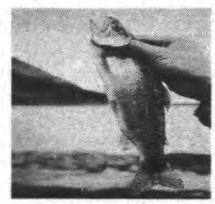
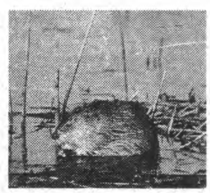
Canada Alberta Northwest Territories

Northern River Basins Study



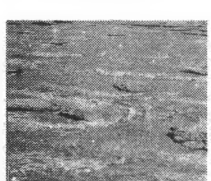




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 28

NUTRIENT LOADING
ON THE PEACE, ATHABASCA AND SLAVE RIVERS





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NUTRIENT LOADING
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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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NORTHERN RIVER BASINS STUDY
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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

(Dr. F.J. Wrona, Ph.D., Science Director) — 16 July 94 (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair) — 19 Sept 94 (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

(Lucille Partington, Co-chair) — Sept. 15/94 (Date)

(Robert McLeod, Co-chair) — Sept. 15/94 (Date)

NUTRIENT LOADING ON THE PEACE, ATHABASCA AND SLAVE RIVERS

STUDY PERSPECTIVE

> ***Related Study Questions***
>
> *2) What is the current state of water quality in the Peace, Athabasca and Slave river basins, including the Peace-Athabasca Delta?*
>
> *5) Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality?*

A particular area of concern related to municipal and industrial effluent discharges in the northern river basins is the effect of nutrients (nitrogen and phosphorus) on the aquatic environment. Nutrients enter a river from municipal and industrial effluents, agricultural and timber-harvesting runoff, natural runoff, groundwater sources and tributary inflow. Added nutrients can cause changes in the abundance and production of benthic biota and on the production, reproduction and survivorship of fish. Nutrients may also decrease dissolved oxygen concentrations as a result of enhanced plant growth, which is, in turn, decomposed by bacteria that consume oxygen. The changes to the biological communities resulting from the addition of nutrients and their subsequent effect on the chemical and physical components of the ecosystem is referred to scientifically as eutrophication. Understanding the impacts of nutrients on the aquatic environment is therefore critical for regulating industrial and municipal effluent discharges to the Peace, Athabasca and Slave rivers in order to minimize eutrophication, protect aquatic habitats and safeguard ecosystem health.

This report provides an overview of historic information and data related to nutrient sources to the Peace, Athabasca and Slave river systems and their effects on river water chemistry, benthic invertebrates and algal communities. Principally, the role of industrial and municipal sources in contributing nutrients to the Athabasca and Peace river systems is examined relative to natural sources and non-point sources such as agriculture.

As of April, 1994, there are five continuously discharging sewage treatment plants, four operating pulp mills, and one mill under construction on the Athabasca River and its tributaries. The increase in nutrient levels with distance downstream on the Athabasca River system is due to point sources and natural tributary inflows, which often have higher concentrations of phosphorus and nitrogen than the mainstem. During the winter of 1991, the contribution of total phosphorus and total nitrogen to the mainstem from all man-made point sources was 44% and 19%, respectively. On an annual basis, however, the relative contribution from point sources is lower (approximately 5% of the total phosphorus load) because the nutrient contribution from the tributaries is much higher during other seasons. When all tributary and point source contributions to the Athabasca River are considered, the total phosphorus load measured near the Athabasca delta during the winter of 1991 was only 36% of the sum of the inputs. Based on the same winter survey, the concentration of total nitrogen increases at downstream locations; the nitrogen load near the Athabasca delta was almost seven times greater than the load upstream of Hinton. Data from the long-term monitoring site at the Town of Athabasca shows an upward trend in mean winter concentrations of total nitrogen in the Athabasca River between 1982 and 1992.

There are five pulp mills on the Peace River and its tributaries, only two of which are in Alberta. Because of its size, the water chemistry of the Peace River is not markedly affected by point source effluent discharges. Between 1977 and 1988, there was a significant decrease in all nitrogen forms and no change in total and dissolved phosphorus in the Peace River at the long-term monitoring site at Dunvegan. However, sewage treatment plant and pulp mill effluents affect the water chemistry of the Wapiti and Smoky rivers. In the winter survey of 1991, man-made point sources contributed the majority of total phosphorus (84%) and total nitrogen (51%) to the Wapiti-Smoky river system. Total and dissolved phosphorus concentrations measured at the long-term monitoring site on the Smoky River at Watino have been highly variable between 1982 and 1992. An upward trend in total and dissolved nitrogen has occurred during this same period.

Pulp mill and treated municipal sewage discharges to the Athabasca and Peace river systems generally cause an increase in the total number of benthic invertebrates downstream of the outfalls. The number of invertebrate taxa (i.e., groups) usually does not change, although it was found that the populations of species sensitive to nutrient enrichment declined in mixing zones below effluent discharges. Statistical and taxonomic analyses of the available data indicate mild to moderate nutrient enrichment in the water without evidence of toxicity. As expected, algae that adhere to the surface of riverbed material generally increase in conjunction with the higher nutrient levels below point source discharges.

The information contained in this document is critical for assessing the effects of nutrient loading from industrial, municipal, agricultural and other sources on river biota. It will also be important for evaluating regulatory requirements, and for developing reliable nutrient fate/response models. These models will be used to predict the relationship between nutrient transport and fate in the aquatic environment, so that the consequences of changes in nutrient loading to northern rivers can be assessed. This report will serve as a basis for formulating additional studies to assess the impact of nutrient loading on the northern river basins.

REPORT SUMMARY

This report is a review and synthesis of the existing reports and databases provided by the Northern River Basins Study (NRBS) on instream nutrient concentrations, nutrient loading, sediment oxygen demand, and benthic communities in the Northern River Basins. The benthic communities include macroinvertebrates and the biofilm. The nutrients include phosphorus and nitrogen.

WATER QUALITY TRENDS

Longitudinal trends in the water chemistry of the Athabasca River were identified in the 1980's. The increase in nutrients down the river system was due to point sources and natural tributary inflows, which often have higher concentrations of phosphorus and nitrogen than the mainstem. In the 1991 winter synoptic survey, the contribution of total phosphorus and total nitrogen from all anthropogenic point sources on the mainstem was 44% and 19%, respectively, of inputs to the mainstem of the Athabasca River including tributary inputs. The contribution from tributaries is much higher on annual basis than it is in the winter; therefore, the percentage of total phosphorus and total nitrogen contributed by point sources would be lower than 44% and 19% on an annual basis.

Winter synoptic surveys on the Athabasca River in 1988 and 1989 found that concentrations of total phosphorus near the delta (Old Fort/Embarras) are higher than concentrations upstream of Hinton while the 1991 and 1992 winter surveys found that concentrations near the delta were lower than concentrations upstream of Hinton. When all tributary and point-source anthropogenic loads* to the Athabasca River are considered, the total phosphorus load measured near the delta during the winter of 1991 is only 36% of the sum of the inputs, indicating a substantial removal of phosphorus from the water column. In contrast to phosphorus, the concentration of total nitrogen increases at downstream locations. The nitrogen load near the delta was almost seven times greater than the load upstream of Hinton, based on the winter of 1991 survey. Data from the long-term monitoring site at the Town of Athabasca shows an upward trend in mean winter concentrations of total nitrogen in the Athabasca River over the last ten years (1982-1992).

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* Load = concentration x discharge. That is, the magnitude of the load depends on both the concentration of the nutrient in a unit of water (e.g. 1 mg/L of total phosphorus) and the volume of water discharged over a unit of time (e.g. 1000 L/d).

A longitudinal trend of increasing nutrients with increasing distance downstream was identified in the Peace River. The upper Peace River in Alberta is not affected by point source discharges but, historically, the concentrations of nutrients have increased in the intermediate reach due primarily to inputs from tributaries, particularly the Smoky River which has higher concentrations of nutrients than the Peace River. The 1991 winter survey of the intermediate reach did not find an increase in total phosphorus or total nitrogen concentrations with distance downstream. In the survey, point sources contributed 1.6% and 3-4% of the instream load of total nitrogen and total phosphorus, respectively. The water chemistry of the downstream section of the Peace River may be strongly influenced by a natural increase in particulates from bottom sediments, although there are also natural nutrient loadings from tributaries. There was a significant decrease in all nitrogen forms and no change in total and dissolved phosphorus in the Peace River at the long-term site monitoring at Dunvegan from 1977 to 1988. In the last three years, mean winter concentrations of total phosphorus (measured at Fort Vermilion) have decreased. (Three years of data are insufficient to establish statistically significant declines in total phosphorus.)

Increases in total nitrogen and total phosphorus in the Wapiti River from 1987 to 1991 have been attributed (Noton 1992a) to the point sources. In the 1991 winter synoptic survey, the contribution of total phosphorus and total nitrogen from all anthropogenic point sources on the Smoky-Wapiti river system was 84% and 51%, respectively, of all inputs including tributary inputs. (These percentages would be lower on an annual basis.) During the winter synoptic survey of 1991, there was an increase in total phosphorus in the Smoky River due to inflow from the Wapiti River containing this point source input. The mass of total phosphorus transported down the Wapiti River and the Smoky River increased by an order-of-magnitude. Total nitrogen loads increased about four to six times background levels in the winter of 1991. Total phosphorus and total nitrogen loads measured in the Smoky River in the winter of 1992 were about one-half and two-thirds, respectively, of the 1991 nutrient loads. Total and dissolved phosphorus concentrations measured at the long-term monitoring site on the Smoky River at Watino have been highly variable over the last ten years. No trend was evident in the winter means (used because they have less scatter). An upward trend in total and dissolved nitrogen has occurred from 1982 to 1992.

Distinct seasonal patterns in the amount and the fractions of nitrogen and phosphorus occurred in the Peace, Athabasca and Wapiti-Smoky Rivers. Concentrations of phosphorus and nitrogen increase during the rising hydrograph due mainly to increases in the particulate fraction. The dissolved fraction of both nutrients generally decreases in the falling hydrograph in the Athabasca and Wapiti-Smoky rivers; this decrease coincides with greater biofilm growth.

SOURCES OF NUTRIENT LOADING

There are five continuously discharging municipal sewage treatment plants, four operating pulp mills and one mill under construction on the Athabasca River and its tributaries. Treated sewage from Fort McMurray is the largest nutrient load from municipal sources. Nearly half of the average annual flow to the Athabasca River comes from the tributaries which contribute a large nutrient load to the mainstem of the river. Other point sources of nutrients such as the Suncor effluent and H.B. Milnor power station effluent are relatively minor.

The Peace River conveys the largest amount of water of any river in Alberta, and its water chemistry is not markedly affected by point source effluent discharges. Of the five pulp mills on the Peace River and its tributaries, only two are in Alberta. Point source impacts from the Grande Prairie sewage treatment plant and the Weyerhaeuser pulp mill affect the water chemistry of the Wapiti River and the Smoky River. Winter surveys have shown increased concentrations of total nitrogen and total phosphorus.

There are seven pulp mills in the NRBS area. Three of the existing pulp mills are kraft mills with aerated stabilization basins; three are chemi-thermomechanical pulp (CTMP) mills with extended aeration activated sludge treatment systems. The seventh mill, a kraft mill with extended aeration activated sludge treatment started up in September 1993. In 1991, the total phosphorus loading from kraft mills was higher than the loading from CTMP mills with the exception of the Alberta Newsprint Company (ANC) mill, a CTMP recycle newsprint mill. When the phosphorus load per tonne of product is considered, kraft mills generally contributed lower phosphorus loadings per tonne of product. Millar Western, a CTMP mill with the lowest load per tonne was the exception. Pulp mills add nutrients to effluent treatment systems to improve BOD** removal. Mills using activated sludge treatment require more nutrients than kraft mills using aerated stabilization basins.

** BOD = biochemical oxygen demand

Nutrient loading from pulp mills is not static; rapid changes have occurred in the last few years. Improvements at mills owned by Weldwood of Canada Ltd. and ANC have substantially reduced their nutrient loading. Weldwood and ANC combined contributed 39% of all inputs of total phosphorus in the 1991 winter survey, but the total phosphorus loads from these mills measured in the 1993 winter survey were about one-fifth the 1991 loading. An important factor appears to be the operation of the treatment system.

Effluents from municipal sewage treatment plants generally have higher concentrations of nutrients, but lower loadings than pulp mill effluents. The concentration of ammonia in municipal effluents are often an order-of-magnitude higher than the concentration in pulp mill effluents. The concentration of total phosphorus is generally higher, as well. The nutrient loads are lower, however, because the volume of effluent from municipal treatment plants is usually less. Grande Prairie and Fort McMurray are important exceptions. Municipalities are not required, as a condition of their discharge license, to monitor the sewage treatment plant effluent for nutrients.

The most significant data gap identified in this report is the lack of sufficient non-point source data. The potential export of phosphorus from the forested and agricultural areas of the Athabasca and Wapiti-Smoky drainage basins was estimated using broad assumptions. Anthropogenic point source loadings were estimated to be only 5% and 6%, respectively, of the potential nutrient export from the Athabasca and Wapiti-Smoky watersheds. Not all the phosphorus that runs off the land into small streams of the watershed reaches the mainstem rivers, but the estimate suggests that further monitoring of non-point sources may be beneficial. Our knowledge of non-point source loading has not kept pace with our knowledge of industrial point source loading. Also, instream water chemistry data from synoptic surveys have increased our knowledge of longitudinal trends in nutrient loading during the winter, but not during other seasons.

BENTHIC EFFECTS

The benthic macroinvertebrate communities have been monitored by Alberta Environment and all of the pulp mills. With the exception of two mills, the data have been collected using comparable methods. There is, therefore, a substantial, good quality database for locations upstream and downstream of many point sources. The pulp mill effluents and the treated municipal sewage discharged to the river generally cause an increase in the number of benthic invertebrates downstream. The number of invertebrate taxa (e.g. species), including both pollution tolerant and intolerant taxa, usually does not change, although the number of taxa increase below Hinton. The population of enrichment-sensitive species, such as *Rithrogena* sp., declined in mixing zones below effluent discharges. The diversity of the benthic invertebrate community generally decreases below point source discharges due to relative increases in the numbers of organisms in some taxa compared to others. This decrease in diversity is not due to a decrease in the number of taxa. Statistical and taxonomic analyses of the data indicate mild to moderate enrichment without evidence of toxicity. The natural changes in the river are equal to, or greater than, the changes caused by the effluents discharged to the river. Longitudinal trends in the benthic community from the headwaters to the river mouth, and seasonal and annual fluctuations are apparent in the data. Tributaries such as the McLeod River affect benthic communities in the mainstem. Natural events such as the high flows in the spring of 1991 have a profound effect on benthic invertebrates causing changes in species dominance and abundance.

Biofilm data are scarce. Epilithic algae, as measured by chlorophyll *a,* generally increased below point source discharges, although the quantity of algae was dependent on substrate and velocity. Epilithic chlorophyll *a* was generally low during spring and summer (attributed to scouring), and in sand or silt substrates. Average epilithic algal densities (as measured by chlorophyll *a*) were generally low in rivers of the NRBS area relative to values recorded in major southern Alberta rivers with the exception of locations affected by point sources. Epilithic chlorophyll *a* concentrations exceed 100 mg/m^2 (the B.C. Ministry of Environment criterion) below some pulp mills, municipal sewage treatment plants and coal mines.

An increase in under-ice sediment oxygen demand (SOD) rates occurs downstream from point sources including pulp mill and municipal effluents. Differences in SOD rates could not be attributed to differences between kraft and CTMP mills. Differences may be the results of other characteristics such as BOD load, dilution, settling, photosynthesis, etc. The SOD downstream from point sources appears to be strongly dependant on water velocity.

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SECTION 1.0

INTRODUCTION

1.0 INTRODUCTION

1.1 OBJECTIVES AND SCOPE OF THE STUDY

In January 1993, SENTAR Consultants Ltd. was authorized by the Northern River Basins Study (NRBS) to compile and review water quality and related data pertaining to nutrients. The objective of this report is to review and synthesize existing information, including both reports and databases, on nutrient concentrations and loading, sediment oxygen demand, and benthic communities within the three northern rivers of the study. The benthic communities included in the study are the benthic biofilm (including algae, fungi and bacteria) and benthic macroinvertebrates. The nutrients are nitrogen and phosphorus. The study will define and identify the commonalities in the impacts of nutrient loadings from point sources.

The project consists of three parts: data collection, the synthesis report, and an annotated bibliography. The synthesis report includes: instream nutrient conditions, nutrient sources, the effects of nutrient loading on the sediment and benthic communities, the commonalities between nutrient impacts from various sources, identification of data deficiencies, and an outline of the data required to construct a nutrient budget.

The study area includes the Peace River, the Athabasca River and the Slave River within Alberta and the Northwest Territories (Fig.1.1.1). The study includes major tributaries to the three rivers; for example, the evaluation of the Peace River will include the Wapiti River and the Smoky River. Also, the Lesser Slave River is a major tributary of the Athabasca River.

1.2 ACKNOWLEDGEMENTS

This report was produced in consultation with the Nutrients Group of the Northern River Basins Study headed by Dr. Patricia Chambers. Her advice; the assistance of Greg Wagner of the NRBS; the data supplied by Leigh Noton, Ian Mackenzie, Anne-Marie Anderson and David Spink of Alberta Environment; the data supplied by Environment Canada; and the cooperation of the pulp mills, coordinated by Brian Steinback, are all greatly appreciated.

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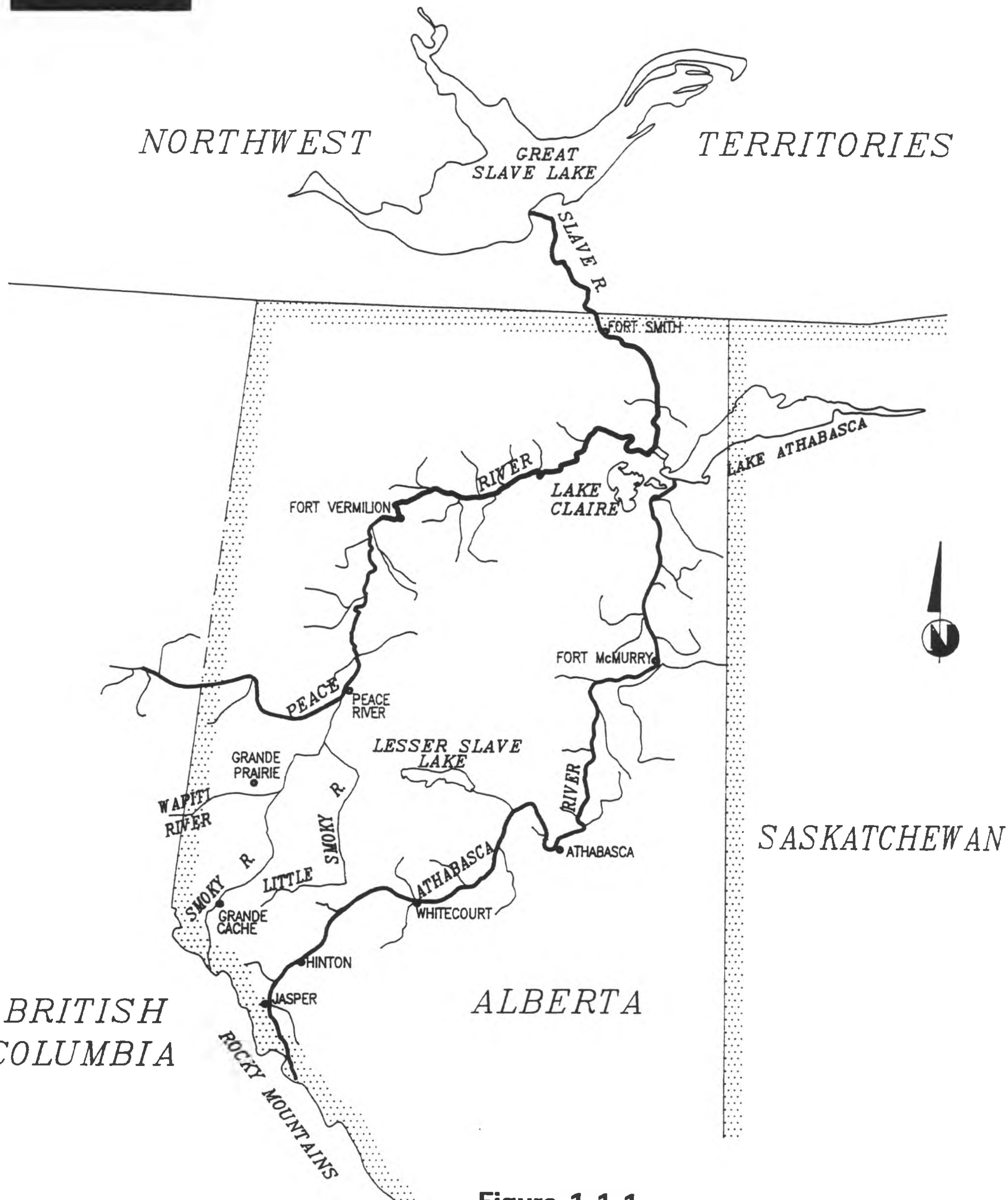

Figure 1.1.1

NORTHERN RIVER BASINS
STUDY AREA

SECTION 2.0

SOURCES OF NUTRIENT LOADING

2.0 SOURCES OF NUTRIENT LOADING

2.1 BASIN DEVELOPMENT

2.1.1 Athabasca River Basin

The Athabasca River is a large, unregulated, northern river which originates near Jasper, crosses Alberta in a northeasterly direction and discharges into the southwestern corner of Lake Athabasca (Fig. 2.1.1). It exhibits seasonal and longitudinal variation in water quality as a result of inputs from relatively large tributaries and anthropogenic sources such as municipal, pulp mill and oil extraction effluents (Hamilton et al. 1985; Noton and Shaw 1989). The major tributaries of the Athabasca River and their average annual[1] contribution to the flow in the lower mainstem at Embarras are: McLeod River (6.7%), Pembina River (4.6%), Lesser Slave River (6.4%), LaBiche River (6.7%), Clearwater River (18.5%) and Berland River (5.6%) (Hamilton et al 1985). The total average annual contribution of the tributaries is 48.5%.

The Athabasca Basin is sparsely populated. The major city is Fort McMurray and the larger towns near the mainstem of the river include Jasper, Hinton, Whitecourt and Athabasca. Slave Lake, Edson, Westlock and Barrhead are also located in the basin, but not on the mainstem. Only a few municipalities continuously discharge effluent directly to the Athabasca River (described in Section 2.4). Smaller municipalities are usually serviced by lagoon systems which may be discharged once or twice a year, normally in autumn and/or spring.

Logging is the dominant land use activity in the watershed. Although there are many sawmills located throughout the basin (Hamilton et al. 1985), most do not discharge effluent to the river. Zeidler Forest Industries Ltd., a wood processing plant at Slave Lake, discharges effluent once a year from a lagoon which contains sewage and water from log washing. Blue Ridge Lumber (1981), a wood processing plant at Whitecourt, discharges only a small quantity of effluent.

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[1] Historic (1970-1983) summary statistics presented by Hamilton et al. (1985).

There are four operating pulp mills and one mill under construction in the basin. Pulp mills are described later in more detail (Section 2.2).

Most agricultural activity occurs south of the mainstem river between the towns of Athabasca and Edson (Hamilton et al. 1985). The major watersheds included in the agricultural zone are the Pembina River and, to a lesser extent, the LaBiche River.

Conventional oil and gas development in the basin is extensive. Approximately 36 conventional oil fields are located partially or wholly within the basin (Hamilton et al. 1985[2]). The basin is estimated to contain 18% of Alberta's total gas reserve, but none of these gas processing plants have a direct effluent discharge to the Athabasca River. Coal mining in the western side of the Athabasca River basin is described in Section 2.3. The largest industrial activity is the surface mining and extraction of tar sands. The Suncor and Syncrude mining and extraction facilities are located downstream from Fort McMurray. Only the Suncor facility discharges treated process effluent to the Athabasca River (Section 2.3).

2.1.2 Peace River Basin

The Peace River originates in north-eastern British Columbia, flows through Williston Reservoir and the Bennett Dam and enters Alberta west of the Town of Peace River. The river flows northeasterly across Alberta and drains into the Slave River, north of Fort Chipewyan (Fig. 2.1.2).

The water quality of the Peace River is, in some respects, unique compared to the other major rivers in Alberta such as the Athabasca River. The water quality of the Peace River is not markedly affected by point-source effluent discharges. Concentrations of dissolved constituents tend to be lower and more constant (both seasonally and longitudinally) in the Peace River as a result of the Cordilleran origin of much of the water in the river, its large size relative to discharge from effluent and tributaries, and the release of water of a relatively constant quality

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2 Hamilton (1985) described development up to 1982.

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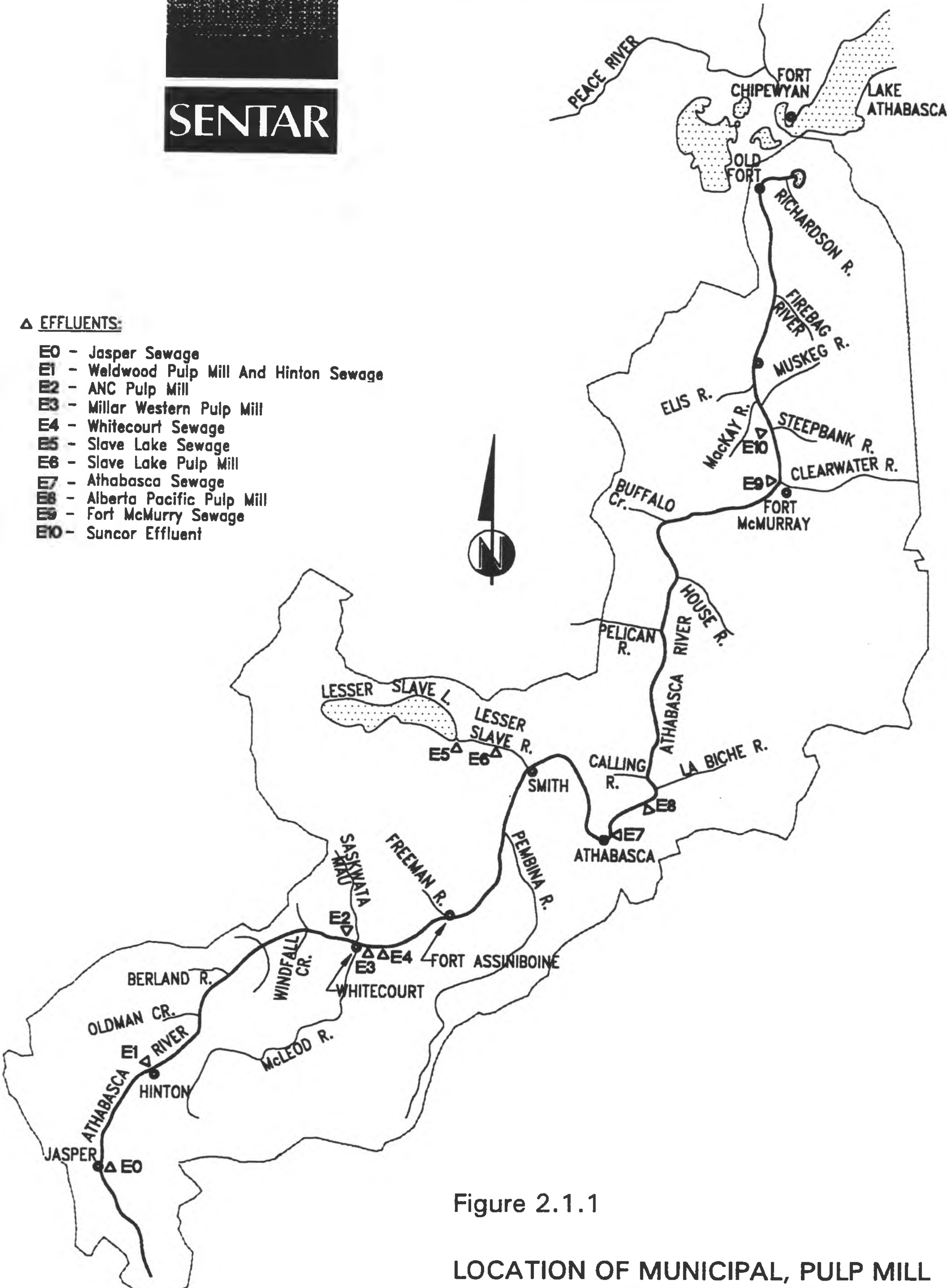

Figure 2.1.1

LOCATION OF MUNICIPAL, PULP MILL AND OTHER INDUSTRIAL DISCHARGES TO THE ATHABASCA RIVER

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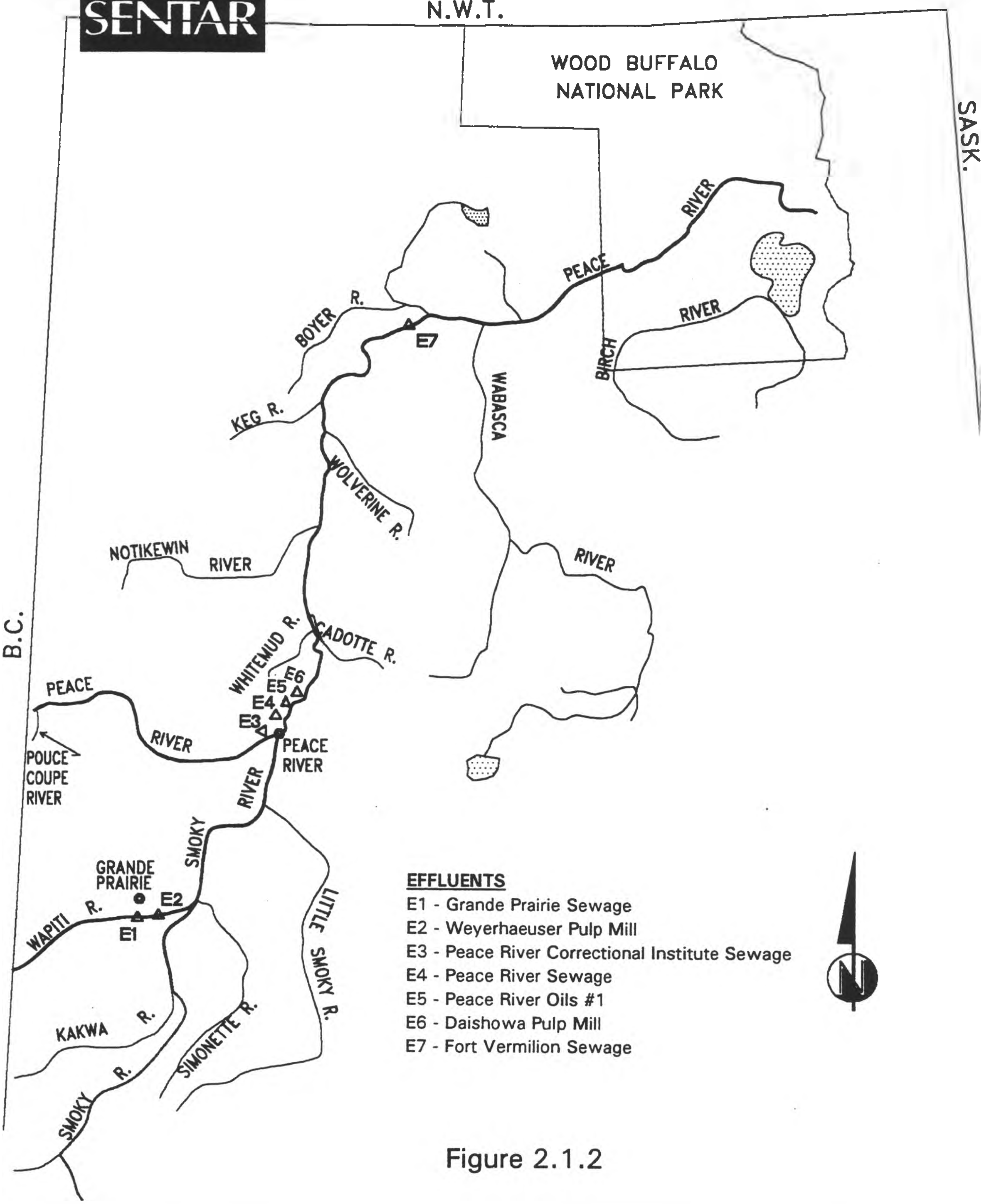

Figure 2.1.2

LOCATION OF MUNICIPAL, PULP MILL AND INDUSTRIAL DISCHARGES TO THE PEACE RIVER IN ALBERTA from Williston Reservoir (Shaw et al. 1990). Concentrations of particulate matter tend to be higher than concentrations in other major Alberta rivers as a result of the high flows and geomorphic conditions in the Peace River and its tributaries.

The entire Peace River Basin is sparsely populated and largely undeveloped. There are only two large towns on the Peace River in Alberta: Grande Prairie and Peace River. The largest municipal effluent load is from the Grande Prairie sewage treatment plant which discharges to the Wapiti River. Only a few municipalities discharge effluent continuously (described in Section 2.4); most have sewage lagoons which discharge once or twice a year.

Historically, agriculture has been the major economic activity in the Peace River Basin; agricultural activity in Alberta occurs in the lowlands surrounding Grande Prairie, Valleyview, High Prairie, Fairview, the Town of Peace River, and to a lesser extent in the High Level-Fort Vermilion district (PRRPC 1982). Diffuse sources of nutrients to the Peace River include run-off of fertilizer from agricultural land, and erosion from logging activities and agricultural land clearing. The water quality of the Pouce Coupé River is distinctly different than other tributaries (Shaw et al. 1990); this was attributed to the high proportion of agricultural land in its drainage basin and the input of municipal sewage from the Town of Dawson Creek, British Columbia.

The three largest industries in the Alberta portion of the basin are associated with forestry; the Canadian Forest Products Ltd. sawmill, the Weyerhaeuser Canada Ltd. (formerly the Procter & Gamble Cellulose Ltd.) pulp mill, and Daishowa Canada Ltd.'s Peace River Pulp Division mill. The largest industrial point source is the Weyerhaeuser pulp mill at Grande Prairie, which discharges treated effluent to the Wapiti River, a tributary of the Smoky River.

2.2 PULP AND PAPER MILL LOADINGS

2.2.1 Pulp and Paper Mills

There are four operating mills and one mill under construction on the Athabasca River and its tributary, the Lesser Slave River (Table 2.2.1). Of the five mills on the Peace River, only two are in Alberta; one on the mainstem and the other on the Wapiti-Smoky River system (Fig. 2.1.2).

TABLE 2.2.1
Pulp and Paper Mills in the Northern River Basins of Alberta

River	Location	Company	Mill Type and 1991 Production (ADt/d)[a]	Effluent Treatment and 1991 Discharge (m^3/d)[b]	Start-up and Modifications
Athabasca	Hinton	Weldwood of Canada Ltd.	Kraft Pulp 1,033	ASB[c] 111,965	Operated since 1957 with many upgrades. Expansion at present capacity in February 1990. ASB dredged annually. Ceased nutrient addition in 1991.
Athabasca	Whitecourt	Alberta Newsprint Co. Ltd.	CTMP and Paper 519	Extended Aeration AST[d] 15,612	Start-up in August 1990 resulted in high nutrients. Phosphorus addition rates reduced in summer of 1992. Started pilot-scale de-inking facility in November 1992.
Athabasca	Whitecourt	Millar Western Pulp Ltd.	CTMP 611	Extended Aeration AST 12,699	Start-up in August 1988. Original ASB was changed to AST in the autumn of 1989.
Lesser Slave	Slave Lake	Slave Lake Pulp Corp.	CTMP 232	AST 3,904	Start-up in fourth quarter of 1990. Added a second secondary clarifier to control suspended solid losses in the third quarter of 1992.
Athabasca	Athabasca	Alberta-Pacific Forest Industries Inc.	Kraft Pulp	Extended Aeration AST	To start-up in September 1993.
Peace	Peace River	Daishowa Canada Co. Ltd. Peace River Pulp Division	Kraft Pulp 794	ASB 63,308	Start-up in July 1990. No significant changes.
Wapiti-Smoky	Grande Prairie	Weyerhaeuser Canada Ltd.	Kraft Pulp 861	ASB 60,495	Start-up in 1973. Improvements include additional aeration and increased retention time.

a. ADt/d = Air dried tonnes per day.
b. m^3/d = cubic metres per day.
c. ASB = Aerated Stabilization Basin
d. AST = Activated Sludge Treatment

Note: the 1991 Production and Discharge means exclude outliers (e.g. shut-down periods).

There are differences in the type of mill process and the wastewater treatment used at Alberta pulp mills (Table 2.2.1). Mills producing kraft pulp and chemi-thermomechanical pulp (CTMP) have different effluent characteristics due to process differences, but the type of effluent treatment system is also important. The two types of wastewater treatment in use are: aerated stabilization basins (ASB), and activated sludge treatment (AST) which may have extended aeration (Table 2.2.1).

Inplant process improvements at two existing kraft mills that reduce BOD, such as extended cooking and oxygen delignification, reduce the need to add phosphorus to the ASB. Weyerhaeuser does not have these inplant processes. The process improvements at the Weldwood of Canada Ltd. mill (such as oxygen delignification) and the substantial improvements in effluent treatment at the Slave Lake Pulp Corporation and Millar Western Pulp Ltd. mills (described in the following summaries) are examples of recent changes in existing mills. In addition, new mills experience variations in flow and nutrient loading at start-up. Thus, nutrient loading from pulp mills is not static; it varies with changes in mill processes, effluent treatment and discharge quantities. The net effect is one of rapid variation in the overall nutrient loading from pulp mills in the last few years.

Weldwood of Canada Ltd. (Weldwood) The Hinton bleached kraft pulp mill has been in operation since 1957. The mill has always used softwood (about 75% spruce and 25% pine). Municipal sewage from the Town of Hinton is combined with the mill effluent and both are discharged to the Athabasca River (Fig. 2.1.1). The Hinton mill was originally North Western Pulp and Power, but the name was changed to St. Regis Paper Co. in 1978, Champion Forest Products (Alberta) Ltd. in 1985, and Weldwood of Canada Ltd., Hinton Division in 1988. The Hinton pulp mill's original production has increased over the years (Fig. 2.2.1).

The Hinton mill has also improved its pollution abatement practices over the years. The effluent system at start-up consisted of a 3-4 day settling basin. A primary clarifier and aerated stabilization basins (ASB) with 5-day retention time became fully operational in October 1967, treating all wastewater from the mill. In 1975, the ASB was expanded by deepening to a 6.3 day design retention time and aeration capacity was increased. In 1978, a foul condensate steam stripper was installed and in 1979, a low odour recovery boiler was installed which improved brownstock washing and lowered liquor losses.

In January 1988, Champion Forest Products received a permit to substantially expand and modernize the mill. The expansion and modernization project included oxygen delignification, a new steam stripper, in-house spill recovery systems, and upgrading of the ASB aeration to 3,000 HP. Although the production capacity of the mill nearly doubled, the 1992 discharge of biochemical oxygen demand (BOD) decreased below the 1986 level (Fig. 2.2.1 provided by Weldwood of Canada Ltd.).

Alberta Newsprint Company (ANC) ANC operates an integrated chemi-thermomechanical pulp (CTMP) and newsprint mill near Whitecourt, Alberta. Although the original intention was to include some hardwood, the mill has always used softwood (about 70% spruce and 30% pine). The mill began operating in August 1990. Water is obtained from the Athabasca River for process use and treated effluent is discharged to the Athabasca River (Fig. 2.1.1). The extended aeration activated sludge treatment (AST) system has a retention time of about 2.5 days in the aeration pond and another 2.5 days in the polishing pond. There have been no significant changes to the treatment system since the mill started. The rates of phosphorus addition were reduced in the summer of 1992. In November 1992, a pilot scale de-inking facility was started up. This facility increases phosphorus discharge but much of the increase is in the form of poly-phosphorus which is considered to be biologically inactive.

Millar Western Pulp Ltd. (Millar Western) Millar Western operates a CTMP mill at Whitecourt about 10 km downstream from the ANC mill. The mill used hardwood (aspen) about 50% of the time and softwood (about 65-70% spruce and 30-35% pine) about 50% of the time. The McLeod River serves as a source of water for process use and treated effluent is discharged to the Athabasca River (Fig 2.1.1). The mill began operating on August 2, 1988, but treated effluent volumes were less than capacity during the fall of that year. The effluent treatment system of the Millar Western mill was originally designed and built as an ASB, but it was changed to an AST process with extended aeration in the fall of 1989. The control philosophy

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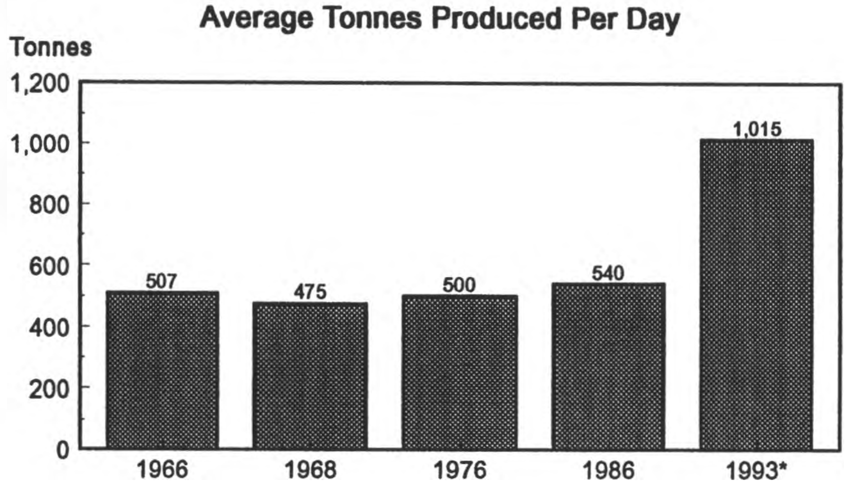

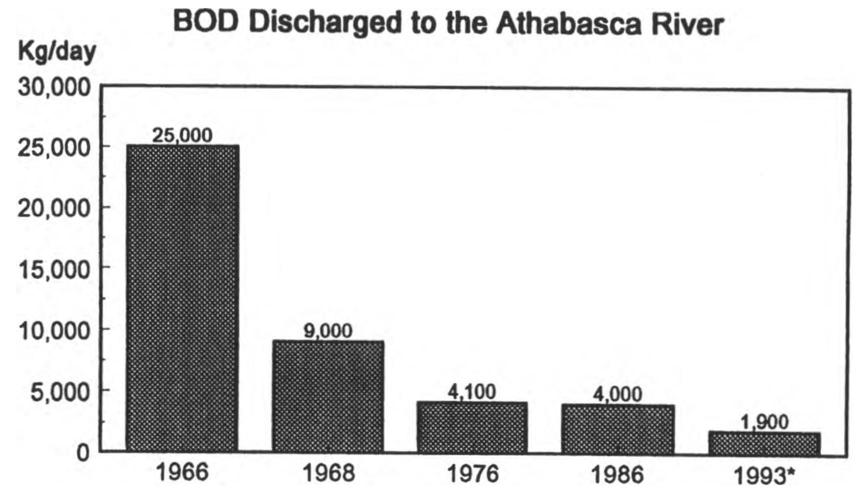

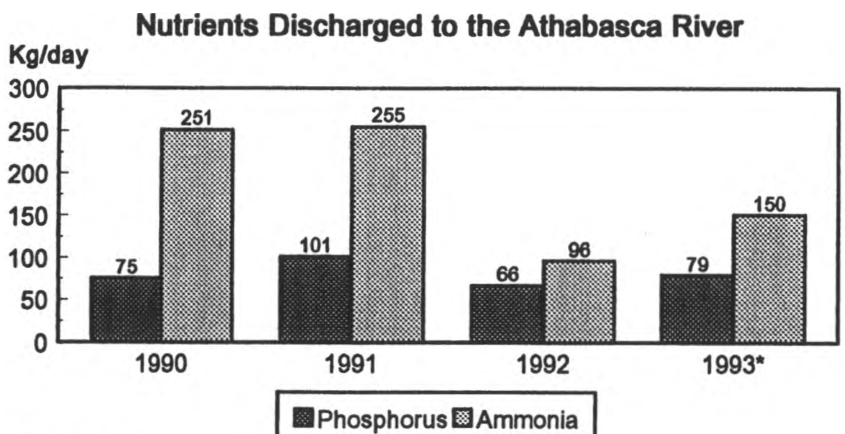

* Partial data,
January to October Inclusive

Figure 2.2.1

CHANGES IN TONNES OF PRODUCT AND BOD DISCHARGED AT THE HINTON PULP MILL
(INFORMATION PROVIDED BY WELDWOOD OF CANADA LTD.)

for nitrogen was changed in September 1992 so that the operational target is now based on sludge age (plus nitrate) rather than ammonia concentrations.

Slave Lake Pulp Corporation (Slave Lake) Construction of the bleached CTMP mill owned by the Slave Lake Pulp Corporation was completed in December 1990. It uses both hardwood and softwood. It has an AST system. In the fall of 1992, a second secondary clarifier was added to control suspended sediment losses. Effluent from this mill is discharged to the Lesser Slave River (Fig. 2.1.1).

Alberta Pacific Forest Industries Inc. (Alberta Pacific) This bleached kraft pulp mill is scheduled to start up in September 1993. It will be able to process either hardwood or softwood, but so far it has processed only hardwood (about 75% aspen and 25% balsam poplar). The AST system will have extended aeration and a hydraulic retention time of about two days. This mill, which is located near the Town of Athabasca, will discharge to the Athabasca River (Fig 2.1.1).

Daishowa Canada Co. Ltd., Peace River Pulp Division (Peace River) This bleached kraft pulp mill can process either hardwood or softwood. It uses hardwood about 70% of the time and softwood about 30% of the time. The effluent which is treated in an ASB is discharged to the Peace River approximately 19 km downstream of the Town of Peace River (Fig. 2.1.2). The mill began operations in July 1990 and there have been no significant changes to the wastewater treatment process since start-up.

Weyerhaeuser Canada Ltd. (Weyerhaeuser) The Weyerhaeuser (formerly Procter & Gamble Cellulose Ltd.) bleached kraft softwood pulp mill at Grande Prairie became operational in 1973. It uses 100% softwood (about 60% spruce and 40% pine), although the mill experimented with hardwood for 1-2 years. It discharges effluent to the Wapiti River, a tributary to the Smoky River. The mill has been upgraded over the years. Mill process changes include: oxygen and peroxide reinforced extraction stage, pressure diffuser, "closed" screen room, and digester washing improvements. The effluent is treated in a primary clarifier and ASB prior to discharge. Effluent treatment improvements include additional aeration and increased hydraulic retention time in the treatment ponds. This mill does not have extended cooking or oxygen delignification as do all other Alberta kraft mills.

2.2.2 Nutrient Loadings

Untreated effluent from pulp mills generally contains insufficient nutrients to maintain an optimum microbial population for high BOD removal; phosphorus and nitrogen have to be added to the raw effluent to enhance the biological treatment. In general, less phosphorus is added to ASB treatment when compared to other forms of secondary treatment such as activated sludge (McCubbin and Folke 1992). Sufficient nutrient residual must exist in the wastewater at all times to ensure that the microbes are not phosphorus limited. For this reason, effluents from pulp mills are major point sources of nutrient loading to the Peace and Athabasca rivers.

The annual mean concentrations and loads for total phosphorus (Table 2.2.2) have been summarized for 1991 (the only year for which data are currently available in the NRBS database prepared for NRBS by N. McCubbin Inc.) and 1992 (data provided by Standards and Approvals Division, Alberta Environment). Monthly mean loads of total and dissolved phosphorus have also been summarized from the McCubbin database for each pulp mill from January 1991 to January 1992 inclusive (Appendix Tables A.1 to A.6). Data provided by Alberta Environment have been summarized for 1992 (Appendix Tables A.7 and A.12).

The 1991 mean annual concentrations of total phosphorus ranged from 0.89 mg/L to 10.08 mg/L in the pulp mill effluents (Table 2.2.2). The Slave Lake and ANC mill effluents contained higher concentrations of phosphorus than the other mill effluents. The high total phosphorus concentrations in ANC effluent occurring during 1991 were reduced in 1992 (Table 2.2.2) and further reduced to 3.6 mg/L in 1993 (data for the first five months). Monthly mean concentrations of total phosphorus concentrations in the Slave Lake Pulp Corporation effluent ranged from 0.28 to 37.42 mg/L in 1991-92 (Tables A.4 and A.10). Weldwood of Canada Ltd. stopped adding nutrients to its ASB in 1991; the nutrients in the sewage from the Town of Hinton are more than sufficient. The total phosphorus mean for the first six months of 1993 is 0.65 mg/L (Todd Andrews pers. comm.) which is similar to the 1992 means.

TABLE 2.2.2
1991 and 1992 Annual Mean Loads of Total Phosphorus in Alberta Pulp Mill Effluents

Pulp Mill			Discharge (m³/d)	Total Phosphorus Concentration (mg/L)	Total Phosphorus Load (kg/d)	Coefficient of Variation of Total Phosphorus Load (%)
Weldwood of Canada Ltd.	1991	Mean	110 870	0.89	97.15	64
		Standard Deviation	9 723	0.59	62.27	
		Number	44	40	40	
	1992[a]	Mean	110 942	0.61	67.94	28
		Standard Deviation	12 232	0.14	19.36	
		Number	49	49	49	
Alberta Newprint Company	1991	Mean	15 210	7.01	103.96	51
		Standard Deviation	3 513	3.44	52.87	
		Number	56	55	55	
	1992	Mean	17 478	4.73	82.36	85
		Standard Deviation	2 255	4.00	69.73	
		Number	46	46	46	
Millar Western Pulp Ltd.	1991	Mean	12 699	1.84	22.88	85
		Standard Deviation	1 468	1.56	19.40	
		Number	52	51	51	
	1992	Mean	11 570	3.46	37.23	94
		Standard Deviation	2 627	2.97	35.04	
		Number	51	51	51	
Slave Lake Pulp Corporation	1991	Mean	3 643	10.08	36.84	138
		Standard Deviation	938	12.94	50.94	
		Number	100	100	100	
	1992[b]	Mean	4 450	7.90	33.03	105
		Standard Deviation	1 236	8.80	34.78	
		Number	26	26	26	
Weyerhaeuser Canada Ltd.	1991	Mean	59 792	1.10	65.24	43
		Standard Deviation	10 205	0.42	28.38	
		Number	62	62	62	
	1992	Mean	65 959	0.94	60.86	78
		Standard Deviation	6 785	0.79	47.45	
		Number	65	65	65	
Daishowa Canada Co. Ltd., Peace River Pulp Division	1991	Mean	68 826	1.70	106.33	41
		Standard Deviation	9 502	0.69	43.94	
		Number	94	91	91	
	1992	Mean	64 896	1.57	101.31	33
		Standard Deviation	6 891	0.52	33.23	
		Number	61	61	61	

Note: All means do not include December 1991 data due to low production and discharge at some mills during this period.

a. Data only to end of November 1992

b. Data from the months of January, February, March, April, May, September and November only.

The total phosphorus loading was higher for kraft pulp mills than for CTMP mills with the exception of the ANC mill, a CTMP mill with high phosphorus loading in 1991. The highest mass load of total phosphorus came from the Peace River mill in 1991 (Table 2.2.2), even though it had the lowest pulp production of the kraft mills in the NRBS study area. Although total phosphorus loading is greater for the kraft pulp mills, the production of these mills is also greater than the CTMP mills.

When the total phosphorus load per tonne of pulp is considered, the highest total phosphorus loads per tonne of pulp (from Table 2.2.1) come from two CTMP mills (ANC and Slave Lake Pulp Corp.). The lowest load per tonne also comes from a CTMP mill (Millar Western). With the exception of Millar Western, the kraft mills using ASB's generally have the lowest total phosphorus load per tonne of product. Since all three CTMP mills have an activated sludge treatment system while all kraft mills have ASB's, it is not possible to separate effluent treatment type from the type of mill. One of the most important factors affecting the nutrient loading from pulp mills to the river appears to be the management of the treatment system (e.g. no phosphorus addition at Weldwood) or problems with the system.

Phosphorus loading varies substantially day to day and month to month (Appendix Tables A.1 to A.6). The coefficients of variation of the total phosphorus load (Table 2.2.2) ranged from 28% to 138%. No seasonal trend is apparent in the discharge data.[3] Winter synoptic survey data are available for 1990 to 1992 (Table 2.2.3). It shows differences from year to year, particularly for the Weldwood and Millar Western effluents.

Total nitrogen concentrations could only be obtained for five of the mills because Slave Lake Pulp Corporation does not measure all the chemical forms of nitrogen (Table 2.2.4). The Slave Lake mill does not report total Kjeldahl nitrogen (TKN) which is a major form of nitrogen in pulp mill effluents (Table 2.2.4). Due to the past emphasis on effluent toxicity, measurement of ammonia nitrogen has taken precedence. The ammonia values for the Slave Lake mill are generally <1.0 mg/L, but eleven values ranging from 11.0 to 55.0 mg/L in February 1991 and 23 values ranging from 3.0 to 16.8 mg/L in May 1991 are responsible for the high standard deviation in Table 2.2.4.

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[3] Data for dissolved phosphorus have been included in Appendix Tables A.1 to A.6 but data are incomplete and contain anomalies (described further in Section 2.6).

TABLE 2.2.3
Mass Loads of Total Phosphorus and Total Nitrogen in Pulp Mill Effluents Measured During Synoptic Surveys[a]

Station	Date (D/M/Y)	Discharge (m^3/d)	Total Nitrogen Concentration (mg/L)	Total Nitrogen Load (kg/d)	Total Phosphorus Concentration (mg/L)	Total Phosphorus Load (kg/d)
Weldwood of Canada Ltd.	14/02/90	67 738	3.23	218.79	0.24	16.26
	14/02/90	67 738	5.52	373.91	0.25	16.93
	15/02/90	67 738				
	15/02/90	67 738				
	15/02/90	67 738				
	06/02/91	92 448	7.06	652.68	4.275	395.22
	06/02/91	92 448				
	06/02/91	92 448	7.27	672.10	4.275	395.22
	29/01/92	95 904	6.277	601.99	0.675	64.74
	29/01/92	95 904	6.54	627.21	0.85	81.52
	29/01/92	95 904				
Alberta Newsprint Company	11/02/91	16 589	3.3	54.74	5.55	92.07
	11/02/91	16 589	2.39	39.65	6.6	109.49
	11/02/91	16 589				
	03/02/92	19 872	2.759	54.83	5.563	110.55
	03/02/92	19 872	2.614	51.95	5.625	111.78
	03/02/92	19 872				
Millar Western Pulp Ltd.	20/02/90	11 750				
	20/02/90	11 750	16.04	188.48	6.8	79.90
	20/02/90	11 750				
	20/02/90	11 750	15	176.26	6.8	79.90
	20/02/90	11 750				
	12/02/91	12 442				
	12/02/91	12 442	8.04	100.03	0.7	8.71
	12/02/91	12 442	7.84	97.54	0.7	8.71
	04/02/92	12 096	7.428	89.85	1.94	23.47
	04/02/92	12 096				
	04/02/92	12 096	7.224	87.38	1.9	22.98
Slave Lake Pulp Corp.	20/02/91	2 851	29.68	84.62	24.401	69.57
	20/02/91	2 851	29.68	83.48	24.201	69.00
	11/02/92	2 592				
	11/02/92	2 592	17.64	45.72	10.001	25.92
	11/02/92	2 592	18.133	47.00	10.151	26.31
Weyerhaeuser Canada Ltd.	27/02/90	44 582				
	27/02/90	44 582	14.07		1.4	62.42
	27/02/90	44 582		627.27		
	26/02/91	63 504	7.66	486.44	0.98	62.23
	26/02/91	63 504	7.26	461.04	0.96	60.96
	12/03/92		7.563		0.55	
Daishowa Canada Co. Ltd.	11/03/91	52 531	3.01	158.12	1.5	78.80
	11/03/91	52 531	2.76	144.99	1.475	77.48

a. Synoptic surveys conducted by Alberta Environment.

TABLE 2.2.4
1991 and 1992 Annual Means for All Nitrogen Forms Monitored by Alberta Pulp Mills

Pulp Mill		Flow (m^3/d)	Ammonia-Nitrogen (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate & Nitrite (mg/L)	Nitrate-Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)
Weldwood of Canada Ltd.	1991 Mean	101 210	2.34	4.87		0.21	0.13
	Standard Deviation	34 399	1.38	1.65		0.22	0.08
	Number	52	52	40		45	45
	1992[a] Mean	110 943	0.91	4.82		0.66	0.18
	Standard Deviation	12 232	0.65	1.30		1.08	0.27
	Number	49	49	28		49	49
Alberta Newsprint Company	1991 Mean	15 210	0.55	2.55	1.70		0.40
	Standard Deviation	3 513	0.86	1.91	3.77		1.43
	Number	56	55	55	55		54
	1992 Mean	17 577	1.57	4.32	0.43		
	Standard Deviation	2 258	2.54	4.01	0.41		
	Number	48	46	46	45		
Millar Western Pulp Ltd.	1991 Mean	12 699	0.31	8.46	0.12		
	Standard Deviation	1 468	0.21	2.98	0.04		
	Number	52	51	47	52		
	1992 Mean	11 626	0.12	7.97		0.15	
	Standard Deviation	2 588	0.19	4.08		0.17	
	Number	54	51	51		37	
Slave Lake Pulp Corporation	1991 Mean	3 903	2.65			0.005	0.005
	Standard Deviation	980	7.96			0.00	0.00
	Number	280	280			7	7
	1992 Mean	4 770	0.76			0.005	0.01
	Standard Deviation	1 432	3.41			0.0	0.04
	Number	346	346			37	37
Weyerhaeuser Canada Ltd.	1991 Mean	59 547	1.86	7.34		6.11	0.12
	Standard Deviation	10 135	1.21	2.97		3.45	0.06
	Number	106	64	37		63	34
	1992 Mean	64 502	1.74	5.45		0.48	0.07
	Standard Deviation	10 196	1.48	1.92		1.56	0.04
	Number	212	163	62		57	62
Daishowa Canada Co. Ltd. Peace River Pulp Division	1991 Mean	62 402	0.18	4.63		0.09	0.06
	Standard Deviation	10 861	0.41	3.23		0.16	0.03
	Number	103	102	88		55	63
	1992 Mean	64 857	0.45	6.22		0.08	0.07
	Standard Deviation	6 941	0.53	0.53		0.05	0.03
	Number	61	56	56		44	39

a. Data only to end of November 1992

The mean loadings of total nitrogen for mills on the Athabasca River and Peace River vary annually (Table 2.2.5). The highest measured nitrogen loading to the rivers comes from the Weldwood effluent (Table 2.2.5). (The Weldwood effluent also contains municipal sewage.)

TABLE 2.2.5
1991 and 1992 Annual Mean Loads of Total Nitrogen in Pulp Mill Effluents

Pulp Mill			Discharge (m^3/d)	Total Nitrogen Concentration (mg/L)	Total Nitrogen Load (kg/d)
Weldwood of Canada Ltd.	1991	Mean	100 384	5.15	566
		Standard Deviation	9 861	1.59	187
		Number	40	40	40
	1992[a]	Mean	112 589	5.61	628
		Standard Deviation	11 221	1.28	139
		Number	28	28	28
Alberta Newsprint Company	1991	Mean	15 203	4.16	64
		Standard Deviation	3 545	4.30	71
		Number	55	55	55
	1992	Mean	17 462	5.05	88
		Standard Deviation	2 261	2.43	41
		Number	46	46	46
Millar Western Pulp Ltd.	1991	Mean	12 701	8.45	107
		Standard Deviation	1 496	3.33	44
		Number	50	50	50
	1992	Mean	11 636	8.06	90
		Standard Deviation	2 526	4.10	45
		Number	51	51	91
Weyerhaeuser Canada Ltd.	1991	Mean	57 612	10.05	562
		Standard Deviation	12 291	4.19	232
		Number	37	37	37
	1992	Mean	63 908	5.58	351
		Standard Deviation	10 722	1.82	123
		Number	61	61	61
Daishowa Canada Co. Ltd. Peace River Pulp Division	1991	Mean	61 482	4.46	268
		Standard Deviation	11 326	3.34	191
		Number	81	81	81
	1992[b]	Mean	65 830	6.71	439
		Standard Deviation	6 102	1.49	96
		Number	24	24	24

a. Data only to the end of November 1992
b. Data for the months of January, February, April, August and October only.

2.3 OTHER INDUSTRIAL EFFLUENTS

The other major industries in the northern river basins are related to the regional resources of coal, tar sands, oil, gas, and gravel.

Coal mining is located in the western region of the Athabasca River basin. Stanley (1987) listed four active coal mines. Two of these, Cardinal River (Luscar) and Gregg River (Manalta) are located in the McLeod River Basin. Coal Valley (Luscar-Sterco) is in the Pembina River basin. Obed Mountain (Obed) is located near the Athabasca River downstream of Hinton. Coal mines do not discharge to surface waters; however, they receive a letter of permission to discharge some of the supernatant from the tailings ponds from time to time (Ian Mackenzie pers. comm.). The supernatant does not contain appreciable amounts of nutrients, but surface run-off from mine sites may contain high concentrations of oitrates from explosives (Ian Mackenzie pers. comm.).

There are many gas plants in the basins. Alberta Environment's Industrial Listing includes 53 gas plants in the Athabasca River basin and 21 in the Peace River basin. None of the gas plants discharge process wastewater. A third to a half of the gas plants may have ponds to contain surface runoff; the remainder may allow surface runoff (Ian Mackenzie pers. comm.). The runoff would be innocuous except for elevated sulphates at plants with sulphur blocks. The gas plants would not be a significant source of nutrients (Ian Mackenzie pers. comm.). A few plants may have sanitary sewage lagoons which discharge in the spring and/or fall. Overall the impact of gas plants to nutrient loading would be negligible.

Water from flowing, abandoned oil wells may also affect surface water quality in the Peace River Basin. One such well, Peace River Oils #1 (Fig. 2.1.2), was sampled during the 1988-1989 synoptic surveys. The Peace River Oils #1 flowing well discharges about 0.04 m^3/s to the Peace River (Alberta Environment 1989).

The Suncor Inc. Athabasca Oil Sands Project has a continuous discharge to the Athabasca River with a discharge to 50,000 m^3/d. Suncor has been monitoring effluent quality as a licence requirement; the only nutrient that is routinely monitored is ammonia nitrogen (Table 2.3.1). There is a long period of record for ammonia nitrogen data beginning in 1973. Suncor does a more complete scan of the constituents in the effluent once annually (Bob Martel pers. comm.).

Total phosphorus is included. Alberta Environment collects split samples of Suncor effluent. Nutrients are measured in these samples (Table 2.3.2). Noton and Shaw (1989) calculated mass loading values for total phosphorus based on the results of synoptic surveys in the winters of 1988 and 1989 and mass loadings of total nitrogen for two synoptic surveys in the winter of 1989. Table 2.3.3 adds the results of more recent synoptic surveys to the Noton and Shaw values.

