ASSINIBOINE RIVER WATER QUALITY STUDY

NITROGEN AND PHOSPHORUS DYNAMICS
MAY 2001 TO MAY 2002

By Nicole Armstrong
Water Quality Management Section,
Water Branch
Manitoba Conservation

November 2002

Manitoba Conservation Report No. 2002-10

Manitoba
Building for the Future

Manitoba Conservation Report No. 2002-10

November 2002

ASSINIBOINE RIVER WATER QUALITY STUDY

NITROGEN AND PHOSPHORUS DYNAMICS
MAY 2001 TO MAY 2002

Nicole Armstrong

Water Quality Management Section
Water Branch
Manitoba Conservation

Manitoba
Building for the Future

Printed on Recycled Paper

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author gratefully acknowledges field support from E. Shipley, A. Frezghi, D. Fehr, I. Currie, G. Jones, C. Hughes, A Bourne, B. Webb, and P. Blahut. Helpful discussions regarding data collection and analysis were held with the members of the Assiniboine River Water Quality Co-ordination Team.

INTRODUCTION

The Assiniboine River flows from its headwaters in eastern Saskatchewan into and across the western portion of Manitoba to its eventual confluence with the Red River within the City of Winnipeg. The Assiniboine River watershed is relatively large, encompassing an area of about 41,500 km^2 (not including the Qu'Appelle and Souris River basins which are generally considered separately). Roughly 60 % (24,900 km^2) of the watershed is within the province of Manitoba and drains an area dominated by agriculture and populated with about 100,000 people, excluding those in the City of Winnipeg. The Assiniboine River itself is used for recreational activities such as boating, canoeing, water skiing, fishing, and swimming. The river provides essential habitat for about 40 species of fish and its shoreline supports numerous plant and animal species. Water drawn from the river is used for irrigation and for facilities such as food processing industries, and is the drinking water source for the cities of Brandon and Portage la Prairie. The Assiniboine River is also the recipient of treated effluent from a number of municipal and industrial wastewater treatment facilities. With many values and uses, the Assiniboine River is a valuable resource.

Nutrient enrichment or eutrophication is one of the most serious water quality issues in western Canada. High concentrations of plant nutrients, in particular nitrogen and phosphorus, can result in an increase in the occurrence and extent of algal blooms, corresponding with an overall decrease in aquatic biodiversity. Algal blooms in a drinking water source can clog treatment plant filters, and impart an unpleasant taste, odour, and appearance to finished water. Treatment of such water for drinking purposes can be very expensive and may prove to be cost prohibitive for some water utilities. Blooms of blue-green algae species, many of which produce potent nerve and liver toxins, may become more common under eutrophic conditions, and consumption of waters during and following such blooms presents a health risk for humans, household pets, and livestock (Carmichael 1991). There is also evidence that the toxins produced by blue-green algae can bioaccumulate and thus be transferred through the aquatic food web (Kotak 1995). Algal blooms and extensive macrophyte growth are also considered aesthetically unappealing and can detract from the recreational use of surface water. The die-off and subsequent decay of algal blooms and macrophyte vegetation consumes dissolved oxygen, leading to extensive fish kills. Increased development within the Assiniboine River basin has lead to questions regarding the ability of the river to assimilate point and non-point source nutrient loads from industrial, municipal, and agricultural sources.

In response to questions regarding development along the Assiniboine River, two major studies were undertaken on the lower reaches of the Assiniboine River (Cooley *et al.* 2001a,b, and North/South Consultants Inc. and Earth Tech (Canada) Inc. 2002). Both studies address the effect of nitrogen and phosphorus inputs on the growth of algae and the associated impacts on downstream water uses. Together these studies cover most of the Assiniboine River between the City of Brandon and its confluence with the Red River. In addition, considerable historical data exist on this same reach of the Assiniboine between the cities of Brandon and Winnipeg (Manitoba Conservation 2002). However, the Assiniboine River between the Saskatchewan border and Brandon has received very little attention despite indications that water quality in the downstream portion is greatly dependent on conditions just upstream of Brandon (Cooley *et al.* 2001a).

Therefore, the upstream portion of the Assiniboine River between Lake of the Prairies and the City of Brandon was studied with the following objectives: 1) to quantify phosphorus and nitrogen loading (both seasonally and longitudinally) to the Assiniboine River from the headwaters at Lake of the Prairies, and the three main tributaries in the upstream reach; 2) to determine the total nitrogen and phosphorus load in the Assiniboine River just upstream of the City of Brandon; 3) to estimate nitrogen and phosphorus export from the watershed; and, 4) to examine potential variables limiting algal production in the Assiniboine River.

METHODS

Fifteen stations were selected along the Assiniboine River between the outlet of Lake of the Prairies and the City of Brandon (Figure 1 and Table 1). Water is released from Lake of the Prairies via a 4.6 m diameter conduit located approximately 3 m from the bottom. Three additional stations were selected on the major tributaries in this reach of the Assiniboine River: Qu'Appelle River, Birdtail Creek, and Little Saskatchewan River. All stations were selected, where possible, to correspond to Water Survey of Canada or Manitoba Conservation (Water Branch) river gauging stations. In addition, stations were selected both upstream and downstream of major and minor

(Gopher Creek, Arrow River) tributary inputs. River distances between stations were calculated with data from Prairie Farm Rehabilitation Administration (1980 revised 1990).

During the ice-free season (May to November), water samples were collected every two weeks at each of the 15 stations along the Assiniboine River from the most upstream site at Lake of the Prairies to the City of Brandon, and from the three tributary stations. With the exception of dissolved oxygen (DO), water samples were collected where possible by a weighed bucket dropped mid-stream from a roadway bridge. Where stations did not correspond with a roadway bridge, samples were collected with a sampling pole from the shoreline. At all times, DO samples were collected with a sampler designed to minimise the production of oxygen bubbles during collection.

During the period of ice cover (December to April), the number of sampling stations on the Assiniboine River was reduced from 15 to nine due to poor winter access at some stations. All three major tributaries were also sampled. Water samples were collected from an 20 cm hole drilled with a needle bar or ice auger. Ice thickness varied from between 30 to 100 cm depending on time of year and location.

After collection, water samples were dispersed into various sized bottles and kept on ice in the dark until delivery at CANTEST Ltd. Profession Analytical Services approximately 24 hours later. Chemical analyses were conducted for pH, turbidity, organic (OP) and inorganic phosphorus (as total reactive phosphorus, InorgP), total (TP), dissolved (DP) and particulate phosphorus (PP), ammonia-N (NH3), nitrate-nitrite-N (NO3NO2), total kjeldahl nitrogen (TKN), DO, biological oxygen demand (BOD), and phytoplankton biomass (as chlorophyll *a*, chla). Total organic nitrogen (ON) was calculated as the difference between TKN and ammonia-N. Total inorganic nitrogen (InorgN) is the sum of NO3NO2 and NH3. Total nitrogen (TN) was estimated as the sum of TKN and NO3NO2. Nutrient limitation was assessed with TN to TP ratios where ratios less than 10 suggest potential nitrogen limitation, ratios greater than 20 suggest phosphorus limitation, and ratios between 10 and 20 suggest periods of either nitrogen or phosphorus limitation (Redfield et al. 1963, Borchardt 1996). Temperature was measured at each site with a mercury thermometer and was recorded along with the time of collection.

Total nitrogen and phosphorus loads were calculated for stations at the beginning (Assiniboine River at the outlet of Lake of the Prairies) and end (Assiniboine River just upstream of

Brandon at the Trans Canada Highway) of the study area, and on the three main tributaries to the Assiniboine River in this reach (Qu'Appelle River at Welby, Birdtail Creek at Birtle, and Little Saskatchewan River at Rivers). Daily or weekly flow averages ($m^3 \cdot s^{-1}$) obtained from Water Survey of Canada or Manitoba Conservation (Water Branch) were converted to $m^3 \cdot d^{-1}$ and multiplied by the average TN or TP concentration ($mg \cdot L^{-1}$) during that time period. The load of TN or TP ($kg \cdot d^{-1}$) in the Assiniboine River at the beginning of the study area was added to the tributary loads to provide an estimate of total measured TN or TP load ($kg \cdot d^{-1}$). Loads of TN and TP determined for each time period of available water quality data were multiplied by the total time period and summed to produce estimates of annual TN and TP load ($kg \cdot y^{-1}$) within the study area. Remaining calculations were done for both daily (for examination of seasonal trends in loading) and annual data (for determination of annual loading rates and export coefficients). Total measured TN or TP load was subtracted from the TN or TP load measured in the Assiniboine River at the end of the study area (City of Brandon) for an estimate of non-measured TN or TP load. Non-measured TN or TP load includes inputs from minor tributaries not included in the loading calculations due to a lack of flow data (Gopher Creek, Arrow River), stream bank/bed erosion, inputs from point sources such as wastewater treatment lagoons and industrial facilities, and non-point source inputs from land runoff. Calculations were repeated as above to determine loads of the various N and P fractions (OP, inorgP, ON, inorganic N).

An estimate of the nutrient load from wastewater treatment facilities to the Assiniboine River watershed was calculated. Eleven wastewater facilities were located within the study area that discharge to the Assiniboine River or to surface waters that flow into the Assiniboine River. Wastewater facilities that discharge to land were not included. Population served by the facility was estimated as the entire community population obtained from Statistics Canada (2001) or from the province of Manitoba's community profiles (Manitoba Intergovernmental Affairs 2002). Communities too small to be included in Statistics Canada estimates and not available on the Manitoba Community profiles were estimated at 200 people. Estimates of TN and TP load from each facility were calculated with population served by the facility, Chambers *et al.'s* (2001) estimates of N and P load/capita/d and literature estimates of treatment efficiencies as in Bourne *et al.* (2002) (Appendix 1).

Nutrient export from the study area (Water Survey of Canada watersheds 05ME and 05MG) was estimated for TP, TN, inorgP, OP, inorgN, and ON. The total annual load of each nutrient

($kg \cdot y^{-1}$) at the beginning of the study area (Shellmouth) was subtracted from the load at Brandon. The input load from the Qu'Appelle and Little Saskatchewan Rivers were also subtracted because these watersheds were not included in the study area. The nutrient load acquired between Lake of the Prairies and the City of Brandon was then divided by the area of the watershed as determined with ArcView (Version 3.2) and Water Survey of Canada watershed shape files.

Land use within the study area was examined with GIS shape files prepared by the Manitoba Remote Sensing Centre and the Manitoba Land Initiative. Land use data were available for approximately 82 % of the study area as defined by Water Survey of Canada watersheds 05ME and 05MG. Approximately 80 % of the study area with land use data was related to agricultural activities with 51 % dedicated to cropland, 26 % to grasslands/pasture land, and 3 % to perennial forage (alflafa and clover) and fall seeded crops such as winter wheat or fall rye. Remaining land use data within the watershed, and the classification descriptions are found in Table 2 and Appendix 2, respectively.

Weather data were obtained from the Environment Canada (2001) station at Shoal Lake (50°27'N, 100°36'W) - the closest station with a full suite of climate data required for further water quality modelling work (dry bulb temperature, tipping bucket rain gauge precipitation, wind, and relative humidity).

RESULTS

Phosphorus in the Assiniboine River

Trends in phosphorus concentration in the Assiniboine River at Lake of the Prairies likely reflect water characteristics at the bottom of the lake since flow comes directly from a conduit only 3 m from the sediment surface. Total phosphorus concentrations ranged between 0.049 and 0.175 $mg \cdot L^{-1}$ (Table 3) during 2001 to 2002 with the highest concentrations observed during September and October (Figure 2). Higher concentrations of inorgP and DP were also observed during this time period as compared to the rest of the study. Particulate phosphorus, colour, turbidity, and TSS were not elevated during the fall as compared to late spring-early summer suggesting that sediment resuspension was not responsible for the elevated TP concentrations. Concentrations of NH3 were also relatively high during this period, particularly in late August and September (Figure 3), and were accompanied by relatively low NO3NO2 concentrations. Anoxic conditions may have existed during late summer-early fall near the lake sediment surface resulting in high rates of denitrification, low rates of nitrification and release of DP, inorgP from the reservoir sediments. Dissolved oxygen concentrations at the bottom of the lake cannot be assessed as turbulent flow through the dam greatly increases the oxygen concentration of samples taken at the outlet. However, a previous study by Fortin and Gurney (1997) found little evidence of oxygen or temperature stratification during the fall period. Weather conditions during Fortin and Gurney's 1991 to 1993 study may not have been conducive to the development of anoxic conditions as compared to conditions during this study. Nevertheless, the most upstream station on the Assiniboine River displays typical hypolimnetic rather than lotic seasonal trends in phosphorus.

Hypolimnetic trends observed in the Assiniboine River just downstream of Lake of the Prairies were not evident just 46 km downstream at Russell. Elevated concentrations of dissolved nutrients (NH3, DP, SRP) observed just downstream of Lake of the Prairies were rapidly depleted over the 46 km reach of the Assiniboine River between Lake of the Prairies and Russell. In late August, NH3, SRP and DP decreased 79, 69, and 62 % respectively, between Lake of the Prairies and Russell. Light penetration was greater just downstream of Lake of the Prairies as compared to Russell (average turbidity for late August-late October was three times higher at Russell) and large cobble lined the streambed. An epilithic algal community was present just downstream of Lake of the Prairies – a phenomenon that did not exist at any other of the sampling stations on the Assiniboine River. Epilithic algae were likely thriving on high nutrient concentrations released from Lake of the Prairies and thereby provided considerable uptake of dissolved nutrients. Low turbidity and shallow depth allowed light to penetrate to the bottom providing adequate light for photosynthesis. While the remaining stations on the Assiniboine River may have adequate nutrients for development of a benthic algal community, median turbidity was on average seven times greater as compared to just downstream of Lake of the Prairies suggesting that light may limit algal growth.

