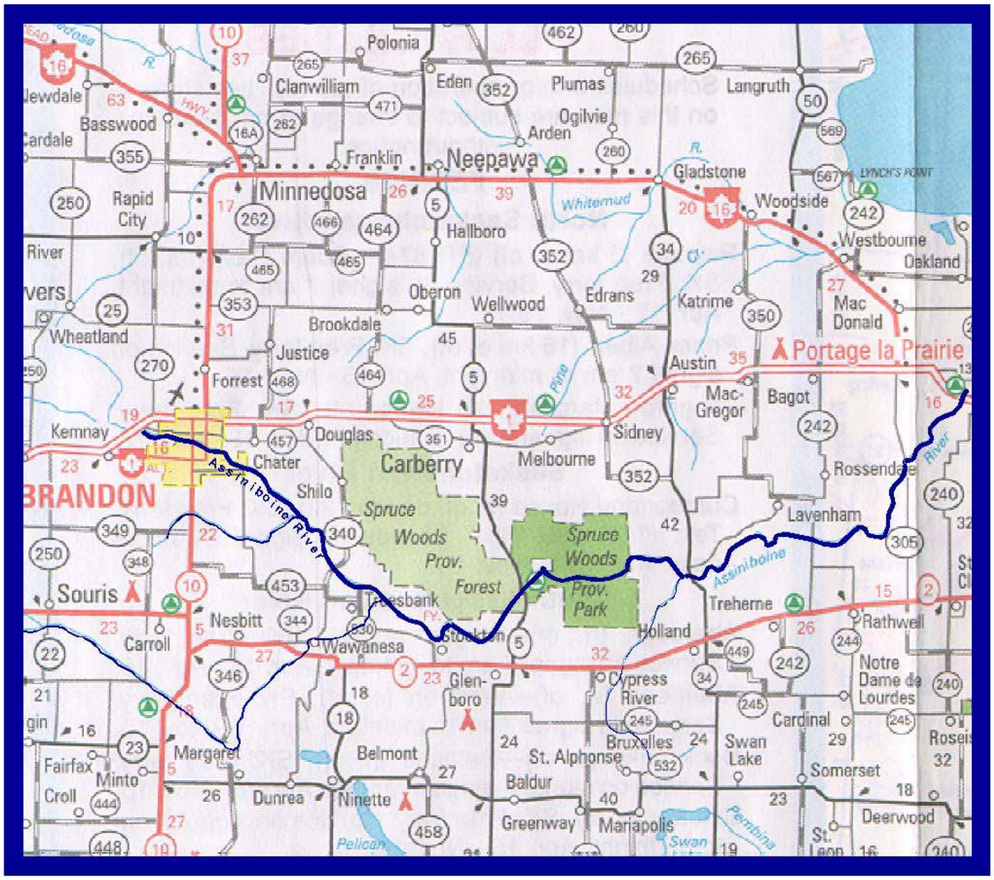
ASSINIBOINE RIVER MONITORING STUDY
WATER QUALITY COMPONENT
WATER QUALITY ASSESSMENT AND MODEL
FOR THE OPEN-WATER SEASON, 2002
MAY 2003



NORTH/SOUTH CONSULTANTS INC.
Aquatic Environment Specialists

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ASSINIBOINE RIVER MONITORING STUDY
WATER QUALITY COMPONENT:
WATER QUALITY ASSESSMENT AND MODEL
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May 2003

A study conducted for the City of Brandon

by

Earth Tech Canada Inc. and North/South Consultants Inc.

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EXECUTIVE SUMMARY

Earth Tech Canada Inc. and North/South Consultants Inc. have been conducting a multi-year study on behalf of the City of Brandon of the Assiniboine River to monitor the effects of wastewater discharge from the Maple Leaf (ML) industrial wastewater treatment facility (IWWTF). The study considered the effect of discharge from the Maple Leaf IWWTF in conjunction with other discharges in the vicinity of Brandon (i.e., the Brandon Municipal WWTF and the Simplot Canada Ltd. fertilizer plant). As part of the study, water quality models, using QUAL2E developed by the United States Environmental Protection Agency (USEPA) have been used to simulate water quality in the study reach under a variety of conditions.