Syncrude holds its process effluent in a large tailings pond, but does discharge mine depressurization and runoff water to the Athabasca River via Poplar Creek. Syncrude Canada Ltd. has small treated sanitary sewage discharge only. Other tar sand operations listed by Alberta Environment such as Shell Canada Ltd. at Peace River and Amoco Canada Petroleum Company Ltd. at Britnell have no discharge.

The largest thermal electric power station in the northern river basins is the 140 megawatt coal-fired station near Grand Cache. The H.B. Milner station was developed to burn coal from the Smoky River Coal (MacIntyre Mines). The Alberta Power Ltd. station discharges process wastewater to the Smoky River. It has a continuous discharge licensed at 1,500 m^3/d (Northern Rivers Intergovernmental Task Force 1990) which has been monitored since 1977. Total phosphorus and total nitrogen monitoring were first included as part of the 1988-1992 licence requirement. A major component of the wastewater is cooling tower blowdown. Compounds added to water in the cooling tower may contain nutrients; therefore, phosphorus is measured weekly and nitrogen is measured monthly. In 1992, the mean and maximum concentrations of total phosphorus were 0.12 and 0.72 mg/L (Kem Singh pers. comm.). The mean and maximum loadings of total phosphorus were 0.09 and 0.4 kg/d (Kem Singh pers. comm.). Mean and maximum concentrations of total Kjeldahl nitrogen were 0.71 and 2.57 mg/L (Kem Singh pers. comm.)[4]. In comparison to nutrient loads from the pulp mills and larger municipalities, the nutrients discharged to the river are very small and the contribution of the H.B. Milner station to the total instream nutrient load is negligible. Other diesel-powered stations are small and require insignificant amounts of water.

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[4] The mean and maximum loadings of total Kjeldahl nitrogen were 0.39 and 1.31 kg/d.

TABLE 2.3.1
Mean Monthly Ammonia Nitrogen Loading to the Athabasca River From the Suncor Inc. Athabasca Oil Sands Project

Date		Mean Monthly Flow (m^3/d)	No. of Samples	Mean Monthly Ammonia Nitrogen (kg/d)	Standard Deviation
1988	January		1	6.50	
	February		3	4.10	5.12
	March		4	2.00	0.89
	April		2	1.45	1.77
	May		1	0.90	
1989	January	26 034	2	2.34	0.62
	February	26 715	2	21.60	24.47
	March	21 008	4	0.83	0.41
	April	26 446	1	0.24	
	May	26 558	3	6.90	5.41
	June	40 734	2	3.83	0.49
	July	39 921	2	2.05	1.77
	September	43 518	1	1.31	
	December	25 203	2	1.00	0.42
1990	January	26 324	2	0.80	0.52
	February	23 155	2	10.60	9.48
	March	24 001	2	2.90	0.57
	April	28 491	2	0.96	0.0
	May	23 295	5	1.56	1.23
	June	15 775	3	2.87	1.80
	July	31 400	4	17.98	16.36
	October	48 435	2	2.29	1.93
	November	40 485	2	0.68	0.31
	December	28 919	2	1.38	0.26
1991	January	30 241	2	0.65	0.31
	February	24 907	3	2.24	1.47
	March	30 775	3	16.30	24.87
	April	39 192	1	9.75	
	May	46 456	4	3.15	3.71
	June	49 424	1	17.30	
	September	57 689	1	3.60	
	November	34 950	2	1.06	0.03
	December	23 449	4	1.65	1.61
1992	January	40 033	3	5.55	8.02
	March	31 688	4	2.56	2.30
	April	35 156	1	10.90	
	September	36 611	5	4.40	3.04
	October	30 852	5	16.30	6.59
	November	30 296	4	14.48	7.07
	December	32 009	3	3.77	2.22

Data provided by Alberta Environment

TABLE 2.3.2
Nutrients from Suncor's Annual Effluent Monitoring

Date (D/M/Y)	Sample Type	Total Kjeldahl Nitrogen	Dissolved Nitrite-Nitrate Nitrogen	Dissolved Nitrite Nitrogen	Ammonia Nitrogen	Dissolved Nitrogen	Total Dissolved Phosphorus	Total Phosphorus
06/03/91	Grab	1.48	0.170	0.024	0.180	1.650	0.106	0.168
25/02/92	Grab	0.50	0.172	0.020	0.020	0.672	0.140	0.200
11/03/93	Grab	1.03	0.977	0.043	0.290[a]	2.007	0.133	0.178
27/11/91	Composite	0.85	1.090	0.257	0.175[a]	2.000	N/A	N/A
28/04/92	Composite	0.91	0.686	0.072	0.025[a]	1.866	N/A	N/A
01/10/92	Composite	1.18	N/A	N/A	0.500[a]	N/A	N/A	0.171

a. These results are dissolved ammonia nitrogen whereas the other 1991 and 1992 results were total ammonia nitrogen.
N/A = not available.

TABLE 2.3.3
Mass Loading of Total Phosphorus and Total Nitrogen From the Suncor Inc. Effluent Measured During Synoptic Surveys[a]

Date (D/M/Y)	Discharge (m^3/s)	Total Nitrogen (mg/L)	Total Nitrogen Loading (kg/d)	Total Phosphorus (mg/L)	Total Phosphorus Loading (kg/d)
15/03/88	0.3	0.932	24.2	0.254	6.6
09/02/89	0.289	0.91	22.7	0.174	4.3
08/03/89		1.01[b]	21.0	0.235	4.9
14/03/90	0.303	0.97	25.4		
06/03/91	0.372	1.65	53.0	0.168	5.4
25/02/92	0.280	0.672	16.3	0.2	4.8

a. Data from Alberta Environment
b. Calculated by Noton and Shaw, 1989

Gravel washing is a minor water use in the basins, but it has no effect on nutrient conditions in the rivers. The Alberta Environment Industrial Listing includes 12 gravel washing enterprises in the Athabasca River basin and one in the Peace River basin. All except one, which is currently not operating, have no discharge.

2.4 MUNICIPAL SEWAGE TREATMENT PLANT EFFLUENTS

Table 2.4.1 lists municipalities that continuously discharge treated sewage to the Peace and Athabasca rivers or their tributaries. The largest volume of municipal effluent entering the Peace River system is discharged by Grande Prairie; the largest volume entering the Athabasca River is discharged by Fort McMurray. Hinton's sewage is combined with Weldwood pulp mill wastes for treatment and discharged as one effluent. Non-continuous municipal discharges are given in Appendix D.

TABLE 2.4.1
Continuously Discharging Municipal Effluents

Source	Type/Treatment System	Receiving Water	Approximate Discharge[a] (m^3/d)	Design Capacity (m^3/d)
PEACE RIVER BASIN				
Grande Cache	Mechanical/Extended Aerobic	Smoky River	1 946	3 636
Grande Prairie	Mechanical/Rotary Biological Contactor	Wapiti River	6 965	18 182
Manning	Mechanical/Aerobic Lagoon	Notikewin River	561	1 136
Peace River	Anaerobic Lagoon	Peace River	3 291	2 570
Peace River Correctional Institute	Oxidation Ditch	Peace River	225[b]	–
ATHABASCA RIVER BASIN				
Jasper	Aerated Lagoon	Athabasca River	5 700	–
Athabasca	Aerated Lagoon	Athabasca River	940	2 045
Fort McMurray	Aerated Lagoon	Athabasca River	11 695	12 721
Whitecourt	Mechanical	Athabasca River	2 550	4 400
Slave Lake	Aerated Lagoon	Lesser Slave Lake	2 358	1 955

a. Discharge data from Northern Rivers Intergovernmental Task Force, 1990.
b. Sampled during 1988-1989 synoptic surveys.

Notes: (1) Hinton municipal effluent is combined with the Weldwood pulp mill effluent and cannot be identified separately.
(2) Grande Prairie sewage treatment plant effluent is discharged for two weeks followed by no discharge for the next two weeks.

During the winter synoptic surveys, Alberta Environment has taken grab samples of the final effluents of the largest sewage treatment plants and analyzed these samples for nutrients (Table 2.4.2). The nutrient loading from the sewage treatment plants is largely bioavailable. The concentration of total phosphorus that is present in the dissolved form (Table 2.4.2) is in the order of 80-90%.

TABLE 2.4.2
Concentrations of Phosphorus and Nitrogen in Municipal Effluents Measured during Synoptic Surveys[a]

Municipality	Date (D/M/Y)	Discharge (m^3/d)	Total Kjeldahl Nitrogen (mg/L)	Total Ammonia Nitrogen (mg/L)	Dissolved Nitrate/ Nitrite Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Phosphorus (mg/L)
Whitecourt	20/02/90	3 370	6.0	5	3.1		
	12/02/90	3 370	1.66	0.25	13.4	2.82	2.82
	05/02/90	3 456	8.75	7.01	5.097	2.95	2.95
Slave Lake	11/02/92	2 592	29.5	21.5	0.01	3.525	3.075
Athabasca	06/03/92	950	29.75	28.0	0.18	6.25	5.32
	22/02/91	864	33.0	26.5	0.06	5.8	4.8
	14/02/92	864	31.25	24.0	0.669	5.1	
Fort McMurray	14/03/90	15 552		27.0			
	14/03/90	15 552	26.0	20.0	0.09	2.6	
	06/03/91	10 973	27.2	22.0	0.1	2.64	2.4
	25/02/92	12 096	30.25	21.0	0.221	2.5	2.275
Grande Prairie[b]	27/02/90	19 872	10.4	6.0	5.75	4.65	
	27/02/90	19 872	10.0	6.2	5.8	4.5	
	27/02/91	19 440	9.6	8.64	6.31	4.65	4.6
	27/02/91	19 440		8.8			
	27/02/91	19 440		8.8			
	27/02/91	19 440	9.6	8.64	6.31	4.65	4.6
	11/03/92		15.75		4.833	4.575	4.4
Peace River	11/03/91	3 370	24.75	15.0	0.01	4.7	3.825

a. Data from Alberta Environment
b. Synoptic surveys are timed to coincide with weeks when Grande Prairie sewage is discharged. Since sewage is only discharged half of the time, the average discharge would be about half of this value.

The mass loadings of total phosphorus and total nitrogen for 1990, 1991 and 1992 have been calculated from these data (Table 2.4.3). Noton and Shaw (1989) also calculated the mass loading of total phosphorus and total nitrogen from earlier synoptic surveys; Table 2.4.2 adds the more recent data to the record of the loading information available from the synoptic surveys.

TABLE 2.4.3
Mass Loads of Nitrogen and Phosphorus
from Municipal Effluents as Measured in Synoptic Surveys[a]

Municipality	Date (D/M/Y)	Discharge (m^3/d)	Total Nitrogen Loading (kg/d)	Dissolved Nitrogen Loading (kg/d)	Total Phosphorus Loading (kg/d)	Dissolved Phosphorus Loading (kg/d)
Whitecourt	20/02/90	3 370	30.67	27.30		
	12/02/90	3 370	50.75	46.00	9.50	9.50
	05/02/90	3 456	47.86	41.84	10.20	10.20
Slave Lake	11/02/92	2 592	76.49	55.75	9.14	7.97
Athabasca	06/03/92	950	28.45	26.78	5.94	
	22/02/91	864	28.56	22.95	5.01	4.60
	14/02/92	864	27.58	21.31	4.41	4.15
Fort McMurray	14/03/90	15 552		419.90		
	14/03/90	15 552	405.75	312.44	40.44	
	06/03/91	10 973	299.56	242.50	28.97	26.33
	25/02/92	12 096	368.58	256.69	30.24	27.52
Grande Prairie[b]	27/02/90	19 872	320.93	233.50	92.40	
	27/02/90	19 872	313.98	238.46	89.42	
	27/02/91	19 440	309.29	290.63	90.40	89.42
	27/02/91	19 440		171.07		
	11/03/92					
Peace River	11/03/91	3 370	83.43	50.58	15.84	12.89

a. Data from Alberta Environment
b. Grande Prairie loading measured in synoptic surveys does not represent average loading because sewage is only discharged half of the time (i.e. two weeks of discharge followed by two weeks of no discharge). Synoptic survey data collected during a two-week discharge period.

Effluent data collected by the municipalities as part of their license requirements do not include nutrients. The compilation of the municipal data into a comprehensive database is the objective of another NRBS contract which is under way; however, completion of this database will not add to the amount of nutrient information available. The synoptic survey data are limited to winter sampling. Split sampling is done by Alberta Environment in conjunction with the municipal sampling (Table 2.4.4). Composite samples collected by municipalities with continuous discharges are split and half of the sampled is picked up by Alberta Environment staff and analyzed. Although the number of samples is small (Table 2.4.4), the results of this sampling and the synoptic survey data are the only data currently available.

TABLE 2.4.4
Concentrations of Nutrients in Municipal Effluents Measured by Alberta Environment from Split Samples

Station	Date (D/M/Y)	Total Annual Flow (m^3)	Nitrate Nitrite (mg/L)	Nitrite (mg/L)	Particulate Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)
Athabasca	18/01/90	318 688	0.75	0.115	0.9	30	27.201	6.6
	18/07/90		12.9	0.67	0.49	3.7	1.95	5.625
	17/01/91		0.41	0.04	0.74	37	29.501	6.05
	18/07/91		7.149	0.267	0.84	13.25	11.801	4.825
	28/05/92		9.04	0.589		20.8	15.6	4.23
Fort McMurray	14/02/90	5 372 500	0.23	0.021	0.78	28	25.201	1.7
	11/06/90		1.27	0.81	0.25	20.5	20.201	1.75
	11/09/91		2.768	0.745		17.25	15.001	1.15
Grande Prairie	12/02/90	3 470 193	9.95	0.515	0.62	12	8	4.625
	19/03/90		4.2	0.35	0.67	13.2	11.401	3.95
	23/04/90		3.9	0.42	1.15	18.4	17.201	4.4
	28/05/90		8.4	0.76	0.97	18.25	15.001	3.7
	18/06/90		10.6	0.785	0.86	8.75	5.9	1.805
	17/07/90		13	1.025	0.6	4.75	1.9	2.975
	13/06/90		13.75	0.63	0.65	5.85	2.9	4.3
	10-09/90		13	1.247	0.78	4.9	3.35	4.8
	22/10/90		4.6	0.905	0.6	15	14.401	5.3
	19/11/90		10.6	0.985	0.74	14.75	9.6	4.15
	04/12/90		10.22	1.08	1.19	13	11.751	5.1
	14/01/91		8.26	0.715	0.36	15.8	13.601	5.2
	12/02/91		11.5	0.975	1.16	12.5	10.601	3.7
	09/04/91		12.634	1.131	0.87	9.65	6.55	3.3
Jasper	22/05/90	2 200 000	0.56	0.162	0.34	17.5	14.801	4.3
	24/10/90		1.27	0.228	0.64	20.5	18.001	4.2
	13/08/91		0.172	0.106	0.52	28	24.501	4.95
Peace River Correctional	14/02/89	45 759	19.401	0.001	0.22	0.88	0.011	2.32
	15/08/89		16.201	0.001	0.27	1.07	0.038	2.06
	20/11/89		9.5	-0.001		0.87	0.013	0.57
	16/01/90		11.101	0.001	0.53	1.25	0.032	1.05
	14/08/90		16.32	0.001	0.17	1.07	0.036	1.56
Slave Lake	13/02/89	986 398	0.04	0.014	0.92	33	25.201	5.15
	20/06/89		0.6	0.137		19	17.701	3.43
	15/05/91		3.058	2.719	2.51	22	18.001	2.65
	22/07/92		0.07	0.035		21	20.8	1.6
Whitecourt	12/02/90	1 296 364	9	0.185	0.36	4.6	3	3.7
	13/06/90		3.85	0.375	0.09	9.75	8.7	1.825
	12/06/91		4.436	0.291	0.35	8.8	3.85	1.775
	20/11/91		7.467	0.741		5.8	5.15	1.75
Peace River Lagoons	17/05/83	1 000 000	-0.05	-0.05	2.9	25.8	22.8	7
	12/06/84		-0.05	-0.05	30	30	24.4	7.3
	24/07/85		-0.05	-0.05	36	36	28.3	8.13
	10/06/86		-0.05	-0.05	28.5	28.5	25.2	7.15

Municipal sewage treatment plants generally have higher concentrations of nutrients in their effluents than pulp mills The concentration of total phosphorus in municipal effluents is usually higher than the concentration in pulp mill effluents except ANC and Slave Lake in 1991. The concentration of ammonia in many municipal effluents (Athabasca, Fort McMurray, Slave Lake, Peace River) is an order of magnitude higher than the concentration in pulp mill effluents.

Grande Prairie and Fort McMurray sewage effluent loads (Table 2.4.3) are within the range of nutrient loads from pulp mills (Table 2.2.2). Loadings from other municipal effluents are considerably less than those from pulp mills because the volume discharged is less. The data from the synoptic surveys and the split sampling, although limited, indicate the importance of treated municipal sewage as a point source of nutrients.

Pulp mills have emerged as the focus of public interest; however, when nutrient loads are considered, sewage treatment plant effluents from the larger municipalities are of equal importance. The ongoing municipal database development by the NRBS will be particularly useful in accurately assessing municipal loading.

2.5 NON-POINT SOURCE LOADING

2.5.1 Importance

The preceding sections describe the nutrient loading from anthropogenic point sources in the Athabasca and Peace Rivers and their tributaries. Because point sources are regulated and monitored, a substantial amount of data are available to include in this report. Less information is available for non-point source loading, although instream monitoring data for tributaries to the mainstem are pertinent (and will be addressed further in Chapter 3).

A literature review of non-point source impacts on aquatic life for the U.S. Environmental Protection Agency (Cunningham 1988) concluded that non-point source pollution is a significant problem that is responsible for 65% of the impairment of rivers and streams reported by U.S. states. Among the 37 states providing data on river miles not fully meeting the requirements of designated uses, non-point sources were the principal source, affecting 65% of assessed river miles where designated uses were impaired. Agricultural activities were reported by more than half the states as a major cause of waterbody impairment; forestry was reported less frequently. The category "nutrient" was one of the four most widely reported categories of concern (Cunningham 1988). This section will explore the potential importance of non-point loading to rivers in the NRBS study area to see if non-point nutrient loads are as significant in northern Alberta as they are in the U.S.

2.5.2 Methods of Estimating Non-Point Source Loads

Phosphorus loads can be measured in typical third and fourth order streams for each type of sub-basin and then extrapolated to include the entire NRBS area. Munn and Prepas (1986) have provided initial data for the Athabasca River. Non-point source loads have been measured in other basins in Alberta (Mitchell 1985, Trew et al. 1987) and elsewhere. In the absence of actual *in situ* measurements for the basins, phosphorus exports, as a function of basin characteristics, can be estimated either by models or by unit area exports (i.e. export coefficients). Since the purpose of this section is simply to estimate the relative importance of the data gap and the need for further study, export coefficients identified during the literature search will be used. Phosphorus export coefficients vary because nutrient export is influenced not only by land use but also by hydrology, geology and landform.

2.5.3 Phosphorus Export Coefficients

When phosphorus export coefficients from other locations are used for the NRBS rivers, the factors that influence nutrient export should be considered. The spatial variance in phosphorus export coefficients may be largely accounted for by differences in the geological characteristics of the basin (when point sources are not important). Land use is often identified as the cause of non-point source pollution when landform is often the controlling factor. As geology has such a large effect on both sediment and phosphorus export, it should be possible to map areas of equal phosphate export potential. Surficial geology, manifested through its effect on the chemical and physical soil properties, was found to be the most important landform determining phosphorus export (Grobler and Siberbauer 1985). The soil type will influence the magnitude of the phosphorus export released from the watershed. Phosphorus export via runoff is generally low on sandy/gravel soils. Clay soils (clay loams, silt loams, etc.) have a high phosphorus adsorption capacity, high erodibility and low infiltration capacity; therefore, total phosphorus export via runoff is high (Reckhow et al. 1980).

Nutrient export from drainage basins depends very strongly on the hydrological regime. Studies of nutrient export and loading such as the studies reported here, usually span a period of one or two years. These studies usually present a single export value for a nutrient as being representative of that system. Minns and Johnson (1979) illustrated the importance of obtaining a range of nutrient export values over a number of years as a consequence of hydrological changes. Their results for one river exhibit as much variation over ten years as was found between major land types (forest-pasture/igneous rock) by Dillon and Kirchner (1975).

Phosphorus export also varies seasonally with spring runoff being particularly important in both agricultural land and forest. In 1983, phosphorus export was quantified for two streams, Two Creek and the Sakwatamau River, draining water from a forested area into the Athabasca River (Munn and Prepas 1986). The influence of changes in discharge on phosphorus concentration and partitioning was examined on an annual and seasonal basis and these data were used to develop empirical models to predict phosphorus concentrations. Phosphorus export peaked during summer storms; 68% of annual total phosphorus loading was transported during twelve days in early summer. Phosphorus increases were larger during storms in early summer than during storms in late summer. In another Alberta study, nutrients were mainly transported to Lake Wabamun, Alberta (Mitchell 1985) by snow melt and heavy summer rains. Snow melt contributed nearly half of the yearly supply of phosphorus. The Wabamun Lake study also showed that the nutrient supply can vary from year to year.

The percentage of phosphorus that is available is much lower for forested land than agricultural land. The average export of available phosphorus from forested land is 38% of total phosphorus in the Baptiste Lake, Alberta, watershed (0.05 kg/ha/yr orthophosphate). The average export coefficient from agricultural land in the Baptiste Lake watershed is 0.30 kg/ha/yr of orthophosphate (as P), which is 59% of the total phosphorus (Trew et al. 1987). In comparison, the proportion of available phosphorus exported from the Lac la Nonne watershed in Alberta ranged upwards from 50% of total phosphorus (Mitchell and Hamilton 1982). The Lac la Nonne watershed was used mainly for grazing and forage production; the higher availability was probably due to the proportion of phosphorus contributed by cattle waste.

It is unlikely that phosphorus losses are equal from all parts of the watershed (Jones et al. 1976). Phosphorus concentration tends to decrease during movement from the initial source to the outlet. Munn and Prepas (1986) found that most of the phosphorus reaching the Athabasca River from a forested area is in the fine particulates rather than the coarse particulates; the fine particulates would be less likely to settle out. Soils and sediments scavenge phosphorus along the way. Thus, the fine particulates will transport bio-available phosphorus. Annual total phosphorus exports were 7.5 and 13.0 mgTP/m^2 and 3.21 and 1.87 TDP/m^2 (watershed area) for the two small tributaries to the Athabasca River (Munn and Prepas (1986).

2.5.4 Potential Phosphorus Export

The Athabasca River and the Smoky River flow through the boreal forest region of Alberta for the most part, although some of the drainage area of the Athabasca River is located in the foothills region and some of the drainage area of the Smoky River is located in the Peace River parkland region. Although forestry is the major land use, agriculture is important in the McLeod, Pembina, Lesser Slave and La Biche sub-basins.

The study by Munn and Prepas (1986) provides valuable phosphorus export data for streams running through glacial till underlying mixedwood forests that are dominated by spruce, pine and poplar. The annual export coefficients for forested land from this study, 7.5 and 13 mg/m^2 of total phosphorus, agree closely with annual coefficients of 10 and 7 mg/m^2 for the forested region of Lake Wabamun, Alberta (Mitchell 1985). The annual coefficients for export from mixed agricultural areas into Lake Wabamun were 13-19 mg/m^2 total phosphorus. The average export of total phosphorus from agricultural land in the Baptiste Lake watershed was 27 mg/m^2 (Trew et al. 1987).

Several export coefficients for total phosphorus have been derived for large regions. Rast et al. (1983) developed an annual export coefficient for total phosphorus of 5-10 mg/m^2 (0.05-0.1 kg/ha as generally applicable to many U.S. waterbodies. The mean export coefficient for total phosphorus in the western U.S. of 12.4 mg/m^2 (0.124 kg/ha) (Omernik 1976, 1977).

An average phosphorus export coefficient of 10 mg/m^2 (10 kg/km^2) was chosen as a reasonable estimate of non-point source export from forested regions. A coefficient of 20 mg/m^2 (20 kg/km^2) was chosen as a reasonable estimate of non-point source export from mixed agricultural regions although it could easily be an underestimate. Livestock management practices, types of crops and fertilizer use can alter the quantity of phosphorus exported from agricultural land. The proportion of agriculture to forestry in a mixed use basin was assumed to be 1:1 for the purposes of this estimate. Although the ratios vary from basin to basin, a 1:1 ratio appeared to be reasonable overall. The total effective drainage of the Athabasca River is 156 597 km^2 (Table 2.5.1). Therefore, the potential export of total phosphorus to the Athabasca River was estimated to be nearly two million kilograms per year (Table 2.5.1). Export of total phosphorus to the Smoky River basin (up to Watino) was estimated at 643 000 kg/yr (Table 2.5.2).

Based on the 1991 loading data for ANC, Millar Western and Slave Lake pulp mills (Appendix Tables A.2 to A.4) and data provided by Weldwood, the total annual phosphorus load discharged into the Athabasca River basin from all pulp mills operating in the basin is approximately 94 000 kg/yr. Improvements at ANC and Weldwood have reduced their loadings to the river since 1991. Fort McMurray has an annual loading of total phosphorus of about 10 000 kg/yr from the sewage treatment plant. Other industrial and municipal loading is relatively minor.

TABLE 2.5.1
Potential Export of Total Phosphorus from Drainage Areas in the Athabasca River Basin

River	Location[a]	Gross Drainage Area (km^2)	Effective Drainage Area[b] (km^2)	Land Use	Estimated Annual Export of Total Phosphorus (kg/yr)
Athabasca	At Hinton	9 784	9 784	Forest	98 000
Berland	Near Mouth	5 655	5 655	Forest	57 000
McLeod	Near Whitecourt	9 100	8 991	Agriculture/Forest	135 000
Sakwatamau	Near Whitecourt	1 139	1 140	Forest	11 000
Pembina	Near Jarvie	13 101	12 613	Agriculture/Forest	189 000
Lesser Slave	At Saulteaux Landing	15 120	14 773	Agriculture/Forest	222 000
La Biche	At Highway 63	4 863	4 741	Agriculture/Forest	71 000
Wandering	Near Wandering River	1 113	1 113	Forest	11 000
House	At Highway 63	764	764	Forest	8 000
Horse	At Abasands Park	2 133	2 133	Forest	21 000
Clearwater	Below Waterways	31 907	31 863	Forest	319 000
Muskeg	Near Mouth	1 458	1 458	Forest	15 000
MacKay	Near Mouth	5 571	5 571	Forest	56 000
Ells	Near Mouth	2 452	2 452	Forest	25 000
Firebag	Near Mouth	5 988	5 988	Forest	60 000
Richardson	Near Mouth	2 696	2 696	Forest	27 000
Other Drainage[c]		45 784	44 861	Agriculture/Forest	673 000
Athabasca[d]	Above Jackfish Creek	158 629	156 597		1 998 000

a. Location of water Survey of Canada gauging stations
b. Data from Agriculture Canada (1991)
c. Other drainage includes small streams and direct runoff to the Athabasca River not included in the drainage areas of the main tributaries.
d. Total drainage area for the Athabasca River including tributaries listed above.

TABLE 2.5.2
Potential Export of Total Phosphorus from Drainage Areas in the Smoky River Basin

River	Location	Gross Drainage Area[a] (km^2)	Effective Drainage Area[b] (km^2)	Land Use	Estimated Annual Export of Total Phosphorus (kg/yr)
Smoky	Above Hells Creek	3 844	3 844	Forest	38 000
Muskeg	Near Mouth	706	706	Forest	7 000
Kakwa		3 303	3 303	Forest	33 000
Cutbank		844	844	Forest	8 000
Wapiti	At Highway 40	11 254	11 120	Agriculture/Forest	167 000
Simonette	Near Goodwin	5 047	5 047	Forest	50 000
Little Smoky	Near Guy	11 095	11 095	Agriculture/Forest	166 000
Other Drainage[c]		14 170	13 631	Agriculture/Forest	204 000
Smoky[d]	At Watino	50 263	49 590		643 000

a. Water Survey of Canada gauging stations
b. Data from Agriculture Canada
c. Other drainage includes small streams and direct runoff to the Smoky River not included in the drainage areas of the main tributaries.
d. Total drainage area for the Smoky River including tributaries listed above.

Point source loadings from pulp mills, other industries and municipalities in the Athabasca River basin are in the order of 104 000 kg/yr total phosphorus compared to a potential non-point source loading of 2 000 000 kg/yr total phosphorus. Anthropogenic point source loadings of total phosphorus to the Athabasca River are about 5% of all potential loadings (point + non-point). Based on the 1991 loading data, the total phosphorus loading to the Smoky River from large point sources is 40 000 kg/yr. Grande Prairie sewage contributes about 16 000 kg/yr and the Weyerhaeuser pulp mill contributes about 24 000 kg/yr. The phosphorus export from the watershed excluding point sources is potentially 643 000 kg/yr. Thus, point source loading is about 6% of all potential loadings (point + non-point). The Peace River has not been estimated from watershed areas since the large reservoir in British Columbia acts as a major nutrient sink.

None of these percentages should be quoted as fact because, by necessity, they are based on broad assumptions that may not be appropriate for specific basins. More significantly, not all the phosphorus exported to third and fourth order streams in the watershed will reach the mainstem of the river. Phosphorus exported from the watershed will, in general, be less bioavailable than the phosphorus from point-source discharges. These estimates are provided to indicate the significance of the gap in our understanding of nutrient loading to the river in the NRBS area. Previous work has been focusing on a small percentage of the nutrient load to the rivers. Our knowledge of the phosphorus export from land use and other factors that affect non-point source loading has not kept pace with our knowledge of point-source loading. More information on instream loads which reflect non-point sources loading to the mainstem from tributaries is presented in Section 3.

2.6 DATA QUALITY AND QUANTITY

2.6.1 Data Quantity

- The most significant data gap is the lack of non-point source data.

- Sufficient data on the bioavailability of municipal, pulp mill and non-point source loads are not available to determine environmental effects.

- Municipalities are not required to measure the concentration of nutrients in their sewage treatment plant effluents. Based on winter synoptic survey data, large municipalities such as Grande Prairie and Fort McMurray discharge about as much phosphorus and nitrogen as pulp mills.

- The pulp mill effluent database prepared by N. McCubbin Inc. for NRBS currently ends in January 1992. Although the database brings together data from all the mills, it contains only one year of data.

- The Slave Lake mill does not analyze the effluent for total Kjeldahl nitrogen. Therefore, all the forms of nitrogen needed to determine a total nitrogen loading to the river are not available. (Generally, pulp mills have supplied a large quantity of data related to nutrient loading.)

- Suncor does not routinely measure any nutrient except ammonia nitrogen in its effluent.

2.6.2 Data Quality

Many examples of inadequate quality control have been encountered in the databases reviewed. The errors detected apply most often to secondary databases and not to primary (long-term) databases such as the Environment Canada water quality database. Although SENTAR appreciated the convenience of using these secondary databases, the addition of a further quality control step would be helpful. These errors include:

- Errors in Data. Examples encountered include: dissolved phosphorus concentrations that exceed total phosphorus concentrations and "less than" values that are much higher than detection limits.

- Errors in Column Headings. Two columns, one with units in kg/d and the other with units of mg/L consistently contain the same numbers (e.g. Kjeldahl N data for Daishowa in McCubbin database).

- Confusion in Column Headings. For example: it is not always clear whether concentrations are NO_3 as N, or NO_3 as NO_3, a significant point in mass loading calculations.

- Questionable Data. Data are encountered which appear to be errors rather than outliers. This error may be an analytical error, or a data entry error.

- Lack of Method Codes. Because method codes have proliferated to an unmanageable level, the tendency has been to combine data into secondary databases removing the method codes. The net result is that differences in data due to differences in methods cannot be discerned.[4] This is a quality assurance issue rather than poor quality control.

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4 One notable exception is Environment Canada; it provided two sets of data, one with method tags and one without (for ease in manipulation). Alberta Environment also supplied detailed water quality data complete with method codes.

SECTION 3.0

INSTREAM LOADINGS AND CONCENTRATIONS OF NUTRIENTS

3.0 INSTREAM LOADINGS AND CONCENTRATIONS OF NUTRIENTS

3.1 INSTREAM MONITORING

Water quality has been monitored routinely at the long-term network stations and the medium-term network stations. Monitoring has been done by both Alberta Environment and Environment Canada. In addition, Alberta Environment has conducted a number of synoptic surveys and site-specific studies on the rivers. Water quality data has been collected by industries as part of environmental impact assessments and operational phase monitoring.

3.1.1 Athabasca River Monitoring

The Athabasca River has been monitored monthly since the 1960's by the Environmental Assessment Division, Alberta Environment at Athabasca townsite and Embarras/Old Fort townsite and by Environment Canada at Athabasca Falls, Jasper National Park. Seven sites on the Athabasca River have been monitored six times per year since 1989: upstream of Hinton, downstream of Hinton, upstream of Whitecourt, at Fort Assiniboine, upstream of Smith, Lesser Slave River at the mouth and upstream of Fort McMurray.

Winter synoptic surveys of water quality were undertaken twice in 1988 (Hinton to Athabasca townsite, February and March 1988), three times in 1989 (Hinton to Lake Athabasca, January 1989; Whitecourt to Athabasca townsite, February 1989; Hinton to Lake Athabasca, February 1989), and once in 1990, 1991, and 1992 (Hinton to Lake Athabasca, February to March). Water quality data were also collected as part of baseline and operational surveys for all new and expanding pulp mill and other industrial developments on the river.

A water quality overview of the Athabasca River basin was prepared for Alberta Environment in 1985 (Hamilton et al. 1985). This was followed by a special study of the winter water quality of the Athabasca River system in 1988 and 1989 by Alberta Environment in response to rapid expansion in the pulp mill industry (Noton and Shaw 1989). Noton (1989, 1990c, Alberta Environment 1993a) continues to address issues related to nutrients in the Athabasca River.

3.1.2 Peace River Monitoring

Monitoring of the Peace River system has been undertaken since the 1960's, but data before 1988 are limited. Five sites are monitored monthly: Slave River at Alberta/NWT border (by Environment Canada, NWT and Alberta since 1970's), Peace River at BC/Alberta Border (by Environment Canada and BC since 1980's), Peace River at Dunvegan (by Environment Canada since 1960's), Peace River at Fort Vermilion (by Alberta Environment since the 1980's), and Smoky River at Watino (Alberta Environment since the 1960's). The most complete water quality data set for the Peace River is from Dunvegan. Since 1989, three medium term sites are monitored six times per year: Wapiti River at Highway No.40, Wapiti River at the mouth and Peace River east of Manning.

A number of water quality investigations have been carried out by Alberta Environment on the Wapiti-Smoky River system since the 1983 survey reported by Noton et al. (1989). Winter synoptic surveys of water quality were undertaken in March 1989, February to March 1990 and February to March 1991 (Noton 1992a) for the Wapiti-Smoky Rivers. The water quality surveys include sampling of effluents and important tributaries, as well as the mainstem rivers. Except for the October 1989 survey, the sampling progressed downstream at approximately river time-of-travel. The Grande Prairie STP generally discharges for two weeks out of four. The water quality surveys were timed to coincide with the effluent discharge during the 1989-91 work (Noton 1992a). In addition, a hydraulic investigation (time-of-travel measurement) was done by Alberta Research Council in February-March 1990. The surveys have been conducted during low flow periods. Water quality data are also collected as part of baseline and operational surveys for all new and expanding developments on the river (e.g. pulp mills).

Alberta Environment carried out an extensive water quality study of the Peace River within Alberta from May 1988 to March 1989. Samples were collected monthly from May through September 1988 and once in December 1988 and February 1989 from ten sites along the mainstem and ten tributary rivers.

An initial overview of the water quality of the Peace River in Alberta was prepared by IEC Beak Consultants Ltd. (1985). The impact of the effluent from the Weyerhaeuser pulp mill on the water quality of the Wapiti and Smoky Rivers has been assessed by Noton et al. (1989) as has the impact of pulp mills on the mainstem of the Peace River (Shaw and Noton 1989). The effect of the abandoned Peace River Oils No. 1 flowing well was also evaluated by Alberta Environment (1989b). Alberta Environment conducted a one year survey in 1988-89 (Shaw et al. 1990) collecting water samples from ten sites on the mainstem, ten sites on the tributaries and six effluents. Shaw et al. (1990) evaluated the water quality data for the mainstem to assess mixing of the Peace and Smoky Rivers, evaluate seasonal, long-term and longitudinal trends in water quality, assess the impact of point and non-point sources on water quality in the mainstem and compare the water quality against objectives and guidelines.

3.2 ATHABASCA RIVER

3.2.1 Seasonal and Annual Trends

Concentrations of phosphorus in the Athabasca River at the Town of Athabasca, a long-term monitoring site, are high and scattered during the summer in response to the high flows and fairly low in the winter (Hamilton et al. 1985). Minimum concentrations occur during the winter throughout the basin. The Alberta surface water quality objective of 0.05 mg/L is regularly exceeded during the summer when 1974 to 1988 data (Fig. 3.2.1) that predates the start-up of the operation of the Millar Western mill is examined (Noton 1990a). The last ten years of data (1982-1992) from the long-term site at Athabasca have been divided into three equal seasons: winter (under ice) (December to March), rising hydrograph (April to July) and falling hydrograph (August to November) (Table 3.2.1) to extend the seasonal information provided by Noton (1990a). The last ten years of data from the Environment Canada long term site at Jasper have also been divided into three seasons (Table 3.2.2). Dissolved phosphorus does not show the pronounced summer rise in levels determined for total phosphorus.

TABLE 3.2.1
Mean Concentrations of Nutrients in the Athabasca River at the Town of Athabasca, 1982-1992

Date		Under Ice				Rising Hydrograph				Falling Hydrograph			
		Nitrogen		Phosphorus		Nitrogen		Phosphorus		Nitrogen		Phosphorus	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
1982	Mean	0.294	0.280	0.009	0.006	0.656	0.308	0.170	0.010	0.301	0.173	0.057	0.004
	Std. Dev.	0.025	0.035	0.001	0.002	0.311	0.107	0.152	0.007	0.112	0.018	0.050	0.001
	N	4	4	4	4	4	4	4	4	4	4	4	4
1983	Mean	0.283	0.278	0.018	0.006	0.460	0.240	0.118	0.007	0.318	0.205	0.037	0.009
	Std. Dev.	0.011	0.011	0.005	0.001	0.186	0.082	0.063	0.001	0.152	0.080	0.035	0.007
	N	4	4	4	4	4	4	4	4	4	4	4	4
1984	Mean	0.332	0.310	0.014	0.010	0.543	0.210	0.080	0.013	0.278	0.170	0.038	0.005
	Std. Dev.	0.063	0.057	0.005	0.003	0.333	0.061	0.031	0.008	0.043	0.064	0.015	0.003
	N	3	3	3	3	4	4	4	4	4	4	4	4
1985	Mean	0.333	0.305	0.012	0.006	0.645	0.215	0.194	0.007	0.343	0.143	0.068	0.007
	Std. Dev.	0.024	0.017	0.003	0.004	0.499	0.114	0.171	0.004	0.191	0.040	0.077	0.004
	N	4	4	4	4	4	4	4	4	4	4	4	4
1986	Mean	0.358	0.313	0.017	0.011	0.445	0.185	0.132	0.009	0.357	0.173	0.053	0.006
	Std. Dev.	0.054	0.051	0.013	0.011	0.094	0.038	0.032	0.004	0.120	0.061	0.021	0.002
	N	4	4	4	4	4	4	4	4	3	3	3	3
1987	Mean	0.386	0.357	0.013	0.006	0.676	0.513	0.077	0.012	0.445	0.283	0.054	0.006
	Std. Dev.	0.134	0.117	0.002	0.000	0.451	0.409	0.057	0.013	0.233	0.109	0.071	0.001
	N	4	4	4	4	3	3	4	4	2	4	4	4
1988	Mean		0.396	0.009	0.005	0.771	0.376	0.183	0.007	0.355	0.255	0.020	0.004
	Std. Dev.		0.105	0.001	0.001	0.466	0.133	0.131	0.005	0.063	0.082	0.009	0.000
	N		4	4	4	4	4	4	4	4	4	4	4
1989	Mean	0.529	0.479	0.027	0.017	1.058	0.373	0.254	0.010	0.407	0.312	0.063	0.010
	Std. Dev.	0.050	0.028	0.016	0.010	0.000	0.145	0.074	0.004	0.025	0.058	0.056	0.005
	N	4	4	4	4	1	3	3	3	3	3	4	4
1990	Mean	0.594	0.552	0.017	0.011	0.717	0.312	0.160	0.011	0.281	0.194	0.035	0.003
	Std. Dev.	0.108	0.115	0.006	0.003	0.324	0.121	0.087	0.005	0.038	0.049	0.025	0.001
	N	4	4	4	4	4	4	4	4	3	3	3	3
1991	Mean	0.563	0.510	0.022	0.016	0.624	0.309	0.267	0.027	0.283	0.203	0.035	0.015
	Std. Dev.	0.058	0.025	0.006	0.007	0.386	0.126	0.243	0.018	0.048	0.048	0.018	0.009
	N	3	3	4	4	4	4	4	4	3	3	3	3
1992	Mean	0.637	0.372	0.029	0.019	0.303	0.228	0.058	0.009	0.475	0.255	0.015	0.003
	Std. Dev.	0.406	0.029	0.011	0.002	0.035	0.033	0.019	0.008	0.091	0.089	0.003	0.001
	N	6	6	6	6	3	3	4	4	2	2	4	

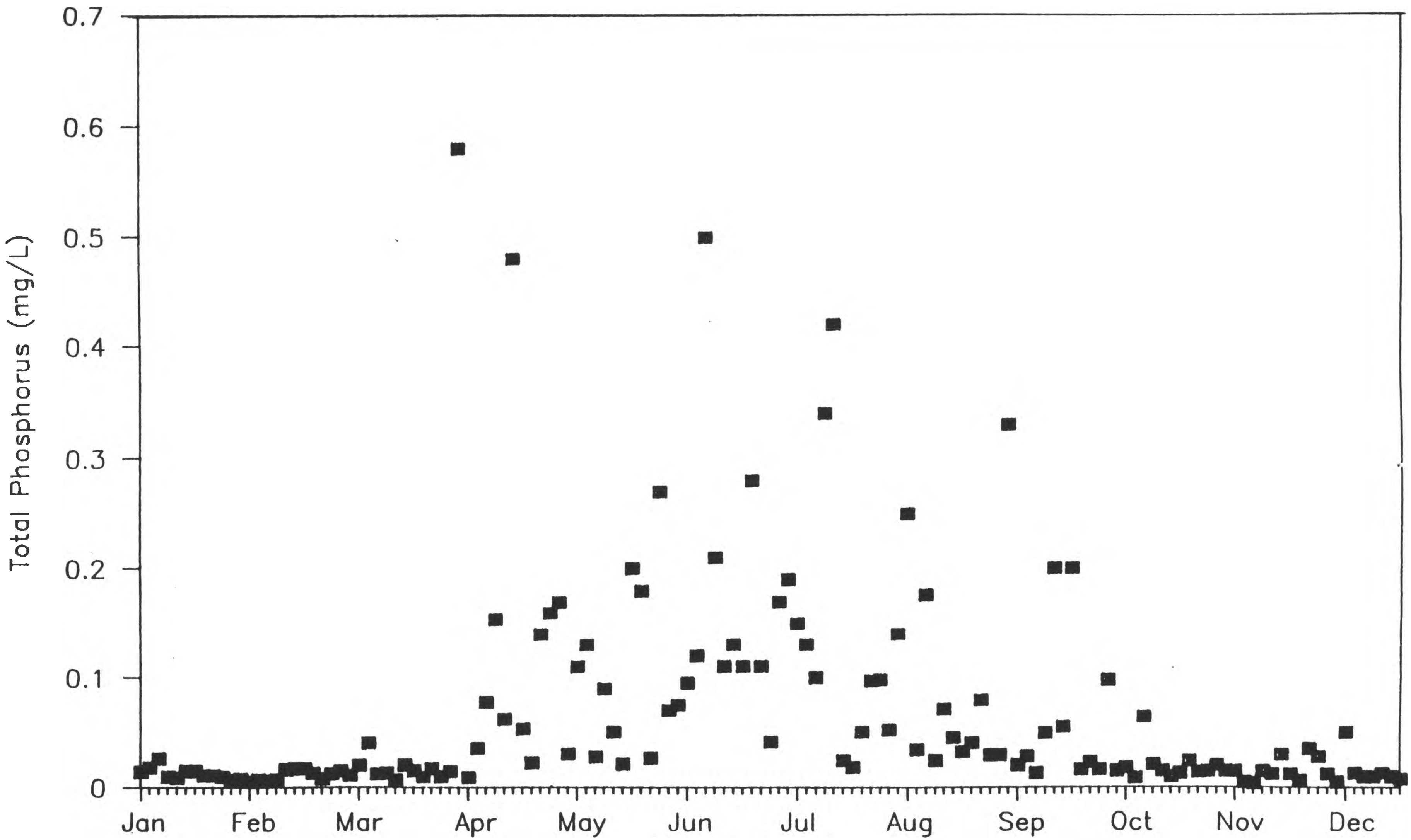

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Figure 3.2.1

TOTAL PHOSPHORUS CONCENTRATIONS IN THE ATHABASCA RIVER AT ATHABASCA, 1974-1988
(from Noton 1990c)

TABLE 3.2.2
Mean Concentrations of Nutrients in the Athabasca River at Athabasca Falls, Jasper National Park, Alberta

Date		Under Ice				Rising Hydrograph				Falling Hydrograph			
		Nitrogen		Phosphorus		Nitrogen		Phosphorus		Nitrogen		Phosphorus	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
1982	Mean		0.108	0.003	0.002		0.098	0.041	0.003		0.071	0.013	0.002
	Std. Dev.		0.010	0.002	--		0.016	0.052	0.002		0.016	0.007	--
	N		8	4	4		8	4	4		8	4	4
1983	Mean		0.098	0.002	0.002		0.078	0.013	0.002		0.078	0.020	0.004
	Std. Dev.		0.004	0.001	0.001		0.017	0.012	0.001		0.021	0.025	0.002
	N		8	4	4		8	4	4		4	4	4
1984	Mean	0.105	0.106	0.006	0.002	0.113	0.086	0.033	0.002	0.083	0.064	0.021	0.002
	Std. Dev.	0.005	0.011	0.005	--	0.047	0.014	0.037	--	0.016	0.013	0.032	--
	N	2	8	4	4	4	8	4	4	4	8	4	4
1985	Mean	0.125	0.129	0.002	0.002	0.140	0.108	0.040	0.002	0.110	0.088	0.016	0.003
	Std. Dev.	0.015	0.019	0.001	--	0.032	0.035	0.034	--	0.019	0.019	0.017	0.001
	N	4	8	4	4	4	4	4	4	4	8	4	4
1986	Mean	0.140	0.126	0.003	0.002	0.160	0.091	0.070	0.003	0.090	0.073	0.010	0.002
	Std. Dev.	0.010	0.009	0.000	0.001	0.104	0.011	0.089	0.001	0.019	0.020	0.008	0.001
	N	4	8	4	4	4	8	4	4	4	8	4	3
1987	Mean	0.118	0.108	0.005	0.002	0.125	0.101	0.023	0.002	0.113	0.089	0.021	0.002
	Std. Dev.	0.004	0.007	0.001	--	0.044	0.030	0.025	--	0.023	0.018	0.022	0.001
	N	4	8	4	4	4	8	4	4	4	8	4	4
1988	Mean	0.138	0.129	0.004	0.002	0.123	0.101	0.029	0.002	0.098	0.080	0.011	0.002
	Std. Dev.	0.008	0.009	0.001	--	0.018	0.023	0.014	--	0.008	0.009	0.005	--
	N	4	8	4	4	4	8	4	4	4	8	4	4
1989	Mean	0.130	0.123	0.003	0.002	0.163	0.115	0.053	0.002	0.103	0.075	0.031	0.003
	Std. Dev.	0.007	0.008	0.002	0.001	0.060	0.036	0.058	0.001	0.025	0.011	0.035	0.001
	N	4	8	4	4	4	4	4	4	4	4	4	4
1990	Mean	0.120	0.110	0.005	0.002	0.125	0.100	0.018	0.001	0.118	0.070	0.051	0.003
	Std. Dev.	0.007	0.007	0.002	0.001	0.025	0.021	0.009	--	0.039	0.023	0.072	0.003
	N	4	4	4	4	4	4	4	4	4	4	4	4
1991	Mean	0.148	0.135	0.002	0.001	0.115	0.103	0.012	0.002	0.098	0.073	0.020	0.002
	Std. Dev.	0.036	0.038	0.001	--	0.015	0.019	0.009	0.001	0.013	0.015	0.024	0.001
	N	4	4	4	4	4	4	4	4	4	4	4	4
1992	Mean	0.115	0.103	0.003	0.002								
	Std. Dev.	0.005	0.004	0.002	0.001								
	N	4	4	4	4								

Notes:
1. For values less than the detection limit, a value of one-half the detection limit was used to calculate the mean and Standard Deviation.
2. Data from NAQUADAT, Environment Canada, Ottawa - supplied by Mark Charette. No total nitrogen data for 1982 and 1983. Sampling is monthly. For dissolved nitrogen for 1982 - 1989 there are two values for each of the four sample dates.
3. Under Ice = December of previous year plus January, February and March of current year. Rising Hydrograph = April, May, June and July. Falling Hydrograph = August, September, October and November.

Downstream at the Embarras/Old Fort monitoring site, the same pattern of low winter levels and high variable summer levels of total phosphorus occurs (Fig. 3.2.2). Much of the total phosphorus is probably associated with inorganic suspended solids and is not available for plant uptake and growth. Noton (1990a) showed a positive correlation between total phosphorus and suspended solids using 1974-1988 Athabasca River data collected at Athabasca. These data included samples collected in the summer when suspended solids concentrations are highest.

The seasonal pattern for total nitrogen at the Town of Athabasca was similar to that for phosphorus with high concentrations occurring in June and July but nitrogen data are more scattered (Fig. 3.2.3). In contrast, maximum total nitrogen at Jasper occurs in winter while no seasonal trend is evident in the total nitrogen data presented by Noton (1990a) for Embarras. In all three seasons, dissolved nitrogen at Athabasca exceeds corresponding values at Jasper and Ft. McMurray. The same occurs for particulate nitrogen, but only during the early open water period. Nitrate + nitrite nitrogen values are greatest under ice and the winter medians at all three sites are similar (0.11 mg/L, 0.10 mg/L, and 0.14 mg/L at Jasper, Athabasca and Fort McMurray, respectively) (Hamilton et al. 1985). Median nitrate + nitrite nitrogen concentrations are low during the late open water seasons, especially at the Town of Athabasca (0.05 mg/L) and Fort McMurray (0.01 mg/L) (Hamilton et al. 1985). A review of the data for the Athabasca River at Athabasca collected since Hamilton et al. (1985) found that nitrite + nitrate nitrogen was always lowest during the falling hydrograph (late summer and fall). Summaries for the total and dissolved nitrogen concentrations for the winter (under ice), rising hydrograph and falling hydrograph are included in Tables 3.2.1 and 3.2.2 for the Town of Athabasca and Jasper sites.

Total nitrogen concentrations continue to be highest and most variable in the rising hydrograph for the Town of Athabasca except in 1992, although winter concentrations of total nitrogen are also high. Dissolved nitrogen levels are highest under ice (Table 3.2.1). Concentrations of total and dissolved nitrogen are lower at the Jasper site where they do not show the same degree of seasonality (Table 3.2.2).

Data from the long-term network station of the Town of Athabasca was used to graph winter concentrations of total and total dissolved phosphorus (Fig. 3.2.4) and total nitrogen (Fig. 3.2.5)

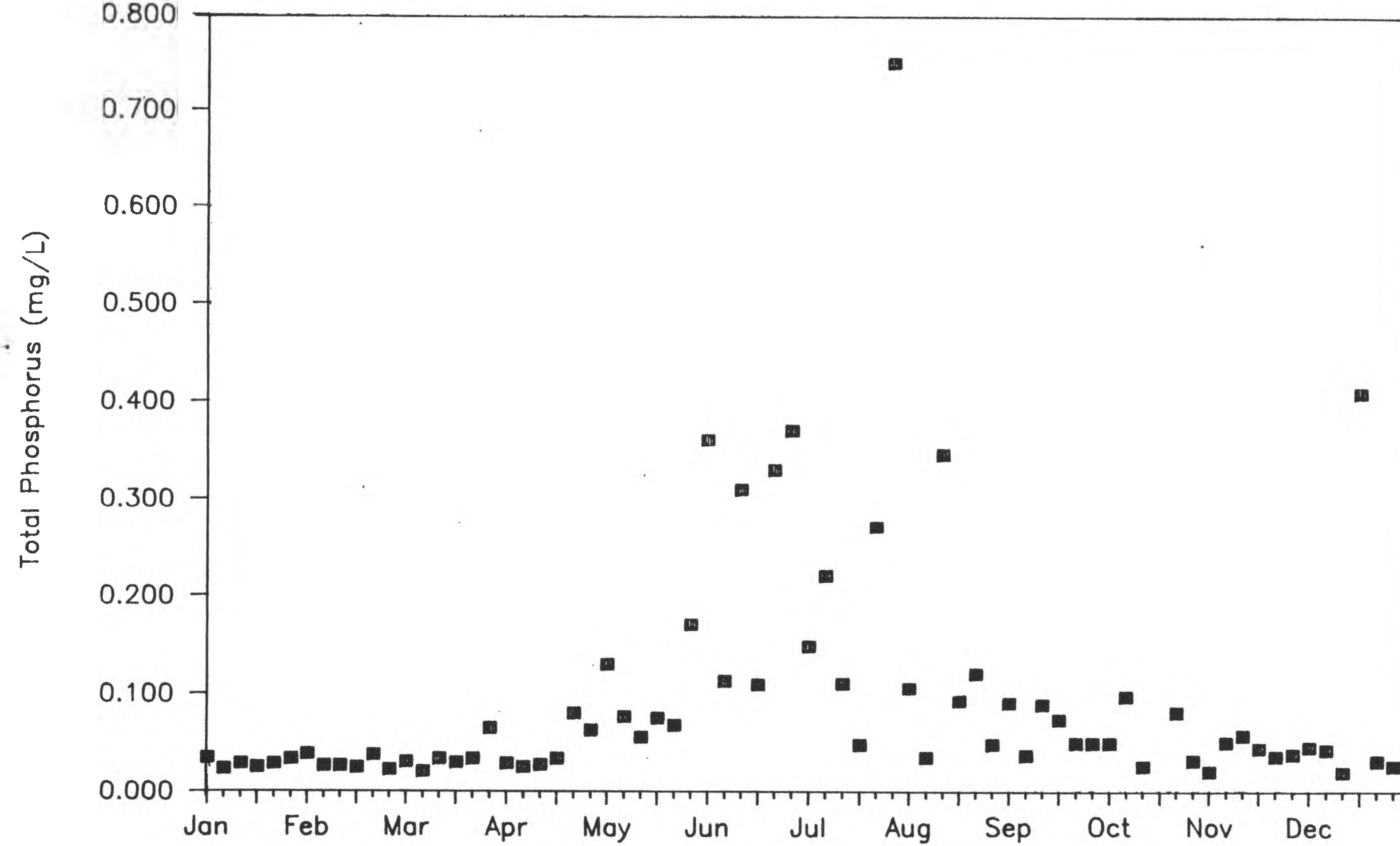

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Figure 3.2.2

TOTAL PHOSPHORUS CONCENTRATIONS IN THE ATHABASCA RIVER AT OLD FORT/EMBARRAS, 1974-1988
(from Noton 1990c)

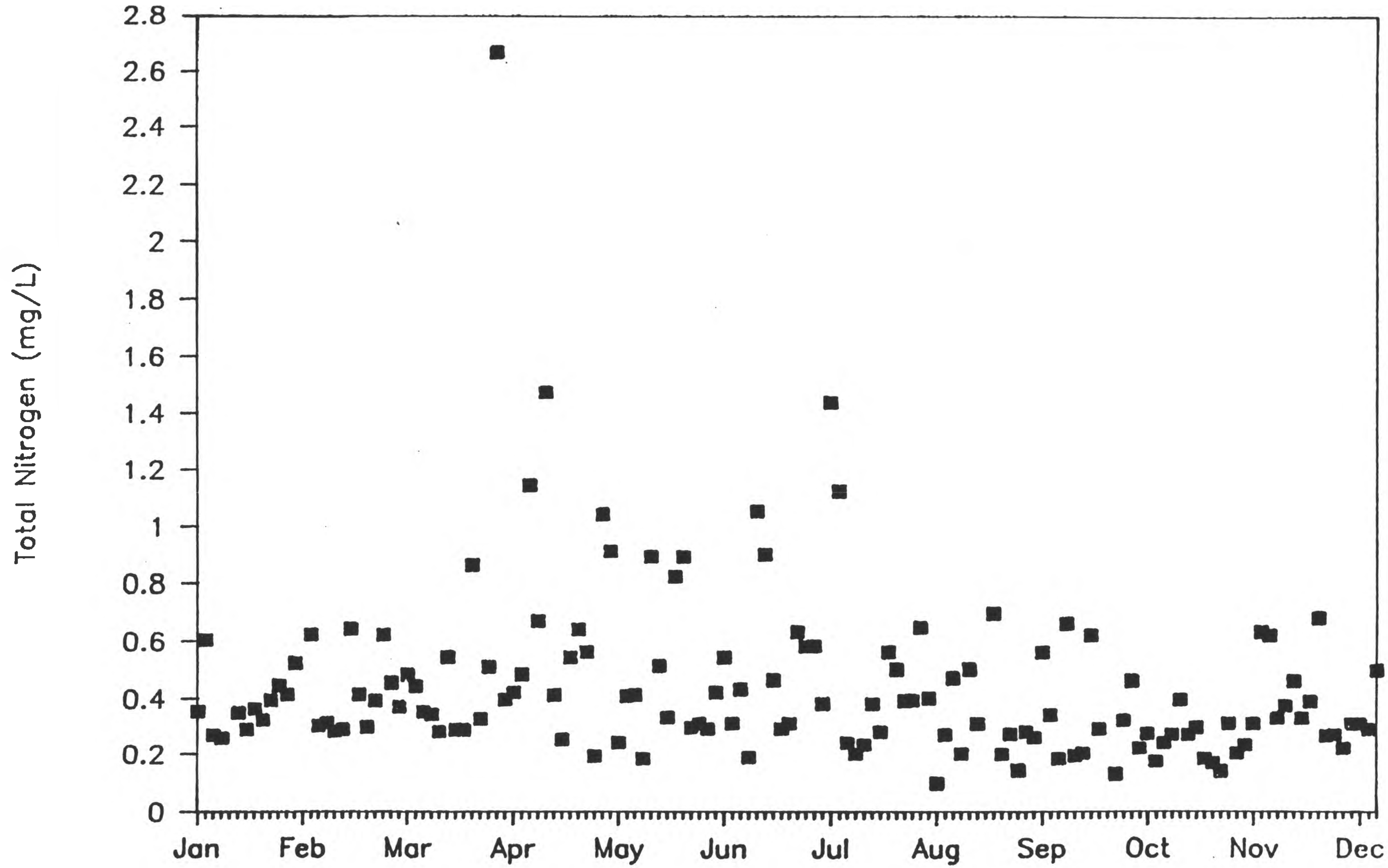

Figure 3.2.3

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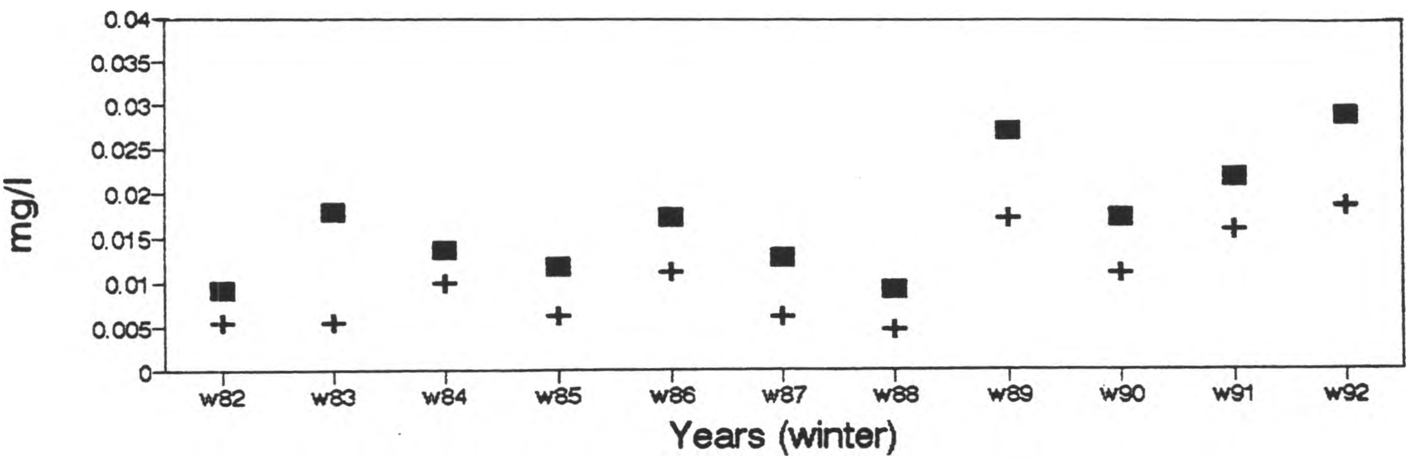
TOTAL NITROGEN CONCENTRATIONS IN THE ATHABASCA RIVER AT ATHABASCA, 1974-1988
(FROM NOTON 1990c)

SENTAR



■ TOTAL PHOSPHORUS

+ DISSOLVED PHOSPHORUS

Figure 3.2.4

WINTER TOTAL AND DISSOLVED PHOSPHORUS CONCENTRATIONS, ATHABASCA RIVER AT ATHABASCA, 1982-1992

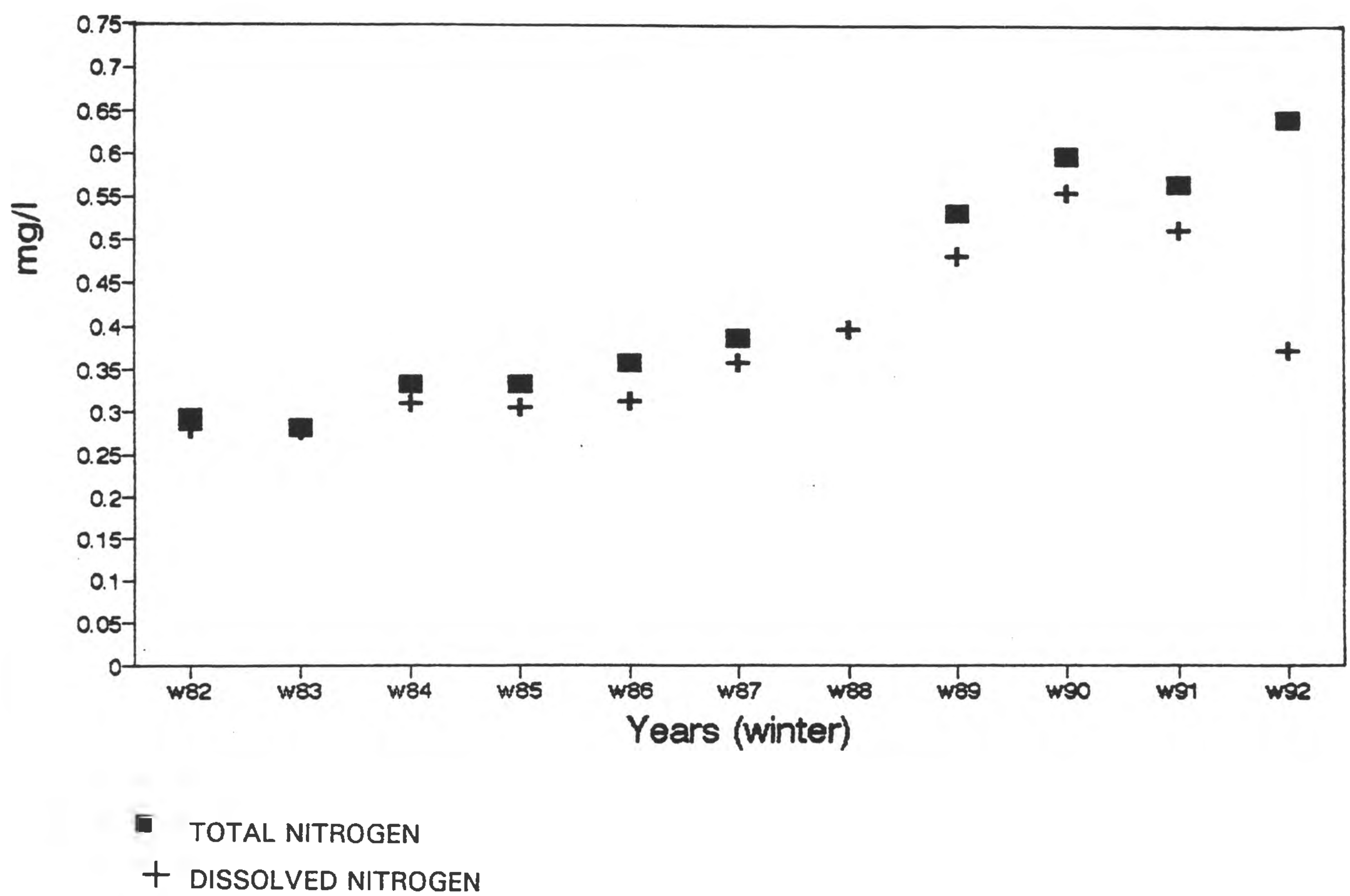


Figure 3.2.5

WINTER TOTAL AND DISSOLVED NITROGEN CONCENTRATIONS, ATHABASCA RIVER AT ATHABASCA, 1982-1992 for the last ten years (1982-1992). Winter data was used to avoid high flow and suspended sediment related factors which increased the scatter in the data points. Noton and Shaw (1989) reported that concentrations of total phosphorus at the Town of Athabasca in the winter of 1989 were high relative to historic data. Winter means for 1991 and 1992 are also slightly higher than historic levels. The 1992 winter mean was 0.03 mg/L total phosphorus; all samples were below the Alberta surface water quality objective of 0.05 mg/L. Noton and Shaw (1989) found that winter total phosphorus concentrations in the Athabasca River were not significantly ($p > 0.05$) correlated to suspended solids ($r = 0.04$, $n = 83$), but concentrations of total dissolved phosphorus were significantly correlated to total phosphorus ($r = 0.92$, $p = < 0.01$). This correlation is evident in the more recent data as well (Fig. 3.2.4).