All stations downstream exhibit different seasonal trends in phosphorus as compared to the Assiniboine River at Lake of the Prairies. Total phosphorus concentrations were highest during spring and early summer 2001, and declined through late summer, fall and winter (Figure 4). Generally, inorgP concentrations mirrored fluctuations in TP concentration. Total phosphorus concentrations then peaked again in spring 2002. Throughout most of the study, TP and inorgP concentrations increased downstream (Figure 5). Total phosphorus concentrations in the

Assiniboine River at Brandon were on average about 70 % higher than those observed at the outlet of Lake of the Prairies (average TP 0.159 mg·L^{-1}). However, longitudinal trends were less obvious during the ice-covered season (Figure 6) and the trend of increasing downstream phosphorus concentration was actually reversed during the period of high phosphorus release from Lake of the Prairies (September-November). Total phosphorus concentrations were on average 46 % higher just downstream of Lake of the Prairies as compared to at Brandon during September to November (Figure 7). Also, near the end of June, a dramatic spike in TP concentration was observed near the downstream end of the Assiniboine River, just upstream of Virden, and continued through to Brandon where TP concentrations were 1000 times higher than at Lake of the Prairies. The spike appeared to coincide with the end of a three-day rainfall event and yet was not observed in a sample collected just two hours earlier about 73 km upstream (at Miniota). While in general, there was a gradual increase in phosphorus concentration in the Assiniboine River between Lake of the Prairies and the City of Brandon, reservoir anoxia, precipitation, and the presence or absence of ice cover influenced both spatial and temporal patterns.

Nitrogen in the Assiniboine River

In contrast with phosphorus, temporal and spatial trends in nitrogen concentration in the Assiniboine River were less clear. At the upstream end of the Assiniboine River at Lake of the Prairies, TN concentrations appeared to peak in late spring, late summer and late winter with spring and summer peaks associated with increased ON, and winter peaks with increased inorgN (Figure 2). Inorganic N (NH3 and NO2NO3) concentrations fluctuated throughout the season with NH3 concentrations peaking in September and late February, perhaps corresponding to periods of anoxia and high decomposition at the bottom of Lake of Prairies. High concentrations of NO2NO3 observed several weeks after the peaks in NH3, and corresponding to decreased NH3 concentration, suggest that rates of nitrification were high. In contrast with longitudinal trends in phosphorus, seasonal patterns in nitrogen persist past the station at Russell, about 46 km downstream.

Seasonal fluctuations in TN concentration on the Assiniboine River downstream of Russell were dramatically different between stations with peaks and declines occurring at different times of the year (e.g. Figures 8 and 9). However, most of the variability appeared to be associated with fluctuations in ON as clear patterns in inorgN were evident. In general, both NH3 and NO2NO3 concentrations remained relatively low until late December after which concentrations of both begin to rise, with NH3 peaking in late January and NO3NO2 peaking in late April. Nitrate-nitrite concentrations then plummeted in May, in combination with a dramatic decline in flows (Figure 10). As with phosphorus, a small peak in both NH3 and NO2NO3 concentrations occurred in late June at the most downstream stations after an intense three-day rainfall. Another small peak in NO2NO3 concentration also occurred in late July in the upstream reaches of the Assiniboine River. While some variations were observed, the lower reaches of the Assiniboine River tended to have dramatically fluctuating ON concentrations, and relatively low and stable inorgN concentration during the ice-free season with higher concentrations observed under ice-cover.

Longitudinal trends in nitrogen concentration contrasted to those observed for phosphorus concentration in the Assiniboine River. Concentrations of TN and inorgN in the Assiniboine River during the ice-free period remained constant or decreased slightly between Lake of the Prairies and the City of Brandon (Figure 11). Any point or non-point sources of nitrogen appeared to be rapidly depleted possibly due to biological uptake and losses through denitrification. In general, uptake of nitrogen during the ice-free season within the Assiniboine River exceeded inputs. Total nitrogen concentrations were also relatively constant longitudinally during the period of ice cover. However, inorgN concentrations increased on average over 100 % in the Assiniboine River between Lake of the Prairies and Brandon during the ice-covered period (Figure 12). Perhaps reduced demand for inorgN from the biological community during winter allowed nitrogen inputs to build up within the river. In addition, losses to the atmosphere (i.e. through denitrification) would be expected to be zero during the ice-covered period.

Nitrogen to Phosphorus ratios in the Assiniboine River

Total nitrogen to phosphorus ratios in the Assiniboine River varied both spatially and temporally. At the most upstream site on the Assiniboine River at Lake of the Prairies, periods of potential nitrogen (<10) and phosphorus (>20) limitation occurred (Figure 13). Total nitrogen to phosphorus ratios of less than 10 occurred during September to November when TP concentrations were relatively high and during April 2001 and 2002 when TN concentrations were relatively low. Periods when ratios were above 20 occurred in both summer and winter and coincided with relatively high TN concentrations. Just 46 km downstream on the Assiniboine River at Russell, low TN:TP ratios (<10) occurred through most of the spring, summer and fall (Figure 14). A dominance of low TN:TP ratios continued downstream with the number of periods with low

TN:TP ratios increasing, and the occurrence of ratios above 20 decreasing. In the Assiniboine River at Brandon, TN:TP ratios were below 20 at all times during the study (Figure 15). A polynomial relationship existed between average TN:TP ratio at each station and distance from Brandon such that minimum TN:TP ratios were observed just upstream of Gopher Creek at about 145 km upstream from Brandon (Figure 16, r2=0.84, P<0.0001). Overall, median TN:TP ratios were higher during ice-cover as compared to ice-free conditions (P<0.0001). While temporal trends in TN:TP ratio appeared to vary between stations, a strong decreasing trend in TN:TP ratio was observed on the Assiniboine River between Lake of the Prairies and the City of Brandon.

Assiniboine River Tributaries: Qu'Appelle River, Birdtail Creek, Little Saskatchewan River

Seasonal trends in phosphorus concentrations in the three major tributaries to the Assiniboine River within the study area were quite similar (Figures 17, 18 and 19). Total phosphorus concentrations were highest during spring runoff and summer but declined in fall and winter. In Birdtail Creek and the Little Saskatchewan River, seasonal trends in inorgP concentrations mirrored those of TP. However, in the Qu'Appelle River, inorgP concentrations remained relatively consistent suggesting that peaks in TP were associated with OP and possibly algal biomass. In fact, algal biomass (as estimated by chla) in the Qu'Appelle River was correlated to OP ($r^2 = 0.496$, $P = 0.001$) but not inorgP ($r^2 = 0$, $P = 0.9710$) during the study period.

As in the Assiniboine River, seasonal TN concentrations fluctuated dramatically while inorgN concentration showed similar patterns in all three major tributaries (Figures 20, 21 and 22). NH3 and NO2NO3 concentrations were relatively low throughout the spring, summer, and fall of 2001 but rose during the winter of 2002. Ammonia concentrations dropped dramatically in late April, while NO2NO3 concentrations dropped two weeks later in early May. Inorganic nitrogen concentrations in Birdtail Creek and the Little Saskatchewan River also peaked slightly during the fall. As with the Assiniboine River, large fluctuations in TN concentration in the three major tributaries appeared to be associated with fluctuations in organic rather than inorganic N.

Nutrient Loading to the Assiniboine River

Total phosphorus load contributed by the three major tributaries to the Assiniboine River also fluctuated seasonally (Figure 23). From the beginning of the study in late May until the end of October, the Little Saskatchewan River contributed the largest TP load to the Assiniboine River

($kg \cdot d^{-1}$), followed by the Qu'Appelle River and Birdtail Creek, respectively. However, throughout the winter until early April, the Qu'Appelle River contributed the largest TP load, followed by the Little Saskatchewan River and Birdtail Creek. By April, the Little Saskatchewan River again contributed the largest proportion of TP load in the Assiniboine River. Over the entire season, the Little Saskatchewan River contributed the largest proportion of the TP load at about 23 % while the Qu'Appelle River and Birdtail Creek contributed 13 and 4 %, respectively (Table 2).

As with TP, tributary contribution to TN load to the Assiniboine River varied seasonally. Total nitrogen load in the Little Saskatchewan River was the largest of the three tributaries from late May until early October (Figure 24). Between late October and mid-December, the Qu'Appelle contributed the largest portion of the TN load. After a period in January, when the Birdtail Creek contributed the largest portion of the TN load, the Little Saskatchewan River was again the largest contributor to TN load in the Assiniboine River. Annually, the Little Saskatchewan River contributed 26 % of the TN load while the Qu'Appelle River and Birdtail Creek contributed 13 and 6 %, respectively.

During the study period, 50.2 % of the TP load acquired by the Assiniboine River between Lake of the Prairies and the City of Brandon was measured as loading from Lake of the Prairies and the three tributaries (Table 2). Of this, only 41.3 % of the inorgP load was measured while 79.5 % of the OP was measured. Similarly, 58.6 % of the TN load acquired by the Assiniboine River within the study was measured with 50.0 % of the inorgN load and 61.0 % of the ON measured. During the study period, the amount of non-measured TP that entered the Assiniboine River varied from less than zero (uptake of TP within the stream exceeded measured inputs) to 1487 $kg \cdot d^{-1}$ (Figure 25). Non-measured inputs of TN also varied from less than zero to 8404 $kg \cdot d^{-1}$. Non-measured TN and TP were strongly correlated with flow at Brandon (Log TN = -4.1062 + 2.379 Log Flow, $P=0.002$, $r^2=0.63$, Log TP = -4.0497 + 2.111 Log Flow, $P<0.0001$, $r^2=0.85$). With the exception of an outlier at the end of June (during the three day extreme precipitation event), non-measured TN and TP were also strongly positively, correlated ($p< 0.003$, $r^2 = 0.64$ and 0.91, respectively) with incremental inflows (Flow at Brandon minus release from Lake of the Prairies minus three main tributary flows). During some times of the year, non-measured inputs of nutrients accounted for a significant portion of instream load. During other periods, instream uptake of nutrients exceeded inputs resulting in lower nutrient loads downstream.

Estimated point source loading of TN and TP to the Assiniboine River from wastewater treatment facilities formed only a small percentage of the non-measured load (5.2 and 3.8 %, respectively). The remaining non-measured load could be accounted for by inputs from minor tributaries not included in the loading calculations due to a lack of flow data (Gopher Creek, Arrow River), stream bank/bed erosion, and non-point source inputs from land runoff. Overall, TN and TP load from wastewater treatment facilities contributed only 2.1 and 1.9 %, respectively to the overall nutrient load in the Assiniboine River at Brandon.

Rates of TP and TN export from the Assiniboine River were at the lower range of those reported in the literature. Total phosphorus export was 4.47 $kg{\cdot}km^{-2}{\cdot}y^{-1}$ while total nitrogen export was 26.6 $kg{\cdot}km^{-2}{\cdot}y^{-1}$. Rates of TP export in 198 watersheds dominated by cropland (>50 % cropland) in North America (reviewed by Chambers and Dale 1997) varied from between 0.6 to 286 $kg{\cdot}km^{-2}{\cdot}y^{-1}$ while TN export in 177 watersheds ranged from between 8.2 and 2920 $kg{\cdot}km^{-2}{\cdot}y^{-1}$.

Interestingly, 88 % of TP export was inorganic while only 26 % of the TN export was inorganic. Chambers and Dale (1997) indicate that export coefficients for SRP are usually 40 to 50 % of that for TP. Measurements of inorgP in this study were expected to be higher than those reported in the literature for SRP as estimates include both soluble and particulate SRP. In the Assiniboine River, inorgP consisted of about 58 % SRP. Export rate of inorgP in the Assiniboine River watershed was 3.93 $kg{\cdot}km^{-2}{\cdot}y^{-1}$, lower than the average export rate for SRP in 172 cropland watersheds (11.8 $kg{\cdot}km^{-2}{\cdot}y^{-1}$). The rate of inorgN export was 7.04 $kg{\cdot}km^{-2}{\cdot}y^{-1}$ as compared to an average of 573 $kg{\cdot}km^{-2}{\cdot}y^{-1}$ found for 166 cropland watershed in North America (Chambers and Dale 1997).

DISCUSSION

Phosphorus and nitrogen concentrations at the study headwaters just downstream of Lake of the Prairies displayed dramatically different trends than were observed elsewhere on the Assiniboine River. Phosphorus concentrations peaked in late summer and fall, and were about double those during the rest of the study period. Ammonia concentrations were also elevated during this period. However, these trends in phosphorus and nitrogen persisted for less than 46 and 68 km, respectively. Visual observations indicated that a large periphyton community, not observed elsewhere in the study reach, flourished due to comparatively high light penetration and adequate nutrient concentrations. Nutrient uptake by periphyton likely depleted excess phosphorus and nitrogen resulting in completely different downstream seasonal trends.