The water quality portion of the monitoring study began in February 1999, with a sampling program focussed on assessing effects related to the input of ammonia and wastes exerting an oxygen demand on the water. Sampling continued with a spring (May 1999) and summer/fall (June-September 1999) program. These studies documented the condition of the river prior to the operation of the Maple Leaf IWWTF (the facility began operating in September 1999, but discharges during the September 1999 study were minimal). Production at the Maple Leaf Plant and effluent discharge have increased since commissioning in September 1999, reaching near one-shift capacity by early 2000. Water quality in the Assiniboine River was examined through intensive monitoring in November 1999 at the time of ice formation, and in early February, May, and June, 2000. Intensive monitoring originally scheduled for summer and fall 2000 was deferred due to high river discharge; however, monitoring at limited sites was continued through September 2000. Additional field work was also conducted through the winter of 2000/2001.

An assessment of water quality and algae data collected in the open-water seasons up to and including the open-water season of 2000 was presented in Cooley et al. (2001a). This report also documented the initial attempts to calibrate water quality models for the open-water season, using QUAL2E. An interpretation of data collected during the ice-cover season, as well as presentation of a calibrated model for winter, have also been completed (Cooley et al. 2001b).

This report provides an analysis and interpretation of water quality data collected during June, July, and August/September 2002, in completion of the sampling program that was deferred in the open-water season of 2000. Results of water quality model development for these time periods, using QUAL2E, are also provided. River discharge was low in the open-water season of 2002, thus providing the opportunity to evaluate effects of effluent discharges on water quality under conditions of low flow. Issues discussed include those related to oxygen, ammonia, and algal populations/nutrient loading. Data collected in the open-water season of 2002 are presented in Toews (2002). All other water quality data collected during the course of the study, including parameters not discussed in this report, have been presented previously (Schneider-Vieira et al. 1999 and 2000, Toews and Schneider-Vieira 2000, Toews et al. 1999, 2000, 2001).

Sampling

Vertically integrated water samples were collected from the Assiniboine River for the analysis of ammonia, nitrate/nitrite, total Kjeldahl nitrogen, orthophosphate, total and dissolved phosphorus, dissolved reactive silica, chlorophyll *a*, total suspended solids, and carbonaceous 5-day biochemical oxygen demand. Samples at selected sites were also microscopically examined for phytoplankton. Dissolved oxygen, pH, turbidity, conductivity, and temperature were measured *in situ*.

Samples were collected at 14 sites along a 300 km reach of the Assiniboine River, with three samples collected per site across transects of the river at Sites 2 through 8 (Brandon to Treesbank), and two samples collected per site at Site 1 and from Site 9 downstream to Site 14 (Stockton to the Portage la Prairie reservoir). The timing of sample collection was staggered to permit sampling within approximately the same parcel of water as it moved downstream from Brandon. Major tributaries and point source inputs of nutrients to the river were sampled, including the Souris River, the discharge from the Brandon Municipal and Maple Leaf WWTFs, and the municipal municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon. Other tributary streams were also sampled during the monitoring programs conducted in the open-water season of 2002 to evaluate other potential nutrient sources to the Assiniboine River (previous studies had not included sampling of these sources).

Samples were also collected weekly at selected sites (Site 3C, 8C, and 13C) from July through the beginning of September, 2002 to evaluate changes in the phytoplankton communities. Periphyton (attached algae) was sampled at selected sites in the mixing zone, during the conduct of the intensive monitoring program to evaluate conditions with respect to attached algal growth, as had been done in previous programs. A periphyton survey was also conducted in early August to evaluate the presence of suitable substrata and the densities of periphyton in areas downstream of the mixing zone that are not typically accessed during the conduct of the monitoring program. Additional measurements collected in the open-water season of 2002 included measurements of sediment oxygen demand and light extinction, to aid in model development and assessment of conditions in the river.

Results

Ammonia

Ammonia was included in the study as it is released in the ML IWWTF effluent, as well as other discharges near Brandon, and in high concentrations is toxic to aquatic life. During the open-water season of 2002, the combined effects of the inputs at Brandon increased ammonia concentrations in the river, although concentrations were reduced to near or slightly above background levels between 20 and 60 km downstream of the ML IWWTF outfall. All ammonia concentrations in the river were below site-specific water quality objectives within and downstream of the mixing zone (Williamson 2002). Overall, ammonia concentrations decreased rapidly downstream of effluent outfalls and were not high enough to pose a threat to aquatic biota. During intensive monitoring periods in the open-water season of 2002, ammonia loads discharged from the IWWTF were low (i.e., < 1kg/day).