Mean winter concentrations of total nitrogen in the Athabasca River at Athabasca are continuing to show an upward trend (Fig. 3.2.5). Dissolved nitrogen concentrations usually follow the same trend although the mean for 1992 was low (Fig 3.2.5).

3.2.2 Longitudinal Trends

Historically, the longitudinal trend has been one of increasing nutrients with increasing distance downstream of the headwaters. The May 1984 to February 1985 data[1] for total phosphorus (Hamilton et al. 1985) showed a mean increase of 0.025 mg/L below Fort Assiniboine compared to concentrations immediately upstream. Levels increased gradually (0.016 mg/L over about 500 km) until another sharp (0.06 mg/L) rise occurred below Fort McMurray. The 1984-1985 data was collected prior to the construction of either the ANC or Millar Western mills. The data for the winter of 1988 and 1989 (Noton and Shaw 1989) showed an increase at Hinton, a more pronounced increase at Whitecourt, a gradual decline, and a further small increase at Fort McMurray (refer to Fig. 2.1.1 for locations). Total phosphorus did not return to background (upstream of Hinton) at Embarras (Noton and Shaw 1989). The ASWQO of 0.05 mg/L was exceeded between Whitecourt and the Town of Athabasca during January to March 1989.

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[1] A total of six samples were collected in May, June, July, September, October 1984 and Febraury 1985 at each location.

Data from the 1991 winter synoptic survey has been tabulated to update the 1988 and 1989 results. In February, 1991, the concentration of total phosphorus near the river delta at Old Fort/Embarras was less than the concentration upstream of Hinton (Table 3.2.3). (The particulate and dissolved fractions may not follow changes in total phosphorus.) Concentrations of total phosphorus increased near point sources in the upstream reaches (i.e. upstream of Athabasca), but remained relatively constant at 0.03 mg/L for lower reaches. Tributaries including the La Biche, Lesser Slave, Pelican, House, Clearwater, Firebag and Richardson Rivers have total phosphorus concentrations higher than the main stem. In spite of these phosphorus rich inputs, there was no upward trend in phosphorus in the mainstem in 1991. In the 1992 synoptic survey, concentrations of total phosphorus were also lower at the downstream location (Old Fort) than at the location upstream of Hinton (upstream Hinton = 0.091 ±0.004; Old Fort = 0.039 ±0.002; n=3 at both locations).

Total phosphorus results from samples collected during the winter of 1992 show a range of 0.087 to 0.096 mg/L (January 30) upstream of Hinton, a range of 0.046 to 0.055 mg/L at Obed, another upstream location sampled on March 3, and a range of 0.037 to 0.041 mg/L at Old Fort, the most downstream location sampled on March 3. Thus, winter data for the last two years do not show a trend of increasing total phosphorus with distance downstream.

The concentration of nitrogen in the Athabasca River increases at downstream locations. Tributaries such as the McLeod, Freeman, Pembina, Lesser Slave, La Biche, Calling, Pelican, House, Clearwater and Muskeg Rivers all add nitrogen to the mainstem of the Athabasca because concentrations of total nitrogen are higher in the tributaries than in the mainstem (Table 3.2.3).

TABLE 3.2.3
Concentrations[a] of Total Phosphorus and Total Nitrogen in the Mainstem and Tributaries of the Athabasca River, February and March 1991

Station or River Reach	No. of Samples	Total Phosphorus ±1 Standard Deviation (mg/L)	Total Nitrogen ±1 Standard Deviation (mg/L)
MAINSTEM			
Upstream Hinton	3	0.080±0.04	0.212±0.028
Hinton to Upstream Berland R.	6	0.126±0.35	0.346±0.055
Marsh Head Cr. to Highway 43	3	0.049±0.009	0.241±0.008
Downstream Whitecourt to Upstream Freeman R.	5	0.045±0.008	0.292±0.013
Upstream Pembina R.	1	0.036	0.303
Athabasca	3	0.033±0.001	0.355±0.006
Upstream La Biche R.	1	0.034	0.37
Calling R. to Pelican R.	2	0.026±0.001	0.421±0.025
Upstream House R.	1	0.036	0.422
Downstream House R. to Upstream Clearwater R.	3	0.029±0.003	0.439±0.009
Downstream Ft. McMurray	1	0.037	0.493
Downstream Bitumount	1	0.05	0.553
Upstream Firebag R.	1	0.034	0.27
Old Fort/Embarras	3	0.033±0.001	0.478±0.013
TRIBUTARY			
Berland R.	1	0.002	0.21
Marsh Head Cr.	1	0.01	0.281
McLeod R.	1	0.004	0.386
Sakwatamau R.	1	0.009	0.242
Freeman R.	1	0.006	0.475
Pembina R.	1	0.02	0.795
Lesser Slave R.	1	0.048	0.609
La Biche R.	1	0.072	1.63
Calling R.	1	0.015	0.68
Pelican R.	1	0.085	2.923
House R.	1	0.066	1.301
Clearwater R.	1	0.055	0.561
Muskeg R.	1	0.022	1.339
Firebag R.	1	0.045	0.034
Richardson R.	1	0.058	0.307

a. Data were pooled for sites when there was no major tributary or point source along that length of river. Data provided by Alberta Environment.

3.2.3 Instream Nutrient Concentrations Measured in the Vicinity of Point Sources

Hamilton et al. (1985) identified the Weldwood pulp mill effluent (which contains treated sewage from Hinton) as the only important anthropogenic impact on water quality in the upper Athabasca River. Initial analysis of the instream data showed that the impact occurred primarily at low flows (<100 m^3/s) and extended from 50 to 75 km below the effluent outfall. During the surveys conducted from 1984 to 1986 (Anderson 1989), total phosphorus concentrations were frequently below detection (0.006 mg/L) above the pulp mill effluent. The total phosphorus concentrations at the 50 km site were similar to those recorded above the effluent; on the dates where measurements were below the detection limit at the upstream site, they were frequently below detection at the 50 km site as well (Anderson 1989).

To elucidate stream processes, particularly below the outfall, data were collected during two low flow surveys in October, 1985 (river flow = 95 m^3/s; dilution = 92:1) and February, 1986 (river flow = 29 m^3/s; dilution = 27:1) (Anderson 1989). During the October survey the increase in total phosphorus was moderate (0.020 to 0.028 mg/L) below the Hinton mill at the 6 km site, and dropped to levels below background (i.e. upstream[2] of Hinton) at the 20 km site. In February, levels of total phosphorus at the 20 km to 60 km sites were similar but remained above background (background = <0.006 mg/L). Dissolved phosphorus and soluble reactive phosphorus were below the detection limit (0.002 mg/L) at all sites sampled in October, 1985. In February, increases were observed below the pulp mill in dissolved phosphorus (0.012 mg/L below mill compared to 0.003 mg/L upstream). Longitudinal trends were also visible for most forms of nitrogen in the Alberta Environment monitoring data from the October 1985 and February 1986 surveys. Most forms of nitrogen dropped to levels near or below background in the October survey by 20 km downstream, but levels were quite variable and remained above background in February when the dilution was reduced to 27:1.

Nutrients have been measured by Weldwood in their January 1991 and 1992 surveys (Appendix Table B.1) and the spring and fall surveys of benthic invertebrates (Appendix Table B.2). The pulp mill effluent mixes poorly at first; the greatest concentration of effluent is found at mid-river at station 2, and on the left side of the river at stations 4 and 5 (refer to Fig. 4.1.5 for location of stations). By station 6, 9 km downstream the mixing is nearly complete (TAEM 1992). Levels of ortho-phosphate and total dissolved phosphorus remain below detection in water samples collected during the benthic surveys. Total phosphorus was below detection limits (<0.005 mg/L total phosphorus) in the spring, 1991, but total phosphorus was present at

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[2] Upstream site is located 2.2 km downstream of Mashuta Creek.

upstream and downstream locations in the fall, 1990. An average increase of 0.14 mg/L TKN was detected below the mill in April 1991.

The water quality of the Athabasca River near Whitecourt has been monitored by ANC during spring and fall benthic invertebrate studies (Appendix Table B.3). Millar Western has monitored spring and fall nutrient concentrations on the McLeod River as well as the Athabasca (Appendix Table B.4). Upstream (control) concentrations of total phosphorus are in the 0.02 to 0.08 mg/L range. No increases over upstream values of total phosphorus and total Kjeldahl nitrogen have been detected below the effluent discharged by the Millar Western and ANC. A winter water sampling program which includes nutrients has been conducted since 1990 (Appendix Table B.5).

Data on the water quality of the Lesser Slave River collected for the Slave Lake Pulp mill during instream studies shows a noticeable increase in total phosphorus and total dissolved phosphorus in May 1991, compared to May 1990 and October 1989 (Appendix Table B.6). May 1991 was the first year of operation of the pulp mill.

3.2.4 Trial Water Balance

The data presented so far have been the **concentrations** of nutrients (measured in mg/L). To estimate the mass **loading** of nutrients to the river, the concentration of the nutrient must be multiplied by the quantity of water discharged at the same location. Discharge data are available from Alberta Environment; discharge was usually reported during the winter synoptic surveys at the time that water samples were collected for nutrient analysis. In the synoptic surveys, the river was sampled from upstream to downstream following the approximate time-of-travel; therefore, these surveys are the best source of data to assess the inputs and losses of nutrients to the river as it flows from the headwaters to the river mouth. The other source of discharge data is the Water Survey of Canada (WSC) monitoring stations on the mainstem and the tributaries.

Since the quantity of water discharged substantially affects the magnitude of the nutrient loading, the first step is to attempt a mass balance of the discharge data. Discharge data supplied by Alberta Environment was used and verified, wherever possible, by WSC data. Although there are quite a few data points for the tributaries, there are numerous small tributaries that are not measured. The discharge of the mainstem is only measured at a few points along its length. There are, therefore long stretches of river where the running total cannot be calibrated against measured values. Discharge balances were completed for 1990, 1991 and 1992. The 1991 balance (Table 3.2.4) was used to determine the nutrient load; the 1990 and 1992 balances are appended (Appendix Table C.1 and C.2). Alberta Environment also provided a balanced flow for the 1991 synoptic survey (Appendix Table C.3). The discharge measured during the 1991 synoptic survey is a median value for recent synoptic surveys. The discharge measured at Fort McMurray in 27 February 1991 of 150 m^3/s lies between the 198 m^3/s for 14 March 1990 and 135 m^3/s for 25 February 1992.

3.2.5 Phosphorus Mass Transport

Noton (1990a) found that the total phosphorus load in the Athabasca River was about twice as high at the delta (Embarras) as it was at the Town of Athabasca. The average annual load was 9600 kg/d at Embarras compared to 4900 kg/d at the Town of Athabasca, based on 1974 to 1988 data. This increase was attributed to both the increase in concentration and the increase in flow at the delta.

Noton (1990a) used all of the data available from 1977 to 1988 which was then broken down by month at these two sites. The large quantities of total phosphorus transported during peak flows in June, July and, to a lesser extent, August dominated the mass transport calculation. Since effluent from the major point sources is generally discharged continuously over the year, the increase at Embarras was primarily due to phosphorus and nitrogen export due to runoff during snow-melt and, to a lesser extent, summer storms.

In this report, the mass transport is calculated differently. The synoptic survey data, to the extent possible, follow the time-of-travel of the mass of phosphorus being transported and, therefore, measure the additions to the same quantity of phosphorus as it flows downstream. An advantage of using winter data is that the watershed export is at a minimum and the impact of anthropogenic point sources is proportionately greater. The lower temperatures also reduce biological removal of nutrients in the river.

TABLE 3.2.4
Athabasca River Discharge Balance During the 1991 Synoptic Survey

Station	Alberta Environment				Water Survey of Canada		
	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)	Calculated Running Total (Athabasca R.) (m^3/s)	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)
Weldwood of Canada Ltd. Effluent	06/02/91	1.070					
Athabasca R. Downstream Hinton	06/02/91		53.9		07/02/91		54.9
Berland R.	08/02/91	12.2		66.1	08/02/91	12.3	
Athabasca R. Downstream Berland R.	08/02/91		65.0				
Marsh Head Cr.	12/02/91	0.323		65.323			
Athabasca R. at Windfall Bridge	12/02/91		65.0		12/02/91		65.0
McLeod R.	13/02/91	10.3		75.3	01/03/91	9.4	
Sakwatamau R.	13/02/91	0.934		76.234	01/03/91	0.732	
Whitecourt Sewage	12/02/91	0.039		76.273			
Alberta Newsprint Company Effluent	11/02/91	0.192		76.465			
Millar Western Pulp Ltd. Effluent	12/02/91	0.144		76.609			
Freeman R.	13/02/91	0.015		76.624	01/03/91	0.64	
Pembina R.	19/02/91	5.820		82.444			
Lesser Slave R.	20/02/91	17.5		99.944			
Athabasca R. Downstream Lesser Slave R.	20/02/91		105				
Athabasca R. at Athabasca	22/02/91		105		22/02/91 (20/02/91)		106 (100)
Athabasca Sewage	22/02/91	0.010		105.010			
La Biche R.	28/02/91	1.890		106.9	26/02/91	1.664	
Calling R. at Mouth	28/02/91	0.034		106.934			
Pelican R. at Mouth	28/02/91	0.295		107.229			
Athabasca R. Upstream House R.	06/03/91		87.8				
House R.	06/03/91	1.140		108.369	05/03/91	0.465	
Athabasca R. Upstream Horse R.	07/03/91		78.6				
Clearwater R.	06/03/91	41.2		149.569	06/03/91	41.9	
Ft. McMurray Sewage	06/03/91	0.127		149.696			
Athabasca R. 6.5 m Downstream Ft. McMurray	27/02/91		157.0		07/03/91		150
Muskeg R.	07/03/91	0.262		149.958			
Firebag R.	15/03/91	9.810		159.768			
Richardson R.	21/03/91	14.5		174.27			
Athabasca R. Upstream Fletcher Channel	14/03/91		172.5				

In the February-March 1991 survey, the total phosphorus load measured at Old Fort/Embarras, the site closest to the river delta, was 456±16 kg/d. The total phosphorus upstream of Hinton, the site closest to the headwaters measured by Alberta Environment, was 363±18 kg/d (Table 3.2.5). The mass of total phosphorus at Old Fort was 125% of the upstream mass. During this time-of-travel, the quantity of water increased 273% due to the inflow of tributaries and point sources. The increase in total mass of phosphorus is small in comparison to the increase in the volume of water. The mass of phosphorus entering the mainstem from pulp mill, industrial and municipal sources was 554 kg/d in 1991 survey, or 44%. Weldwood and ANC contributed 496 kg/d due to the high concentration of total phosphorus in their effluent. The municipal effluent from the Town of Hinton contributes to the high concentration of total phosphorus at Weldwood. Millar Western contributed only 9 kg/d. The mass of phosphorus entering from tributary streams was 346 kg/d. The tributary input from Lesser Slave River includes the effluent from the Slave Lake pulp mill. In the 1991 winter synoptic survey, the direct contribution to the mainstem from pulp mills was 40%[3] of all measured phosphorus inputs to the mainstem including tributary inputs.

Both Weldwood and ANC have taken steps to reduce nutrients in their effluent since this survey. In February 1993, ANC discharged 40 kg/d total phosphorus and Weldwood discharged 64 kg/d, primarily because the concentrations of total phosphorus in the effluent have been reduced to 3.6 mg/L and 0.64 mg/L, respectively. The February 1993 loading of phosphorus from these mills is about one-fifth the 1991 loading shown in Table 3.2.5.

All of the phosphorus added to the mainstem of the Athabasca River does not reach the delta in winter. The total input to the mainstem is the initial incoming mass of 363 kg/d total phosphorus above Hinton, 554 kg/d from anthropogenic point sources and 346 kg/d from measured tributaries. The tributary inputs shown in Table 3.2.6 during the synoptic survey are for those rivers and creeks that were measured; many small creeks were not measured. Thus, actual total input is likely to be greater than that shown in Table 3.2.6. The sum of all three inputs is 1263 kg/d while the load measured at Embarras near the delta is only 456 kg/d, or 36% of the total inputs. There are substantial differences between calculated and measured loads at most gauging stations on the mainstem (Table 3.2.6). Some of the differences are instream losses, but some are also due to sampling.

[3] This percentage does not include the effluent from Slave Lake Pulp Corp. mill which is not a direct input to the mainstem. The nutrients from this mill form part of the Lesser Slave River loading considered a tributary load to the mainstem.

TABLE 3.2.5
Mass Loading Balance for Total Phosphorus for the Athabasca River for the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Phosphorus			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Athabasca R. - Upstream Hinton	1	07/02/91	4 564 512	0.080 ±0.004		363 ±18	3
Weldwood Canada Ltd. Effluent	1	06/02/91	92 448	4.28 ±0.00		395 ±0	2
Athabasca R. - Hinton to Upstream Berland R.	6	07-08/02/91	4 656 960	0.126 ±0.35	758	586 ±164	6
Berland R.	1	08/02/91	1 054 080	0.002		2	1
Marsh Head Cr.	1	12/02/91	27 907	0.01		0.3	1
Athabasca R. - Marsh Head Cr. to Hwy 43	4	12/02/91	5 616 000	0.049 ±0.009	588	274 ±49	3
McLeod R.	1	12/02/91	889 920	0.004		4	1
Sakwatamau R.	1	12/02/91	80 698	0.009		0.7	1
Athabasca Newsprint Company Effluent	1	11/02/91	16 589	6.08 ±0.74		101 ±12	2
Millar Western Pulp Ltd. Effluent	1	12/02/91	12 442	0.70 ±0.00		9 ±0	2
Whitecourt Sewage	1	12/02/91	3 370	2.82		10	1
Athabasca R. - Downstream Whitecourt to Upstream Freeman R.	5	13/02/91	6 610 378	0.045	399	299 ±53	5
Freeman R.	1	13/02/91	1 296	0.006		0	1
Athabasca R. - Upstream Pembina R.	1	19/02/91	6 611 674	0.036	299	238	1
Pembina R.	1	19/02/91	502 848	0.02		10	1
Lesser Slave R.	1	21/02/91	1 512 000	0.048		73	1
Athabasca R. at Athabasca	1	23/02/91	9 072 000	0.033	321	299 ±9	3
Athabasca Sewage	1	22/02/91	864	5.80		5	1
Athabasca R. - Upstream La Biche R.	1	26/02/91	9 072 864	0.034	304	308	1
La Biche R.	1	26/02/91	163 296	0.072		12	1
Calling R.	1	28/02/91	2 938	0.015		0	1
Athabasca R. - Calling R. to Pelican R.	2	26/02/91	9 239 098	0.026 ±0.001	320	240 ±13	2
Pelican R.	1	26/02/91	25 488	0.085		2	1
Athabasca R. - Upstream House R.	1	05/03/91	9 264 586	0.036	242	334	1
House R.	1	05/03/91	98 496	0.066		7	1
Athabasca R. - Downstream House R. to Upstream Clearwater R.	3	05-06/03/91	9 363 082	0.029 ±0.003	341	275 ±30	3
Clearwater R.	1	06/03/91	3 559 680	0.055		196	1
Ft. McMurray Sewage	1	06/03/91	10 973	2.64		29	1
Athabasca R. - Downstream Ft. McMurray	1	07/03/91	12 933 734	0.037	500	479	1
Suncor Effluent	1	06/03/91	32 141	0.17		5	1
Muskeg R.	1	07/03/91	22 637	0.022		1	1
Athabasca R. - Downstream Bitumount	1	07/03/91	13 101 869	0.05	485	655	1
Athabasca R. - Upstream Firebag R.	1	14/03/91	13 101 869	0.034		445	1
Firebag R.	1	26/03/91	857 584	0.045		38	1
Athabasca R. at Old Fort/Embarras	1	14/03/91	13 961 549	0.033 ±0.001	480	456 ±16	3
Richardson R.	1	14/03/91	1 252 800	0.058		73	1

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

TABLE 3.2.6
Mass Loading Balance for Total Nitrogen in the Athabasca River During the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Nitrogen			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Athabasca R. - Upstream Hinton	1	07/02/91	4 564 512	0.212 ±0.028		970 ±127	3
Weldwood Canada Ltd. Effluent	1	06/02/91	92 448	7.17 ±0.15		662 ±14	2
Athabasca R. - Hinton to Upstream Berland R.	6	07-08/02/91	4 656 960	0.346 ±0.055	1632	1610 ±256	6
Berland R.	1	08/02/91	1 054 080	0.21		126	1
Marsh Head Cr.	1	12/02/91	27 907	0.281		8	1
Athabasca R. - Marsh Head Cr. to Hwy 43	4	12/02/91	5 616 000	0.241 ±0.008	1744	1354 ±48	3
McLeod R.	1	12/02/91	889 920	0.386		344	1
Sakwatamau R.	1	12/02/91	80 698	0.242		20	1
Athabasca Newsprint Company Effluent	1	11/02/91	16 589	2.85 ±0.64		47 ±11	2
Millar Western Pulp Ltd. Effluent	1	12/02/91	12 442	7.94 ±0.14		99 ±2	2
Whitecourt Sewage	1	12/02/91	3 370	15.06		51	1
Athabasca R. - Downstream Whitecourt to Upstream Freeman R.	5	13/02/91	6 610 378	0.292 ±0.013	1915	1932 ±84	5
Freeman R.	1	13/02/91	1 296	0.475		0.6	1
Athabasca R. - Upstream Pembina R.	1	19/02/91	6 611 674	0.303	1916	2003	1
Pembina R.	1	19/02/91	502 848	0.795		400	1
Lesser Slave R.	1	21/02/91	1 512 000	0.609		921	1
Athabasca R. at Athabasca	1	23/02/91	9 072 000	0.355 ±0.006	3324	3224 ±50	3
Athabasca Sewage	1	22/02/91	864	33.06		29	1
Athabasca R. - Upstream La Biche R.	1	26/02/91	9 072 864	0.37	3253	3357	1
La Biche R.	1	26/02/91	163 296	1.63		266	1
Calling R.	1	28/02/91	2 938	0.68		2	1
Athabasca R. - Calling R. to Pelican R.	2	26/02/91	9 239 098	0.421 ±0.025	3625	3885 ±229	2
Pelican R.	1	26/02/91	25 488	2.923		75	1
Athabasca R. - Upstream House R.	1	05/03/91	9 264 586	0.422	3960	3910	1
House R.	1	05/03/91	98 496	1.301		128	1
Athabasca R. - Downstream House R. to Upstream Clearwater R.	3	05-06/03/91	9 363 082	0.439 ±0.009	4038	4114 ±87	3
Clearwater R.	1	06/03/91	3 559 680	0.561		1997	1
Ft. McMurray Sewage	1	06/03/91	10 973	27.3		300	1
Athabasca R. - Downstream Ft. McMurray	1	07/03/91	12 933 734	0.493	6411	6376	1
Suncor Effluent	1	06/03/91	32 141	1.65		53	1
Muskeg R.	1	07/03/91	22 637	1.339		30	1
Athabasca R. - Downstream Bitumount	1	07/03/91	13 101 869	0.553	6459	7245	1
Athabasca R. - Upstream Firebag R.	1	14/03/91	13 101 869	0.27		3538	1
Firebag R.	1	26/03/91	857 584	0.034		29	1
Athabasca R. at Old Fort/Embarras	1	14/03/91	13 961 549	0.478 ±0.013		6669 ±174	3
Richardson R.	1	14/03/91	1 252 800	0.307		385	1

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

Phosphorus is a non-conservative parameter that is biologically assimilated by epilithic algae, fungi and bacteria. It is also adsorbed to organic matter and sediments, particularly clay minerals. Fine grained silty sediments have a higher phosphorus sorption capacity than coarse sandy sediments. All of these factors are relevant to the fate of phosphorus on the Athabasca River. Scouring causes the suspension of particulate phosphorus and downstream transport of phosphorus during high flows; therefore, some of the phosphorus that does not reach Embarras during the winter may be transported during high summer flows.

3.2.6 Nitrogen Mass Transport

In contrast to phosphorus which increased very little downstream, the nitrogen load near the delta was almost seven times greater than the load upstream of Hinton. The total nitrogen load in the Athabasca River at Old Fort was 6669 kg/d in the winter of 1991 compared to 970 kg/d upstream of Hinton (Table 3.2.6). The input to the mainstem includes the initial upstream load of 970 kg/d total nitrogen, 1241 kg/d from anthropogenic point sources and 4347 kg/d from tributary streams. The sum of all inputs is 6558 kg/d which is close to 6669 kg/d total nitrogen measured at Old Fort. The total nitrogen load from pulp mills, municipalities and industry was about 19% of the total instream load in the winter of 1991.

3.3 PEACE RIVER

3.3.1 Seasonal and Annual Trends

Data collected monthly from 1978 to 1988 at the long-term water quality monitoring site at Dunvegan were tested by Shaw et al. (1990) for flow-dependency, seasonality, serial correlation, and long-term trends. For flow-dependent variables, both the actual and flow-adjusted concentrations were tested for long-term trends. At Dunvegan, all of the nutrient variables except total dissolved phosphorus were flow dependent. Data from 1989 to 1992 from the Peace River monitoring site at Fort Vermilion has been divided into three flow-related periods: winter (under ice), rising hydrograph and falling hydrograph (Table 3.3.1 on the following page). There were sufficient historical data from Dunvegan for Shaw et al. (1990) to assess seasonality of nutrients

TABLE 3.3.1
Mean Concentrations of Nutrients in the Peace River at Ft. Vermilion

Date		Under Ice				Rising Hydrograph				Falling Hydrograph			
		Nitrogen		Phosphorus		Nitrogen		Phosphorus		Nitrogen		Phosphorus	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	(Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
1989	Mean					0.272	0.272	0.395	0.011	1.593	0.373	0.567	0.008
	Std. Dev.					0.096	0.096	0.244	0.006	1.703	0.139	0.697	0.005
	N					3	3	3	3	3	3	3	3
1990	Mean	0.336	0.254	0.025	0.009	6.359	0.464	0.986	0.022	0.226	0.113	0.062	0.002
	Std. Dev.	0.184	0.127	0.019	0.009	5.721	0.164	0.747	0.001	0.029	0.025	0.032	0.001
	N	4	4	4	4	4	4	4	4	3	3	3	3
1991	Mean	0.272	0.212	0.015	0.004	1.349	0.402	0.412	0.036	0.492	0.379	0.039	0.009
	Std. Dev.	0.023	0.003	0.006	0.001	0.614	0.049	0.216	0.016	0.313	0.196	0.016	0.008
	N	2	2	4	4	3	3	3	3	3	3	3	3
1992	Mean	0.262	0.242	0.010	0.004	0.607	0.832	0.259	0.010	0.267	0.227	0.048	0.004
	Std. Dev.	0.006	0.006	0.002	0.000	0.181	0.614	0.151	0.003	0.138	0.138	0.028	0.000
	N	3	3	3	3	2	3	3	3	2	2	3	3

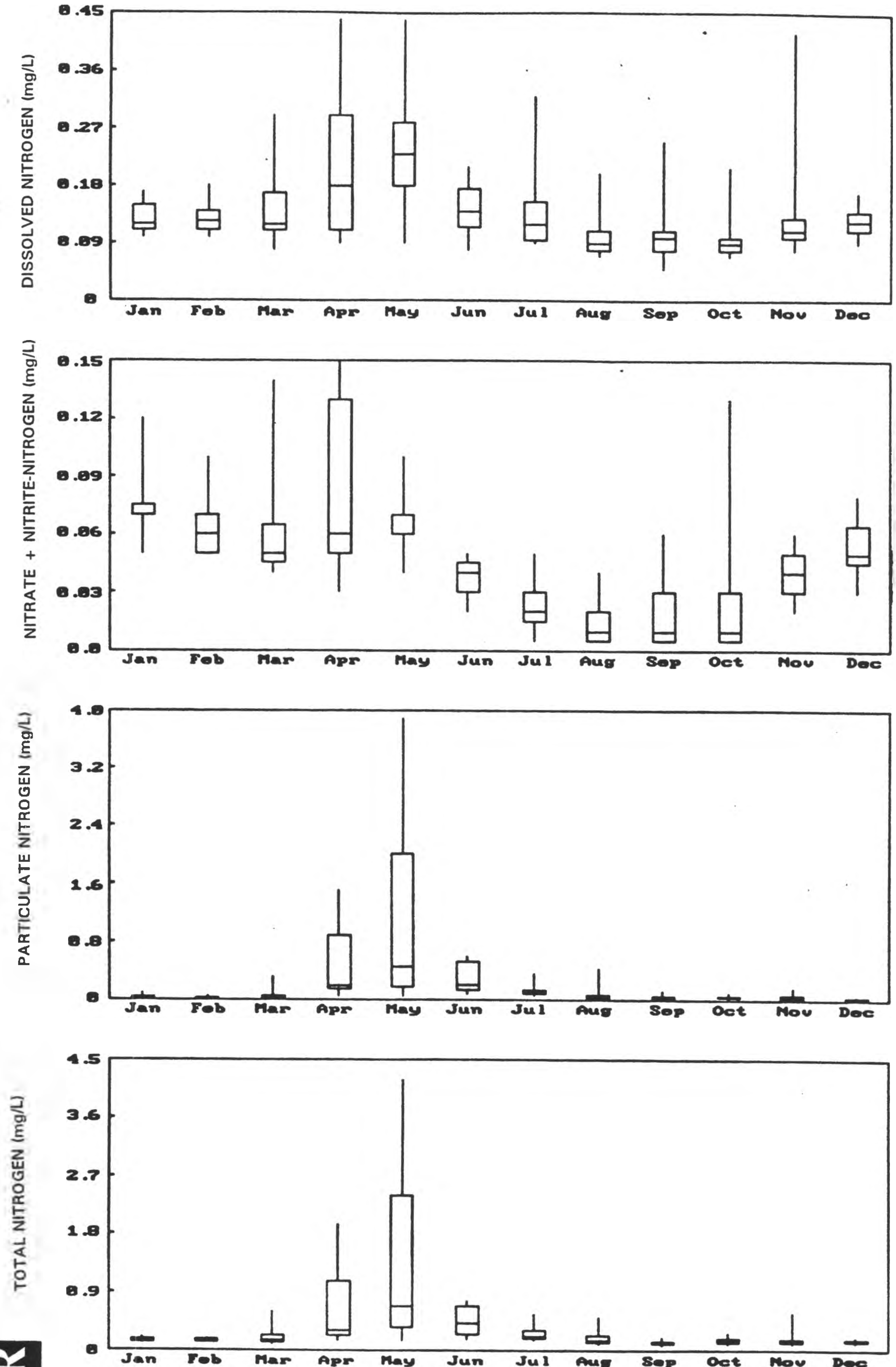

Figure 3.3.1

SEASONAL PATTERNS FOR NITROGEN
IN THE PEACE RIVER AT DUNVEGAN

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(Table 3.3.2). There was no significant monthly difference in total dissolved phosphorus. For all but one of the flow-dependent nutrients, there were significant monthly differences in both the actual and flow-adjusted[4] concentrations. For dissolved nitrogen, seasonality of the flow-adjusted concentrations was significant, but the seasonality of the unadjusted concentrations was not significant.

Table 3.3.2
Kruskal-Wallis Test for Seasonality of Data Collected Monthly in the Peace River at Dunvegan, 1977 to 1988

Variables	Test Statistic	
	Unadjusted	Flow-Adjusted
Flow-Independent Variable		
- Total Dissolved Phosphorus	-7.3	
Flow-Dependent Variables		
- Nitrogen (Dissolved)	-5.5	25.8[a]
- Nitrogen (Particulate)	208.8[a]	72.4[a]
- Nitrogan (Total)	71.7[a]	53.0[a]
- Nitrite + Nitrate	40.2[a]	73.7[a]
- Phosphorus (Total)	76.6[a]	66.3[a]
- Suspended Solids	65.8[a]	74.1[a]

a. $P < 0.05$
Source: Shaw et al. 1990

At Dunvegan (Shaw et al. 1990), all nitrogen fractions increased significantly with discharge (Fig. 3.3.1). Concentrations of dissolved nitrogen followed a seasonal pattern of peaks in April and May and lows in August to October. Peak concentrations of particulate nitrogen and total nitrogen occurred from April to June and the lows from January to February. This pattern is similar to that for concentrations of suspended solids. In contrast, concentrations of nitrite-nitrate nitrogen were highest in winter and spring and lowest in summer and early fall. Low levels of nitrite-nitrate nitrogen have also occurred in the falling hydrograph at Fort Vermilion for the last three years (Table 3.3.3). This seasonal pattern for nitrite-nitrate nitrogen has been observed in other rivers in Alberta (Hamilton et al. 1985) and may be a result of nitrate assimilation during the summer by bacteria and algae and nitrification during the winter.

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4 For flow-dependent variables, a regression model was used by Shaw et al. (1990) to determine flow-adjusted concentrations which are the actual concentrations minus the expected concentrations from the regression model.

TABLE 3.3.3
Results of Nitrogen Analyses for the Peace River at Ft. Vermilion

		Nitrogen					
		Total (mg/L)	Particulate (mg/L)	Dissolved (mg/L)	Dissolved Kjeldahl (mg/L)	Total Ammonia (mg/L)	Dissolved Nitrite-Nitrate (mg/L)
1990							
Under Ice	Mean	0.336	0.083	0.254	0.158	0.018	0.079
	Std. Dev.	0.184	0.065	0.127	0.101	0.004	0.027
	N	4	4	4	4	4	4
Rising Hydrograph	Mean	6.359	5.895	0.464	0.315	0.073	0.076
	Std. Dev.	5.721	5.874	0.164	0.094	0.055	0.048
	N	4	4	4	4	4	4
Falling Hydrograph	Mean	0.226	0.113	0.113	0.100	0.005	0.008
	Std. Dev.	0.029	0.034	0.025	0.028	0.000	0.009
	N	3	3	3	3	3	3
1991							
Under Ice	Mean	0.272	0.060	0.212	0.140	0.020	0.052
	Std. Dev.	0.023	0.020	0.003	0.020	0.000	0.024
	N	2	2	2	2	3	2
Rising Hydrograph	Mean	1.349	0.947	0.402	0.307	0.053	0.042
	Std. Dev.	0.614	0.589	0.049	0.082	0.068	0.017
	N	3	3	3	3	3	3
Falling Hydrograph	Mean	0.492	0.113	0.379	0.347	0.015	0.017
	Std. Dev.	0.313	0.118	0.196	0.210	0.007	0.022
	N	3	3	3	3	3	3
1992							
Under Ice	Mean	0.262	0.020	0.242	0.167	0.005	0.071
	Std. Dev.	0.006	0.000	0.006	0.009	0.000	0.004
	N	3	3	3	3	3	3
Rising Hydrograph	Mean	0.607	0.210	0.832	0.573	0.018	0.240
	Std. Dev.	0.181	0.190	0.614	0.303	0.010	0.312
	N	2	2	3	3	3	3
Falling Hydrograph	Mean	0.267	0.040	0.227	0.200	0.013	0.014
	Std. Dev.	0.138	0.000	0.138	0.120	0.008	0.010
	N	2	2	2	2	2	2

Both actual and flow-adjusted concentrations of total phosphorus were highest in late spring and summer and lowest in fall and winter. There were no significant changes in phosphorus concentrations from 1978 to 1987 (Shaw et al. 1990). On average, 80% of phosphorus in the Peace River at Dunvegan was particulate, and concentrations of total phosphorus were highly correlated to suspended solids ($r^2=0.88$; $df=124$; $P<0.001$). Thus, the seasonal pattern for total phosphorus concentrations followed the seasonal pattern for suspended solids concentrations (Shaw et al. 1990).

Recent data (Table 3.3.1) show that total phosphorus is about an order-of-magnitude higher during the rising hydrograph and lower in the winter. Although Shaw et al. (1990) found that total dissolved phosphorus was not affected by season, total dissolved phosphorus has been higher during the rising hydrograph every year since 1989 (Table 3.3.1). Mean winter concentrations of total phosphorus have decreased in the last three years (Fig. 3.3.2), although there has been little change in total and total dissolved nitrogen (Fig. 3.3.3).

There were sufficient data from Dunvegan to test nutrients for long-term monotonic[4] trends (Table 3.3.4). There were significant decreases in all nitrogen forms and no change in total and total dissolved phosphorus (test statistics shown in Table 3.3.4). For most flow-dependent variables, similar results were obtained for both actual and flow-adjusted concentrations. Possible reasons for the decreases in nitrogen concentrations are: (1) lower concentrations in the Williston Reservoir as a result of reservoir aging, and/or (2) a decrease in the nitrogen load to the river from sewage effluents and diffuse sources such as surface runoff of agricultural fertilizers.

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[4] In monotonic trends, the fluctuations about the trend do not increase or decrease.

Table 3.3.4
Kendall Tests for Long-term Trends in Data Collected in the Peace River Mainstem at Dunvegan, 1977 to 1988[a]

Variable	Test Statistic			Trend	
	Kendall	Seasonal[d] Kendall		Actual	Flow-Adjusted
Nitrogen (Dissolved)		-3.88[b]	(-3.40[b])	decrease	decrease
Nitrogen (Particulate)		-2.28[c]	(-0.66)	decrease	none
Nitrogen (Total)		-2.62[b]	(-2.14[c])	decrease	decrease
Nitrite + Nitrate		-2.53[b]	(-1.72)	decrease	none
Phosphorus (Total Dissolved)		-1.46		none	
Phosphorus (Total)		-0.81	(0.05)	none	none
Suspended Solids	-0.73			none	

a. For flow-dependent variables, results are given for both actual and flow-adjusted (inside brackets) concentrations.
b. Two-tailed $\alpha=0.01$: Critical value is 2.58
c. Two-tailed $\alpha=0.01$: Critical value is 1.96
d. The seasonal Kendall test is a generalization of the Mann-Kendall test which computes the Mann-Kendall test statistic and its variance separately for each season. It is used if seasonal cycles are present in the data so that these cycles will not interfere with the determination of trend.

Source: Shaw et al. 1990

3.3.2 Longitudinal Trends

Three relatively homogeneous sections of the river were identified by Shaw et al. (1990). The upstream reach, which extends from the British Columbia border to the Smoky River, has few tributaries and no direct effluent inputs. Municipal effluent from the Town of Dawson Creek affects the water quality of the Pouce Coupe River adversely, however, no effects on the water quality of the Peace River were found by Shaw et al. (1990) during the 1988-89 synoptic surveys.

The intermediate reach extends from the Smoky River to near Fort Vermilion. Concentrations of most constituents increase gradually along the intermediate reach as a result of tributary inputs, diffuse surface runoff from agricultural land, groundwater inflow and effluent discharge (Shaw et al. 1990). Water from the Smoky River, which is the largest tributary to the Peace River, does not mix fully with water of the Peace River for at least 100 km downstream (Shaw et al. 1990). Even though the Smoky River is the largest point source load for most constituents, there

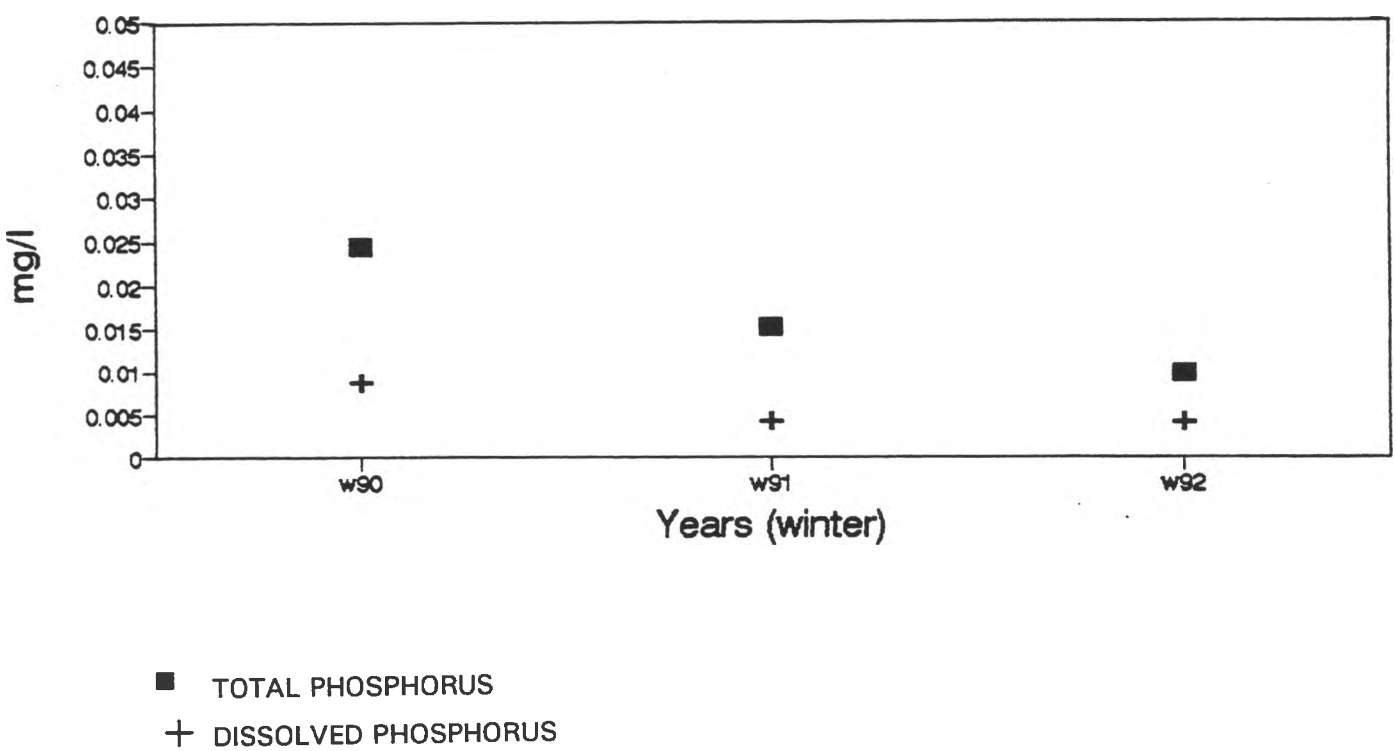

Figure 3.3.2

TOTAL AND DISSOLVED PHOSPHORUS CONCENTRATIONS IN THE PEACE RIVER AT FORT VERMILION, WINTER 1990-1992

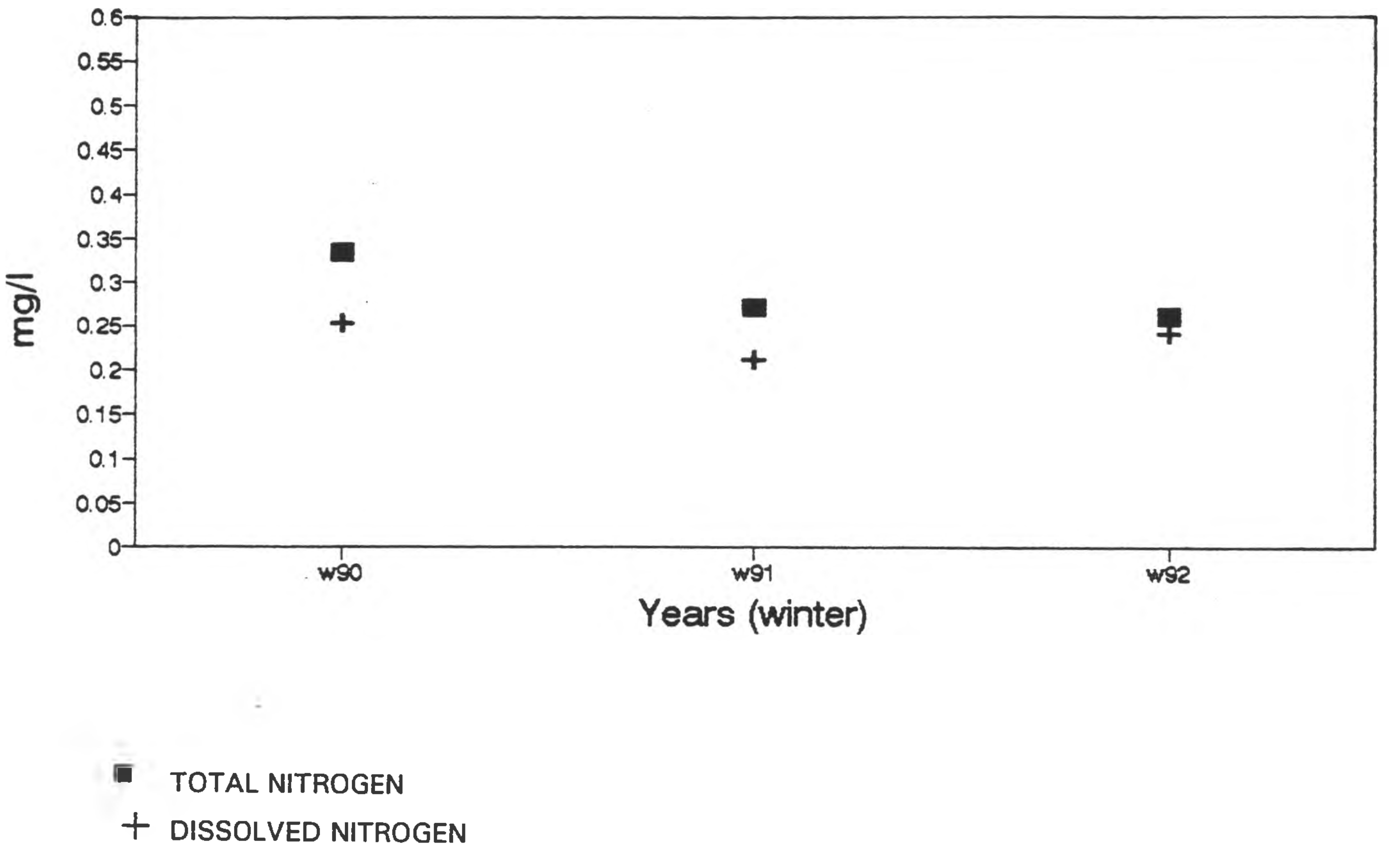

Figure 3.3.3

TOTAL AND DISSOLVED NITROGEN CONCENTRATIONS IN THE PEACE RIVER AT FORT VERMILION, WINTER 1990-1992 was no dramatic increase in concentrations (e.g. phosphorus in Fig. 3.3.4 and nitrogen in Fig. 3.3.5) in the Peace River downstream of the Smoky River (Shaw et al. 1990). Concentrations of phosphorus and inorganic nitrogen were considerably higher in the Smoky River than in the Peace River (Figs. 3.3.6 and 3.3.7); elevated levels of these constituents would be expected in the Smoky River plume which was not sampled.

The downstream reach extends from Fort Vermilion to the mouth of the Peace River. Water quality is partly influenced by the quality of natural tributary inflows, but more strongly by a change from gravel to sand and silt in the river bed and bank, which cause an increase in suspended solids. The Wabasca River, which is the second largest tributary source load to the Peace River occurs in this reach.

Total phosphorus concentrations in the Peace River increased significantly with distance (Fig. 3.3.4) (Shaw et al. 1990). The results of May 1988 to March 1989 survey showed that mean concentrations of total phosphorus increased along the Peace River from 0.07 mg/L at the BC-Alberta border to 0.37 mg/L at Peace Point, largely due to the increase in suspended solids concentrations. Mean concentrations of total phosphorus in the tributaries were quite variable, although generally higher than in the mainstem (Fig. 3.3.6). Particulate phosphorus accounted for 75% of total phosphorus during the 1988-89 surveys. Mean total dissolved phosphorus concentrations along the mainstem followed a similar longitudinal pattern to that observed for total phosphorus (Fig. 3.3.4). Mean concentration of total dissolved phosphorus in the tributaries were always higher than in the mainstem (Fig. 3.3.6).

Both the historical and the May 1988 to February 1989 survey data presented by Shaw et al. showed that most samples from the mainstem and tributaries were non-compliant with the ASWQO of 0.05 mg/L total phosphorus. Shaw et al. (1990) attributed non-compliance to naturally high suspended solids concentrations.

The May 1988 to February 1989 survey showed that mean concentrations of total nitrogen along the Peace River increased from approximately 0.3 mg/L near the BC-Alberta border to 0.9 mg/L near Peace Point (Fig. 3.3.5) (Shaw et al. 1990). Mean concentrations of total nitrogen in the tributaries were higher than in the mainstem (Fig. 3.3.7). Even so, loading from the tributaries that were sampled could not account for the longitudinal increase along the mainstem. Rather, the increase in total nitrogen concentrations was attributed to increased concentrations of suspended solids in the lower reaches of the river by Shaw et al. (1990) because the concentrations of total nitrogen and suspended solids were highly correlated (1988-89 mainstem data: $r=0.74$; $df=68$, $P<0.001$).

In both the mainstem and tributaries, total nitrogen was largely organic. TKN minus ammonia averaged 87% of total nitrogen in 1988-89 survey (Shaw et al. 1990). In winter, the inorganic fraction was predominantly nitrite-nitrate (as nitrogen) and in summer predominantly ammonia (as nitrogen). Data for the last three years (Table 3.3.3) shows that non-winter data is not dominated by either ammonia or nitrite-nitrate. Similar to total nitrogen, ammonia (as nitrogen) concentrations were highest in the lower reaches of the river, although there was an initial decline in concentrations from the BC-Alberta border to the confluence with the Smoky River; average concentrations were considerably higher in the tributaries than in the mainstem (Fig. 3.3.7) (Shaw et al. 1990). Average concentrations of nitrite-nitrate (as nitrogen) were relatively constant along the mainstem (Fig 3.3.5) and mean concentrations in the tributaries were similar to, or only slightly higher than, the mainstem.

Particulate nitrogen formed 89% of the total nitrogen in the rising hydrograph in 1990 and 1991 but dissolved nitrogen was dominant in 1992 (Table 3.3.3). Dissolved nitrogen made up 81% of the total nitrogen under ice for the last three years. The dissolved nitrogen was predominantly organic (dissolved total Kjeldahl nitrogen - ammonia nitrogen).

Both historical and current data indicate that total nitrogen values from the mainstem and most tributaries were often non-compliant with the Alberta Surface Water Quality Objective of 1.0 mg/L total nitrogen.

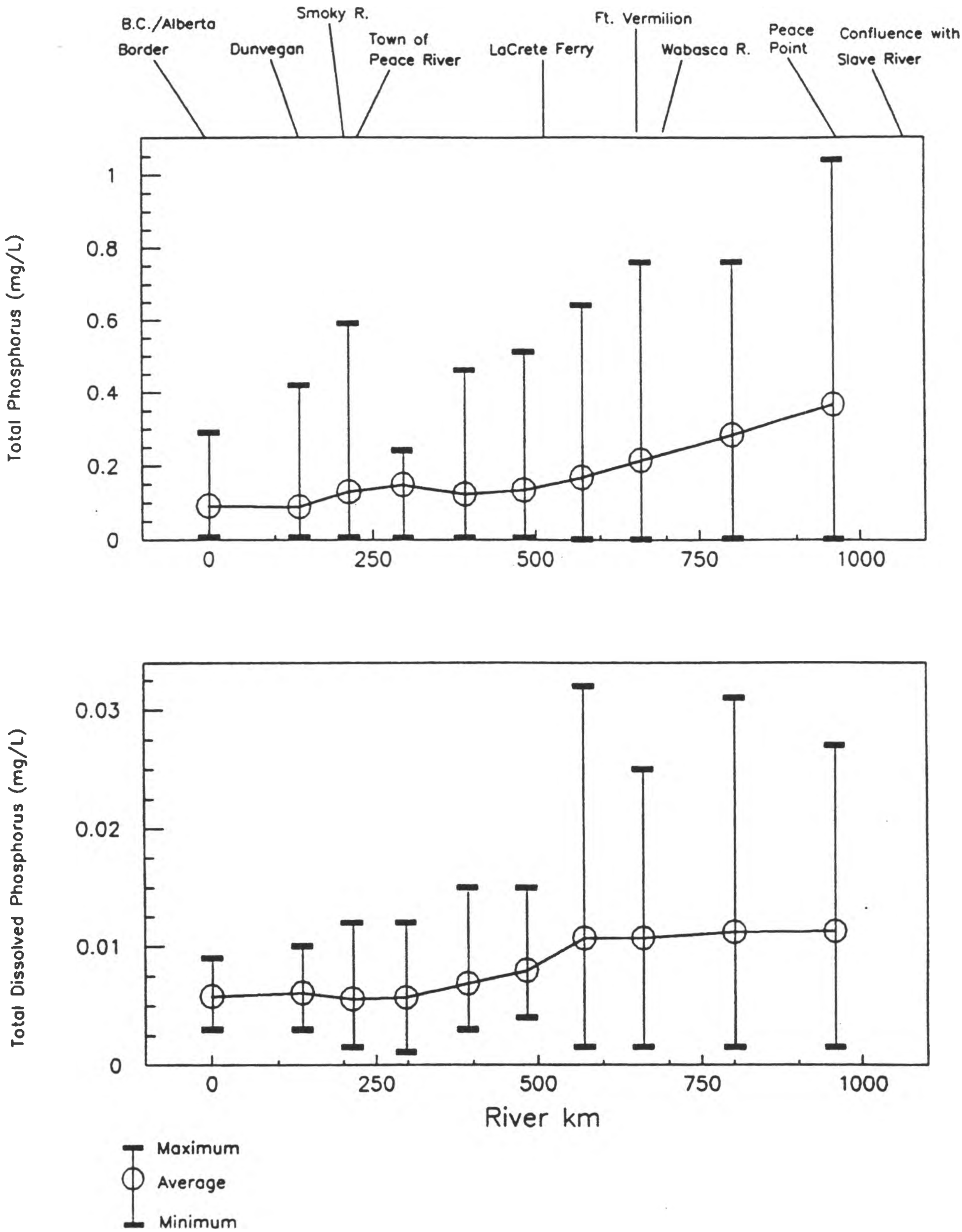

Figure 3.3.4

TOTAL AND TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS IN THE PEACE RIVER, 1988-89

(SHAW ET AL. 1990)

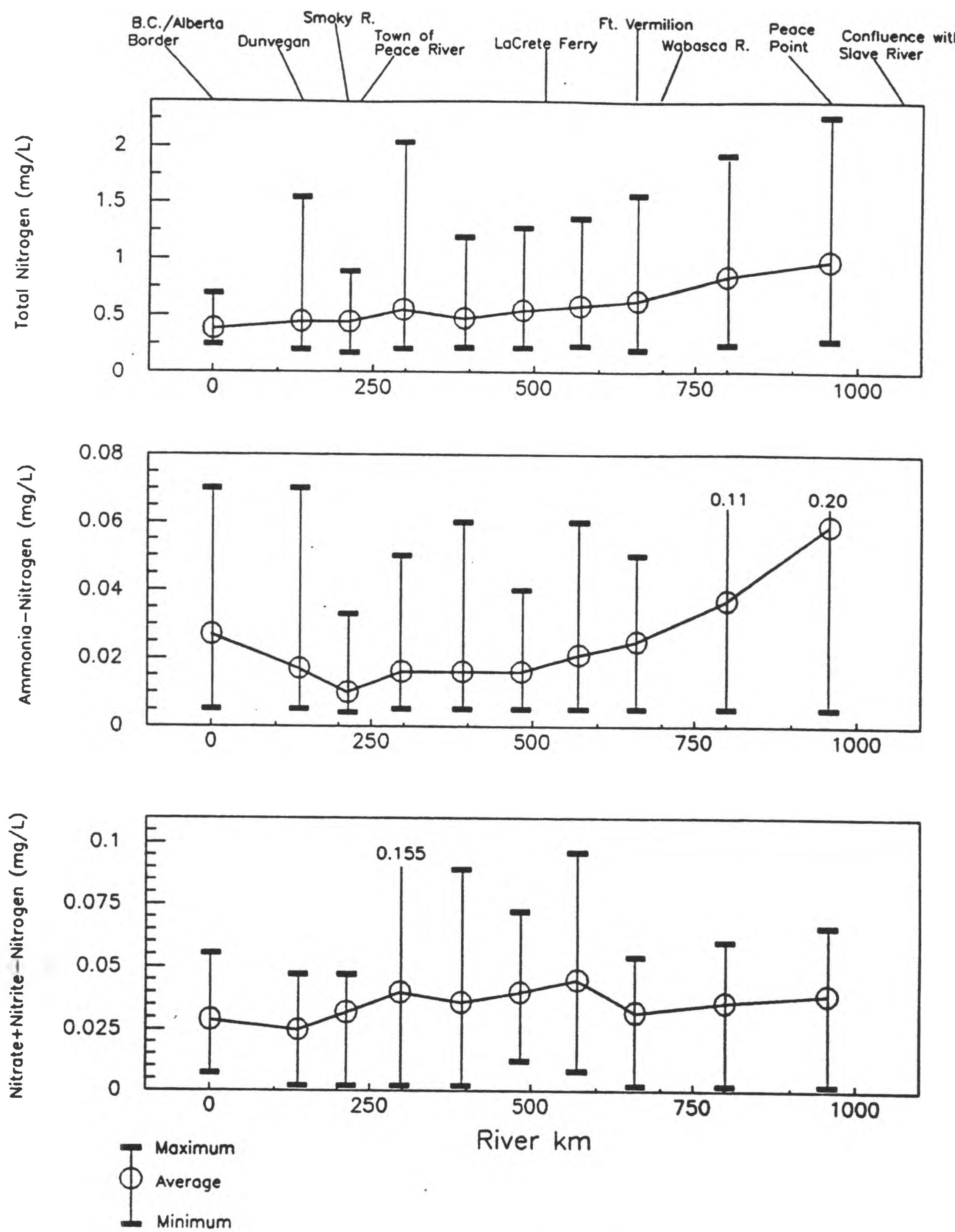

Figure 3.3.5

TOTAL NITROGEN, AMMONIA AND NITRATE+NITRITE CONCENTRATIONS IN THE PEACE RIVER, 1988-89

(SHAW ET AL. 1990)

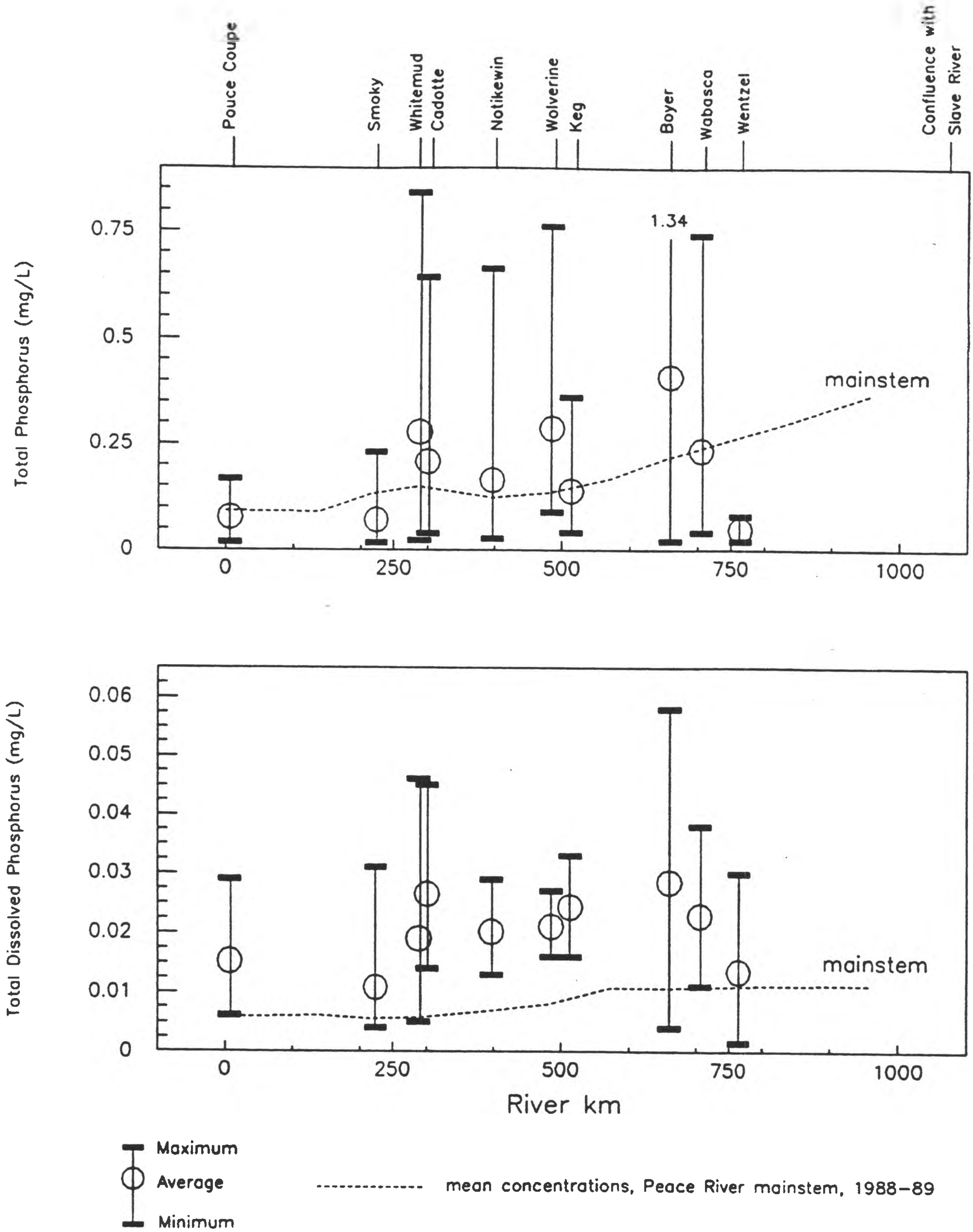

Figure 3.3.6

TOTAL AND TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS IN TRIBUTARIES TO THE PEACE RIVER, 1988-89

(SHAW ET AL. 1990)

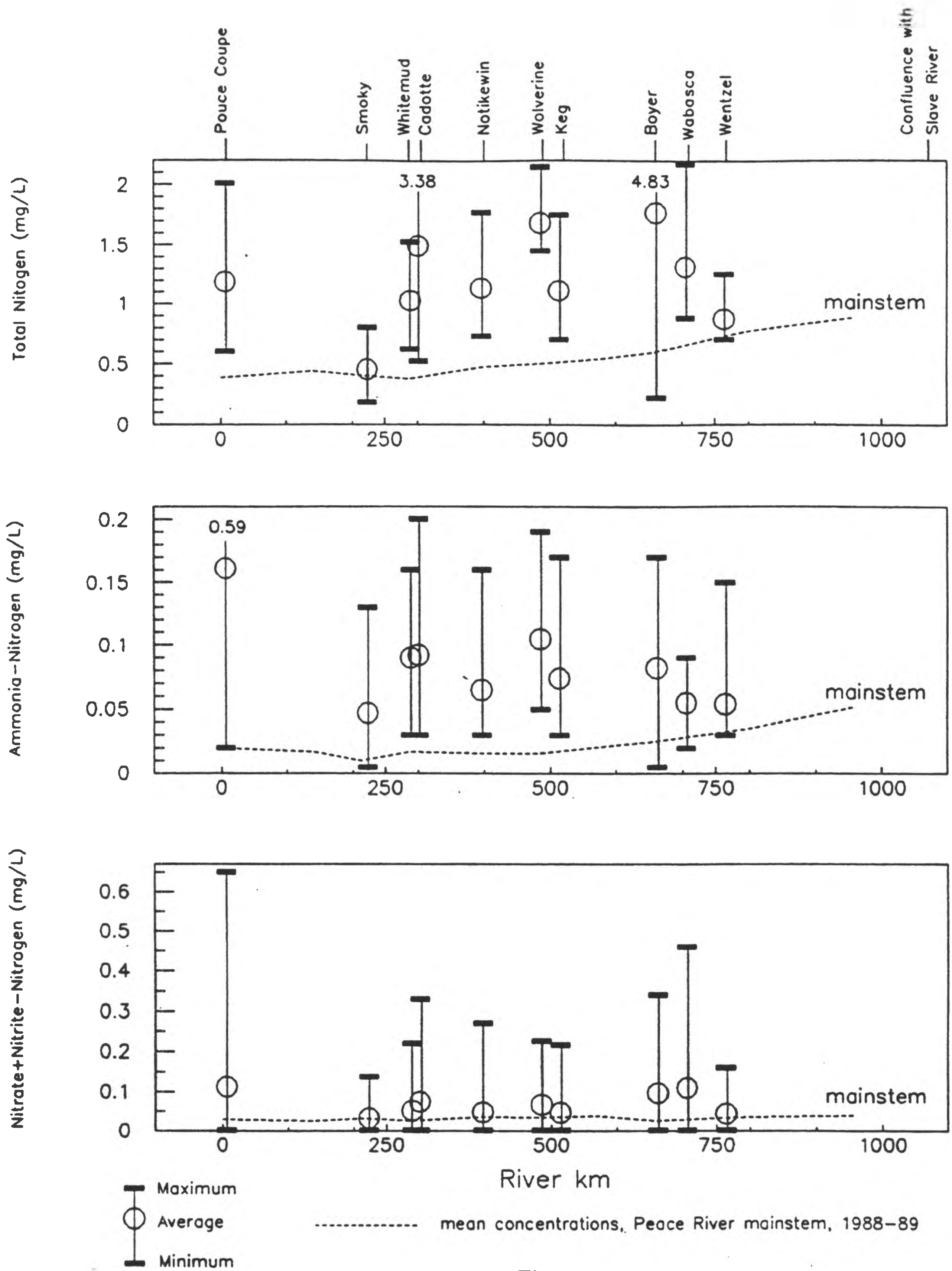

Figure 3.3.7

TOTAL NITROGEN, AMMONIUM AND NITRATE+NITRITE CONCENTRATIONS IN TRIBUTARIES TO THE PEACE RIVER, 1988-89

(SHAW ET AL. 1990)

3.3.3 Instream Nutrient Concentrations Measured in the Vicinity of Point Sources

The Peace River Pulp Division of Daishowa Canada Co. Ltd. monitors nutrients during its benthic invertebrate studies (Monenco 1990a,b,d; 1991a; 1992a,b) (Appendix Table B.7). Total phosphorus values show a seasonal pattern with spring highs reaching a maximum of 0.982 upstream of the mill in 1991. No impact from the mill effluent was evident from the total phosphorus or total Kjeldahl nitrogen data (Appendix Table B.7; location of sampling sites in Fig. 4.1.9).

