All regressions are significant at $P \leq 0.0001$.

	Equation	r^2	*n*
Epilithic chlorophyll *a*			
Spring			
Eqn 20	$Epichla_{sp} = 8.27 + 0.31(NO_2+NO_3)_{sp} + 0.54(TDP)_{sp} - 0.27(NFR)_{sp} - 0.18(Flow)_{sp}$	0.36	232
Eqn 21	$Epichla_{sp} = 7.78 + 0.50(TDP)_{sp} + 0.31(NO_2+NO_3)_{sp} - 0.22(Turb)_{sp} - 0.18(Flow)_{sp}$	0.35	227
Summer			
Eqn 22	$Epichla_{su} = 7.81 + 0.57(TDP)_{sp} + 0.22(NO_2+NO_3)_{sp} - 0.21(Flow)_{max}$	0.33	253
Eqn 23	$Epichla_{su} = 7.31 + 0.57(TDP)_{sp} + 0.21(NO_2+NO_3)_{sp} - 0.18(Flow)_{sp}$	0.32	279
Fall			
Eqn 24	$Epichla_{fa} = 7.47 + 0.23(NO_2+NO_3)_{fa} - 0.54(Turb)_{fa} + 0.53(TP)_{fa}$	0.35	286
Eqn 25	$Epichla_{fa} = 7.06 + 0.21(NO_2+NO_3)_{fa} + 0.42(TDP)_{fa} - 0.35(Turb)_{fa}$	0.34	286
All seasons			
Eqn 26	$Epichla = 8.03 + 0.50(TDP) - 0.48(NFR) + 0.21(NO_2+NO_3) + 0.28(TKN)$	0.31	873
Eqn 27	$Epichla = 8.25 + 0.52(TDP) - 0.45(NFR) + 0.17(NO_2+NO_3) + 0.16(NH_3diss)$	0.30	427
Planktonic chlorophyll *a*			
Spring			
Eqn 28	$Phytchla_{sp} = 1.55 + 0.86(TN)_{sp} + 0.09(Flow)_{sp}$	0.41	206
Eqn 29	$Phytchla_{sp} = 2.72 + 0.36(TP)_{sp} + 0.11(NO_2+NO_3)_{sp}$	0.23	222
Summer			
Eqn 30	$Phytchla_{su} = 2.70 + 0.78(TN)_{su} + 0.31(TP)_{su}$	0.50	243
Eqn 31	$Phytchla_{su} = 1.99 + 0.79(TKN)_{su} + 0.14(Flow)_{ann} + 0.15(TDP)_{su}$	0.46	249
Fall			
Eqn 32	$Phytchla_{fa} = 4.95 + 0.66(TP)_{fa} - 0.23(Flow)_{max} + 0.08(NO_2+NO_3)_{fa} - 0.09(NFR)_{fa}$	0.49	207
Eqn 33	$Phytchla_{fa} = 4.45 + 0.58(TP)_{fa} - 0.22(Flow)_{max} + 0.09(NO_2+NO_3)_{fa}$	0.48	207
All seasons			
Eqn 34	$Phytchla = 2.06 + 0.78(TN) + 0.18(TDP) + 0.09(Flow)_{ann}$	0.42	678
Eqn 35	$Phytchla = 2.52 + 0.79(TN) + 0.20(TDP)$	0.41	678

Chlorophyll *a* and associated nutrient concentrations have shown modest increases in some Alberta rivers over the last two decades, whereas declines in concentrations are notable in other rivers. The Bow River witnessed the most dramatic decline in nutrient concentrations following upgrades to Calgary's sewage treatment plant in 1982 and further upgrades in the late 1980's and early 1990's (Fig. 3). Improvements in water quality in the Bow River since the early 1980's have been accompanied by more gradual declines in periphyton abundance. The slow decline in periphyton chlorophyll *a* as compared to P probably reflects more efficient P uptake and cycling by the biota in the river, as well as gradual P-release from bottom sediments, creating a lag in response of the primary producers to nutrient reductions. This process may also explain the apparent contradictory trends observed in the Oldman (Fig. 5) and Athabasca (Fig. 9) rivers, where gradual declines in TP, TDP and NH_3 (Oldman) and NO_2+NO_3 (Athabasca) were accompanied by gradual increases in benthic chlorophyll *a* from 1980 to 1995. The Highwood-Sheep and Elbow river systems (Fig. 4) and the South Saskatchewan River (Fig. 5), although sampled infrequently, showed a more predictable response whereby declines in nutrient concentrations were accompanied by declines in chlorophyll *a*. Weak trends in chlorophyll *a* and nutrients were detected in the Red Deer (Fig. 7) and North Saskatchewan (Fig. 8) rivers with the general pattern being declines in the earlier years of sampling followed by slow increases in concentrations in later years.

Longitudinal trends along Alberta's major rivers show the impact of cities on nutrient concentrations and algal abundance in spring, summer and fall (Figs. 10-15). The general trend observed across the province was of increased periphyton abundance and nutrient concentrations immediately downstream of a city or town (Calgary in the Bow River: Fig. 10; Lethbridge in the Oldman River: Fig. 11; Medicine Hat in the South Saskatchewan River: Fig. 12; Red Deer in the Red Deer River: Fig. 13; Edmonton in the North Saskatchewan River: Fig. 14; and Hinton in the Athabasca River: Fig. 15) followed by returns to near upstream conditions some distance beyond the municipality. Planktonic chlorophyll *a* in the Bow, North Saskatchewan and Athabasca rivers tended to increase linearly downstream of municipal sewage outfalls with no return to upstream conditions. These trends were most evident in the spring and fall across the province, when discharges were low compared to summer values. Although it is not clear that the planktonic chlorophyll *a* investigated in this study represents true river plankton (Charlton et al. 1986), the linear increase in planktonic chlorophyll *a* with increasing distance downstream in some Alberta rivers is consistent with predictions from the River Continuum Concept that instream plankton will develop with increasing river size (Vannote et al. 1980). Morever, the fact that there was almost no relationship between epilithic and planktonic chlorophyll *a* in this study ($r^2 = 0.04$, $n = 1755$, linear regression on ln-transformed variables) suggests that the planktonic algae represents, for the most part, a community unto itself that could be composed of either true river plankton or phytoplankton washed in from connecting lakes and reservoirs. Either way, planktonic chlorophyll *a* is independent of the periphyton.

The multiple regression models for algal abundance based on nutrients, flow, and surrogates for light (Turbidity and NFR) revealed that instantaneous water chemistry samples were generally poor predictors of benthic and planktonic chlorophyll *a* for all Alberta rivers (Table 3). However, the relationships were slightly improved when the data were subdivided according to major drainage basins within the province, with 23 to 34% of the variability in benthic chlorophyll *a* explained by instantaneous samples of nutrients and indicators of light availability on a drainage-basin scale (Table 4). In the case of the Saskatchewan River drainage basin, relationships were further improved when the data were divided into North and South basins such that water chemistry predicted up to 41% of the epilithic and planktonic chlorophyll *a* in each basin (Table 4). The high predictability of instantaneous algal abundance based on water quality in the Bow River ($0.74 \leq r^2 \leq 0.81$; Table 4) is unusual given that other rivers did not display similar patterns and may reflect the fact that water quality in the Bow River has undergone dramatic changes in P and N concentrations over the past 15 years, thus providing a broader range of water quality conditions for modelling (Fig. 3). In general, the most important predictors of benthic chlorophyll *a* based on instantaneous water chemistry were phosphorus (usually TDP), a light variable (turbidity or NFR), followed by a form of inorganic N. By comparison, instantaneous DIN or TN was usually the most important predictor of planktonic chlorophyll *a*, followed by some combination of P and light variables (Tables 3 and 4).

The predictability of seasonal mean concentrations of benthic and planktonic chlorophyll *a* based on water quality for all Alberta rivers was equal to or better than the instantaneous relationships developed for each major drainage basin (Table 6). This is not surprising given that seasonal mean concentrations are more likely to better reflect average growing conditions in a river and will not be as sensitive to the large fluctuations in water chemistry and flow that may be observed on any given sampling day. Whereas all seasons were approximately similar in terms of their benthic chlorophyll *a* predictability ($0.28 \leq r^2 \leq 0.36$), planktonic chlorophyll *a* was best-predicted in summer and fall, and least well-predicted in the spring (Table 5). This is probably because benthic chlorophyll *a* was higher and more variable in summer and fall in most Alberta rivers whereas planktonic biomass was less variable in these seasons than in the spring (Figs. 10 -15). When the seasonal data were combined and algal abundance was modelled against mean water chemistry from the season in which it was sampled, the predictability dropped slightly compared to models for specific seasons. However, this drop in predictability is offset by an increase in sample size for the models giving equal confidence to the individual and combined seasonal models (Table 6).

Total dissolved phosphorus and NO_2+NO_3 concentrations were the two most important predictors of epilithic chlorophyll *a* in spring, summer and fall models. This suggests that benthic algae are co-limited by N and P and that the importance of N vs P varies over the year and may be related to instream N to P ratios, as observed by Chessman et al. (1992). Moreover, the availability of light to benthic algae, expressed as turbidity or NFR concentration, was important in predicting epilithic chlorophyll *a* in spring and fall models and for all seasons combined (Table 6), indicating that periphyton in Alberta rivers is light-limited to some extent for most of the year. Discharge was also an important predictor of biomass in the spring and summer, reflecting the high flows typical of these seasons compared to fall (refer to Appendix B for annual hydrographs for sites along each river).

Seasonal mean planktonic chlorophyll *a* was better modelled by water column nutrients than epilithic chlorophyll *a* with approximately 10% more variability explained by similar combinations of variables (Table 6). Light variables were almost never important in the planktonic models, indicating that suspended algae are not light-limited in Alberta rivers. The most important predictors of planktonic biomass, then, were a form of N (TN, NO_2+NO_3, or TKN) and a form of P (TP or TDP). The relative importance of N to P varied with season, as it did with the periphyton data. Flow was also an important predictor of planktonic biomass but its relationship to abundance was not consistent. That is, suspended algae in the spring, summer and in all seasons combined were positively related to flow, whereas a negative relationship was present in the fall data.

Our models as well as those of others show that nutrients are only moderately successful at predicting periphyton biomass. The pattern observed in this study, where nutrients are better predictors of suspended algal abundance than of benthic algal abundance, is consistent with results from other studies (Tables 6, 7). In contrast, open-water P and N concentrations are excellent predictors of phytoplankton biomass in lakes, with surveys of Florida, North American and U.S. lakes reporting 70 to 95% of the variability in phytoplankton biomass explained by P and N (Dillon and Rigler 1974, Canfield 1983, Søballe and Kimmel 1987). The poorer relationships for periphyton, as compared to phytoplankton, in lotic systems may be due to the higher concentrations of particulate matter that are typically found in flowing waters and that vary with discharge. Another confounding factor is that heterotrophic organisms in benthic biofilms will also have a nutrient demand. Studies relating nutrient concentrations to periphyton abundance have shown that TP concentrations of 0.10 to 0.20 mg l^{-1} correspond to about 450 mg m^{-2} benthic chlorophyll *a in situ* (Lohman et al. 1992; Dodds et al. 1997) whereas TP concentrations of only 0.02 to 0.05 mg l^{-1} will yield about 450 mg m^{-2} in artificial streams (Horner et al. 1983, Horner et al. 1990, Walton et al.

Table 7. Empirical models predicting biomass of benthic and planktonic chlorophyll *a* (Chl*a*) in rivers worldwide reported in scientific literature. Abbreviations defined in text.

Stream systems	Model	Reporting Units: Chl*a*	Reporting Units: Nutrients	r^2	*n*	*P*	Reference
Benthic chlorophyll *a*							
10 streams in Denmark	$Chla_{max}$ = 929(SRP)/(49.2 + SRP)	mg m^{-2}	μg l^{-1}	0.61	21	<0.001	Kjeldsen 1994
9 streams in New Zealand	Chl*a* ∝ TP	mg m^{-2}	μg l^{-1}	0.55	9	< 0.05	Biggs & Close 1989
	Chl*a* ∝ TDP	mg m^{-2}	μg l^{-1}	0.53	9	< 0.05	
	Chl*a* ∝ NH_3	mg m^{-2}	μg l^{-1}	0.52	9	< 0.05	
12 streams in Missouri	Chl*a* = 76.9log(TN) - 155.8 (1985)	mg m^{-2}	μg l^{-1}	0.58	22	≤ 0.001	Lohman et al. 1992
	Chl*a* = 69.3log(TN) - 116.7 (1986)	mg m^{-2}	μg l^{-1}	0.60	22	≤ 0.001	
	Chl*a* = 39.9log(TP) - 18.1 (1985)	mg m^{-2}	μg l^{-1}	0.47	22	≤ 0.001	
	Chl*a* = 41.1log(TP) - 4.1 (1986)	mg m^{-2}	μg l^{-1}	0.60	22	≤ 0.001	
205 North American and New Zealand streams	$\log(Chla)_{mean} = 2.83\log(TN) - 0.43\log(TN)^2 + 0.25\log(TP) - 3.22$	mg m^{-2}	μg l^{-1}	0.43	205	< 0.01	Dodds et al. 1997
	$\log(Chla)_{max} = 2.79\log(TN) - 0.43\log(TN)^2 + 0.31\log(TP) - 2.70$	mg m^{-2}	μg l^{-1}	0.35	205	< 0.05	
Athabasca, Wapiti and Smoky Rivers	Chl*a* = 0.809(SRP) + 0.005(DIN) + 3.395 (early fall 1994)	μg cm^{-2}	μg l^{-1}	0.38		< 0.001	Scrimgeour & Chambers 1996
	Chl*a* = 0.256(SRP) + 0.10(DIN) + 10.38 (late fall 1994)	μg cm^{-2}	μg l^{-1}	0.57		< 0.0001	
9 Ontario streams	log(Chl*a*) = 0.81log(TP) + 0.224	mg m^{-2}	μg l^{-1}	0.25	9	< 0.01	Cattaneo et al. 1997
Planktonic chlorophyll *a*							
Missouri streams	log(Chl*a*) = 0.1 + 0.39log(TP) + 0.34log(TN)	mg m^{-3}	mg m^{-3}	0.53	36	< 0.05	Jones et al. 1984
Rideau R., Ontario	log(Chl*a*) = 0.84log(TP) - 0.42	μg l^{-1}	μg l^{-1}	0.16	36	0.016	Basu & Pick 1995
31 Eastern Canada rivers	log(Chl*a*) = -0.26 + 0.73log(TP)	μg l^{-1}	μg l^{-1}	0.76	31	< 0.001	Basu & Pick 1997
Temperate streams	$\log(Chla) = 1.99\log(TP) - 0.28\log(TP)^2 - 1.65$	mg m^{-3}	mg m^{-3}	0.67	292	< 0.01	Van Nieuwenhuyse &Jones 1996

1995). This greater biomass per unit P in artificial streams may be due to the presence of less detritus (due to filtered water supplies, shorter water residence times, constant velocities) and, thus, a greater availability of nutrients to the periphyton rather than to heterotrophic organisms. In addition to detrital uptake, nutrient cycling by biofilms may also obscure nutrient - periphyton relationships. This cycling or "nutrient spiralling" entails the biotic uptake of N and P, their release as a result of tissue decomposition, and their subsequent re-uptake by organisms further downstream (Newbold et al. 1981, Paul and Duthie 1989, Mulholland et al. 1990). The potential for nutrient spiralling to obscure nutrient - biomass relationships is evident from studies showing that nutrient cycling intensifies as periphyton biomass increases (*e.g.*, Mulholland et al. 1994, Peterson and Grimm 1992) and as nutrient limitation becomes more severe (*e.g.*, Paul and Duthie 1989). Thus, nutrient - periphyton relationships appear inherently less predictable than nutrient - phytoplankton relationships.

Phosphorus is generally considered to be the principal limiting nutrient in freshwater systems worldwide and as a result it has often been the only variable examined in empirical models of algal growth and nutrient concentrations. However, this study and those by Dodds et al. (1997), Chessman et al. (1992), and Lohman et al. (1992) indicate that N is also an important limiting nutrient in river ecosystems and should not be overlooked when considering nutrient-biomass relationships. Thus, although many studies have not examined the importance of nitrogen in empirical models (and this is particularly true for lakes), the results of this investigation are consistent with other studies on rivers that showed that nitrogen is equal to or more important than phosphorus in the prediction of chlorophyll *a* in rivers. However, our models are unique in that they include light and flow in addition to nutrients as significant predictors of algal abundance. The predictability of our models for both benthic and planktonic chlorophyll *a* falls near the midpoint of the range reported in other studies (Table 7).

4.1 Development of nutrient guidelines

The development of a nutrient guideline (be it based on nutrient concentrations or the response of nutrient-sensitive biota) must consider ecosystem responses (*e.g.*, changes in abundance and taxonomic composition of appropriate assemblages), impacts on human use of the resource (*e.g.*, aesthetics, recreation, fisheries, water supply, etc.), and achievability (as related to background or reference water quality). This report considers ecosystem responses (*i.e.*, relationships between nutrient concentrations and algal abundance) and achievability as it relates to reference conditions (*i.e.*, sites upstream of major point source or agricultural inputs) for Alberta rivers. No attempt has been made to quantify or incorporate user-perceived impairment. In Alberta rivers, a management issue with respect to eutrophication in rivers and algal growth is excessive growth of periphyton. Potamoplankton (suspended algae) biomass is typically low (Table 2) and not a management issue. Excessive macrophyte growth is also an important issue in the eutrophic rivers of southern Alberta, where macrophytes have clogged intake pipes, affected dissolved oxygen and impaired aesthetics.