Oxygen

Dissolved oxygen is essential for the survival of most aquatic life and is one of the basic parameters used to assess the integrity of aquatic ecosystems. In general, daytime DO concentrations were high in the study area (at the times measured) during the intensive monitoring periods and were typically in excess of 80% saturation. Several exceptions to this generalization occurred in the mixing zone in June and July 2002. In addition, DO concentrations in the mixing zone in July 2002 were lower than observed in either June or July, 2002 or in previous years (Cooley et al. 2001a) or in June and August 2002 and several individual measurements obtained were below Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs). These 'exceedences' were likely due to the combination of low upstream DO, high water temperatures, and effects of effluent inputs (i.e., biological uptake).

There is some evidence of overnight oxygen depletion in the study area in the growing season, based on continuous DO measurements collected during the intensive monitoring periods and by Manitoba Conservation. Collectively, dissolved oxygen data collected in 2000 and 2002 indicate that photosynthesis and respiration by periphyton, and to a lesser extent phytoplankton, within the mixing zone contribute to wide fluctuations in daily dissolved oxygen concentrations. During some time periods, overnight DO concentrations fell below the acute DO objective of 5 mg/L at Site 8. Measurements collected at other sampling locations also indicated significant decreases in DO overnight.

Nutrients and Algae

Inputs of nitrogen and phosphorus may stimulate the growth of algae, including both attached forms (periphyton) and floating (phytoplankton). The potential for proliferation of algae in the water column was identified as a key concern in this study, in particular in relation to water quality in the Portage Reservoir.

Overall, during the sampling periods in June, July, and August/September 2002, the City of Brandon Municipal WWTF and the Maple Leaf IWWTF collectively increased the total phosphorus load carried by the Assiniboine River at Brandon by 141%, 129%, and 146%, respectively. The combined discharge of the effluents from the City of Brandon Municipal WWTF and the Maple Leaf IWWTF and the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon increased the total nitrogen load in the Assiniboine River at Brandon by 84%, 98%, and 103% during the June, July, and August/September sampling periods, respectively.

Synthesis

Data collected during the open-water season of 2002 improved our understanding of ammonia and oxygen dynamics during the growing season, as well as provided insights into the relationship between nutrient inputs at Brandon and algal growth. These data were particularly important because they provided information on the conditions in the river under low flow conditions, as well as the effects of effluents on water quality under these low discharges.

The following points synthesize our current understanding of conditions in the Assiniboine River during the growing season and the effects of effluents on water quality in the study area, based primarily on information gathered during June, July, and August/September 2002, and to a lesser extent, data collected in May and June 2000.

Ammonia

- The largest point source of ammonia to the study area was the Brandon Municipal wastewater treatment facility (WWTF) effluent during the monitoring periods in 2002. The municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon also contributed a significant load of ammonia, most notably in June 2002. The ML IWWTF discharged less than 1 kg/day of ammonia during the conduct of the intensive monitoring programs, which was one to two orders of magnitude lower than upstream loads in the river.

- Some tributary streams and drains also contributed significant loads of ammonia at certain times in the open-water season 2002 (e.g., the Cypress River contributed 11.5 kg/day of ammonia in June 2002). These loads were often higher than those originating from the ML IWWTF.

- Effluents caused a measurable increase in the in-stream concentrations of ammonia within the mixing zone.

- All ammonia concentrations measured in the study area in 2002 were within the proposed MWQSOGs (Williamson 2002), as observed in earlier studies.

- Ammonia loads in effluents were rapidly removed from the water column, likely as a result of biological processes (e.g., uptake by algae, nitrification).

- Large declines in ammonia concentrations within the mixing zone were observed in the open-water season of 2002, as observed in May and June 2000.

- As the relative contributions of algae (i.e., phytoplankton and periphyton) and bacteria (i.e., nitrification) to the observed reduction in ammonia in the river were not determined, the extent to which ammonia dynamics would be affected by conditions not favourable for algal growth (e.g., low light) is not known.

- Accumulation of ammonia by periphyton is believed to play a role in reducing ammonia concentrations in the water column, notably in the mixing zone where periphyton are abundant. However, the relative magnitude of this route compared to other factors that may reduce ammonia loads is not known.