3.3.4 Nitrogen and Phosphorus Mass Transport

Mass transport of constituents was evaluated at selected sites along the mainstem and at all tributaries and effluents that were sampled in May 1988 to February 1989 to (1) identify the major point-source loads to the river, and (2) determine whether loading from the tributaries and/or effluents could account for the observed longitudinal changes in water quality of the Peace River mainstem (Shaw et al 1990). Mass loads were calculated as the average concentration times the average discharge, as measured during the synoptic surveys. Surveys were not evaluated individually.

For the May 1988 to February 1989 survey, Shaw et al. (1990) calculated mass transport of nutrients for selected sites along the mainstem and for all tributaries and effluents that were sampled. The mass loads from the tributaries and effluents are summarized in Table 3.3.5 as a percentage of the upstream load in the Peace river mainstem (i.e. load in mainstem upstream of confluence of tributary or point of effluent discharge). The Smoky and Wabasca Rivers contribute the largest percentage of nutrients to the Peace River followed by the Notikewin, Boyer and Wolverine rivers.

A synoptic survey was carried out on the Peace River by Alberta Environment in the winter of 1991. There were no surveys on the Peace River in 1990 or 1992. The 1991 survey data included measurements of nutrients but not discharge, therefore, Water Survey of Canada data are used in this report to calculate mass loading. The synoptic survey contained data for the mainstem of the Peace River and anthropogenic point sources. Other than data from the Smoky River, there are no data for tributaries. Tables 3.3.6 and 3.3.7 show the longitudinal changes in nutrient load in the mainstem.

The 1991 synoptic data do not show a continuous downstream increase in the total phosphorus loading during the winter. The loading measured near Carcajou downstream of the Wolverine River is similar to the loading 20 km upstream of the Town of Peace River. The mean and standard deviation were greater at Fort Vermilion during this survey. A similar pattern occurs for nitrogen loading during the winter; total nitrogen load upstream of the Town of Peace River equals the load for Fort Vermilion, the downstream site. Anthropogenic point sources contributed 409 kg/d of total nitrogen or 1.6% of the instream load of total nitrogen. These point sources contributed 94.3 kg/d of total phosphorus or 3-4% of the instream load of total phosphorus.

TABLE 3.3.5
Mean Tributary and Effluent Load as a Percent of Upstream Load in the Peace River, 1988-1989[a]

	Phosphorus		Nitrogen			
	Total	Total Dissolved	Ammonia	Nitrite + Nitrate	Total Kjeldahl	Total
Pouce Coupe	0.2	0.5	1.4	0.7	0.6	0.6
Peace River Correctional Institute STP	0.0	0.0	0.0	0.0	0.0	0.0
Smoky	7.2	26.1	64.5	14.0	15.1	15.0
Grande Prairie STP	0.1	2.0	2.3	0.4	0.1	0.1
Weyerhaeuser	0.4	4.7	4.6	0.2	1.2	1.1
Peace River STP	0.1	1.7	3.3	0.0	0.1	0.1
Peace River Oils	0.0		5.7	0.0	0.2	0.2
Whitemud	1.7	1.7	2.5	0.9	1.4	1.3
Cadotte	1.1	2.0	2.1	1.1	1.7	1.6
Notikewin	2.9	6.5	9.0	2.9	5.5	5.3
Wolverine	2.3	2.9	6.4	1.8	3.6	3.5
Keg	0.4	1.1	1.6	0.5	0.9	0.8
Boyer	3.3	4.6	5.5	6.6	4.8	4.9
Wabasca	10.2	21.0	21.5	43.5	20.0	21.0
Wentzel	0.3	1.3	2.3	1.8	1.5	1.5

a. Table from Shaw et al. 1990

Note: Ft. Vermilion STP discharges approximately 20 days per year and was only sampled once during the survey. Effluent loads from this source were negligible compared to background loads in the Peace River, thus, it was excluded from this table.

TABLE 3.3.6
Mass Loading Balance for Total Phosphorus in the Peace River During the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Phosphorus			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Peace R. Downstream Shaftbury Ferry (≈20 km upstream Peace R.)	1	11/03/91	131 747 904	0.015 ±0.011		1932 ±1521	3
Smoky R.	1	11/03/91	3 888 000	0.024		93	1
Peace R. Sewage	1	11/03/91	3 370	4.70		16	1
Peace R. Downstream Peace R.	1	12/03/91	135 651 370	0.01 ±0.00	2041	1357 ±0	2
Peace R. Pulp Division Effluent	2	11/03/91	52 531	1.49 ±0.01		78 ±1	2
Peace R. 22 km Downstream Peace R.	1	12/03/91	135 703 901	0.01	1435	1357	1
Peace River Oils #1 Spring	1	12/03/91	5 357	0.055		0.3	1
Peace R. Upstream Whitemud Cr.	1	12/03/91	135 711 072	0.01 ±0.00	1357	1312 ±78	3
Peace R. Upstream Buchanan Cr.	1	12/03/91	135 711 824	0.007 ±0.002		995 ±207	3
Peace R. Near Carcajou	1	18/03/91	135 715 824	0.014		1900	1
Peace R. at Hwy 67 - Ft. Vermilion	1	18/03/91	135 715 910	0.022 ±0.011		3047 ±1449	2

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

TABLE 3.3.7
Mass Loading Balance for Total Nitrogen in the Peace River During the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Nitrogen			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Peace R. Downstream Shaftbury Ferry (≈20 km upstream Peace R.)	1	11/03/91	131 747 904	0.18 ±0.03		23 671 ±3536	3
Smoky R.	1	11/03/91	3 888 000	0.374		1454	1
Peace R. Sewage	1	11/03/91	135 651 370	24.76		83	1
Peace R. Downstream Peace R.	1	12/03/91	135 651 370	0.137 ±0.071	25 208	18 539 ±9624	3
Peace R. Pulp Division	2	11/03/91	52 531	2.89 ±0.18		152 ±9	2
Peace R. 22 km Downstream Peace R.	1	12/03/91	135 703 901	0.14	18 691	18 998	1
Peace River Oils #1 Spring	1	12/03/91	5 357	32.51		174	1
Peace R. Upstream Whitemud Cr.	1	12/03/91	135 711 072	0.116 ±0.049	19 172	15 742 ±6621	5
Peace R. Upstream Buchanan Cr.	1	12/03/91	135 711 824	0.11 ±0.04		14 386 ±5726	5
Peace R. Near Carcajou	1	18/03/91	135 715 824	0.15		20 357	1
Peace R. at Hwy 67 - Ft. Vermilion	1	18/03/91	135 715 910	0.19 ±0.02		25 108 ±2879	2

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

3.4 WAPITI-SMOKY RIVERS

3.4.1 Longitudinal Trends

The lower Wapiti, the Smoky and the Peace River near the confluence with the Smoky were sampled in March, May, September and November 1983, a year of average flows (Noton et al. 1989). Background ammonia nitrogen levels in the Wapiti River at Highway 40 and the Smoky River upstream of the Wapiti River ranged from 0.005 to 0.120 mg/L, but the concentration of ammonia nitrogen in the Wapiti River near the confluence with the Smoky River exceeded 0.2 mg/L in March. The high levels may have been due to the Grande Prairie sewage lagoon discharge which was at that time discharged to the Bear River in the spring and fall and the Procter and Gamble (now Weyerhaeuser) pulp mill effluent (Noton et al. 1989).

The surveys in 1983 were followed up by further work in 1987-1991 which included more sites on the Wapiti River and more surveys during low flows (Noton 1992a). During these surveys, total nitrogen and total phosphorus concentrations for the Wapiti-Smoky River System were above the Alberta Surface Water Quality Objectives (ASWQO) on at least one occasion (Noton 1992a) (Fig. 3.4.1 and 3.4.2). Large increases in total nitrogen on the Wapiti River were attributed to the combined influence of the Grande Prairie sewage and the pulp mill effluent. A large increase in total phosphorus on the Wapiti River was attributed to these two sources and the tributaries (Noton 1992a). Concentrations of total phosphorus were usually higher than the ASWQO of 0.05 mg/L. The one exception was total phosphorus in the 1991 synoptic survey of the Smoky River where concentrations remained below 0.03 mg/L (Fig 3.4.1). Levels of total nitrogen were greater than the ASWQO of 1.0 mg/L in the Wapiti River downstream of the discharges in 1989 but, with one exception, levels of total nitrogen were below the ASWQO during other recent surveys (Fig. 3.4.1).

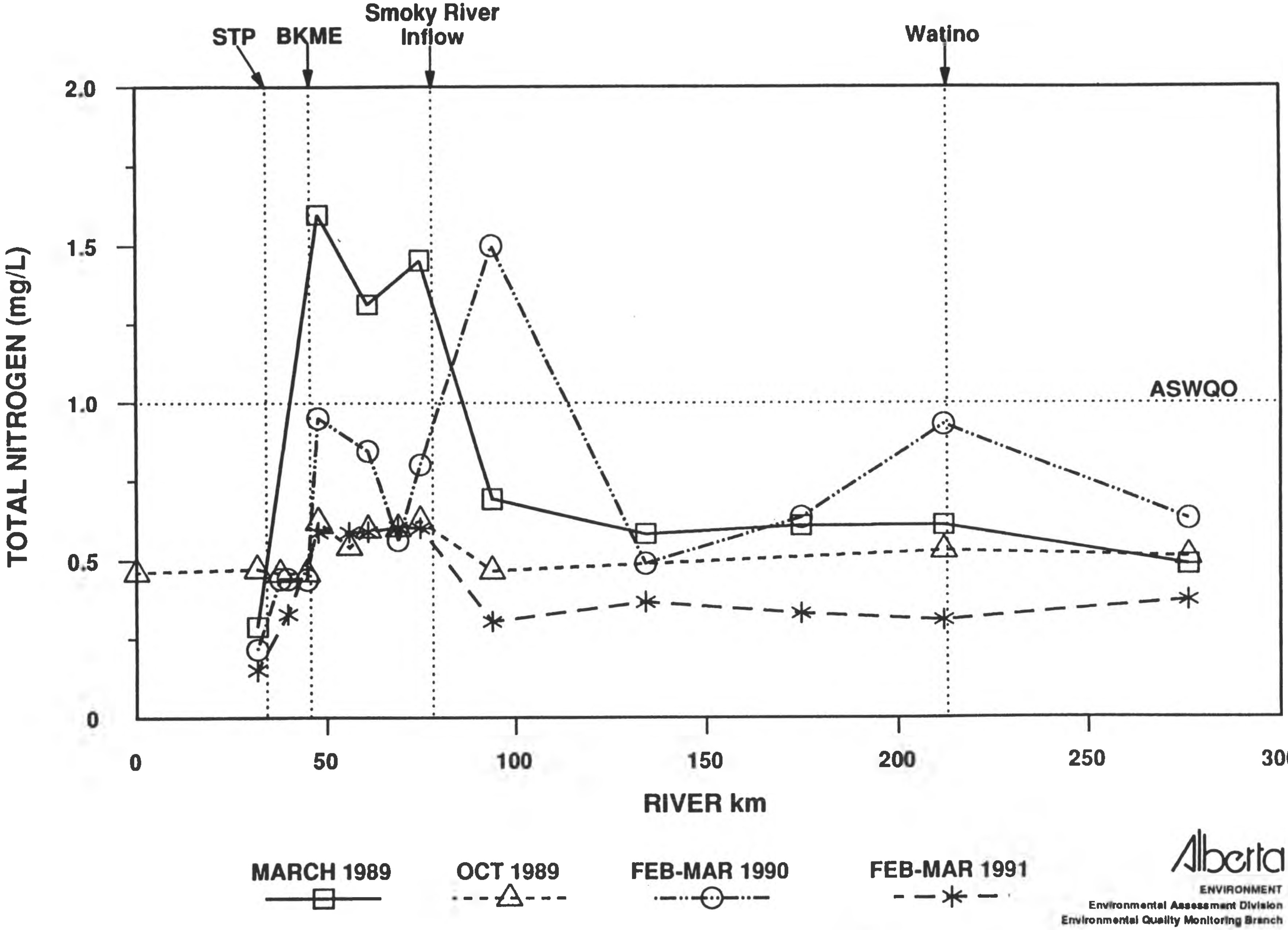

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Figure 3.4.1

TOTAL NITROGEN IN THE WAPITI-SMOKY RIVER SYSTEM
(from Noton 1992a)

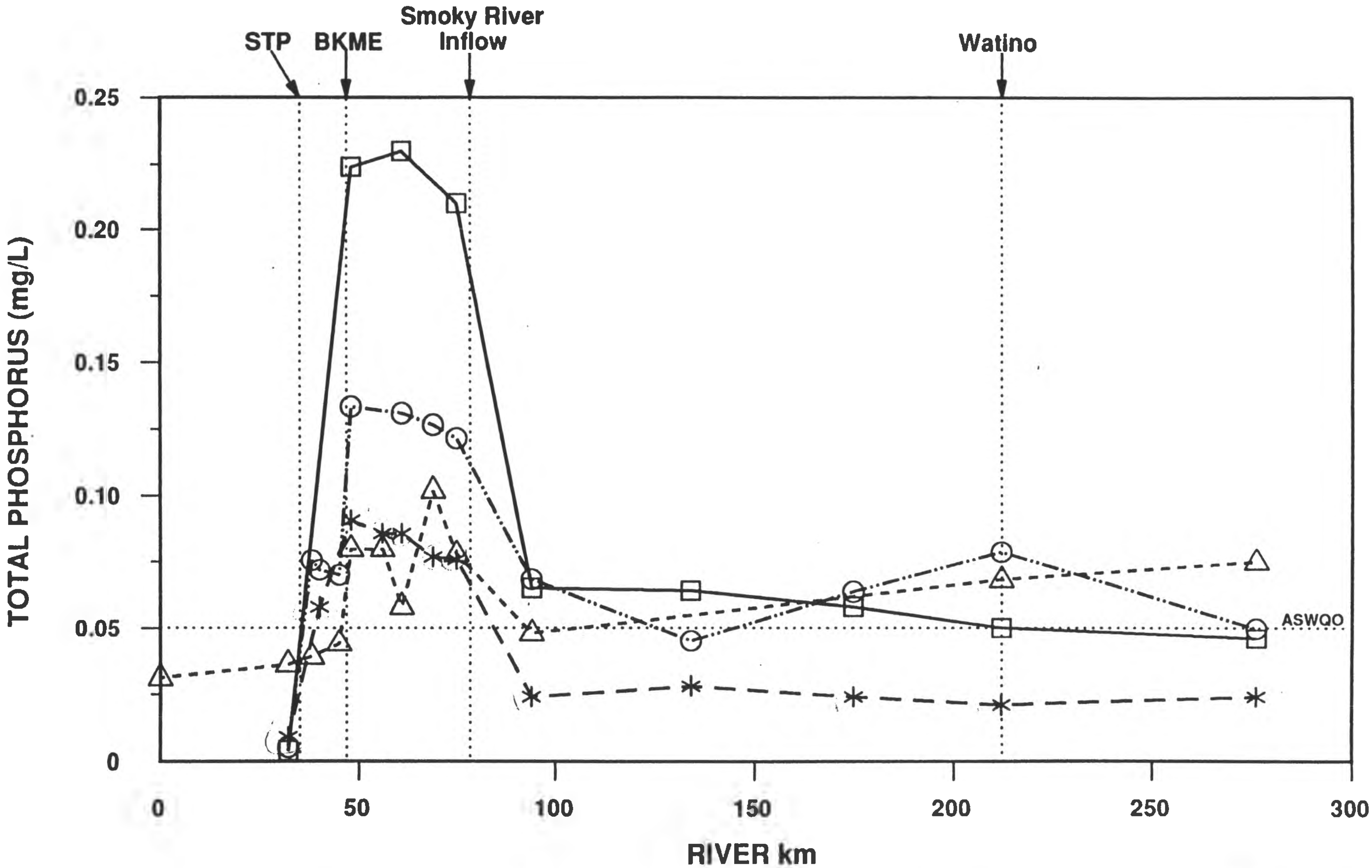

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Figure 3.4.2

TOTAL PHOSPHORUS IN THE WAPITI-SMOKY RIVER SYSTEM
(from Noton 1992a)

3.4.2 Seasonal and Annual Trends

The year to year variation in the Alberta Environment synoptic surveys (Noton 1992a) is likely due to variations in dilution since river flows were lowest in 1989 and highest in 1991. The flow on 01 March 1989 at Grande Prairie was below the 7Q10 while the flow in 27 February 1991 was above the long term (1960-88) average (Table 3.4.1).

Table 3.4.1
Discharge in the Wapiti River at Highway 40
Near Grande Prairie During Synoptic Surveys

Date	Discharge (m^3/s)
01 March 1989	5.0
27 February 1990	13.0
27 February 1991	16.0
Mean February (1960-1988)	13.2
7Q10	6.95

Source: Noton 1992.

For this report, nutrient data for 1982 to 1992 from the long-term monitoring site at Watino was divided into three flow-rated categories: winter (under ice), rising hydrograph and falling hydrograph (Table 3.4.2). Over the last ten years, total phosphorus concentrations have been about an order-of-magnitude greater in the rising hydrograph than during the winter (Table 3.4.2), due to increases in particulate phosphorus. The dissolved phosphorus concentrations were similar in the winter and the rising hydrograph. In most years, the lowest mean concentration of dissolved phosphorus in the river occurred in the falling hydrograph. The low values may be due to greater algal uptake since it coincides with the greater growth of epilithic algae in the fall (see also Section 4.2). Concentrations of total and dissolved phosphorus vary considerably over the ten years (Table 3.4.2), but no upward or downward trend is discernable (Fig. 3.4.3).

TABLE 3.4.2
Mean Concentrations of Nutrients in the Smoky River at Watino

Date		Under Ice				Rising Hydrograph				Falling Hydrograph			
		Nitrogen		Phosphorus		Nitrogen		Phosphorus		Nitrogen		Phosphorus	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
1982	Mean	0.254	0.223	0.020	0.010	0.879	0.263	0.294	0.023	0.409	0.200	0.144	0.017
	Std. Dev.	0.062	0.043	0.009	0.002	0.628	0.169	0.262	0.019	0.379	0.089	0.189	0.011
	N	4	4	4	4	4	4	4	4	4	4	4	4
1983	Mean	0.211	0.183	0.054	0.017	0.968	0.288	0.331	0.030	0.253	0.168	0.037	0.010
	Std. Dev.	0.048	0.015	0.189	0.011	0.597	0.131	0.264	0.005	0.053	0.015	0.022	0.001
	N	4	4	4	4	4	4	4	4	4	4	4	4
1984	Mean	0.300	0.235	0.044	0.012	0.463	0.170	0.258	0.021	0.263	0.138	0.075	0.005
	Std. Dev.	0.070	0.074	0.044	0.005	0.160	0.078	0.189	0.009	0.126	0.071	0.070	0.004
	N	4	4	4	4	4	4	4	4	4	4	4	4
1985	Mean	0.495	0.325	0.079	0.016	0.588	0.140	0.178	0.014	0.313	0.137	0.100	0.006
	Std. Dev.	0.327	0.184	0.072	0.013	0.359	0.091	0.064	0.015	0.042	0.026	0.035	0.003
	N	4	4	4	4	4	4	4	4	3	3	3	3
1986	Mean	0.395	0.320	0.051	0.033	1.025	0.210	0.430	0.015	0.158	0.115	0.032	0.006
	Std. Dev.	0.242	0.181	0.057	0.036	0.869	0.112	0.368	0.011	0.063	0.048	0.016	0.003
	N	4	4	4	4	4	4	4	4	4	4	4	4
1987	Mean	0.404	0.364	0.024	0.014	0.533	0.288	0.113	0.013	0.509	0.299	0.051	0.007
	Std. Dev.	0.177	0.169	0.007	0.008	0.246	0.101	0.036	0.011	0.275	0.132	0.060	0.002
	N	3	3	3	3	2	2	4	4	2	4	4	4
1988	Mean		0.405	0.021	0.009	0.710	0.290	0.178	0.008	0.254	0.209	0.017	0.006
	Std. Dev.		0.066	0.014	0.003	0.087	0.066	0.061	0.002	0.104	0.119	0.007	0.002
	N		4	4	4	4	4	4	4	4	4	4	4
1989	Mean	0.545	0.485	0.038	0.028	1.110	0.543	0.241	0.011	0.549	0.394	0.117	0.008
	Std. Dev.	0.080	0.066	0.012	0.011	0.000	0.345	0.133	0.006	0.190	0.081	0.136	0.004
	N	4	4	4	4	1	4	4	4	4	4	4	4
1990	Mean	0.868	0.672	0.102	0.056	1.020	0.355	0.423	0.013	0.194	0.114	0.020	0.003
	Std. Dev.	0.514	0.320	0.073	0.039	0.602	0.119	0.335	0.004	0.049	0.075	0.010	0.001
	N	4	4	5	5	4	4	4	4	3	3	3	3
1991	Mean	0.498	0.437	0.030	0.016	0.841	0.361	0.348	0.026	0.351	0.306	0.044	0.006
	Std. Dev.	0.085	0.092	0.014	0.010	0.470	0.113	0.130	0.007	0.215	0.203	0.039	0.006
	N	3	4	4	4	3	3	3	3	5	5	5	5
1992	Mean	0.729	0.529	0.056	0.016	0.546	0.179	0.133	0.006	0.538	0.268	0.065	0.028
	Std. Dev.	0.350	0.204	0.050	0.008	0.438	0.147	0.108	0.007	0.106	0.176	0.010	0.036
	N	3	3	3	3	3	3	4	4	3	3	3	3

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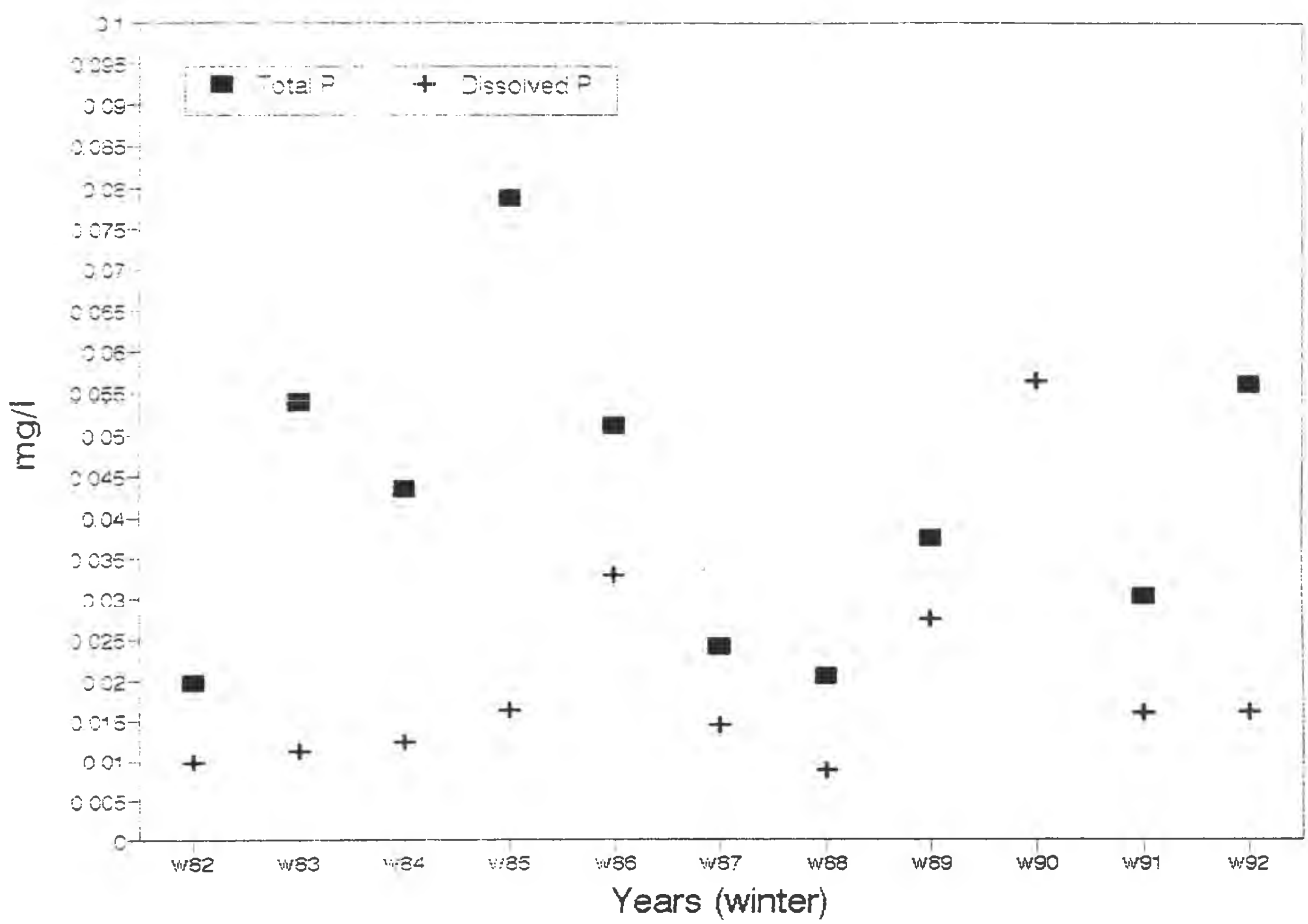

Figure 3.4.3

TOTAL AND DISSOLVED PHOSPHORUS CONCENTRATIONS, SMOKY RIVER AT WATINO

In the last ten years (except 1992), total nitrogen concentrations are greatest during the rising hydrograph due to an increase in particulate nitrogen but not dissolved nitrogen. Concentrations of dissolved nitrogen are visually lowest in the falling hydrograph coinciding with increased algal growth in the late summer and fall. Over the 1982 to 1992 period, winter concentrations of total and dissolved nitrogen have gradually increased (Fig. 3.4.4).

3.4.3 Instream Nutrient Concentrations Measured in the Vicinity of Point Sources

Some nutrients measured in the Wapiti River by TAEM during the benthic invertebrate monitoring for the Weyerhaeuser pulp mill increased due to the pulp mill effluent (Appendix Table B.8; locations of sampling sites shown in Fig. 4.1.11). Ammonia and ortho-phosphate increased marginally in samples collected during the October 1990 survey, but were unchanged in the April 1991 survey (Appendix Table B.8). The April 1991 results may reflect the greater river flows and resulting increased effluent dilution. Alberta Environment found evidence of ammonification in the Wapiti River (Noton 1992) during their winter synoptic surveys.

The other nutrient parameters, total Kjeldahl nitrogen (TKN) and total phosphorus, increased due to the pulp mill effluent during both the October 1990 and the April 1991 surveys. In October 1990 a small increase in TKN was found at downstream sites O1, O2 and O3 (Appendix Table B.8; refer to Fig. 4.1.11 for location) with the largest increase occurring at stations O4 and O5 (Appendix Table B.8), which appear to be influenced by the high TKN at Bear Creek. Similar increases in TKN at O4 and O5 below Bear Creek were found in April 1991. In October 1990, elevated levels of total phosphorus were found at stations O1 and O2, the first two stations located below the pulp effluent outfall; total phosphorus returned to background levels at the downstream stations. Elevated levels were also found in Bear Creek (Appendix Table B.8). Total phosphorus increased at all sites during the April 1991 survey.

In January 1992, ammonia was the only nutrient affected by treated pulp effluent when compared to the control stations. Ammonia levels increased in samples collected from the observations stations (Appendix Table B.8). The other nutrient parameters measured, dissolved phosphorus and ortho-phosphate, were not influenced by the treated pulp effluent in January 1992.

3.4.4 Nutrient Transport

The synoptic surveys of the Wapiti River and Smoky River carried out by Alberta Environment during the winters of 1990, 1991 and 1992 were used to calculate trial balances of discharges from the Wapiti River at Highway 40 to the Smoky River at Watino. Their data were compared to Water Survey of Canada(WSC) data available for these two locations.

In 1991, the AE and WSC discharge values for the most upstream location, the Wapiti River at Highway 40, were similar (Table 3.4.3). The Grande Prairie sewage treatment plant effluent, the Weyerhaeuser effluent and stormwater, and the discharge of a small creek are the measured downstream inputs. There is no measured value for the mainstem of the Wapiti River before it joins the Smoky River; therefore, the running total of 17.598 m^3/s cannot be compared to a measured value (Table 3.4.3). The discharge for the Smoky River at Bezanson is calculated as a running total from the upstream stations. Below this point, the running total for upstream stations is calculated by subtracting inputs from the downstream value at Watino measured by Alberta Environment. The WSC values agree with the Alberta Environment value at Watino.

The difference in the running total between the Smoky River at Bezanson on March 1 of 46.92 m^3/s (calculated from measured upstream values) and the Smoky River below the Puskwaskau River on March 5 of 36.26 m^3/s (calculated from measured downstream values) is 10.67 m^3/s. Over the sampling period, the discharge at Watino dropped from 46.92 m^3/s on March 1 to 34.9 m^3/s on March 6. It is possible that the synoptic survey was not following the exact time-of-travel of the river and part of the discrepancy can be explained by the falling hydrograph. The difference remains, however, and will affect the nutrient balance.

A trial balance of discharges has been calculated for 1990 (Appendix Table C.4) in a manner similar to that described above for 1991 (Table 3.4.3). According to WSC data, the Smoky River at Watino rose from 64.6 m^3/s on March 1 to 81.6 m^3/s on March 8, an increase of 17 m^3/L. This increase may explain, in part, the difference between the running total of 59.357 m^3/s and the measured value of 81.0, a difference of 21.6 m^3/s (Appendix Table C.4). The WSC data for 1992 was not available to verify the Alberta Environment data. Therefore, trial balances were done for 1990 and 1991 only.

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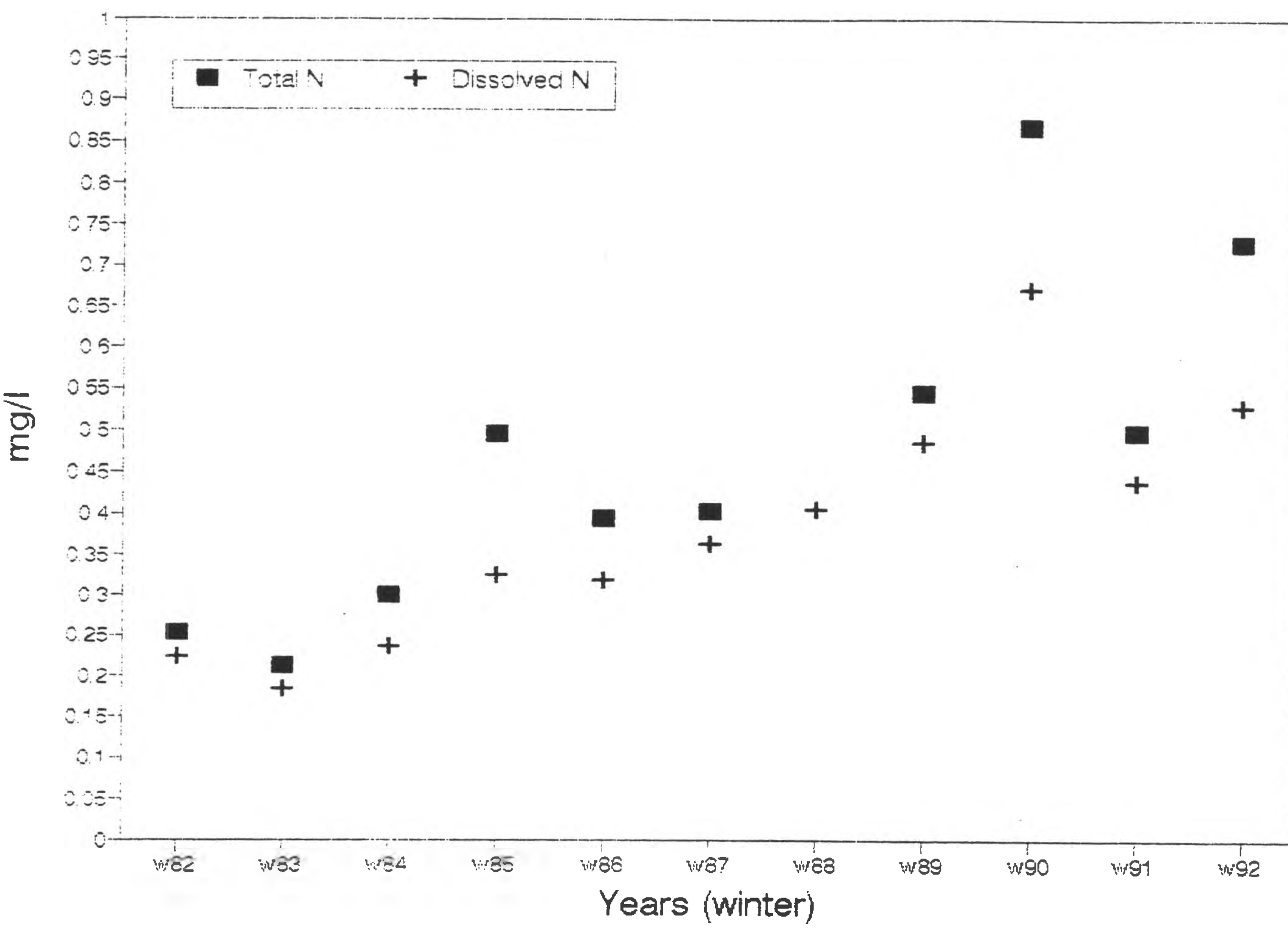

Figure 3.4.4

TOTAL AND DISSOLVED NITROGEN CONCENTRATIONS, SMOKY RIVER AT WATINO

TABLE 3.4.3
Wapiti-Smoky Rivers Discharge During the 1991 Synoptic Survey

Station	Alberta Environment						Water Survey of Canada			
	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Wapiti River (m^3/s)	Calculated Running Total (Wapiti R.) (m^3/s)	Smoky River (m^3/s)	Calculated Running Total (Smoky R.) (m^3/s)	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Wapiti River ($m^3/$)	Smoky River (m^3/s)
Wapiti R. at Hwy 40	27/02/91		16.0				27/02/91		15.7	
Grande Prairie Sewage	27/02/91	0.225		16.225						
Weyerhaeuser Effluent	26/02/91	0.735		16.96						
Weyerhaeuser Storm Sewer	27/02/91	0.016		16.976						
Bear Cr.	28/02/91	0.622		17.598						
Smoky R. Upstream Wapiti R.	28/02/91				25.70					
Smoky R. Downstream Wapiti R.	28/02/91					43.298				
Simonette R.	28/02/91						01/03/91	3.62		
Smoky R. at Bezanson	01/03/91					46.92				
Puskwakau R.	05/03/91	0.003				36.26	05/03/91	4.78		
Little Smoky R.	05/03/91	3.240				39.5				
Smoky R. at Watino	05/03/91				39.5[a]		05/03/91			39.5
Smoky R. at Watino	06/03/91				34.10		06/03/91			34.9

a. Water Survey of Canada data

The differences between measured and calculated values were less in 1991 than in 1990. The nutrient balance will be done on 1991 data for this reason and also to be consistent with other Sections of the report. The trial balance has demonstrated differences in mainstem discharge values calculated from tributary and effluent inputs compared to discharges measured on the mainstem at downstream locations. A review of trends in the WSC hydrograph over the sampling period suggests that the differences may be due, at least in part, by rapid changes in discharge. This problem would be greater in seasons of the year when fluctuations in discharge are greater than winter fluctuations. The difference may also be due, in part, to water losses that are not accounted for. The causes cannot be isolated without more data points on the mainstem of the river.

In February 1991, the mass of total phosphorus in the Wapiti River increased from 12 kg/d at Highway 40 to 116 kg/d near the mouth, an order-of-magnitude increase (Table 3.4.4). In this synoptic survey, the contribution of total phosphorus from all anthropogenic point sources on the Wapiti-Smoky river system was 84% of all inputs to the system including tributary inputs. This percentage is higher than an annual percentage would be because the contribution from tributaries is higher in other seasons. The major contributors were the treated sewage from Grande Prairie at 90 kg/d and Weyerhaeuser pulp mill effluent at 62 kg/d. These two point sources account for 118% of the increase measured below the point sources in February 1991. There is an increase from 9 kg/d to 93 kg/d in the Smoky River due to the Wapiti River and, to a lesser extent, the Simonette River. The total phosphorus load carried by the Smoky River at the mouth, 93 kg/d, is the same as the load below the Simonette River. The 1991 loading data for the Wapiti-Smoky rivers are the first set of data in this report which show a downstream increase in total phosphorus. This river system is, however, much shorter (about 300 km) than the Athabasca River (about 1300 km) or the Peace River (about 1000 km). It is not surprising that the results are different. A further assessment of data from other years would be needed to determine whether an increase in total phosphorus with distance downstream is occurring on the Wapiti-Smoky rivers.

TABLE 3.4.4
Mass Loading for Total Phosphorus in the Wapiti/Smoky Rivers During the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Phosphorus			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Wapiti R. at Hwy 40	1	27/02/91	13 824 400	0.009 ±0.001		12 ±2	2
Grande Prairie Sewage	1	27/02/91	19 440	4.65		90	1
Wapiti R. at Weyerhaeuser Haul Road	1	27/02/91	1 401 840	0.058	102	81	1
Weyerhaeuser Effluent	1	26/02/91	63 504	0.97 ±0.01		62 ±1	2
Weyerhaeuser Storm Sewer	1	27/02/91	1 382	0.135		0.2	1
Wapiti R. from Downstream Weyerhaeuser Effluent to Upstream Bear Cr.	3	27-28/02/91	1 466 726	0.088 ±0.003	143	129 ±4	3
Bear Cr.	1	28/02/91	53 741	0.143		8	1
Wapiti R. - Bear Cr. to Smoky R.	2	28/02/91	1 520 467	0.077 ±0.000	137	116 ±1	2
Smoky R. Upstream Wapiti R.	1	01/03/91	2 220 480	0.004		9	1
Simonette R.	1	01/03/91	312 768	0.009		3	1
Smoky R. - Simonette R. to Puskwaskau R.	2	01-05/03/91	1 053 888	0.026 ±0.003	128	93 ±7	2
Puskwaskau R.	1	05/03/91	259	0.01		0	1
Smoky R. Upstream Little Smoky R.	1	05/03/91	3 132 864	0.024	93	75	1
Little Smoky R.	1	06/03/91	279 936	0.016		4	1
Smoky R. at Watino	1	06/03/91	2 946 240	0.021	79	62	1
Smoky R. at Mouth	1	11/03/91	3 888 000[b]	0.024		93	1

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

b. Water Survey of Canada data

An increase in total nitrogen from 207 kg/d to 920 kg/d occurs in the Wapiti River (Table 3.4.5). Inflow from the Wapiti River and, to a lesser extent, the Simonette River increases total nitrogen load in the Smoky River from 209 kg/d to 1195 kg/d below the Simonette. There is little change in the load carried by the Smoky River from this reach to the confluence with the Peace River (Table 3.4.5). The total nitrogen contribution from all anthropogenic point sources is 51% of the contribution from all sources including tributaries.

Instream loading is subject to seasonal and annual fluctuations. This section has estimated the transport of nutrients during the winter of 1991. If synoptic data were available for the rising hydrograph, it would be expected to show much higher phosphorus loads due to increases in particulates and water volumes. There would be a seasonal effect. To look at the annual variation, the long-term data for the Smoky River at Watino was examined for annual changes within the same season. Total and dissolved phosphorus loading (Fig. 3.4.5) and total and dissolved nitrogen loading (Fig. 3.4.6) were plotted for the winter season. Higher loadings occurred in 1988 and 1990. Winter loadings for 1991 and 1992 do not show an increase, even though 1991 had above normal discharges.

3.5 MASS TRANSPORT CALCULATIONS

One of the objectives of this report was to do trial mass transport calculations to obtain a better understanding of nutrient sinks and sources. The calculations have demonstrated that there are phosphorus, but not necessarily nitrogen, losses in the river and the general trends have been identified for each river. The mass balance is not a sensitive method for identifying river reaches that are sinks or sources without more data from both gauging stations (especially on the mainstem) and water sampling.

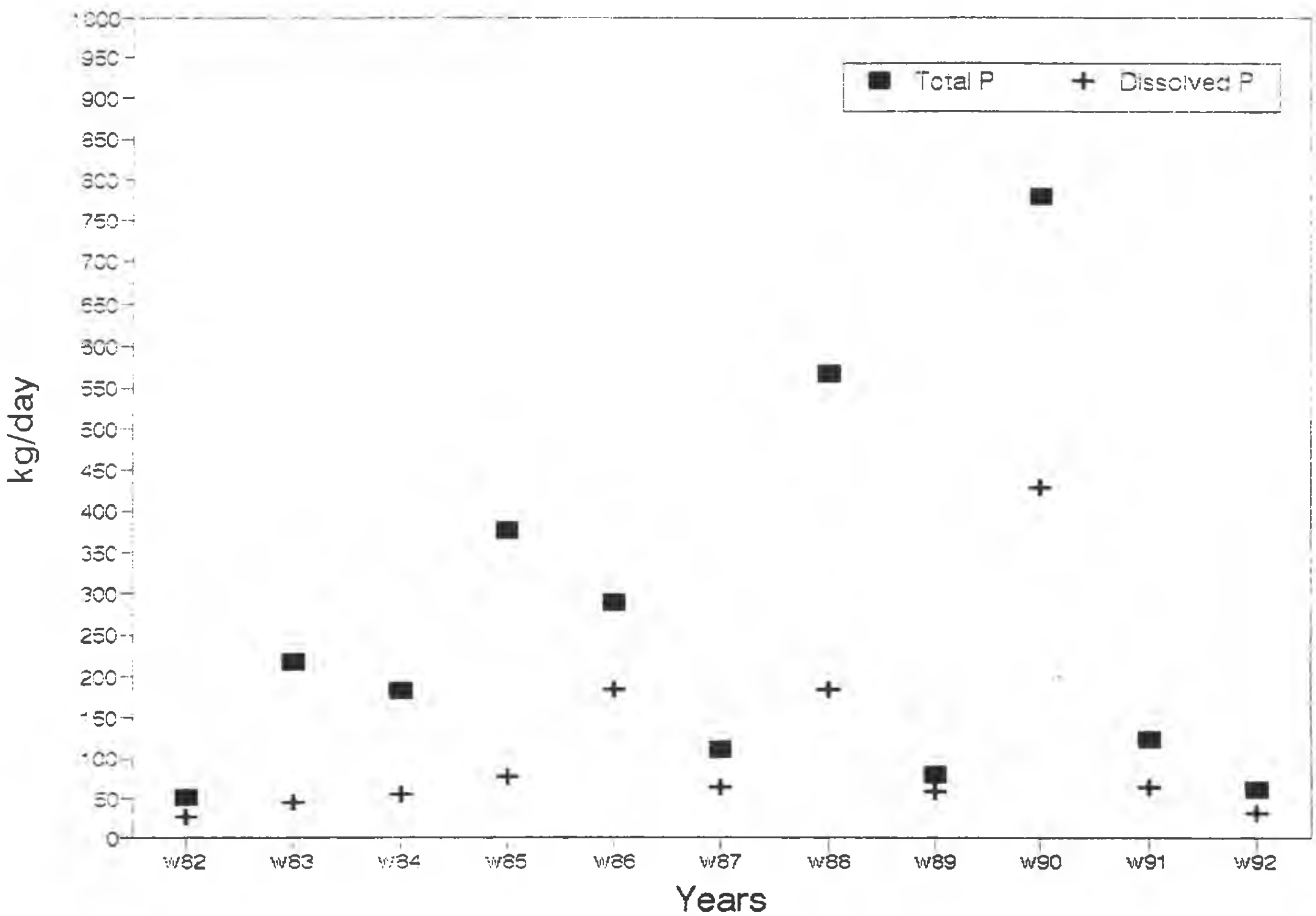

Figure 3.4.5

TOTAL AND DISSOLVED PHOSPHORUS LOADING, SMOKY RIVER AT WATINO (WINTERS)

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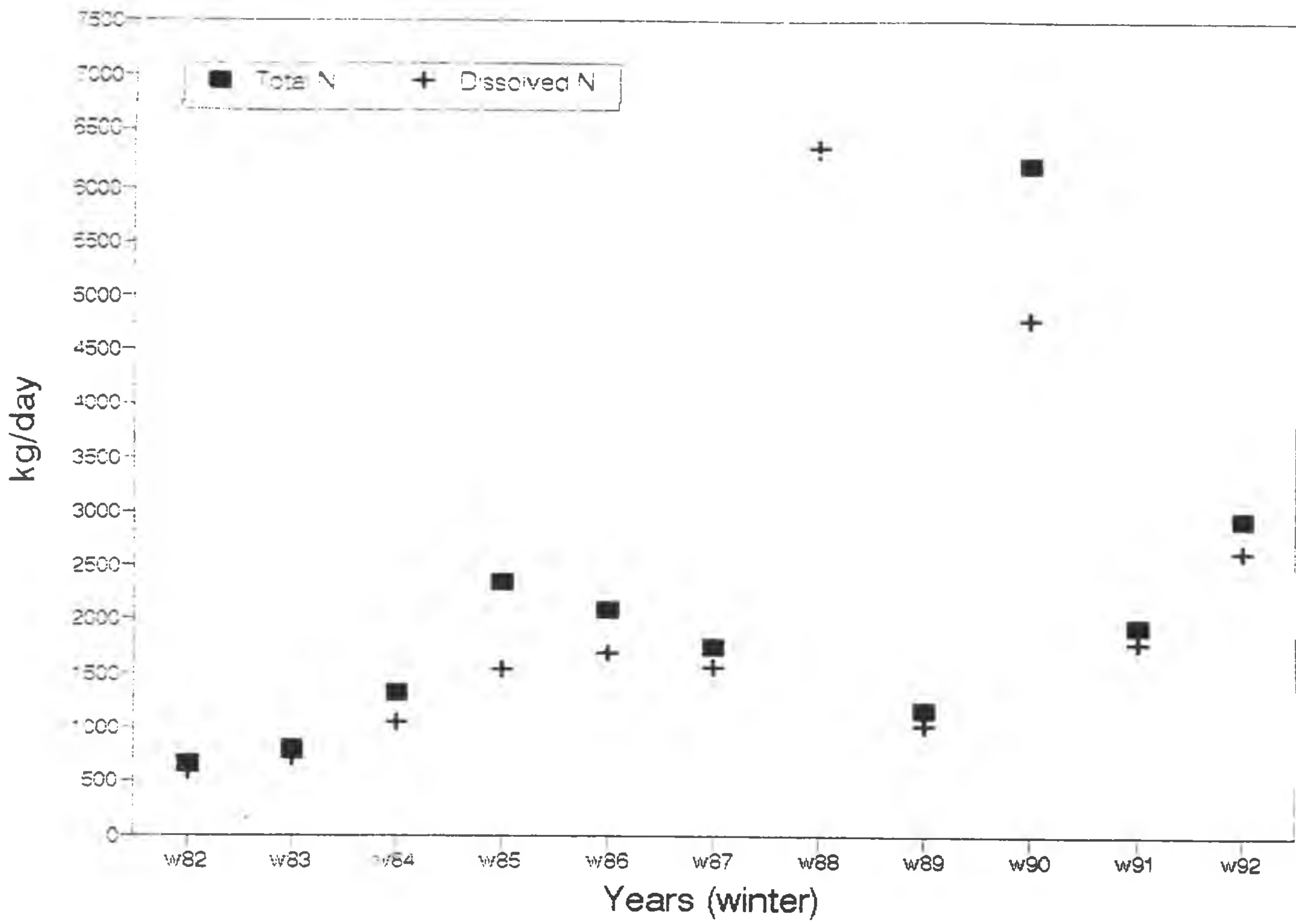

Figure 3.4.6

TOTAL AND DISSOLVED NITROGEN LOADING, SMOKY RIVER AT WATINO (WINTERS)

TABLE 3.4.5
Mass Loading for Total Nitrogen in the Wapiti-Smoky Rivers During the 1991 Synoptic Survey

Station or River Reach	No. of Sites Included	Date (D/M/Y)	Discharge (m^3/d)	Total Nitrogen			No. of Samples
				Concentration ±1 Standard Deviation (mg/L)	Loading Calculated[a] (kg/d)	Loading ±1 Standard Deviation Measured (kg/d)	
Wapiti R. at Hwy 40	1	27/02/91	1 382 400	0.15 ±0.01		207 ±20	2
Grande Prairie Sewage	1	27/02/91	19 440	15.91		309	1
Wapiti R. at Weyerhaeuser Haul Road	1	27/02/91	1 401 840	0.33	516	463	1
Weyerhaeuser Effluent	1	26/02/91	63 504	7.46 ±0.28		474 ±18	2
Weyerhaeuser Storm Sewer	1	27/02/91	1 382	0.38		0.5	1
Wapiti R. from Downstream Weyerhaeuser Effluent to Upstream Bear Cr.	3	27-28/02/91	1 466 726	0.591 ±0.001	937	866 ±2	3
Bear Cr.	1	28/02/91	53 741	2.325		125	1
Wapiti R. - Bear Cr. to Smoky R.	2	28/02/91	1 520 467	0.605 ±0.000	991	920 ±2	2
Smoky R. Upstream Wapiti R.	1	01/03/91	2 220 480	0.094		209	1
Simonette R.	1	01/03/91	312 768	0.27		84	1
Smoky R. - Simonette R. to Puskwaskau R.	2	01-05/03/91	4 053 888	0.337 ±0.045	1213	1195 ±59	2
Puskwaskau R.	1	05/03/91	259	0.003		0.7	1
Smoky R. Upstream Little Smoky R.	1	05/03/91	3 132 864	0.332	1196	1040	1
Little Smoky R.	1	06/03/91	279 936	0.413		116	1
Smoky R. at Watino	1	06/03/91	2 946 240	0.31	1156	913	1
Smoky R. at Mouth	1	11/03/91	3 888 000[b]	0.374		1454	1

a. Calculated means that measured tributary and effluent values have been added to measured mainstream values to predict a downstream load (assuming no losses) which can then be compared to the measured load at the downstream station. The measured value rather than the calculated value is used for the calculation in the next reach.

b. Water Survey of Canada data

There are a number of factors that may contribute error to the mass transport:

1. Discharge was not measured at all sites where loads were calculated. The number of gauging stations on the mainstem are particularly limited. In such cases, discharge was estimated from the nearest gauged site by adding the contribution from intervening tributaries.

2. Concentrations of constituents vary over time and may vary spatially across the width of the river; thus, single grab samples may differ somewhat from the average water quality at a site in a river. When a single grab sample is multiplied by a large discharge volume, this error is magnified.

3. The sampling progression did not match the river's time of travel so that calculated loads do not represent actual mass balances for a specific flow event. If the hydrograph is rising or falling rapidly, the error can be increased.

4. Many nutrients are non-conservative; their concentrations may change because of in-river physical, chemical, and biological processes.

5. Since most of the synoptic surveys are done during winter, the high nutrient loads that are carried into the mainstem from the tributaries during the rising hydrograph are not as well understood. Scouring of the river during the rising hydrograph may also increase nutrient concentrations in the lower river reach, if the longitudinal trends were better documented for the other seasons.

SECTION 4.0

BIOLOGICAL EFFECTS OF NUTRIENTS

4.0 BIOLOGICAL EFFECTS OF NUTRIENTS

4.1 BENTHIC INVERTEBRATES

4.1.1 Athabasca River

The benthic invertebrate communities in the Athabasca River have been assessed by Alberta Environment (Anderson 1989, 1991; Gregoire and Anderson 1987) and monitored by Weldwood of Canada Ltd., Alberta Newsprint Company and Millar Western Pulp Ltd. The benthic invertebrates in the Lesser Slave River, a tributary to the Athabasca River, have been monitored by Slave Lake Pulp Corporation. Although monitoring has been done by the pulp mills, benthic communities are often impacted by both municipal sewage treatment plant effluents and pulp mill effluents. The effort has been limited to sampling stations located above and below important point sources, but the spacing of the towns and pulp mills provides a "snapshot" of the benthic invertebrates at upstream locations (Hinton and Slave lake) and further downstream at Whitecourt.

Because a measure of standardization has been introduced into the sampling methods, sampling frequency and sample replication by Alberta Environment (1990e) and because the level of sampling and identification effort by different consultants has been similar on the mainstem, it is possible to compare the Athabasca River data. Lesser Slave River data are not comparable due to differences in substrate and methodology (Section 4.1.4.1). Data summaries for the spring of 1991 were available for all of the operating mills on the Athabasca River; therefore, they were graphed.

In the spring of 1991, the total number of invertebrate taxa (Fig. 4.1.1) was greatest at Hinton. In contrast, samples from Whitecourt in the fall of 1991 contained approximately twice as many taxa as spring samples. This striking seasonal difference is independent of point source impacts. The reduction in the total number of taxa is probably due to high spring flows. The response of the benthic invertebrate community to point source discharges also differs from one reach of the river to the other and one season to another. At Hinton, the number of taxa increased downstream of the combined mill and municipal effluents. The epilithic periphyton and the benthic community it supports may be limited by the amount of nutrients available at locations above Hinton. In the spring, the number of taxa decreased slightly below the ANC and Millar Western effluents, although the number of taxa exceeded upstream (control) numbers at stations located 20-30 km downstream. In the fall, the total number of taxa remained unchanged below the ANC mill and increased below the Millar Western mill. In general, effect of point-source discharges on the number of taxa is slight. An increase in species richness is usually present at 20 - 40 km downstream. Further statistical analysis would be required to determine whether the increase in species richness is significant. An increase in the number of taxa also occurs on the Lesser Slave River.

The total number of organisms (standing crop) increases downstream of the point sources at Hinton (Fig. 4.1.2) and Slave Lake. This increase did not occur at Whitecourt in the spring of 1991, probably due to high flows, but did occur in the fall of 1991 (Tables 4.1.7 and 4.1.10). The Shannon Weaver Index (Fig. 4.1.3) indicates a drop in diversity for approximately the first three kilometres below the discharge at all locations, followed by a return to upstream levels. The diversity is generally higher at Hinton but also more variable.

The Ephemeroptera (mayflies) which contains many species known to be sensitive to pollution is also common in the Athabasca River. The mayfly population decreased as a percentage of the total below the Weldwood mill (Fig. 4.1.4). This change was associated with an increase in the number of midges (Chironomidae) rather than a decrease in mayflies. In 1992, the mean number of mayflies collected at the first four stations below the effluent increased to 1738 compared to 1417 mayflies at upstream control stations although this increase may not be significant (TAEM 1992b). In the Whitecourt area the percentage of the mayfly population increases in a downstream direction (Fig. 4.1.4). This family is not common in the upper reaches of the Lesser Slave River.