The remainder of our analysis focuses on periphyton, where the first task in setting a guideline is to determine the boundary between acceptable and unacceptable periphyton abundance. Abundances of periphyton that are unacceptable from the perspective of aesthetics/recreation or protection of aquatic life have been proposed by several investigators or agencies (Table 8). These recommendations are typically based on periphyton biomass expressed as chlorophyll *a* concentration and range from 50 to 150 mg m^{-2}. The British Columbia Ministry of Environment, Lands and Parks has periphyton chlorophyll *a* criteria of 50 mg m^{-2} for the protection of aesthetics and recreation and 100 mg m^{-2} for the protection of aquatic life (particularly for streams containing salmonids) (Nordin 1985). Welch and Dodds (pers. comm.) provided to the US EPA a definition of nuisance periphyton as seasonal mean values exceeding 100 mg m^{-2} chlorophyll *a* and seasonal maximum values exceeding 150 mg m^{-2} chlorophyll *a*, based upon an extensive literature review of nutrient-periphyton relationships (Dodds et al. 1997). The New Zealand Ministry of Environment

Table 8. Suggested values for unacceptable benthic algal abundance for recreational / aesthetic uses or protection of aquatic life. "Chl*a*" and "AFDW" denote chlorophyll *a* concentration and ash-free dry weight, respectively.

River Systems	Criterion	Reference
	When all stones covered by algal filaments	Thomas 1978
New Zealand streams (provisional guideline)	> 40% maximum cover and/or > 100 mg m^{-2} chl*a* and/or 40 mg m^{-2} AFDW by periphyton as filamentous growths or mats (> ca. 3 mm thick) (recreation)	New Zealand Ministry of Environment 1992
USA streams (proposed guidelines)	> 150 mg m^{-2} chl*a* maximum	Dodds et al. 1997
British Columbia streams (guideline)	> 50 mg m^{-2} (recreation) > 100 mg m^{-2} (aquatic life)	Nordin 1985
Streams in Washington, USA	100 - 150 mg m^{-2} (recreation/aesthetics)	Horner et al. 1983 Welch et al. 1988
	> 150-200 mg m^{-2} maximum (recreation/aesthetics)	Welch et al. 1989
Data from approximately 200 streams	oligotrophic: <20 (mean) and <60 (max) mg m^{-2} mesotrophic: 20-70 (mean) and 60-200 (max) mg m^{-2} eutrophic: >70 (mean) and >200 (max) mg m^{-2}	Dodds et al. 1998

(1992) has a provisional guideline for protection for contact recreation that states that seasonal maximum cover of streambeds by periphyton as filamentous growths or mats (> ca. 3 mm thick) should not exceed 40% and/or biomass should not exceed 100 mg m^{-2} chlorophyll *a* and/or 40 g m^{-2} AFDW (ash-free dry weight) of exposed surface area. Although not a guideline, Dodds et al. (1998) noted from an assessment of approximately 200 North American and New Zealand rivers that periphyton chlorophyll *a* concentrations were less than 20 mg m^{-2} (seasonal mean) or 60 mg m^{-2} (seasonal maximum) for one-third of the rivers and greater than 70 mg m^{-2} (seasonal mean) or 200 mg m^{-2} (seasonal maximum) for another third of the rivers. On this basis, they proposed a provisional trophic classification whereby seasonal mean periphyton biomass (expressed as chlorophyll *a*) was < 20 mg m^{-2} for oligotrophic rivers, 20 to 70 mg m^{-2} for mesotrophic rivers, and > 70 mg m^{-2} for eutrophic rivers. Corresponding seasonal maximum biomass for periphyton is < 70 mg m^{-2} for oligotrophic rivers, 70 to 200 mg m^{-2} for mesotrophic rivers and > 200 mg m^{-2} for eutrophic rivers.

For Alberta rivers, periphyton chlorophyll *a* concentrations for sites upstream of major point sources (*i.e.*, North Saskatchewan River upstream of Edmonton, Red Deer River upstream of Red Deer, Bow River upstream of Calgary, Oldman River upstream of Lethbridge, Athabasca River upstream of Hinton) averaged 44 ± 4 mg m^{-2} (mean ± 1 SE). This means that, 95 percent of the time, seasonal mean periphyton chlorophyll *a* concentration upstream of point source inputs falls between 37 and 51 mg m^{-2}. This value is comparable to the seasonal mean values of 20 to 70 mg m^{-2} which Dodds et al. (1998) defined as the range for mesotrophic rivers. A frequency distribution of all periphyton data for Alberta also showed that 45% of all seasonal mean chlorophyll *a* concentrations from sites upstream and downstream of point sources were less than the reference site average of 44 mg m^{-2} chlorophyll *a* (Fig. 16). Thus, many sites on Alberta rivers have periphyton chlorophyll *a* concentrations typical of reference conditions and that, compared with temperate streams throughout North America and New Zealand, these sites can be classed as oligotrophic or mesotrophic.

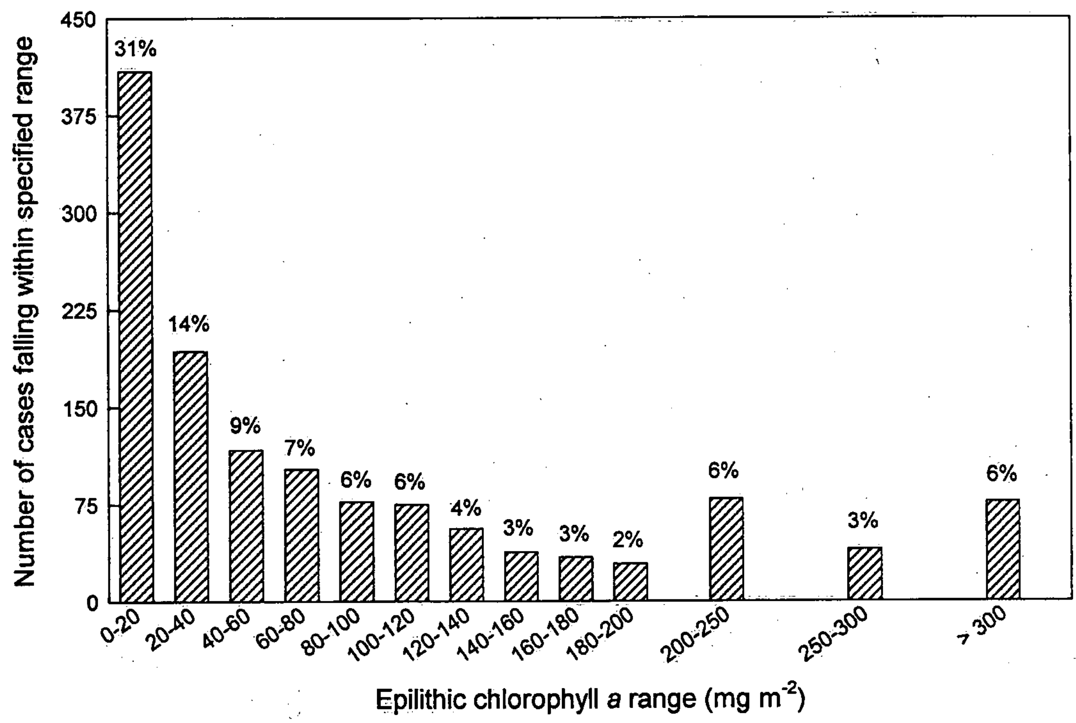

Figure 16. Frequency distribution of seasonal mean epilithic chlorophyll *a* for all Alberta rivers for spring, summer and fall data. Percentages are the number of cases within a specific chlorophyll *a* range relative to the total number of cases.

Management of an ecosystem based on biotic guidelines requires a predictive relationship between the biological response variable and the factors controlling the response, particularly the factors that are under management control (*e.g.*, point-source inputs). Considerable statistical variation exists in our regression models relating instantaneous or seasonal mean periphyton biomass (expressed as chlorophyll *a*) to water-column N and P concentrations, a surrogate for underwater light (turbidity or non-filterable residue), and flow. Recognizing this, we examined our data using two approaches to identify the water-column nutrient concentrations that would result in periphyton chlorophyll *a* concentrations of < 50, < 100 and < 150 mg m^{-2} [breakpoints that other agencies or investigators have used to define acceptable versus unacceptable conditions (Dodds et al. 1997; New Zealand MOE 1992; Nordin 1985)]. First, we used the regression models with the greatest number of samples and greatest r^2 value for the instantaneous, spring, summer, fall or combined seasonal data sets (Equations 2, 20, 23, 24 and 26) to predict P (TP or TDP) and N (DIN or NO_2+NO_3) concentrations corresponding to 50, 100 and 150 mg m^{-2} chlorophyll *a* (Table 9). Second, we used a frequency distribution approach described by Hieskary and Walker (1988) whereby we plotted the frequency with which the four critical chlorophyll *a* concentrations were exceeded for defined ranges (quartiles) of TP, TDP, TN and DIN (Fig. 17).

Focusing first on phosphorus, results from our instantaneous, fall, and combined seasonal regression models showed that under conditions of high light penetration (the surrogate terms for light set to zero) and average discharge, approximately 0.008 mg l^{-1} TP in the fall and 0.005 - 0.026 mg l^{-1} instantaneous, spring or all-season TDP (averaging these predictions yields 0.012 mg l^{-1} TDP) will yield periphyton chlorophyll *a* concentrations of 50 mg m^{-2} or less (Table 9). Periphyton growth of about 100 mg m^{-2} chlorophyll *a* will occur when TP concentrations average 0.019 mg l^{-1} in fall, or when TDP ranges between 0.009 and 0.062 mg l^{-1} depending on the season or type of sample (instantaneous or seasonal mean). Periphyton growth of about 150 mg m^{-2} will occur when TP concentrations average 0.033 mg l^{-1} in fall, or when TDP concentrations range between 0.014 and 0.105 mg l^{-1}, averaging 0.062 mg l^{-1} for the mean of all four TDP predictions for 150 mg m^{-2}

Table 9. Predicted phosphorus and nitrogen concentrations for specific concentrations of epilithic chlorophyll a, based on instantaneous relationships (Table 3) and seasonal relationships (Table 6) for all rivers. The models with the highest sample size (*n*) and r^2 were selected to estimate P and N concentrations. Units for predicted P and N concentrations are mg l^{-1}. Assumptions explained below.

Data set		Predicted Variable	Epilithic chlorophyll *a* (mg m^{-2})		
			50	100	150
Phosphorus predictions					
Eqn 2	Instantaneous samples	TDP	0.008	0.038	0.093
Eqn 20	Spring means	TDP (spring)	0.009	0.021	0.034
Eqn 23	Summer means	TDP (spring)	0.026	0.062	0.105
Eqn 24	Fall means	TP (fall)	0.008	0.019	0.033
Eqn 26	All seasons	TDP	0.005	0.009	0.014
Nitrogen predictions					
Eqn 2	Instantaneous samples	DIN	0.058	0.276	0.671
Eqn 20	Spring means	NO_2+NO_3 (spring)	0.047	0.106	0.170
Eqn 23	Summer means	NO_2+NO_3 (spring)	0.129	0.315	0.527
Eqn 24	Fall means	NO_2+NO_3 (fall)	0.005	0.034	0.058
Eqn 26	All seasons	NO_2+NO_3	0.023	0.047	0.071

Assumptions: We assumed the ratio of N:P was 7.23:1, based on Redfield ratio by mass (Ryding and Rast 1989), such that TN = 7.23(TP) and DIN = 7.23(TDP). We set the ratio of nitrogen pools to total and dissolved pools based on average proportions from Table 2, such that: DIN = 0.35(TN); NO_2+NO_3 = 0.70(DIN); NH_3diss = 0.30(DIN); TKN = 3(DIN). We set irradiance surrogate variables (Turb, NFR) equal to zero, to simulate no light limitation in the rivers. We entered the grand mean annual flow in the instantaneous models and either the grand seasonal or annual mean flows into the seasonal models. We then solved for a form of either P or N.

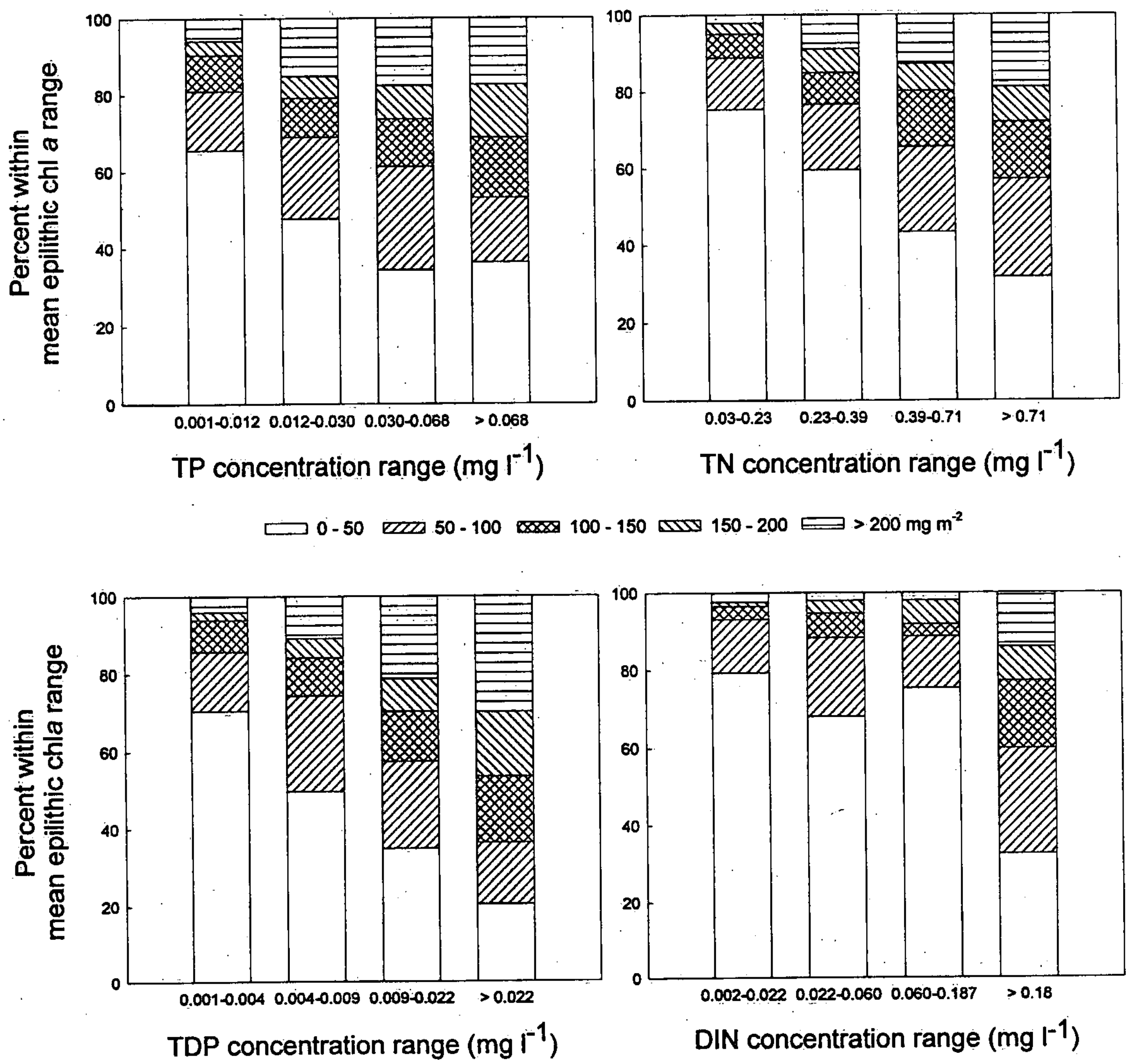

Figure 17. Percentage of mean seasonal benthic chlorophyll *a* values falling within predefined ranges for each of four separate TP, TDP, TN or DIN concentration ranges. Nutrient parameters are divided such that each concentration range has equal numbers of observations. Data are from spring, summer and fall seasons.

chlorophyll *a*. Our frequency distribution plots also showed that periphyton biomass was < 50 mg m^{-2} chlorophyll *a* for about 70% of all cases and was > 150 mg m^{-2} for only 10% of all cases when mean annual TP concentration was < 0.012 mg l^{-1} and TDP was < 0.004 mg l^{-1} (Fig. 17). In contrast, when mean annual P concentrations exceeded 0.030 mg l^{-1} TP or 0.009 mg l^{-1} TDP, periphyton biomass was < 50 mg m^{-2} chla for only 35% of all cases and was > 150 mg m^{-2} for about 30% of all cases.

Focusing next on nitrogen, the multiple regression models predict that 50 mg m^{-2} chlorophyll *a* will occur when instantaneous DIN concentrations average 0.058 mg l^{-1} or when seasonal mean NO_2+NO_3 concentrations range between 0.005 and 0.129 mg l^{-1}, averaging 0.050 mg l^{-1} (this value is the average of the four predictions of NO_2+NO_3 at 50 mg m^{-2} chlorophyll *a* in Table 9). Similarly, the models predict chlorophyll *a* values near 100 mg m^{-2} when instantaneous DIN concentrations are 0.276 mg l^{-1} or when NO_2+NO_3 concentrations average approximately 0.126 mg l^{-1}. Instantaneous DIN concentrations ≥ 0.671 mg l^{-1} and average NO_2+NO_3 concentrations ≥ 0.207 mg l^{-1} will result in chlorophyll *a* values ≥ 150 mg m^{-2} (Table 9). Examining the distribution of chlorophyll *a* concentrations with respect to nitrogen, we see that approximately 50 mg m^{-2} chlorophyll *a* occurs in 70% of cases and ≥ 150 mg m^{-2} occurs in less than 10% of cases when DIN concentrations are ≤ 0.187 mg l^{-1} (Fig. 17). In contrast, 50 mg m^{-2} chlorophyll *a* occurs in less than 35% of cases and ≥ 150 mg m^{-2} occurs in more than 20% of cases when DIN concentrations exceed 0.187 mg l^{-1}.