Oxygen

- In general, DO was high in the study area and was typically in excess of 80% saturation.

- In June and July 2002, lower DO concentrations were observed in the mixing zone around Sites 6 and 7.

- DO concentrations at Sites 6 and 7 in July 2002 were below the acute (and chronic) water quality objective. These low concentrations were believed to reflect high water temperatures, low upstream DO concentrations, and effects of effluents (i.e., biological activity).

- Declines in DO were observed overnight at all sites examined, including Sites 5, 6, 8, 9, 12, and 14.

- Wide diurnal fluctuations in DO were observed in the mixing zone. For example, DO dropped by approximately 8 mg/L overnight at Site 6 in August. This was thought to largely reflect the effect of dense periphyton growth in this area, and to a lesser extent, phytoplankton.

- During some periods, DO concentrations fell below the acute water quality objective (5 mg/L) overnight at Site 8.

- High densities of periphyton may be associated with extreme fluctuations in oxygen concentrations, and the occurrence of critically low levels overnight, in the growing season.

- Sloughing and die-off of periphyton in fall would also contribute to oxygen depletion through decay.

Nutrients and Algae

- Algal growth is potentially limited by many factors, including flow, light, temperature, and nutrients. Site-specific characteristics (e.g., appropriate substrata for attached algae) are also important.

- Examination of nutrient concentrations and ratios indicated that, in instances where other factors do not limit growth, nitrogen was the nutrient which would limit algal production in much of the Assiniboine River under low flow conditions. It should be noted that a few species of bluegreen algae are able to fix atmospheric nitrogen; these groups may become relatively more abundant and form large blooms in nitrogen-limited water if other factors (e.g., temperature) are favourable. Typically, nitrogen limitation occurs at Sites 1 and 2, upstream of effluent sources, and downstream of the mixing zone. In July 2002, upstream concentrations were high and nitrogen limitation did not occur in this area.

- In June, July, and August/September 2002, phosphorus concentrations were well above the levels where algal growth would be limited and consistently above MWQSOGs for phosphorus in streams at all sites in the study area (i.e., upstream and downstream of effluent inputs at Brandon).

- Data and modelling exercises indicate that there may be an unidentified source of nutrients, algae, and total suspended solids beyond Site 9 or 10. Loads of these substances notably increased at Sites 11, 12, and 13 in June, July, and August 2002 in the river, although modelling predictions indicated that in-stream loads/concentrations should have remained quite constant.

- Effluents increased the concentrations of nitrogen and phosphorus in the mixing zone. In general, the largest sources of nitrogen and phosphorus to the river were the Brandon Municipal WWTF and the ML IWWTF. At times the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was a large source of nitrogen.

- Nitrogen and phosphorus concentrations and loads declined markedly in the mixing zone. Comparisons between mass-balance model simulations and observed loads of nitrogen and phosphorus indicated a substantive loss of nutrients was occurring in the study area, notably in the mixing zone. Similar observations were reported previously (Cooley et al. 2001a).

- Tributary streams, most notably the Cypress and Souris rivers, were also major sources of total nitrogen and phosphorus to the Assiniboine River, with the relative contributions varying somewhat over the sampling periods.

- Chlorophyll *a* concentrations in June 2002 were markedly greater (ranging from 11 µg/L to 46 µg/L) than in previous years, and those observed in July and August/September 2002. Most measurements were above what are considered 'nuisance levels' by some jurisdictions (Rounds and Wood 2001).

- Chlorophyll *a* concentrations in July and August/September ranged from <5 to 15 µg/L, similar to previous studies.

- High chlorophyll *a* concentrations observed in the mixing zone reflected algae discharged in effluents and sloughed benthic algae and not solely algae (i.e., phytoplankton) that were reproducing in the river.

- Conversely, as in 2000, high densities of periphyton were observed in the mixing zone, during the intensive monitoring periods. Densities, which ranged from 492 mg/m^2 to 1138 mg/m^2, in the mixing zone (Sites 5, 7, and 8) were consistently and notably above numeric criteria (50 mg/m^2 or 100 mg/m^2) proposed by other jurisdictions for the protection of aquatic life (Carr and Chambers 1998).