These graphs show differences due to natural impacts on the river as well as differences in upstream to downstream conditions at a point-source. In the Whitecourt area, the downstream communities are similar to upstream communities, although a local effect can sometimes be detected. Moderate enrichment translates into increases in both the number of taxa and the

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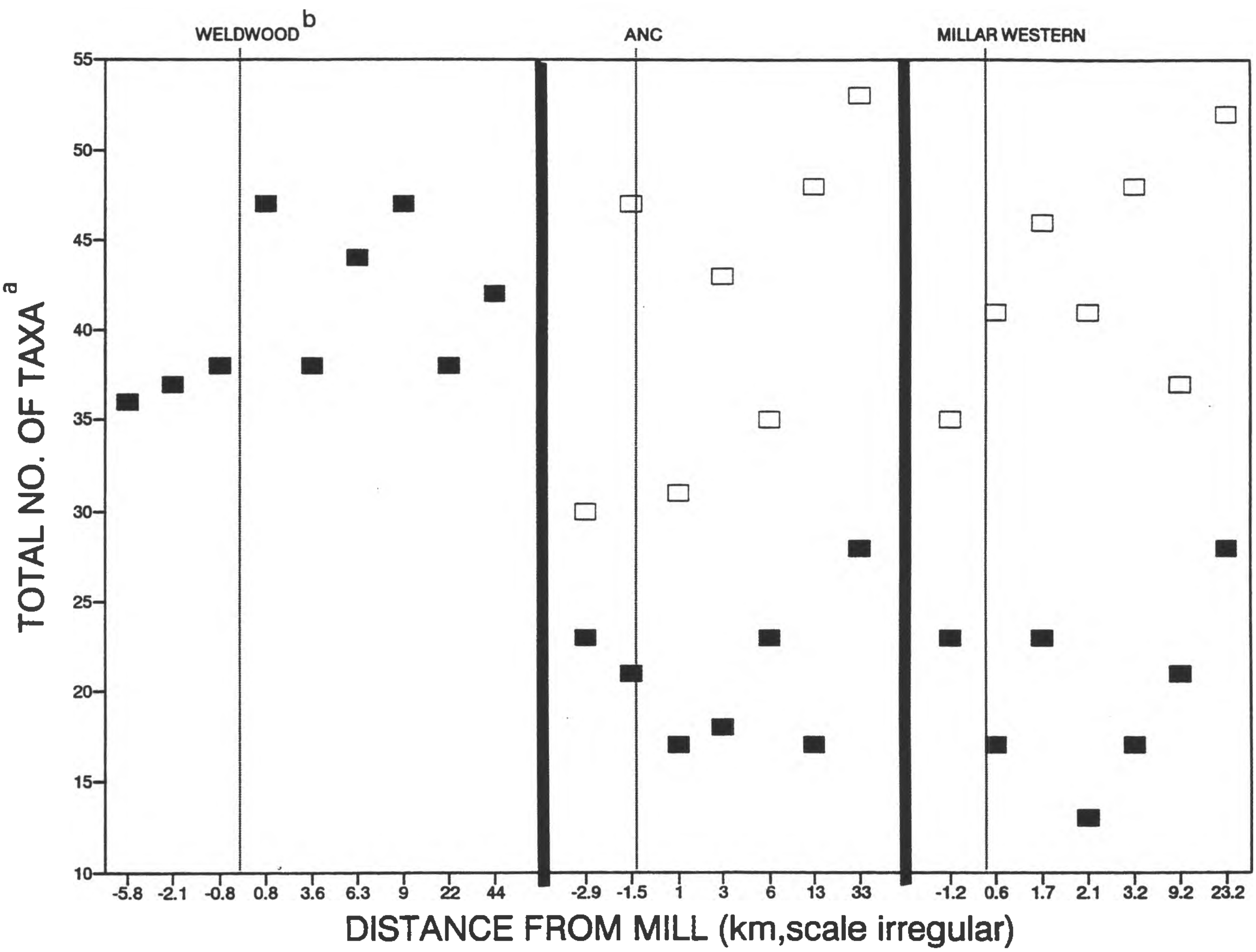

NOTE:

a. TOTAL NUMBER OF TAXA COLLECTED FROM ALL REPLICATE BENTHIC SAMPLES FROM EACH SITE.

b. FALL DATA FOR WELDWOOD ARE NOT AVAILABLE.

Figure 4.1.1

TOTAL NUMBER OF BENTHIC INVERTEBRATE TAXA AT SAMPLING LOCATIONS ON THE ATHABASCA RIVER IN THE SPRING (■) AND FALL (□), 1991
(data from TAEM 1991c and SENTAR Consultants Ltd. 1992b, 1992c)

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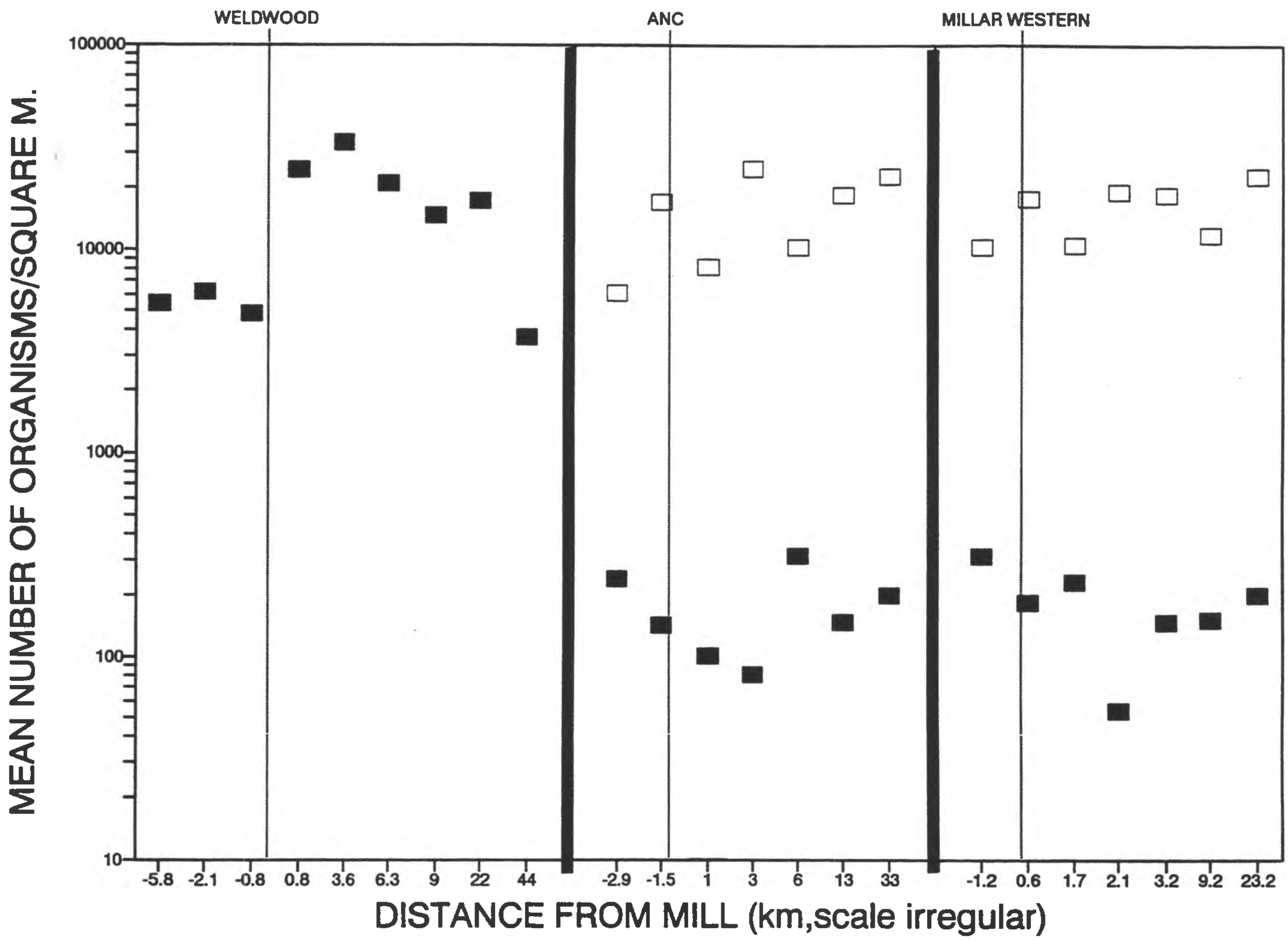

Figure 4.1.2

MEAN NUMBER OF BENTHIC INVERTEBRATES PER SQUARE METRE AT SAMPLING LOCATIONS ON THE ATHABASCA RIVER IN THE SPRING (■) AND FALL (□), 1991
(data from TAEM 1991c and SENTAR Consultants Ltd. 1992b, 1992c)

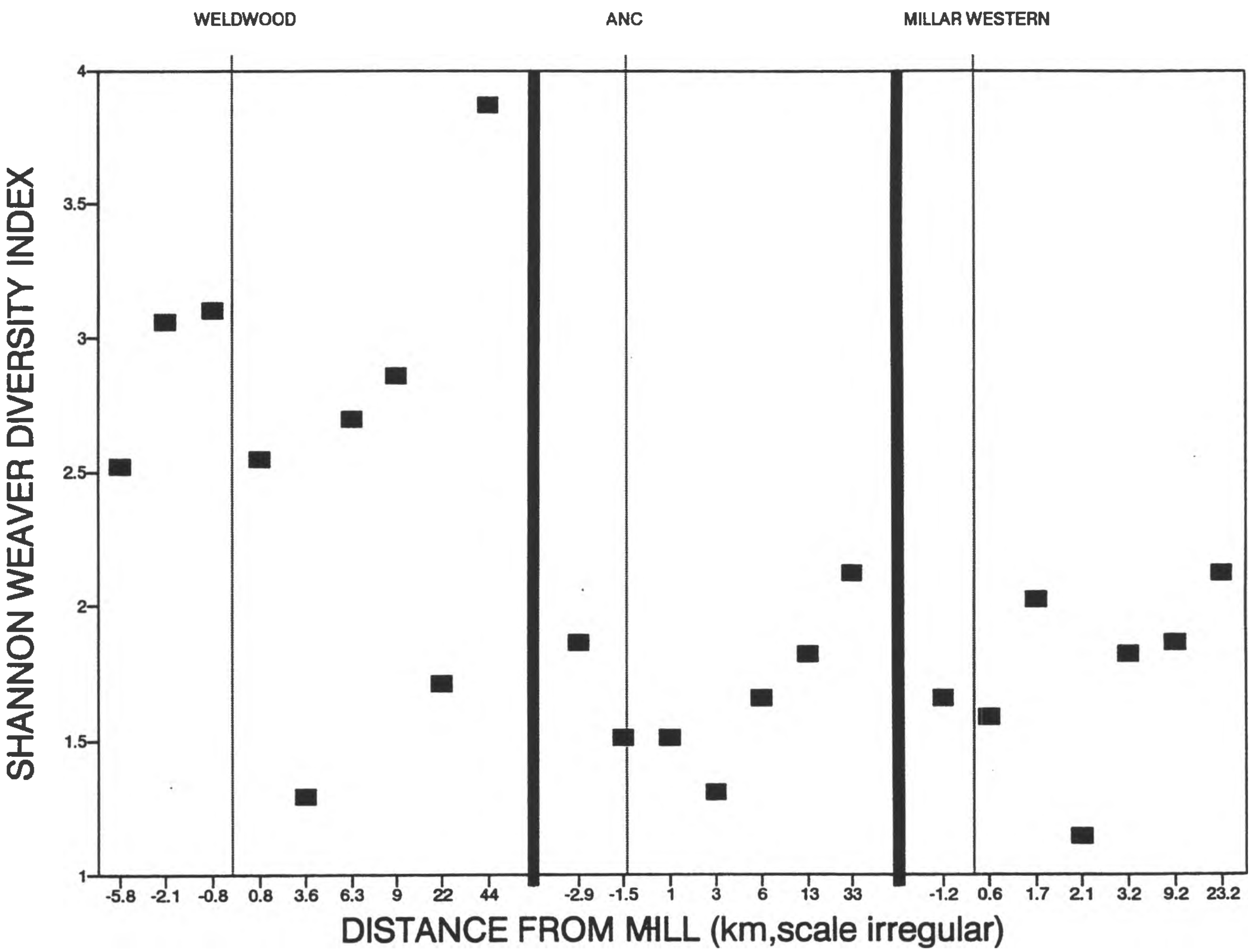

Figure 4.1.3

THE DIVERSITY INDEX OF BENTHIC INVERTEBRATES SAMPLED AT LOCATIONS ON THE ATHABASCA RIVER IN THE SPRING 1991
(data from TAEM 1991c and
SENTAR Consultants Ltd. 1992b, 1992c)

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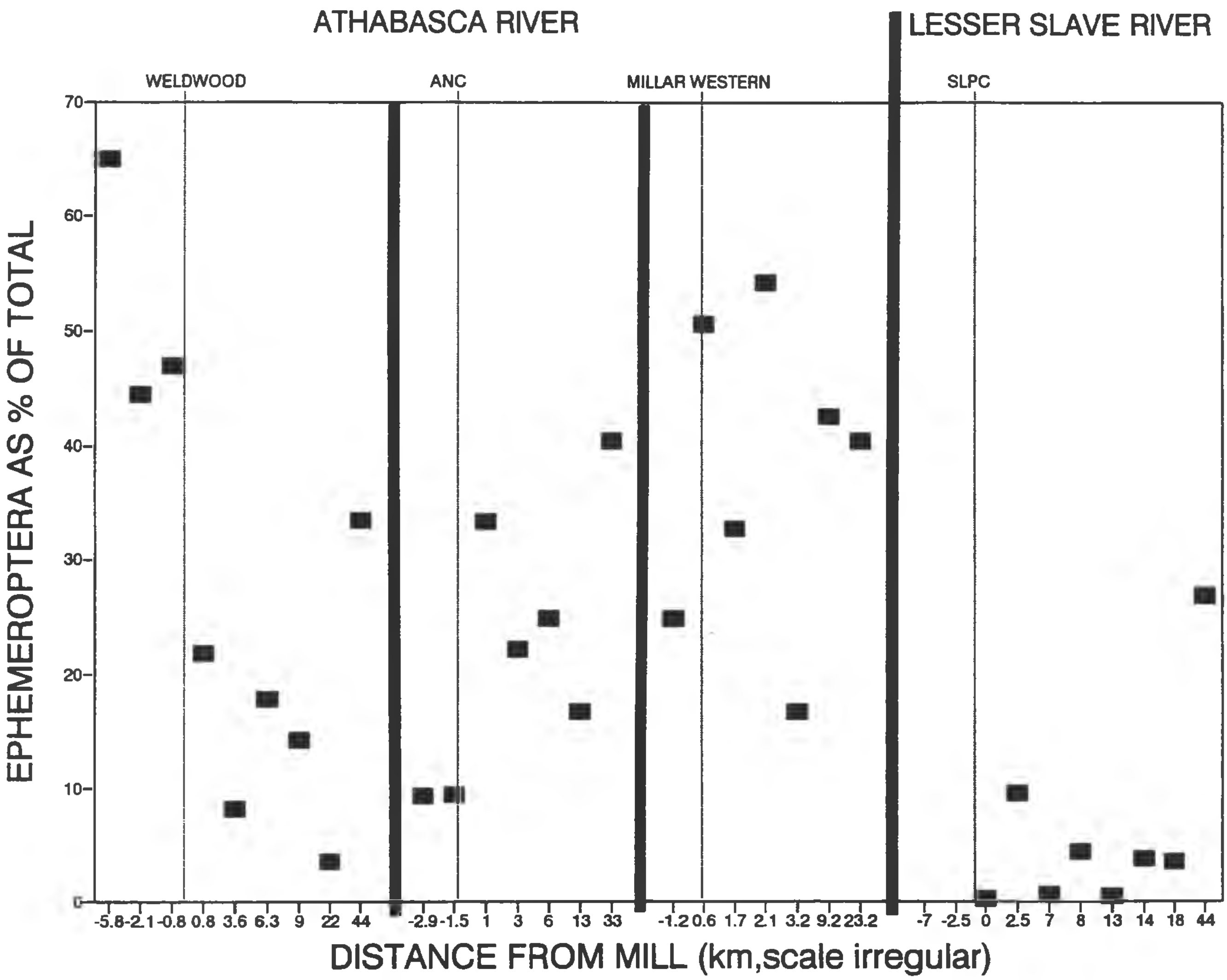

Figure 4.1.4

THE PERCENTAGE ABUNDANCE OF EPHEMEROPTERA (MAYFLIES) AT SAMPLING LOCATIONS ON THE ATHABASCA RIVER AND LESSER SLAVE RIVER IN THE SPRING 1991
(data from TAEM 1991c and SENTAR Consultants Ltd. 1992b, 1992c)

number of individuals in the downstream reaches on both the Athabasca River at Hinton and the Lesser Slave River. The differences in community response between the Hinton and Whitecourt areas may be due to the background nutrient regime in these regions and to changes in substrate and velocity. One possibility is that there is a nutrient limitation upstream of Hinton.

4.1.2 Athabasca River Near Hinton

4.1.2.1 Review of Field Surveys and Methods

The benthic invertebrate community in the vicinity of Hinton was surveyed in May 1960, again in August 1972, and five more times during the 1970's by Beak Consultants Ltd. using artificial substrate trays (Table 4.1.1).

TABLE 4.1.1
Summary of Benthic Invertebrate Surveys
Conducted by the Hinton Pulp Mill on the Athabasca River[a]

Sampling Date	Method	Author
May 1960	Artificial Substrate	T.W. Beak (1960)
August 1972	Artificial Substrate	T.W. Beak Consultants Ltd. (1973)
July 22 to September 6, 1974	Artificial Substrate	Beak Consultants Ltd. (1975b)
October 1976	Artificial Substrate	Beak Consultants Ltd. (1977b)
April 25 to May 20, 1977	Artificial Substrate	Beak Consultants Ltd. (1978)
September 20 to October 23, 1979	Artificial Substrate	Beak Consultants Ltd. (1980)
April 1984	Neill Cylinder	Integrated Environmental Sciences Inc. (1984)
April 8, 1986	Neill Cylinder	Integrated Environmental Sciences Inc. (1986a)
April 25, 1989	Neill Cylinder	TAEM (1989b)
October 10-12, 1990	Neill Cylinder	TAEM (1991b)
April 17-18, 1991	Neill Cylinder	TAEM (1991c)
April 14-15, 1992	Neill Cylinder	TAEM (1992b)

a. In addition to the studies by consultants working for the pulp mill, Alberta Environment conducted two surveys on the upper Athabasca River between 1984 and 1986 (Anderson 1989) as well as spring and fall sampling at two sites from 1983 to 1987 as part of the long-term zoobenthic monitoring in Alberta (Anderson 1991).

In 1984, the Hinton mill changed consultants and the sampling method changed to instream sampling of the natural benthic communities. There is consistency in the sampling method and the number of samples since 1984. All sampling stations were chosen, as much as possible, for comparable substrate, water depth and water velocity. The substrate was mainly cobble (60%-95%) and gravel (5%-40%) underlain by sand. Epilithic chlorophyll *a* data are presented in Section 4.2.2. Five samples were collected at three stations upstream and six stations downstream (Fig. 4.1.5) using the Neill cylinder sampler as recommended by Alberta Environment (1990e). The entire samples were sorted and identified to genus except for Nematoda. The taxonomic effort was consistent and thorough: for example, nineteen genera of Chironomidae in five subfamilies were identified. Benthic invertebrate samples were collected from three stations upstream of the Weldwood pulp mill effluent and six stations downstream to a distance of about 44 km below the mill outfall. TAEM (1992b) estimated that the effluent, which includes treated sewage from the Town of Hinton, was not completely mixed until about 9 km below the mill. This sequence of sampling provided data before and after the expansion of the Weldwood mill.

One of the most important factors in the monitoring is the alteration between spring and fall sampling. Samples were collected once each year during the summer of 1974; during the fall in 1976, 1979, 1990 and 1992 and during the spring in 1977, 1984, 1986, 1989, 1991 and, 1992. TAEM (1992b) found higher numbers of organisms at the control stations in the fall. Anderson also found that invertebrates were generally much more abundant in the fall. Both spring and fall samples were collected for the first time in 1992. Because many insects have seasonal patterns of emergence, a change of season or even a change of one month can alter the numerical abundance of organisms and the species that are present.

The percent standard error of the mean (a measure of the deviation of the sample mean from the population mean) has been determined by TAEM each year as a measure of sample reliability. For benthic macroinvertebrate samples, a percent standard error of 20% is considered reasonable (Elliott 1977). Historically, the percent standard error of 20% has not been exceeded since the biomonitoring survey conducted in 1986 (Table 4.1.2), except for one control station in 1991.

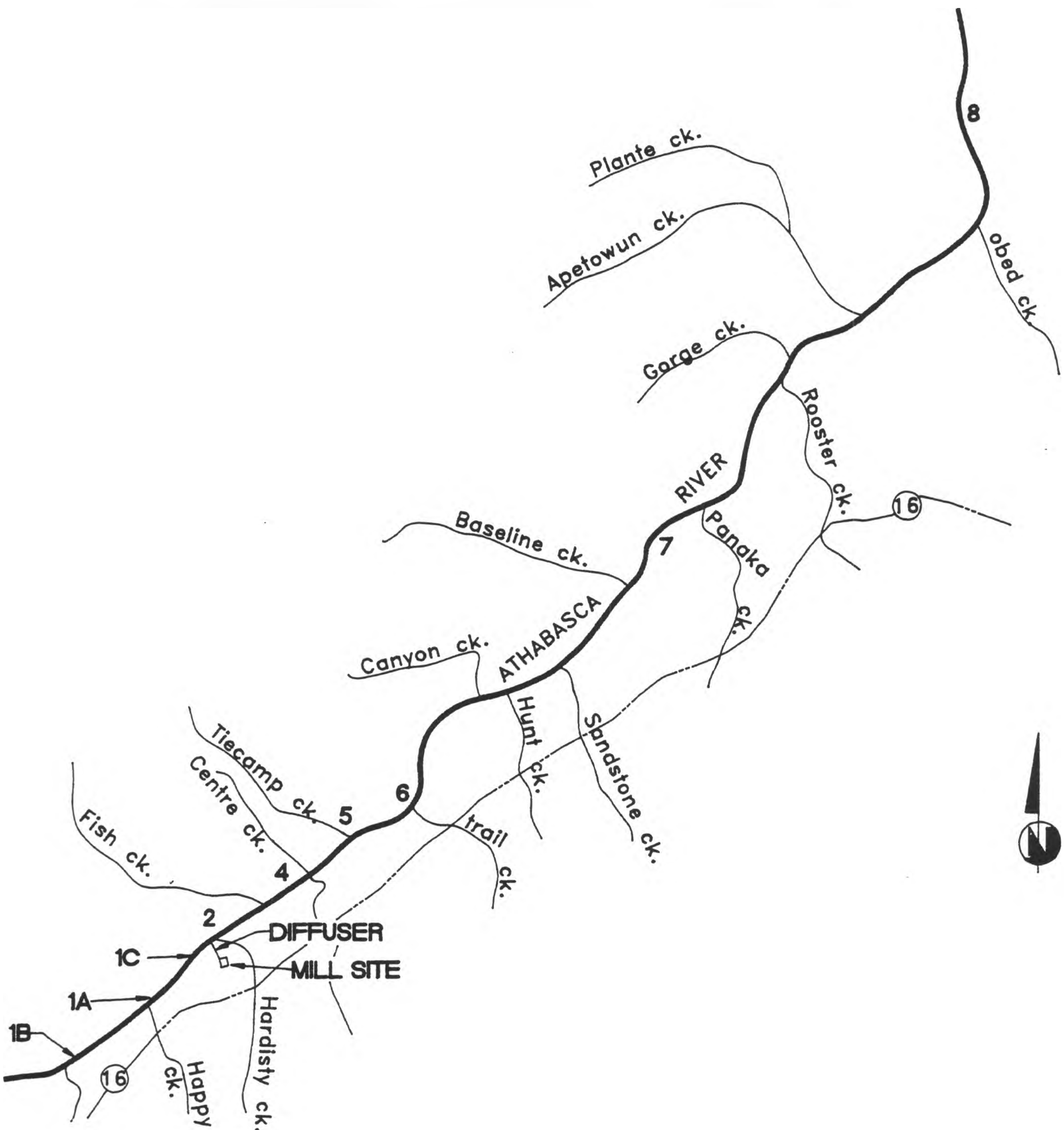

Figure 4.1.5

BENTHIC INVERTEBRATE SAMPLING SITES ON THE ATHABASCA RIVER NEAR HINTON
(redrawn from TAEM 1991c)

TABLE 4.1.2
Percent Standard Error[a] for Samples Collected by TAEM[b]

Date	Distance from Discharge (km)								
	Upstream Control Stations			Downstream Experimental Stations					
	5.8	2.1	0.8	0.8	3.6	6.3	9.0	22.0	44.0
April 1992	11.97	16.23	16.46	12.47	7.61	9.98	17.80	10.72	14.27
April 1991	12.40	14.70	23.80	7.79	12.14	7.95	12.42	16.41	6.71
October 1990	16.35	11.32	11.75	8.98	13.18	5.41	8.75	10.00	8.21
April 1989	10.26	11.84	15.67	11.45	–	7.60	12.95	14.07	8.58
April 1986	42.2	10.3	–	35.2	6.9	6.8	25.0	12.1	15.8
April 1984	10.3	10.6	–	7.5	10.6	13.2	21.2	25.3	6.7

a. The percent standard error of the sample mean is 100 times the standard deviation of the sample means at each site and indicates the amount of error in the sample mean when it is used to estimate the true population mean.

b. Data from TAEM (1992b)

Alberta Environment has also sampled benthic invertebrates in this area. Anderson (1989) evaluated the effects of the combined pulp mill and municipal effluent discharges at Hinton on the zoobenthic community in May 1984 and October 1985. Hinton was also one of the long-term zoobenthic monitoring sites monitored by the Environmental Quality Monitoring Branch from 1983 to 1987 (Anderson 1991). The TAEM and the Alberta Environment sampling methods were virtually the same. Both TAEM and Anderson attempted to standardize the substrate, flow velocity and sampling depth, but both reported some variation at different sites. Both TAEM and Anderson collected samples in primarily cobble and coarse gravel (with varying amounts of silt and sand) at a depth of 30-40 cm in riffle areas with a moderately fast flow. Anderson and TAEM used a modified Neill cylinder sampler with a sampling area of 0.1 m^2 and a mesh aperture size of 0.210 mm. Five replicates were collected at each site by both TAEM and Anderson.

From April 1989 to the present, TAEM analyzed data using the Shannon-Weaver diversity index, equitability, richness and dominance. These methods are described in more detail by TAEM (1993). In addition, TAEM subjected the log (X+1)-transformed data to two multivariate techniques beginning in 1990. In October 1990 and April 1991, cluster analysis was combined with principal components analysis. Use of cluster analysis has continued to the present, but reciprocal averaging (RA) was introduced in April 1992 to replace principal components analysis. In October 1992, TAEM (1993) replaced RA with detrended correspondence analysis (DCA) which is also an ordination procedure. Alberta Environment performed cluster analysis, and principal components analysis on the log (X+1)-transformed data as well as other statistical tests including one-way analysis of variance and the Student-Neuman-Keuls test.

4.1.2.2 Results

Anderson (1989) found that the zoobenthic communities underwent two distinct longitudinal changes:

- Immediately below the effluent (1 to 6 km), most populations of pollution tolerant and intolerant species increased in size.

- Further downstream (20 to 50 km), there was a shift in species composition wherein taxa such as midges (Chironomidae, in particular) or worms (Oligochaeta) undant and taxa such as mayflies (Ephemeroptera) rse, and somewhat less abundant.

Changes in the zoobenthos immediately below the combined effluent discharge are typical of moderate organic enrichment. Higher numbers of organisms occurred at the 1 km site (both banks). The change in total invertebrate numbers was highly significant (ANOVA $p<0.0001$) (Anderson 1989). Anderson (1991) also analyzed long-term monitoring results for spring and fall samples from 1983 to 1986 inclusive. The analysis confirmed that there were higher numbers of organisms and invertebrate taxa (including both tolerant and intolerant taxa) at the 1 km site over this period.

Principal components analysis divided the fall data into: (i) an upstream cluster of sites which included the upstream (control), (ii) 1 km downstream and 6 km downstream sites, and (iii) a downstream cluster of sites which groups the 20 km, 30 km and 50 km sites (Anderson 1989).

This separation in the first component accounted for 40% of the variance. The water quality factor most often associated with Group (ii) is enrichment. Anderson (1989) noted that the substrate of sites in Group (iii) included more sand and silt than the substrate of sites in Group (ii).

In the 1 km to 6 km stretch of the river full lateral mixing of the effluent occurs only at low flows, and invertebrates which inhabit the river edge were not consistently exposed to the effluent (Anderson 1989). Further downstream where lateral mixing is always complete, the zoobenthos were consistently exposed to the effluent. Changes which occur in this area could be due to stress induced by the effluent.

Changes in species composition could also have been induced by site-to-site differences in substrate (Anderson 1989). Standardization of substrate, flow velocity and sample depth was attempted, but there were notable differences between sites. The coarse gravel and cobble with interstitial silt and sand was most common, but substrates at the 20 km and 50 km sites had more silt and sand than substrates at the 1 km and 6 km sites.

Weldwood of Canada Ltd. monitoring surveys showed a consistent increase in the number of organisms at stations below the treated effluent (Table 4.1.3). There was an order of magnitude increase in the number of organisms found 0.8 to 9 km downstream, during most spring surveys with a return to background at 44 km downstream. Epilithic chlorophyll *a* also increased below the effluent. The increase in invertebrates was not evident in samples from October 1990, the only fall survey, primarily because the upstream numbers of organisms were also high. Multivariate analysis of the 1991 and 1992 data showed an effluent effect on the benthic community that is indicative of moderate nutrient enrichment (TAEM 1992b).

There was an increase in the number of taxa at some of the downstream stations in 1991 and 1992, following the mill expansion to present capacity in February 1990 (Table 4.1.4). The variety (richness) of taxa remained high in all years and the species identified each year were similar to the species found in earlier surveys. A decrease in the diversity of the benthic community is apparent at some stations (Table 4.1.5); the diversity index is influenced by increases in numbers of organisms within taxa in addition to the variety of taxa.

TABLE 4.1.3
Total Number of Benthic Invertebrates per Square Metre in the Athabasca River Near Hinton[a]

Date	Distance from Discharge (km)								
	Upstream Control Stations			Downstream Experimental Stations					
	5.8	2.1	0.8	5.8	3.6	6.3	9.0	22.0	44.0
April 1992	6 624	3 202	6 010	13 072	21 100	22 478	18 636	3 802	7 294
Std Deviation	177.24	116.18	221.19	364.58	358.84	501.79	741.59	91.16	232.73
April 1991	5 362	6 196	4 826	24 340	33 472	21 118	14 830	17 262	3 682
Std Deviation	149.00	204.00	256.83	424.16	908.61	375.44	411.90	633.31	55.20
October 1990	14 256	15 512	20 076	13 378	23 406	19 690	13 144	29 120	28 068
Std Deviation	521.2	392.7	527.6	268.6	689.8	238.4	257.2	651.2	461.0
April 1989	1 336	5 936	3 888	22 618	–	11 680	6 064	2 840	2 632
Std Deviation	30.64	157.12	136.19	578.86	–	198.40	175.50	89.34	50.49
April 1986	1 674	9 386	–	359 614	12 158	21 328	13 410	4 292	2 548
Std Deviation	94.4	216.9	–	28 307.2	84.3	326.4	750.9	116.2	93.5
April 1984	3 420	5 468	–	13 188	13 974	8 742	6 452	19 394	11 014
Std Deviation	83.2	131.6	–	220.0	339.1	258.0	306.0	1 095.6	164.4

a. data from TAEM (1992b)

TABLE 4.1.4
Total Number of Benthic Invertebrate Taxa in the Athabasca River Near Hinton[a]

Date	Distance from Discharge (km)								
	Upstream Control Stations			Downstream Experimental Stations					
	5.8	2.1	0.8	0.8	3.6	6.3	9.0	22.0	44.0
April 1992	36	31	33	47	37	41	50	30	42
April 1991	36	37	38	47	38	44	47	38	42
October 1990	30	30	36	38	30	29	34	36	34
April 1989	30	36	33	42	–	37	41	34	32
April 1986	30	36	–	34	39	39	46	28	33
April 1984	32	37	–	37	30	33	27	28	38

a. data from TAEM (1992b)

TABLE 4.1.5
Diversity Index of Benthic Invertebrates
Collected in the Athabasca River Near Hinton[a]

Date	Distance from Discharge (km)								
	Upstream Control Stations			Downstream Experimental Stations					
	5.8	2.1	0.8	0.8	3.6	6.3	9.0	22.0	44.0
April 1992	2.94	2.94	3.40	2.83	2.54	2.60	2.77	2.97	3.87
April 1991	2.52	3.06	3.10	2.55	1.29	2.70	2.86	1.71	3.87
October 1990	2.22	2.39	2.73	3.13	2.43	2.58	2.83	2.47	3.04
April 1989	3.60	3.01	3.33	2.98	–	1.15	1.62	3.07	3.87
April 1986	3.56	2.28	–	0.10	2.61	1.04	1.11	1.22	1.96
April 1984	2.36	2.53	–	3.04	1.58	1.30	1.83	1.20	1.89

a. data from TAEM (1992b)

At the control stations, the benthic community was usually dominated by Ephemeroptera (mayflies) and Chironomidae (midges). They comprised 52% and 40% of the population, respectively in 1991 (Fig. 4.1.5), and 59% and 44% in 1990. Below the effluent, midges increased to 80% in 1991 and 69% in 1990. This shift in abundance was due to an overall increase in the number of midges and not a decrease in mayflies; therefore, there was an overall increase in numbers of organisms. These results suggest nutrient enrichment in the absence of toxicity. The 1992 taxonomic analysis identified several enrichment-sensitive species that showed population declines below the effluent discharge.

In 1992, the Chironomidae dominated the upstream samples as well as the downstream samples. The Chironomidae represented 61% of the total invertebrate population and the Ephemeroptera represented 30% at the upstream stations. There was very little change at the downstream stations (Chironomidae = 61% and Ephemeroptera = 27%). This dominance of Chironomidae at the control stations was different than previous findings.

4.1.3 Athabasca River Near Whitecourt

4.1.3.1 Review of Field Surveys and Methods

Alberta Newsprint Company (ANC) The CTMP mill began operating near Whitecourt in August, 1990. From 1989 to 1991 SENTAR Consultants Ltd., formerly Beak Associates Ltd., conducted biannual benthic monitoring studies for ANC on the Athabasca River in the vicinity of the ANC paper mill (Beak Associates 1990b, 1991b; SENTAR Consultants Ltd. 1992b). Benthic invertebrate surveys were conducted in June and October, 1989 and May 1990 to provide pre-operational data. Surveys in October 1990, and May and October 1991 provided post operational (start-up) data. Five replicate samples were collected at seven sites using a modified Neill-Hess cylinder sampler with a mesh size of 0.250 mm and enclosing an area of 0.0892 m^2. All sampling sites were in riffle/run areas. Sites 1 and 2 were located upstream of the ANC mill; sites 3, 4 and 5 were located between the outfall and the confluence with the McLeod River; and sites 6 and 7 were located approximately 13 and 33 km downstream of ANC's effluent (Fig. 4.1.6). The latter two sites are also downstream of the effluents discharged by the Millar Western pulp mill and the Town of Whitecourt sewage treatment plant. Water velocity, depth and substrate type were kept as similar as possible. Substrates were mainly cobbles and pebbles. Sites 1 to 3 and 7 were dominated by pebbles (61.5%-71.3%) while sites 4 and 6 were dominated by cobbles (60.3% and 61.7%). Because it is not always possible to completely eliminate site variation, substrates were classified and the mean particle size composition of loose substrates was determined by sieving and weighing. The thickness of algal growth was also estimated. There was a consistently high level of taxonomic effort; all benthic invertebrates were identified to genus except Nematoda and Hydracarina identified to phyla. All Chironomidae were identified and counted. The same taxonomist has been used for all survey years to provide consistency in identifications. ANC requested EVS Consultants to critique the benthic invertebrate studies and SENTAR's evaluations of the benthic data (EVS 1992b). This request was related primarily to federal Environmental Effects Monitoring (EEM) requirements.

Millar Western Pulp Ltd. (Millar Western) The CTMP mill began operating on 2 August 1988. A baseline benthic invertebrate monitoring program was conducted during the spring and

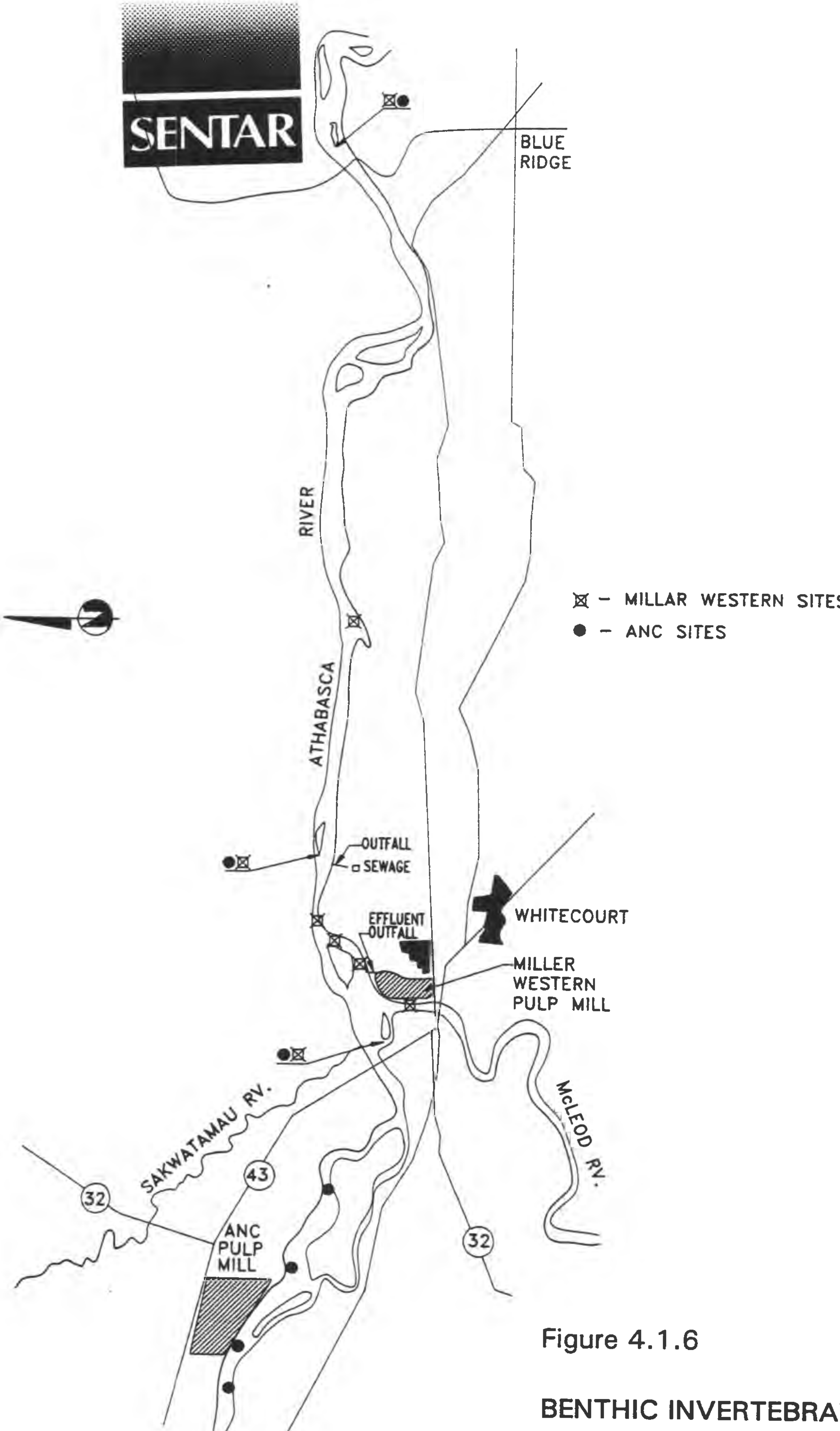

Figure 4.1.6

BENTHIC INVERTEBRATE SAMPLING SITES ON THE ATHABASCA RIVER NEAR WHITECOURT
(redrawn from SENTAR Consultants Ltd. 1992c)

fall of 1987, and the spring of 1988 by Beak Associates Consulting Ltd. (Beak Associates 1988a, 1989a) for Millar Western Pulp Ltd to establish pre-operational conditions on the Athabasca River and the McLeod River. Treated effluent was released at partial capacity during the first post-operational monitoring in the fall of 1988. The monitoring program has continued (Beak Associates 1989a, 1990a, 1991a, SENTAR Consultants 1992b). Two control sites (one on the Athabasca River and one on the McLeod River), three potential impact and recovery sites (at 0.5, 2 and 4 km downstream of the effluent discharge), and three additional sites (at 10, 24 and 40 km downstream) were established (Fig. 4.1.6). Data for left bank and right bank were collected separately for the 0.5 and 2 km sites. Five replicates were collected at each site. Luoma and Shelast (Beak Associates 1988a) concluded that the benthic invertebrate data for each season should be analyzed separately and only data from the same season should be compared between years to separate seasonality from effects due to water quality impacts from the mill. The influence of the McLeod River flows must also be considered when interpreting results. Since the surveys were done by Beak Associates/SENTAR Consultants, the sampling and analysis methods are the same as described for the ANC surveys. The substrates were cobbles and pebbles.

4.1.3.2 Results

Alberta Newsprint Company (ANC) The baseline data showed that most sites were supporting a complex and diverse benthic community dominated by Ephemeroptera (mayflies) and Chironomidae (midges); oligochaeta (aquatic worms) also dominated the May 1990 samples. Diversity indices ranged from 1.83 to 2.87 in June 1989 indicating relatively high variability. The mean number of taxa, mean standing crop and mean species diversity at most sites in the spring of 1990 were lower than during the spring of 1989 due to natural factors. The benthic community structure at all sites on the Athabasca River indicated the presence of mild organic enrichment which was naturally occurring except at the seventh, most downstream, site which was influenced by the Millar Western and Whitecourt sewage treatment effluents. The changes noted by Beak Associates (1990b, 1991b) were a typical response to mild organic enrichment which is largely natural.

In the fall of 1990 (start-up), the mean numbers of taxa at all sites were similar to pre-operational values (Table 4.1.6). There was no noticeable change in species richness. The mean standing crop (number of organisms) was higher in the fall of 1990 (Table 4.1.7) and the mean species diversity was lower (Table 4.1.8) at all downstream sites compared to pre-operational values. In general, the benthic community structure of all downstream stations during the fall of 1990 was similar to the pre-operational surveys except that some taxa increased in numbers in response to the organic loading from the pulp mill and sewage effluent. Increases occurred in Chironomidae, Ephemeroptera and also Plecoptera.

TABLE 4.1.6
The Mean Number of Benthic Invertebrate Taxa Identified in Pre- and Post-Operational[a] Surveys by ANC[b]

Date	Upstream Control Stations		Downstream Experimental Stations				
	1	2	3	4	5	6	7
June 1989	21	25	23	22	20	32	32
October 1989	24	26	25	23	21	24	27
May 1990	14	19	18	31	11	12	13
October 1990	21	29	23	23	24	21	26
May 1991	9	7	6	5	10	8	10
October 1991	19	29	18	27	24	32	36

a. Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with start-up conditions in the fall of 1990.
b. Data from Beak Associates 1990b, Beak Associates 1991b and SENTAR Consultants Ltd. 1992c.

TABLE 4.1.7
Mean Number of Benthic Invertebrates per Square Metre Collected in Pre- and Post-Operational[a] Surveys by ANC[b]

Date	Upstream Control Stations		Downstream Experimental Stations				
	1	2	3	4	5	6	7
June 1989	2 018	3 161	1 661	1 303	5 211	7 128	23 359
October 1989	3 803	5 226	5 096	3 309	3 507	7 482	9 670
May 1990	643	1 242	2 224	5 184	702	735	596
October 1990	1 760	10 428	11 480	20 989	20 955	15 195	18 191
May 1991	242	143	101	81	316	148	200
October 1991	6 045	17 103	8 170	24 922	10 188	18 587	23 047

a. Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with startup conditions in the fall of 1990.
b. Data from Beak Associates 1990b, Beak Associates 1991b and SENTAR Consultants Ltd. 1992c.

TABLE 4.1.8
Diversity Index of Benthic Invertebrates
Collected in Pre- and Post-Operational[a] Surveys by ANC[b]

Date	Upstream Control Stations		Downstream Experimental Stations				
	1	2	3	4	5	6	7
June 1989	2.46	2.70	2.67	2.68	1.95	2.57	1.83
October 1989	2.54	2.17	2.29	2.37	2.29	2.15	2.37
May 1990	1.90	2.09	1.57	1.97	1.72	1.18	2.00
October 1990	2.42	2.17	1.15	1.33	1.11	1.18	1.75
May 1991	1.86	1.51	1.51	1.31	1.66	1.82	2.12
October 1991	1.98	1.73	1.62	1.72	2.04	2.15	2.16

a. Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with startup conditions in the fall of 1990.
b. Data from Beak Associates 1990b, Beak Associates 1991b and SENTAR Consultants Ltd. 1992c.

High flows occurring in the spring of 1991 were the probable cause of an overall reduction in the mean number of taxa and organisms in May (SENTAR Consultants Ltd. 1992c). The reduction occurred at all locations, including control locations, and there were no significant differences in the mean numbers of taxa between sites ($P>0.05$; one-way ANOVA). The number of taxa and organisms increased, however, in the fall. In October 1991, the mean numbers of taxa at all sites except sites 1 and 3 were higher than values found during the pre-operational survey in 1989 (Table 4.1.6). The mean number of taxa was significantly greater ($P>0.05$; Student-Newman-Keuls test) at the most downstream site which is impacted by effluent from ANC, Millar Western and the Town of Whitecourt. The mean numbers of organisms within both the tolerant taxa such as Chironomidae and the less tolerant taxa such as Ephemeroptera and Plecoptera increased downstream in response to the organic enrichment.

Trophic analysis[1] indicated that shifts in the structure of feeding groups occurred as a result of changes in the nature of the food supply caused by organic enrichment from the effluents.

1 A trophic guild (feeding group) analysis was used in conjunction with RA. This trophic classification depends on the dominant food consumed and/or feeding mechanisms of the species. The feeding group assigned to each taxon was determined from the available literature. The limited available literature and research to date does not allow the trophic guild analysis to be accurate at the species level or to take into account that organisms may change their feeding habits during their life history. The percent contribution of each feeding group to the total numbers per sample and site was calculated to determine any differences in benthic community feeding structure between sites.

Detritivore/herbivore species dominated the community, followed by detritivores. Reciprocal averaging (RA) analysis found that the dominant benthic community structures of the control sites indicated mild organic enrichment, as did the downstream sites.

The mean standing crop of organisms was also higher at most sites during start-up conditions in the fall of 1990 than during the pre-operational survey in 1989 and higher at all sites in the fall of 1991 (Table 4.1.7). The mean species diversity reflected the changes in standing crop (Table 4.1.8). The diversity was generally lower in the fall of 1991 at background sites as well as impacted sites.

EVS Consultants concluded that the ANC mill discharge has increased standing crop of organisms particularly in the near field areas, without eliminating any taxa. As a result, diversity (Shannon-Weaver diversity index) has decreased downstream of the discharge relative to upstream. These changes are indicative of mild enrichment in addition to that already present prior to mill operation (EVS 1992b). The results also demonstrate the importance of annual variation in the benthic community due to natural factors such as high flows which effect upstream control sites as well as downstream sites.

<u>Millar Western Pulp Ltd. (Millar Western)</u> Statistical analyses of the baseline benthic invertebrate monitoring program conducted during 1987 indicated that there were significant differences in numbers of taxa and numbers of organisms between sites and between sampling. Significant interactions between site and sampling time appeared to be due to the influence of the McLeod River on the 0.5 km site on the Athabasca River which is located immediately below the McLeod River. The RA analysis of the benthic data indicated that the benthic community structure at the McLeod River site differed from sites on the Athabasca River.

The monitoring continued in 1988 to establish an additional pre-operational survey in the spring and the first survey of operational conditions in the fall (Beak Associates 1989a). The effluent was released at less than capacity during this start-up period. The mean number of taxa were similar in the fall of 1987 and 1988 (Table 4.1.9). Species diversity values measured during the fall start-up were similar to background levels. There was no evidence of a deleterious effect by the treated effluent on the mean number of benthic invertebrates in the Athabasca River in 1988 (Table 4.1.10).

TABLE 4.1.9
Mean Number of Benthic Invertebrate Taxa Identified in Pre- and Post-Operational Surveys[a] by Millar Western Pulp Ltd.[b]

Date	Upstream Control Stations		Downstream Experimental Stations					
	1	2	3	4	5	6	7	4A
June 1987	33	20	36	14	29	-	-	-
November 1987	48	32	34	30	36	-	-	-
June 1988	45	20	33	33	31	-	-	-
October 1988	48	37	44	45	43	-	-	-
June 1989	41	20	35	25	32	22	27	32
October 1989	27	21	23	20	24	21	19	27
May 1990	19	11	27	26	12	17	13	15
October 1990	35	24	18	21	21	15	26	18
May 1991	16	10	8	4	8	8	10	9
October 1991	43	24	28	31	32	25	36	25

a. Pre-operational surveys included the spring and fall of 1987 and the spring of 1988. Treated effluent was released at partial capacity during the fall of 1988.
b. Data from Beak Associates 1989a, 1990a, 1991a and SENTAR Consultants 1992b.

TABLE 4.1.10
Mean Number of Benthic Invertebrates per Square Metre Collected in Pre- and Post-Operational Surveys[a] by Millar Western Pulp Ltd.[b]

Date	Upstream Control Stations		Downstream Experimental Stations					
	1	2	3	4	5	6	7	4A
June 1987	11 108	2 807	13 796	697	7 408	-	-	-
November 1987	19 122	7 686	10 623	7 487	12 220	-	-	-
June 1988	42 760	7 204	17 070	6 478	10 756	-	-	-
October 1988	63 735	23 643	46 522	28 890	29 314	-	-	-
June 1989	53 406	5 211	2 774	1 173	7 128	3 935	5 287	23 359
October 1989	5 141	3 507	4 511	3 426	7 482	1 980	5 937	9 670
May 1990	2 278	702	4 206	5 984	735	1 628	596	1 415
October 1990	23 155	20 955	10 753	11 238	15 195	4 161	18 191	5 085
May 1991	760	316	186	54	148	152	200	233
October 1991	42 513	10 188	17 536	19 164	18 587	11 664	23 047	10 399

a. Pre-operational surveys included the spring and fall of 1987 and the spring of 1988. Treated effluent was released at partial capacity during the fall of 1988.
b. Data from Beak Associates 1989a, 1990a, 1991a and SENTAR Consultants 1992b.

From 1989 to 1991 (Beak Associates 1990a, 1991a; SENTAR Consultants 1992b), the mean number of taxa dropped below 1988 levels during four of the six surveys (Table 4.1.9). The lowest mean number of taxa occurred in the spring of 1991. This decrease occurred at upstream control stations as well as downstream stations. In the fall of 1991, the number of taxa had returned to pre-operational levels.

The mean number of taxa and organisms varied seasonally with higher values in the fall. The seasonal and annual changes in the numerical abundance overshadow impacts of the effluent discharge. Decreases in the mean number of invertebrates occurred at both upstream (control) and downstream stations in the fall of 1989, the spring of 1990 and the spring of 1991 (Table 4.1.10). Diversity decreased generally in 1990 (Table 4.1.11). The decreases in the mean number of organisms, mean number of taxa and mean species diversity (at most sites) in the spring of 1991 were likely the result of high flows encountered during the survey (SENTAR Consultants 1992b). A similar decrease in the spring of 1990 was also attributed to natural causes.

TABLE 4.1.11
Diversity Index of Benthic Invertebrates
Collected in Pre- and Post-Operational Surveys[a] by Millar Western Pulp Ltd.[b]

Date	Upstream Control Stations		Downstream Experimental Stations					
	1	2	3	4	5	6	7	4A
June 1987	2.43	1.91	2.11	2.20	1.86	-	-	-
November 1987	2.59	2.22	2.46	2.00	2.16	-	-	-
June 1988	2.45	1.78	2.26	2.57	2.14	-	-	-
October 1988	2.66	2.33	2.76	2.61	2.40	-	-	-
June 1989	2.23	1.95	2.85	2.65	2.57	1.91	1.83	1.91
October 1989	2.56	2.29	2.47	2.61	2.15	1.65	2.37	2.37
May 1990	1.72	1.72	1.70	1.43	1.18	1.42	2.00	1.63
October 1990	2.46	1.11	1.28	1.13	1.18	1.07	1.75	0.97
May 1991	2.09	1.66	1.59	1.14	1.82	1.86	2.12	2.02
October 1991	2.03	2.04	2.01	1.80	2.15	2.02	2.16	2.08

a. Pre-operational surveys included the spring and fall of 1987 and the spring of 1988. Treated effluent was released at partial capacity during the fall of 1988.
b. Data from Beak Associates 1989a, 1990a, 1991a and SENTAR Consultants 1992b.

A longitudinal gradient of organic enrichment was evident between sites on most surveys. Although all sites appeared to be influenced by mild organic enrichment, it was more evident at sites downstream of the pulp mill and Whitecourt sewage treatment discharges. Enrichment appears to cause changes in the order of dominant taxa and shifts in the feeding group structure.

4.1.4 Lower Athabasca River

4.1.4.1 Historical Studies

The Alberta Oil Sands Environmental Research Program (AOSERP) which was conducted primarily on the lower Athabasca River and its tributaries from 1975 to 1979 included benthic invertebrate sampling (Crowther and Lade 1981; Hartland-Rowe et al. 1979). A wide variety of samplers were used in this early work including artificial substrates, kick sampling, Surber samplers and dredges. Invertebrate data for the Athabasca, Muskeg and Steepbank rivers were gathered as baseline information in 1976 and 1977 (Barton and Wallace 1980). A comparative study of benthic algal primary production was also conducted on five tributaries to the Athabasca River in 1978 and 1979 (Charlton et al. 1981; Hickman et al. 1982; Charlton and Hickman 1984). Syncrude Canada Ltd. also studied the Athabasca and MacKay rivers; their study included periphyton and macroinvertebrate data (McCart et al. 1977, 1978).

Benthic invertebrate monitoring continued into the early 1980's. Data are also available from eight sites in the Athabasca River from the Horse River upstream of Fort McMurray to the Tar River confluence for 1981 (Walder and Mayhood 1985). In the following summer (1982), the distribution and abundance of macrobenthos in the Athabasca River was sampled from Fort McMurray to the Ells River (Boerger 1983).

4.1.4.2 Review of Field Surveys and Methods

The Alberta Environment long-term monitoring network had two sampling stations on the lower reach of the Athabasca River: upstream of the Horse River (upstream of Fort McMurray) and at the Embarras airstrip. Benthic invertebrates were sampled in the spring and fall from 1983 to 1987 (Anderson 1991). Sampling methods are described in Alberta Environment (1990e). Five replicate samples were collected using a Neill cylinder with a sampling area of 0.1 m^2 and a net mesh size of 0.210 mm. The Fort McMurray site had a riffle habitat while the Embarras site was primarily depositional (sand, silt). Identifications were carried out to the highest practical level of taxonomic resolution (usually genus).

4.1.4.3 Results

The invertebrate communities upstream of Fort McMurray and at Embarras were typical of a larger, slower moving river where substrates are more depositional in nature. This applies particularly to Embarras where the river has a sandy bottom. Population densities and community diversity tended to be considerably lower in the Fort McMurray-Embarras area than in the Hinton area where the Athabasca River is typical of a large turbulent mountain stream (Anderson 1991). Burrowing organisms such as many Chironomidae, Oligochaeta and Nematoda were the main components of the invertebrate fauna at the Embarras site. In contrast with the sites in the Hinton area, Ephemeroptera, Plecoptera and Trichoptera were of minor numerical importance at the Embarras site.

Seasonal differences in the zoobenthos were similar to those encountered in many other rivers of Alberta. Population densities are higher in the fall than in the spring (Table 4.1.12).

Year-to-year variability (indicated by differences in mean numbers from year to year) was large and appeared to be season- and site-specific (Table 4.1.12). For example, total invertebrate densities at the downstream sites on the Athabasca River (upstream of Fort McMurray and near Embarras) were less variable from year to year in the fall than in the spring. Year-to-year variability at the Hinton sites (upstream and downstream of Hinton) were somewhat greater in the fall. The effect of rapid discharge fluctuations as a result of heavy summer or fall rain storms in the mountain area may explain the large variability in invertebrate numbers at the Hinton sites.

TABLE 4.1.12
Total Number of Benthic Invertebrates and
Number of Invertebrate Taxa in the Athabasca River[a]

Site	Year	Total No. of Organisms		No. of Taxa	
		Mean	S.E.[b]	Mean	S.E.[b]
ATHABASCA RIVER - SPRING					
Upstream Hinton	1983	168	24	13.8	0.7
	1984	189	34	23	1.8
	1985	151	48	18.2	3.2
	1986	224	14	21.8	0.5
	1987	240	44	20.4	1.5
Downstream Hinton	1983	344	55	17.2	0.6
	1984	502	66	21.6	1.4
	1985	238	40	22.2	2.3
	1986	460	71	32	1.2
	1987	455	36	26.4	1.1
Upstream Horse River	1983	315	117	9	0.9
	1984	75	16	9.2	1
	1985	269	23	12.4	0.9
	1986	131	17	16.4	1
	1987	38	5	8.2	1
Embarras	1983	407	50	15.2	1.2
	1984	305	46	15.6	0.7
	1985	13	3	7.2	1.3
	1986	70	8	14.2	1
	1967	15	2	7.8	0.9
ATHABASCA RIVER - FALL					
Upstream Hinton	1983	801	57	17	1.1
	1984	0	–	0	–
	1985	1827	246	36.4	1.3
	1986	296	64	18.6	2
	1987	726	58	24	1.6
Downstream Hinton	1983	2180	172	19.2	1
	1984	0	–	0	–
	1985	3373	680	40	1.2
	1986	921	182	35.2	2.3
	1987	1942	227	31.2	1.3
Upstream Horse River	1983	1490	234	19.8	1
	1984	198	41	16.8	0.8
	1985	159	17	20.6	1.5
	1986	166	20	19.4	0.7
	1987	42	4	13.8	1.8
Embarras	1983	810	166	6.8	0.9
	1984	863	148	17.6	0.9
	1985	705	194	17.8	2.2
	1986	447	72	13.6	0.7
	1967	50	7	9.4	1

a. data from Anderson 1991   b. S.E. = Standard Error   "–" = Taxon not present

Principal components analysis also identified these differences in year-to-year variability. In particular, the tight cluster formed by lower Athabasca sites contrasted with the loose cluster in spring and suggested that the community was more predictable in the fall than the spring in this part of the river (Anderson 1991). Multivariate analysis did not separate the two sites in the Hinton area nor the two sites in the Fort McMurray-Embarras area of the lower Athabasca River.

Multivariate analysis of detailed taxonomic data from the five years consistently separated the invertebrate fauna from the upper and the lower Athabasca River sites. Taxa which accounted most for this separation were characteristic of the upper Athabasca River sites, including mayflies, stoneflies, caddisflies and mites.

4.1.5 Lesser Slave River

4.1.5.1 Review of Field Surveys and Methods

Slave Lake Pulp Corporation (Slave Lake) began operating its CTMP mill on the Lesser Slave River in December 1990. Baseline benthic invertebrate surveys were conducted by EVS Consultants Ltd. in May and October 1989, and May and September 1990 (EVS 1990, 1991). In the first year of mill operation, benthic samples were collected in May and September 1991 (EVS 1992a).

The type of substrate changes substantially on the Lesser Slave River with fine sediments dominating the upper reaches and cobble areas occurring in the lower reaches. Fine sediments offer few spatial refugia and little opportunity for detritus to accumulate or primary producers to become abundant. As a result, fewer invertebrate species and lower numbers of invertebrates tend to colonize depositional substrates compared to gravel or stone (cobbles). Samples from upstream and downstream depositional areas (stations 1, 7, 13, 18, 24 and 36 on Fig. 4.1.7) were collected with a Ponar dredge. Samples from downstream cobble areas (stations 26, 37, 42 and 87 on Fig. 4.1.7) were collected using a Hess sampler. Six samples were collected at each of the ten stations. Three replicates were collected along the upstream bank and three were collected

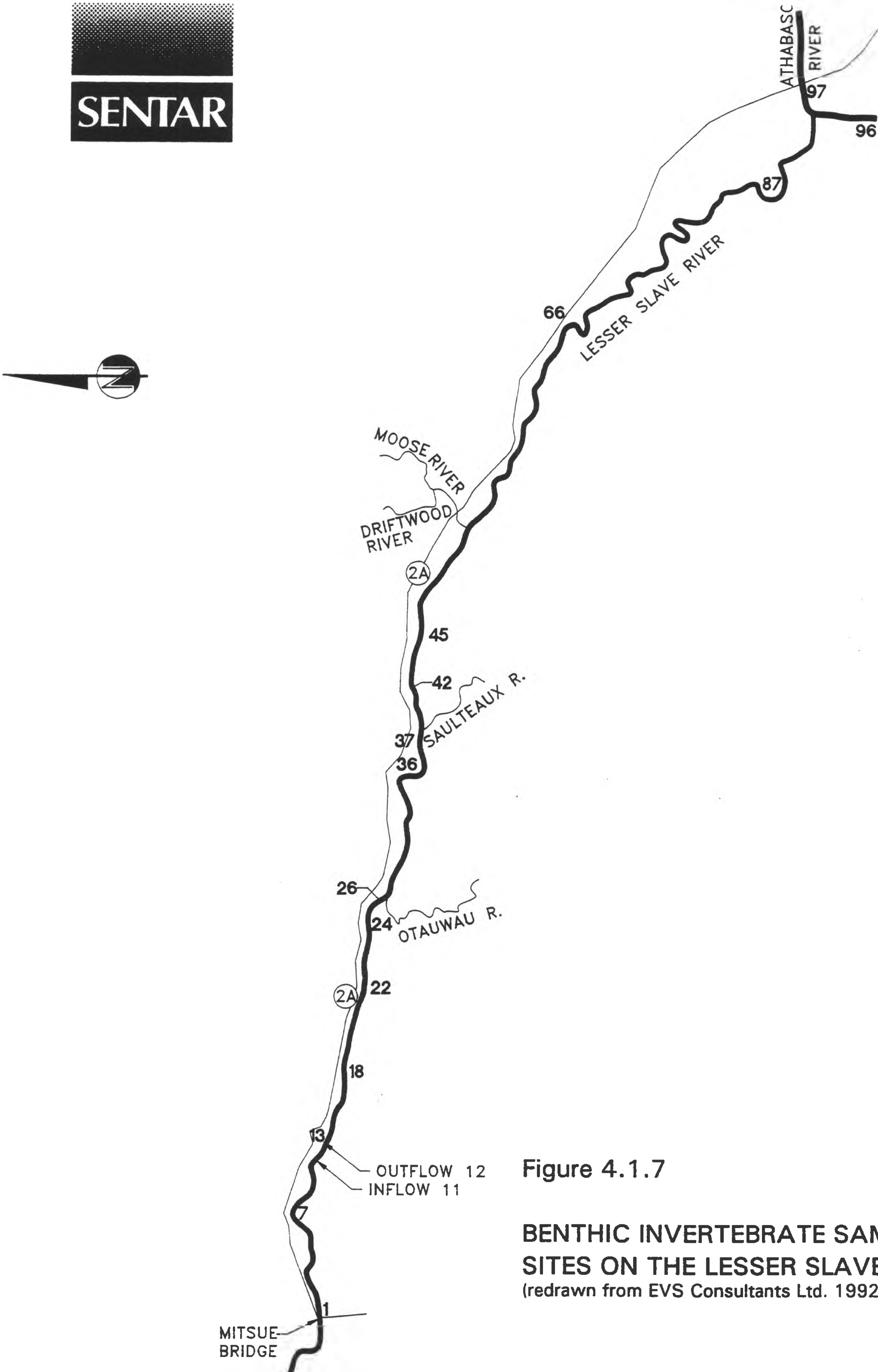

Figure 4.1.7

BENTHIC INVERTEBRATE SAMPLING SITES ON THE LESSER SLAVE RIVER
(redrawn from EVS Consultants Ltd. 1992a)

down the centre of the river in depositional areas. Periphyton chlorophyll *a* was measured and periphyton species were identified (Section 4.2.4).