Given the high degree of statistical variation about our multiple regression models, there is remarkable overlap between the predictions for chlorophyll *a* values from the multiple regression models (Table 9) and the frequency distribution plots (Fig. 17). This is particularly true for phosphorus, but DIN predictions also overlap between the two models. The information presented in the preceding two paragraphs should be viewed as a starting point for further refining not only the numeric guidelines for P and N but also the approaches for developing guidelines. Moreover, it should be noted that all the rivers assessed in this report originate in the mountains; the nutrient-algal relationships reported here may not apply to streams that arise in the prairies or boreal parkland.

The periphyton - nutrient frequency distributions and multiple regression models indicated that TP concentrations > 0.030 mg l^{-1} and TDP concentrations between 0.009 and 0.062 mg l^{-1} were often associated with periphyton chlorophyll *a* concentrations > 150 mg m^{-2}. Dodds et al. (1997), in an assessment of data from about 200 North American and New Zealand rivers, recommended < 0.030 mg l^{-1} TP to achieve mean chlorophyll *a* concentrations < 100 mg m^{-2} and maximum chlorophyll *a* concentrations < 150 mg m^{-2}. From studies of streams in Washington, Welch et al. (1989) advised < 0.010 mg l^{-1} SRP (soluble reactive P) to maintain periphyton abundances of < 200 mg m^{-2} chlorophyll *a*. The New Zealand provisional water quality guidelines (New Zealand Ministry of Environment 1992) note that SRP concentrations must be below approximately 0.015 - 0.030 mg l^{-1} to have any effect on periphyton abundance and that below these concentrations, production should decline with decreasing nutrient concentrations. These jurisdictional recommendations are difficult to compare as they differ not only in the form of phosphorus used (SRP and TP versus our TDP or TP models) and the periphyton chlorophyll *a* concentrations considered unacceptable (100 to 200 mg m^{-2}), but also in their expression of periphyton biomass (seasonal mean versus maximum). The use of seasonal mean versus maximum values is particularly difficult to interpret without knowing the frequency of sampling in the case of the mean value or, in the case of the maximum value, the frequency with which the site was observed. Yet despite these limitations, the phosphorus values corresponding to unacceptable periphyton biomass are surprisingly similar: 0.01 to 0.03 mg l^{-1} SRP and 0.030 to 0.035 mg l^{-1} TP.

This study found that chlorophyll *a* concentrations ≥ 150 mg m^{-2} could be expected when DIN concentrations regularly exceeded between 0.062 (from the multiple regression models, Table 9) and 0.187 mg l^{-1} (from the frequency distribution plots, Fig. 17). The New Zealand provisional guidelines identify DIN concentrations below between 0.040 to 0.100 mg l^{-1} as being important in influencing periphyton growth (New Zealand Ministry of Environment 1992). Dodds et al. (1997) predicted that instream total N concentrations < 0.350 mg l^{-1} would result in mean and maximum chlorophyll *a* concentrations below 100 and 150 mg m^{-2}, respectively. If we assume, as we did in Table 9, that DIN = 0.35 × TN, then the prediction made by Dodds et al. (1997) for TN corresponds to approximately 0.120 mg l^{-1}. Again, despite the limitations explained above and the assumptions made in the prediction of DIN from TN, there is a high degree of correspondence between our predictions and published predictions for N concentrations that yield specific levels of periphyton biomass.

It is less common to set water quality guidelines for N, probably because of the inherent difficulties in managing for N and also because of the commonly held belief that most freshwater systems are P-limited. Nevertheless, N has been identified as a limiting nutrient in many lotic ecosystems (Lohman et al. 1991; Welch et al. 1989; Chessman et al. 1992) and N-limitation may be exacerbated when bodies of water receive wastewater with a naturally low N:P ratio or in systems where the bedrock is naturally rich in P (Welch 1992). In Alberta rivers, there is documented evidence for P-limitation (Scrimgeour and Chambers 1996, 1997; Anderson et al. 1998). Nevertheless, our models show that N and P share approximately equal importance in the prediction of benthic chlorophyll levels, suggesting that management should focus on the control of both nutrients.

4.2 Recommendations for water quality monitoring

Most rivers in Alberta are sampled regularly for water chemistry but less frequently for epilithic chlorophyll *a*. This makes it difficult to analyse for temporal trends in water quality, particularly epilithic chlorophyll *a*, and to draw inferences about the long-term impact of human activity in a river's watershed. A sampling scheme should be devised that consists of reference stations upstream of areas that are likely to be impacted by human activity and sites along the length of the river that are located in regions considered to be of concern (*e.g.*, downstream of a municipal sewage outfall or industrial effluent, or below a large agricultural region). When possible, sites should also be selected that are far enough downstream of human activities to enable the evaluation of the degree of recovery to reference station conditions. Future statistical analyses would be better facilitated if there was better correspondence between discharge and water chemistry stations.

Alberta Environmental Protection's electronic water quality database currently records values for water quality variables that fall below the analytical limit of detection as "less than detection limit". These data are censored in that a numerical value is not entered into the database because of analytical uncertainty around that value. A number of studies have demonstrated that censoring hinders statistical analysis of the data and that values should be reported with their observed value (be this above or below detection limit) and an estimate of measurement uncertainty (Gilliom et al. 1984; Porter et al. 1988; Newman et al. 1989; Newman 1995). Despite the availability of statistical techniques to deal with censored data (e.g., Travis and Land 1990; Helsel 1990; Hinton 1993; Slymen et al. 1994; Newman 1995), the recommendation in the scientific literature remains that analytical values should ideally be reported even when there is high uncertainty around these numbers. Thus, we recommend that Alberta Environmental Protection begin a practice of entering the analytical value of an observation and record the measurement uncertainty around that observation, rather than censoring their data by entering values as "less than detection limit". This will result, ultimately, in data sets that can be analysed with more robust parametric statistics.

Chlorophyll *a* is an accepted measure of algal biomass among aquatic biologists and analytical methods typically follow procedures similar to those described by Bergman and Peters (1980), where chlorophyll *a* is filtered out of the water, extracted with warm ethanol and analysed spectrophotometrically (*c.f.*, Fairchild and Sherman 1992; Biggs and Hickey 1994; Cattaneo 1996). Other techniques exist where different extractants are used (*e.g.*, acetone or acetone-methanol:

Rowan 1989; DMSO (dimethylsulfoxide): Rosemond et al., 1993; Basu and Pick 1997) and the chlorophyll can be analysed fluorometrically (Wetzel and Likens 1991) or by high-pressure liquid chromatography (HPLC) (Schanz and Rai 1988; Uehlinger et al. 1996). Schanz and Rai (1988) reported that the latter two methods yield slightly more sensitive results than spectrophotometry. However, both spectrophotometry and fluorometry are commonly used in scientific studies and both are appropriate for the purpose of management questions within Alberta rivers.

Field methods for the collection of benthic algae were reviewed by Aloi (1990), who reported that scraping a known area of rock with a brush or scalpel was the most commonly used technique to collect epilithic algae. These methods are employed almost universally within the periphyton literature, with the only variations being in the number of rocks scraped and whether an entire rock is scraped or whether a specific area on a rock is scraped.

Analysis of algal samples for species composition may yield information regarding the distribution of taxa among Alberta rivers. Although this may be an interesting exercise, it is unlikely that the labour and expenses involved in such an analysis would be warranted for routine monitoring.

5.0 CONCLUSIONS

Results from this investigation showed that nutrient and chlorophyll *a* concentrations in Alberta's major rivers fell within expected ranges for similar systems across North America and abroad. Nutrients and chlorophyll *a* in the Bow River have undergone dramatic declines since the early 1980's as a result of upgrades to Calgary's sewage treatment plant. However, changes in water quality were not as evident in other systems within the province: some rivers showed moderately improved water quality (as characterized by decreased chlorophyll *a* and nutrients) whereas others showed slightly diminished water quality. The impact of Alberta's major urban areas (Calgary, Edmonton, Lethbridge, Red Deer, and Hinton) on water quality was most evident during low-flow seasons (spring and fall) and was manifested as high chlorophyll *a* and nutrient concentrations immediately downstream of the cities followed by gradual returns to near-upstream conditions along the lengths of the rivers.

Assessment of seasonal periphyton chlorophyll *a* concentrations from river sites throughout Alberta showed that reference sites (*i.e.*, upstream of any major point sources) averaged 44 mg m^{-2} periphyton chlorophyll *a* and that 45% of all river sites in Alberta had periphyton chlorophyll *a* concentrations less than the average reference conditions. In general, mean seasonal periphyton concentrations of less than 50 mg m^{-2} chlorophyll *a* will occur when P concentrations (TP or TDP depending on the method used to predict chlorophyll *a* based on nutrients) are less than about 0.012 mg l^{-1}. Similarly, DIN concentrations less than between 0.058 and 0.187 mg l^{-1} or NO_2+NO_3 concentrations less than 0.050 mg l^{-1} will also result in benthic chlorophyll *a* levels near 50 mg m^{-2}. These values are very approximate because of the statistical uncertainty in our regression models ($0.21 \leq r^2 \leq 0.36$; Tables 3, 6 and 9). Management of an ecosystem based on biotic guidelines requires a solid predictive understanding of the relationship between the biological response variables and the factors controlling the response. There are several potential approaches for improving predictions of periphyton biomass. Empirical models could be expanded to include other variables that may influence periphyton abundance (e.g., temperature, abundance of grazing organisms, irradiance, N:P ratios). However, the effects of these variables on periphyton biomass appears less consistent than the effects of nutrients. Dodds et al. (1997) also noted from their analysis of over 200 distinct sites or rivers that latitude, temperature, stream gradients, discharge and light were not as useful predictors of stream chlorophyll *a* as N or P. Another approach is to move from empirical models constructed on a provincial or multiple drainage-basin scale to models developed for a specific basin. Our results showed that models constructed for the basins in the northern and southern portions of the Saskatchewan River basin had higher r^2 values than models constructed for the entire basin. Separation of rivers by ecoregion may therefore improve model predictions, particularly if there is a high number of samples and the nutrient or periphyton measures span a wide trophic range. Yet another approach is to rely upon mechanistic rather than empirical models to predict periphyton biomass. Although these models should theoretically provide better predictions as they model processes governing biomass gain and loss, the extensive data they require on ambient conditions and process rates are usually not available (Carr et al. 1997). A mechanistic model that has been calibrated for a particular river may provide a useful tool for predicting biomass and undertaking scenario investigations for that particular river. However, a mechanistic model calibrated for a particular river can not be made sufficiently general to give reasonable predictions for other rivers.

Both empirical and mechanistic models are based upon relationships between nutrients and periphyton abundance. An alternative to this approach is to set a periphyton chlorophyll *a* guideline that is based upon a fixed percentage increase above a reference or baseline concentration. For example, mean seasonal periphyton chlorophyll *a* concentrations for a specific river reach could be set, for example, to at most 25% greater than a particular reference reach. Ontario Ministry of Environment (1990) is evaluating what is referred to as a "proportional phosphorus increase" whereby P in lakes could increase by up to 50% above background providing: (1) TP does not exceed 20 μg l^{-1}, (2) at least 2/3 of the original lake trout habitat is preserved for lake trout lakes, and (3) dissolved oxygen at 2 m from the bottom is > 2 mg l^{-1} in lakes with naturally oxic hypolimnia (Ontario Ministry of Environment 1990). The "proportional increase" approach has the advantage of linking an impacted site with a reference site or sites, thereby permitting the response variable at the impact site(s) to track the inter-annual changes in abundance at the reference site(s). Although this allows for inter-annual variation in periphyton abundance, it necessitates having appropriate reference sites. In addition, management action to ensure that the response variable does not exceed the allowed proportional increase can only be undertaken if a predictive relationship exists between the response variable and the factors controlling the response (particularly those amenable to management action).

Finally, another question to ask is whether biomass or standing crop (chlorophyll *a* concentration or ash-free dry mass) is the most sensitive variable to be measuring for periphyton. Other possible variables include productivity or photosynthetic rate, species composition, and alkaline phosphatase activity (an indicator of phosphorus stress). Biomass metrics are easiest to measure but may not be the most responsive measure. Minimally, further research is needed to determine whether these various metrics are showing similar trends in response to enrichment and which metric is most closely linked to nutrient concentrations in river water.

In conclusion, our work has shown that the abundance of periphyton and potamoplankton in Alberta rivers is correlated with nutrient concentrations in the river water although the predictive capability of the models is limited. Potamoplankton is not generally perceived as a problem in Alberta rivers and thus, we focused our regulatory assessment on benthic algae. Further study is required to validate the recommended periphyton guidelines from the perspective of human perceptions of water quality and to improve periphyton-nutrient models. Research is also recommended to validate approaches for establishing guidelines and to assess the most sensitive variable for measuring the response for periphyton to enrichment.

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APPENDIX A

Alberta Environmental Protection (AEP) water quality and Environment Canada (HYDAT) discharge monitoring stations

A.0 LEGEND TO TABLES A1 - A3

AEP	Alberta Environmental Protection
N/A	Data not available
T	Tributary

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations.

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt	AEP Long
Milk River and tributaries				
AB11AA0010	MILK RIVER UPSTREAM OF CONFLUENCE TO NORTH MILK RIVER	N/A	490807	1122240
AB11AA0020	NORTH MILK RIVER UPSTREAM OF CONFLUENCE TO MILK RIVER	N/A	490810	1122249
AB11AA0030	MILK RIVER DOWNSTREAM OF TOWN OF MILK RIVER	N/A	490722	1120314
AB11AA0050	MILK RIVER AT HWY 878	N/A	490613	1114158
Oldman River and tributaries				
AB05AA0050	OLDMAN RIVER NEAR WALDONS CORNER	0	494851	1141100
AB05AA0220	CROWSNEST RIVER UPSTREAM OF CONNELLY CREEK	T	493545	1140625
AB05AA0270	CROWSNEST RIVER NEAR THE MOUTH	T	493552	1140525
AB05AA0400	CASTLE RIVER AT CASTLE RIVER RECREATION AREA	T	493300	1140130
AB05AA0410	CASTLE RIVER AT HIGHWAY #3 BRIDGE NEAR COWLEY	T	493236	1140154
AB05AB0040	OLDMAN RIVER NEAR BROCKET - RIGHT BANK SAMPLE	6.41	493327	1134920
AB05AB0130	OLDMAN RIVER AT FORT MACLEOD - RIGHT BANK SAMPLE	65.59	494315	1132700
AB05AB0160	OLDMAN RIVER AT FORT MACLEOD - LEFT BANK SAMPLE	65.59	494319	1132700
AB05AB0170	WILLOW CREEK DOWNSTREAM OF CHAIN LAKES	T	500945	1140350
AB05AB0200	WILLOW CREEK UPSTREAM OF THE DIVERSION	T	500745	1134745
AB05AB0220	WILLOW CREEK DOWNSTREAM OF PINE COULEE	T	500005	1134250
AB05AB0250	WILLOW CREEK AT SEC.HWY. #519	T	495230	1133245
AB05AB0260	WILLOW CREEK AT SEC.HWY. #811	T	494526	1132425
AB05AC0010	OLDMAN RIVER NEAR MONARCH - RIGHT BANK SAMPLE	115.02	494725	1130725
AB05AC0040	OLDMAN RIVER NEAR MONARCH - LEFT BANK SAMPLE	115.02	494725	1130721
AB05AD0010	OLDMAN RIVER ABOVE LETHBRIDGE LONG TERM ORGANIC SITE	171.02	494230	1125230
AB05AD0300	OLDMAN RIVER U/S OF LETHBRIDGE LEFT BANK GRAB	158.82	494803	1125146
AB05AD0370	OLDMAN RIVER ABOVE LETHBRIDGE STP OUTFALL -HWY#3 RIGHT BANK SAMPLE	171.32	494237	1125142
AB05AD0390	OLDMAN RIVER ABOVE LETHBRIDGE STP OUTFALL -HWY#3 LEFT BANK SAMPLE	171.32	494237	1125148
AB05AD0400	OLDMAN RIVER NEAR OLD RIFLE RANGE MACROPHYTE SAMPLE SITE	173	494336	1125116
AB05AD0450	OLDMAN RIVER AT ALEXANDER WILDERNESS PARK RIGHT BANK PLUS 5 METERS	176.68	494408	1125155
AB05AD0490	OLDMAN RIVER AT ALEXANDER WILDERNESS PARK RIGHT BANK PLUS 90 METERS	176.68	494408	1125155
AB05AD0500	OLDMAN RIVER AT PAVAN PARK D/S OF LETH. STP RIGHT BANK PLUS 10 METERS	179.29	494521	1125108
AB05AD0590	OLDMAN RIVER AT PAVAN PARK RIGHT BANK PLUS 98 METERS	179.37	494521	1125117
AB05AD0600	OLDMAN RIVER SOUTHWEST OF DIAMOND CITY MACROPHYTE SAMPLE SITE RIGHT BANK SAMPLE - 0.0 METERS	182.11	494649	1125030
AB05AD0710	OLDMAN RIVER NORTHEAST OF DIAMOND CITY MACROPHYTE SAMPLE SITE	183	494845	1124644
AB05AD0740	OLDMAN RIVER BELOW PICTURE BUTTE AT HWY. #845 RIGHT BANK SAMPLE	213.72	495130	1123724
AB05AD0790	OLDMAN RIVER AT HWY 845 LEFT BANK SAMPLE	213.72	495138	1123724
AB05AC0080	LITTLE BOW RIVER AT HIGHWAY #2 SOUTHEAST OF HIGH RIVER	T	503218	1134930
AB05AC0100	LITTLE BOW RIVER AT HIGHWAY #533 EAST OF NANTON	T	502118	1133133
AB05AC0160	MOSQUITO CREEK AT HWY. #529 EAST OF PARKLAND	T	501518	1133306