Seasonal trends in phosphorus and nitrogen concentration at the remaining stations on the Assiniboine River were relatively similar. Phosphorus concentrations were highest in spring and declined through the summer, fall, and winter. InorgN concentrations were highest during the ice-covered season, and remained comparatively low and constant during the ice-free period. In some instances, large rainfall events resulted in short peaks in nutrient concentration. Total nitrogen to phosphorus ratios were highest under ice-cover and declined during the ice-free season. Spring, summer, and fall TN:TP ratios were below 20 suggesting that algal biomass was likely N- rather than P-limited (Redfield et al. 1963, Borchart 1996) in the Assiniboine River during most of the growing season.

Longitudinal trends in phosphorus and nitrogen concentration along the Assiniboine River were seasonal. Except during the fall, TP and inorgP concentrations increased with distance downstream of Lake of the Prairies. The trend was reversed in the fall during the period of high phosphorus release from Lake of the Prairies. In contrast, TN concentrations remained constant or decreased with distance downstream throughout the entire study. InorgN concentrations also remained constant or decreased with distance downstream during the ice-free season but increased during the ice-covered season. In general, TN:TP ratios decreased with distance downstream suggesting that N- rather than P-limitation occurred more frequently in the downstream portions of the Assiniboine River.

Phosphorus and nitrogen loads in the Assiniboine River increased on average 26 and 13 fold, respectively, between the outlet of Lake of the Prairies and the City of Brandon. Measurement of phosphorus and nitrogen loads at the headwaters at Lake of the Prairies, and in the three main tributaries accounted for 50 and 59 % of the phosphorus and nitrogen loads at Brandon, respectively. Estimated point source loads from wastewater treatment facilities accounted for an additional 2.1 and 1.9 % of the nitrogen and phosphorus loads, respectively. It is estimated that the remaining nitrogen and phosphorus load was contributed by non-point sources such as erosion and runoff. The strong correlation between non-measured phosphorus and nitrogen, and incremental inflows through most of the ice-free season suggests that non-gauged inflows (direct runoff from precipitation, small tributaries) accounted for a large proportion of the non-measured nutrients.

Rates of nutrient export from the Assiniboine River watershed during 2001 to 2002 were low as compared to those found throughout the literature for other watersheds in North America with over 50 % cropland (Chambers and Dale 1996). Below average precipitation in the watershed during more than 75 % of the study period (Environment Canada 2002) and correspondingly low river flows may have reduced nutrient export from the watershed. Flows in the Assiniboine River at Russell were below the median (1970 to 1999) for all but one two-week period during the study and in fact, at many times, flows were below the lower decile (10 %). A relatively low runoff year in the Assiniboine River watershed may have resulted in low rates of nutrient export as compared to those reported in the literature.

WATER QUALITY MODELLING IMPLICATIONS

The final product for the Assiniboine River project will be a water quality model, developed to predict the influence of anthropogenic (wastewater discharge, altered flow regimes from Lake of the Prairies, land use practices, etc.) and natural (annual variability in precipitation and temperature) changes on water quality in the Assiniboine River. Modelling efforts will be guided by some of the conclusions of this report.

As expected from previous efforts towards water quality modelling on the Assiniboine River (Cooley *et al.*. 2001a,b), separate models will be required for ice-free and ice-covered seasons. In addition to fundamental differences in temperature, aeration, and flow, different spatial and temporal patterns in phosphorus and nitrogen concentrations were evident during the ice-free and ice-covered seasons on the Assiniboine River. Estimates of non-measured nitrogen and phosphorus were also higher during the ice-free as compared to ice-covered season suggesting that the addition of incremental non-point source nutrients will only be a component of ice-free water quality models.

In general, algal biomass in the Assiniboine River between Lake of the Prairies and Brandon appears to be nitrogen or light limited. Total nitrogen to phosphorus ratios of less than 10 predominate for much of the year, and in particular, in the downstream portion of the watershed. However, turbidity was relatively high throughout most of the study area, suggesting that light limitation may also be a factor. Water quality modelling will aid in determination of the influence of light on algal biomass within the Assiniboine River and provide further clarification on the issue of algal limitation.

REFERENCES

Borchardt, M.A. 1996. Nutrients. In: Stevenson, R. J., Bothwell, M.L., and Lowe, R. L. editors. Algal Ecology. Academic Press, Toronto. pp 183-227.

Bourne, A., Armstrong, N., and Jones, G. 2002. A preliminary estimate of total nitrogen and total phosphorus loading to streams in Manitoba, Canada. Water Quality Management Section. Manitoba Conservation Report No. 2002 - 04.

Carmichael, W.W. 1991. Toxic freshwater blue-green algae (cyanobacteria): an overlooked health treat. Health and Environment Digest 5:1-4.

Chambers, P.A. and Dale, A.R. 1997. Contribution of Industrial, Municipal, Agricultural and Groundwater Sources to Nutrient Export, Athabasca and Wapiti-Smoky Rivers, 1989-1993.

Chambers, P.A., Guy, M., Roberts, E.S., Charlton, M.N., Kent, R., Gagnon, C., Grove, G., and Foster, N. 2001. Nutrients and their impact on the Canadian environment. Agriculture and Agrifood Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada. Hull, Quebec, Canada. 241pp.

Cooley, M., Schneider-Vieira, F., and Towes, J. June 2001a. Assiniboine River Monitoring Study Water Quality Component: Winter Water Quality Assessment and Model. North/South Consultants Inc. Winnipeg, Manitoba. 63pp. plus Appendices.

Cooley, M., Schneider-Vieira, F., and Towes, J. October 2001b. Assiniboine River Monitoring Study Water Quality Component: Water Quality Assessment and Model for the Open Water Season. North/South Consultants Inc. Winnipeg, Manitoba. 156pp. plus Appendices.

Environment Canada. 2001. Weather data from Shoal Lake Climate Station. Meteorological Service of Canada.

Environment Canada. 2002. Seasonal Forecasts: Verification of Past Forecasts. www.weatheroffice.ec.gc.ca/saisons/index_e.html

Fortin, R. V. and Gurney, S.E. 1997. Phosphorus loading to Shellmouth Reservoir. Manitoba Environment Report No. 97-05. Winnipeg, Manitoba, 79pp.

Kotak, B.G. 1995. Concentration and toxicity of microcystin-LR in compartments and organisms of aquatic food webs. Ph.D. thesis. Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada. 327pp.

Manitoba Conservation. 2002. Unpublished data. Water Quality Management Section, 123 Main Street, Suite 160 Winnipeg MB R3C 1A5.

Manitoba Intergovernmental Affairs. 2002. Manitoba Community Profiles. www.communityprofiles.mb.ca

North/South Consultants Inc. and Earth Tech (Canada) Inc. 2002. Assiniboine River Monitoring Study: Portage la Prairie to Headingley. Proposed Workplan 2001-2004 (Draft).

Prairie Farm Rehabilitation Administration. 1980 revised 1990. Report on Determination of River Distances for the Saskatchewan-Nelson River Basin: Hydrology Report #95. Hydrology Division, PFRA.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963. The influence of organisms on the composition of seawater. In: Hill, M.N. The Sea. Wiley-Interscience, New York. pp.26-77.

Statistics Canada. 2001. 2001 Community Profiles. www12.statcan.ca/english/profil01/PlaceSearchForm1.cfm

TABLES

Table 1. Assiniboine River and tributary station descriptions and locations.

Station	Location Description	Latitude	Longitude	Distance from Brandon (km)
MB05MDS023	ASSINIBOINE RIVER AT OUTLET FROM SHELLMOUTH	50.9625	101.4167	435.0
MB05MES048	ASSINIBOINE RIVER NEAR RUSSELL AT CONJURNING CREEK	50.8099	101.4338	388.9
MB05MES053	ASSINIBOINE RIVER AT MILLWOOD (579)	50.6898	101.4132	367.4
MB05MES035	ASSINIBOINE RIVER AT PR #478, WEST OF BINSCARTH	50.6236	101.4178	350.9
MB05MES040	ASSINIBOINE RIVER AT OLD PTH #41, N OF QU'APPELLE R.	50.4408	101.3189	313.2
MB05MES049	ASSINIBOINE RIVER DOWNSTREAM OF THE QU'APPELLE RIVER	50.4420	101.3192	312.4
MB05MES050	ASSINIBOINE RIVER UPSTREAM OF BIRDTAIL	50.2809	101.1910	267.4
MB05MES051	ASSINIBOINE RIVER DOWNSTREAM OF BIRDTAIL	50.2487	101.1743	262.4
MB05MES042	ASSINIBOINE RIVER AT PTH #83, SOUTH OF MINIOTA	50.1097	101.0356	216.9
MB05MGS040	ASSINIBOINE DOWSTREAM OF ARROW RIVER	50.0818	100.9318	206.9
MB05MGS034	ASSINIBOINE RIVER AT PR #259, NORTH EAST OF VIRDEN	49.8744	100.8486	145.0
MB05MGS035	ASSINIBOINE RIVER AT E. OF VIRDEN	49.8417	100.8167	130.7
MB05MGS037	ASSINIBOINE RIVER AT PTH #21, NORTH OF GRISWOLD	49.8425	100.4608	61.7
MB05MGS042	ASSINIBOINE UPSTREAM OF THE LITTLE SASKATCHEWAN RIVER	49.8722	100.1675	5.1
MB05MHS002	ASSINIBOINE RIVER AT TCH, WEST OF BRANDON	49.8681	100.0983	0
MB05MES034	BIRDTAIL RIVER, BELOW DAM AT BIRTLE	50.4208	101.0617	
MB05MES036	QU'APPELLE RIVER AT OLD PTH #41, WEST OF ST. LAZARE	50.4422	101.3247	
MB05MFS098	LITTLE SASKATCHEWAN RIVER AT PTH #25 NEAR RIVERS	50.0236	100.2067	

Table 2. Percentage of the study area occupied by each type of land use (For Land Use Category descriptions please see Appendix 2).

Land Use Category	% Cover
Agriculture	51.11
Grassland	25.86
Forage Crops	2.83
Deciduous Forest	10.60
Open Deciduous Forest	1.43
Mixedwood Forest	0.40
Conifer Forest	0.14
Water	1.60
Marsh/Fens	3.32
Bogs	0.08
Bare rock/sand/gravel	0.01
Cultural	0.14
Roads/Trails	2.46

Table 3. Average chemical concentrations for 15 Assiniboine River and three tributary stations for May 2001 to May 2002.

Station		N	pH	Specific conductivity (uS/cm)	True color (color units)	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (mg/L)	TC (mg/L)	TOC (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO2NO3 (mg/L)	TP (mg/L)	TDP (mg/L)	OrthoP (mg/L)	Chla (µg/L)
MDS023	Average	18	8.23	707	14	2.77	491	5	8.48	3.1	69	14	0.125	1.283	0.126	0.094	0.071	0.058	19.3
	Std. Deviation		0.13	59	6	2.99	66	3	2.47	3.7	4	1	0.101	1.561	0.111	0.046	0.043	0.050	33.0
MES048	Average	18	8.26	753	15	16.35	530	30	8.17	2.3	71	14	0.111	1.211	0.140	0.130	0.062	0.082	15.6
	Std. Deviation		0.13	78	6	12.05	70	23	2.97	1.6	4	2	0.099	0.844	0.170	0.050	0.028	0.040	13.8
MES053	Average	14	8.33	743	19	13.74	522	25	8.69	2.1	70	15	0.076	1.371	0.145	0.117	0.059	0.070	19.1
	Std. Deviation		0.11	83	7	9.69	58	12	2.53	1.5	3	1	0.056	1.543	0.285	0.031	0.023	0.024	17.4
MES035	Average	18	8.26	771	17	14.35	543	31	7.85	1.7	71	14	0.076	1.239	0.172	0.120	0.052	0.083	8.6
	Std. Deviation		0.13	86	7	9.47	64	22	2.27	0.9	4	2	0.043	1.580	0.333	0.040	0.020	0.032	7.2
MES040	Average	18	8.19	808	17	18.37	565	34	7.27	2.2	75	13	0.064	0.856	0.194	0.119	0.049	0.077	8.5
	Std. Deviation		0.17	113	9	13.84	95	27	1.93	1.7	7	2	0.045	0.430	0.387	0.045	0.016	0.037	7.3
MES049	Average	18	8.25	969	17	17.02	681	36	7.78	3.5	78	13	0.060	0.817	0.129	0.141	0.056	0.081	17.3
	Std. Deviation		0.16	155	12	9.91	75	23	2.08	5.2	6	1	0.044	0.396	0.160	0.047	0.017	0.034	15.2
MES050	Average	10	8.27	887	18	14.25	635	35	5.74	2.1	74	13	0.043	0.840	0.103	0.131	0.049	0.068	19.6
	Std. Deviation		0.12	135	16	8.91	79	22	5.47	1.2	8	2	0.026	0.435	0.205	0.032	0.015	0.027	9.4
MES051	Average	13	8.32	815	21	15.38	562	40	8.26	3.1	79	14	0.037	0.792	0.072	0.133	0.048	0.082	10.7
	Std. Deviation		0.12	72	12	8.20	80	32	1.56	4.8	8	2	0.021	0.403	0.137	0.060	0.016	0.057	5.5
MES042	Average	18	8.22	914	16	16.01	659	38	7.25	2.1	79	12	0.059	0.906	0.146	0.132	0.055	0.092	14.7
	Std. Deviation		0.19	126	9	11.00	73	30	2.15	1.3	7	2	0.047	0.717	0.213	0.059	0.020	0.049	8.1
MGS040	Average	13	8.28	893	18	22.27	630	59	7.05	2.2	78	13	0.043	0.946	0.099	0.171	0.065	0.114	16.2
	Std. Deviation		0.13	97	10	18.11	63	50	2.25	1.4	8	1	0.025	0.459	0.204	0.079	0.025	0.069	7.8
MGS034	Average	14	8.29	897	23	37.50	625	118	7.71	2.6	78	13	0.050	1.000	0.109	0.246	0.071	0.177	17.5
	Std. Deviation		0.19	142	13	55.52	87	219	1.95	2.4	10	1	0.039	0.619	0.218	0.282	0.040	0.256	6.5

Table 3. Average chemical concentrations for 15 Assiniboine River and three tributary stations for May 2001 to May 2002 (continued).