The minimum taxonomic levels of identification for organisms collected were: class for Coelenterata; family for Annelida and Diptera; genus for Mollusca, Ephemeroptera, Trichoptera, Plecoptera; and order for the remaining Arthropoda.

The study done by EVS Consultants differs from the studies done by the other consultants. Chironomidae (midges) were not identified to genus. Given the importance of midges in the benthic samples, the number of taxa will appear to be comparatively less in the Lesser Slave River due to the lower taxonomic effort. Two sampling methods were used. Although the two methods were dictated by substrate differences, data collected in different substrates by different samplers cannot be readily compared. The number of replicate samples (3) at each site is also lower than the number of replicates (5) used by the other consultants.

4.1.5.2 Results

The 1990 baseline monitoring found that total abundance of benthic organisms and taxonomic richness were significantly different among stations and between sampling seasons (May and September). Stations located in riffle habitats had more invertebrates than stations located in deeper, depositional habitats. On average, there was a 142% increase in invertebrates collected in September relative to values reported for May (EVS 1991).

The baseline study showed that the upper portion of the river consists of fine sediments, slower and deeper waters characterizing a depositional or run habitat. Consequently, the upstream area, down to and including the outfall, was dominated by chironomids, ceratopogonids, nematodes and oligochaetes. The total abundance of organisms was low. These groups are generally found in aquatic environments with fine sediments and also tend to be more pollution tolerant than many other benthic groups. From the outfall to the Saulteaux River (Fig. 4.1.7), the river changes and the habitat is dominated by faster flowing, riffle areas causing a shift to benthic communities dominated by scrapers/collectors including mayflies, stoneflies and caddisflies.

Comparisons between operational (1991) and baseline (1990) data were done separately for depositional (Ponar samples) and riffle habitats (Hess samples). In general, species richness (adjusted for abundance) was higher at the near-field stations (downstream of the outfall but upstream of the Otauwau River) during the spring and fall operational surveys (Table 4.1.13). For the depositional habitats, dominance of midges (Chironomidae) or worms (Oligochaeta) was not as pronounced at the near-field stations (EVS 1992a). The changes in the near-field stations suggest mild enrichment of nutrients with no accompanying drop in dissolved oxygen levels (EVS 1992a). The average abundance (number/m^2) shows a clear trend of increasing abundance with increasing distance downstream (Table 4.1.14).

4.1.6 Peace River

4.1.6.1 Overview of Longitudinal Gradients

In the Peace River, gradients are apparent in water chemistry, substrate type, river discharge, current velocity, and the slope of the riverbed (Shaw et al. 1990). All of these factors influence zoobenthic distribution directly, or indirectly.

Along the upstream reach (i.e. BC/Alberta border to Smoky River), the substrate consists primarily of loose cobble with some pebble and sand. This substrate is heterogeneous and offers spatial refugia to a variety of invertebrates (Shaw et al. 1990). In addition, the amount of detritus that may become trapped could contribute to spatial preference because detritus is a major source of food for many invertebrates (Flecker and Allan 1984). The presence of epilithic algae, which was most abundant in this reach, also contributes to the invertebrate food base. The net result is a diverse and abundant invertebrate community in this reach (Shaw et al. 1990).

TABLE 4.1.13
Summary of Total Abundance and Species Richness for Ponar and Hess Samples on the Lesser Slave River

Variable	Type of Sampler	Station	1989		1990		1991	
			May	Oct	May	Sept	May	Sept
Abundance	Ponar	1	22	131	37	49	27	11
	Ponar	7	38	67	3	45	22	6
		Mill Outfall						
	Ponar	13	46	252	18	ND	62	7
	Ponar	18	17	58	21	31	12	14
	Ponar	24	243	317	9	68	21	93
	Hess	26	211	1164	520	1524	221	2734
		Otauwau River						
	Ponar	36	392	659	86	258	170	1440
	Hess	37	649	2630	675	1826	482	2479
		Salteaux River						
	Hess	42	ND	5203	564	ND	963	2033
		Driftwood River						
	Hess	87	ND	1554	1124	1067	303	1760
Species Richness	Ponar	1	2.4	5.8	4.2	5.1	1.3	1.4
	Ponar	7	4.2	3.4	1.4	5.1	1.9	1.3
		Mill Outfall						
	Ponar	13	3.2	6.7	2.3	ND	6.7	2.2
	Ponar	18	2.8	4.0	3.5	4.2	2.7	3.8
	Ponar	24	6.8	8.4	2.2	5.3	3.7	8.8
	Hess	26	7.1	13.5	10.9	18.9	10.9	15.1
		Otauwau River						
	Ponar	36	5.1	7.6	7.2	9.6	4.6	9.9
	Hess	37	10.1	14.9	11.4	17.5	12.0	13.0
		Salteaux River						
	Hess	42	ND	15.8	12.8	ND	15.9	15.8
		Driftwood River						
	Hess	87	ND	12.1	16.5	18.1	13.9	23.0
Richness (adjusted for abundance)	Ponar	1	2.8	4.8	4.1	7.8[a]	1.4	2.8
	Ponar	7	4.1	3.6	3.3	6.2	2.2	3.2
		Mill Outfall						
	Ponar	13	2.9	NC	2.9	ND	5.7	NC
	Ponar	18	3.5	4.4	4.2	5.9	3.8	7.0
	Ponar	24	3.7	5.0	3.4	5.5	4.3	8.2
	Hess	26	NC		10.9		11.5	
		Otauwau River						
	Ponar	36	2.3	3.5	5.5	6.2	2.7	3.4
	Hess	37	NC		11.2		12.1	
		Salteaux River						
	Hess	42	ND		12.7		15.4	
		Driftwood River						
	Hess	87	ND		15.8		14.4	

ND = No Data (not sampled)
NC = Not Calculated (excluded from analysis)
a. One outlier with low adjusted richness deleted
Notes: Values are geometric means
Data from EVS Consultants Ltd. 1992a

TABLE 4.1.14

Mean Number (number/m²) of Benthic Invertebrates Collected in the Lesser Slave River

		Upstream Stations		Outfall Stations				Downstream Stations			
		1	7	13	18	24	26	36	37	45/42	87
May 1989	Total	775.2	1 439.2	1 394.7	611.2	6 484.6	4 336.6	8 846.2	8 008.1	9 028.7	
	S.E.	363.8	784.3	471.1	307.9	2 665.0	1 750.9	3 433.9	1 894.6	2 342.2	
	C.V.	1.150	1.335	0.827	1.234	1.007	0.967	0.951	0.529	0.635	
October 1989	Total	5 148.3	2 864.5	12 788.7	2 750.5	14 705.7	13 581.9	13 880.6	31 428.3	63 975.1	18 812.9
	S.E.	2 041.1	1 160.6	7 740.5	1 386.0	6 345.4	2 002.0	4 135.3	4 746.3	13 448.8	3 591.0
	C.V.	0.971	0.992	1.483	1.234	1.057	0.361	0.730	0.370	0.515	0.468
May 1990	Total	2 836.7	366.7	1 180.0	2 046.7	273.3	6 137.0	2 370.0	7 987.0	8 148.1	13 011.1
	S.E.	1 649.8	334.9	772.2	1 256.9	70.4	937.8	645.7	1 243.1	2 351.4	1 818.2
	C.V.	1.43	2.24	1.60	1.50	0.63	0.37	0.67	0.38	0.71	0.34
September 1990	Total	1 673.3	4 140.0		2 616.7	4 810.0	20 331.5	6 430.0	20 948.1	22 640.7	12 988.9
	S.E.	638.2	3 004.6		2 245.9	3 066.3	5 512.7	1 778.6	2 371.8	4 135.9	2 273.9
	C.V.	0.93	1.78		2.10	1.56	0.66	0.68	0.28	0.45	0.43
May 1991	Total	570	493.3	1 323.3	280.0	493.3	2 918.5	3 620.0	9 133.3	10 798.1	3 596.3
	S.E.	77.6	85.3	223.4	70.2	90.4	897.1	574.0	4 292.2	637.2	565.6
	C.V.	0.33	0.42	0.41	0.61	0.45	0.75	0.39	1.15	0.14	0.39
September 1991	Total	243.3	160.0	213.3	373.3	2 803.3	32 763.0	30 910.0	31 051.0	27 114.8	22 400.0
	S.E.	41.8	43.8	80.4	134.2	849.6	5 565.1	4 996.7	7 130.1	6 825.6	4 847.4
	C.V.	0.42	0.67	0.92	0.88	0.74	0.42	0.40	0.56	0.62	0.53

Notes: Station numbers are described in Fig. 4.1.7. Standard error (S.E.) and coefficient of variation (C.V.) of the total abundance are also presented.
Data from EVS Consultants Ltd. 1992a.

The substrate at Notikewin and Carcajou in the intermediate reach (Smoky River to Fort Vermillion) is predominantly pebble. It also contains more sand and silt than sites from the upstream reach, but less than those from the downstream reach. The invertebrate association that inhabits this area tends to have transitional features as well which translate into higher diversity but lower numbers. Substrate characteristics alone do not explain the differential zoobenthic composition on the left and right banks of the Peace River, upstream of the Whitemud River. Incomplete lateral mixing of the Peace and Smoky Rivers in this reach may be the cause of the differences between the left and right banks.

The sandy substrate of the downstream reach (i.e. LaCrete to Peace Point) offers a less stable and less physically diverse habitat for benthic invertebrates. The general result is low numbers and low diversity in the benthic invertebrate population (Shaw et al. 1990).

4.1.6.2 Review of Field Surveys and Methods

The Environmental Quality Monitoring Branch, Alberta Environment, has conducted benthic invertebrate surveys in the Peace River. Benthic invertebrates were sampled at ten sites along the mainstem from the B.C.-Alberta border to Peace Point (Fig. 4.1.8) in September 1988. Additional samples were collected at mainstem sites near the B.C.-Alberta border in May and September 1987, and July and September-October 1988. Also, a more detailed study of the reach between the Smoky and Notikewin Rivers was done in July and October 1988 (Fig. 4.1.9). Shaw et al. (1990) focused primarily on data from one synoptic survey conducted on the Peace River in September-October 1988; its prime objective was to document major longitudinal trends in the river's zoobenthos.

In selecting sampling sites for zoobenthos, attempts were made to standardize substrate, current velocity and sampling depth, all of which are known to influence benthic invertebrate distribution. Samples were usually collected at a depth between 30 cm and 40 cm in moderately fast flow. Zoobenthos sampling was performed with a modified Neill cylinder sampler with an opening of 0.1 m^2 and a mesh size of 0.210 mm. Five replicate samples were collected at each site.

Benthic invertebrate surveys have also been conducted by Monenco Consultants Ltd. (1990a,b,d; 1991a; 1992a,b) for Peace River Pulp Division of Daishowa Canada Co. Ltd. at Peace River, Alberta. Benthic monitoring began July 1989 (Monenco 1990a) with subsequent monitoring each spring and fall. Fourteen sampling sites were established from 14 km upstream to 55 km downstream of the mill location (Fig. 4.1.9). This distance downstream was reduced to 30 km in April 1991 and the number of sites has varied between ten and fourteen.

Five replicate samples were collected with a Hess cylindrical sampler; the Ponar dredge was used in depositional areas. The substrate was predominantly large gravel to small cobble. Epilithic chlorophyll *a* was not measured; therefore, information on key food resources is not available. Benthic invertebrate densities were extremely low with a complete absence of organisms at some locations. This may be due to high water levels inundating areas not normally covered with water during most of the year. Some sampling sites may have only been underwater for a few days to a few weeks. High velocities and turbidity restricted sampling to near shore areas. The degree of taxonomic effort was less than that used by Alberta Environment. Insects such as Ephemeroptera and Plecoptera were identified to the genus level, but Diptera (including Chironomidae) were only identified to family. Since Chironomidae are often very diverse, the number of taxa reported will not be comparable to the number reported by Alberta Environment.

4.1.6.3 Peace River Survey Results

A diverse assemblage of benthic invertebrates was collected by Alberta Environment (Shaw et al. 1990) in the Peace River in 1987 and 1988; a total of 106 taxa was recorded in the 230 samples collected during these two years. The total number of taxa recorded in the synoptic survey samples ranged from 9 (upstream Wood Buffalo National Park) to 46 (upstream Whitemud River, left bank) (Table 4.1.15). The total number of taxa ranged from 19 to 46 at Carcajou and all sites further upstream, but was below 15 at all sites further downstream.

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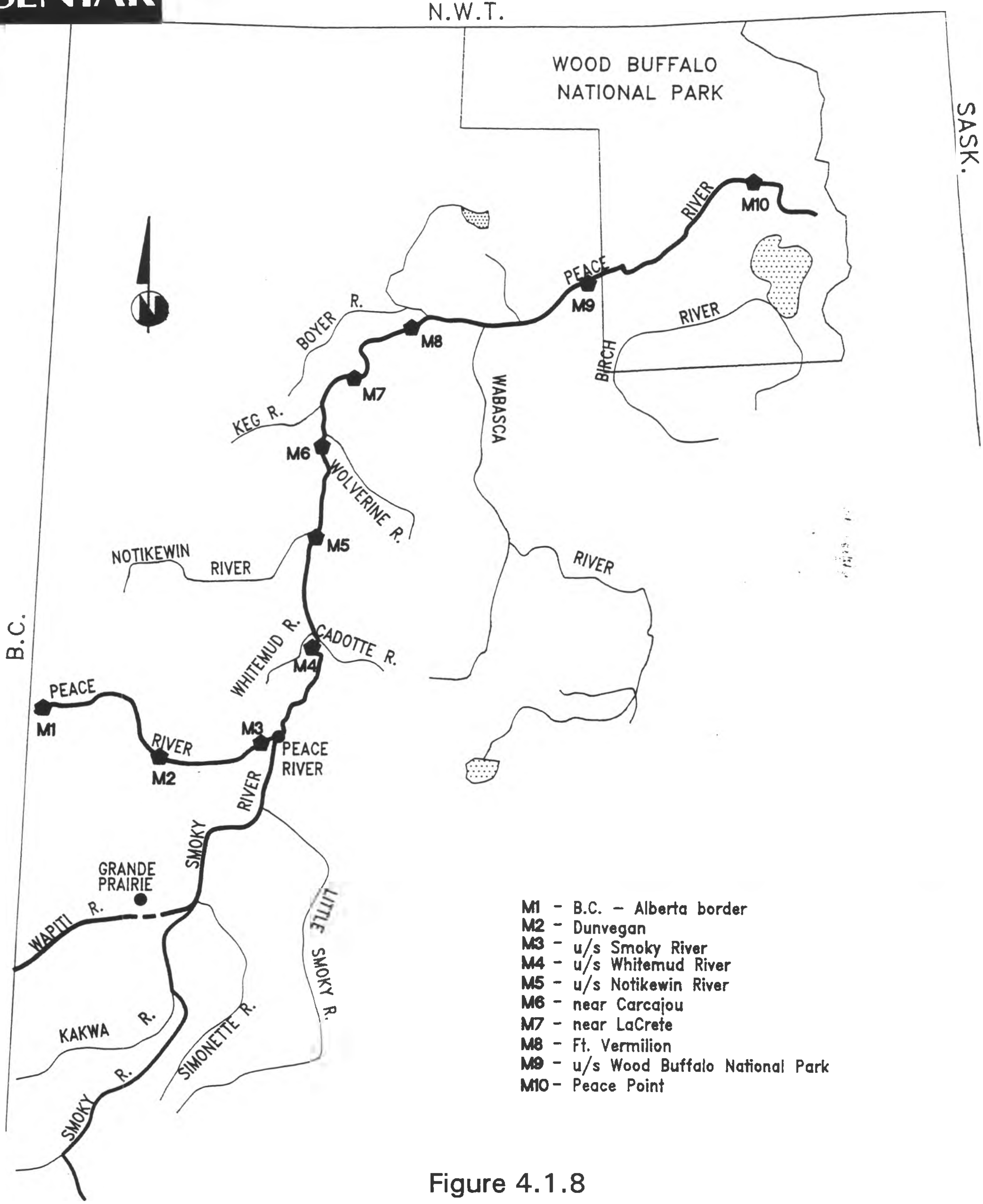

M1 - B.C. - Alberta border
M2 - Dunvegan
M3 - u/s Smoky River
M4 - u/s Whitemud River
M5 - u/s Notikewin River
M6 - near Carcajou
M7 - near LaCrete
M8 - Ft. Vermilion
M9 - u/s Wood Buffalo National Park
M10 - Peace Point

Figure 4.1.8

BENTHIC INVERTEBRATE SAMPLING SITES ON THE PEACE RIVER
(redrawn from Shaw et al. 1990)

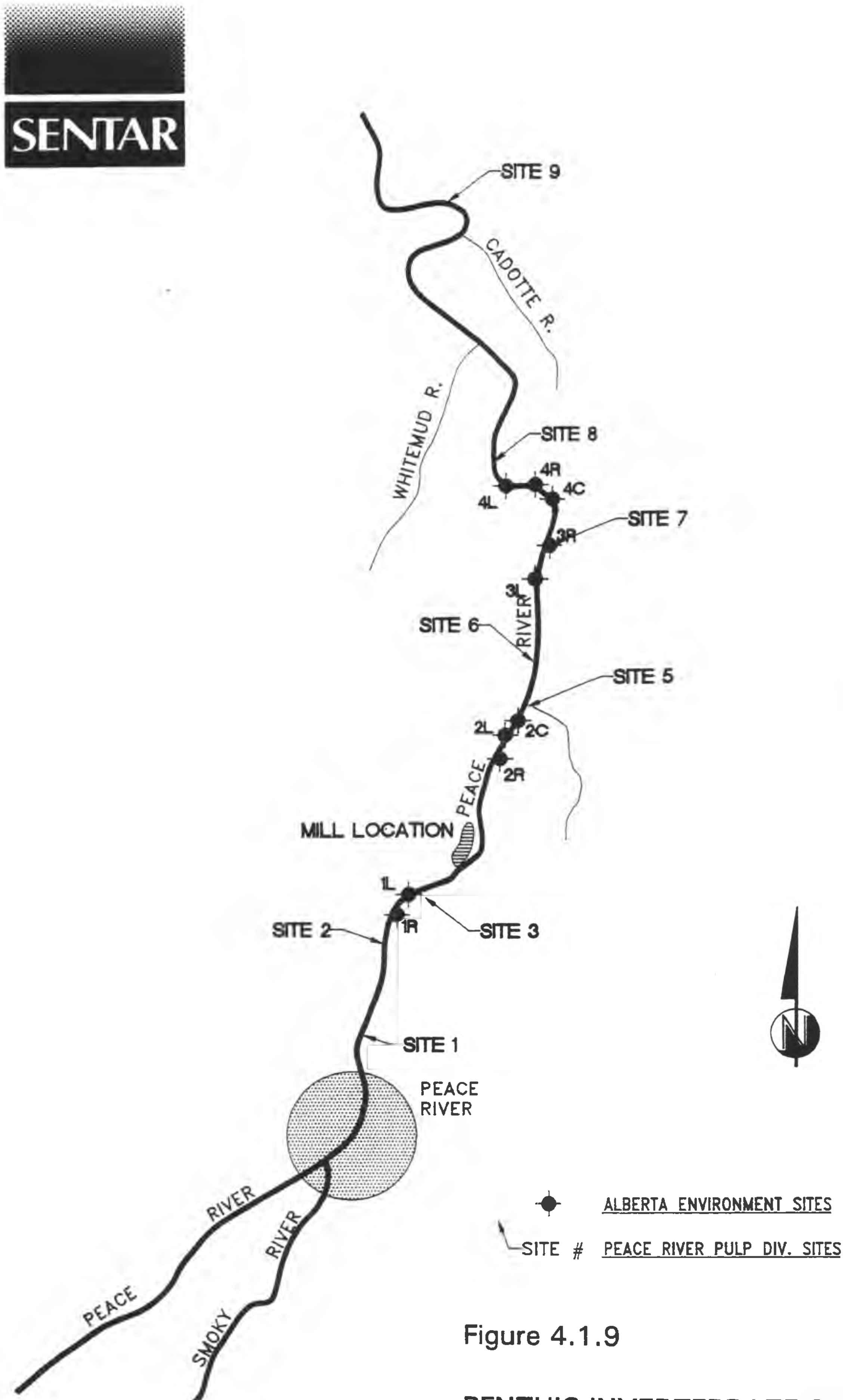

Figure 4.1.9

BENTHIC INVERTEBRATE SAMPLING SITES ON THE PEACE RIVER NEAR THE PEACE RIVER PULP MILL
(redrawn from Monenco Consultants Ltd. 1992a and Shaw et al. 1990)

TABLE 4.1.15
Total Number of Benthic Invertebrate Taxa in the Peace River[a]

Site	1987		1988	
	Spring	Fall	Spring	Fall
Border (left bank)	26	46	40	19
Border (right bank)	34	44	45	26
4.2 km Upstream Clear River (centre)	29	36		
0.25 km Upstream Clear River (left bank)	24	39	33	24
0.25 km Upstream Clear River (right bank)	37	41	40	31
Dunvegan (left bank)				28
Above Smoky River				25
4 km Upstream Daishowa			19	36
3 km Upstream Daishowa			17	35
2 km Downstream Daishowa			30	41
5 km Downstream Daishowa			22	36
7 km Downstream Daishowa			29	28
17 km Downstream Daishowa			28	36
20 km Downstream Daishowa			35	27
32 km Downstream Daishowa			30	31
33 km Downstream Daishowa			24	29
35 km Downstream Daishowa			28	33
Above Notikewin River				23
Near Carcajou (centre)				25
Near La Crete				14
At Fort Vermilion				9
Above Wood Buffalo Park				10
Near Peace Point (centre)				12

a. Data from Shaw et al. (1990)

There was a decline of total invertebrate numbers along the mainstem. At sites from the B.C.-Alberta border to the Whitemud River, mean numbers exceeded 400 specimens per sample (4000 organisms/m^2) with the exception of the spring of 1987 (Table 4.1.16). At the Notikewin, Carcajou, and Lacrete sites, numbers dropped below 200 specimens per sample (2000 organisms/m^2), and at the three most downstream sites numbers were less than 50 specimens per sample (500 organisms/m^2). Total invertebrate numbers ranged from a mean of seventeen specimens per sample (174 organisms/m^2), upstream of Wood Buffalo in fall 1988, to a mean of 2295 specimens per sample (22,952 organisms/m^2) at the B.C.-Alberta border left bank site in fall 1988 (Table 4.1.16). Invertebrate population densities in the Peace River were low compared to those recorded in more productive rivers.

TABLE 4.1.16
Total Number of Benthic Invertebrates per Square Metre in the Peace River[a]

Site	1987		1988	
	Spring	Fall	Spring	Fall
Border (left bank)	1 640	3 485	6 478	22 952
Border (right bank)	798	4 832	7 340	6 686
4.2 km Upstream Clear River (centre)	3 356	4 000		
0.25 km Upstream Clear River (left bank)	1 210	5 166	7 466	8 794
0.25 km Upstream Clear River (right bank)	1 224	3 524	6 276	1 958
Dunvegan (left bank)	10	10		3 708
Above Smoky River	12	12		9 118
4 km Upstream Daishowa	10	10	1 176	12 678
3 km Upstream Daishowa	12	12	464	13 574
2 km Downstream Daishowa	10	10	2 272	14 400
5 km Downstream Daishowa	12	12	2 127	8 470
7 km Downstream Daishowa	10	10	2 478	2 986
17 km Downstream Daishowa	12	12	2 244	9 276
20 km Downstream Daishowa	10	10	2 122	2 458
32 km Downstream Daishowa	12	12	1 670	6 350
33 km Downstream Daishowa	10	10	958	2 192
35 km Downstream Daishowa	12	12	2 938	15 808
Above Notikewin River			10	1 594
Near Carcajou (centre)			12	1 826
Near La Crete				1 056
At Fort Vermilion				198
Above Wood Buffalo Park				174
Near Peace Point (centre)				437

a. Data from Shaw et al. (1990)

The total number of invertebrates per square metre tended to be low in the spring and summer, and high in the fall (Table 4.1.16). While statistical analyses of the data have not been performed, the number of taxa does not appear to display a seasonal trend (Table 4.1.15). Numbers of invertebrates collected in the vicinity of the pulp mill (two years before start-up) were nearly an order of magnitude lower in the summer of 1988 than in the fall of the same year; however, numbers at the border sites were similar in summer and fall 1988.

Dominant taxa in the Peace River zoobenthos were Oligochaeta (bristle worms), Chironomidae larvae (midge larvae), and Nematoda (round worms). At most sites, these three taxa comprised at least 50% of the total invertebrate numbers. The remaining 50% is comprised of Ephemeroptera, Trichoptera, Plecoptera, Coleoptera, Hemiptera, Diptera (other than

Chironomidae), Coelenterata, Turbellaria, Crustacea, Collembola, Arachnida, Mollusca and Tardigrada. The downstream decline in numbers of Nematoda and Chironomidae was relatively smaller than that of other taxa; proportions of these two groups tended to increase downstream. Plecoptera larvae (stoneflies) were an important component of the zoobenthos at the sites upstream of the Whitemud River, upstream of the Notikewin River, and near Carcajou where they represented 30% or more of the total numbers.

Cluster analysis (CA) and principal components analysis (PCA) were performed on zoobenthic data from the fall 1988 in an attempt to identify groups of sites with similar zoobenthic associations. Cluster analysis divided the Peace River sites into three clusters (Fig. 4.1.10): two sites (left and the right bank) located upstream of the Whitemud River (Cluster I); all sites upstream of these two sites (Cluster II); and all sites downstream of these two sites (Cluster III). This last cluster splits into two sub-clusters, one of which consists of the Notikewin and Carcajou sites (Cluster IIIa) and the other (Cluster IIIb) is made up of the four most downstream sites (LaCrete, Fort Vermillion, Wood Buffalo National Park and Peace Point).

The site groupings obtained by CA were compatible with the results obtained with PCA. The first component accounted for 28.5% of the variance and separated the first cluster defined in CA from all other site groups, primarily because the two sites at the Whitemud River were typified by relatively high overall densities of stoneflies, mayflies, chironomid larvae and mites.

4.1.6.4 Peace River Pulp Mill Results

The density of benthic invertebrates has been consistently low in the Peace River near the vicinity of the mill (Table 4.1.17). Monenco attributed the low organism densities to the effects of daily and seasonal fluctuations in river flow. In the fall of 1990 and 1991, the area sampled had been under water for only a few days prior to sampling (Monenco 1992b). Stream flow fluctuations resulting from the operation of the WAC Bennet Dam have probably had the greatest influence upon the benthic community in this area of the Peace River. The continued inundation and dewatering of riffle habitats over relatively short periods of time markedly reduce invertebrate colonization and the availability of periphyton.

TABLE 4.1.17
Total Number of Benthic Invertebrates per Square Metre in the Vicinity of the Peace River Pulp Mill[a]

Date	UPSTREAM							DOWNSTREAM										
	Site 1			Site 2		Site 3		Site 5			Site 6		Site 7			Site 8		Site 9
	Left	Centre	Right	Left	Right	Left	Right	Left	Centre	Right	Left	Right	Left	Centre	Right	Left	Centre	Left
Fall 1989	38		120	56	38	82	117	68	92		39	100		43	81		63	6
Spring 1990	54 (108)	11 (22)	19 (38)			35 (70)	43 (86)	59 (118)	42 (84)					149 (298)		148 (296)	88 (176)	45 (90)
Fall 1990	42 (84)		8 (16)	5 (10)	0	43 (86)	23 (46)	55 (110)	44 (88)		4 (8)			3 (6)	9 (18)		109 (218)	2 (2)
Spring 1991	9 (18)		27 (54)	6 (12)					48 (96)		15 (30)	9 (18)		10 (20)	9 (18)	14 (28)	12 (24)	
Fall 1991	90 (180)	33 (66)	25 (50)	25 (50)		45 (90)	18 (36)		26 (52)	64 (128)	16 (32)			38 (76)	30 (60)		25 (50)	25 (50)
Spring 1992	66 (132)	49 (98)	44 (88)	26 (52)	16 (32)	163 (326)			62 (126)	85 (168)	32 (64)		52 (104)	37 (74)	24 (48)	42 (84)	87 (174)	12 (24)

a. Invertebrate Density (number/m^2) is indicated in parenthesis

Note: Total numbers based on Hess sampler aerial coverage in 5 replicate samples from each site.

Data from Monenco 1990a,b,d; 1991a; 1992a,b; HBT Agra 1992.

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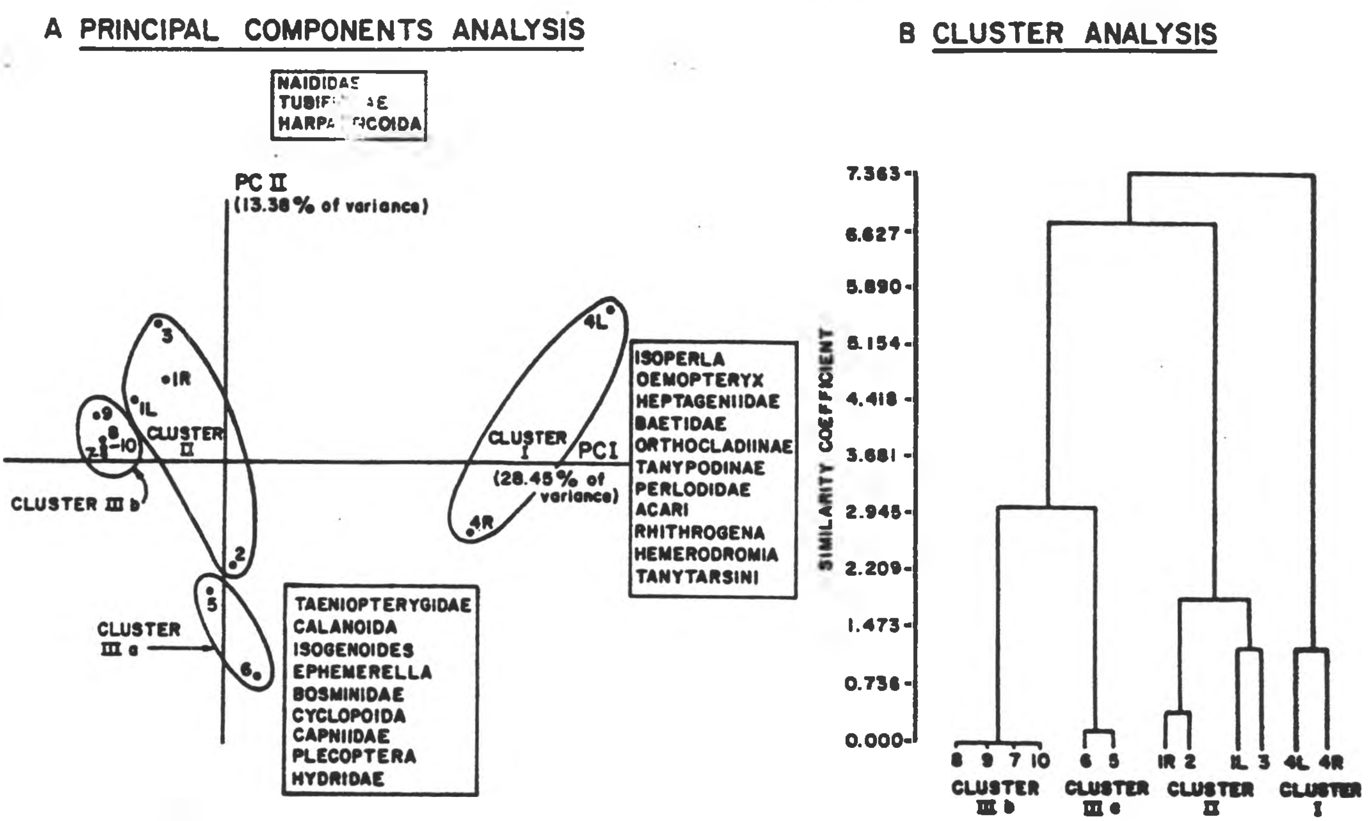

Figure 4.1.10

Alberta ENVIRONMENT
Environmental Quality Monitoring Branch

MULTIVARIATE ANALYSES OF ZOOBENTHIC DATA FROM THE PEACE RIVER, SEPTEMBER - OCTOBER 1988
(Shaw et al. 1990)

In April 1991, benthic invertebrate densities were lower than usual at all sampling sites, including upstream control sites, and ranged from 12 to 96 organisms/m^2. The low densities were attributed by Monenco (1992a) to large fluctuations in water levels of the Peace River. Statistical comparison of April 1991 benthos data with data collected in April 1990 showed a significant reduction in the total numbers of organisms and taxa in 1991. However, invertebrate community structure (measured by diversity and similarity indices) were not significantly different between 1990 and 1991. An analysis of variance conducted on the Fall 1990 and 1991 benthos diversity data sets demonstrated that the Fall 1991 diversity indices were significantly higher than the diversity indices calculated for the Fall 1990 benthos data (Table 4.1.18).

Analyses of benthic diversity (Table 4.1.18) and community structure have been done for each survey from 1989 to 1992. They have failed to demonstrate any definite pattern related to their spatial orientation or the mill location. The number of invertebrate taxa varies considerably among sites and sampling periods (Table 4.1.19). When the Kruskal-Wallis test, the non-parametric equivalent of the ANOVA, was applied to the benthos data for the spring of 1990, 1991 and 1992, and the fall of 1991, it showed that the benthic populations at different dates and locations on the Peace River could not be considered to be different from one another (HBT Agra 1992). Benthos data were also analyzed by ANOVA and MANOVA. There was a significant difference from one site to another in 1990, the first time a significant difference had been detected by ANOVA since sampling began in July 1989. Further examination of the 1990 pre-operational data found differences among upstream sites and among downstream sites. Multiple analysis of variance of later data including the spring of 1992 continues to show similar differences (HBT Agra 1992).

There appears to be substantial differences in the data collected by Alberta Environment in 1987-88 compared to the data supplied by Monenco since 1989. The raw data from Shaw et al. (1990) has been tabulated by SENTAR (Tables 4.1.15 and 4.1.16) so that the results can be compared to the Monenco results in Tables 4.1.17 and 4.1.19. The number of taxa and organisms are generally lower in the Monenco samples. Since these differences are present prior to the start-up of the Daishowa pulp mill, they may be due to the differences in methods and, possibly, annual variation.

TABLE 4.1.18
Diversity Index of Benthic Invertebrates Collected in the Vicinity of the Peace River Pulp Mill

Date	UPSTREAM							DOWNSTREAM										
	Site 1			Site 2		Site 3		Site 5			Site 6		Site 7			Site 8		Site 9
	Left	Centre	Right	Left	Right	Left	Right	Left	Centre	Right	Left	Right	Left	Centre	Right	Left	Centre	Left
Fall 1989	1.94	-	2.04	1.39	1.88	1.37	1.40	1.63	1.24		1.57	1.78	-	1.43	1.66	-	1.73	1.10
Spring 1990	1.96	1.16	2.31	-	-	1.47	1.00	1.78	0.61	-	-	-	-	1.69	-	1.66	1.73	1.87
Fall 1990	2.03	-	0.38	1.33	0.00	2.15	2.19	2.24	2.02	-	1.04	-	-	1.10	1.89	-	2.28	0.00
Spring 1991	1.22	-	1.32	1.33	-	-	-	-	1.70		1.99	1.43	-	1.83	1.22	1.42	1.36	-
Fall 1991	2.91	2.82	2.60	3.16	-	3.16	3.08	-	3.11	2.47	2.61	-	-	2.69	2.45	-	3.18	1.98
Spring 1992	1.86	2.01	2.39	1.17	1.36	1.87	-	-	1.79	1.59	1.15	-	1.64	1.90	1.21	2.09	1.42	0.72

TABLE 4.1.19
Total Number of Benthic Invertebrate Taxa in the Vicinity of the Peace River Pulp Mill

Date	UPSTREAM							DOWNSTREAM										
	Site 1			Site 2		Site 3		Site 5			Site 6		Site 7			Site 8		Site 9
	Left	Centre	Right	Left	Right	Left	Right	Left	Centre	Right	Left	Right	Left	Centre	Right	Left	Centre	Left
Fall 1989	10		15	8	10	10	11	8	7		7	11		8	19		11	3
Spring 1990	11	5	12			7	6	13	6					15		12	12	10
Fall 1990	11		2	4	0	10	10	13	12		3			3	7		14	1
Spring 1991	4		6	4					10		8	5		7	4	6	5	
Fall 1991	14	13	8	10		11	10		11	13	8			8	7		11	7
Spring 1992	10	13	14	5	6	14			9	12	6		11	9	5	11	10	3

a. data from Monenco 1990a,b,d; 1991a; 1992a,b; HBT Agra 1992.

4.1.7 Wapiti-Smoky Rivers System

4.1.7.1 Review of Field Surveys and Methods

Since little data were available for the Smoky River, a river study was carried out by Alberta Environment in 1983 to assess the impact of the pulp mill and to augment the database and understanding of the Smoky River system (Noton et al. 1989). A number of benthic invertebrate studies have bee carried out by Alberta Environment on the Wapiti-Smoky River system since 1983. These include a benthic survey in October 1989, and February 1991.

Benthic macroinvertebrates (zoobenthos) were sampled in May and September 1983 on the left and right banks at the river sites shown in Figure 4.1.11. The habitat sampled was erosional gravel-cobble and was standardized as much as possible between sites with regard to substrate, depth and current velocity. Epilithic chlorophyll *a* was measured; data are presented in Section 4.2.6. Five replicate samples were collected at each location with a modified Neill cylinder sampler (area = 0.1 m^2; net mesh size = 0.210 mm). River flows were near average in 1983, and the mill effluent constituted from 0.2% to 6% of the flow in the Wapiti River during sampling occasions.

Benthic invertebrate surveys of the Wapiti River have been conducted by Terrestrial and Aquatic Environmental Managers (TAEM) Ltd. since 1987 (TAEM 1990, 1991a, 1992a) for Weyerhaeuser Canada Ltd. and the previous owner, Procter & Gamble. Five Neill cylinder samples (area = 0.1 m^2; net mesh size = 0.210 mm) were collected for each of the eleven benthic invertebrate sampling locations (Fig. 4.1.12). Five additional samples were collected at two more stations in October 1990 to sample a complete transect across the Wapiti River. Riffle areas were selected for sampling. Sorting, taxonomic identification and enumeration of the benthic invertebrates were performed by a qualified invertebrate taxonomist. Individuals were usually identified to genus, but identification to species was done where practicable. Surveys were conducted in different seasons. The last three surveys have been done in October 1990, April 1991 and January 1992.

TAEM reports the percent standard error of the mean of the replicate samples. TAEM (1992a) considers a percent standard error of 20% to be reasonable (based on Elliott 1977). This was exceeded at one of the eleven stations sampled in October 1990, three stations in April 1991 and one station in January 1992.

4.1.7.2 Alberta Environment Results

Previous benthic monitoring by Alberta Environment indicated little effect of the mill effluent in the mid-1970's (Noton et al. 1989). In 1980, following low river flows, water quality impacts occurred at the town of Peace River. Benthic monitoring by Alberta Environment indicated that the pulp mill effluent was causing a noticeable reduction in numbers of the zoobenthos in the Wapiti River.

The 1983 Alberta Environment study showed that the negative impact had lessened since 1980. Benthic macroinvertebrates in the Smoky River and lower Wapiti River appeared to be enriched in numbers (Table 4.1.20) and to some extent in taxa as a result of the pulp mill effluent and Grande Prairie sewage. The reduction in benthos found in 1980 no longer appeared to be occurring. The effect was observable downstream to about Watino (about 200 km) (Noton et al. 1989).

A diverse assemblage of benthic macroinvertebrates was collected in spring and fall samples from the study area. Crustacea and Chironomidae dominated the spring samples numerically with Nematoda and Oligochaeta next in abundance. Fall samples were dominated by Chironomidae; Oligochaeta and Plecoptera were next most abundant. The number of benthic macroinvertebrates collected in the study area increased noticeably downstream of the mill effluent (Table 4.1.18). Numbers generally declined down the Smoky River to around 150 per sample (1500 organisms/m^2) at the lower Smoky and Peace River sites. Mean numbers of organisms per site ranged from 100 to 600 per sample (1000-6000 organisms/m^2) in spring, but were higher in the fall when mean numbers ranged from about 100 to over 3000 per sample (1000-3000 organisms/m^2).

SENTAR

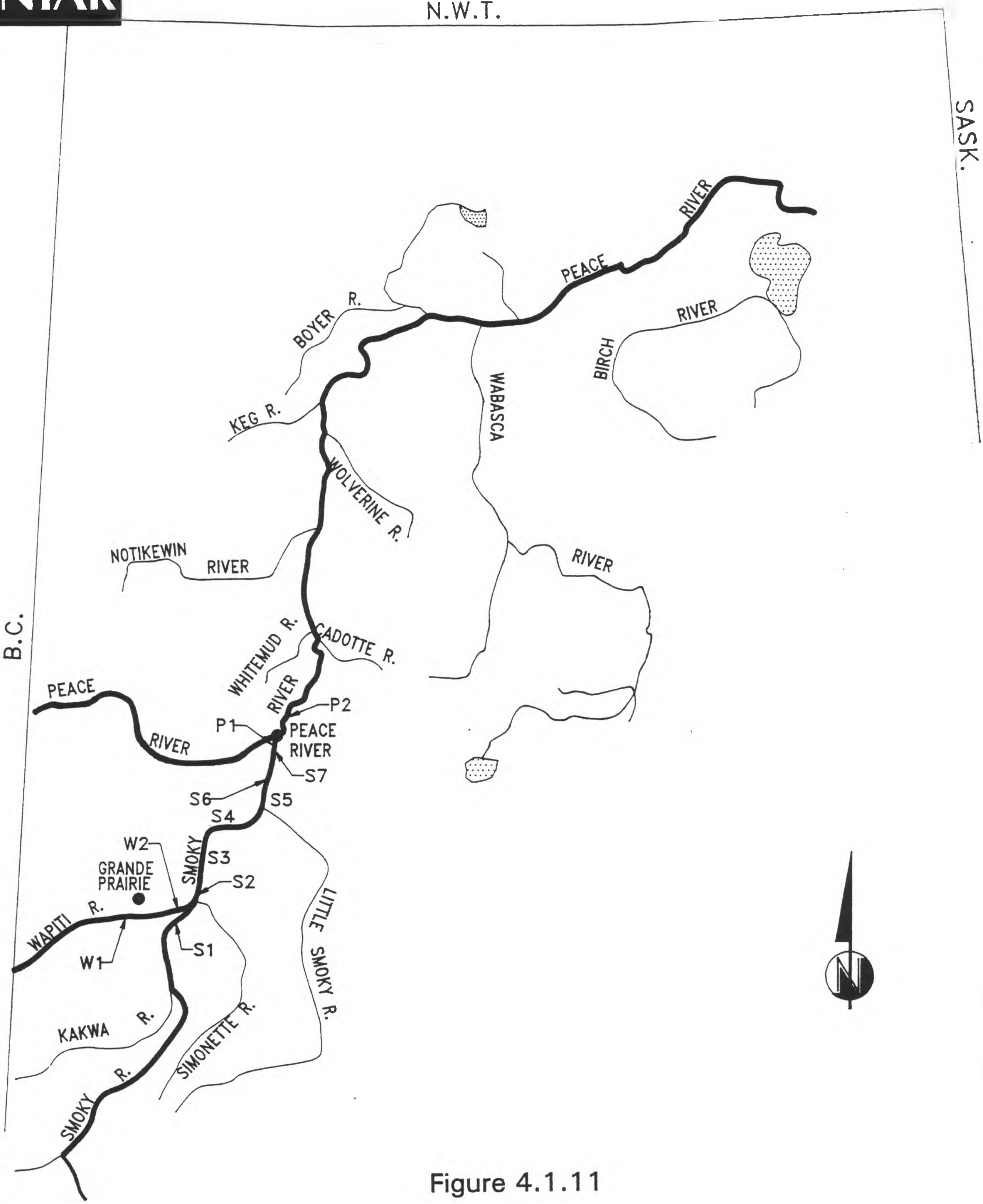

Figure 4.1.11

BENTHIC INVERTEBRATE SAMPLING SITES ON THE WAPITI, SMOKY AND PEACE RIVERS
(sites from Noton et al. 1989)

SENTAR

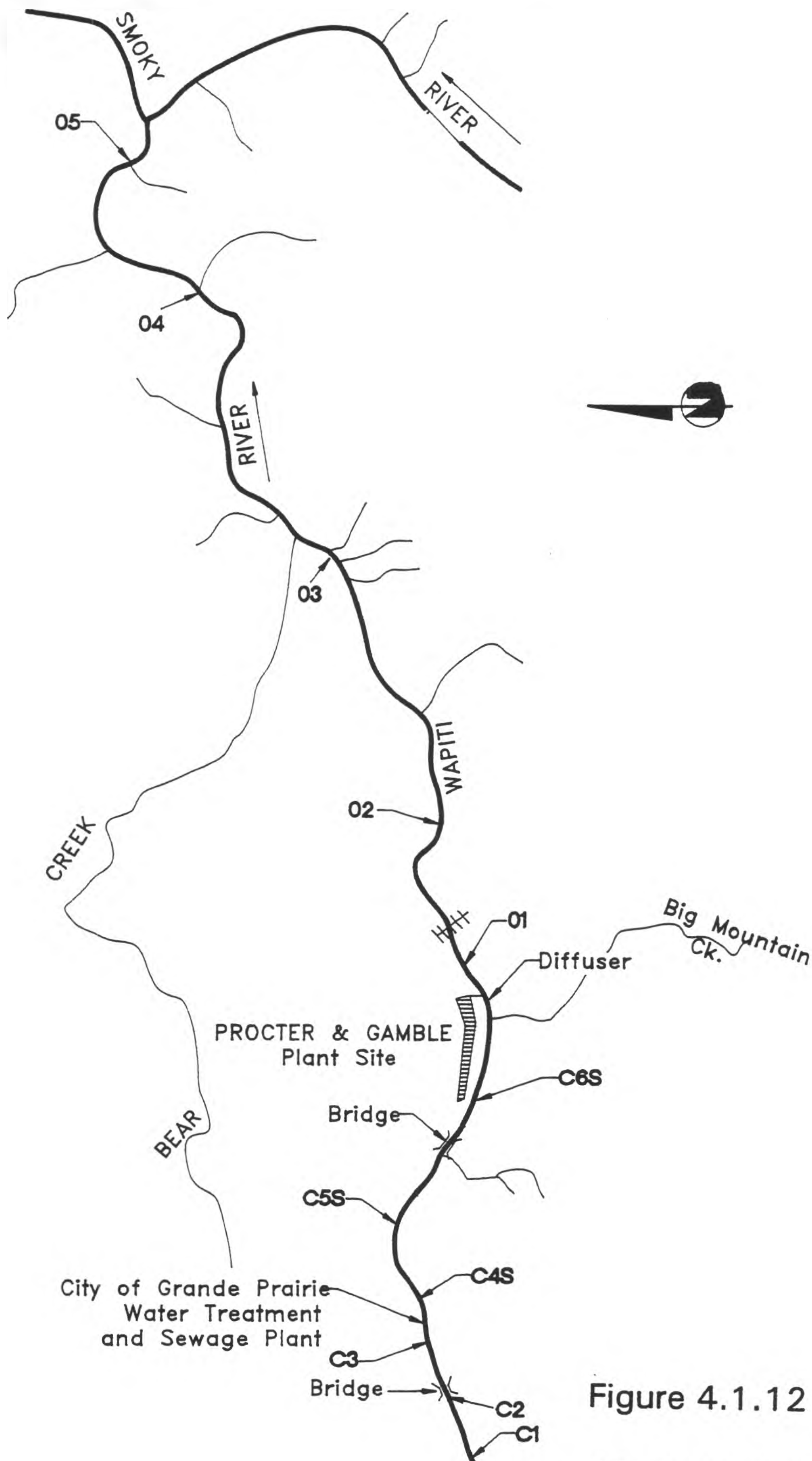

Figure 4.1.12

BENTHIC INVERTEBRATE SAMPLING SITES ON THE WAPITI RIVER
(redrawn from TAEM 1991a)

TABLE 4.1.20
Mean Number of Benthic Invertebrates and Taxa in the Wapiti, Smoky and Peace Rivers[a]

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Wapiti River														
May 1983														
- Mean Total	209	254	626	592										
- S.E.	28	36	54	47										
- Taxa	24	22	18	16										
September 1983														
- Mean total	367	143	3198	1738										
- S.E.	60	12	368	477										
- Taxa	20	16	22	21										
Smoky River														
May 1983														
- Mean Total	46	95	230	181	415	510	339	248	296	127	117	101	101	314
- S.E.	6	12	27	27	33	49	23	28	25	5	14	16	9	47
- Taxa	11	11	15	11	13	15	15	14	13	10	12	14	10	14
September 1983														
- Mean Total	272	196	1293	257	577	496	298	617	75	278	114	68	172	217
- S.E.	42	33	157	45	24	49	79	77	14	43	7	11	11	27
- Taxa	18	14	22	13	23	23	17	21	12	20	17	14	9	19
Peace River														
May 1983														
- Mean Total	124	130	109	71										
- S.E.	5	9	7	6										
- Taxa	17	18	17	11										
September 1983														
- Mean Total	172	188	115	141										
- S.E.	17	23	17	42										
- Taxa	19	15	15	17										

a. data from Noton et al. 1989
S.E. = Standard Error

Benthic biota (algae, invertebrates) in the Wapiti-Smoky River system show evidence of enrichment (eutrophication). There is no evidence of toxicity which may mean that either there is no toxicity or the effect of enrichment exceeds that of toxicity. Effluents from the Weyerhaeuser pulp mill appear to be the main cause of the impacts although treated sewage and urban runoff from Grande Prairie as well as tributary inflows also contribute nutrients (Noton 1992). The number of organisms and number of taxa increase downstream of the Weyerhaeuser pulp mill and Grande Prairie sewage treatment plant outfall (Noton et al. 1989). The two recent benthic surveys of October 1989 and February 1991 both indicated that the main effect on benthic biota in the Wapiti River is one of enrichment (Noton 1992). Both benthic chlorophyll a and benthic invertebrates tended to be more abundant downstream of the effluents, at least in shallow water. Sampling was not carried out in the deeper parts of the river. The zoobenthos data for the winter of 1991 had not been analyzed in detail when Noton made his comments in 1992, but the data available from that survey did not show toxic effects, based on the taxonomic composition and abundance of invertebrates. Total numbers were higher downstream of the effluents while the number of taxa were approximately the same upstream and downstream. There appeared to be some decline in mayflies and stoneflies downstream of the effluents but it is not known whether this was due to eutrophication or toxicity. These groups are known to decline in enriched situations whereas chironomids and aquatic worms generally increase, as was the case.

4.1.7.3 Weyerhaeuser Results

TAEM (1992a) found that the relative composition of the benthic community in the Wapiti River was altered by the effluents. The October 1990 data show an enrichment effect, a relative increase in chironomid numbers over mayfly and stonefly numbers, but the April 1991 data do not demonstrate this. Tthe benthic macroinvertebrate community sampled in October 1990 at control stations C1, C2 and C3 (Fig. 4.1.12), was dominated by three taxonomic groups: Ephemeroptera (48.48%), Plecoptera (26.56%) and Chironomidae (17.31%) comprising about 92% of the population. At stations C4S, C4S and C6S located below the city sewage effluent, there was a shift in the ranking of the major taxonomic groups in the population. The population was dominated by Chironomidae (77.31%); the Ephemeroptera (11.83%) and Plecoptera (4.71%)

comprised much less of the population. The Chironomidae continued to dominate at stations located below the pulp mill effluent, comprising about 80% of the organisms collected. The remaining major taxonomic groups were all fairly evenly represented, with most groups comprising about 3% to 4% of the population.

In contrast, the upstream control stations sampled in April 1991 were dominated by Chironomidae (76.55%), but the relative abundance of Chironomidae dropped to 58.56% below the sewage effluent. This drop in the relative abundance of Chironomidae differs from the increase in relative abundance in 1990. The Chironomidae increased to 84.55% below the pulp mill effluent, slightly above levels at the control station. The Naididae, a minor group in 1990, increased substantially to be the second largest group below the sewage discharge (26.52%) and the pulp mill effluent (9.61%) in April 1991. These data illustrate the marked changes in the benthic invertebrate communities that can occur due to natural causes.

Recent studies by TAEM (1990, 1991a and 1992a) show a substantial increase in the total number of organisms found per unit area (Table 4.1.21) as a result of the municipal and pulp mill effluents. This change was apparent in October 1990, April 1991 and January 1992. The increase in the number of organisms at the first site impacted by the Grande Prairie sewage, C4S, ranged from an order of magnitude increase in January 1992 to a four-fold increase in April 1991.

The number of invertebrates also increased as a response to treated pulp mill effluent at all the observation stations in 1988, 1990, 1991 and 1992. The number of organisms reached a maximum of $47,406/m^2$ at station O2 (Fig. 4.1.12) in 1992. The increase in the number of organisms collected is an indication of nutrient enrichment by the pulp mill effluent. The 1982-87 results show that the numbers of organisms above and below the pulp mill are much lower than the numbers for 1988 onwards (Table 4.1.22). The City of Grande Prairie began releasing sewage effluent into the Wapiti River upstream of the pulp mill's effluent in 1987.

TABLE 4.1.21
Total Number of Benthic Invertebrates Collected in the Wapiti River Near Grande Prairie[a]

Date	Control Stations						Observation Stations Below Mill Effluent				
	Upstream			Below Municipal Effluent							
	C1	C2	C3	C4	C5	C6	O1	O2	O3	O4	O5
October 1982	n/d[b]	n/d	n/d	n/d	194	133	539	678	865	896	666
Standard Deviation	n/d	n/d	n/d	n/d	6.9	5.6	11.5	18.1	35.9	33.2	15.3
October 1983	n/d	n/d	n/d	n/d	1018	1084	3278	2348	1616	3046	3142
Standard Deviation	n/d	n/d	n/d	n/d	28.3	35.6	63.6	55	21.1	100.2	94
October 1985	n/d	n/d	n/d	n/d	2478	1996	2670	4284	2912	2706	3166
Standard Deviation	n/d	n/d	n/d	n/d	74.6	104.9	76.5	65.4	84.8	69.4	76.7
October 1987	n/d	n/d	n/d	n/d	3994	3966	1678	1892	1512	1760	3102
Standard Deviation	n/d	n/d	n/d	n/d	143.2	202.6	113.5	50.2	57.2	42.8	151.3
October 1988	n/d	1348	6306	5802	2978	1842	14136	5564	13302	18502	50442
Standard Deviation	n/d	60.9	217.0	349.5	96.5	62.3	904.1	57.5	226.8	397.7	1388
October 1990	4652	4024	3962	17226	21516	19896 left	34212	31230	19910 left	29396	45150
Standard Deviation	205.9	51.7	48.3	444.4	511.1	332.0 left	873.1	1203.3	341.6 left	598.1	2306.4
						22934 right			18506 right		
						618 right			523.8 right		
April 1991	2306	2000	3386	8336	2686	18000	14130	20626	14130	19400	35604
Standard Deviation	72.7	94.3	84.5	428	40	1504	247.3	267.2	452	112.8	1066
January 1992	2098	224	3418	21000	2598	1080	37196	60046	47406	18886	26462
Standard Deviation	15.8	9.3	69.9	750.1	105.5	75.3	760.2	1767.2	542.5	636.1	1077.3

a. data from TAEM (1992a)
b. n/d = no data

TABLE 4.1.22
Total Number of Benthic Invertebrate Taxa Collected in the Wapiti River Near Grande Prairie[a]

Date	Control Stations						Observation Stations Below Mill Effluent				
	Upstream			Below Municipal Effluent							
	C1	C2	C3	C4S	C5S	C6S	O1	O2	O3	O4	O5
October 1982	n/d[b]	n/d	n/d	n/d	23	24	37	38	36	33	36
October 1983	n/d	n/d	n/d	n/d	30	27	31	31	28	27	32
October 1985	n/d	n/d	n/d	n/d	35	31	39	39	35	34	36
October 1987	n/d	n/d	n/d	n/d	31	30	37	31	27	31	31
October 1988	n/d	30	31	29	29	33	30	40	30	30	39
October 1990	25	27	35	33	31	31 left 38 right	35	39	31 left 30 right	39	39
April 1991	36	30	40	34	33	43	45	43	43	44	42
January 1992	23	15	34	37	30	22	43	44	38	30	37

a. data from TAEM (1992a)
b. n/d = no data

In a review of the data from earlier benthic surveys (1970-1988), TAEM (1990) showed a trend to increasing river productivity based on the increasing number of organisms found at control sites and sites downstream of the pulp mill. An historical analysis of the biotic indices showed the continuation of a complex and diverse community. The number of taxa has not shown a downward trend. Over the years (Table 4.1.20), the treated pulp effluent has had either a positive influence on the number of taxa found or no effect. The results of the October 1990 survey found an increase in the number of taxa at all observation stations except O4. The results of the April 1991 and January 1992 surveys showed little, or no, influence of the effluents on the number of taxa.

The diversity index showed little change in diversity except for station O1, the first station below the pulp effluent outfall where pulp effluent is not yet fully mixed in the river. At this station, there was a reduction in the community diversity in October 1988 and April 1991 (Table 4.2.23). Conditions comparable to conditions immediately upstream of the mill were found at stations O2 and O3. An influence on the benthic community structure was found at stations O4 and O5, the stations sampled in the Wapiti River downstream from Bear Creek. At these stations, there was a reduction in the community diversity in October 1991, with the population dominated by fewer groups of organisms. The diversity below Bear Creek increased in 1992.

Results of the biotic indices for dominance and diversity indicate some alteration in the proportional distribution of organisms found as a result of city sewage and pulp mill effluents. An increase in dominance values and a decrease in diversity values occurred at station C4S in response to city sewage effluent, and at stations O2 and O3 in response to treated pulp effluent in October 1990. The numerical increases of the benthic community at these three stations were not spread evenly over all taxonomic groups. The results of the multivariate analysis indicated that the taxonomic assemblages of the benthic macroinvertebrate populations differed from control stations in response to both city sewage and treated pulp effluent. The only change in dominance and diversity detected in April 1991 occurred immediately below the pulp mill. Some taxonomic groups benefit from the enrichment over others. The index of species richness did not change as a result of the two inputs. Therefore, the overall change was an increase in the populations of some species without a loss in species.

TABLE 4.1.23
Diversity Index for Benthic Invertebrates Collected in the Wapiti River Near Grande Prairie[a]

Date	Control Stations						Observation Stations Below Mill Effluent				
	Upstream			Below Municipal Effluent							
	C1	C2	C3	C4S	C5S	C6S	O1	O2	O3	O4	O5
October 1982	n/d[b]	n/d	n/d	n/d	2.16	2.57	2.42	2.40	2.46	2.17	2.32
October 1983	n/d	n/d	n/d	n/d	2.19	2.14	1.72	2.47	2.32	2.38	2.46
October 1985	n/d	n/d	n/d	n/d	2.44	2.19	2.84	2.54	2.48	2.39	2.63
October 1987	n/d	n/d	n/d	n/d	2.66	2.40	3.65	3.23	3.60	3.76	3.19
October 1988	n/d	3.53	3.15	3.15	3.13	3.77	1.26	3.87	3.10	2.48	1.37
October 1990	3.20	3.25	3.44	3.23	3.11	3.38 left 3.40 right	3.30	3.19	3.42 left 3.22 right	3.15	2.87
April 1991	3.38	3.53	4.00	3.30	3.76	3.07	1.93	3.05	2.99	3.36	3.22
January 1992	3.06	3.58	3.44	2.85	3.82	3.26	3.68	2.10	2.81	4.15	4.26

a. data from TAEM (1992a)
b. n/d = no data

A number of taxa had been found on previous surveys of the Wapiti River to respond to pulp effluent; these taxa were considered as indicator taxa (Table 4.1.24) (TAEM 1991a). An increase in abundance of many of these indicator organisms at stations below the pulp effluent outfall occurred in October 1990 and April 1991; while some taxa increased in number, others decreased. Many other taxa were essentially uninfluenced by either sewage or pulp effluent.

TABLE 4.1.24
Taxa Selected by TAEM as Indicators of Pulp Mill Effluent Effects

Ephemeroptera:	*Rhithrogena* sp. *Baetis* sp. *Ephemerella* spp.
Plecoptera:	*Taenionema* sp. *Acrynopteryx* sp.
Trichoptera:	*Hydropsyche* sp.
Diptera:	Orthocladiinae
Oligochaeta:	Naididae

Although the previous biomonitoring survey of October 1988 found only a limited response to sewage effluent, the October 1990 and April 1991 surveys showed a clear response to city sewage. This was realized by an increase in number of all the indicator species monitored during both surveys. Only *Rhithrogena* sp., a species that appears to be more sensitive to organic loading, showed a negative response to sewage effluent.

The taxonomic analysis also suggested that water from Bear Creek contributes organic loading of the Wapiti River. The October 1990 and April 1991 data found that those species whose densities are increased by mild organic enrichment increased in number at sampling station located below Bear Creek. *Rhithrogena* sp., a species sensitive to organic loading, was reduced in number at these stations.

4.2 BIOFILM

The biofilm is the biological community which adheres to the surface of riverbed material. It is primarily epilithic algae, but the term biofilm has been used here to give a broader perspective to this community which may also contain aquatic bacteria, fungi and other microscopic organisms. Benthic macroinvertebrates have been discussed in the preceding section; invertebrate grazers interact directly with the biofilm. Rooted aquatic plants (macrophytes) are not present in the mainstems of the major rivers of the NRBS area.

Because there is a direct relationship between epilithic chlorophyll *a* content and cell biomass, this photosynthetic pigment has been used by Alberta Environment and others, as an indirect measure of algal biomass (Anderson 1989). The epilithic chlorophyll *a* samples were obtained by scraping defined areas of rocks from the river substrate. A few studies have identified the algal species present in the biofilm (e.g. EVS 1991). Beak Associates Ltd. (now SENTAR Consultants Ltd.) ranked the algal growth by measuring the thickness of the algal mat. Epilithic algae remain fixed to the substrate and, therefore, epilithic algal data are preferred over planktonic (free-floating) algal data. Planktonic algae originate upstream of a sampling site and do not necessarily reflect conditions at the site. Chlorophyll *a* concentration in epilithic algae is one of the best indicators available of the effect of phosphorus on algae in the phosphorus-limited stream.

On the other hand, non-photosynthetic species in the biofilm are not assessed by chlorophyll *a* measurements. Determination of the sediment oxygen demand (SOD) (to be discussed in section 4.3) includes the net oxygen consumption of all members of the benthic community including algae, bacteria, fungi and invertebrates. Although SOD has not been used in the study area to assess biofilm productivity, this and standing-stock measures, such as ash-free dry mass, lipid analysis, etc., should also be considered in future assessment of biofilm.