- Observed chlorophyll *a* concentrations and nutrient concentrations, in conjunction with model simulations, indicate that the observed decline in nutrients in the mixing zone was not solely due to phytoplankton growth. Removal of nutrients by periphyton likely plays a role in this decline.

- The proportion of the biomass of periphyton in the mixing zone which can be attributed to nutrient input from the Maple Leaf IWWTF and the Municipal WWTF has not been determined. The flux of nutrients from the water column indicates that these substances may be taken up by the attached algae in this area; however, high densities of periphyton were also found on suitable substrata upstream of the nutrient inputs at Brandon, as well as at sites downstream of the mixing zone.

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1.0 INTRODUCTION

Earth Tech Canada Inc. and North/South Consultants Inc. have been conducting a study, on behalf of the City of Brandon, to determine the effects of effluent release from the industrial wastewater treatment facility (IWWTF) constructed for the Maple Leaf (ML) Pork's processing facility on water quality in the Assiniboine River. The main objective of this study was to evaluate the effect of effluent from the ML IWWTF in conjunction with other major inputs at Brandon, specifically the City of Brandon Municipal wastewater treatment facility (WWTF) and flow from a municipal drainage ditch that receives discharge from both the Simplot Canada Ltd. fertilizer plant and Manitoba Hydro's Brandon Thermal Generating Station ash lagoon.

A preliminary assessment of the potential effects of effluent from the IWWTF on water quality in the Assiniboine River was completed in June 1998 (Lawrence and Bernhardt 1998). The predictions made in that assessment were based on existing data and results of model simulations using the Water Quality Analysis Simulation Program (WASP) developed by the United States Environmental Protection Agency (USEPA). A multi-year sampling program was developed to address information deficiencies identified in the preliminary assessment and to monitor effects on the Assiniboine River during the initial phase of operation of the Maple Leaf IWWTF.

The study has addressed two major issues:

i) the effect of effluent addition on the aquatic environment at, and downstream of, the Maple Leaf IWWTF, with respect to ammonia and dissolved oxygen (DO); and,

ii) the effect of nitrogen (N) and phosphorus (P) inputs on the growth of phytoplankton (algae in the water column), and to a lesser extent periphyton (attached algae), in particular with respect to effects on water quality for downstream users, including the City of Portage la Prairie.

These issues were addressed by two approaches:

i) conditions in the river just prior to and during initial operation of the Maple Leaf IWWTF were monitored within the study area, extending from the 18th Street Bridge in Brandon (upstream of any effluent inputs at Brandon) to immediately upstream of the control structure at Portage La Prairie (Figure 1). Measurements of critical water quality parameters provided information as to conditions in the river, and provided the basis for assessing effects of effluent from the Maple Leaf IWWTF; and,

ii) water quality models were developed to provide the following:

- simulations of water quality under varying conditions, both natural (e.g., river discharge) and due to development (e.g., effluent loading);
- an insight into mechanisms affecting water quality under existing conditions, in particular during critical conditions (e.g., low flows,) to reduce the need for continuous field monitoring; and,
- identification of factors critical in determining the levels of environmentally important parameters to assist in planning future development.

The Assiniboine River Monitoring Study was initiated in fall 1998 with an examination of fish habitat in the Assiniboine River within, as well as areas immediately upstream and downstream of, the mixing zone of the proposed IWWTF (Toews and Schneider-Vieira 1999). Field work to develop an hydraulic model of the river between Brandon and Portage la Prairie began in late 1998 and continued through 1999. An initial hydraulic model was completed in late 1999 (Reid Crowther & Partners Ltd. 1999), the model was revised on several occasions (Earth Tech Canada Inc. 2001), and most recently, the model was converted to a HEC-RAS format.

The first samples for the water quality assessment were collected in February 1999 (Schneider-Vieira et al. 1999) and from May through September 1999 (Toews et al. 1999) to assess conditions during the ice-cover and open-water seasons prior to operation of the Maple Leaf IWWTF. The IWWTF began operating in September 1999; however, discharges in September were small and did not have a significant effect on river water quality (Toews et al. 2000). Post-operational samples were collected for winter monitoring in late November 1999 and February 2000. Monitoring during the open-water season was scheduled for the period of April through September 2000. Intensive sampling beyond the June 2000 period was aborted due to the occurrence of flood conditions in the study area and was deferred until such time that low river discharge conditions occurred. Thereafter, sampling was conducted at a reduced density (i.e., biweekly at Sites 3, 8, and 13 only) in the open-water season of 2000.