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt	AEP Long.
AB05AC0190	LITTLE BOW RIVER AT CARMANGAY	T	500806	1130809
AB05AG0070	OLDMAN RIVER ABOVE TABER (HWY#864) RIGHT BANK SAMPLE	257.24	494855	1121020
AB05AG0090	OLDMAN RIVER ABOVE TABER (HWY#864) LEFT BANK SAMPLE	257.24	494859	1121020
AB05AG0100	OLDMAN RIVER BELOW TABER RIGHT BANK SAMPLE	281.38	495740	1120500
AB05AG0120	OLDMAN RIVER BELOW TABER LEFT BANK SAMPLE	281.38	495734	1120500
AB05AG0190	OLDMAN RIVER AT FINCASTLE RIGHT BANK SAMPLE	318.12	495500	1114526
AB05AG0220	OLDMAN RIVER NEAR FINCASTLE ADJACENT TO DATASONDE MONITORING SITE	318.12	495500	1114526
AB05AG0230	OLDMAN RIVER AT THE MOUTH	327	495602	1114148
Bow River				
AB05BA0010	BOW RIVER UPSTREAM OF LAKE LOUISE AT HWY #1 GRAB SAMPLE	50.13	512637	1161242
AB05BA0030	BOW RIVER DOWNSTREAM OF LAKE LOUISE AND UPSTREAM OF ISLAND LAKE OUTLET - GRAB	58.84	512357	1160744
AB05BB0010	BOW RIVER BELOW BOW FALLS AND UPSTREAM OF SPRAY RIVER GOLF COURSE STUDY SITE #1	122	510955	1153326
AB05BB0020	BOW RIVER AT BANFF SPRINGS MAINTENANCE AREA GOLF COURSE STUDY SITE #2	123	511008	1153300
AB05BB0030	BOW RIVER AT BANFF SPRINGS CLUB HOUSE GOLF COURSE STUDY SITE #3	124	511032	1153213
AB05BB0040	BOW RIVER AT EASTERN EDGE OF BANFF SPRINGS GOLF COURSE GOLF COURSE STUDY SITE #4	125	511049	1153139
AB05BB0050	BOW RIVER UPSTREAM OF BANFF SEWAGE DISCHARGE GOLF COURSE STUDY SITE #5	126.46	511042	1153026
AB05BB0060	BOW RIVER DOWNSREAM OF BANFF SEWAGE DISCHARGE GOLF COURSE STUDY SITE #6	127.07	511023	1153026
AB05BE0010	BOW RIVER U/S OF CANMORE	138.73	510722	1152312
AB05BE0030	BOW RIVER AT CANMORE BRIDGE - LEFT BANK SAMPLE	143.5	510508	1152147
AB05BE0050	BOW RIVER AT CANMORE BRIDGE - RIGHT BANK SAMPLE	143.5	510508	1152152
AB05BE0070	BOW RIVER AT THREE SISTERS CONTROL SITE C U/S OF ATP RDB	145.15	510416	1152052
AB05BE0090	BOW RIVER BELOW CANMORE AT HIGHWAY # 1 BRIDGE RIGHT BANK SAMPLE	N/A	510351	1151926
AB05BE0100	BOW RIVER BELOW CANMORE AT HIGHWAY # 1 BRIDGE LEFT BANK SAMPLE	N/A	510354	1151926
AB05BE0140	BOW RIVER DOWNSTREAM OF DEADMANS FLATS LEFT BANK SAMPLE	156.05	510234	1151416
AB05BE0160	BOW RIVER DOWNSTREAM OF DEADMANS FLATS RIGHT BANK SAMPLE	156.05	510230	1151416
AB05BE0190	BOW RIVER UPSTREAM OF EXSHAW CREEK LEFT BANK SAMPLE	164.8	510324	1150939
AB05BE0210	BOW RIVER UPSTREAM OF EXSHAW CREEK RIGHT BANK SAMPLE	164.8	510322	1150939
AB05BE0240	BOW RIVER AT BOW VALLEY PROVINCIAL PARK RIGHT BANK SAMPLE	171.44	510513	1150526
AB05BE0250	BOW RIVER NEAR MORLEY	198.74	511022	1145100
AB05BE0260	BOW RIVER BELOW GHOST DAM	208.86	511314	1144208
AB05BE0270	BOW RIVER UPSTREAM OF ALBERTA NATURAL GAS FINAL EFFLUENT	225.45	511221	1143144
AB05BH0010	BOW RIVER AT COCHRANE LONG TERM ORGANIC SITE	227.13	511025	1142800
AB05BH0100	BOW RIVER AT GLENBOW RANCH	239.75	510908	1142230
AB05BH0110	BOW RIVER BELOW BEARSPAW DAM	250.22	510510	1141720
AB05BH0140	BOW RIVER UPSTREAM OF 85 STREET BRIDGE	254.53	510600	1141236
AB05BH0450	BOW RIVER NEAR INGLEWOOD GOLF COURSE BONNYBROOK STUDY M1 KILOMETRE 0	277.14	505941	1140131
AB05BH0510	BOW RIVER UPSTREAM OF BONNYBROOK STP DISCHARGE RDB	279.12	510032	1140109

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt.	AEP Long.
AB05BH0520	BOW RIVER BELOW BONNYBROOK SEWAGE PLANT OUTFALL BONNYBROOK STUDY M2 KILOMETRE 2	279.14	505849	1140147
AB05BH0530	BOW RIVER NEAR ACADIA TRAILER PARK	281.14	505820	1140143
AB05BH0610	BOW RIVER NEAR QUEENSLAND DOWNS BONNYBROOK STUDY M4 KILOMETRE 8	285.14	505628	1140019
AB05BM0010	BOW RIVER BELOW CARSELAND DAM LONG TERM ORGANIC SITE	349.76	504950	1132500
AB05BM0030	BOW RIVER NEAR DEER RUN BONNYBROOK STUDY M5 KILOMETRE 12	291.14	505441	1135954
AB05BM0120	BOW RIVER APPROX 200 YARDS D/S FROM CONFLUENCE OF FISH CREEK SURVEY LOCATION NO. 11	293.64	505418	1140023
AB05BM0140	BOW RIVER NEAR ACADEMY BONNYBROOK STUDY M7 KILOMETER17.5	296.64	505222	1135929
AB05BM0150	BOW RIVER AT STIERS RANCH	304.81	505118	1135600
AB05BM0170	BOW RIVER NEAR TREE NURSERY BONNYBROOK STUDY M9 KILOMETER 30.0	309.14	505101	1135056
AB05BM0180	BOW RIVER BELOW CONFLUENCE OF HIGHWOOD RIVER BONNYBROOK STUDY M10 KILOMETER 37.0	316.14	504907	1134635
AB05BM0190	BOW RIVER BELOW CONFLUENCE OF HIGHWOOD RIVER	316.14	504843	1134414
AB05BM0200	BOW RIVER NEAR DALEMEAD BONNYBROOK STUDY M11 KILOMETER 45.0	326.99	504832	1134050
AB05BM0420	BOW RIVER ABOVE CARSELAND WEIR BONNYBROOK STUDY M12 KILOMETER 52.0	331.14	504749	1133500
AB05BM0470	BOW RIVER BELOW CARSELAND WEIR UPSTREAM OF HIGHWAY #24	326.53	504956	1132446
AB05BM0500	BOW RIVER NEAR STRANGMUIR BONNYBROOK STUDY M13 - KILOMETER 74	353.14	505049	1132050
AB05BM0580	BOW RIVER NEAR ARROWOOD AT HWY #828	392.15	504619	1130752
AB05BM0590	BOW RIVER AT CLUNY	426.78	504100	1125010
AB05BM0640	BOW RIVER AT CROWFOOT FY	457.31	504755	1123844
AB05BM0670	BOW RIVER BELOW BASSANO DAM	471.63	504452	1123127
AB05BN0010	BOW RIVER RONALANE BRIDGE LONG TERM ORGANIC SITE	625.61	500247	1113528
AB05BN0080	BOW RIVER AT BOW CITY BRIDGE	533.78	502555	1121319
AB05BN0150	BOW RIVER AT SCANDIA	565.58	501340	1120420
AB05BN0210	BOW RIVER AT RONALANE BRIDGE	625.61	500239	1113452
AB05BN0260	BOW RIVER BEFORE CONFLUENCE WITH OLDMAN RIVER		495627	1114125
Elbow River				
AB05BJ0120	ELBOW RIVER D/S OF BRAGG CREEK TOWN JUNE 1988	N/A	505730	1143330
AB05BJ0170	ELBOW RIVER AT HIGHWAY #22	N/A	510155	1142805
AB05BJ0220	ELBOW RIVER UPSTREAM OF GLENCOE GOLF COURSE GOLF COURSE STUDY OCTOBER 1990	N/A	510150	1141915
AB05BJ0230	ELBOW RIVER UPSTREAM OF GLENCOE GOLF AND COUNTRY CLUB - MAIN CHANNEL	N/A	510156	1141915
AB05BJ0240	ELBOW RIVER MID-COURSE OF GLENCOE GOLF COURSE GOLF COURSE STUDY OCTOBER 1990	N/A	510157	1141840
AB05BJ0250	ELBOW RIVER MIDCOURSE OF GLENCOE GOLF AND COUNTRY CLUB, DOWNSTREAM OF PIPELINE CROSSING	N/A	510201	1141809
AB05BJ0280	ELBOW RIVER AT GLENCOE GOLF CLUB JUNE 1988	N/A	510155	1141815
AB05BJ0290	ELBOW RIVER UPSTREAM OF TWIN BRIDGES AT HIGHWAY # 8	N/A	510100	1141425
AB05BJ0300	ELBOW RIVER AT SARCEE BRIDGE JUNE 1988	N/A	505942	1140955
AB05BJ0340	ELBOW RIVER UPSTREAM OF CALGARY GOLF&COUNTRY CLUB GOLF COURSE STUDY OCTOBER 1990	N/A	510003	1140531
AB05BJ0350	ELBOW RIVER AT CALGARY GOLF AND COUNTRY CLUB	N/A	510000	1140545
AB05BJ0370	ELBOW RIVER D/S OF CALGARY GOLF&COUNTRY CLUB GOLF COURSE STUDY OCTOBER 1990	N/A	510034	1140508

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt.	AEP Long.
AB05BJ0450	ELBOW RIVER AT 9TH. AVE. BRIDGE	N/A	510235	1140230
Highwood and Sheep Rivers				
AB05BL0160	HIGHWOOD RIVER BELOW PEKISKO CREEK - REACH #1	N/A	503045	1140452
AB05BL0180	HIGHWOOD RIVER ABOVE HIGH RIVER - REACH #2	N/A	503434	1135352
AB05BL0230	HIGHWOOD RIVER - REACH #3 BELOW HIGH RIVER AT SOD FARM	N/A	503745	1135045
AB05BL0390	HIGHWOOD RIVER DOWNSTREAM OF HWY.547 BRIDGE NEAR ALDERSYDE - REACH #4 FEBRUARY 1988	N/A	504206	1135124
AB05BL0470	SHEEP RIVER 1.6 KM. DOWNSTREAM OF HWY. #2	N/A	504252	1135138
AB05BL0490	HIGHWOOD RIVER AT HIGHWAY #552 -REACH #5	N/A	504640	1134933
South Saskatchewan River				
AB05AJ0010	SOUTH SASKATCHEWAN RIVER BELOW THE CONFLUENCE OF BOW AND OLDMAN RIVERS	0	495505	1114102
AB05AJ0040	SOUTH SASKATCHEWAN RIVER AT HIGHWAY #879	18	495419	1112820
AB05AK0020	SOUTH SASKATCHEWAN RIVER ABOVE MEDICINE HAT	103	500236	1104320
AB05AK0370	SOUTH SASKATCHEWAN RIVER BELOW MEDICINE HAT	136	500830	1103928
AB05AK0490	SOUTH SASKATCHEWAN RIVER AT HIGHWAY #41 BRIDGE	258	504355	1100416
Red Deer River				
AB05CB0010	RED DEER RIVER WEST OF BOWDEN UPSTREAM DICKSON DAM IMPACT STUDY - SITE 1	0	515635	1142955
AB05CC0010	RED DEER RIVER AT HIGHWAY # 2 BRIDGE -ABOVE RED DEER LONG TERM ORGANIC SITE	N/A	521602	1135149
AB05CC0020	RED DEER RIVER 4KM. BELOW DICKSON DAM DAM IMPACT STUDY - SITE 3	54	520400	1141300
AB05CC0170	RED DEER RIVER AT INNISFAIL HWY. 54 BRIDGE DAM IMPACT STUDY SITE - 4	60	520414	1135910
AB05CC0200	RED DEER RIVER ABOVE RED DEER FT. NORMANDEAU DAM IMPACT STUDY - SITE 5	101	521539	1135241
AB05CC0230	RED DEER RIVER U/S OF RED DEER STP EFFL.TRANSECT POINT 8 OF 8(RT BANK) 9M. FROM R. BANK(FACING D/S)	N/A	521842	1134703
AB05CC0300	RED DEER RIVER U/S OF RED DEER STP EFFL. TRANSECT POINT 1 OF 8(L BANK) 79M. FROM R BANK(FACING D/S)	N/A	521842	1134717
AB05CC0310	RED DEER R D/S OF STP EFFL, U/S OF BLINDMAN R TRANSECT PT 8 OF 8 (RT BANK) 10 M. F. RT BANK(FACING D/S)	N/A	521852	1134614
AB05CC0380	RED DEER R D/S OF STP EFFL, U/S OF BLINDMAN R TRANSECT PT 1 OF 8(L BANK) 85 M. F. RT BANK (FACING D/S)	N/A	521906	1134614
AB05CC0390	RED DEER RIVER - 10 KM ABOVE CONFLUENCE OF BLINDMAN RIVER	117	522000	1134700
AB05CC0410	RED DEER RIVER U/S OF BLINDMAN RIVER AND DOWNSTREAM OF RED DEER S.T.P EFFL	N/A	522034	1134513
AB05CD0010	RED DEER R D/S OF BLINDMAN R U/S OF UNION CARBIDE FINAL EFFL PT 8 OF 8 (R.BANK) 12 M. F RT BANK (D/S)	N/A	522042	1134337
AB05CD0080	RED DEER R D/S OF BLINDMAN R U/S OF UNION CARBIDE FINAL EFFL PT 1 OF 8(L BANK) 107 M. F RT BANK(D/S)	N/A	522056	1134337
AB05CD0100	RED DEER RIVER BELOW RED DEER JOFFRE BRIDGE DAM IMPACT STUDY - SITE 6	146	521600	1133505
AB05CD0120	RED DEER RIVER AT JOFFRE BRIDGE TRANSECT POINT 8 OF 8(RIGHT BANK) 15 M. FROM RIGHT BANK(FACING D/S)	146	521606	1133504
AB05CD0190	RED DEER RIVER AT JOFFRE BRIDGE TRANSECT POINT 1 OF 8(LEFT BANK) 115 M. FROM RIGHT BANK(FACING D/S)	146	521606	1133518
AB05CD0220	RED DEER RIVER RICHARDSON FARM D/S OF COMINCO EFFL	N/A	521426	1132442
AB05CD0250	RED DEER RIVER AT NEVIS BRIDGE TRANSECT POINT 8 OF 8(RIGHT BANK) 9 M. FROM RIGHT BANK(FACING D/S)	194	521823	1130445
AB05CD0320	RED DEER RIVER AT NEVIS BRIDGE TRANSECT POINT 1 OF 8(LEFT BANK) 94 M. FROM RIGHT BANK(FACING D/S)	194	521823	1130431
AB05CD0370	RED DEER RIVER - AT HWY. #585 BRIDGE NEAR TROCHU	259	515000	1130000
AB05CE0010	RED DEER RIVER AT MORRIN BRIDGE - CENTER LONG TERM ORGANIC SITE	280	513910	1125415
AB05CE0030	RED DEER RIVER ABOVE DRUMHELLER AT HWY 9 - LEFT BANK	315	512805	1124245