Samples of epilithic algae may not represent the nutrient-related growth potential of the site because algae are removed when the riverbed is scoured by high water velocities or ice. In rivers, water velocity is often the factor limiting plant biomass; the nutrient-related growth potential may not be realized. Other factors limiting plant biomass are turbidity, light penetration, grazing, sediment type and temperature.

4.2.1 Athabasca River

Yonge (1988) reviewed the NAQUADAT 1980 to 1988 data on epilithic chlorophyll *a* for Alberta rivers (Table 4.2.1). Average epilithic algal densities, as measured by chlorophyll *a*, were low in the rivers of the NRBS relative to values recorded in major southern Alberta rivers. In southern rivers, average densities in the range of 100 to 200 mg/m^2 chlorophyll *a* were not uncommon, and maximum values of 800 mg/m^2 have been recorded (Charlton et al. 1986).

TABLE 4.2.1
Range of Median Epilithic Chlorophyll *a* Concentrations (mg/m^2) in Alberta Rivers[a]

River	Above Discharges	Below Discharges
Milk	18.6[b]	6.1 - 176.5
Oldman	22.8 - 30.7	89.5 - 163.2
Bow	23.5 - 39.3	111.9 - 393.9
Highwood	36.8 - 47.6	132.5 - 176.3
South Saskatchewan	1.9 - 6.9	41.8[b]
Red Deer	19.6[b]	54.8 - 224.9
North Saskatchewan	0.2 - 12.9	8.5 - 179.4
Pembina	–	23.5 - 70.4
Lovett	8.3[b]	47.3 - 63.2
McLeod	4.1 - 42.8	50.4 - 201.7
Gregg	4.3[b]	110.4[b]
Athabasca		0.6 - 12.7

a. Data from Yonge (1988). The data were not sorted by season; effects related to different sampling dates were not evaluated.
b. Median for single stations from 1980 to 1988.

Yonge (1988) found that the range of chlorophyll *a* concentrations in the Athabasca River was the lowest (0.643 to 12.7 mg/m^2) of all rivers sampled in the province[2]. Concentrations were low from the most upstream sampling site to the Obed Mountain Coals bridge (0.737 to 8.2

2 Note: TAEM (Table 4.2.3) found greater concentrations which are as high as those for southern Alberta rivers.

mg/m^2), then generally increased from this point to Smith (5.0 to 12.7 mg/m^2) (Table 4.2.2). A synoptic survey of the Athabasca River in 1984-85 (Hamilton et al. 1985) measured the maximum average standing crops downstream of Hinton to Fort Assiniboine. Reduced levels were generally observed downstream of Fort Assiniboine. Tributaries between Athabasca and Fort McMurray including the Calling River and the House River had high average concentrations of chlorophyll *a* (Hamilton et al. 1985). Values decreased sharply from Smith to the farthest sampling point at Embarras (0.2 to 4.0 mg/m^2 in Yonge's study).

The 1980 to 1988 data (Table 4.2.2) included a number of tributaries to the Athabasca River. The epilithic chlorophyll *a* levels in the Lovett River, a tributary of the Pembina River, were generally low, but increased to 63.2 mg/m^2 below the Luscar Sterco Ltd. coal mine. Chlorophyll *a* concentrations where somewhat higher in the upper reaches of the Pembina River (23.5 to 70.4 mg/m^2) than other northern rivers (Yonge 1988). An increase in nutrients and chlorophyll *a* downstream of the confluence of the Lovett River suggested an impact by coal mining activities in the Lovett River watershed. The chlorophyll *a* recovered at the confluence with the Athabasca River (4.8 mg/m^2).

The McLeod River enters the Athabasca River at Whitecourt downstream of the ANC discharge but upstream of Millar Western effluent and the Town of Athabasca sewage discharge. The upper reach of the McLeod River had atypically high levels of 4.1 to 42.8 mg/m^2 due to inputs of nutrients from coal mines on Luscar Creek and the Gregg River (Yonge 1988). The chlorophyll *a* concentrations in the Gregg River were low (4.3 to 12.9 mg/m^2) initially but increased to 110.4 mg/m^2 below the Gregg River Resources coal mine. The level of chlorophyll *a* increased (50.4 to 201.7 mg/m^2) below Edson. There was a decline in chlorophyll *a* from Edson to the confluence with the Athabasca River (Yonge 1988).

A review of the Alberta Environment database (supplied by L. Noton) found no epilithic chlorophyll *a* data for the medium or long-term sites. The database from synoptic surveys of the Athabasca River contained only planktonic chlorophyll *a*, although synoptic surveys of the Peace River and the Wapiti-Smoky River system sampled epilithic chlorophyll *a* (Noton 1992a, Shaw et al. 1990).

TABLE 4.2.2
Epilithic Chlorophyll *a* Concentrations (mg/m^2) in the Northern River Basin Study Area[a]

River	Site	Location	Epilithic Chlorophyll *a*	
			n	Median
Athabasca	1	Old Entrance Town Site (comp left, right)	5	4.744
	2	Old Entrance Town Site, Right	3	8.200
	3	Below Hinton at 5 km Bridge, Left	4	3.048
	4	Below Hinton at 5 km Bridge, Right	5	0.737
	5	Obed Mountain Coals Bridge, Left	5	4.777
	6	Obed Mountain Coals Bridge, Right	5	10.632
	7	50 km Below Hinton (comp left & right)	5	5.470
	8	Above Confluence Windfall Creek	4	6.064
	9	Whitecourt, Upstream Hwy 43 Bridge, Right	3	12.700
	10	Above Fort Assiniboine, Centre	4	6.902
	11	Above Fort Assiniboine, Left	3	5.040
	12	Above Smith Hwy 2 Bridge (comp left & right)	3	10.280
	13	Above Smith, Downstream RR Bridge	4	0.643
	14	45 km Above Athabasca, Centre	4	0.714
	15	Athabasca 1 km Above Hwy 813 Bridge, Left	3	4.050
	16	Athabasca 1 km Above Hwy 813 Bridge, Centre	5	0.831
	17	13.3 km Downstream Pelican River, Centre	5	2.070
	18	100 m Above Confluence Horse River	5	3.633
	19	3.3 km Upstream Poplar Creek, Centre	5	0.200
	20	5 km Downstream Bitumount, Centre	4	1.119
	21	Embarras Airport	3	1.412
Berland	1	Before Confluence Athabasca River	5	3.422
Calling	1	Before Confluence Athabasca River	3	7.559
Clearwater	1	Near Waterways	5	4.750
Embarras	1	Above Confluence McLeod River	5	21.690
Gregg	1	Above Gregg River Mine	3	4.290
	2	0.5 km Below Gregg River Mine	3	110.360
	3	Near Hwy 40	2	11.800
	4	Downstream Warden Creek	2	12.885
	5	Before Confluence McLeod River	9	10.440
House	1	Before Confluence Athabasca River, Left	5	4.063
La Biche	1	Before Confluence Athabasca River	4	5.986
Lovett	1	Above Confluence Coal Creek	9	8.330
	2	Lovettville	6	47.375
	3	Downstream Lovettville	9	63.270

TABLE 4.2.2 (continued)

River	Site	Location	Chlorophyll *a*	
			n	Median
McLeod	1	Above Cadomin	6	33.915
	2	Above Confluence Luscar Creek	3	24.250
	3	1.5 km Downstream Luscar Creek	3	4.070
	4	Near Cadomin at WSC Gauge	3	12.940
	5	2 km Downstream Confluence MacKenzie Creek	3	22.040
	6	Steeper	6	26.365
	7	Downstream Tri-Creeks Study Area	6	31.360
	8	Downstream Mary Gregg Creek	6	29.020
	9	Above Confluence Gregg River	6	23.995
	10	Below Confluence Gregg River	6	42.805
	11	Above Confluence Embarras River	10	27.500
	12	Below Confluence Embarras River	5	14.420
	13	Below confluence Embarras River, Left	2	11.845
	14	100 m Above Edson Sewage, Left	2	20.825
	15	100 m Below Edson Sewage	2	108.440
	16	Art's Place, Left	2	201.680
	17	Art's Place, Right	2	180.465
	18	Below Confluence Wolf Creek, Left	2	167.895
	19	Below Confluence Wolf Creek, Right	2	137.335
	20	Downstream Rosevear Ferry	5	45.940
	21	Downstream Rosevear Ferry, Left	2	81.755
	22	Downstream Rosevear Ferry, Right	2	76.060
	23	Peers, Left	2	76.495
	24	Mahaska	5	50.400
	25	3 km Above Whitecourt	5	6.990
	26	Whitecourt, Hwy 43 Bridge, Left	3	9.480
	27	Whitecourt	4	4.896
Pembina	1	Above Centre Creek	3	23.570
	2	Adjacent Hwy 40	3	70.400
	3	Hwy 40 Bridge	2	38.530
	4	10 km Downstream Hwy 40 Bridge	3	44.550
	5	Before Confluence Athabasca River, Right	3	4.853
Poplar Creek	1	21.6 km North Fort McMurray	5	11.268

a. Median for single station from 1980 to 1988.

Data from Yonge 1988.

The Athabasca River generally has high flows, high turbulence and, therefore, high levels of suspended solids during the summer months, resulting in poor light penetration and scouring. Epilithic algal densities are relatively low in the summer, in spite of the optimum temperature conditions. Flows and suspended solids decrease in the fall and epilithic algal densities generally increase (Noton 1990a). Substrates that are coarse and more stable provide better substrate for the growth of epilithic algae. These occur especially in the Hinton to Fort Assiniboine area and again in the Calling River to Fort McMurray area. Higher values for epilithic algae tend to occur between Hinton and Whitecourt, and also in the Calling River to Fort McMurray area (Noton 1990a).

4.2.2 Athabasca River Near Hinton

Epilithic chlorophyll *a* data are available from a survey on the upper Athabasca River by Anderson (1989). It evaluated the effects of the combined pulp mill and municipal effluent discharged at Hinton from May to October, 1984.

Very low chlorophyll *a* values (<2.00 mg/m^2) were measured in June and July at both upstream and downstream locations. At this time of year, high water velocities and high suspended solids loads scour the river bed. High water levels also make submerged rocks less accessible introducing a potential sampling error.

Differences between the chlorophyll *a* levels upstream of Hinton and 50 km downstream were measured in the fall. In September, 1984, concentrations of 10.2 and 18.5 mg/m^2 chlorophyll *a* were recorded above and 50 km below the effluent outfall, respectively. In October 1984, values of 12.3 and 53.8 mg/m^2 chlorophyll *a* were recorded at the same sites. The maximum value of about 85 mg/m^2 was recorded about 20 km downstream on the right side of the river. All sites sampled downstream of the effluent outfall had epilithic chlorophyll *a* values greater than 30 mg/m^2, whereas the concentration upstream was below 15 mg/m^2. With minor exceptions, 1984-85 epilithic chlorophyll *a* levels, for both mainstem and tributary sites were highest in September and October. Densities were extremely low during June and July when river flows and therefore substrate scour were high. Overall maximum densities occurred downstream of Hinton during October.

Epilithic algae were scraped from the upper surface of randomly selected rocks collected by TAEM and analyzed for chlorophyll *a* and phaephytin *a* by Enviro-Test Laboratories as part of the annual biological and water quality surveys conducted for Weldwood of Canada Ltd., Hinton. Triplicate samples each consisting of quantitative scrapings from three rocks at depths of 30-50 cm were taken using either a 2 or 4 cm^2 template. Algae scrapings from three rocks were placed in GF/C filters to form a single sample, covered with powdered magnesium carbonate, wrapped in tin foil and placed in a cooler and then frozen. Three years of chlorophyll *a* data are available (Table 4.2.3). Levels of chlorophyll *a* are higher downstream than at the control sites for 22 km. The variability in the data may be due in part to incomplete mixing of the effluent which occurs up to about 9 km downstream. Except for October 1990, levels have returned to background 44 km downstream of the mill.

TABLE 4.2.3
Epilithic Chlorophyll *a* in the Athabasca River* Near Hinton**

Distance (km)		October 1990 ($\mu g/cm^2$)	April 1991 (mg/m^2)	April 1992 (mg/m^2)	October 1992 (mg/m^2)
Upstream	5.8	8.0	35.3	48.0[a]	14.4
	2.1	7.4	43.6	20.0[b]	17.8
	0.8	8.1	35.8	16.0[a]	30.5
Downstream	0.8	18.2	268.0	60.0	191.0
	3.6	15.0	106.5	190.0	163.4
	6.3				53.1
	9.0	22.2	118.5	134.0[b]	63.1
	22.0	36.8	105.8	106.0[b]	140.7
	44.0	32.0	37.0	40.0[a]	27.0

* All sampling stations are mid-channel except as noted: a = Left side; b = Right side
** Data from TAEM (1991b, 1991c; 1992b; 1993)

4.2.3 Athabasca River Near Whitecourt

SENTAR Consultants Ltd. (1992c) estimated the amount of algal growth in the Athabasca River in the vicinity of the Millar Western and ANC pulp mills and the Town of Whitecourt. The algal growth was classified into three categories, based on the thickness of the algal mat on the substrate: light (<1 mm thickness), moderate (2 to 5 mm thickness) and heavy (6 to 10 mm thickness). The depth was measured on three substrates at each site with three measurements per substrate. Measurement of epilithic chlorophyll *a* is scheduled to begin in 1993.

In 1990, a qualitative assessment of the amount of algae found growing on the substrates in the vicinity of the ANC mill indicated that generally more algae were present in October than May (Beak Associates 1991b). In May, a light growth of algae was observed on the substrates at sites 1 to 5 located above and below the ANC mill and a moderate to heavy growth of algae at sites 6 and 7 which are impacted by other point sources. In October, a light growth of algae was observed on the substrates at the control sites 1 and 2 and a moderate to heavy growth at all downstream sites 3 to 7.

No algal growth was obvious in May 1991 (SENTAR 1992c). The high flows encountered during the spring survey likely caused scouring of the substrate and, therefore, a loss of the algal growth. Additionally, increased flows and the associated increase in water levels and depth would preclude sampling in areas that were under water year-round. Because the sample sites were only recently inundated with water, the absence of algal growth would be expected. In October 1991, a light growth of algae was found on the substrates at sites 1, 2 and 7, a moderate growth of algae at sites 4 and 6, and a heavy growth of algae at sites 3 and 5 (Table 4.2.4). These results indicate an increase in the algal mat below the ANC pulp mill compared to upstream controls.

TABLE 4.2.4
The Thickness of Algal Growth on the Athabasca River Substrate in the Vicinity of Whitecourt

Date	Site	Algal Thickenss[a] (mm)									Mean	Algal Growth Category
		Cobble 1			Cobble 2			Cobble 3				
ANC Monitoring												
October 1991	1	1	1	<1	1	1	<1	<1	<1	<1	<1	Light
	2	<1	<1	<1	1	<1	<1	1	<1	<1	<1	Light
	3	4	5	4	8	8	7	8	9	7	7	Heavy
	4	2	3	3	4	3	3	4	3	4	3	Moderate
	5	8	6	6	8	7	7	6	5	7	7	Heavy
	6	2	2	2	3	3	2	2	1	2	2	Moderate
	7	1	1	1	-	-	-	-	-	-	1	Light
April 1992	1	-	-	-	-	-	-	-	-	-	-	None[b]
	2	-	-	-	-	-	-	-	-	-	-	None
	3	-	-	-	-	-	-	-	-	-	-	None
	4	-	-	-	-	-	-	-	-	-	-	None
	5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
	6	1	1	1	1	1	1	1	1	1	1	Light
	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
October 1992	1	<1	1	<1	1	<1	<1	<1	<1	<1	<1	Light
	2	1	1	<1	1	1	<1	<1	<1	1	<1	Light
	3	4	2	4	2	2	1	3	3	4	3	Moderate
	4	2	2	1	3	1	2	2	1	1	2	Moderate
	5	2	2	1	1	1	<1	1	<1	<1	1	Light
	6	1	1	1	1	1	<1	1	<1	<1	1	Light
	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
Millar Western Monitoring												
October 1991	1	2	2	2	<1	<1	<1	2	1	<1	1	Light
	2	8	6	6	8	7	7	6	5	7	7	Heavy
	3	3	4	5	4	5	6	2	5	5	5	Medium
	4	3	4	5	6	6	5	4	3	5	5	Medium
	4A	5	4	7	5	5	3	3	4	3	4	Medium
	5	2	2	2	3	3	2	2	1	2	2	Medium
	6	5	5	4	5	5	4	4	5	4	5	Medium
	7	1	1	1	-	-	-	-	-	-	1	Light
April 1992	1	1	2	2	2	2	3	2	2	2	2	Moderate
	2	<1	<1	<1	1	1	<1	<1	1	1	<1	Light
	3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
	4	<1	<1	<1	<1	<1	<1	1	1	1	<1	Light
	4A	-	-	-	-	-	-	-	-	-	-	None[b]
	5	1	1	1	1	1	1	1	1	1	1	Light
	6	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light
October 1992	1	2	2	3	2	2	2	3	3	3	2	Moderate
	2	2	2	1	1	1	<1	1	<1	<1	1	Light
	3	3	3	3	3	3	2	4	4	3	3	Moderate
	4	1	1	<1	1	<1	<1	2	3	2	1	Light
	4A	1	1	<1	<1	<1	<1	1	<1	<1	<1	Light
	5	1	1	1	1	1	<1	1	<1	<1	1	Light
	6	2	3	3	3	3	2	2	2	3	3	Moderate
	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Light

a. Three measurements were taken for each cobble.
b. No algal growth was obvious.
Note: Data from SENTAR 1992b,c. Sites are shown in figure 4.1.6.

The qualitative assessment of algal growth has been done for a longer time in the vicinity of the Millar Western mill and Whitecourt. Site 1 is an upstream control site on the McLeod River; sites 3, 4 and 5 are located in the Athabasca River below the Millar Western effluent outfall and the confluence with the McLeod River. During the October 1988 sampling program, it was noted that a substantial amount of algae was present on the substrate, especially at sites 1, 3, 4 and 5, compared to June 1988 when only small amounts were present. Very few algae were present on the substrate during the spring and fall 1987 (Beak Associates 1989a).

In 1989, generally more algae were present in October than June. In June a light growth of algae was observed on the substrates at all sites on the Athabasca River, except Sites 3 and 4 below the Millar Western effluent (Beak Associates 1990a), where no algal growth was obvious. Site 1 on the McLeod River had a heavy growth of algae on the substrates in June indicating for a second time that the McLeod River is eutrophic. In October, a light to moderate growth of algae was observed on the substrate at sites above and below the Millar Western mill and a heavy growth at sites 5, 6 and 7 which receive multiple inputs.

Beak Associates Ltd. (1991a) continued to find that, generally, more algae were present in October than May. In May 1990, a light growth of algae was observed on the substrates at sites 1, 2, 3, 4 and 4A and a moderate to heavy growth of algae at downstream sites. In October 1990, a light to moderate growth of algae was observed at sites 3, 6 and 7, and a moderate to heavy growth of algae at upstream sites 1, 2 and 5 on both the Athabasca and McLeod Rivers. The ANC mill, which became operational in August 1990, was likely the cause of the increase in algae growth at background site 2 during October, due to the discharge of treated pulp effluent.

No algal growth was obvious in May 1991, except for a light growth at site 1 on the McLeod River (SENTAR 1992b). The absence of algal growth during the spring survey can be attributed to two factors. The high flows encountered during the spring of 1991 and the associated increase in water levels and depth would preclude sampling in areas that were under water year-round. In October, a light growth of algae was found on the substrates at sites 1 and 7, a moderate growth of algae at sites 3, 4, 4A, 5 and 6, and a heavy growth of algae at site 2 (Table 4.2.4).

The routine monitoring, although only qualitative, does indicate several important trends. Firstly, the continued heavy growth of algae at the control site on the McLeod River indicates that the McLeod River is likely an important point source of nutrients to the Athabasca River. The second trend is an increase in algae downstream of the combined point source inputs at sites 5, 6 and 7. The third trend is the light to non-detectable growth in the spring compared to heavier fall growth of algae. It is evident that algal biomass is controlled, not only in high flow years such as the spring of 1991, but also on an annual basis. The control has been attributed to scouring by high velocity and suspended sediments. High flows make sampling difficult; therefore, the amount of algal growth across the river cross-section is not known.

4.2.4 Lesser Slave River, Tributary to the Athabasca River

EVS Consultants Ltd. (1990, 1991) conducted an environmental baseline survey of river periphyton prior to the start-up of the Slave Lake Pulp Corporation mill on the Lesser Slave River. In 1989, artificial substrates (7 cm x 7 cm ceramic tiles) were used to characterize the periphytic community in the Lesser Slave River. Losses of artificial substrates through dewatering prevented analysis of a number of samples. Intact samples were retrieved from station 13 at the proposed outfall and station 37 near the confluence of the Saulteaux River. Chlorophyll *a* ranged from 10.93 mg/m^2 at station 13 to <0.05 mg/m^2 at station 37 (EVS 1990).

Periphyton was collected from submerged rocks on September 19 and 25, 1990; half of the sample was preserved in Lugol's solution for taxonomic identification and the other half was filtered onto glass fibre filter papers and, frozen inside aluminum foil for chlorophyll *a* determination.

An order of magnitude increase in periphyton chlorophyll *a* with distance downstream in the Lesser Slave River was measured indicating an increase in periphyton biomass with distance downstream. Chlorophyll *a* ranged from 12.34 to 153.6 mg/m^2 in the Lesser Slave River and between 14.9 and 19.2 mg/m^2 in the Athabasca River (EVS 1991).

In 1991, the first year of operational monitoring, periphyton chlorophyll *a* ranged from 2.05 to 22.66 mg/m^2 in the Lesser Slave River and between 3.75 and 25.71 mg/m^2 in the Athabasca River (Figure 4.2.1). In the Lesser Slave River, there was no predictable trend in chlorophyll *a* with distance downstream, or with respect to the location of the mill outfall. The concentration of periphyton chlorophyll *a* in the most downstream station on the Lesser Slave River was significantly higher than the concentration in the Athabasca River (96). The mean concentration of chlorophyll *a* increased in the Athabasca River downstream of the Lesser Slave River. In 1991, periphyton chlorophyll *a* was substantially lower per unit area than during the 1990 survey and closer to values first reported in the 1989 survey. Reduced concentrations of chlorophyll *a* measured during the current study appear to reflect natural temporal variations in periphytic growth.

There were 86 species of Bacillariophyceae (diatoms), 14 species of Chlorophyceae (greens), eight species of Cyanophyceae (bluegreens) and one taxon of Rhodophyceae (red algae) identified in the pre-operational study. The dominant taxa include *Phormidium autumnale*, a blue green algae which forms visible mats on the substrate; *Cladophora glomerata*, a green algae that forms visible branched filaments; *Cocconeis pediculus*, an epiphytic diatom found extensively on *C. glomerata; Navicula* spp., *Synedra* spp. and *Nitzschia* spp., diatoms which contribute to the silty layer on the substrate; *Gomphonema olivaceum*, a diatom that forms a slick film on the substrate or grows epiphytically.

The algal communities identified in the pre-operational study were dominated by nutrient sensitive taxa that include *Cladophora* and *Nitzschia* which will be useful in monitoring nutrient levels. Many of the taxa found in the survey are indicative of high levels of nutrients. *Cladophora* was the most common algal taxon, and it is normally found in eutrophic waters. Diatoms were a major component of the algal taxa found in the survey. The algae identified in the samples have a widespread distribution in North America; some are more commonly found in lakes and probably originated in Lesser Slave Lake.

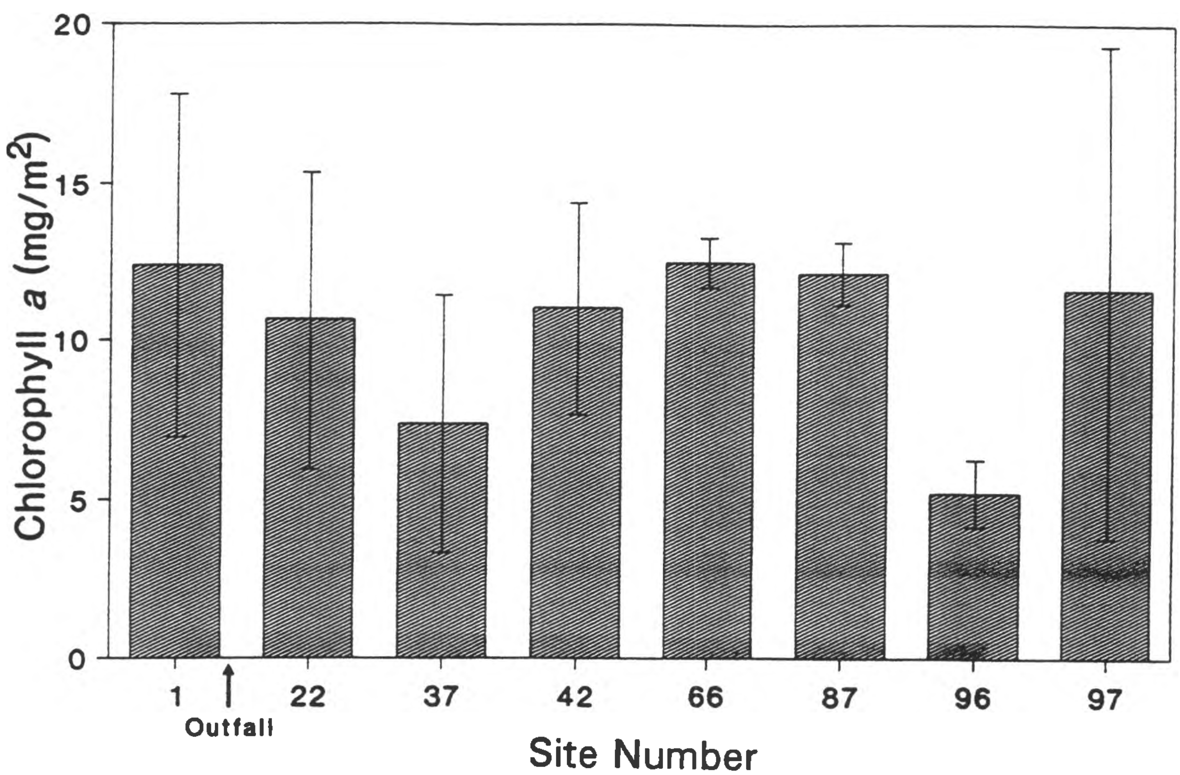

Figure 4.2.1

PERIPHYTON CHLOROPHYLL *A* CONCENTRATIONS IN THE LESSER SLAVE AND ATHABASCA RIVERS, SEPTEMBER 1991
(from EVS 1992; see Fig. 4.1.7 for site locations)

4.2.5 Peace River

Epilithic chlorophyll *a* values were measured in the mainstem of the Peace River, during synoptic surveys done in 1988 (Shaw et al. 1990). They were not measured downstream of Ft. Vermilion because of the lack of suitable substrate (i.e. rocks) at the sampling sites. Epilithic chlorophyll *a* values were highly variable and ranged from 1.0 to 99 mg/m^2, although values tended to decrease along the length of the river (Table 4.2.5). This spatial pattern may be related to the increased suspended solid concentrations and turbidity along the mainstem. Chlorophyll *a* concentrations were low in May and July 1988 (<25 mg/m^2), greatest in August and intermediate in September. The maximum value occurred upstream of Dunvegan in August. In the Peace River, the lowest values were measured in July 1988, perhaps as a result of scouring of the periphyton by the high suspended solids content and/or because the rocks that were sampled during high flows were only recently colonized. In general, the highest values were recorded in August, probably as a result of the relatively clear waters (i.e. low turbidity) and warm water temperatures.

Environmental monitoring by the Peace River Pulp Division mill in the vicinity of the Town of Peace River did not include measurement of epilithic algae or chlorophyll *a* (HBT Agra Ltd. 1992). The description of the substrate for the macroinvertebrate surveys included an estimate of the percentage of plant/algal debris. The average of all sites in October 1991 and May 1992 was 29% and 23.7%, respectively, compared to only 9% in April 1991. Plant/algal debris was also scarce in April and September 1990. The plant/algal debris is not attached to rocks and, therefore, not comparable to epilithic algal data for other sites. Evidence of scouring by ice and variable flows is reported, but attached plant material is generally scarce. A dense microbial growth on cobbles and rocks at downstream sites closer to the Town of Peace River was reported in September 1991 before the pulp mill started up (Monenco 1989).

TABLE 4.2.5
Epilithic Chlorophyll *a* Measured During 1988 Water Quality Survey of the Peace River and its Tributaries

Station	Code	Date (D/M/Y)	Epilithic Chlorophyll *a* (mg/m²)
Peace River Near Border	00BC7FD1050	09/05/88	14.4
		21/07/88	15.2
		22/08/88	26.2
		03/10/88	63.5
Peace River Near Dunvegan	00AL07FD1600	09/05/88	23.8
		21/07/88	2.1
		22/08/88	99.1
		27/09/88	35.4
Peace River Upstream of Smoky River	00AL07FD4600	09/05/88	14.3
		22/08/88	68.6
		28/09/88	32.6
Peace River Upstream of Whitemud River	00AL07HA2850	10/05/88	1.7
		21/07/88	1
		22/08/88	49.9
		12/12/88	7.3
Peace River Upstream of Notikewin River	00AL07HC1200	10/05/88	1
		22/08/88	15.7
		28/09/88	5.7
Peace River Near Carcajou	00AL07HD1030	10/05/88	1.1
		23/08/88	10.8
		28/09/88	52
Peace River Near Ft. Vermilion	00AL07HF1720	11/05/88	4.4
		23/08/88	3

Data from Environmental Quality Monitoring Branch, Alberta Environment (Shaw et al. 1990)

4.2.6 Wapiti-Smoky River System, Tributary to the Peace River

A study of the water quality of the Wapiti-Smoky River system in 1983 included an algal growth potential (AGP) test of the water from the lower Wapiti River, the Smoky River, and the Peace River near the confluence with the Smoky River (Noton et al. 1989). The algal growth tests are assays in which a test species *Selenastrum capricornutum* is incubated in a water sample in the laboratory. The results were quite variable and there was no consistent effect of the pulp mill wastewaters on AGP. Sites downstream of the mill had AGP that were higher, lower or no different than sites upstream of the mill. There was a poor correlation between AGP and total phosphorus within each sampling period. Both AGP and total phosphorus were much higher in May when high flows occurred, than in September or November.

A benthic chlorophyll *a* survey in October 1989 and February 1991 indicated that chlorophyll *a* tended to be more abundant downstream of the Grande Prairie sewage treatment plant and the Weyerhaeuser pulp mill effluents, at least in the shallow waters where sampling was carried out. The data were, however, quite variable (Table 4.2.6). The coefficient of variation is highest downstream of the sewage treatment plants and lowest at upstream sites on the Wapiti River during both years, although coefficients were higher in 1991. Concentrations of chlorophyll *a* were usually <1.0 mg/m^2 at highway #40, the upstream control station and had returned to baseline level of <1.0 mg/m^2 in the Wapiti River upstream of the confluence with the Smoky River.

The amount of epilithic algae was measured as chlorophyll *a* by TAEM (1991a) during surveys of the Wapiti River in October 1990 and April 1991. Chlorophyll *a* was not measured during the January 1992 study (TAEM 1992a). Chlorophyll *a* levels showed an increase at a sampling location below the sewage treatment plant outfall (Table 4.2.7). This was most apparent during the October 1990 survey when chlorophyll *a* levels increased from <1 mg/m^2 to 225 mg/m^2 at station C4S (TAEM 1991a). The increase in April was smaller, possibly due to scour from the heavy silt load found in the river at the time of the survey. Levels of chlorophyll *a* below the pulp mill were similar to those below the sewage outfall. There was a further increase in chlorophyll *a* levels at all stations below the treated pulp mill effluent outfall in October 1990. The greatest levels were found at stations 04 and 05 indicating an apparent nutrient influence by Bear Creek.

TABLE 4.2.6
Epilithic Chlorophyll *a* in the Wapiti and Smoky Rivers, 1989 and 1991[a]

Sample Location	Sample Number	Mean (mg/m²)	Standard Deviation	Coefficient of Variation (%)	Maximum (mg/m²)	Minimum (mg/m²)
1989 - Wapiti River						
Upstream of Grande Prairie (Hwy 40 to 1 km upstream of STP)	3	0.50	0.00	0	0.5	<1
Downstream of Grande Prairie STP: Upstream of Weyerhaeuser Effluent	3	1.79	2.24	125	4.379	<1
Downstream of Weyerhaeuser Effluent (train bridge to mouth)	6	2.64	1.03	39	3.826	1.215
1989 - Smoky River						
Upstream of Wapiti River	2	0.50	0.00	0	<1	<1
Benzanson Bridge	1	2.92				
At Confluence of Puskawau River	1	0.50				
At Watino	1	5.27				
1991 - Wapiti River						
Upstream of Grande Prairie (Hwy 40)	10	0.62	0.25	40	1.1	<1
Downstream of Grande Prairie STP: Upstream of Weyerhaeuser Effluent	10	32.61	55.94	172	140.3	<1
Downstream of Weyerhaeuser Effluent (0.25 km downstream of effluent to mouth)	35	34.05	39.29	115	144.6	<1

a. Data provided by Environmental Quality monitoring Branch, Alberta Environment (Noton 1992a).

TABLE 4.2.7
Epilithic Chlorophyll *a* (mg/m²) in the Wapiti River near Grande Prairie[a]

Date	Control Stations						Observation Stations Below Mill Effluent				
	Upstream			Below Municipal Effluent							
	C1	C2	C3	C4S	C5S	C6S	O1	O2	O3	O4	O5
April 1991	7.4	4.5	12.5	85	74.5	63.8	15	7.2	62.2	65.4	23.7
October 1990	<1 centre	<1 centre	<1 centre	225 centre	184 centre	153 left	347 centre	493 right	295 right	555 centre	628 centre

a. Data from TAEM 1991a.

4.2.7 Discussion

Data on biofilm is limited to epilithic algae. Measurements are restricted by depth and velocity; therefore, total coverage of the river bed in cross-section and in longitudinal section is not known. Without mapping the area covered, the importance of the biofilm in the oxygen regime of the river is difficult to assess. If velocity and light penetration restrict algal growth to a strip along the shore, the importance of epilithic algae in the oxygen regime will be less than if it extends across the river.

Measurement of chlorophyll *a* and mat depth, although useful, do not provide data on the respiration rate of the algae under ice when dissolved oxygen levels are critical. The reduction in temperature and light that exists in late winter may make the epilithic algal component of the SOD small in comparison to bacterial components of the SOD and instream BOD. It is not possible to separate the relative contribution of phosphorus supported algal respiration over organic carbon support bacterial respiration using existing data. All effluents contain phosphorus and organic carbon.

Since nutrients are added to secondary treatment facilities at the pulp mills in order to maximize BOD reductions and prevent system upsets, introducing effluent phosphorus limits that are not consistently achievable may increase the risk of higher discharges of organic carbon and lower dissolved oxygen in the river. The first step is to verify that phosphorus is having a significant environmental effect on instream levels of dissolved oxygen. Although the role that phosphorus plays in the dissolved oxygen regime of the river is beyond the scope of this review, this review shows that benthic biofilm data is inadequate to assess this role.

Most provinces have water quality objectives stating that nuisance growths of aquatic weeds should not be present. The B.C. Ministry of the Environment alone has set criteria for chlorophyll *a* levels. These are relevant to the NRBS because they apply to epilithic algae rather than rooted macrophytes (aquatic weeds). They are also quantitative. To protect aquatic life, particularly in streams containing salmonids, the criterion states that epilithic chlorophyll *a* should not exceed 100 mg/m^2 (Nordin 1985). The criterion related to aesthetics and recreation is

50 mg/m^2 chlorophyll *a*. Ambient concentrations of chlorophyll *a* in the Athabasca River do not exceed criteria levels except in areas directly affected by point sources. These criteria are exceeded from 0.8 to 22 km below the Weldwood discharge, but they are not exceeded 44 km downstream. Chlorophyll *a* data are not available for ANC, Millar Western and Peace River mills. The criteria are not exceeded on the Lesser Slave River but they are exceeded on the Wapiti River from the Grande Prairie sewage and Weyerhaeuser mill effluents downstream to the Smoky River. These criteria have also been exceeded in tributaries including the McLeod, Gregg and Pembina Rivers.

4.3 SEDIMENT OXYGEN DEMAND

One of the reasons that nutrients are of potential concern in northern rivers is that they may contribute to the sediment oxygen demand (SOD). The SOD is an important component of the overall oxygen demand and, therefore, the oxygen regime of a river, particularly during ice-cover when re-aeration is minimal. Nutrients may promote the growth of benthic algae and the decay of organic material; both processes increase the respiration of the benthic community and, therefore, the sediment oxygen demand.

4.3.1 Methods and Locations of Field Studies

Three field studies have measured SOD *in situ* during winter low flow conditions in the study area (Casey 1990, Casey and Noton 1989, Monenco Inc. 1993). Hydrologic and substrate variables, including qualitative observations of epilithic algal growth, were also reported for each location.

An *in situ* chamber method to measure SOD was developed in 1989 by Alberta Environment. Open chambers were used in areas where a seal could be obtained between the chamber and the substrate; closed chambers were used at the other sites. The SOD was measured at five locations between Hinton and Fort Assiniboine on the Athabasca River during the winter of 1989 (Fig. 4.3.1). Sampling sites were located about 1 km downstream of the Weldwood and Millar

Western pulp mills at Hinton and Whitecourt, respectively. The Hinton, but not the Whitecourt, site included municipal effluent.

In 1990, the method was improved and the study was expanded to include five sites on the Wapiti-Smoky River system and five on the Athabasca River (Fig. 4.3.2). Three of the Athabasca River sites were close to those used in 1989. The SOD was measured 1 km below the Millar Western mill and 2.5 km below the Weyerhaeuser mill. The measurement below the Weyerhaeuser mill also included the impact of the Grande Prairie sewage.

The SOD of the Athabasca River was measured in the winter of 1992 by Monenco (1993) for the Northern River Basins Study. Due to physical conditions in the downstream reaches of the river, Monenco had difficulty with the chamber method and substituted a sediment core method. Alpac was the most downstream station that they were able to sample. The new method was tested in March, 1992 in conjunction with chamber methods at Hinton, Whitecourt and Athabasca, and alone at Alpac. Closed chamber measurements were also made at Windfall bridge and Smith.

The 1990 SOD rates were relatively stable over the incubation period which was generally about 48 h. In contrast, there was a general decrease in SOD rates over the 48 h test period in 1989 and again in the winter of 1992. Measurements taken over the same incubation period (approximately 48 h) were used when comparing the three studies.

The coefficient of variation (CV) was used as a measure of variability for groups of chambers at a site. The sites on the Athabasca River had a greater range of variability. The mean CV for the sites, excluding the control sites, after 48 h were 48% (1-140%) and 35% (0-123%) for the Athabasca River in 1989 and 1990, respectively and 34% (12-69%) for the Wapiti-Smoky River system. The mean CV for all sites employing chambers in the 1992 study was 36%. At sites where cores were used, the CV values ranged from 18% at Whitecourt to 70% at Alpac (Monenco 1993). There is, therefore, considerable variability within sites and between sites.

4.3.2 Results

Longitudinal Trend The results (Casey 1990, Casey and Noton 1989, Monenco 1993) showed a clear longitudinal trend in SOD rates which was similar for both the Athabasca River and the Wapiti-Smoky River system (Fig. 4.3.3 and 4.3.4). The SOD increased sharply from very low SOD rates at the control sites (the Athabasca River at Windfall and the Wapiti River at Highway 40) to the highest rates immediately[3] downstream of point sources including pulp mill and municipal effluents (located at Hinton, Whitecourt and Grande Prairie). The SOD declined at Smith, located 220 km downstream of Whitecourt but was not as low as the upstream control site at Windfall bridge (Fig. 4.3.3).

The majority of the study locations and sampling sites, including the site below the Hinton pulp mill exhibited only small amounts of attached epilithic algal growth (Table 4.3.1). Abundant growth was noted below the pulp mills at Whitecourt and Grande Prairie. At Whitecourt, a gelatinous covering was interspersed with an abundance of filamentous algae (Monenco 1993), although Casey (1990) reported only the gelatinous covering. Encrusting algae were abundant downstream of the Grande Prairie pulp mill.

Temporal Trend An increase in SOD was measured at Whitecourt on the Athabasca River over the winter (Casey 1990, Monenco 1993). The winter increase of SOD is probably due to the accumulation of organic matter downstream of the pulp mill effluent during the low flows. Abundant benthic biomass was also noted at that location (Table 4.3.1). The increase in SOD was not evident at the control location. A direct relationship between stream productivity and SOD has been measured in northern streams in Alaska (Duncan and Brusven 1985).

The winter increase in SOD depends, however, on the absence of scouring. The SOD values measured downstream of the Weyerhaeuser mill on the Wapiti River in February 1990 were similar to the values at Whitecourt, but the SOD was reduced by approximately half in March (Tables 4.3.2 and 4.3.3). The reduction may be due to the erosion of the river bed by flooding

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[3] 1 km downstream at Hinton and Whitecourt and 2.5 km downstream at Grande Prairie.

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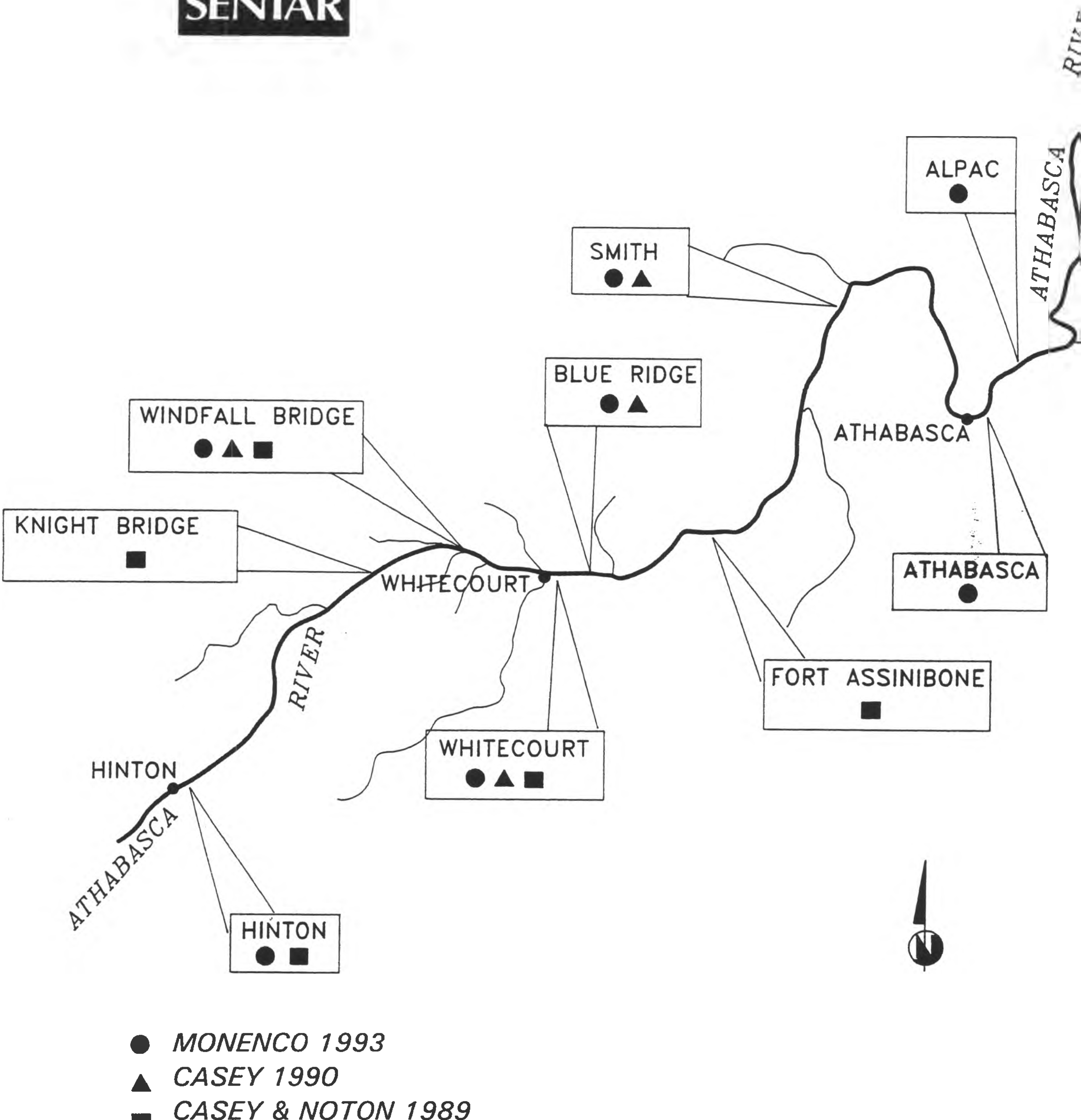

Figure 4.3.1

SEDIMENT OXYGEN DEMAND (SOD) SAMPLING SITES ON THE ATHABASCA RIVER

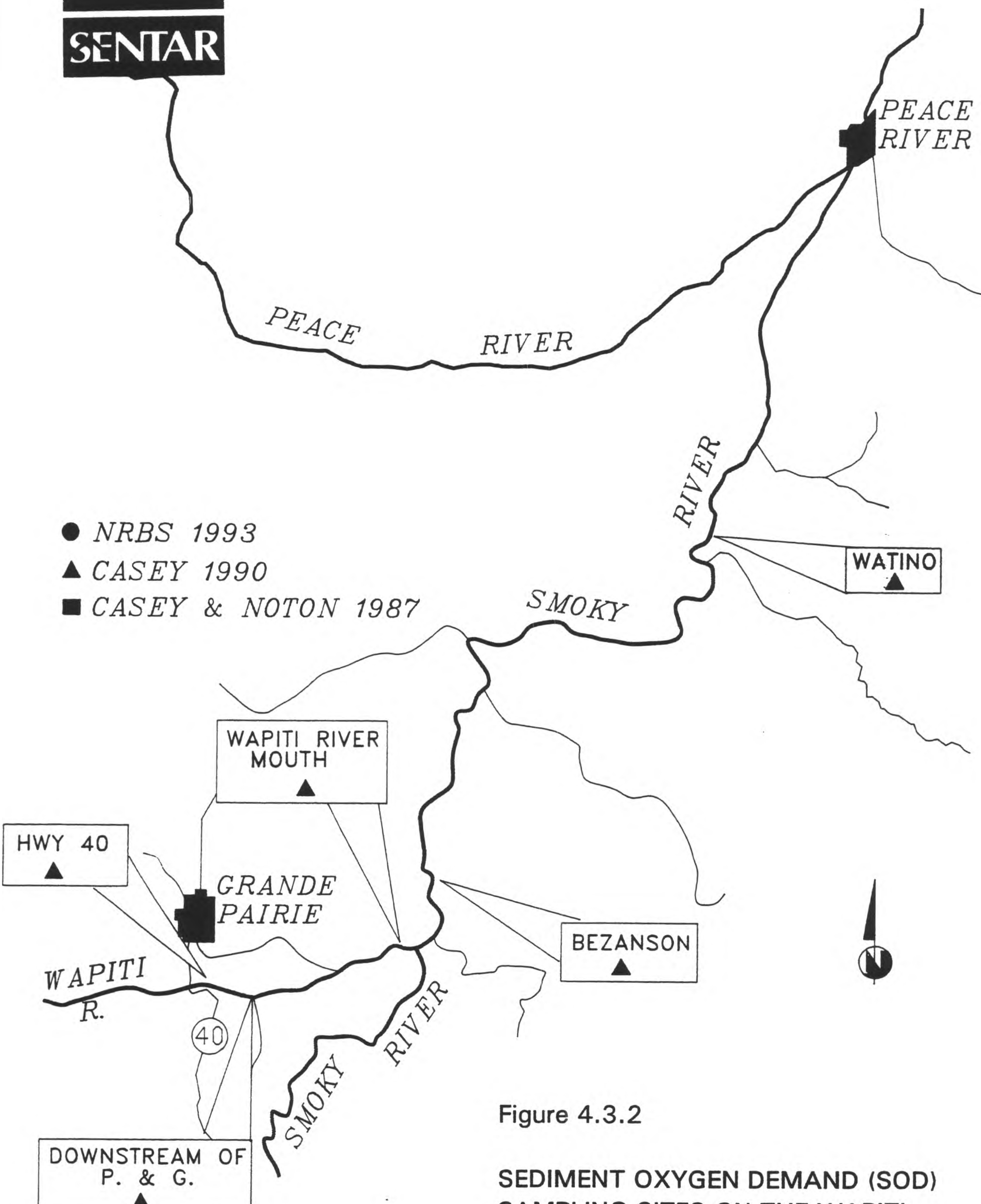

Figure 4.3.2

SEDIMENT OXYGEN DEMAND (SOD) SAMPLING SITES ON THE WAPITI-SMOKY RIVER SYSTEM

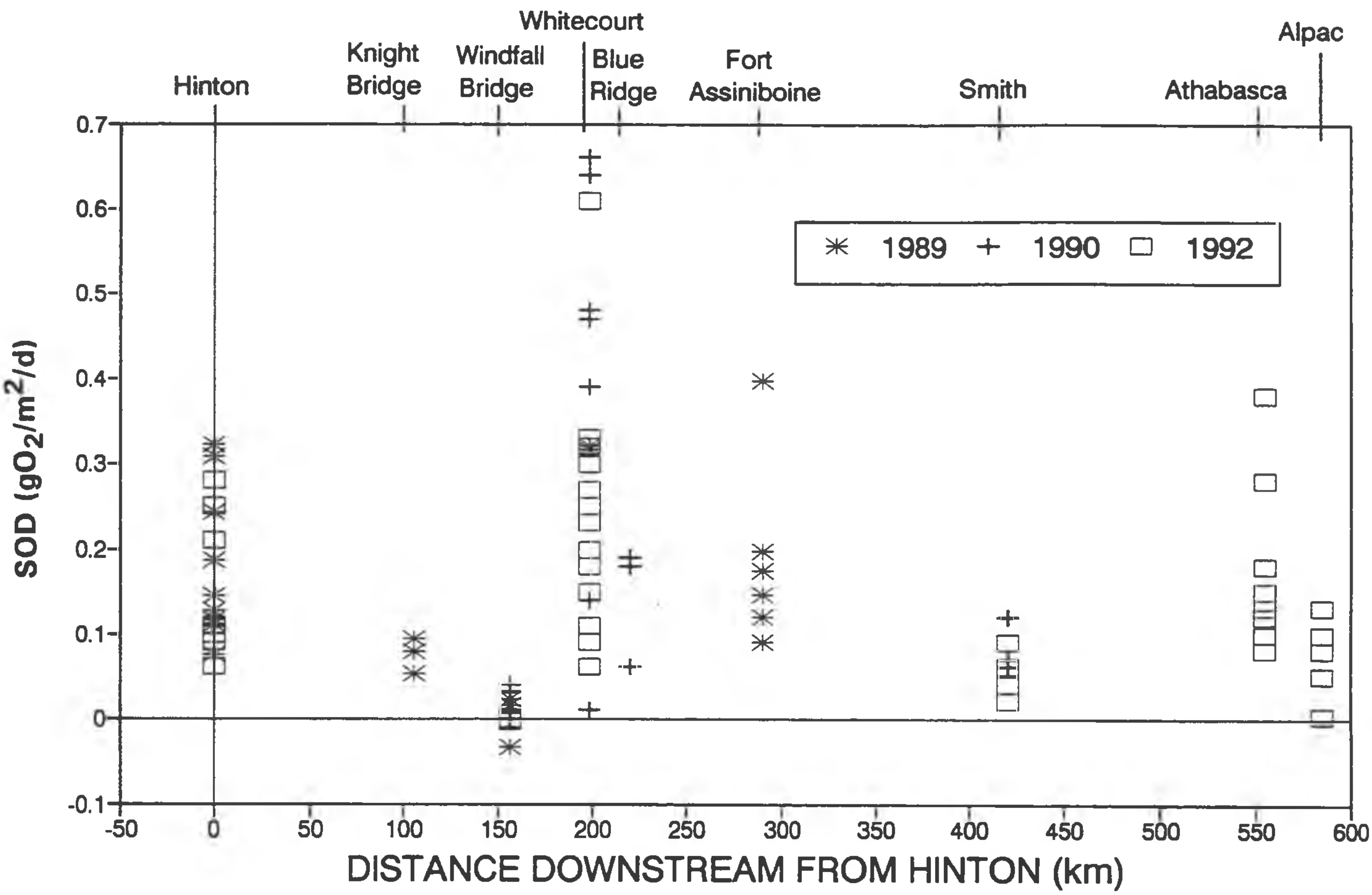

Figure 4.3.3

LONGITUDINAL TREND IN SEDIMENT OXYGEN DEMAND (SOD) ON THE ATHABASCA RIVER

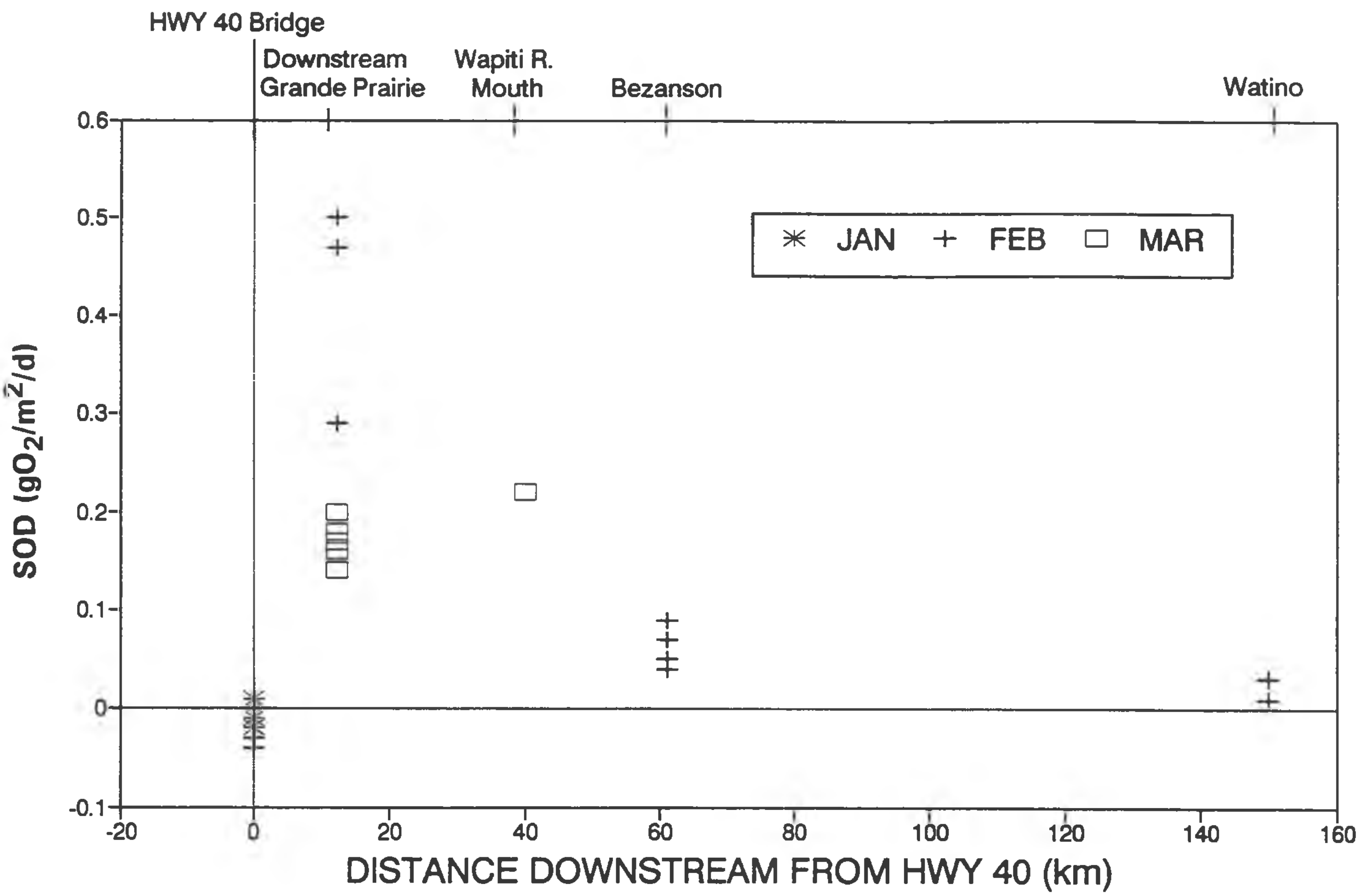

Figure 4.3.4

LONGITUDINAL TREND IN SEDIMENT OXYGEN DEMAND (SOD) ON THE WAPITI-SMOKY RIVER SYSTEM, 1990

(Casey 1990). Presumably, scouring of the river bed reduces benthic deposits and biomass, thereby lowering SOD. Scouring of epilithic organic matter and associated organisms by high flows was observed on the Athabasca River at Whitecourt in March, 1992; this scouring coincided with SOD reductions.

Casey (1990) describes the changes over the winter as temporal. The changes may be dependant on the hydraulic conditions in the river. When biomass is able to accumulate undisturbed under low flow conditions, the SOD increases; when it is disturbed, the SOD decreases.

Another possible explanation for the temporal trend has come to light (Noton pers. comm.). During the 1993 continuous dissolved oxygen monitoring, diurnal cycling of dissolved oxygen was observed near Smith and Grand Rapids, attributable to photosynthesis under ice. Snow cover was negligible and there was significant light penetration. Dissolved oxygen was fluctuating as much as 2 mg/L/d, with a rise during daylight and a nearly equivalent decline during night. The decline during night indicates that algal respiration was much enhanced once algal photosynthesis began. It seems possible that enhanced algal respiration, as winter progresses and the angle of the sun increases, could be responsible for the apparent increase in SOD through the winter at the Whitecourt site. That site was ice-free and benthic algae would receive sufficient light for photosynthesis. Unfortunately, photosynthetic dissolved oxygen production was not measured during the SOD work since only opaque chambers were employed.

TABLE 4.3.1
Characteristics of Epilithic Algal Growth at SOD Study Sites on the Athabasca River and Wapiti-Smoky River System

Study Area	Description	Epilithic Growth		
		1989	1990	1992
Athabasca River				
Hinton #1	1 km downstream of Weldwood mill effluent and Hinton sewage (combined)	small amount, patchy		small amount, patchy
Hinton #2	same as #1	small amount, patchy		small amount, patchy
Hinton #3	same as #1	none visible		small amount, patchy
Knight Bridge		fairly uniform cover		
Windfall Bridge		small amount, patchy	small amount, patchy	none visible
Whitecourt #1	1 km downstream of Millar Western mill effluent upstream of Whitecourt sewage	abundant	gelatinous cover, abundant	moderate to abundant, filamentous algae and gelatinous cover
Whitecourt #2 & #3				small amount, patchy
Blue Ridge			none visible	
Fort Assiniboine		none visible	none visible	
Smith			macrophytic and encrusting algae common	small amount, encrusting algae
Athabasca #1 & #2				very small amount
Alpac				very small amount
Wapiti-Smoky River System				
Highway #40			small amount, patchy	
Grande Prairie #1	2.5 km downstream of Weyerhaeuser mill effluent and Grande Prairie Sewage - main channel		encrusting algae, abundant	
Grande Prairie #2	same as #1 - backwater		none visible	
Wapiti River Mouth			encrusting algae, common	
Benzanson			none visible	
Watino			small amount, patchy	

TABLE 4.3.2
Mean Sediment Oxygen Demand (SOD) at Locations on the Athabasca River

Locations	Date	Chamber Type	SOD ($g/m^2/d$)			
			Mean	Range	N	CV(%)
Hinton	16/03/92	Open	0.16	0.06 - 0.21	5	36
	16/03/92	Core[a]	0.23	0.12 - 0.28	5	29
	22/02/89	Closed	0.190	0.116 - 0.308	3	55
	21/02/89	Open	0.174	0.074 - 0.322	4	63
	28/02/89	Open	0.185	0.127 - 0.243	2	44
Knight Bridge	20/03/89	Closed	0.074	0.051 - 0.093	3	29
Windfall Bridge	13/02/92	Closed	-0.002	-0.004 - 0.00	3	NA
	14/03/89	Closed	0.001	-0.035 - -0.022	3	NA
	17/01/90	Closed	0.00	0.00 - 0.00	3	NA
	09/02/90	Closed	0.03	0.03 - 0.04	3	17
	07/03/90	Closed	0.01	0.01 - 0.01	3	0
Whitecourt	29/01/92	Closed	0.12	0.06 - 0.18	5	38
	11/02/92	Closed	0.16	0.09 - 0.25	5	45
	19/03/92	Closed	0.38	0.27 - 0.61	4	41
	20/03/92	Open	0.26	0.20 - 0.32	3	23
	20/03/92	Core[a]	0.24	0.18 - 0.30	5	18
	21/03/89	Closed	0.319	0.316 - 0.321	2	1
	16/01/90	Closed	0.08	0.01 - 0.14	2	123
	08/02/90	Closed	0.42	0.39 - 0.47	3	11
	06/03/90	Closed	0.59	0.48 - 0.66	3	17
Blue Ridge	12/02/90	Closed	0.06	-	1	-
	09/03/90	Closed	0.19	0.18 - 0.19	2	4
	09/03/90	Open	0.19	-	1	-
Fort Assiniboine	29/03/89	Closed	0.188	0.091 - 0.398	6	58
	10/03/90	Closed[b]	0.07	0.02 - 0.11	3	39
Smith	17/02/92		0.06	0.02 - 0.09	5	51
	12/03/90	Closed	0.08	0.06 - 0.12	3	39
Athabasca	22/03/92	Core[a]	0.19	0.08 - 0.38	5	69
	23/02/92	Closed	0.15	0.12 - 0.18	5	18
Alpac	24/03/92	Core[a]	0.07	0.002 - 0.13	5	70

N = Number of test/sample replicates
CV(%) = Coefficient of variation or standard deviation expressed as a percentage of the mean
NA = CV(%) not calculated for data with negative values
a. Core = sediment core type of SOD sampler
b. 68 h - 72 h incubation. (The incubation period for all other data was about 48 h.)