Station		N	pH	Specific conductivity (uS/cm)	True color (color units)	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (mg/L)	TC (mg/L)	TOC (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO2NO3 (mg/L)	TP (mg/L)	TDP (mg/L)	OrthoP (mg/L)	Chla (µg/L)
MGS035	Average	18	8.21	931	18	25.01	659	66	7.13	2.3	80	12	0.080	0.978	0.168	0.188	0.065	0.133	15.0
	Std. Deviation		0.22	120	12	28.11	85	91	1.79	2.1	8	2	0.062	0.520	0.261	0.140	0.027	0.127	8.0
MGS037	Average	18	8.22	956	20	21.86	675	51	6.98	2.0	81	13	0.078	0.956	0.199	0.165	0.076	0.120	15.4
	Std. Deviation		0.23	117	13	18.35	84	49	2.57	1.6	10	2	0.053	0.331	0.275	0.087	0.038	0.077	8.6
MGS042	Average	14	8.34	931	21	21.59	665	46	8.68	2.4	80	13	0.044	1.007	0.155	0.164	0.077	0.121	15.5
	Std. Deviation		0.12	129	12	10.18	91	27	4.08	1.8	12	2	0.033	0.365	0.295	0.057	0.042	0.065	8.5
MHS002	Average	18	8.29	894	20	20.62	628	46	7.31	2.5	81	14	0.065	0.922	0.205	0.159	0.073	0.121	12.3
	Std. Deviation		0.24	117	12	33.25	85	81	2.17	1.8	9	2	0.057	0.463	0.291	0.115	0.038	0.114	7.6
MES036	Average	18	8.22	1137	12	16.61	764	38	8.06	2.7	83	15	0.077	0.967	0.124	0.148	0.058	0.084	21.3
	Std. Deviation		0.20	154	8	7.70	204	20	1.82	1.7	8	13	0.083	0.549	0.146	0.048	0.019	0.026	16.4
MES034	Average	18	8.18	764	24	10.25	545	18	7.77	1.7	92	14	0.123	1.222	0.175	0.103	0.062	0.073	4.5
	Std. Deviation		0.17	191	12	7.41	123	18	1.95	0.8	11	3	0.121	1.219	0.247	0.050	0.030	0.037	4.3
MFS098	Average	18	8.25	685	29	2.20	497	5	7.67	2.1	81	18	0.163	1.383	0.095	0.147	0.114	0.101	15.3
	Std. Deviation		0.22	155	11	0.83	106	4	1.99	1.5	11	3	0.161	0.908	0.115	0.060	0.055	0.060	12.8

FIGURES

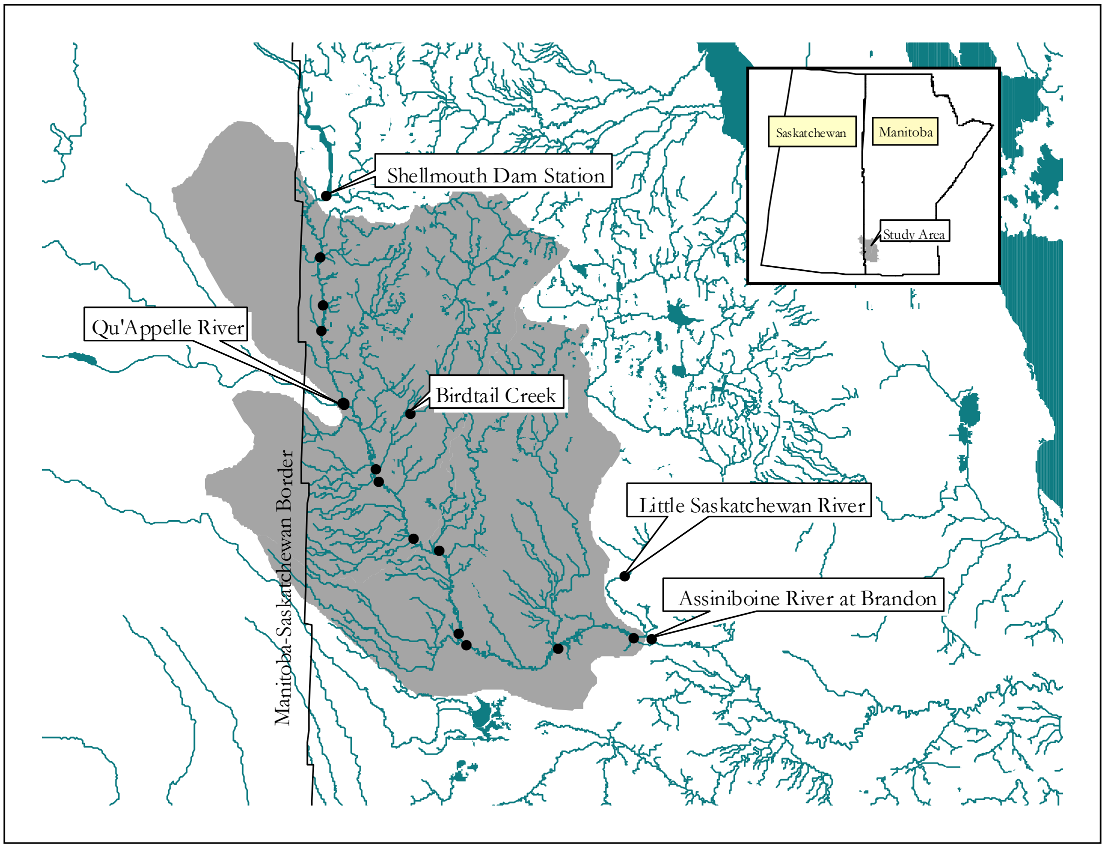

Figure 1. Map of the study area (grey shading) and sampling stations (●).

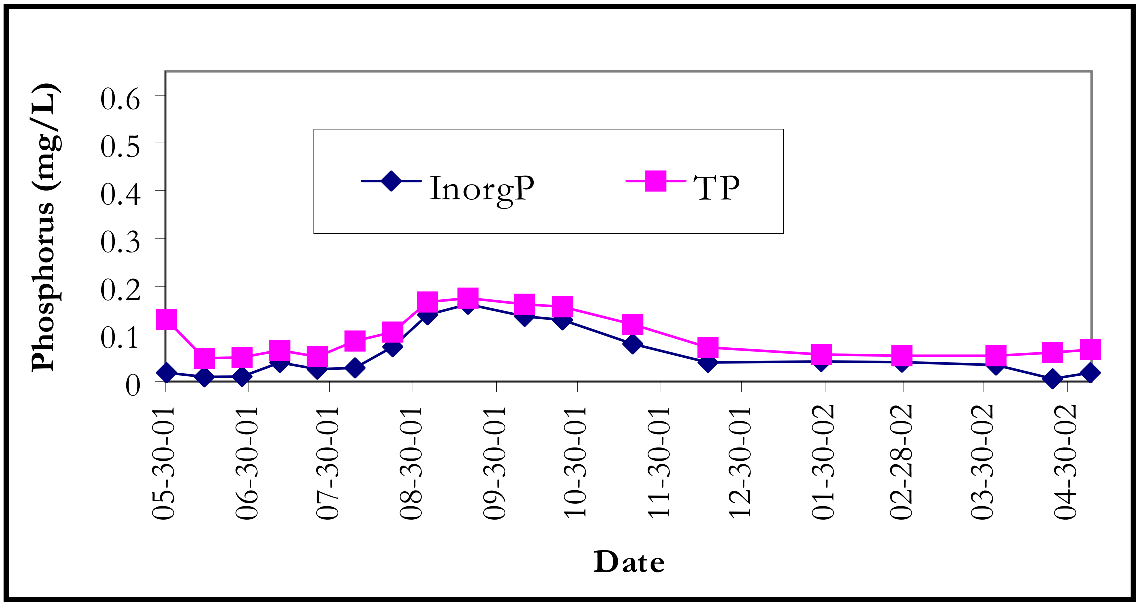

Figure 2. Total and inorganic phosphorus concentration in the Assiniboine River, downstream of Lake of the Prairies.

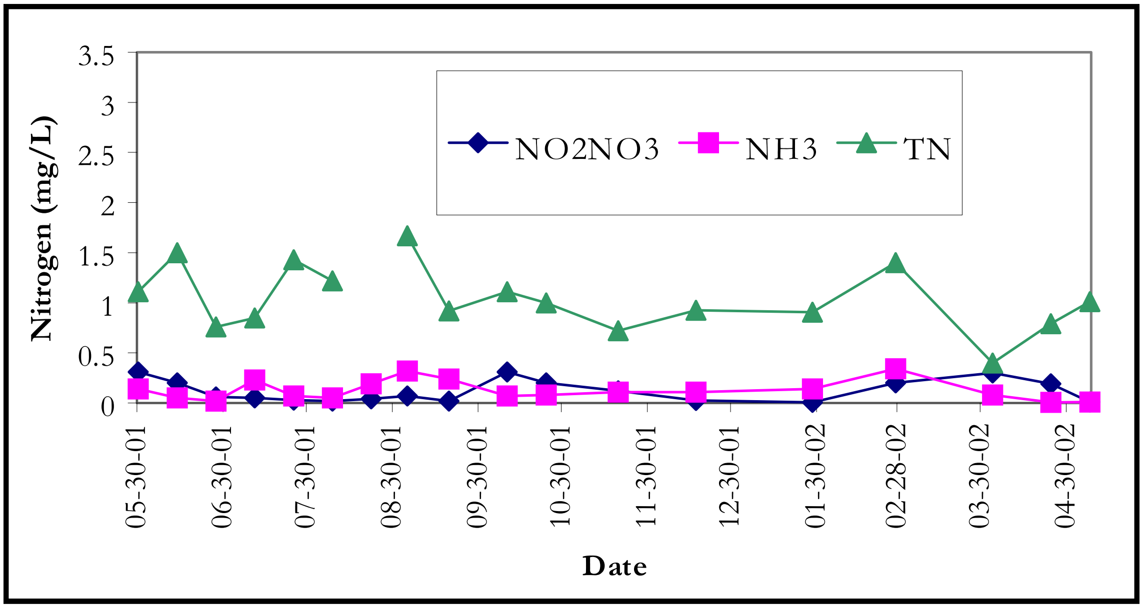

Figure 3. Total nitrogen, NH3, and NO2NO3 concentration in the Assiniboine River, downstream of Lake of the Prairies.

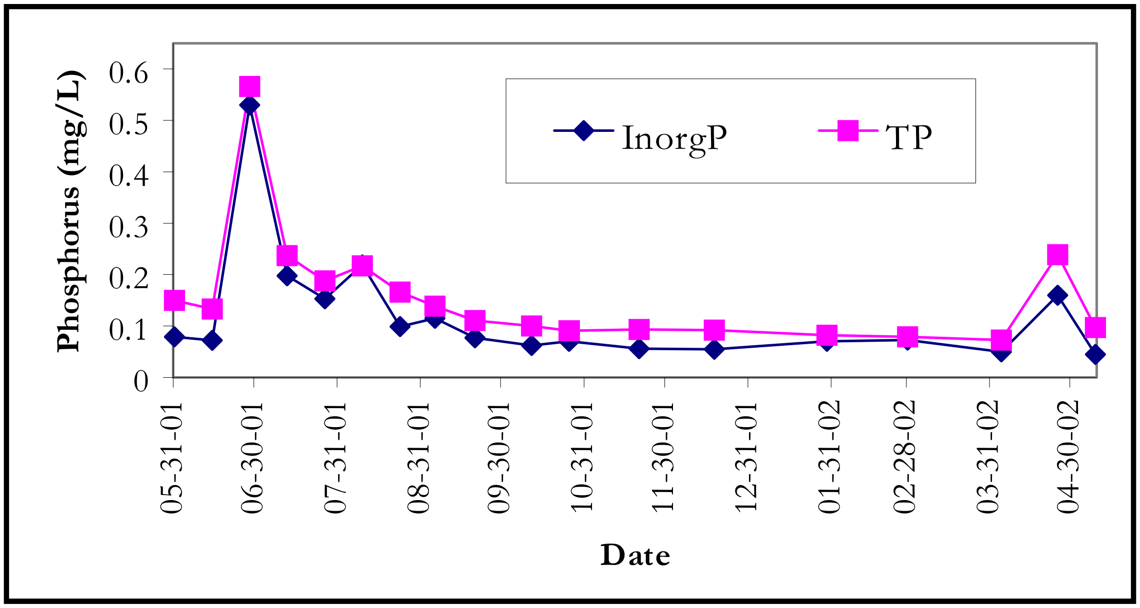

Figure 4. Total and inorganic phosphorus concentration in the Assiniboine River at Brandon.