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Lat.	AEP Long.
AB05CE0120	RED DEER RIVER BELOW DRUMHELLER NEAR EAST COULEE AT HWY 10 - LEFT BANK	338	511956	1122850
AB05CG0010	RED DEER RIVER AT FINNEGAN ABOVE HWY. 36 - RIGHT BANK	379	510729	1120511
AB05CJ0070	RED DEER RIVER D/S DINOSAUR PROV. PK. AT HWY. 884 NEAR JENNER - RIGHT BANK	498	505019	1111036
AB05CK0060	RED DEER RIVER NEAR BORDER	634	505750	1100144
North Saskatchewan River				
AB05DA0010	NORTH SASKATCHEWAN RIVER AT WHIRLPOOL POINT	21	520010	1162820
AB05DC0010	NORTH SASKATCHEWAN RIVER BELOW BIGHORN RESERVOIR(LAKE ABRAHAM)	65	522045	1161600
AB05DC0030	NORTH SASKATCHEWAN RIVER AT ANCONA	120	522630	1155400
AB05DC0050	NORTH SASKATCHEWAN RIVER - 3KM. ABOVE ROCKY MOUNTAIN HOUSE	186	522130	1145740
AB05DC0060	NORTH SASKATCHEWAN RIVER 1KM. ABOVE BAPTISTE RIVER	228	523930	1150310
AB05DC0080	NORTH SASKATCHEWAN RIVER 1KM. ABOVE BRAZEAU RIVER	266	525430	1151240
AB05DE0020	NORTH SASKATCHEWAN RIVER AT DRAYTON VALLEY BRIDGE	320	531240	1145530
AB05DE0030	NORTH SASKATCHEWAN RIVER AT DRAYTON VALLEY BRIDGE LEFT BANK SAMPLE - OCTOBER 15, 1988	320	531240	1145530
AB05DE0040	NORTH SASKATCHEWAN RIVER AT DRAYTON VALLEY BRIDGE RIGHT BANK SAMPLE - OCTOBER 15, 1988	320	531240	1145530
AB05DE0060	NORTH SASKATCHEWAN RIVER AT GENESEE BRIDGE	407	532250	1141640
AB05DE0070	NORTH SASKATCHEWAN RIVER AT GENESEE BRIDGE LEFT BANK SAMPLE - OCTOBER 15, 1988	407	522250	1141640
AB05DE0080	NORTH SASKATCHEWAN RIVER AT GENESEE BRIDGE RIGHT BANK SAMPLE - OCTOBER 15,1988	407	522250	1141640
AB05DF0120	NORTH SASKATCHEWAN RIVER DEVON LEFT BANK 84	449	532218	1134450
AB05DF0130	NORTH SASKATCHEWAN RIVER DEVON RIGHT BANK 84	449	532218	1134451
AB05DF0140	NORTH SASKATCHEWAN RIVER UPSTREAM OF DEVON BRIDGE COMPOSITE SAMPLE - LEFT,CENTRE,RIGHT	449	532219	1134450
AB05EB0020	NORTH SASKATCHEWAN RIVER AT 109 STREET BRIDGE LEFT BANK SAMPLE - OCTOBER 15,1988	495	533144	1133034
AB05EB0190	NORTH SASKATCHEWAN RIVER LEFT BANK 50TH STREET FOOT BRIDGE 90M UPSTREAM	500	533352	1132503
AB05EB0210	NORTH SASKATCHEWAN RIVER RIGHT BANK 50TH STREET FOOT BRIDGE 90M UPSTREAM	500	533347	1132503
AB05EB0300	NORTH SASKATCHEWAN RIVER LEFT BANK RUNDLE FOOT BRIDGE - 90M UPSTREAM	501	533312	1132334
AB05EB0320	NORTH SASKATCHEWAN RIVER RIGHT BANK RUNDLE FOOT BRIDGE - 90M UPSTREAM	501	533309	1132343
AB05EB0360	NORTH SASKATCHEWAN RIVER LEFT BANK BEVERLY RAILWAY TRESTLE 180M DOWNSTREAM	504	533428	1132318
AB05EB0380	NORTH SASKATCHEWAN RIVER RIGHT BANK BEVERLY RAILWAY TRESTLE 180M DOWNSTREAM	504	533425	1132311
AB05EB0430	NORTH SASK R @ CAPITAL RGN STP .5 KM ABOVE HORSEHILLS CRK -TRANSECT SITE RT BANK - GRAB SAMPLE	N/A	533730	1131920
AB05EB0470	NORTH SASK R @ CAPITAL RGN STP .5 KM ABOVE HORSEHILLS CRK -TRANSECT SITE L BANK - GRAB SAMPLE	N/A	533730	1131920
AB05EB0550	NORTH SASKATCHEWAN RIVER LEFT BANK ABOVE FORT SASK. RAILWAY TRESTLE 90M UPSTREAM	528	534253	1131427
AB05EB0570	NORTH SASKATCHEWAN RIVER RIGHT BANK ABOVE FORT SASK. RAILWAY TRESTLE 90M UPSTREAM	528	534247	1131420
AB05EB0600	NORTH SASK R BELOW FORT SASK APPROX. 1 KM. ABOVE MOUTH OF STURGEON RIVER LEFT BANK SAMPLE	539	534530	1131018
AB05EB0790	NORTH SASKATCHEWAN RIVER VINCA BRIDGE - RIGHT BANK AUGUST 1988	555	535100	1130400
AB05EB0830	NORTH SASKATCHEWAN RIVER VINCA BRIDGE - LEFT BANK AUGUST 1988	555	535100	1130400
AB05EB0850	NORTH SASKATCHEWAN RIVER AT VINCA TRAILER SITE - RIGHT BANK	560	535243	1130050
AB05EB0860	NORTH SASKATCHEWAN RIVER AT VINCA TRAILER SITE - LEFT BANK	560	535245	1130050
AB05EB0910	NORTH SASKATCHEWAN RIVER LEFT BANK DOWNSTREAM OF CONFLUENCE WITH BEAVERHILLS CREEK	N/A	535602	1135417

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt.	AEP Long.
AB05EB0930	NORTH SASKATCHEWAN RIVER RIGHT BANK DOWNSTREAM OF CONFLUENCE WITH BEAVERHILLS CREEK	N/A	535556	1135411
AB05EC0090	NORTH SASKATCHEWAN RIVER AT WASKATENAU BRIDGE	583	540050	1125000
AB05EC0160	NORTH SASKATCHEWAN RIVER LEFT BANK ABOVE PAKAN BRIDGE 90M UPSTREAM	611	535930	1122847
AB05EC0170	NORTH SASKATCHEWAN RIVER CENTRE ABOVE PAKAN BRIDGE - 90M UPSTREAM	611	535926	1122847
AB05EC0180	NORTH SASKATCHEWAN RIVER RIGHT BANK ABOVE PAKAN BRIDGE 90M UPSTREAM	611	535922	1122847
AB05EC0210	NORTH SASKATCHEWAN RIVER -PAKAN BRIDGE	611	540000	1122446
AB05ED0010	NORTH SASKATCHEWAN RIVER AT DUVERNAY LEFT BANK SAMPLE - OCT.15,1988	687	534720	1114130
AB05ED0020	NORTH SASKATCHEWAN RIVER AT DUVERNAY MARCH,87	687	534720	1114130
AB05ED0030	NORTH SASKATCHEWAN RIVER AT DUVERNAY RIGHT BANK SAMPLE - OCT.15,1988	687	534720	1114130
AB05ED0110	NORTH SASKATCHEWAN RIVER - AT ELK POINT	747	535145	1105330
AB05ED0120	NORTH SASKATCHEWAN RIVER AT ELK POINT BRIDGE RIGHT BANK SAMPLE - OCT.15,1988	747	535145	1105330
AB05EF0010	NORTH SASKATCHEWAN RIVER - AT LEA PARK	799	533930	1102020
AB05EF0060	NORTH SASKATCHEWAN RIVER AT LEA PARK RIGHT BANK SAMPLE - OCT.15,1988	799	533930	1102020
AB05EF0080	NORTH SASKATCHEWAN RIVER AT LLOYDMINSTER FERRY MARCH,87	830	533550	1095925
AB05EF0100	NORTH SASKATCHEWAN RIVER AT LLOYDMINSTER FERRY LEFT BANK SAMPLE - OCT.15,1988	830	533550	1095925
AB05EF0120	NORTH SASKATCHEWAN RIVER AT LLOYDMINSTER FERRY RIGHT BANK SAMPLE - OCT.15,1988	830	533550	1095925
Athabasca River and tributaries				
AB07AC0010	BERLAND RIVER-BEFORE CONFLUENCE WITH ATHABASCA RIVER MOUTH: ARC KM 1139.2	T	530015	1165050
AB07AD0050	ATHABASCA RIVER AT OLD ENTRANCE TOWN SITE (COMPOSITE OF LEFT AND RIGHT BANK)	125.9	532203	1174324
AB07AD0060	ATHABASCA RIVER AT OLD ENTRANCE TOWN SITE RIGHT BANK SAMPLE	125.9	532203	1174327
AB07AD0220	ATHABASCA RIVER BELOW HINTON AT BRIDGE ON CHAMPION HAUL ROAD LEFT BANK SAMPLE	177.8	532550	1173325
AB07AD0260	ATHABASCA RIVER BELOW HINTON AT BRIDGE ON CHAMPION HAUL ROAD RIGHT BANK SAMPLE	177.8	532545	1173323
AB07AD0350	ATHABASCA R AT OBED MTN COALS BRIDGE APPROX. 20KM BELOW HINTON LEFT BANK SAMPLE ARC KM 1220.5	157.9	533129	1172151
AB07AD0380	ATHABASCA R AT OBED MTN COALS BRIDGE APPROX. 20KM BELOW HINTON RIGHT BANK SAMPLE ARC KM 1220.5	157.9	533126	1172144
AB07AD0460	ATHABASCA R APPROX 50 KM. BELOW HINTON ON CHAMPION HAUL RD BRIDGE COMPOSITE SAMPLE L&R BANK	185	534209	1170945
AB07AE0080	ATHABASCA RIVER - NEAR WINDFALL 1.5 KM. UPSTREAM OF PASS CREEK SAMPLED AT CENTRE OF RIVER	312.1	541410	1161730
AB07AE0330	ATHABASCA R 0.5 KM ABOVE THE CONFLUENCE WITH THE MCLEOD R RT BANK ZOOBENTHIC SITE (A2R) MAR '89	344.7	540907	1154243
AB07AE0360	ATHABASCA RIVER AT WHITECOURT AT HIGHWAY #43 BRIDGE RIGHT BANK SAMPLE RIGHT BANK SAMPLE	344.7	540856	1154315
AB07AE0380	ATHABASCA RIVER AT THE CONFLUENCE OF THE MCLEOD RIVER LEFT BANK ZOOBENTHIC SITE(A2L) MARCH 1988	344.7	540905	1154306
AB07AF0050	MCLEOD RIVER U/S OF CADOMIN	T	530037	1171955
AB07AF0060	MCLEOD RIVER ABOVE CONFLUENCE WITH LUSCAR CREEK	T	530305	1171908
AB07AF0100	MCLEOD RIVER 1.5KM DOWNSTREAM OF LUSCAR CREEK	T	530414	1171641
AB07AF0120	MCLEOD RIVER NEAR CADOMIN AT WSC GAUG NEAR FIDLER	T	530444	1171150
AB07AF0150	MCLEOD RIVER 2KM. DOWNSTREAM OF CONFLUENCE WITH MACKENZIE CREEK	T	530628	1170745
AB07AF0170	MCLEOD RIVER AT STEEPER	T	530820	1170614
AB07AF0180	MCLEOD RIVER DOWNSTREAM OF TRI-CREEKS STUDY AREA	T	530945	1171600
AB07AF0190	MCLEOD RIVER DOWNSTREAM OF MARY GREGG CREEK	T	531045	1161800

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt.	AEP Long.
AB07AF0200	MCLEOD RIVER ABOVE CONFLUENCE WITH THE GREGG RIVER	T	531736	1171645
AB07AF0210	GREGG RIVER ABOVE GREGG RIVER RESOURCE MINE	T	530400	1172700
AB07AF0240	GREGG RIVER - 0.5 KM BELOW GREGG RIVER RESOURCE MINE	T	530534	1172622
AB07AF0260	GREGG RIVER NEAR HIGHWAY #40	T	530124	1172950
AB07AF0310	GREGG RIVER DOWNSTREAM OF WARDEN CREEK	T	531210	1172941
AB07AF0330	GREGG RIVER BEFORE CONFLUENCE WITH MCLEOD RIVER	T	531506	1172133
AB07AF0340	MCLEOD RIVER BELOW CONFUENCE WITH GREGG RIVER	T	531944	1171511
AB07AF0350	MCLEOD RIVER ABOVE CONFLUENCE OF EMBARRAS RIVER AT FEDERAL GAUGING SITE	T	532730	1163715
AB07AF0380	EMBARRAS RIVER ABOVE CONFLUENCE WITH MCLEOD RIVER	T	532731	1163700
AB07AF0390	LOVETT RIVER ABOVE CONFLUENCE OF COAL CREEK	T	530350	1164850
AB07AG0010	MCLEOD RIVER DOWNSTREAM OF CONFLUENCE WITH THE EMBARASS RIVER	T	533000	1163448
AB07AG0020	MCLEOD RIVER DOWNSTREAM OF CONFLUENCE OF EMBARASS RIVER - LEFT BANK	T	533000	1163448
AB07AG0070	MCLEOD RIVER 100 METERS UPSTREAM OF EDSON SEWAGE OUTFLOW - LEFT BANK SAMPLE	T	533625	1161853
AB07AG0090	MCLEOD RIVER 100 METERS UPSTREAM OF EDSON SEWAGE OUTFLOW - RIGHT BANK SAMPLE	T	533625	1161853
AB07AG0100	MCLEOD RIVER 100 METERS BELOW EDSON SEWAGE OUTFLOW - LEFT BANK SAMPLE	T	533630	1151853
AB07AG0120	MCLEOD RIVER 100 METERS BELOW EDSON SEWAGE OUTFLOW - RIGHT BANK SAMPLE	T	533630	1151853
AB07AG0130	MCLEOD RIVER 100 METERS BELOW EDSON SEWAGE OUTFLOW	T	533630	1151853
AB07AG0150	MCLEOD RIVER AT ART'S PLACE LEFT BANK SAMPLE	T	533534	1161705
AB07AG0160	MCLEOD RIVER AT ART'S PLACE CENTER OF RIVER SAMPLE	T	533534	1161705
AB07AG0170	MCLEOD RIVER AT ART'S PLACE RIGHT BANK SAMPLE	T	533539	1161800
AB07AG0180	WOLF CREEK AT WSC GAUGE (HIGHWAY #16 BRIDGE)	T	533555	1161615
AB07AG0200	MCLEOD RIVER BELOW CONFLUENCE OF WOLF CREEK LEFT BANK SAMPLE	T	533915	1161652
AB07AG0210	MCLEOD RIVER BELOW CONFLUENCE OF WOLF CREEK RIGHT BANK SAMPLE	T	533915	1161650
AB07AG0220	EDSON CREEK BEFORE CONFLUENCE WITH MCLEOD RIVER	T	533942	1161619
AB07AG0230	UNNAMED CREEK BEFORE CONFLUENCE WITH MCLEOD RIVER	T	534100	1160928
AB07AG0240	MCLEOD RIVER DOWNSTREAM OF ROSEVEAR FERRY	T	534200	1160920
AB07AG0250	MCLEOD RIVER DOWNSTREAM OF ROSEVEAR FERRY LEFT BANK SAMPLE	T	534200	1160920
AB07AG0270	MCLEOD RIVER DOWNSTREAM OF ROSEVEAR FERRY RIGHT BANK SAMPLE	T	534200	1160920
AB07AG0290	MCLEOD RIVER AT PEERS LEFT BANK SAMPLE	T	534300	1160100
AB07AG0300	MCLEOD RIVER AT PEERS RIGHT BANK SAMPLE	T	534300	1160100
AB07AG0310	MCLEOD RIVER AT MAHASKA	T	535325	1155215
AB07AG0320	MCLEOD RIVER AT MAHASKA LEFT BANK	T	535325	1155215
AB07AG0340	GROAT CREEK ON EDSON HIGHWAY	T	540200	1155030
AB07AG0350	MCLEOD RIVER 2.7 KM ABOVE THE CONFLUENCE WITH ATHABASCA R L. BANK ZOOBENTHIC SITE(MCL1R) MAR '88	T	540849	1154233
AB07AG0370	MCLEOD RIVER AT WHITECOURT - HIGHWAY # 43 BRIDGE LEFT BANK SAMPLE	T	540810	1154200
AB07AG0380	MCLEOD RIVER AT WHITECOURT AT HIGHWAY #43 BRIDGE CENTER OF RIVER CHANNEL MOUTH: ARC KM 1032.4	T	540810	1154150
AB07AG0420	MCLEOD RIVER AT WHITECOURT	T	540819	1154151