An assessment of water quality and algae data collected in the open-water seasons up to and including the open-water season of 2000 was presented in Cooley et al. (2001a). This report also documented the initial attempts to calibrate water quality models for the open-water season, using the Enhanced Stream Water Quality Model (QUAL2E), which is supported and distributed by the United States Environmental Protection Agency (USEPA). An interpretation of data collected during the ice-cover season, as well as presentation of a calibrated model for winter, have also been completed (Cooley et al. 2001b).

Low river discharges occurred in the open-water season of 2002 and three rounds of intensive monitoring were conducted in June, July, and August/September of 2002 to complete the post-project monitoring program that was deferred due to high flows in June 2000. This report presents: (i) an analysis of conditions in the Assiniboine River in the open-water season based on data collected in June, July, and August/September 2002; and, (ii) results of water quality modelling using the QUAL2E model for the open-water period, based on data collected in June, July, and August/September 2002. Details regarding the modelling are presented in Appendix 1.

2.0 ENVIRONMENTAL SETTING

2.1 STUDY AREA

The area under study consists of approximately 300 km of the Assiniboine River, extending from the 18th Street Bridge in the City of Brandon eastward to just upstream of the control structure at the City of Portage la Prairie (Figure 1). A description of various influences to the river (such as tributaries), and their locations relative to the sampling sites used for monitoring purposes in the Assiniboine River Study, is provided in Table 1.

Within the reach of the river included in the study area are two fixed weirs: (1) at 3rd Street in Brandon; and, (2) at Manitoba Hydro's Brandon Thermal Generating Station, just downstream of Brandon. East of Brandon, the river flows for approximately 60 km through land that is primarily agricultural, with a high proportion of pasture. Portions of this reach contain riffles and rapids (particularly near sampling Sites 4 and 5). The 100 km reach of the river east of the town of Stockton (Site 9) is primarily parkland (Figure 1). Near the confluence with the Souris River, the substrata underlying the Assiniboine River undergo a gradual transition from predominantly cobble and rock to sandy sediments. The last 100 km of the Assiniboine River in the study reach is surrounded mainly by cultivated agricultural land. Impoundment at the Portage la Prairie control structure creates a mud-bottomed reservoir that is approximately seven kilometres long. Each winter, this reservoir is drawn down, confining flow to the original river channel.

2.1.1 Sources of River Discharge

Significant sources of water to the Assiniboine River within the study area in the open-water season are the Souris River and groundwater from the Carberry Aquifer, which underlies the Assiniboine River from Brandon to approximately the community of Lavenham (just upstream of Site 12). Groundwater from the aquifer enters the river via springs, which may discharge either above or below the surface of the river. Smaller tributaries within the study area include Willow Creek, the Little Souris River, Five Mile Creek, Epinette Creek, and the Cypress River. Two drains, one located upstream of Site 8 and the other located upstream of Site 13, have also been observed to discharge to the Assiniboine River during some periods in the open-water season. Additionally, surface runoff may contribute a significant fraction of river discharge, as well as direct inputs from precipitation during the open-water season.

2.1.2 Wastewater Inputs

Three point sources of ammonia and oxygen-consuming substances (i.e., biochemical oxygen demand, BOD) within the study area are the wastewater discharges from the Brandon Municipal WWTF, the Maple Leaf IWWTF, and the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon. Within the City of Brandon, the river also receives discharge from four combined sewer overflows, the furthest upstream being located just downstream of the 18th Street Bridge.

The municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon enters at the left bank of the river (looking upstream) approximately 1 km downstream of the thermal generating station weir, or about 13 km downstream of the 18th Street Bridge. The operating licence for Simplot Canada Ltd. limits discharge to the period of September 15 to May 15.

Approximately 4 km downstream of the generating station weir, along the right bank, is the outfall from Cell 5 of the municipal lagoon system, which is the normal discharge point from the City of Brandon Municipal WWTF. The outfall from the Maple Leaf IWWTF is located approximately 500 m further downstream, on the opposite bank of the river.

Approximately 700 m downstream of the Maple Leaf IWWTF outfall, on the right bank, is the outfall from Cell 3 of the municipal lagoon system, which is normally only used when volumes of wastewater are very high, such as during prolonged heavy rainfall events. This outfall was not used during the conduct of water quality monitoring in the open-water season of 2002.