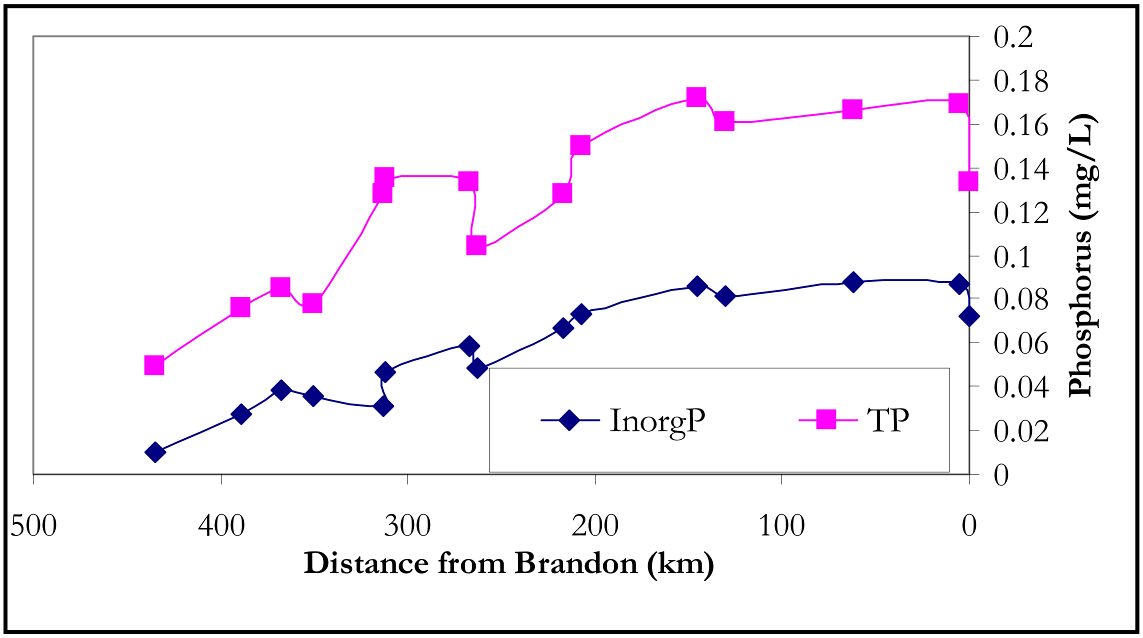

Figure 5. Longitudinal trends in TP and inorgP concentration on June 13 and 14, 2001 in the Assiniboine River.

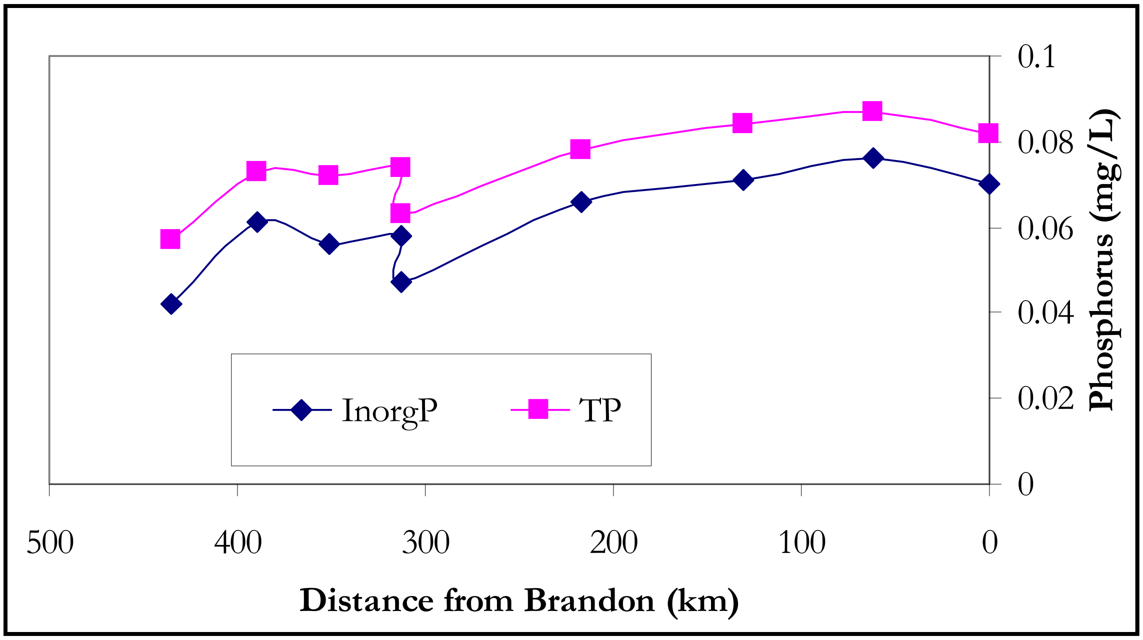

Figure 6. Longitudinal trends in TP and inorgP concentration on January 28 and 29, 2002 in the Assiniboine River.

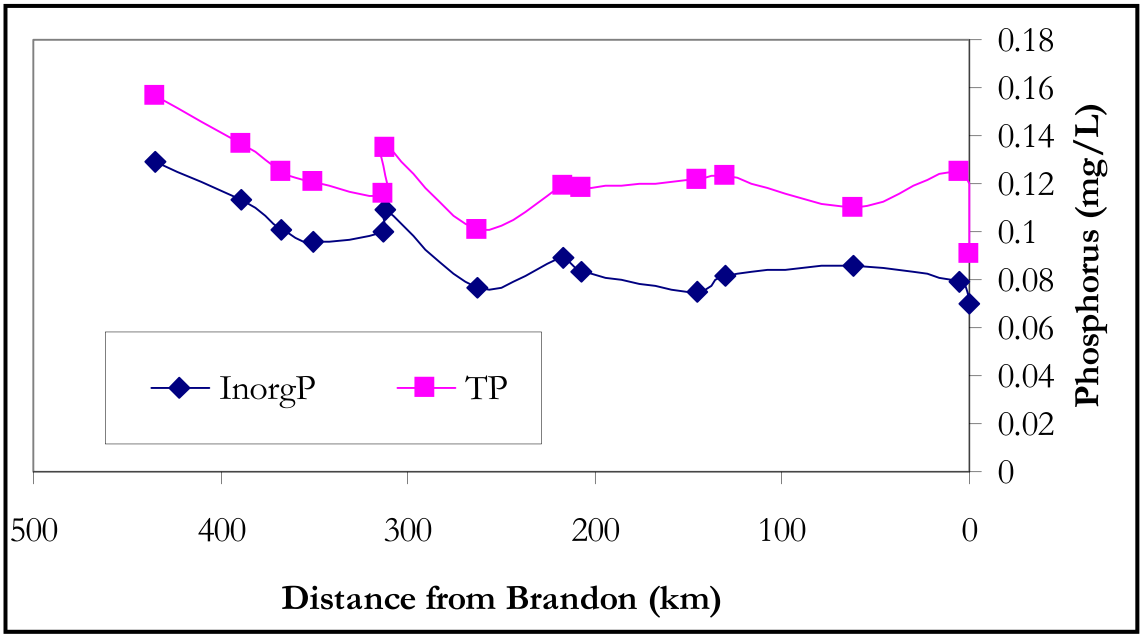

Figure 7. Longitudinal trends in TP and inorganic P concentration on October 24 and 25, 2001 in the Assiniboine River.

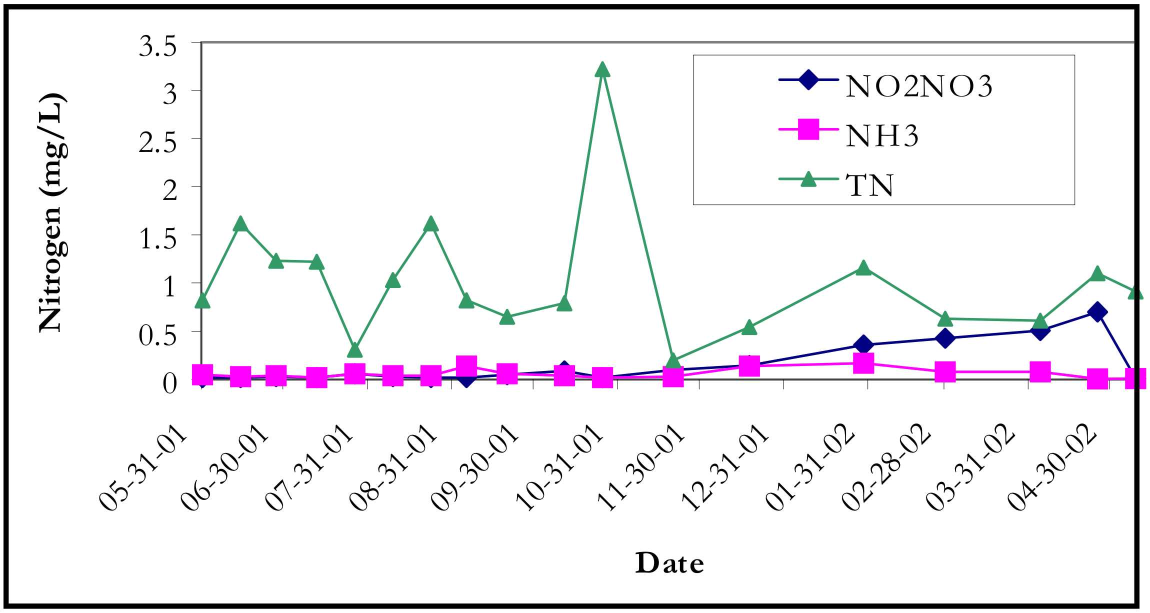

Figure 8. Total nitrogen, NH3, and NO2NO3 concentration in the Assiniboine River at Miniota.

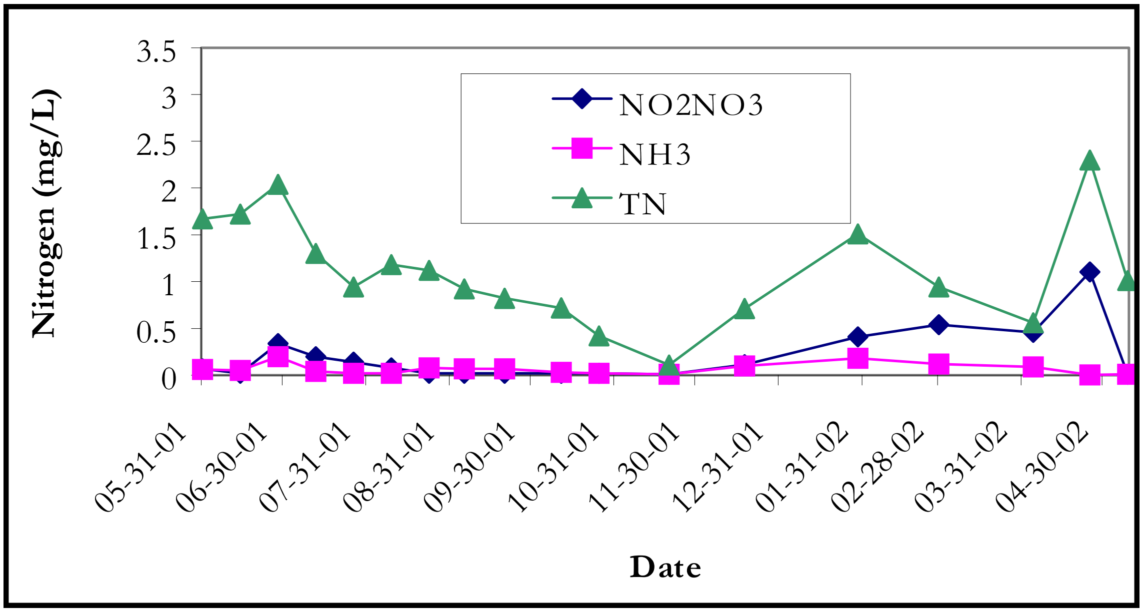

Figure 9. Total nitrogen, NH3, and NO2NO3 concentration in the Assiniboine River at Brandon.

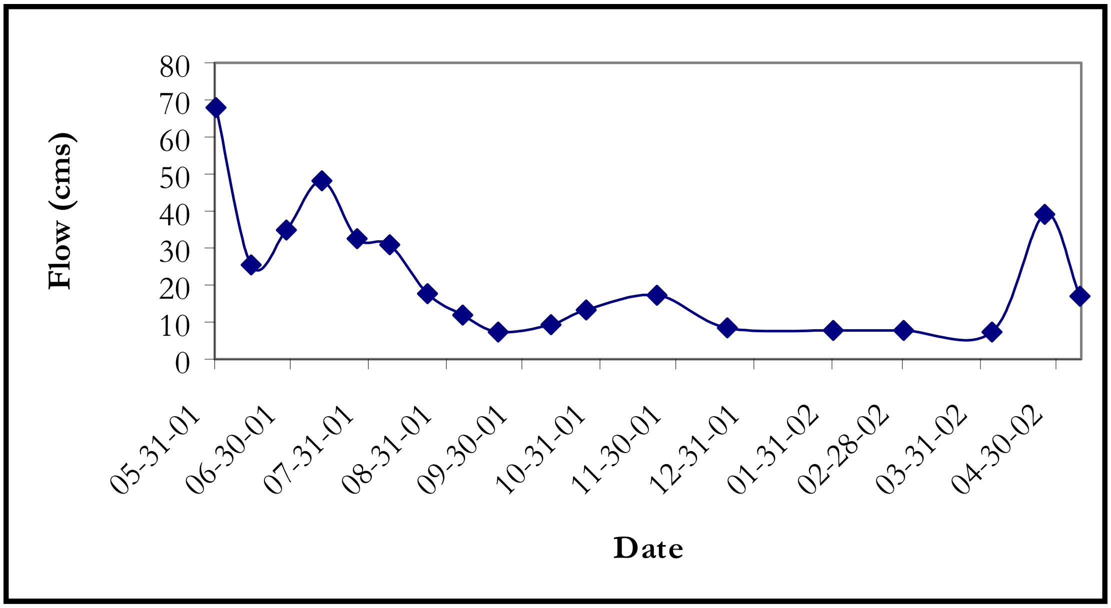

Figure 10. Flows in the Assiniboine River at Brandon (cms).