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Latt	AEP Long
AB07AG0430	CARROT RIVER ON ROAD NEAR MCLEOD RIVER	T	534300	1155800
AB07AH0020	ATHABASCA RIVER 0.5 KM. DOWNSTREAM OF MILLAR WESTERN PULP MILL DIFFUSER LEFT BANK SAMPLE	3434	540919	1154108
AB07AH0040	ATHABASCA RIVER 0.5 KM. DOWNSTREAM OF MILLAR WESTERN PULP MILL DIFFUSER RIGHT BANK SAMPLE	343.4	540913	1154101
AB07AH0060	ATHABASCA RIVER 0.8 KM BELOW THE CONFLUENCE OF MCLEOD R CENTER ZOOBENTHIC SITE(A3C) MAR '88	343.7	540912	1154128
AB07AH0070	ATHABASCA RIVER 0.8 KM BELOW CONFL OF MCLEOD RIVER RIGHT BANK ZOOBENTHIC SITE(A3R) MARCH 1988	343.7	540906	1154128
AB07AH0090	ATHABASCA R 2.3 KM BELOW CONFL OF MCLEOD R AT PIPELINE CROSSING CTR ZOOBENTHIC SITE(A4C) MAR '88	345.2	540956	1154011
AB07AH0100	ATHABASCA R 2.5 KM BEL CONFL OF MCLEOD R AT PIPELINE CROSS RT BANK ZOOBENTHIC SITE(A4R) MAR '88	345.4	541005	1153957
AB07AH0120	ATHABASCA RIVER 3.0 KM. DOWNSTREAM OF MCLEOD RIVER CONFLUENCE - LEFT BANK SAMPLE	345.9	540956	1153937
AB07AH0140	ATHABASCA RIVER 3.0 KM. DOWNSTREAM OF MCLEOD RIVER CONFLUENCE - RIGHT BANK SAMPLE	345.9	540950	1153937
AB07AH0150	ATHABASCA R 4.5 KM BEL CONFL OF MCLEOD R N OF STP OUTFALL CENTER ZOOBENTHIC SITE(A5C) MARCH 1988	347.4	540959	1153840
AB07AH0160	ATHABASCA RIVER 4.5 KM BELOW CONFLUENCE OF MCLEOD RIVER RIGHT BANK ZOOBENTHIC SITE (A5R) MAR '89	347.4	540942	1153857
AB07AH0260	ATHABASCA RIVER AT BRIDGE NORTH OF BLUE RIDGE LEFT BANK SAMPLE	370.9	540934	1152330
AB07AH0290	ATHABASCA RIVER AT BRIDGE NORTH OF BLUE RIDGE RIGHT BANK SAMPLE	370.9	540930	1152324
AB07AH0330	ATHABASCA RIVER 14 KM. UPSTREAM OF FREEMAN RIVER SAMPLED AT CENTRE OF RIVER	426.7	541920	1145610
AB07AH0350	ATHABASCA RIVER 14 KM. UPSTREAM OF FREEMAN RIVER LEFT BANK SAMPLE	426.7	541919	1145610
AB07BA0010	PEMBINA RIVER ABOVE CENTRE CREEK	T	525835	1164150
AB07BA0020	LOVETT RIVER AT TOWN OF LOVETTVILLE	T	530158	1164125
AB07BA0030	LOVETT RIVER DOWNSTREAM OF LOVETTVILLE AT FEDERAL GAUGING STATION	T	530055	1164015
AB07BA0040	PEMBINA RIVER DOWNSTREAM OF CONFLUENCE WITH LOVETT RIVER	T	525906	1163816
AB07BA0050	PEMBINA RIVER ADJACENT TO HIGHWAY #40	T	525754	1163600
AB07BA0060	PEMBINA RIVER AT HIGHWAY #40 BRIDGE	T	525600	1163405
AB07BA0070	PEMBINA RIVER 10.0 KM DOWNSTREAM OF HWY. #40 BRIDGE	T	530034	1163015
AB07BA0140	PEMBINA RIVER - SITE #8 0.2 KM UPSTREAM FROM EASYFORD BRIDGE (T50-W4M-R9-S1-LSD11)	T	531713	1111124
AB07BB0020	PEMBINA RIVER AT PEMBINA RIVER PROVINCIAL PARK	T	533632	1150000
AB07BB0040	PEMBINA RIVER AT HIGHWAY #53	T	535936	1142254
AB07BC0010	PEMBINA RIVER AT ROSSINGTON L SHORELINE ~10 M DOWNSTREAM OF HIGHWAY 18 BRIDGE (SE-9 60-1-W5)	T	541000	1140449
AB07BC0070	PEMBINA RIVER NEAR CONFLUENCE WITH ATHABASCA RIVER CENTER OF RIVER CHANNEL MOUTH: ARC KM 849.6	T	544528	1141556
AB07BC0080	PEMBINA RIVER BEFORE CONFLUENCE WITH ATHABASCA RIVER RIGHT BANK SAMPLE	T	544528	1141556
AB07BD0090	ATHABASCA RIVER ABOVE TOWN OF SMITH AT HIGHWAY #2 BRIDGE COMPOSITE OF LEFT AND RIGHT BANK	572.2	550415	1140533
AB07BD0100	ATHABASCA RIVER - ABOVE SMITH DOWNSTREAM OF RAILWAY BRIDGE	583.1	550940	1140320
AB07BE0310	ATHABASCA R 45 KM US TOWN OF ATHABASCA & 10.2 KM N OF HOWIE LAKE CTR OF RIV SAMPLE ARC KM 732.3	645.8	550157	1132840
AB07BE0330	ATHABASCA RIVER AT ATHABASCA TOWN 1 KM UPSTREAM OF HIGHWAY 813 BRIDGE LEFT BANK SAMPLE	691.1	544328	1131657
AB07BK0120	LESSER SLAVE RIVER APPROXIMATELY 15KM. BEFORE CONFLUENCE WITH THE ATHABASCA RIVER	T	551346	1140854
AB07CA0040	LA BICHE RIVER BEFORE CONFLUENCE WITH ATHABASCA RIVER MOUTH: ARC KM 825.6	T	550058	1124334
AB07CB0360	ATHABASCA RIVER BELOW ATHABASCA TOWN 5.0 KM DS OF HWY. #813 BRIDGE CENTRE OF RIVER SAMPLE	696.1	544546	1131427
AB07CB0440	ATHABASCA RIVER 5 KM. DOWNSTREAM OF DEEP CREEK LEFT BANK SAMPLE _ ARC KM. 657.0	721.1	545427	1130414
AB07CB0450	ATHABASCA RIVER 0.1 KM. UPSTREAM OF ALPAC DIFFUSER RIGHT BANK SAMPLE _ ARC KM. 643.0	735.1	545805	1125419

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist.(km)	AEP Latt.	AEP Long.
AB07CB0490	ATHABASCA RIVER 1 KM. DOWNSTREAM OF ALPAC DIFFUSER ARC 641	737.1	545801	1125324
AB07CB0550	ATHABASCA RIVER 11 KM. DOWNSTREAM OF ALPAC DIFFUSER RIGHT BANK SAMPLE _ ARC KM. 631	747.1	545811	1124432
AB07CB0610	ATHABASCA RIVER 4 KM. DOWNSTREAM OF LABICHE RIVER ARC KM. 622	756.1	550257	1124629
AB07CB0640	CALLING RIVER NEAR CONFLUENCE WITH ATHABASCA RIVER MOUTH ARC KM.610.1	T	550523	1125259
AB07CB0660	ATHABASCA RIVER 3 KM. DOWNSTREAM OF CALLING RIVER RIGHT-CENTRE SAMPLE - ARC KM.607.0	771.1	550657	1125151
AB07CB0730	ATHABASCA RIVER 13.3 KM DOWNSTREAM OF PELICAN RIVER CENTRE OF RIVER SAMPLE	890.1	555520	1123828
AB07CB0770	HOUSE RIVER - BEFORE CONFLUENCE WITH ATHABASCA RIVER LEFT BANK SAMPLE MOUTH: ARC KM 443.0	T	561200	1122945
AB07CC0010	ATHABASCA RIVER 100 METERS ABOVE THE CONFLUENCE WITH THE HORSE RIVER - AOSERP	1080.5	564306	1112411
AB07CD0100	CLEARWATER RIVER NEAR WATERWAYS MOUTH: ARC KM 292.8	T	564205	1111946
AB07DA0090	ATHABASCA RIVER - BELOW FT. MCMURRAY 3.3 KM UPSTREAM OF POPLAR CREEK CENTRE OF RIVER SAMPLE	1108.1	565441	1112504
AB07DA0110	POPLAR CREEK 21.6 KM NORTH OF FT. MCMURRAY VIA HIGHWAY #63 - AOSERP	T	565450	1112729
AB07DA0860	ATHABASCA RIVER 5.0 KM DOWNSTREAM OF BITUMOUNT CENTRE OF RIVER SAMPLE ARC KM 214.4	1164.1	572553	1113832
AB07DD0040	ATHABASCA RIVER AT EMBARRAS AIRPORT - AT WSC GAUGE ARC KM. 111.3 - AOSERP	1267.2	581218	1112324
Peace, Wapiti and Smoky Rivers				
AB07FD0050	PEACE RIVER AT DUNVEGAN 1.5 KM UPSTREAM OF BRIDGE-LEFT BANK JULY 1988	N/A	555541	1183740
AB07FD0070	PEACE RIVER AT DUNVEGAN 1.5 KM UPSTREAM OF BRIDGE-RIGHT BANK JULY 1988	N/A	555518	1183720
AB07FD0100	PEACE RIVER ABOVE SMOKY RIVER 0.75 KM BELOW SHAFTESBURY FERRY ON SEC. HWY. #740 L BANK JUL 88	N/A	560555	1173340
AB07FD0110	PEACE RIVER ABOVE SMOKY RIVER 0.75 KM BELOW SHAFTESBURY FERRY ON SEC. HWY. #740 R BANK JUL 88	N/A	560545	1173256
AB07GC0020	WAPITI RIVER 5 KM UPSTREAM OF THE REDWILLOW RIVER CENTER-GRAB DECEMBER 1989	255	550016	1192317
AB07GE0020	WAPITI RIVER AT HIGHWAY #40 BRIDGE SOUTH OF GRANDE PRAIRIE CENTRE CHANNEL - KM 44	250	550419	1184817
AB07GE0050	WAPITI RIVER 0.1 KM UPSTREAM OF THE GRANDE PRAIRIE STP EFFLUENT RIGHT BANK-GRAB DECEMBER 1989	247.1	550436	1184643
AB07GE0060	WAPITI RIVER 5.0 KM DOWNSTREAM OF THE GRANDE PRAIRIE STP EFFLUENT RIGHT BANK-GRAB DECEMBER 1989	242	550441	1184337
AB07GE0070	WAPITI RIVER DOWNSTREAM OF THE PROCTOR & GAMBLE HAUL ROAD CENTER-GRAB DECEMBER 1989	240	550406	1184219
AB07GE0080	WAPITI RIVER 1 KM UPSTREAM OF PROCTOR & GAMBLE EFFLUENT RIGHT BANK-GRAB DECEMBER 1989	239	550346	1183957
AB07GE0100	WAPITI RIVER - 0.25 KM D/S OF PROCTOR AND GAMBLE EFFLUENT - LEFT BANK GAMBLE EFFLUENT	237.75	550349	1183847
AB07GE0130	WAPITI RIVER AT RAILWAY BRIDGE DOWNSTREAM OF PROCTOR & GAMBLE EFFLUENT-CENTER GRAB DEC 1989	236	550429	1183655
AB07GE0170	WAPITI RIVER 10 KM DOWNSTREAM OF PROCTOR & GAMBLE EFFLUENT CENTER-GRAB DECEMBER 1989	227	550450	1183210
AB07GE0180	WAPITI RIVER 0.1 KM UPSTREAM OF BEAR RIVER CONFLUENCE CENTRE CHANNEL SAMPLE - KM 18.5	220	550624	1182814
AB07GE0200	WAPITI RIVER 10 KM. UPSTREAM OF MOUTH	216	550719	1182404
AB07GE0210	WAPITI RIVER APPROX. 6 KM UPSTREAM OF THE MOUTH CENTER-GRAB DECEMBER 1989	210	550823	1182139
AB07GF0030	SMOKY RIVER UPSTREAM OF THE WAPITI RIVER LEFT BANK-GRAB DECEMBER 1989	N/A	550806	1181803
AB07GF0050	SMOKY RIVER UPSTREAM OF THE WAPITI RIVER RIGHT BANK-GRAB DECEMBER 1989	N/A	550806	1181753
AB07GJ0030	WAPITI RIVER ABOVE CONFLUENCE OF SMOKY RIVER CENTRE CHANNEL - KM 0.5 SITE W2C	206	550806	1181830
AB07GJ0080	SMOKY RIVER AT BEZANSON BRIDGE - HWY 34 CENTRE CHANNEL - KM 186 SITE S3C	200	551413	1181526
AB07GJ0110	SMOKY RIVER 0.1 KM UPSTREAM OF PUSKWASKAU RIVER CONFLUENCE CENTRE CHANNEL SAMPLE KM 146	190	552903	1180931
AB07GJ0190	SMOKY RIVER AT WATINO CENTRE CHANNEL SAMPLE - KM 68	170	554257	1173721
AB07HA0210	PEACE RIVER 1.5 KM ABOVE THE CONFLUENCE OF THE WHITEMUD RIVER LEFT BANK JULY 1988	N/A	563918	1170854

Table A1. Alberta Environmental Protection (AEP) water quality monitoring stations (continued).

AEP Station Code	AEP Station Name	River Dist (km)	AEP Lat.	AEP Long.
AB07HA0250	PEACE RIVER 1.5 KM ABOVE THE CONFLUENCE OF THE WHITEMUD RIVER RIGHT BANK JULY 1988	N/A	563929	1170842
AB07HC0070	PEACE RIVER 15.5 KM ABOVE THE CONFLUENCE OF THE NOTIKEWIN RIVER CENTER SAMPLE JULY 1988	N/A	571037	1170551
AB07HD0010	PEACE RIVER NEAR CARCAJOU 0.5 KM ABOVE SCULLY CREEK CENTER SAMPLE JULY 1988	N/A	574253	1170654
AB07HF0060	PEACE RIVER AT FORT VERMILION CENTER SAMPLE JULY 1988	N/A	582416	1160741

Table A2. Environment Canada (HYDAT) discharge stations.

HYDAT Station Code	HYDAT Station Name	Latitude	Longitude
AB05AA008	CROWSNEST RIVER @ FRANK	493549	1142433
AB05AA022	CASTLE RIVER NEAR BEAVER MINES	492918	1140840
AB05AA023	OLDMAN RIVER NEAR WALDON'S CORNER	494850	1141100
AB05AA024	OLDMAN RIVER BELOW OLDMAN DAM	493334	1135238
AB05AA028	CASTLE RIVER @ RANGER STATION	492355	1142020
AB05AB002	WILLOW CREEK NEAR NOLAN	494738	1133213
AB05AB013	BEAVER CREEK NEAR BROCKET	493821	1134738
AB05AB021	WILLOW CREEK NEAR CLARESHOLM	500105	1134250
AB05AB028	WILLOW CREEK ABOVE CHAIN LAKES	501147	1141246
AB05AB039	WILLOW CREEK BELOW LANE CREEK	500825	1135621
AB05AC003	LITTLE BOW RIVER @ CARMANGAY	500739	1130702
AB05AC012	LITTLE BOW RIVER BELOW TRAVERS DAM	500804	1124014
AB05AC023	LITTLE BOW RIVER NEAR MOUTH	495400	1123020
AB05AC031	MOSQUITO CREEK NEAR MOUTH	501520	1133315
AB05AC034	LITTLE BOW RIVER ABOVE TRAVERS RESERVOIR	551215	1125840
AB05AD007	OLDMAN RIVER NEAR LETHBRIDGE	494230	1125230
AB05AH005	SEVEN PERSON'S CREEK @ MEDICINE HAT	500125	1104102
AB05AJ001	SOUTH SASKATCHEWAN RIVER @ MEDICINE HAT	500235	1104040
AB05AK001	SOUTH SASKATCHEWAN RIVER @ HWY 41	500415	1100545
AB05BA001	BOW RIVER @ LAKE LOUISE	512542	1161115
AB05BB001	BOW RIVER @ BANFF	511030	1153410
AB05BE004	BOW RIVER NEAR SEEBE	510710	1150200
AB05BE006	BOW RIVER BELOW GHOST DAM	511250	1143640
AB05BE008	BOW RIVER @ CANMORE	510505	1152151
AB05BH004	BOW RIVER @ CALGARY	510300	1140300
AB05BH008	BOW RIVER BELOW BEARSPAW DAM	510558	1141331
AB05BJ001	ELBOW RIVER BELOW GLENMORE DAM	510055	1140533
AB05BJ004	ELBOW RIVER @ BRAGG CREEK	505653	1143410
AB05BJ006	ELBOW RIVER ABOVE ELBOW FALLS	505120	1144737
AB05BJ010	ELBOW RIVER @ SARCEE BRIDGE	505940	1141000
AB05BK003	FISH CREEK @ BOW BOTTOM TRAIL	505425	1140056
AB05BL003	HIGHWOOD RIVER @ HIGH RIVER	503500	1135220
AB05BL004	HIGHWOOD RIVER BELOW LITTLE BOW CANAL	503508	1135207
AB05BL009	HIGHWOOD RIVER NEAR ALDERSYDE	504158	1135123
AB05BL019	HIGHWOOD RIVER @ DIEBEL'S RANCH	502420	1142950
AB05BL024	HIGHWOOD RIVER NEAR THE MOUTH	504700	1134913
AB05BM002	BOW RIVER BELOW CARSELAND DAM	504926	1132631
AB05BM004	BOW RIVER BELOW BASSANO DAM	504500	1123220
AB05BM008	CROWFOOT CREEK NEAR CLUNY	505000	1124540
AB05BM014	WEST ARROWOOD CREEK NEAR ARROWOOD	504550	1131400
AB05BN012	BOW RIVER NEAR MOUTH	500247	1113528
AB05CA001	BLINDMAN RIVER NEAR BLACKFALDS	522114	1134735
AB05CA002	JAEMS RIVER NEAR SUNDRE	515537	1144104
AB05CA007	MEDICINE RIVER NEAR ECKVILLE	521908	1142033
AB05CA009	RED DEER RIVER BELOW BURNT TIMBER CREEK	513846	1150105
AB05CC002	RED DEER RIVER @ RED DEER	521636	1134857
AB05CD006	HAYNES CREEK NEAR HAYNES	521955	1132141
AB05CE001	RED DEER RIVER @ DRUMHELLER	512802	1124238
AB05CE002	KNEEHILLS CREEK NEAR DRUMHELLER	512812	1125837
AB05CE005	ROSEBUD RIVER @ REDLAND	511736	1130038
AB05CE007	THREEHILLS CREEK NEAR CARBON	513353	1130418
AB05CK001	BLOOD INDIAN CREEK NEAR MOUTH	505726	1110330
AB05CK004	RED DEER RIVER NEAR BINDLOSS	505410	1101750
AB05CK005	ALKALI CREEK NEAR MOUTH	505354	1103030
AB05DA009	NORTH SASKATCHEWAN RIVER @ WHIRLPOOL POINT	520006	1162810
AB05DC001	NORTH SASKATCHEWAN RIVER NEAR ROCKY MOUNTAIN HOUSE	522251	1145621
AB05DC010	NORTH SASKATCHEWAN RIVER BELOW BIGHORN PLANT	521836	1161921
AB05DC012	BAPTISTE RIVER NEAR MOUTH	523951	1150430
AB05DD005	BRAZEAU RIVER BELOW BRAZEAU PLANT	525445	1152150
AB05DE003	WABAMUN CREEK NEAR DUFFIELD	532742	1142200
AB05DE007	ROSE CREEK NEAR ALDER FLATS	525548	1150036
AB05DF001	NORTH SASKATCHEWAN RIVER @ EDMONTON	533215	1132904

Table A2. Environment Canada (HYDAT) discharge stations (continued).