2.2 CONDITIONS DURING DATA COLLECTION: OPEN-WATER SEASON 2002

2.2.1 River Discharge

Water Survey of Canada measures discharge of the Assiniboine River upstream of Brandon and at Holland, approximately 170 km downstream of Brandon. Differences in discharge between these two sites during the open-water season are primarily due to inputs from the Souris River, smaller streams such as the Cypress River, and groundwater. Median, 1Q10 (the lowest 1-day flow expected within a 10 year period), 7Q10 (the lowest 7-day average flow with a return frequency of 10 years), and 30Q10 (the lowest 30-day average flow within a 10 year period) river discharges for the months of April - November are presented in Tables 2 to 5, respectively. Discharges measured during the monitoring periods in the open-water season in 2002 are presented in Figures 2 through 4.

2.2.1.1 June 2002

Flows in the Assiniboine and Souris Rivers at the start of the June sampling period were near lower decile levels (Figures 2-4). However, heavy rain beginning 8 June created substantial runoff and elevated river discharge, particularly in the Assiniboine River. Due to the spatial variability of the heavy rain events, accurate estimates of discharge in portions of the river downstream of Site 9 at the time of sampling were difficult to determine. High flows in small tributaries and visibly elevated suspended sediment in tributaries and in the Assiniboine River were observed during sampling in the downstream end of the study reach.

2.2.1.2 July 2002

Weather during the July sampling period was mainly clear with daytime high temperatures between approximately 26EC and 30EC. Water temperatures were also atypically high during the July sampling period, ranging from 22.8 to 29.4 ^{o}C. For comparison, the maximum observed water temperature at the Manitoba Conservation water quality monitoring station at Brandon for the month of July over the period of 1993 to 2002 was 22.5 ^{o}C and the median temperature for the same period was 19.8 ^{o}C. Heavy rain at and upstream of Brandon during the week prior to the sampling period produced a crest of approximately 30 m^3/s in the Assiniboine River (http://www.gov.mb.ca/conservation/watres/index.html 12 July 2002). Sampling coincided with the tail end of this crest from Brandon to Portage la Prairie (Figures 2 and 3). During this period, the Souris River discharge was above the median level due to heavy rains in the U.S. portion of the watershed in June.

2.2.1.3 August 2002

As with the previous two sampling periods, heavy rain preceded the late August/early September sampling period, with 25 - 50 mm of rain falling within the study area between 16 and 18 August. From 20 to 28 August, the weather was generally clear (except for 21 August), with morning low temperatures between 9EC and 14EC, and highs between 23EC and 31EC. The weather on 28 - 31 August was cooler and overcast with thundershowers, and from 3 to 5 September was clear with high temperatures of 23 - 25EC.

The August sampling period took place during a period of increasing flows in the Assiniboine River due to preceding heavy rainfall and increases in water release from the Shellmouth and Rivers reservoirs in early August. At the time of sampling, Assiniboine River discharge was approaching the median level (Figures 2 and 3). Discharge in the Souris River, however, had been reduced in late July, and was near the lower decile at the time of sampling (Figure 4).

2.2.1.4 Sources of Discharge

The contribution of various sources of flows to the discharge of the Assiniboine River at Portage varied considerably across the sampling periods (Table 6). During data collection in the open-water season of 2002, incoming river flows measured at Brandon comprised approximately one half the flow in the Assiniboine River near Portage la Prairie. Flow from the Souris River contributed less than 10% of total Assiniboine River flows by Portage in June and August but almost 30% of flows for the July sampling period. Flows from tributaries other than the Souris River comprised relatively small fractions of flow in July and August but approximately 11% of total flow of the Assiniboine River at Portage in June. The higher contribution in June is likely a reflection of heavy rains at this time. “Other flows”, which are defined as the combination of groundwater flows and point and non-point sources not captured in the sampling program, comprised as much as 42% of total river discharge at Portage. These ‘other sources’ can therefore be quite significant in defining river discharge in the Assiniboine River.

2.2.2 Effluent Inputs at Brandon

2.2.2.1 Municipal WWTF

Concentrations and loads of relevant water quality parameters for the Brandon Municipal Cell 5 effluent discharges measured during the June, July, and August/September 2002 monitoring periods are presented in Tables 7 to 12. Effluent quality data for the open-water season 2002 provided by the City of Brandon are presented in Table 13.