TABLE 4.3.3
Mean Sediment Oxygen Demand (SOD) at Locations on the Wapiti-Smoky River System

Locations	Date	Chamber Type	SOD ($g/m^2/d$)			
			Mean	Range	N	CV(%)
Wapiti River						
Highway #40	26/01/90	Closed	-0.01	-0.02 - 0.01	3	NA
	25/02/90	Closed	-0.03	-0.04 - -0.03	3	NA
Downstream of Weyerhaeuser Mill Effluent						
- Site #1	22/02/90	Closed	0.42	0.29 - 0.50	3	27
- Site #2	20-03/90	Closed	0.16	0.14 - 0.18	3	13
- Site #3	20-03/90	Open	0.18	0.16 - 0.20	3	12
Wapiti Mouth	20/03/90	Closed	0.22	-	1	-
Smoky River						
Bezanson	26/02/90	Closed	0.07	0.04 - 0.09	2	54
	26/02/90	Open	0.05	0.04 - 0.07	3	29
Watino	23/02/90	Closed	0.02	0.01 - 0.03	3	69

N = Number of test/sample replicates
CV(%) = Coefficient of variation or standard deviation expressed as a percentage of the mean
NA = CV(%) not calculated for data with negative values

<u>Differences Between Rivers</u> Casey (1990) concluded that the mean SOD rates were generally greater on the Athabasca River than on the Wapiti-Smoky River system. When the 1990 data were examined more closely, however, they show that the means were skewed by differences due to hydraulic conditions at individual sampling sites. In February, the only month when data were not affected by scouring, the data points for locations receiving similar impacts clearly overlap (Tables 4.3.2 and 4.3.3).

When the results of the 1992 study are added to earlier data for the Athabasca River at Whitecourt they show that the low levels observed on the Wapiti-Smoky River system also occur on the Athabasca river (Fig. 4.3.3 and 4.3.4). The February 1992 results for Whitecourt are as low as the lowest value for the Wapiti-Smoky River system below the Weyerhaeuser mill (Tables 4.3.2 and 4.3.3). The March 1992 results also show low SOD values (e.g. 0.18 $g/m^2/d$) for individual sites that are identical to those measured below the Weyerhaeuser mill in March 1990. Thus, no general difference in SOD rates could be found between rivers.

<u>**Differences Between Mills**</u> Casey (1990) concluded that the Millar Western Ltd. CTMP mill and the Whitecourt municipal effluent appeared to have a greater effect on the rate of SOD, and the longitudinal trend in SOD in the Athabasca River, than the effect of the Weyerhaeuser bleached kraft mill effluent and Grande Prairie municipal effluent in the Wapiti-Smoky River system. Also, the SOD rates downstream of the Millar Western STMP mill were greater than the SOD rates about 1 km downstream of the Weldwood bleached kraft pulp mill at Hinton (Casey and Noton 1989). Casey suggested that the difference between SOD rates may be due to the type of pulp mill and effluent.

This hypothesis may be premature; the differences below the pulp mills may not be significant. If results attributed to scouring are removed from the database, the remaining data for locations below Whitecourt and Grande Prairie overlap (Fig. 4.3.5). When data for all three years is combined, the SOD values also overlap since the 1992 values for Whitecourt are generally lower than in earlier studies (Fig. 4.3.5). The high SOD loadings for the Millar Western mill were recorded for its first two years of operation (1989 and 1990) and the BOD loading of the effluent may have been unusually high. The differences may also be due to scouring events which coincided with sampling rather than the type of mill or treatment. As the database grows to include scour-related data at all locations, the results that appeared to be differences in 1990 become part of the variability of the data.

4.3.3 Quality of Data

Casey and Noton (1989) reviewed the potential errors in the SOD measurements (Table 4.3.4) and found that the results are likely an underestimate of the true SOD. Only one potential error would cause the SOD rates to overestimate the true SOD. They reviewed potential errors; the extent that the error occurs in the field was not measured. The methods and the results were compared to the published literature, but were not field tested against other methods. There is no accepted standard method available to measure SOD. Laboratory results are not directly comparable to *in situ* results. Casey and Noton (1989) found few SOD estimates using *in situ* methods during the winter; the coefficient of variation they determined in the Athabasca River was similar to relevant coefficients found in the literature.

The 1989 methods were modified in 1990 to reduce the potential errors. Smaller water samples were taken from the chambers to measure dissolved oxygen, control chambers were used at all sites and the accuracy of the volume measurement was improved. Nevertheless, reduced mixing of water in the chamber and reduced water velocity at the substratum-water interface continued in 1990 and would likely cause an underestimate of the true SOD.

TABLE 4.3.4
Potential Factors Affecting SOD Rates for the Athabasca River
(Modified slightly from Casey and Noton 1989)

Factors Affecting SOD Rates Measured by *in situ* Chambers	**Probable Effect on SOD Rate**
Use of chambers versus measuring the oxygen balance of the river	Underestimate
Reduced water mixing in the chamber and reduced water velocity at substratum-water interface	Underestimate
Disturbance and mixing of sediment	No Effect
Resuspension of sediment	No Effect
Reduced DO concentration in chamber due to extraction of samples and use of portholes	Underestimate
Use of BOD bottles instead of blank chambers as controls in 1989	Underestimate
Measurement error of volume of water in chamber where fine (soft) sediment used	Overestimate

The SOD was measured by open and closed chambers concurrently at three sites during 1989 and 1990 studies. At all sites the SOD rates were similar for the two types of chambers. In 1992 Monenco added the sediment core method. Sediment core sampling was done concurrently with chamber measurements at locations, but the sediment core samples were conducted in low velocity areas of fine sediment only. Thus, the sites where the sediment core and chamber methods were used are not comparable. In spite of the obvious differences in hydrologic and substrate characteristics between closed chamber and coring sites, the mean 24 h SOD rates were the same or nearly the same at each of the study locations where both were used (Monenco

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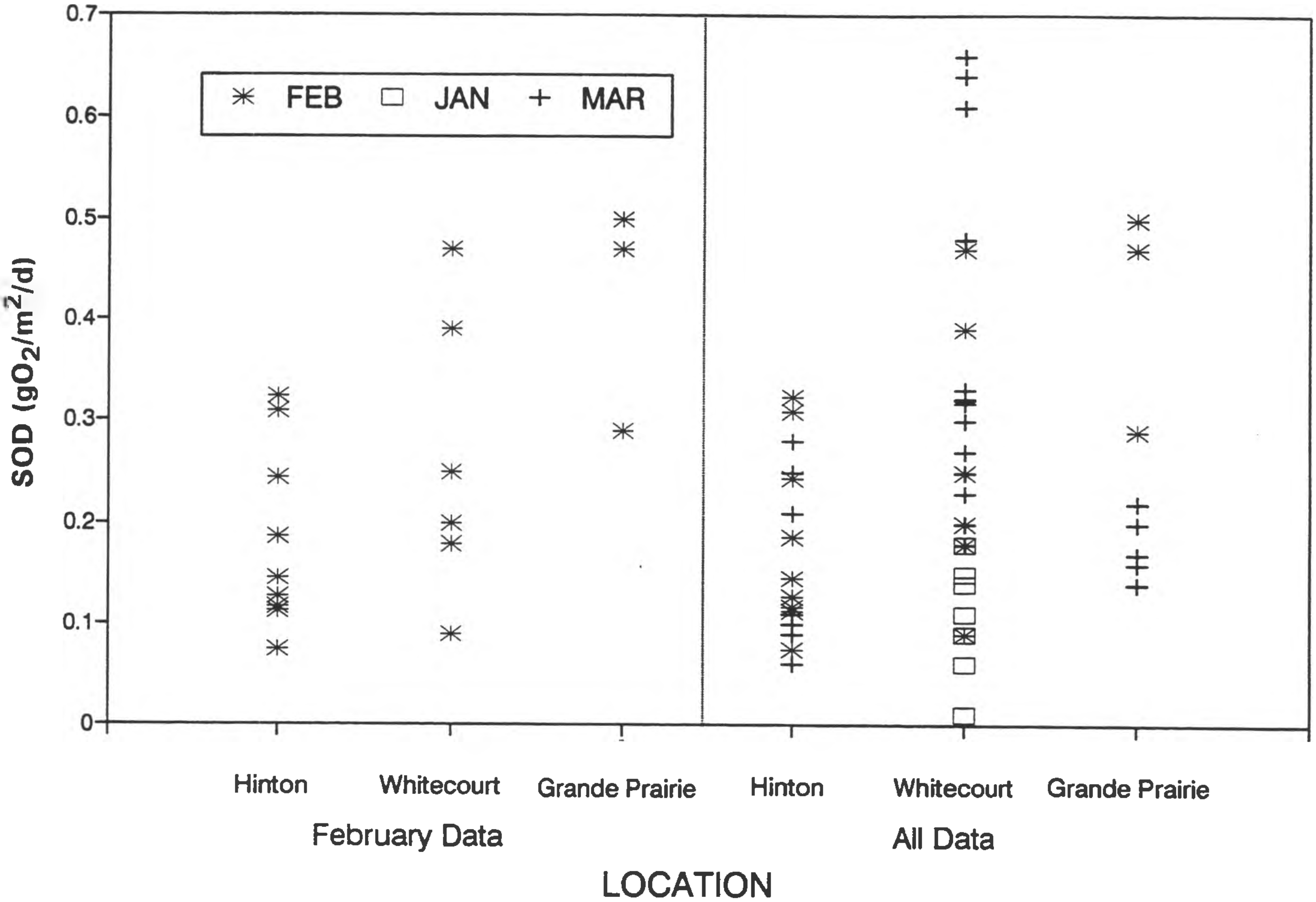

Figure 4.3.5
COMPARISON OF SEDIMENT OXYGEN DEMAND (SOD) RATES BELOW PULP MILLS AT HINTON, WHITECOURT AND GRANDE PRAIRIE

1993). This result differs from the 1989 results which found that SOD rates for rocky substrate were greater than those for fine sediments (Casey and Noton 1989). Until the sediment core method is compared to the closed chamber method under the same substrate and velocity conditions, comparison of sediment core data with chamber data should be made cautiously. Differences in the velocity and substrate sampling sites at the same location will increase the coefficient of variation for sampling locations where a variety of substrate types exist.

Although the SOD measurements may underestimate the SOD, Casey and Noton (1989) considered the data to be a reasonable representation of the relative rates from place to place.

Nearly all the SOD work to date has been done in shallow, near-shore depths for logistical reasons. Although the data fit an interpretable pattern and appear reasonable, the results are spatially limited. Much uncertainty remains concerning the SOD in the centre of the channel.

SECTION 5.0

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5.0 LITERATURE CITED

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APPENDIX A

NUTRIENT LOADS FROM PULP MILLS

Table A.1
Monthly Mean Loading of Total and Dissolved
Phosphorus in Weldwood of Canada Ltd. Effluent, 1991

DATE		FLOW (m3/d)	DISSOLVED PHOSPHORUS (mg/L)	DISSOLVED PHOSPHORUS LOADING (kg/d)	TOTAL PHOSPHORUS (mg/L)	TOTAL PHOSPHORUS LOADING (kg/d)
January 91	MEAN	105730			0.87	92.78
	STD DEV	4838			0.30	35.53
	N	5			5	5
February 91	MEAN	100925			1.87	188.39
	STD DEV	2034			0.79	78.76
	N	4			4	4
March 91	MEAN	103593	0.30	30.53	0.70	72.73
	STD DEV	5119	0.34	33.91	0.12	12.37
	N	4	4	4	4	4
April 91	MEAN	106260	0.22	23.12	0.54	57.48
	STD DEV	2747	0.12	12.78	0.30	31.81
	N	5	5	5	5	5
May 91	MEAN	104125	0.08	7.38	0.49	51.87
	STD DEV	16078	0.07	6.24	0.18	21.64
	N	4	4	4	4	4
June 91	MEAN	120500	0.16	19.58		
	STD DEV	2192	0.12	13.96		
	N	4	4	4		
July 91	MEAN	120070	0.64	77.35	0.85	102.88
	STD DEV	6100	0.40	49.68	0.33	41.42
	N	5	5	5	5	5
September 91	MEAN	115725	0.27	31.42	0.49	56.33
	STD DEV	6445	0.04	4.92	0.17	20.54
	N	4	4	4	4	4
October 91	MEAN	118900	0.21	25.48	0.75	91.33
	STD DEV	6746	0.09	10.96	0.33	41.17
	N	5	5	5	5	5
November 91	MEAN	111000	1.15	126.66	1.56	171.63
	STD DEV	1688	0.42	45.13	0.60	64.53
	N	4	4	4	4	4
December 91	MEAN	107	0.71	0.08	1.16	0.13
	STD DEV	4	0.81	0.09	0.78	0.08
	N	5	5	5	5	5

NOTE: No phosphorus data for August of 1991.

Table A.2
Monthly Mean Loading of Total and Dissolved Phosphorus in Alberta Newsprint Company Effluent, 1991

DATE		FLOW (m3/d)	DISSOLVED PHOSPHORUS (mg/L)	DISSOLVED PHOSPHORUS LOADING (kg/d)	TOTAL PHOSPHORUS (mg/L)	TOTAL PHOSPHORUS LOADING (kg/d)
January 91	MEAN	12212	6.41	80.79	7.42	91.97
	STD DEV	2152	1.48	30.25	1.33	28.87
	N	4	4	4	4	4
February 91	MEAN	13591	8.40	114.21	9.60	130.49
	STD DEV	2388	3.08	61.06	3.60	70.06
	N	5	4	4	4	4
March 91	MEAN	14711	7.94	115.81	8.59	125.09
	STD DEV	1703	1.89	29.34	2.20	33.65
	N	4	4	4	4	4
April 91	MEAN	13582	7.82	100.55	8.92	114.18
	STD DEV	2899	4.05	46.15	5.10	58.45
	N	5	5	5	5	5
May 91	MEAN	13575	9.33	126.94	9.95	135.62
	STD DEV	2058	3.26	51.81	4.15	64.70
	N	5	5	5	5	5
June 91	MEAN	15826	4.47	71.74	4.55	72.92
	STD DEV	1381	0.88	20.04	0.86	19.89
	N	4	4	4	4	4
July 91	MEAN	14369	2.83	40.54	3.02	43.33
	STD DEV	859	0.91	12.97	0.94	13.21
	N	5	5	5	5	5
August 91	MEAN	18749	5.11	96.41	5.45	102.65
	STD DEV	826	1.58	31.64	1.31	26.87
	N	5	5	5	5	5
September 91	MEAN	14761	6.40	90.82	7.40	105.07
	STD DEV	5586	0.97	34.18	1.32	41.23
	N	5	5	5	5	5
October 91	MEAN	14057	6.60	91.29	7.44	103.43
	STD DEV	5332	0.28	33.07	0.70	39.68
	N	4	4	4	4	4
November 91	MEAN	18271	5.68	108.63	6.71	124.27
	STD DEV	2652	3.04	65.99	3.41	65.86
	N	5	5	5	5	5
December 91	MEAN	18003	5.30	93.00	5.61	99.36
	STD DEV	1633	3.36	51.31	2.94	45.96
	N	5	5	5	5	5

Table A.3
Monthly Mean Loading of Total and Dissolved
Phosphorus in Millar Western Pulp Ltd. Effluent, 1991

DATE		FLOW (m3/day)	DISSOLVED PHOSPHORUS (mg/l)	DISSOLVED PHOSPHORUS LOADING (kg/day)	TOTAL PHOSPHORUS (mg/l)	TOTAL PHOSPHORUS LOADING (kg/day)
January 91	MEAN	13327			2.38	32.29
	STD DEV	1126			0.79	12.79
	N	5			5.00	5.00
February 91	MEAN	13754			0.87	11.90
	STD DEV	886			0.45	5.93
	N	4			4.00	4.00
March 91	MEAN	12960			0.50	6.39
	STD DEV	1611			0.36	4.88
	N	4			4.00	4.00
April 91	MEAN	13767			1.65	22.09
	STD DEV	818			1.99	25.76
	N	5			5.00	5.00
May 91	MEAN	11765			1.71	19.63
	STD DEV	2746			0.58	7.71
	N	4			4.00	4.00
June 91	MEAN	13380			0.80	10.70
	STD DEV	294			0.23	3.11
	N	4			4.00	4.00
July 91	MEAN	11904			0.57	6.78
	STD DEV	595			0.13	1.22
	N	5			4.00	4.00
August 91	MEAN	11890			3.02	35.45
	STD DEV	775			1.43	15.87
	N	4			4.00	4.00
September 91	MEAN	12151			4.51	54.21
	STD DEV	855			1.56	16.98
	N	3			3.00	3.00
October 91	MEAN	12302	2.67	33.45	3.70	46.32
	STD DEV	1115	0.79	11.94	1.05	16.51
	N	5	5.00	5.00	5.00	5.00
November 91	MEAN	11803	1.54	17.09	2.11	23.74
	STD DEV	1960	0.59	4.85	0.74	7.50
	N	4	4.00	4.00	4.00	4.00
December 91	MEAN	13039	0.17	2.20	0.65	8.46
	STD DEV	539	0.14	1.82	0.20	2.27
	N	5	5.00	5.00	5.00	5.00

Table A.4
Monthly Mean Loading of Total Phosphorus in Slave Lake Pulp Corporation Effluent, 1991

DATE		FLOW (m3/day)	TOTAL PHOSPHORUS (mg/l)	TOTAL PHOSPHORUS LOADING (kg/day)
February 91	MEAN	3149	4.39	14.28
	STD DEV	897	7.55	25.37
	N	19	19	19
March 91	MEAN	3466	2.85	9.96
	STD DEV	598	1.81	7.26
	N	19	19	19
April 91	MEAN	3589	17.56	60.65
	STD DEV	728	12.61	44.96
	N	28	28	28
May 91	MEAN	3451	37.42	132.09
	STD DEV	1482	4.80	63.92
	N	5	5	5
June 91	MEAN	4781	30.25	144.58
	STD DEV	227	11.58	54.24
	N	4	4	4
July 91	MEAN	4077	11.13	44.42
	STD DEV	1190	8.49	33.51
	N	4	4	4
August 91	MEAN	4749	1.50	7.00
	STD DEV	832	0.29	1.44
	N	4	4	4
September 91	MEAN	3968	1.38	6.12
	STD DEV	615	1.65	8.03
	N	4	4	4
October 91	MEAN	3559	2.12	7.61
	STD DEV	938	1.62	6.67
	N	5	5	5
November 91	MEAN	3857	0.56	2.35
	STD DEV	870	0.32	1.40
	N	4	4	4
December 91	MEAN	4340	0.51	2.25
	STD DEV	960	0.23	1.33
	N	4	4	4

NOTE: No phosphorus data for January of 1991.

Table A.5
Monthly Mean Loading of Total and Dissolved Phosphorus in Weyerhaeuser Canada Ltd. Effluent, 1991

DATE		FLOW (m3/d)	DISSOLVED PHOSPHORUS (mg/L)	DISSOLVED PHOSPHORUS LOADING (kg/d)	TOTAL PHOSPHORUS (mg/L)	TOTAL PHOSPHORUS LOADING (kg/d)
January 91	MEAN	62417			1.15	71.90
	STD DEV	4262			0.07	7.61
	N	4			4	4
February 91	MEAN	63339			1.00	62.93
	STD DEV	1871			0.14	7.71
	N	4			4	4
March 91	MEAN	65081			0.94	60.87
	STD DEV	3470			0.10	5.27
	N	5			5	5
April 91	MEAN	62555			0.91	57.69
	STD DEV	3938			0.39	26.75
	N	5			5	5
May 91	MEAN	56993			0.71	40.35
	STD DEV	8426			0.05	6.52
	N	6			6	6
June 91	MEAN	59702			0.88	52.02
	STD DEV	5640			0.22	12.18
	N	5			5	5
July 91	MEAN	63596	0.64	42.57	1.79	115.86
	STD DEV	5591	0.65	42.71	0.64	48.74
	N	5	5	5	5	5
August 91	MEAN	69015	0.84	57.74	0.95	65.87
	STD DEV	1619	0.17	10.70	0.21	15.11
	N	6	6	6	6	6
September 91	MEAN	56587	0.93	52.16	1.49	85.20
	STD DEV	8882	0.17	10.88	0.21	19.44
	N	6	6	6	6	6
October 91	MEAN	41110	0.79	23.25	1.29	44.06
	STD DEV	20676	0.56	20.16	0.45	15.76
	N	5	5	5	5	5
November 91	MEAN	60310	0.32	18.51	0.95	58.25
	STD DEV	2001	0.43	24.48	0.47	29.18
	N	5	5	5	5	5
December 91	MEAN	57787	0.39	22.78	1.19	68.93
	STD DEV	4586	0.19	11.62	0.12	11.49
	N	6	6	6	6	6

Table A.6
Monthly Mean Loading of Total and Dissolved Phosphorus in Daishowa Canada Co. Ltd., Peace River Pulp Division, 1991

DATE		FLOW (m3/day)	DISSOLVED PHOSPHORUS (mg/l)	DISSOLVED PHOSPHORUS LOADING (kg/day)	TOTAL PHOSPHORUS (mg/l)	TOTAL PHOSPHORUS LOADING (kg/day)
January 91	MEAN	68668	0.85	58.08	1.05	71.63
	STD DEV	5206	0.15	10.90	0.13	7.41
	N	9	9	9	9	9
February 91	MEAN	61976	0.87	53.83	1.17	72.14
	STD DEV	7013	0.14	11.12	0.14	9.90
	N	8	8	8	8	8
March 91	MEAN	61896	1.24	76.29	1.40	85.98
	STD DEV	8010	0.08	9.39	0.16	12.02
	N	9	9	9	9	9
April 91	MEAN	68772	0.74	50.30	1.08	73.44
	STD DEV	7037	0.34	21.33	0.20	11.23
	N	7	7	7	7	7
May 91	MEAN	61993	0.69	42.74	0.95	58.40
	STD DEV	8417	0.18	12.34	0.13	9.62
	N	10	10	10	10	10
June 91	MEAN	60866	1.31	79.91	1.68	101.19
	STD DEV	13628	0.30	25.56	0.53	33.35
	N	8	8	8	8	8
July 91	MEAN	62928	2.34	147.15	2.74	172.41
	STD DEV	5899	0.37	24.99	0.40	30.78
	N	13	13	13	13	13
August 91	MEAN	63891	1.71	109.58	1.86	118.56
	STD DEV	8641	0.23	21.71	0.21	20.29
	N	8	8	8	8	8
September 91	MEAN	58473	2.32	138.06	2.64	157.08
	STD DEV	2859	0.20	11.42	0.18	8.00
	N	9	6	6	6	6
October 91	MEAN	40236	1.85	71.89	2.08	81.12
	STD DEV	23672	0.15	40.81	0.14	46.84
	N	5	5	5	5	5
November 91	MEAN	65219	1.98	129.14	2.24	146.14
	STD DEV	6339	0.07	16.13	0.08	18.07
	N	4	4	4	4	4
December 91	MEAN	66908	1.65	110.73	1.98	132.59
	STD DEV	9886	0.06	20.36	0.05	19.53
	N	5	5	5	5	5

NOTE: The values for dissolved phosphorus were switched for total phosphorus in August and November of 1991, and January of 1992, in the database. This was corrected for this table after verbal confirmation from Tom Tarpey of Peace River Pulp Division.

APPENDIX B

INSTREAM MONITORING BY PULP MILLS

TABLE B.1
Concentrations of Nutrients in the Athabasca River Near Hinton from Spring and Fall Surveys[a]

Parameter[b]	Control Stations[c]			Experimental Stations[c]					
	1B	1A	1C	2	4	5	6	7	8
October 1990									
Ammonia	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 L
Total Kjeldahl Nitrogen	0.26 C	0.26 C	0.22 C	0.31 C	0.26 C	0.32 C	0.22 C	0.23 C	0.21 L
Total Phosphate	<0.005 C	0.060 C	0.242 C	0.155 C	0.111 C	0.118 C	0.069 C	0.063 C	0.031 L
Ortho-Phosphate	0.005 C	0.010 C	0.005 C	0.005 C	0.005 C	0.005 C	0.005 C	0.005 C	0.005 L
April 1991									
Ammonia	0.08 R	0.17 C	0.07 C	0.39 C	0.10 R	0.05 C	0.06 R	0.02 C	0.03 L
Total Kjeldahl Nitrogen	0.24 R	0.19 C	0.22 C	0.40 C	0.31 R	0.43 C	0.37 R	0.30 C	0.30 L
Total Phosphorus	<0.005 R	<0.005 C	<0.005 C	<0.005 C	<0.005 R	<0.005 C	<0.005 R	<0.005 C	<0.005 L
Ortho-Phosphate	<0.005 R	<0.005 C	<0.005 C	<0.005 C	<0.005 R	<0.005 C	<0.005 R	<0.005 C	<0.005 L
April 1992									
Ammonia	0.03 L	0.04 R	<0.005 L	0.07 C	0.04 C	0.02 C	0.02 R	0.01 R	<0.005 L
Total Kjeldahl Nitrogen	<0.05 L	<0.05 R	0.06 L	0.20 C	0.35 C	0.12 C	<0.05 R	0.08 R	0.16 L
Total Phosphorus	<0.05 L	<0.05 R	<0.05 L	<0.05 C	<0.05 C	<0.05 C	<0.05 R	<0.05 R	<0.05 L
Total Dissolved Phosphorus	<0.05 L	<0.05 R	<0.05 L	<0.05 C	<0.05 C	<0.05 C	<0.05 R	<0.05 R	<0.05 L
October 1992									
Ammonia	0.009 L	0.015 R	0.009 L	0.02 C	0.009 C	<0.005 C	<0.005 R	<0.005 R	<0.005 L
Total Kjeldahl Nitrogen	0.21 L	0.21 R	0.21 L	0.29 C	0.33 C	0.33 C	0.34 R	<0.05 R	<0.05 L
Total Phosphorus	<0.05 L	0.09 R	0.09 L	0.12 C	<0.05 C	<0.05 C	<0.05 R	<0.05 R	<0.05 L
Total Dissolved Phosphorus	<0.05 L	<0.05 R	0.05 L	<0.05 C	<0.05 C	<0.05 C	<0.05 R	<0.05 R	<0.05 L

a. measured during benthic invertebrate surveys (data reported by TAEM 1991b,c; 1992b,c)
b. Units are mg/L
c. R = right bank; C = centre; L = left bank; stations are shown on Fig. 4.1.5

TABLE B.2

Concentrations of Nutrients in the Athabasca River near Hinton from Winter Surveys[a]

Parameter[b]	Sample Location									
	2 km Upstream	River Pumphouse	Mill Effluent	Calculated Downstream	Obed Mountain Bridge 20 km	Weldwood Bridge 50 km	Knight Bridge 125 km	Windfall Bridge 165 km			Field Blank
January 1991											
Nitrogen											
Ammonia as N	<0.005		3.07	0.09	0.04	0.03	<0.005	<0.005	<0.005	<0.005	<0.005
Kjeldahl Nitrogen	0.47		4.31	0.58	0.43	0.32	0.13	0.22	0.12	0.18	<0.05
Nitrite as N	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrate as N	0.06		<0.05		<0.05	<0.05	0.06	0.06	0.06	0.06	<0.05
Phosphorus											
Total	<0.005		0.46	0.013	0.02	<0.005	<0.005	0.005	0.005	0.005	<0.005
Phosphate as P	<0.005		0.11		<0.005	<0.005	<0.005	0.005	0.005	0.005	<0.005
January 1992											
Nitrogen											
Ammonia as N	0.15	0.16	0.69	0.16		0.29	0.21		0.19		0.13
Kjeldahl Nitrogen	0.8	0.2	5.7			0.3	0.5		0.2		0.2
Nitrite as N	0.01	0.01	0.05			0.02	0.02		0.02		<0.01
Nitrate as N	0.12	0.12	0.26			0.13	0.14		0.15		0.03
Phosphorus											
Total	0.05	0.02	0.70	0.07		0.31	0.02		0.02		0.02
Phosphate as P	0.02	0.02	0.12			0.31	0.02		0.02		0.02

a. Data from Weldwood of Canada

b. Units are in mg/L

TABLE B.3
Concentrations of Nutrients in the Athabasca River in the Vicinity of the Alberta Newsprint Company

Parameter[a]	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1990														
Total Phosphorus (as P)	0.08	0.02	0.04	0.02	0.03	0.08	0.02	0.06	0.04	0.02	0.03	0.02	0.04	0.03
Total Kjeldahl Nitrogen (as N)	0.4	0.2	0.4	0.2	<0.1	0.3	<0.1	0.2	<0.1	0.2	<0.1	0.2	<0.1	0.2
1991														
Total Phosphorus (as P)	0.04	0.02	0.01	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.07	0.02	0.02	0.05
Total Kjeldahl Nitrogen (as N)	0.6	<0.1	0.7	<0.1	0.6	<0.1	0.8	<0.1	0.4	<0.1	0.7	<0.1	0.6	<0.1

Notes: Spring and fall sampling for 1990 and 1991 was conducted in May and October (data reported by Beak Associates 1991b, SENTAR Consultants Ltd. 1992c). Location of sites is shown in Fig. 4.1.6

a. Units are mg/L

TABLE B.4

Concentrations of Nutrients in the McLeod and Athabasca Rivers Near Whitecourt

Parameter	Site 1		Site 2		Site 3		Site 3A		Site 4		Site 4A		Site 5		Site 6		Site 7		Site 8	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1987																				
Total Phosphate	0.204	0.079	0.219	0.070	0.246	0.134	0.164	--	0.255	0.082	0.213	0.091	0.277	0.097	0.210	0.100	0.146	0.091	0.477	--
Total Kjeldahl Nitrogen	4.2	3.0	2.8	2.2	2.2	3.4	2.3	--	3.2	3.0	1.8	2.6	1.3	3.5	1.8	2.2	2.0	2.4	3.7	--
1988																				
Total Phosphate	0.165	0.02	0.258	<0.01	0.175	0.01	0.160	0.03	0.180	0.03	0.158	0.02	0.195	0.02	0.197	0.06	0.185	0.03	0.371	0.04
Total Kjeldahl Nitrogen	1.8	1.3	1.8	0.9	1.5	0.9	1.6	0.8	1.7	0.9	1.5	0.9	1.6	0.8	1.7	0.8	1.5	0.8	3.2	1.2
1989																				
Total Phosphate	0.15	0.06	0.12	0.03	0.21	0.06			0.18	0.09	0.27	0.03	0.18	0.09	0.21	0.09	0.18	0.03		
Total Kjeldahl Nitrogen	0.5	0.5	0.4	0.3	0.3	0.4			0.4	0.4	0.2	0.4	0.3	0.4	0.3	0.4	0.4	0.3		
1990																				
Total Phosphorus	0.06	0.03	0.04	0.02	0.04	0.01			0.04	0.01	0.03	0.04	0.03	0.02	0.04	0.04	0.04	0.03		
Total Kjeldahl Nitrogen	<0.1	0.3	<0.1	0.2	0.5	0.1			<0.1	0.2	0.3	0.2	<0.1	0.2	<0.1	0.2	<0.1	0.2		
1991																				
Total Phosphorus	0.04	0.02	0.03	0.02	0.03	0.02			0.03	0.02	0.03	0.02	0.07	0.02	0.01	0.02	0.02	0.05		
Total Kjeldahl Nitrogen	0.7	<0.1	0.4	<0.1	0.5	<0.1			0.6	<0.1	0.7	<0.1	0.7	<0.1	0.6	<0.1	0.6	<0.1		

Notes: Spring and Fall Sampling: 1987 - June & November; 1988 - June & October; 1989 - June & October; 1990 - May & October; 1991 - May & October (data reported by Beak Associates 1991a, SENTAR Consultants Ltd. 1992b).
Parameters measured in mg/L.
-- = Not sampled due to icing of river
Location of stations shown in Fig. 4.1.6

TABLE B.5
Concentrations of Nutrients for Winter Water Samples Collected from the Athabasca River

Parameter[a]	Windfall	ANC Effluent	ANC Site[b]		Whitecourt	McLeod River	Millar Western Effluent	1 km Down-stream Millar Western	Whitecourt STP	Blue Ridge	Fort Assiniboine	Pembina River	Hondo
February 21-23, 1990													
Total Phosphate (as PO_4)	<0.01			<0.01	<0.01	-	3.16	0.09	-	<0.01	0.09	-	0.03
Nitrate & Nitrite Nitrogen	0.1			<0.1	0.3	-	1.2	0.1	-	<0.1	0.2	-	0.1
Ammonia Nitrogen	<0.1			<0.1	<0.1	-	<0.1	<0.1	-	<0.1	<0.1	-	<0.1
Total Kjeldahl Nitrogen	0.5			0.5	0.3	-	16	0.6	-	0.6	0.6	-	0.5
February 20-21, 1991			N	S									
Total Phosphorus (as P)	<0.005	10.1	<0.005	<0.005	<0.005	-	0.680	0.070	3.67	0.040	0.260	-	<0.005
Dissolved Phosphorus (as P)	<0.005	10.1	<0.005	<0.005	<0.005	-	<0.005	<0.005	3.37	<0.005	<0.005	-	<0.005
Nitrate & Nitrite Nitrogen	0.10	0.52	0.10	0.10	0.09	-	<0.05	0.09	4.97	0.10	0.19	-	0.17
Total Kjeldahl Nitrogen	0.31	1.99	0.13	0.13	0.38	-	7.73	<0.05	6.42	0.38	0.75	-	0.19
Ammonia Nitrogen	0.170	0.180	0.130	0.120	0.080	-	0.170	0.100	5.20	0.120	0.100	-	
February 25-27, 1992			N	S									
Total Phosphorus (as P)	0.106	6.400	0.052	0.055	0.054	-	0.343	0.077	2.860	0.049	0.151	-	0.059
Dissolved Phosphorus (as P)	0.003	6.300	0.043	0.049	0.054	-	0.055	0.038	2.450	0.038	0.058	-	0.043
Nitrate & Nitrite Nitrogen	0.23	<0.05	0.21	0.24	0.23	0.31	<0.05	0.21	2.75	0.21	0.29	0.42	0.30
Total Kjeldahl Nitrogen	0.20	3.48	0.14	0.06	0.10	-	7.05	0.12	6.43	0.48	0.36	-	0.14
Ammonia Nitrogen	0.067	0.087	0.053	0.040	<.005	-	0.070	0.040	5.38	<0.005	0.060	-	0.090

a. Units are mg/L (data reported by Beak Associates 1991c, 1990c; SENTAR Consultants Ltd. 1992a).
b. In 1991 and 1992 the ANC Site was sampled 0.5 km downstream of effluent; N = North, S = South

TABLE B.6
Concentrations of Nutrients in the Lesser Slave River and Athabasca River[a]

Parameter[b]	Station Number and Location							
	1 Mitsue Bridge	11 Effluent Inflow	22 Upstream Otauwau	35 Upstream Saulteaux	52 Upstream Driftwood	54 Downstream Driftwood	96 Athabasca at Highway 2	97 Athabasca at Smith
October 1989								
Nitrogen								
Total Ammonia	0.008	0.006	0.006	0.009	0.005	0.007	0.005	<0.005
Kjeldahl Nitrogen	0.30	0.22	0.42	0.22	0.18	0.19	0.23	0.18
Nitrite	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrate	<0.005[b]	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Phosphorus								
Total	0.052	0.035	0.036	0.098	0.031	0.047	0.093	0.10
May 1990								
Nitrogen								
Total Ammonia	0.02	0.02	0.02	0.01	0.03	0.02	0.01	0.02
Kjeldahl Nitrogen	0.56	0.48	0.48	0.56	0.64	0.70	0.38	0.58
Nitrite	<0.003	<0.003	<0.003	0.004	0.004	0.003	<0.003	0.003
Nitrate	0.01	0.009	0.009	0.015	0.012	0.007	<0.003	0.006
Phosphorus								
Total Dissolved	0.010	0.010	0.010	0.026	0.025	0.023	0.020	0.030
Total	0.016	0.018	0.021	0.050	0.050	0.050	0.035	0.050
May 1991								
Nitrogen								
Total Ammonia	0.09	0.08	0.06	0.05	0.03	0.01	0.04	0.02
Kjeldahl Nitrogen	2.28	0.96	0.80	0.72	0.80	0.52	0.64	0.64
Nitrite	0.008	0.007	0.011	0.007	0.006	<0.003[b]	0.005	0.008
Nitrate	0.208	0.146	0.106	0.030	0.033	<0.003	0.060	0.045
Phosphorus								
Total Dissolved	0.079	0.040	0.046	0.055	0.048	0.039	0.039	0.051
Total	0.664	0.363	0.271	0.171	0.219	0.049	0.296	0.184

a. Data from EVS Consultants Ltd. 1990, 1991, 1992a
b. Units are mg/L

Notes: < = compound at levels less than detection limit
The locations of Stations 1 to 97 are shown on Figure 4.1.7.

TABLE B.7
Concentrations of Nutrients in Peace and Smoky Rivers Near Peace River[a]

Parameter[b]	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
July 1989									
Total Kjeldahl Nitrogen	0.11±0.08	0.75±0.05	0.06±0.03 L 0.94±0.05 R	0.10±0.06 L 0.88±0.22 R	0.38±0.09 L 1.00±0.09 R	0.52±0.09 L 1.20±0.09 R	0.42±0.07 L 0.54±0.07 R	0.75±0.12	0.90±0.12
Total Phosphorus	0.03±0.02	0.05±0.03	<0.01 L 0.04±0.00 R	<0.01 L 0.10±0.06 R	0.04±0.00 L 0.07±0.03 R	0.06±0.04 L 0.06±0.03 R	0.05±0.03 L 0.03±0.01 R	0.08±0.04	0.07±0.06
October 1989									
Total Kjeldahl Nitrogen	0.2	0.1	0.1 L 0.2 R	0.1 L 0.1 R	0.2 L <0.1 R		<0.1 L <0.1 R	<0.1 L <0.1 R	
Total Phosphorus	0.06	0.07	0.05 L 0.26 R	0.14 L 0.04 R	0.06 L 0.12 R		0.04 L 0.05 R	0.04 L 0.07 R	
April 1990									
Total Kjeldahl Nitrogen	0.33	0.36	0.36 L 0.39 R	0.33 L 0.47 R	0.39 L 0.33 R		0.18 L 0.33 R		
Total Phosphorus	0.53	0.43	0.53 L 0.11 R	0.53 L 0.53 R	0.45 L 0.52 R		0.53 L 0.55 R		
September 1990									
Total Kjeldahl Nitrogen	0.99	0.56	0.47 L 0.53 R	0.36 L 0.42 R	0.30 L 0.53 R	0.42 L 0.36 R	0.21 L 0.27 R		
Total Phosphorus	0.07	0.05	0.02 L 0.06 R	0.03 L 0.01 R	0.02 L 0.03 R	0.03 L 0.03 R	0.06 L 0.09 R		
April 1991									
Total Kjeldahl Nitrogen	<0.05	2.03	0.73 L 1.77 R	0.87 L 1.59 R	0.86 L 1.60 R	1.00 L 1.60 R	0.96 L 1.94 R		
Total Phosphorus	0.662	0.982	0.542 L 0.902 R	0.622 L 0.862 R	0.542 L 0.862 R	0.662 L 1.02 R	0.662 L 0.862 R		
October 1991									
Total Kjeldahl Nitrogen	0.74	0.81	0.85 L 0.89 R	0.65 L 0.71 R	0.59 L 0.86 R	0.52 L 0.73 R	0.59 L 0.74 R		
Total Phosphorus	0.091	0.067	0.068 L 0.068 R	0.060 L 0.066 R	0.069 L 0.065 R	0.068 L 0.069 R	0.060 L 0.074 R		
May 1992									
Total Kjeldahl Nitrogen	0.20	0.43	0.13 L 0.30 R	0.17 L 0.28 R	0.19 L 0.22 R	0.31 L 0.27 R	0.28 L 0.22 R		
Total Phosphorus	0.25	0.25	0.25 L 0.25 R	0.25 L 0.25 R	0.25 L 0.25 R	0.25 L 0.25 R	0.25 L 0.25 R		

a. Data from Monenco (1990a,b,d; 1991a; 1992a,b)
b. Units are mg/L

Note: L = left; R = right
The locations of sites 1 to 9 are shown on Figure 4.1.9

TABLE B.8
Concentrations of Nutrients in the Wapiti River Near Grande Prairie[a]

Parameter[b]	Control Stations[c]						Observations Stations[c]					
	C1	C2	C3	C4S	C5S	C6S	O1	O2	O3	Bear Creek	04	O5
October 1990												
Ammonia	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 C	<0.005 R <0.005 C <0.005 L	<0.005 R 0.02 C <0.005 L	<0.005 R <0.005 C 0.09 L	0.05 C	0.3 C	0.05 C	<0.005 C
Total Kjeldahl Nitrogen	0.32 C	0.32 C	0.32 C	0.35 C	0.36 C	0.41 C 0.38 C 0.42 L	0.42 R 0.41 C 0.52 L	0.44 R 0.44 C 0.57 L	0.44 C	1.68 C	0.58 C	0.64 C
Total Phosphate	0.162 C	0.156 C	0.135 C	0.129 C	0.116 C	0.109 R 0.173 C 0.099 L	0.231 R 0.241 C 0.218 L	0.195 R 0.208 C 0.185 L	0.172 C	0.181 C	0.131 C	0.128 C
Ortho-Phosphate	0.043 C	0.032 C	0.029 C	0.047 C	0.036 C	0.023 R 0.030 C 0.019 L	0.048 R 0.120 C 0.066 L	0.09 R 0.086 C 0.09 L	0.083 C	0.044 C	0.067 C	<0.060 C
April 1991												
Ammonia	0.27 C	0.03 C	0.03 R	0.1 L	0.13 C	0.1 R 0.1 C 0.27 L	0.1 R 0.1 C 0.13 L	0.13 R 0.53 C 0.17 L	0.17 R		0.13 C	0.2 C
Total Kjeldahl Nitrogen	0.27 C	0.03 C	0.19 R	0.39 L	0.35 C	0.39 R 0.24 C 0.3 L	0.21 R 0.93 C 1.07 L	0.84 R 0.84 C 0.75 L	0.7 R		0.89 C	0.86 C
Total Phosphate	0.11 C	0.11 C	0.083 R	0.39 L	0.22 C	0.13 R 0.14 C 0.08 L	0.11 R 0.33 C 0.38 L	0.28 R 0.26 C 0.28 L	0.29 R		0.34 C	0.33 C
Ortho-Phosphate	<0.005 C	<0.005 C	<0.005 R	<0.005 L	<0.005 C	<0.005 R <0.005 C <0.005 L	<0.005 R <0.005 C <0.005 L	<0.005 R <0.005 C <0.005 L	<0.005 R		<0.005 C	<0.005 C
January 1992												
Ammonia	0.136 L	<0.05 C	0.248 C	0.15 L	0.18 L	0.21 C	0.56 C	0.56 C	0.468 C		0.56 C	0.56 C
Dissolved Phosphorus	<0.05 L	<0.05 C	<0.05 C	<0.05 L	<0.05 L	<0.05 C	<0.05 C	<0.05 C	0.07 C		<0.05 C	<0.05 C
Ortho-Phosphate	<0.05 L	<0.05 C	<0.05 C	<0.05 L	<0.05 L	<0.05 C	<0.05 C	<0.05 C	0.07 C		<0.05 C	<0.05 C

a. Data from TAEM 1991a, 1992a
b. Units are mg/L; left and right banks are facing upstream
c. R = right bank; C = centre; L = left bank

Note: Locations of Stations C1 to O5 are shown in Figure 4.1.12

APPENDIX C

RIVER DISCHARGES

DURING SYNOPTIC SURVEYS

TABLE C.1
Athabasca River Discharge Balance - 1990 Synoptic Survey

Station	Alberta Environment				Water Survey of Canada		
	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)	Calculated Running Total (Athabasca R.) (m^3/s)	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)
Athabasca R. Upstream of Hinton	13/02/90		33.0		14/02/90		30.0
Weldwood of Canada Ltd. Effluent	14/02/90	0.784		33.784			
Oldman Cr. at Mouth	16/02/90	1.12		34.904			
Berland R. at Mouth	14/20/90	8.91		43.814	01/03/90	11.3	
Spring - 13.5 km downstream from Berland R.	16/02/90	0.019		43.833			
Marsh Head Cr. at Mouth	15/02/90	0.279		44.112			
Windfall Cr. at Mouth	20/02/90	0.919		45.031			
Athabasca R. at Windfall Bridge	20/02/90		49.80		20/02/90		49.8
McLeod R.	21/02/90	9.480		59.28	01/03/90	15.0	
Sakwatamau R.	21/02/90	0.931		60.211			
Whitecourt Sewage	21/02/90	0.041		60.252			
Alberta Newsprint Company Effluent		ND					
Millar Western Pulp Ltd. Effluent	20/02/90	0.136		60.388			
Freeman R.	22/02/90	0.783		61.171			
Pembina R. Near Athabasca	22/02/90	6.770		67.941			
Lesser Slave R.	07/02/90	37.0		104.941			
Athabasca R. at Athabasca	27/02/90		115		27/02/90		114
Athabasca Sewage	07/03/90	0.011		115.011			
Lac La Biche R. at Mouth	07/03/90	2.34		117.351	07/03/90	1.955	
Calling R. at Mouth	07/03/90	0.13		117.481			
Pelican R. at Mouth	07/03/90	0.75		118.231			
Athabasca R. Upstream House R.	08/03/90		125.0				
House R.	08/03/90	1.62		126.62	08/03/90	0.247	
Athabasca R. Upstream Horse R.	13/03/90		120.0				
Clearwater R.	13/03/90	58.60		185.22	13/03/90	58.8	
Ft. MacMurray Sewage	14/03/90	0.180		185.4			
Athabasca R. Downstream Ft. MacMurray					14/03/90		198
Suncor Effluent	14/03/90	0.303		185.703			
Muskeg R.	14/03/90	0.377		186.08			
Ells R.	14/03/90	1.830		187.91			
Firebag R.	15/03/90	10.2		198.11			
Richardson R.	21/03/90	14.5					

TABLE C.2
Athabasca River Discharge Balance - 1992 Synoptic Survey

Station	Alberta Environment				Water Survey of Canada		
	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)	Calculated Running Total (Athabasca R.) (m^3/s)	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Athabasca River (m^3/s)
Athabasca R. Upstream Hinton	30/01/92		47.2		30/01/92		47.2
Weldwood of Canada Ltd. Effluent	29/01/92	1.110		48.210			
Athabasca Upstream Berland R.	31/01/92		53.7				
Berland R.	31/01/92	12.3		66.0	31/01/92	12.3	
Marsh Head Cr.	04/02/92	0.359		66.359			
Athabasca R. at Windfall Bridge	04/02/92		70.8		04/02/92		70.8
McLeod R.	05/02/92	11.0		81.8	01/03/92	16.5	
Sakwatamau R.	05/02/92	1.122		82.922	01/03/92	2.95	
Whitecourt Sewage	05/02/92	0.040		82.962			
Alberta Newsprint Company Effluent	03/02/92	0.230		83.192			
Millar Western Pulp Ltd. - Effluent	04/02/92	0.14		83.332			
Pembina R.	11/02/92	4.960		88.292			
Lesser Slave R.	12/02/92	15.1		103.392			
Athabasca R. Downstream Lesser Slave R. (Smith)	12/02/92		92.7				
Athabasca Upstream Hwy 813	14/02/92		87.5		14/02/92		87.6
Athabasca Sewage	14/02/92	0.010		87.51			
Lac La Biche R.	18/02/92	1.260		88.77	18/02/92	1.008	
Calling R.	18/02/92	0.047		88.817			
Pelican R.	10/02/92	0.450		89.267			
Athabasca R. Upstream House R.	24/02/92		71.7				
House R.	24/02/92	1.430		73.13	01/03/92	0.831	
Athabasca R. Upstream Horse R.	25/02/92		81.1				
Clearwater R.	25/02/92	48.8		129.9	25/02/92	48.8	
Ft. MacMurray Sewage	25/02/92	0.140		130.04			
Athabasca R. Downstream Ft. MacMurray					25/02/92		135
Suncor Effluent	25/02/92	0.280		130.32			
Muskeg R.	27/02/92	0.489		130.809	01/03/92	0.480	
Ells R.	27/02/92	1.750		132.559			
Firebag R.	06/03/92	9.890		142.449	10/03/92	10.1	
Richardson R.	06/03/92	12.0					

TABLE C.3
Balanced Flows for the Athabasca River System

Site	Date (D-M-Y)	Mean Daily Discharge (cm)
Athabasca Upstream Hinton	06-02-91	51.7
Athabasca at Obed	06-02-91	51.9
Berland	08-02-91	12.2
Marshead Creek	09-02-91	0.323
Athabasca at Windfall	10-02-91	65.0
Sakwatamau	11-02-91	0.934
McLeod	11-02-91	10.3
Freeman	12-02-91	0
Athabasca at Ft. Assiniboine	13-02-91	79.2
Pembina	17-02-91	5.78
Athabasca Upstream Smith	19-02-91	86.7
Lesser Slave Lake at Mouth	19-02-91	17.5
Athabasca at Athabasca	23-02-91	105
Labiche	26-02-91	1.89
Calling	26-02-91	0.03
Pellican	26-02-91	0.295
Athabasca Above House River	05-03-91	108
House River	05-03-91	1.14
Athabasca Above Horse River	09-03-91	110
Clearwater	09-03-91	41.2
Athabasca Below McMurray	10-03-91	152
Muskeg	10-03-91	0.262
Ells	11-03-91	TRACE
Firebag	12-03-91	9.81
Athabasca at Old Fort	12-03-91	163
Richardson River	16-03-91	15.0
Athabasca at Winter Road	16-03-91	178
Athabasca at Mouth	18-03-91	

This table was prepared by the Hydrology Branch, Alberta Environment.

TABLE C.4
Wapiti-Smoky Rivers Discharge Balance - 1990

Station	Alberta Environment						Water Survey of Canada			
	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Wapiti River (m^3/s)	Calculated Running Total (Wapiti R.) (m^3/s)	Smoky River (m^3/s)	Calculated Running Total (Smoky R.) (m^3/s)	Date (D/M/Y)	Tributary/ Effluent (m^3/s)	Wapiti River (m^3/s)	Smoky River (m^3/s)
Wapiti R. at Hwy 40	27/02/90		13.0				27/02/90		13.6	
Grande Prairie Sewage	27/02/90	0.230		13.230						
Big Mountain Cr.	27/02/90	0.172		13.402						
Weyerhaeuser Effluent	27/02/90	0.516		13.918						
Weyerhaeuser Storm Sewer	28/02/90	0.048		13.966						
Smoky R. Upstream Wapiti R.	01/03/90				24.7					
Smoky R. Downstream Wapiti R.						38.666				
Simonette R.	02/03/90	3.160				41.826	02/03/90	3.18		
Puskwaskau R.	07/03/92	0.341				63.469				
Little Smoky R.	06/03/90	15.0				63.81	07/03/90	10.4		
Bad Heart R.	07/03/90	2.190				78.81				
Smoky R. at Watino	08/03/90				81.0		07/03/90			78.6

APPENDIX D

PERIODIC MUNICIPAL DISCHARGERS

APPENDIX D. Periodic Municipal Dischargers.

NAME	LICENSE_NO	DRAINAGE BASIN	DISCHARGE SEASON	WATER BODY CONNECTION
Atikameg School	86-ML-043 R1(91)	Peace	fall	Utikama Lake
Bear Canyon	NO LICENCE	Peace		
Beaverlodge	86-ML-003 R3(93)	Peace	spring/fall	minor tributary - Beaverlodge River
Berwyn	81-ML-042 R2(92)	Peace	fall	Peace River - via road ditch
Bezanson	87-ML-129 R1(92)	Peace	spring	minor tributary - Smoky River (upstream of confluence with Little Smoky River)
Bishop Routhier School		Peace		
Blue Ridge	81-ML-047 R1(89)	Athabasca	fall	minor tributary - Bull Creek, then to the Athabasca River
Bluesky	78-ML-007 R2(92)	Peace	fall	minor tributary - Chocolate Creek, then to the Burnt River
Boyle	81-ML-005 R3(93)	Athabasca	spring/fall	Flat Lake - via minor tributary
Cleardale	91-ML-046	Peace	fall	major tributary - Clear River
Colinton	80-ML-028 R2(93)	Athabasca	fall	major tributary - Tawatinaw River
Deadwood School	80-ML-084	Peace		
Debolt	81-ML-008 R1 (88)	Peace	fall	minor tributary - Debolt Creek
Dixonville	85-ML-046 R1(91)	Peace	fall	minor tributary - Whitemud River via drainage course
Donelly	86-ML-039 R1(91)	Peace	fall	minor tributary - Peavine Creek
Eaglesham	89-ML-035	Peace	spring/fall	Peace River - via farmer's field and road ditch
Enilda	89-ML-064	Athabasca	fall	minor tributary - Arcadia Creek to Lesser Slave Lake
Entwistle	78-ML-053 R2(93)	Athabasca	spring/fall	minor tributary - Pembina River
Evansburg	80-ML-077 R2(93)	Athabasca	spring/fall	minor tributary - Lobstick River, then to the Pembina River
Evergreen Park (Gr. Prairie)	90-ML-002	Peace	fall	
Fairview	80-ML-044 R2(90)	Peace	spring/fall	primary tributary - Boucher Creek, then to Peace River
Falher	78-ML-015 R2(91)	Peace	fall	minor tributary - Peavine Creek, then to Little Smoky River
Faust	78-ML-038 R1(89)	Athabasca	fall	primary tributary - unnamed creek, then to Lesser Slave Lake
Footner Lake Forestry Site	87-ML-010 R1(92)	Peace	fall	Footner Lake
Fort Assiniboine	78-ML-006 R1(90)	Athabasca	spring/fall	Athabasca River
Fort McKay	89-ML-072	Athabasca	fall	Athabasca River
Fort Vermillion	80-ML-013 R2(91)	Peace	spring/fall	Peace River
Fox Creek	86-ML-068 R1(91)	Peace	spring/fall	minor trib - Iosegun L, then Iosegun R., then Little Smoky R. then to Peace R.
Gift Lake	86-M2-054	Peace		
Girouxville	85-ML-051 R1(91)	Peace	fall	minor tributary - unnamed creek to Little Smoky River
Grande Cache Forest Industries	87-WL-109	Peace		
Grande Prairie Airport	88-ML-029 R1 (93)	Peace		
Grandview Hutterite Colony		Peace		Bear Lake
Grassland	80-ML-012 R3(93)	Athabasca	fall	minor tributary - unnamed creek, to Pine Creek, then to La Biche River
Gregoire Lake Prov. Park	81-ML-009 R1 (89)	Athabasca	fall	minor - Gregoire Lake
Grimshaw	86-ML-041 A1(87) R1(90)	Peace	fall	Peace River - via drainage course

APPENDIX D. Periodic Municipal Dischargers.

NAME	LICENSE_NO	DRAINAGE BASIN	DISCHARGE SEASON	WATER BODY CONNECTION
Grouard	87-ML-024 R1(92)	Athabasca	fall	Lesser Slave Lake via drainage ditch
Guy	87-ML-007 R1(92)	Peace	fall	major tributary - Little Smoky River
High Level	81-ML-034 R2(92)	Peace	spring/fall	minor tributary - Bushe River
High Prairie	78-ML-041 R2(91)	Athabasca	spring/fall	secondary trib - West Prairie R, to S. Heart R, then to Lesser Slave L
Hines Creek	80-ML-085 R2(91)	Peace	fall	minor tributary - Jack Creek
Hythe	78-ML-039 R2(92)	Peace	spring/fall	minor tributary - Beaverlodge River
Janvier School	86-MP-048 R1 (91)	Athabasca		
Jean Cote	87-ML-006 R1(92)	Peace	fall	minor tributary - Little Smoky River
Joussard	85-ML-043 R1(91)	Athabasca	fall	minor tributary - Mission Creek to Lesser Slave Lake
La Crete	86-ML-061 R1(91)	Peace	fall	drainage course to a slough area
La Glace	86-ML-006 R1(91)	Peace	fall	minor tributary - Mulligan Creek to Bear River
Loon Lake School	93-ML-031	Peace	fall	secondary tributary - Loon River, to Wabasca River to Peace River
Mayerthorpe	78-ML-042 R2(92)	Athabasca	spring/fall	minor tributary - Little Paddle River, then to the Paddle River
McLennan	86-ML-007 R1(91)	Peace	spring/fall	Kimiwan Lake
Nampa	85-ML-016 R1(90)	Peace		
Nose Creek School		Peace		minor - Nose Creek
Peace River Airport		Peace		
Peerless Lake School	87-ML-111 R1(92)	Peace		
Peoria	87-ML-009 R1(92)	Peace		
Pibroch	85-ML-015 R1(90)	Athabasca	spring	minor tributary - drainage ditch to Bath Creek, then to the Pembina River
Pine Shadow Estates	88-ML-092	Athabasca	fall	minor tributary - unnamed tributary to the McLeod River
Queen Elizabeth Prov. Park		Peace		
Ridge Valley	86-ML-050 R1(91) A1(91)	Peace	fall	minor tributary - Cornwall Creek to Wapiti River
Robb	80-ML-076 R2(91)	Athabasca	spring/fall	minor tributary - Hay Creek, then to the Embarras River
Rycroft	80-ML-033 R1(91)	Peace	fall	minor tributary - Spirit River
Sangudo	80-ML-050 R1(89) A1(91)	Athabasca	spring/fall	minor tributary - Pembina River
Sexsmith	78-ML-037 R1(93)	Peace	spring/fall	
Shell-Peace River In-Situ	89-WL-030 (Closed)	Peace		
Spirit River	80-ML-043 R2(90)	Peace	fall	minor tributary - Rat Creek then to Spirit River(?) then to Peace River
St. Isadore	89-ML-007	Peace	fall	minor tributary - unnamed creek, then to the Peace River
Swan Hills	80-ML-004 R3(92)	Athabasca	spring/fall	tertiary trib - Morse Cr, then Morse R, then Freeman R, then to Athabsca R
Triple L Mobile Home Park	87-ML-133 R1 (93)	Peace	fall	minor tributary - Five Mile Creek
Trout Lake School		Peace		
Valleyview	86-ML-021 R2(92)	Peace	fall	tertiary trib - unnamed cr, to Sturgeon Cr, to Smoky R, to Peace R
Wandering River	86-ML-009 R1(91)	Athabasca	fall	primary tributary - La Biche River to Athabasca River
Wanham	86-ML-044 R1(91)	Peace	fall	minor tributary - Saddle River

APPENDIX D. Periodic Municipal Dischargers.

NAME	LICENSE_NO	DRAINAGE BASIN	DISCHARGE SEASON	WATER BODY CONNECTION
Wembley	80-ML-040 R2(90)	Peace	spring/fall	minor trib - unnamed Cr, to Ringling L, to Wapiti R, to Smoky R, to Peace R
Westlock	80-ML-052 R2(92)	Athabasca	fall	secondary tributary - Wabash Cr, then Pembina R, then to Athabasca R.
Westwind Mobile Home Park	92-ML-046	Athabasca	fall	minor tributary - Muskeg Creek, then directly to the Athabasca River
Whitelaw	81-ML-033 R2(92)	Peace	fall	major tributary - Leith River
Wildwood	81-ML-048 R1(89) A2(91)	Athabasca	fall	secondary tributary - Lobstick River to Pembina R, then to Athabasca R.
Woking	81-ML-046 R2(92)	Peace	fall	minor tributary - drainage course to Braeburn Creek, then to the Saddle River
Worsley	86-ML-019 R1(92)	Peace	fall	tertiary tributary - unnamed creek, to Eureka River, to Clear River, to Peace R
Young's Point Provincial Park	81-ML-025 R1(90)	Peace	fall	minor tributary - Eagle Creek to Sturgeon Lake

APPENDIX E

TERMS OF REFERENCE

NORTHERN RIVER BASINS STUDY

SCHEDULE A - TERMS OF REFERENCE

PROJECT 2601-B1 Nutrient Data Compilation and Review

I. Objective

The objective of this project is to produce a comprehensive review and synthesis of existing information (literature and data) on nutrient loading (nitrogen and phosphorus), sediment oxygen demand and biotic communities for the Peace (including the Wapiti and Smoky), Athabasca and Slave river systems to define and identify commonalities in the impacts of nutrient loading from various point sources.

II. Requirements

A. Data Collection

1. Obtain existing data on nutrients (N and P) in the study area, screen it for acceptability and compile. Where appropriate, review and evaluate any raw data. Review existing reports relevant to nutrients in the study area rivers. Identify any data bases including their form (i.e. electronic or hardcopy). The Northern River Basins Study Office will assist the Contractor in obtaining relevant data and reports from Alberta Environment.

2. Obtain and compile data and review existing reports on aquatic biota (the benthic biofilm and invertebrates) in the study area relevant to nutrient effects. Identify all databases including their form (i.e. hardcopy or electronic). The Northern River Basins Study Office will assist the Contractor in obtaining relevant data and reports from Alberta Environment.

3. Where appropriate, comment on the quality of the data, quality control/quality assurance measure, experimental design, including methods and replication, and statistical analysis.

B. Annotated Bibliography

1. produce an annotated bibliography of databases, government and non-government reports, journal papers, books, book chapters, student theses, etc. on nutrient loading relevant to the study rivers and its impact on water and sediment chemistry, aquatic organisms and aquatic habitats.

C. Synthesis Report

1. Based on the information reviewed in 1, above, prepare a comprehensive synthesis report on nutrient loading and its effects on the environment in the Peace, Athabasca and Slave river systems. The report should include the following:

   - a description of existing nutrient conditions in the river systems with regard to concentrations, fractions, seasonality, longitudinal change and temporal change (trends);
   - to the extent possible, provide a description of nutrient sources from headwaters, tributaries, effluents, and instream/diffuse inputs or sinks;
   - to the extent possible, provide a discussion of the existing or potential effects of nutrient loading on the aquatic environment (water and sediment chemistry, aquatic organisms, aquatic habitats, etc.);
   - identify any data deficiencies;
   - outline data requirements to construct a nutrient budget for the northern river systems, and;
   - analyze the data to identify commonalities between nutrient impacts from various point sources on sediment chemistry, and benthic biofilm and invertebrate communities.

   The report will be produced in consultation with members of the Northern River Basins Study Nutrients Group (Dr. Patricia Chambers, Nutrient Group Leader).

III. Reporting Requirements

1. Provide ten draft copies of the annotated bibliography to the Department's representative by March 15, 1993.

2. Three weeks after receipt of review comments on the draft annotated bibliography, provide the Department's representative with five serlox bound copies and two unbound, camera ready copies of the final report. At the same time, provide to the Department's representative an electronic copy, in WordPerfect V5.1 format, and on 5 1/4 or 3 1/2 inch floppy discs, of the final report. Data for any tables, figures or appendices in the report are also to be submitted in DBase IV format on 5 1/4 or 3 1/2 floppy discs. The final report will include an executive summary.

3. By January 15, 1993, provide the Department's representative and Nutrients Group Leader with an outline for the synthesis report. Based on the review of the draft outline, prepare a draft synthesis report.

4. By March 15, 1993, provide the Department's representative with ten draft copies of the synthesis report.

5. Three weeks after receipt of review comments on the draft synthesis report, provide the Department's representative with five serlox bound copies and two unbound, camera ready copies of the final report. At the same time, provide to the Department's representative an electronic copy, in WordPerfect V5.1 format, and on 5 1/4 or 3 1/2 inch floppy discs, of the final report. Data for any tables, figures or appendices in the report are also to be submitted in DBase IV format on 5 1/4 or 3 1/2 floppy discs. The final report will include an executive summary.

6. Provide the Department's representative with Lotus 1-2-3 files of any databases created or obtained during the course of this project.