HYDAT Station Code	HYDAT Station Name	Latitude	Longitude
AB05DF004	STRAWBERRY CREEK NEAR MOUTH	531841	1140302
AB05EA001	STURGEON RIVER NEAR FORT SASKATCHEWAN	534714	1131323
AB05EB015	BEAVERHILL CREEK NEAR MOUTH	535321	1125657
AB05EC002	WASKATENAU CREEK NEAR WASKATENAU	540723	1124658
AB05EC004	NAMEPI CREEK NEAR MOUTH	540147	1125044
AB05EC005	REDWATER RIVER NEAR MOUTH	535349	1125946
AB05EC006	WHITE EARTH CREEK NEAR SMOKY LAKE	540656	1121800
AB07AA002	ATHABASCA RIVER NEAR JASPER	525436	1180325
AB07AC007	BERLAND RIVER NEAR MOUTH	540047	1165747
AB07AD002	ATHABASCA RIVER @ HINTON	532523	1173414
AB07AE001	ATHABASCA RIVER NEAR WINDFALL	541225	1160345
AB07AF002	MCLEOD RIVER ABOVE EMBARRAS RIVER	532812	1163745
AB07AF013	MCLEOD RIVER NEAR CADOMIN	530444	1171150
AB07AF014	EMBARRAS RIVER NEAR WEALD	532231	1164820
AB07AF015	GREGG RIVER NEAR MOUTH	531507	1172123
AB07AF906	GREGG RIVER NEAR HINTON	531508	1172130
AB07AF909	EMBARRAS RIVER @ ROBB	531319	1165804
AB07AG001	MCLEOD RIVER NEAR WOLF CREEK	533915	1161650
AB07AG003	WOLF CREEK @ HWY 16A	533555	1161615
AB07AG004	MCLEOD RIVER NEAR WHITECOURT	540046	1155018
AB07AG007	MCLEOD RIVER NEAR ROSEVEAR	534149	1160942
AB07AG008	GROAT CREEK NEAR WHITECOURT	540157	1155030
AB07BA001	PEMBINA RIVER BELOW PADDY CRREEK	530747	1151930
AB07BA003	LOVETT RIVER NEAR MOUTH	525950	1163920
AB07BB002	PEMBINA RIVER NEAR ENTWISTLE	533618	1150014
AB07BC002	PEMBINA RIVER @ JARVIE	542705	1135930
AB07BE001	ATHABASCA RIVER @ ATHABASCA	544320	1131710
AB07BK001	LESSER SLAVE RIVER @ SLAVE LAKE	551819	1144508
AB07BK006	LESSER SLAVE RIVER @ HWY 2A	551739	1143526
AB07CA011	LA BICHE RIVER @ HWY 63	545610	1123010
AB07CB002	HOUSE RIVER @ HWY 63	553830	1120925
AB07CD001	CLEARWATER RIVER @ DRAPER	564107	1111515
AB07CD005	CLEARWATER RIVER ABOVE CHRISTINA RIVER	563940	1105540
AB07DA001	ATHABASCA RIVER BELOW McMURRAY	564650	1112400
AB07DD003	EMBARRAS RIVER BELOW DIVERGENCE	582520	1113305
AB07FD003	PEACE RIVER @ DUNVEGAN BRIDGE	555509	1183619
AB07GA001	SMOKY RIVER ABOVE HELL'S CREEK	535646	1190940
AB07GD003	REDWILLOW RIVER NEAR BEAVERLODGE	550455	1193130
AB07GE001	WAPITI RIVER NEAR GRANDE PRAIRIE	550420	1184810
AB07GH002	LITTLE SMOKY RIVER NEAR GUY	552725	1170940
AB07GJ001	SMOKY RIVER @ WATINO	554256	1173719
AB07HA001	PEACE RIVER @ PEACE RIVER	561441	1171846
AB07HA005	WHITEMUD RIVER NEAR DIXONVILLE	563040	1173932
AB07HB001	CADOTTE RIVER @ OUTLET CADOTTE LAKE	562912	1162558
AB07HC001	NOTIKEWIN @ MANNING	565510	1173705
AB07HF002	KEG RIVER @ HWY 35	574440	1173720
AB11AA001	NORTH MILK RIVER NEAR INTERNATIONAL BOUNDARY	490119	1125816
AB11AA005	MILK RIVER @ MILK RIVER	490837	1120444
AB11AA025	MILK RIVER @ WESTERN INTERNATIONAL BOUNDARY	490027	1123242
AB11AA031	MILK RIVER @ EASTERN INTERNATIONAL BOUNDARY	485903	1102810
AB11AA038	VERDIGRIS COULEE NEAR MOUTH	493639	1114531
SK05EF001	NORTH SASKATCHEWAN RIVER NEAR DEER CREEK	533100	1093640

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations

AEP Station Code	HYDAT Station Code
Milk River and tributaries	
AB11AA0010	AB11AA025
AB11AA0020	AB11AA001
AB11AA0030	AB11AA005
AB11AA0050	AB11AA005+AB11AA038
Oldman River and tributaries	
AB05AA0050	AB05AA023
AB05AA0220	AB05AA008
AB05AA0270	AB05AA008
AB05AA0400	AB05AA022
AB05AA0410	AB05AA022
AB05AB0040	AB05AA024
AB05AB0130	AB05AA024+AB05AB013
AB05AB0160	AB05AA024+AB05AB013
AB05AB0170	AB05AB028
AB05AB0200	AB05AB039
AB05AB0220	AB05AB021
AB05AB0250	AB05AB002
AB05AB0260	AB05AB002
AB05AC0010	AB05AB002+AB05AB013+AB05AA024
AB05AC0040	AB05AB002+AB05AB013+AB05AA024
AB05AD0010	AB05AD007
AB05AD0300	AB05AD007
AB05AD0370	AB05AD007
AB05AD0390	AB05AD007
AB05AD0400	AB05AD007
AB05AD0450	AB05AD007
AB05AD0490	AB05AD007
AB05AD0500	AB05AD007
AB05AD0590	AB05AD007
AB05AD0600	AB05AD007
AB05AD0710	AB05AD007
AB05AD0740	AB05AD007
AB05AD0790	AB05AD007
AB05AC0080	N/A
AB05AC0100	AB05AC003-AB05AC031
AB05AC0160	AB05AC031
AB05AC0190	AB05AC003
AB05AG0070	AB05AD007+AB05AC023
AB05AG0090	AB05AD007+AB05AC023
AB05AG0100	AB05AD007+AB05AC023
AB05AG0120	AB05AD007+AB05AC023
AB05AG0190	AB05AD007+AB05AC023
AB05AG0220	AB05AD007+AB05AC023
AB05AG0230	AB05AD007+AB05AC023
Bow River	
AB05BA0010	AB05BA001
AB05BA0030	AB05BA001
AB05BB0010	AB05BB001
AB05BB0020	AB05BB001
AB05BB0030	AB05BB001
AB05BB0040	AB05BB001
AB05BB0050	AB05BB001
AB05BB0060	AB05BB001
AB05BE0010	AB05BE008
AB05BE0030	AB05BE008
AB05BE0050	AB05BE008
AB05BE0070	AB05BE008
AB05BE0090	AB05BE008
AB05BE0100	AB05BE008
AB05BE0140	AB05BE008
AB05BE0160	AB05BE008
AB05BE0190	AB05BE008
AB05BE0210	AB05BE008

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations (continued).

AEP Station Code	HYDAT Station Code
AB05BE0240	AB05BE008
AB05BE0250	AB05BE004
AB05BE0260	AB05BE006
AB05BE0270	AB05BE006
AB05BH0010	AB05BH004
AB05BH0100	AB05BH004
AB05BH0110	AB05BH004
AB05BH0140	AB05BH004
AB05BH0450	AB05BH004
AB05BH0510	AB05BH004
AB05BH0520	AB05BH004
AB05BH0530	AB05BH004
AB05BH0610	AB05BH004
AB05BM0010	AB05BM002
AB05BM0030	AB05BH004
AB05BM0120	AB05BH004+AB05BK003
AB05BM0140	AB05BH004+AB05BK003
AB05BM0150	AB05BH004+AB05BK003
AB05BM0170	AB05BH004+AB05BK003
AB05BM0180	AB05BH004+AB05BL024
AB05BM0190	AB05BH004+AB05BL024
AB05BM0200	AB05BH004+AB05BL024
AB05BM0420	AB05BH004+AB05BL024
AB05BM0470	AB05BM002
AB05BM0500	AB05BM002
AB05BM0580	AB05BM002+AB05BM014
AB05BM0590	AB05BM002+AB05BM014
AB05BM0640	AB05BM002+AB05BM014+AB05BM008
AB05BM0670	AB05BM004
AB05BN0010	AB05BN012
AB05BN0080	(AB05BN012+AB05BM004)/2
AB05BN0150	(AB05BN012+AB05BM004)/2
AB05BN0210	AB05BN012
AB05BN0260	AB05BN012
Elbow River	
AB05BJ0120	AB05BJ004
AB05BJ0170	AB05BJ010
AB05BJ0220	AB05BJ010
AB05BJ0230	AB05BJ010
AB05BJ0240	AB05BJ010
AB05BJ0250	AB05BJ010
AB05BJ0280	AB05BJ010
AB05BJ0290	AB05BJ010
AB05BJ0300	AB05BJ010
AB05BJ0340	AB05BJ001
AB05BJ0350	AB05BJ001
AB05BJ0370	AB05BJ001
AB05BJ0450	AB05BJ001
Highwood and Sheep Rivers	
AB05BL0160	AB05BL003 or ABO05BL004
AB05BL0180	AB05BL003 or ABO05BL004
AB05BL0230	AB05BL003 or ABO05BL004
AB05BL0390	AB05BL009
AB05BL0470	AB05BL024-AB05BL009
AB05BL0490	AB05BL024
South Saskatchewan River	
AB05AJ0010	AB05AJ001
AB05AJ0040	AB05AJ001
AB05AK0020	AB05AJ001
AB05AK0370	AB05AJ001+AB05AH005
AB05AK0490	AB05AK001
Red Deer River	

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations (continued).

AEP Station Code	HYDAT Station Code
AB05CB0010	AB05CA009+AB05CA002
AB05CC0010	AB05CC002
AB05CC0020	AB05CC002-AB05CC007
AB05CC0170	AB05CC002
AB05CC0200	AB05CC002
AB05CC0230	AB05CC002
AB05CC0300	AB05CC002
AB05CC0310	AB05CC002
AB05CC0380	AB05CC002
AB05CC0390	AB05CC002
AB05CC0410	AB05CC002
AB05CD0010	AB05CC002+AB05CC001
AB05CD0080	AB05CC002+AB05CC001
AB05CD0100	AB05CC002+AB05CC001
AB05CD0120	AB05CC002+AB05CC001
AB05CD0190	AB05CC002+AB05CC001
AB05CD0220	AB05CC002+AB05CC001
AB05CD0250	AB05CC002+AB05CC001+AB05CD006
AB05CD0320	AB05CE001-(AB05CE002+AB05CE007)
AB05CD0370	AB05CE001-(AB05CE002+AB05CE007)
AB05CE0010	AB05CE001-(AB05CE002+AB05CE007)
AB05CE0030	AB05CE001
AB05CE0120	AB05CE001+AB05CE005
AB05CG0010	AB05CE001+AB05CE005
AB05CJ0070	AB05CK004-(AB05CK001+AB05CK005)
AB05CK0060	AB05CK004
North Saskatchewan River	
AB05DA0010	AB05DA009
AB05DC0010	AB05DC010
AB05DC0030	AB05DC010
AB05DC0050	AB05DC001
AB05DC0060	AB05DC001
AB05DC0080	AB05DC001+AB05DC012
AB05DE0020	AB05DC001+AB05DC012+AB05DD005+AB05DE007
AB05DE0030	AB05DC001+AB05DC012+AB05DD005+AB05DE007
AB05DE0040	AB05DC001+AB05DC012+AB05DD005+AB05DE007
AB05DE0060	AB05DF001-(AB05DE003+AB05DF004)
AB05DE0070	AB05DF001-(AB05DE003+AB05DF004)
AB05DE0080	AB05DF001-(AB05DE003+AB05DF004)
AB05DF0120	AB05DF001
AB05DF0130	AB05DF001
AB05DF0140	AB05DF001
AB05EB0020	AB05DF001
AB05EB0190	AB05DF001
AB05EB0210	AB05DF001
AB05EB0300	AB05DF001
AB05EB0320	AB05DF001
AB05EB0360	AB05DF001
AB05EB0380	AB05DF001
AB05EB0430	AB05DF001
AB05EB0470	AB05DF001
AB05EB0550	AB05DF001
AB05EB0570	AB05DF001
AB05EB0600	AB05DF001
AB05EB0790	AB05DF001+AB05EA001
AB05EB0830	AB05DF001+AB05EA001
AB05EB0850	AB05DF001+AB05EA001
AB05EB0860	AB05DF001+AB05EA001
AB05EB0910	AB05DF001+AB05EA001+AB05EC005+AB05EB015
AB05EB0930	AB05DF001+AB05EA001+AB05EC005+AB05EB015
AB05EC0090	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004
AB05EC0160	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations (continued).

AEP Station Code	HYDAT Station Code
AB05EC0170	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002
AB05EC0180	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002
AB05EC0210	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002
AB05ED0010	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05ED0020	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05ED0030	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05ED0110	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05ED0120	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05EF0010	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05EF0060	AB05DF001+AB05EA001+AB05EC005+AB05EB015+AB05EC004+AB05EC002+AB05EC006
AB05EF0080	SK05EF001
AB05EF0100	SK05EF001
AB05EF0120	SK05EF001
Athabasca River and tributaries	
AB07AC0010	AB07AC007
AB07AD0050	AB07AD002
AB07AD0060	AB07AD002
AB07AD0220	AB07AD002
AB07AD0260	AB07AD002
AB07AD0350	AB07AD002
AB07AD0380	AB07AD002
AB07AD0460	AB07AD002
AB07AE0080	AB07AE001
AB07AE0330	AB07AE001
AB07AE0360	AB07AE001+AB07AG004
AB07AE0380	AB07AE001+AB07AG004
AB07AF0050	AB07AF013
AB07AF0060	AB07AF013
AB07AF0100	AB07AF013
AB07AF0120	AB07AF013
AB07AF0150	AB07AF013
AB07AF0170	AB07AF013
AB07AF0180	AB07AF013
AB07AF0190	AB07AF013
AB07AF0200	AB07AF013
AB07AF0210	AB07AF906
AB07AF0240	AB07AF906
AB07AF0260	AB07AF906
AB07AF0310	AB07AF906
AB07AF0330	AB07AF906
AB07AF0340	AB07AF906+AB07AF013
AB07AF0350	AB07AF002
AB07AF0380	AB07AF014
AB07AF0390	AB07BA003
AB07AG0010	AB07AG007-AB07AG003
AB07AG0020	AB07AG007-AB07AG003
AB07AG0070	AB07AG007-AB07AG003
AB07AG0090	AB07AG007-AB07AG003
AB07AG0100	AB07AG007-AB07AG003
AB07AG0120	AB07AG007-AB07AG003
AB07AG0130	AB07AG007-AB07AG003
AB07AG0150	AB07AG007-AB07AG003
AB07AG0160	AB07AG007-AB07AG003
AB07AG0170	AB07AG007-AB07AG003
AB07AG0180	AB07AG003
AB07AG0200	AB07AG003
AB07AG0210	AB07AG003
AB07AG0220	N/A
AB07AG0230	N/A
AB07AG0240	AB07AG007
AB07AG0250	AB07AG007
AB07AG0270	AB07AG007

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations (continued).

AEP Station Code	HYDAT Station Code
AB07AG0290	AB07AG007
AB07AG0300	AB07AG007
AB07AG0310	AB07AG007
AB07AG0320	AB07AG007
AB07AG0340	AB07AG008
AB07AG0350	AB07AG004
AB07AG0370	AB07AG004
AB07AG0380	AB07AG004
AB07AG0420	AB07AG004
AB07AG0430	N/A
AB07AH0020	AB07AE001+AB07AG004
AB07AH0040	AB07AE001+AB07AG004
AB07AH0060	AB07AE001+AB07AG004
AB07AH0070	AB07AE001+AB07AG004
AB07AH0090	AB07AE001+AB07AG004
AB07AH0100	AB07AE001+AB07AG004
AB07AH0120	AB07AE001+AB07AG004
AB07AH0140	AB07AE001+AB07AG004
AB07AH0150	AB07AE001+AB07AG004
AB07AH0160	AB07AE001+AB07AG004
AB07AH0260	AB07AE001+AB07AG004
AB07AH0290	AB07AE001+AB07AG004
AB07AH0330	AB07AE001+AB07AG004
AB07AH0350	AB07AE001+AB07AG004
AB07BA0010	N/A
AB07BA0020	AB07BA003
AB07BA0030	AB07BA003
AB07BA0040	N/A
AB07BA0050	N/A
AB07BA0060	N/A
AB07BA0070	N/A
AB07BA0140	AB07BA001
AB07BB0020	AB07BB002
AB07BB0040	AB07BB002
AB07BC0010	AB07BC002
AB07BC0070	AB07BC002
AB07BC0080	AB07BC002
AB07BD0090	AB07AE001+AB07AG004+AB07BC002
AB07BD0100	AB07AE001+AB07AG004+AB07BC002
AB07BE0310	AB07BE001
AB07BE0330	AB07BE001
AB07BK0120	AB07BK006
AB07CA0040	AB07CA011
AB07CB0360	AB07BE001
AB07CB0440	AB07BE001
AB07CB0450	AB07BE001
AB07CB0490	AB07BE001
AB07CB0550	AB07BE001
AB07CB0610	AB07BE001+AB07CA011
AB07CB0640	N/A
AB07CB0660	AB07BE001+AB07CA011
AB07CB0730	N/A
AB07CB0770	AB07CB002
AB07CC0010	N/A
AB07CD0100	AB07CD001
AB07DA0090	AB07DA001
AB07DA0110	N/A
AB07DA0860	N/A
AB07DD0040	N/A
Peace, Wapiti and Smoky Rivers	
AB07FD0050	AB07FD003
AB07FD0070	AB07FD003

Table A3. AEP monitoring stations and matching Environment Canada (HYDAT) flow stations (continued).