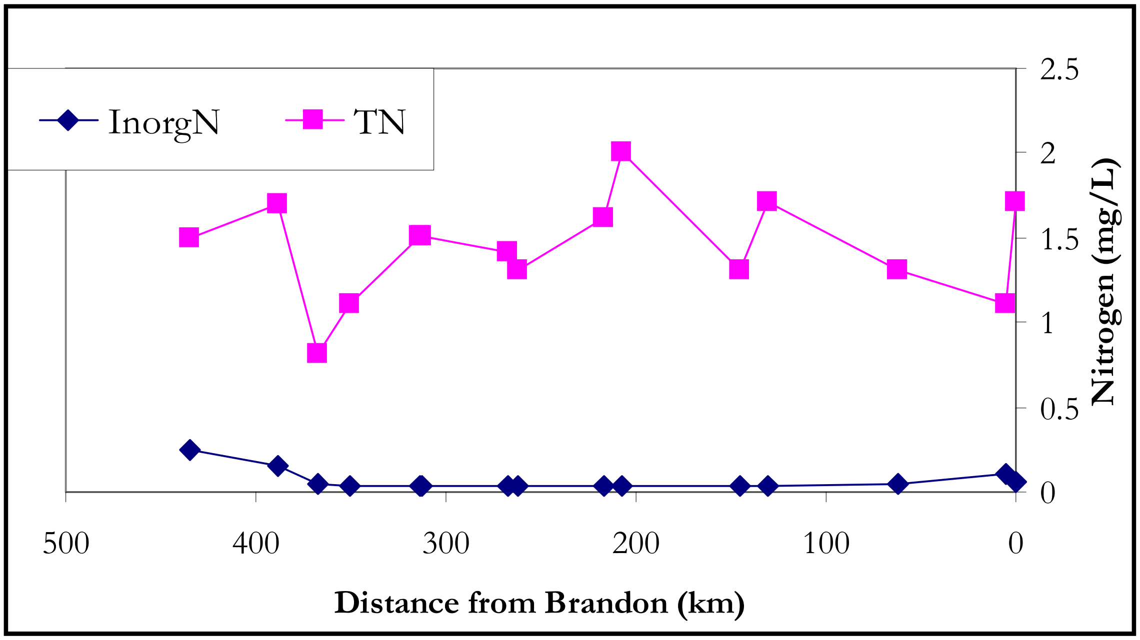

Figure 11. Longitudinal trends in TN and inorgN concentration on June 13 and 14, 2001 in the Assiniboine River.

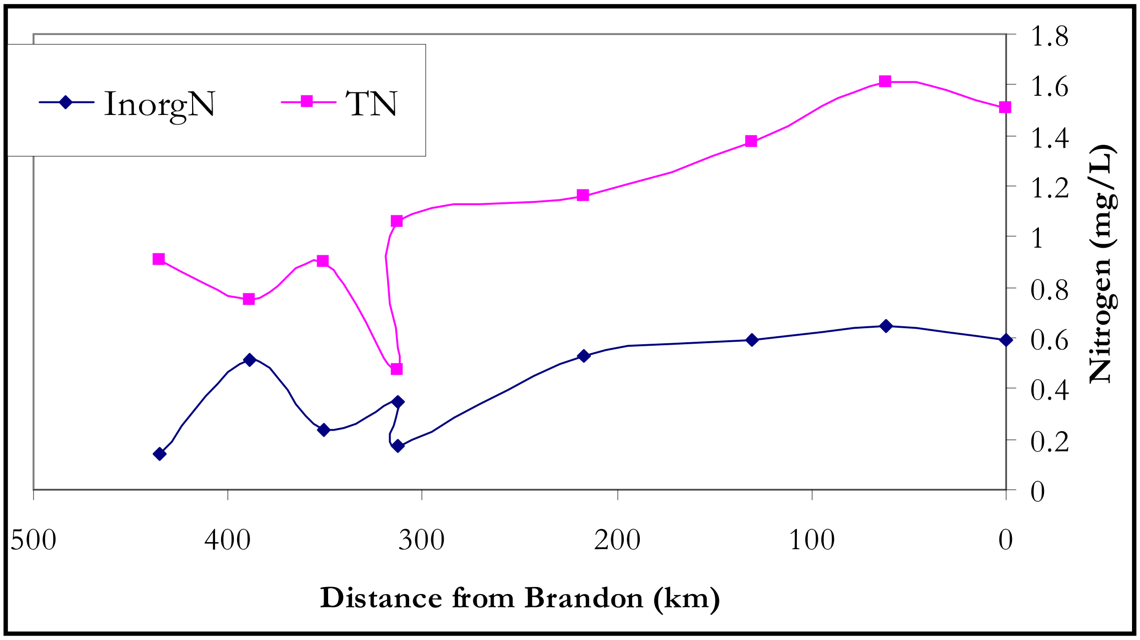

Figure 12. Longitudinal trends in TN and inorgN concentration on January 28 and 29, 2002 in the Assiniboine River.

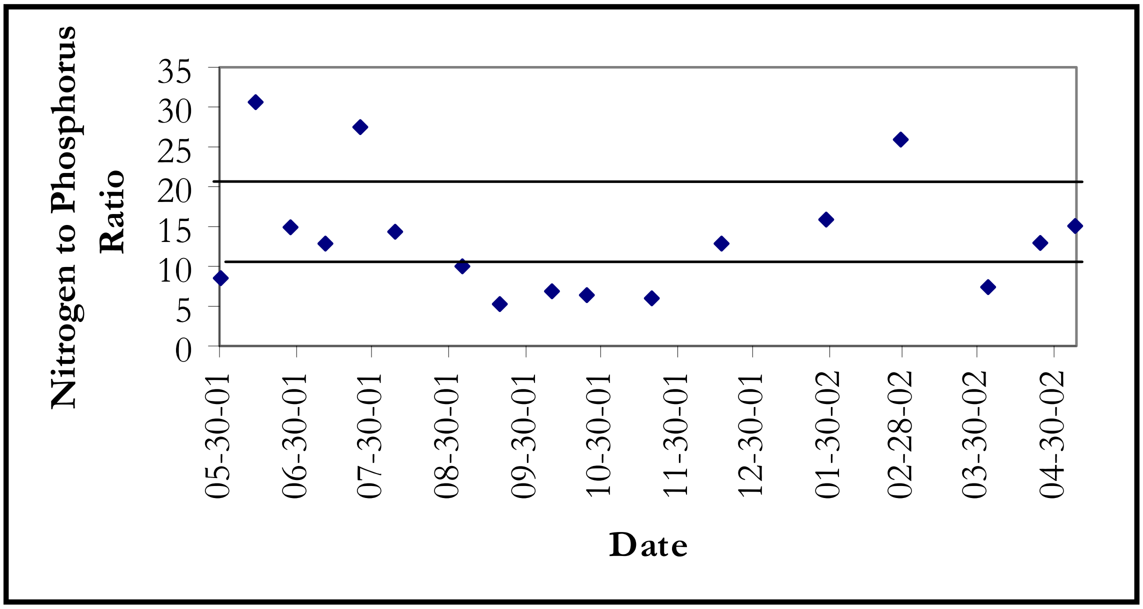

Figure 13. Observed seasonal fluctuations in N to P ratios in the Assiniboine River, downstream of Lake of the Prairies.

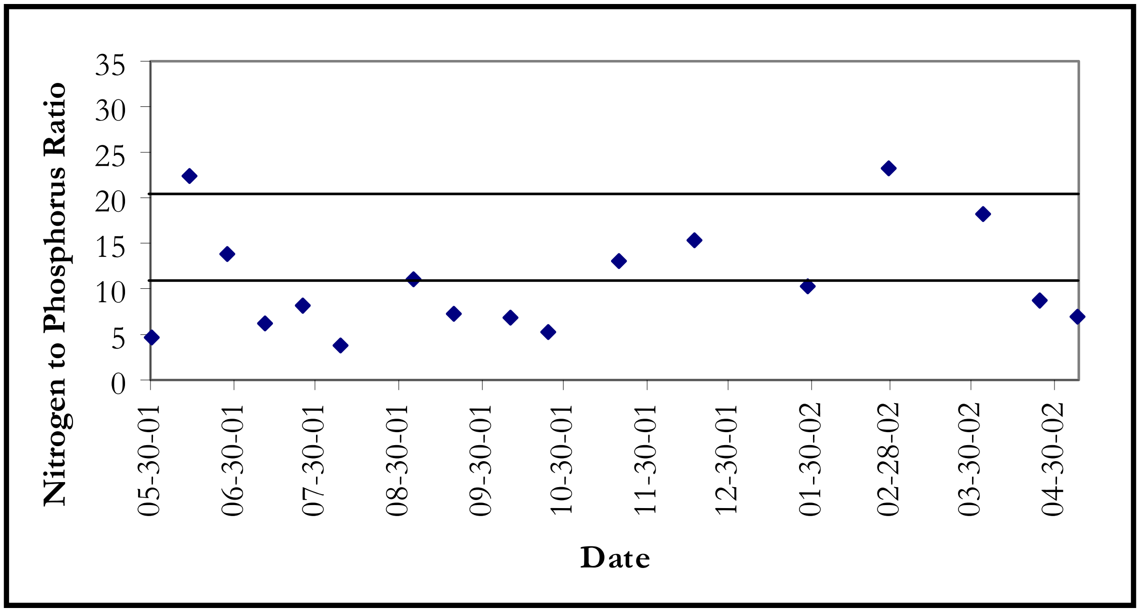

Figure 14. Observed seasonal fluctuations in N to P ratios in the Assiniboine River at Russell.

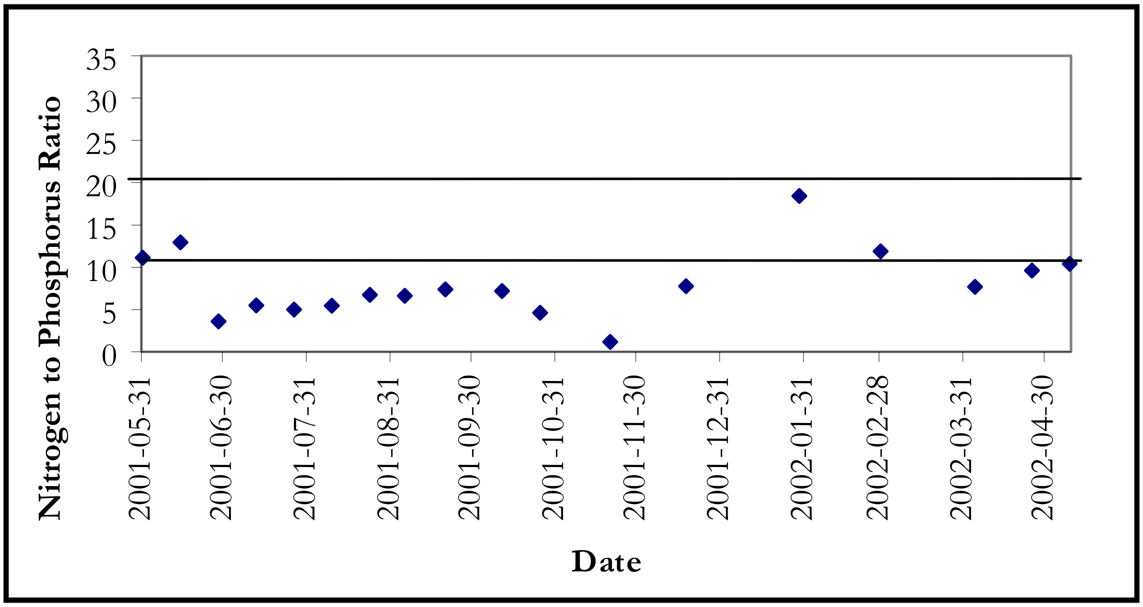

Figure 15. Observed seasonal fluctuations in N to P ratios in the Assiniboine River at Brandon.