AEP Station Code	HYDAT Station Code
AB07FD0100	AB07HA001-AB07GJ001
AB07FD0110	AB07HA001-AB07GJ001
AB07GC0020	AB07GE001-AB07GD003
AB07GE0020	AB07GE001
AB07GE0050	AB07GE001
AB07GE0060	AB07GE001
AB07GE0070	AB07GE001
AB07GE0080	AB07GE001
AB07GE0100	AB07GE001
AB07GE0130	AB07GE001
AB07GE0170	AB07GE001
AB07GE0180	AB07GE001
AB07GE0200	AB07GE001
AB07GE0210	AB07GE001
AB07GF0030	N/A
AB07GF0050	N/A
AB07GJ0030	AB07GE001+AB07GE005
AB07GJ0080	AB07GJ001-AB07GH002
AB07GJ0110	AB07GJ001-AB07GH002
AB07GJ0190	AB07GJ001
AB07HA0210	AB07HA001
AB07HA0250	AB07HA001
AB07HC0070	AB07HA001+AB07HA005+AB07HB001
AB07HD0010	AB07HA001+AB07HA005+AB07HB001+AB07HC001
AB07HF0060	AB07HA001+AB07HA005+AB07HB001+AB07HC001+HF002

APPENDIX B

Mean monthly flow hydrographs for discharge stations along mainstems of major Alberta rivers

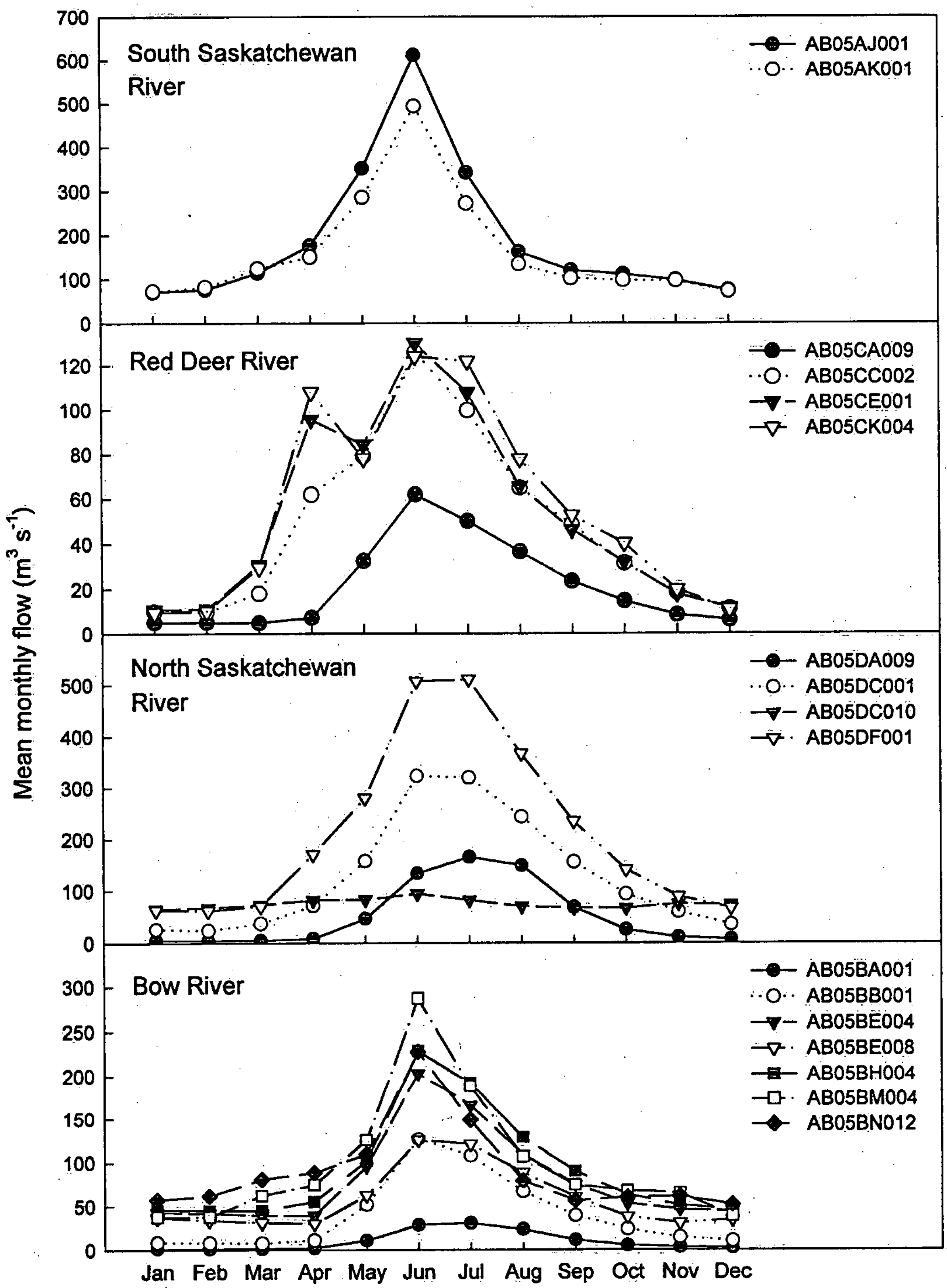

Figure B1. Mean monthly discharge at Environment Canada (HYDAT) stations along the South Saskatchewan, Red Deer, North Saskatchewan and Bow rivers. Data from each station are historical means for the entire period of discharge monitoring.

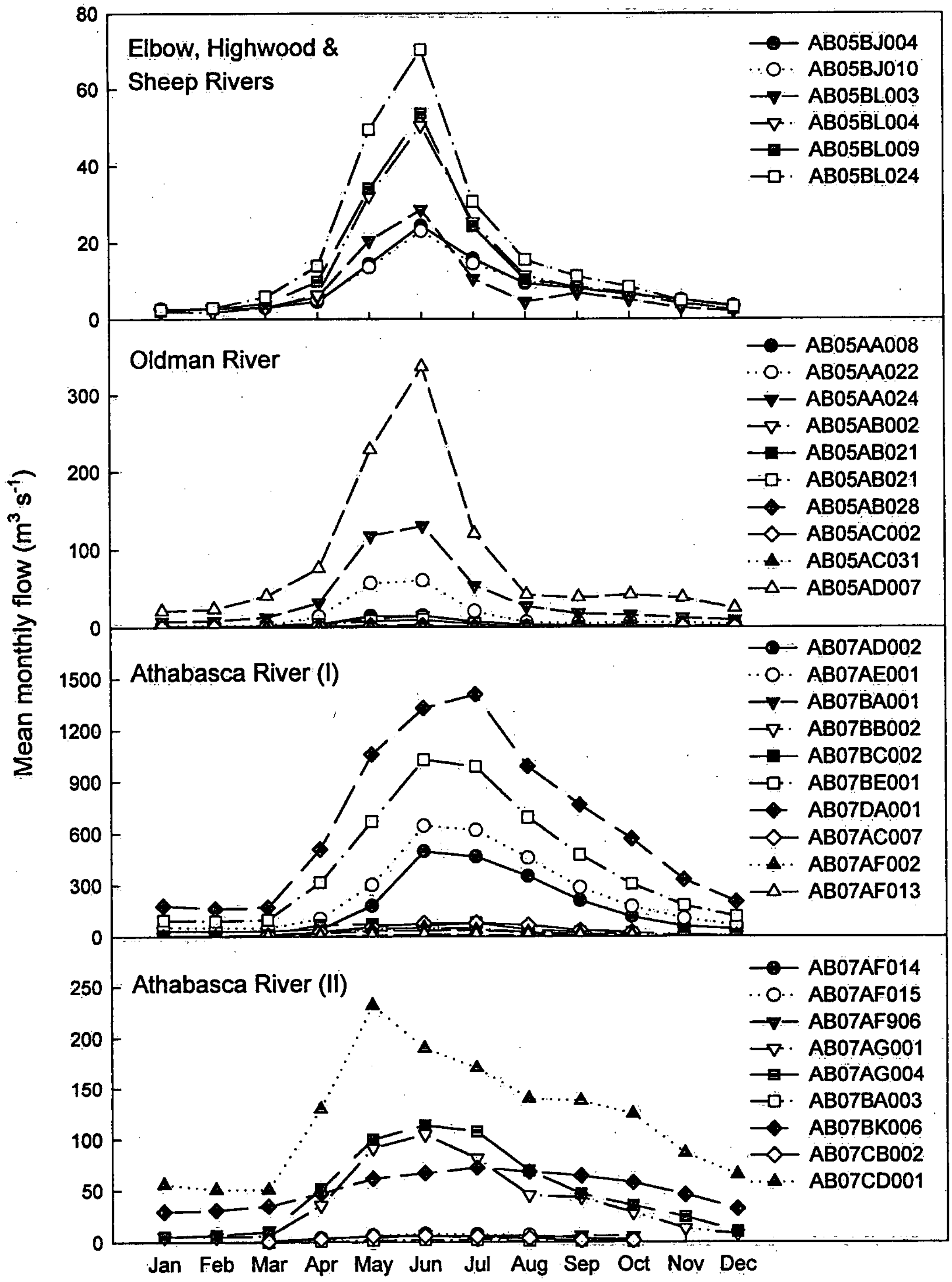

Figure B2. Mean monthly discharge at Environment Canada (HYDAT) stations along the Elbow, Highwood, Sheep, Oldman and Athabasca rivers. Data from each station are historical means for the entire period of discharge monitoring.

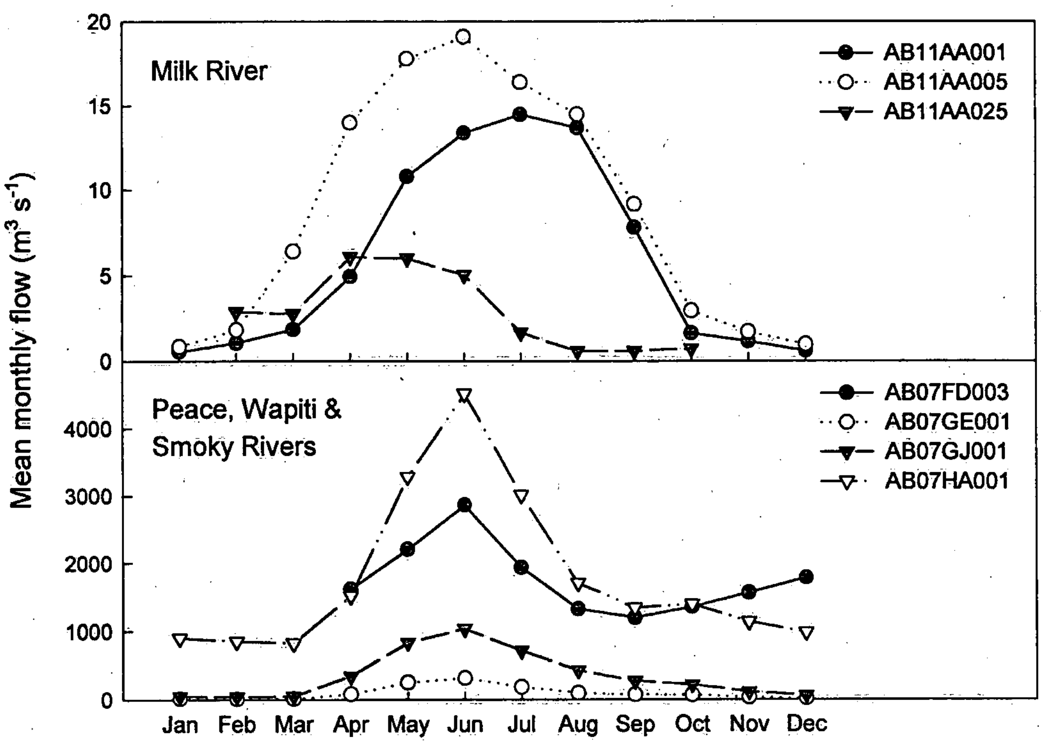

Figure B3. Mean monthly discharge at Environment Canada (HYDAT) stations along the Milk, Peace, Wapiti and Smoky rivers. Data from each station are historical means for the entire period of discharge monitoring.

APPENDIX C

Correlation matrices of water quality and flow parameters in instantaneous and seasonal databases

Table C1. Pearson correlation coefficients for variables used as predictors of instantaneous epilithic and planktonic chlorophyll *a* in multiple regression models. "n.s." denotes non-significant ($P > 0.05$) coefficients. Abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed.

Variable	TP	TDP	TKN	NO_2 $+NO_3$	NH_3 (diss)	TN	DIN	TDS	Turbi-dity	NFR	Flow
TP	-	0.77	0.64	0.28	0.53	0.59	0.34	0.12	0.59	0.65	0.32
TDP		-	0.52	0.39	0.53	0.54	0.41	0.21	0.17	0.25	0.14
TKN			-	0.16	0.56	0.86	0.32	0.14	0.37	0.37	0.11
NO_2+NO_3				-	0.51	0.56	0.94	0.12	0.06	0.04	0.22
NH_3 (dissolved)					-	0.66	0.71	0.28	0.13	0.11	0.17
TN						-	0.67	0.17	0.29	0.27	0.14
DIN							-	0.20	n.s.	n.s.	0.09
TDS								-	-0.12	-0.12	-0.02
Turbidity									-	0.85	0.35
NFR										-	0.34
Flow											-

Table C2. Pearson correlation coefficients for variables used as predictors of seasonal mean epilithic and planktonic chlorophyll *a* in multiple regression models. "n.s." denotes non-significant ($P > 0.05$) coefficients. Flow subscripts denote the type of flow (annual mean = ann, annual maximum = max, seasonal mean = sea). All other abbreviations defined in text. Variable units according to Table 2. All variables are ln-transformed.

Variable	TP	TDP	TKN	NO_2 $+NO_3$	NH_3 (diss)	TN	DIN	TDS	Turbi-dity	NFR	$Flow_{max}$	$Flow_{ann}$	$Flow_{sea}$
Spring chemistry													
TP	-	0.74	0.67	0.38	0.49	0.68	0.33	0.29	0.71	0.78	0.32	0.23	0.34
TDP		-	0.62	0.53	0.61	0.61	0.50	0.21	0.32	0.40	0.17	0.14	0.19
TKN			-	0.25	0.49	0.89	0.30	0.21	0.54	0.50	n.s.	n.s.	0.13
NO_2+NO_3				-	0.49	0.58	0.94	0.33	0.13	0.19	0.15	0.16	0.15
NH_3(diss)					-	0.6	0.70	0.33	0.41	0.35	0.39	0.29	0.36
TN						-	0.65	0.27	0.43	0.42	0.13	0.12	0.15
DIN							-	0.37	n.s.	n.s.	n.s.	n.s.	n.s.
TDS								-	0.20	0.19	0.35	0.21	0.25
Turbidity									-	0.89	0.41	0.30	0.36
NFR										-	0.37	0.25	0.32
$Flow_{max}$											-	0.89	0.87
$Flow_{ann}$												-	0.95
$Flow_{sea}$													-
Summer chemistry													
TP	-	0.69	0.59	0.15	0.47	0.53	n.s.	n.s.	0.66	0.69	0.27	0.31	0.33
TDP		-	0.53	0.29	0.48	0.58	0.23	n.s.	0.17	0.24	n.s.	n.s.	0.11
TKN			-	n.s.	0.51	0.87	n.s.	n.s.	0.37	0.38	n.s.	0.12	n.s.
NO_2+NO_3				-	0.30	0.35	0.94	0.26	n.s.	n.s.	0.18	0.21	0.23
NH_3(diss)					-	0.55	0.53	0.27	0.25	0.31	n.s	n.s.	n.s.
TN						-	0.50	n.s.	0.27	0.33	n.s.	n.s.	n.s.
DIN							-	0.33	n.s.	n.s.	n.s.	n.s.	n.s.
TDS								-	-0.27	-0.21	0.27	n.s.	n.s.
Turbidity									-	0.89	0.43	0.39	0.41
NFR										-	0.25	0.29	0.28
$Flow_{max}$											-	0.89	0.92
$Flow_{ann}$												-	0.97
$Flow_{sea}$													-
Fall chemistry													
TP	-	0.84	0.62	0.36	0.47	0.63	0.39	n.s.	0.55	0.59	0.39	0.32	0.30
TDP		-	0.46	0.48	0.62	0.56	0.52	n.s.	0.18	0.24	0.14	0.16	0.15
TKN			-	0.12	0.60	0.76	0.35	0.59	0.34	0.48	n.s.	n.s.	n.s.
NO_2+NO_3				-	0.50	0.61	0.94	-0.35	n.s.	n.s.	n.s.	0.13	0.15
NH_3(diss)					-	0.68	0.70	0.20	0.32	0.32	n.s.	n.s.	n.s.
TN						-	0.70	n.s.	0.34	0.34	n.s.	n.s.	n.s.
DIN							-	n.s.	n.s.	0.31	-0.29	n.s.	n.s.
TDS								-	n.s.	0.70	n.s.	n.s.	n.s.
Turbidity									-	0.77	0.33	0.32	0.34
NFR										-	0.15	0.13	0.16
$Flow_{max}$											-	0.89	0.77
$Flow_{ann}$												-	0.94

Table C2 *(continued)*

Variable	TP	TDP	TKN	NO_2 $+NO_3$	NH_3 (diss)	TN	DIN	TDS	Turbidity	NFR	$Flow_{max}$	$Flow_{ann}$	$Flow_{sea}$
$Flow_{sea}$													-
All seasons													
TP	-	0.76	0.64	0.31	0.49	0.62	0.29	n.s.	0.66	0.71	0.31	0.26	0.33
TDP		-	0.53	0.44	0.57	0.59	0.42	n.s.	0.24	0.31	0.13	0.13	0.15
TKN			-	0.12	0.53	0.84	0.24	0.40	0.44	0.48	0.06	0.04	0.09
NO_2+NO_3				-	0.43	0.52	0.94	-0.13	0.09	0.14	0.12	0.16	0.18
NH_3(diss)					-	0.61	0.64	0.28	0.33	0.33	0.14	0.16	0.18
TN						-	0.62	n.s.	0.37	0.38	n.s.	0.08	0.11
DIN							-	0.25	n.s.	0.17	n.s	n.s.	n.s.
TDS								-	0.11	0.43	n.s.	n.s.	n.s.
Turbidity									-	0.86	0.37	0.31	0.38
NFR										-	0.22	0.18	0.26
$Flow_{max}$											-	0.89	0.83
$Flow_{ann}$												-	0.93
$Flow_{sea}$													-