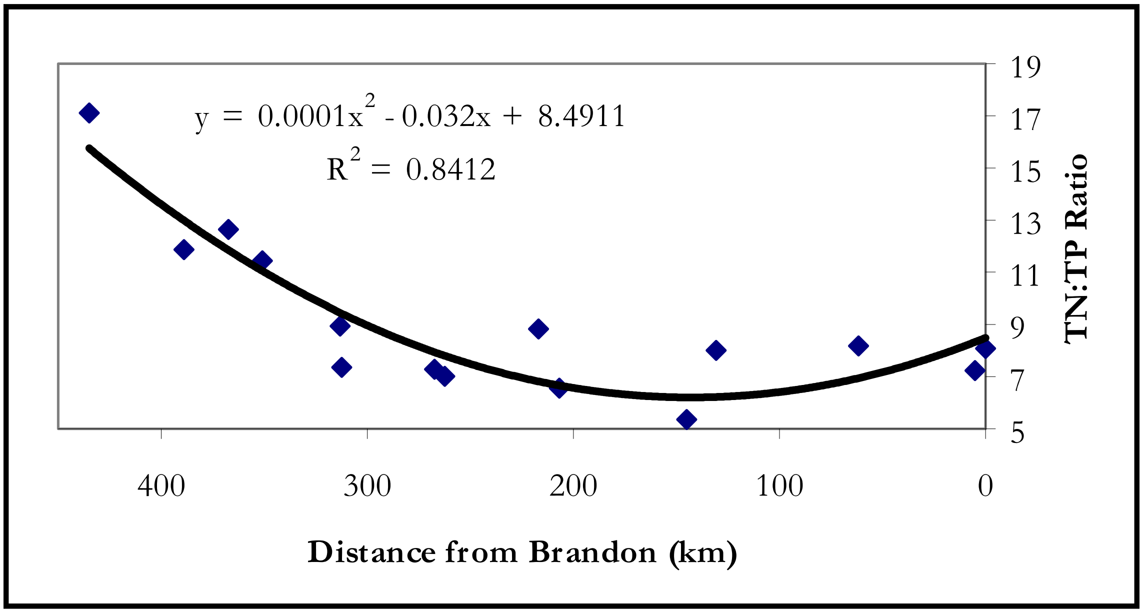

Figure 16. Change in average N to P ratio over distance in the Assiniboine River.

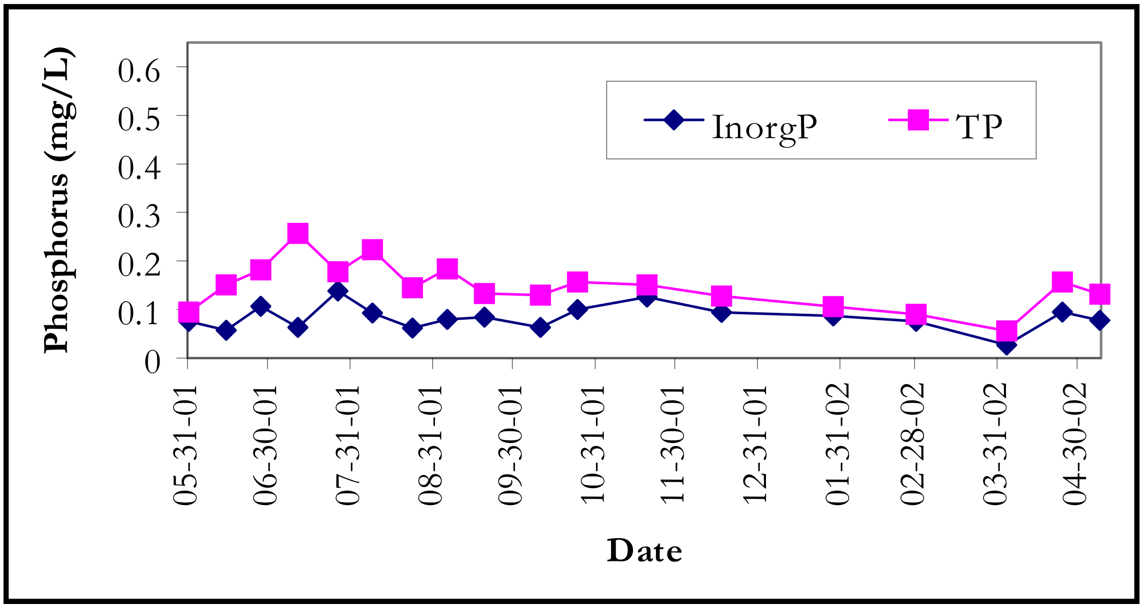

Figure 17. Total and inorganic phosphorus concentration in the QuAppelle River at St. Lazare.

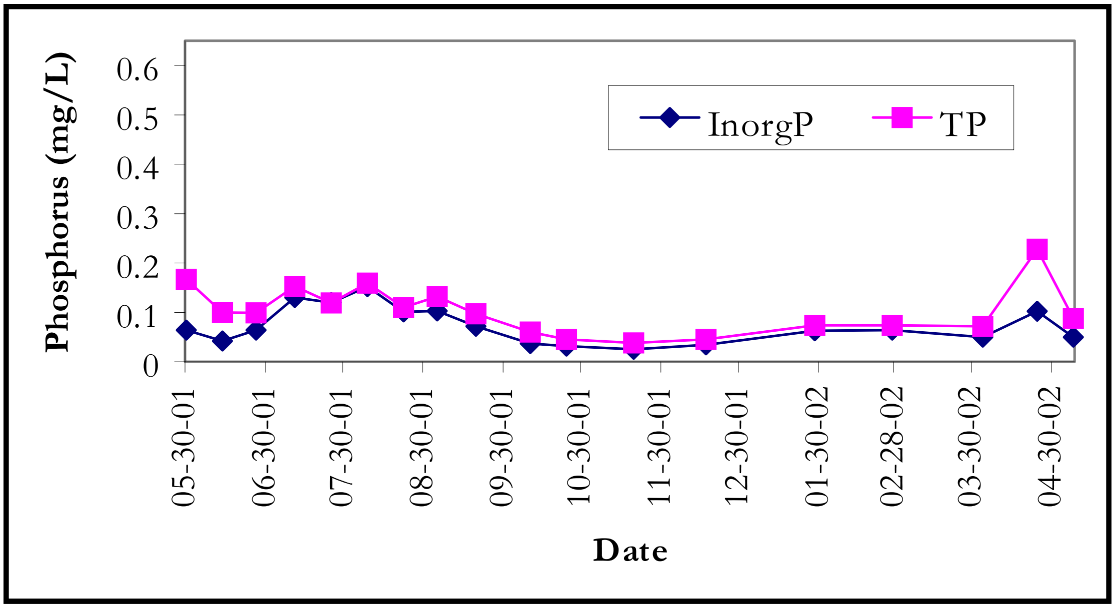

Figure 18. Total and inorganic phosphorus concentration in Birdtail Creek at Birtle.

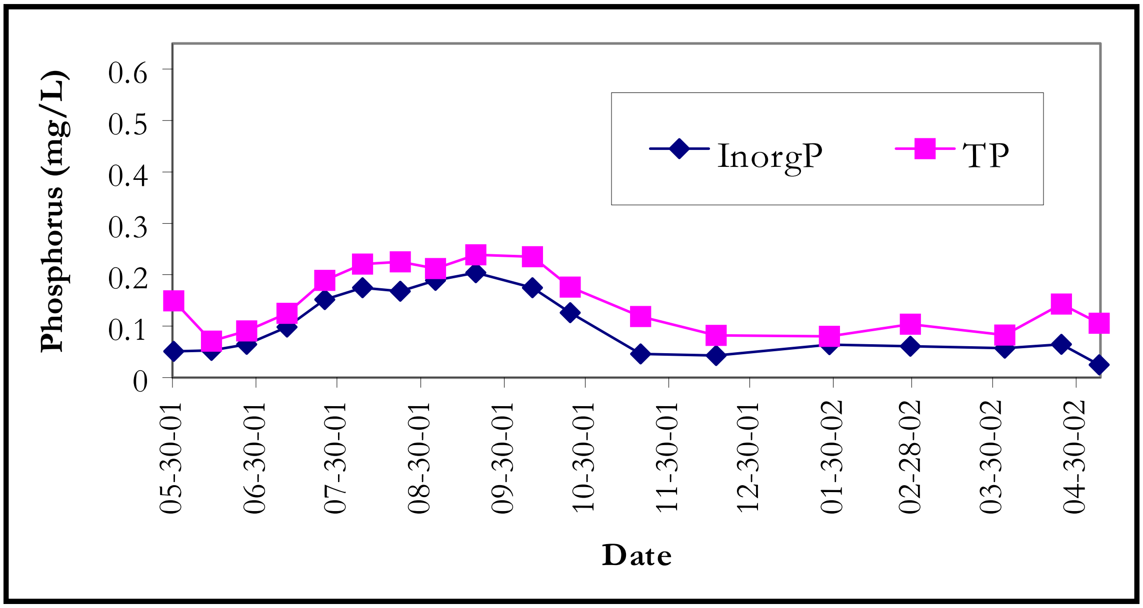

Figure 19. Total and inorganic phosphorus concentration in the Little Saskatchewan River at Rivers.

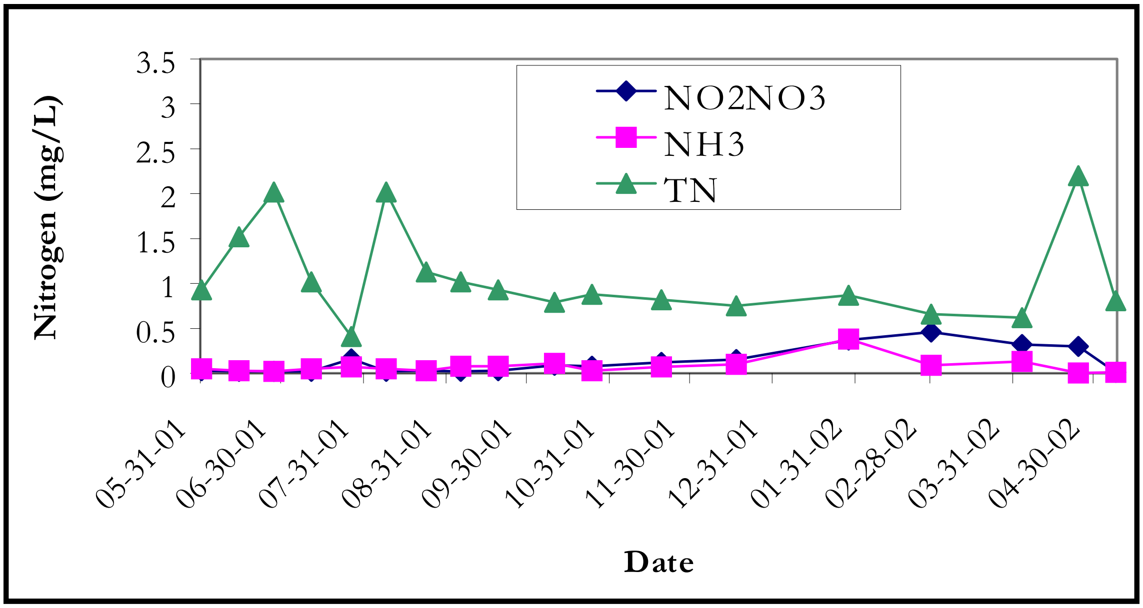

Figure 20. Total nitrogen, NH3, and NO2NO3 concentration in the Qu'Appelle River at St. Lazare.

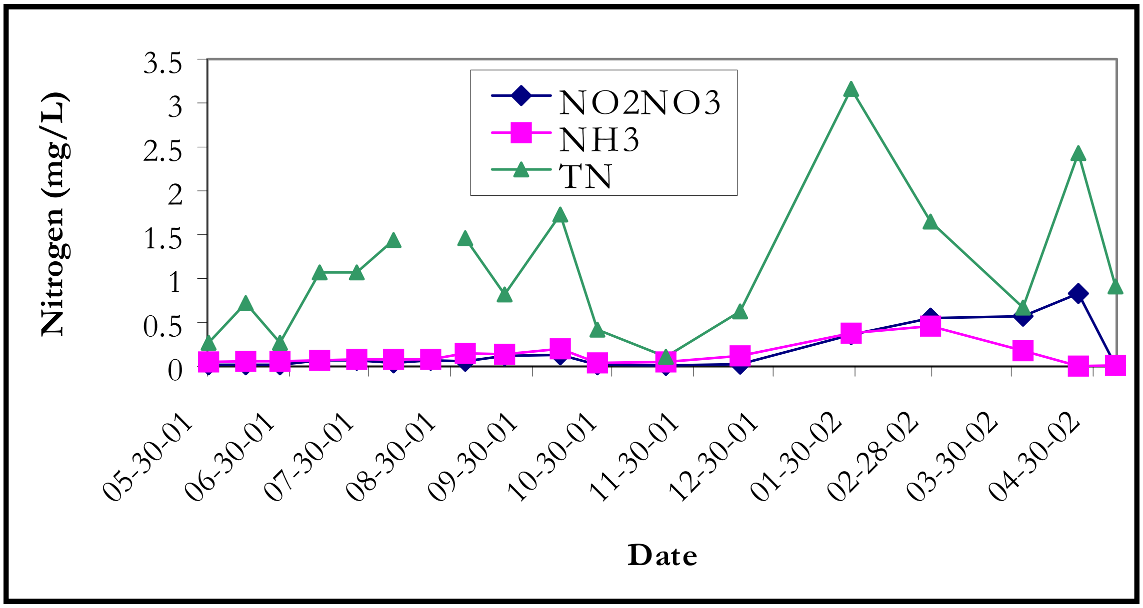

Figure 21. Total nitrogen, NH3, and NO2NO3 concentration in Birdtail Creek at Birtle.

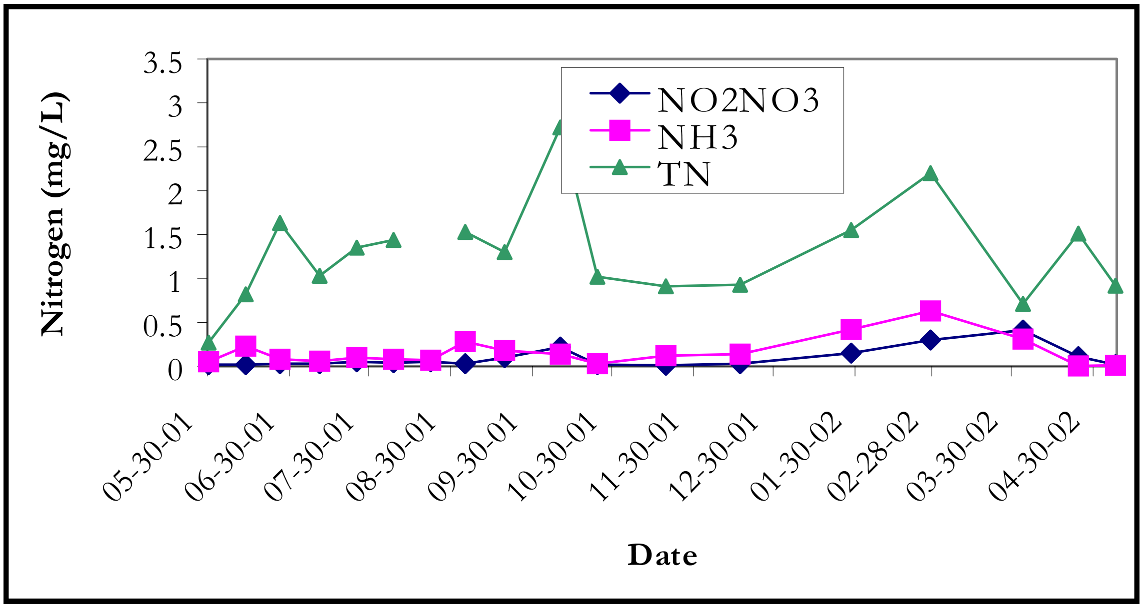

Figure 22. Total nitrogen, NH3, and NO2NO3 concentration in the Little Saskatchewan River at Rivers.

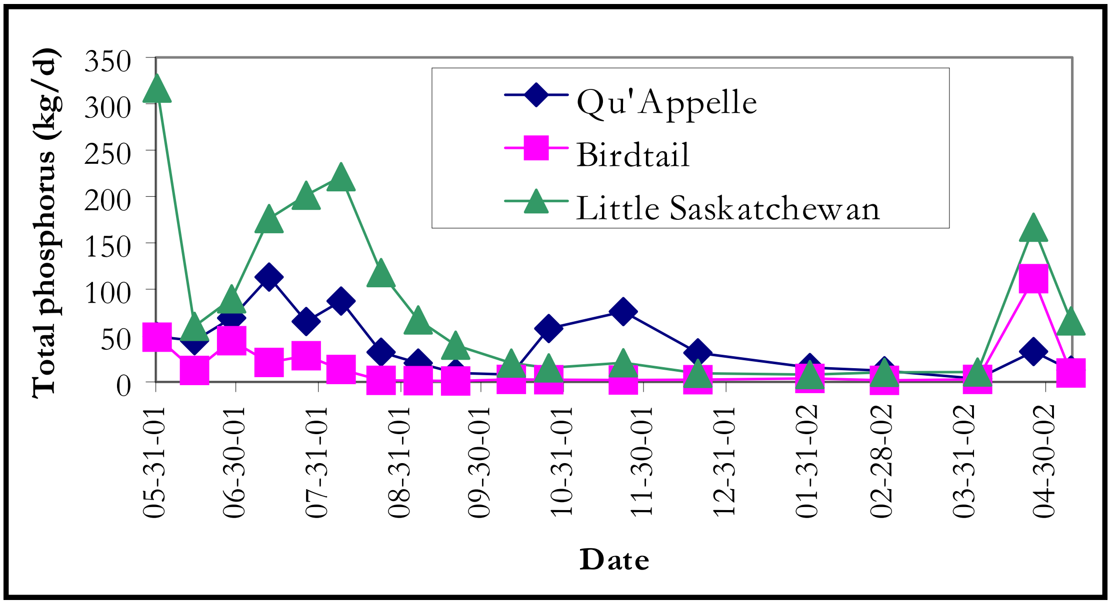

Figure 23. Seasonal fluctuations in total phosphorus loading to the Assiniboine River from the three major tributaries.

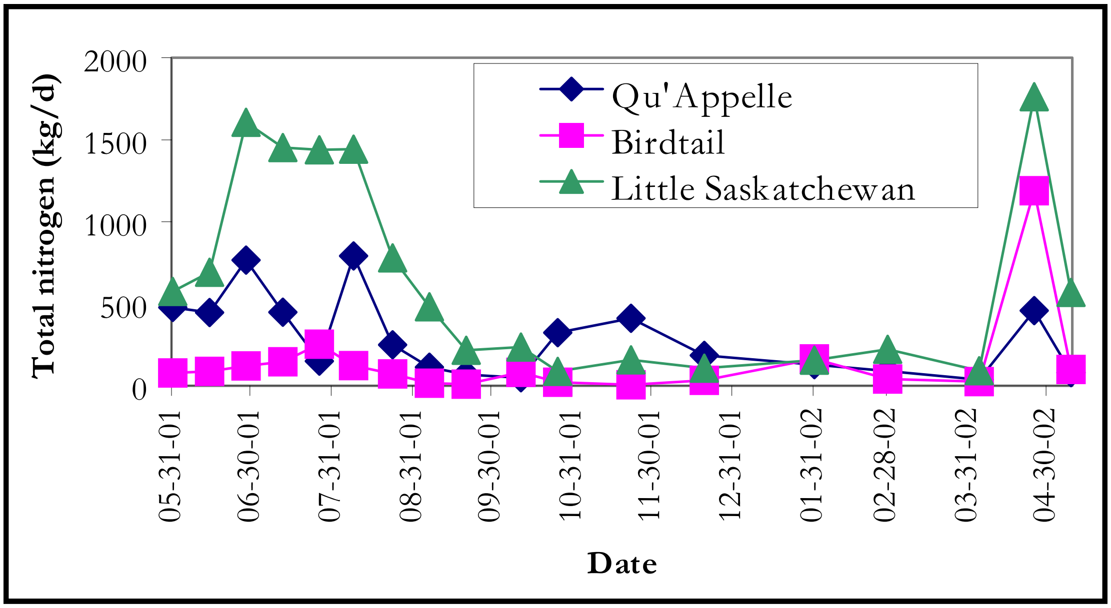

Figure 24. Seasonal fluctuations in total nitrogen loading to the Assiniboine River from the three major tributaries.

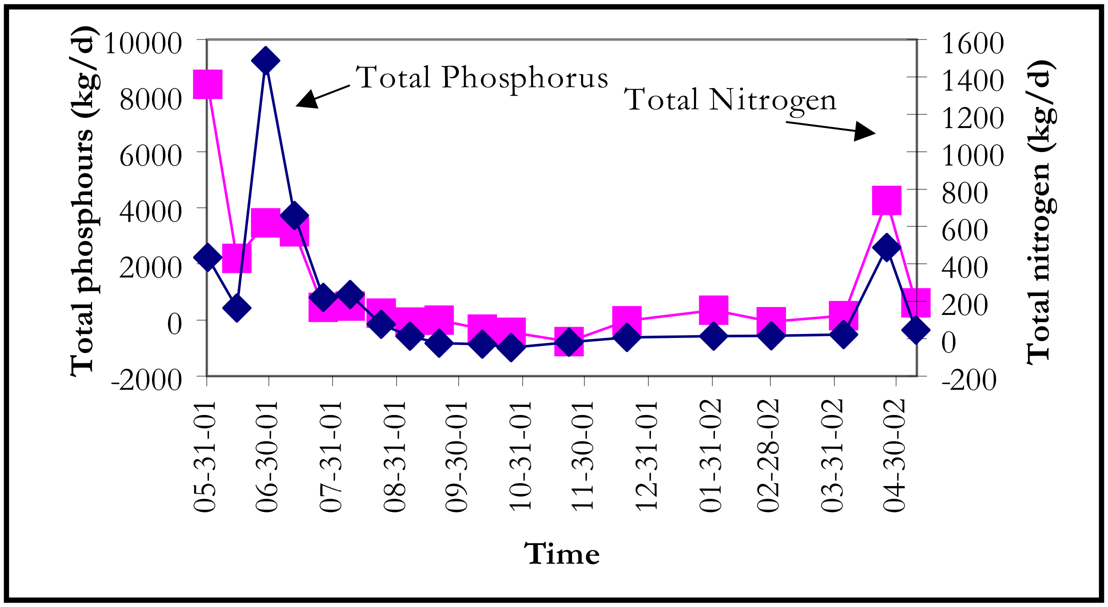

Figure 25. Observed seasonal fluctuations in non-measured inputs of total phosphorus and total nitrogen to the Assiniboine River.

APPENDIX ONE

Table 1. Estimated nutrient loading calculations for wastewater facilities.

Wastewater Facility	Estimated Population Served by Facility	Phosphorus load/capita/d[1]	Influent P load (g/d)	Total P removal efficiency	Effluent P load (kg/yr)	Nitrogen load/capita/d[1]	Influent N load (g/d)	Effluent N load (kg/yr)	Final Discharge
KENTON	200	3.38	676	65.5	85	10	2000	657	Assiniboine River
MCAULEY	200	3.38	676	65.5	85	10	2000	657	Scissors Creek
ELKHORN	470	3.38	1589	65.5	200	10	4700	1544	Bosshill Creek
MINIOTA	215	3.38	727	65.5	92	10	2150	706	Assiniboine River
BINSCARTH	445	3.38	1504	65.5	189	10	4450	1462	Assiniboine River
ANGUSVILLE	200	3.38	676	65.5	85	10	2000	657	Slough
BIRTLE	715	3.38	2417	65.5	304	10	7150	2349	Birdtail Creek
RUSSELL	1587	3.38	5364	65.5	675	10	15870	5213	Silver Creek
FOXWARREN	200	3.38	676	65.5	85	10	2000	657	Snake Creek
OAK LAKE	359	3.38	1213	65.5	153	10	3590	1179	Oak River
OAK RIVER	150	3.38	507	65.5	64	10	1500	493	Oak River

[1] From Chambers *et al*.. 2001

APPENDIX TWO

Land Use and Land Cover Mapping of Manitoba Codes

1. Agricultural Cropland; All lands dedicated to the production of annual cereal, oil seed and other speciality crops. This class can be further sub-divided into three crop 0 % - 33 %, 34 % - 66 %, and 67 % - 100 %.

2. Deciduous Forest;75 % - 100 % of the forest canopy is deciduous. Dominant species include trembling aspen (Populus tremuloides), balsam poplar (Populus balsamifera), and white birch (Betula papyrifera). May include small patches of grassland, marsh or fens less than two hectares in size.

3. Water Bodies; All open water - lakes, rivers, streams, ponds and lagoons.

4. Grassland/Rangeland; Mixed native and/or tame prairie grasses and herbs. May also include scattered stands of willow (Salix L.), choke cherry (Prunus virginiana), pin cherry (Prunus pensylvanica) and saskatoon (Amelanchier alnifolia). Many of these areas are used for cutting of hay and grazing. Both upland and lowland meadows fall into this class. There is normally less than 10 % shrub or tree cover.

5. Mixedwood Forest; 25 % - 75 % of the canopy is coniferous. May include patches of treed bog, marsh or fens less than two hectares in size.

6. Marsh and Fens; Wet areas with standing or slowly moving water. Vegetation consists of grasses and/or sedge. Marshes will include common hydrophytic vegetation such as cattail and rushes. Fens will be formed on minerotrophic sites. Areas are frequently interspersed with channels or pools of open water.

7. Treed and Open Bogs; Peat covered or peat filled depressions with a high water table. The bogs are covered with a carpet of Spagnum spp. and ericaceous shrubs and may be treeless or treed with black spruce (Picea mariana) and/or tamarack (Larix laricina).

8. Coniferous Forest; 75 % - 100 % of the canopy are coniferous. Pine (Pinus spp.) and spruce (Picea spp.) are dominant species. May include patches of treed bog, marsh or fens less than two hectares in size.

9. Open Deciduous; Lands characterized by rough topography, shallow soil, or poor drainage. Supports a growth of shrubs such as willow (Salix spp.), alder (Alnus spp.) saskatoon (Amalanchier spp.) and/or stunted deciduous (Populus spp.) tree cover. An area could have up to 50 % scattered tree or shrub cover.

10. Forage Crops; Consists of perennial forage such as alflafa, and clover or blends of these with tame species of grass. Fall seeded crops such as winter wheat or fall rye are included here.

11. Cultural Features; Built-up areas such as cities and towns, peat farms, golf courses, cemeteries, shopping centres, large recreation sites, auto wreck yards, airports, cottage areas, race tracks.

12. Bare Rock, Gravel and Sand; Exposed areas of bedrock, sand dunes, and beaches, gravel quarry/pit operations, mine tailings, borrow pits, and rock quarries.

13. Roads and Trails; All highways, secondary roads, trails, cut survey lines, right-of-ways, railway lines and transmission lines.