2.2.2.2 Maple Leaf IWWTF

Concentrations and loads of relevant water quality parameters discharged by the Maple Leaf IWWTF measured during the monitoring periods in June, July, and August/September 2002 are presented in Tables 7 to 12. Concentrations and loads of relevant parameters for the Maple Leaf IWWTF effluent discharges for the open-water season 2002, as reported by the City of Brandon, are provided in Table 14.

The Maple Leaf IWWTF began operating in September 1999, with subsequent ramping up of effluent discharges to a single-shift capacity. During monitoring periods in June, July, and August/September 2002, production was near full one-shift capacity. Effluent quality for some parameters varied considerably from that observed during the conduct of earlier open-water season monitoring (i.e., 2000). Specifically, effluents discharged during the 2002 monitoring periods contained considerably higher loads of nitrogen than those discharged during the monitoring periods in 2000 (Cooley et al. 2001a). The increased nitrogen loading was largely due to higher loads of nitrate/nitrite-nitrogen in the effluent in 2002; loads increased by a factor of about 2 to 4 times that observed in 2000. Loads of phosphorus, however, were quite similar between 2000 and 2002.

2.2.2.3 Municipal Drainage Ditch That Receives Discharge From the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon

The municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was monitored during the sampling periods in 2002. The Environmental Act Licence for Simplot Canada permits effluent discharges from September 15 to May 15. However, previous studies have demonstrated that this municipal drainage ditch is a substantive source of nutrient loading, particularly for nitrogenous compounds, during the summer months when no discharge from Simplot Canada occurs. Therefore, routine sampling at the outfall of this municipal ditch was incorporated into the monitoring program after July 1999 and continued in 2002.

Concentrations and loads of relevant water quality parameters measured in the municipal drainage ditch during the intensive monitoring periods in June, July, and August/September 2002 are presented in Tables 7 to 12.

3.0 DATA COLLECTION

3.1 SAMPLE COLLECTION

Water sampling for model calibration was conducted in a staggered fashion for three intensive monitoring periods: June; July; and, August/September 2002. Monitoring of selected nutrients and phytoplankton was conducted weekly from July 15 through September 11, 2002, at Sites 3, 8, and 13.

Detailed descriptions of materials and methods used in these sampling programs, as well as data collected for each of the study components, are provided in Toews (2002).

3.2 WATER SAMPLING

For the collection of data to be used in the development of the water quality models, vertically integrated water samples were collected from 14 sites on the Assiniboine River (Table 1, Figure 1). Three samples (designated left, center, and right facing upstream) were collected in transects across the river at each of Sites 2 - 8, and two samples were collected at each of Sites 1 and 9 to 14. Point sources of discharge to the river were also sampled, including the Souris River and the discharges from the Maple Leaf IWWTF, the Brandon Municipal WWTF, and the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon. Additional tributaries were sampled during these studies, where discharge exceeded 0.1 m^3/s. These included Willow Creek, the Little Souris River, Five Mile Creek, Epinette Creek, and the Cypress River. Two drains, one located upstream of Site 8 and the other located upstream of Site 13, have also been observed to discharge to the Assiniboine River during some periods in the open-water season. These drains were sampled when flow was significant (i.e., < 0.1 m^3/s).

Samples were submitted to Enviro-Test Laboratories in Winnipeg for analysis of dissolved ammonia nitrogen, dissolved nitrate/nitrite-N, total and dissolved Kjeldahl nitrogen, dissolved orthophosphate, total and dissolved phosphorus, chlorophyll *a*, pheophytin, dissolved reactive silica, total suspended solids (TSS), and carbonaceous biochemical oxygen demand (CBOD). Dissolved oxygen, specific conductance, turbidity, and temperature were measured *in situ*. Samples were also collected from selected sites and submitted to Algal Taxonomy and Ecology for analysis of total algal biomass and taxonomic identification.

The collection of samples was staggered, to the extent possible, to permit sampling from the same parcel of water as it moved from Brandon to Portage la Prairie. Travel times of water in the river were estimated through use of a revised hydraulic model, initially developed as part of the Assiniboine River Monitoring Study (Reid Crowther and Partners 1999, Earth Tech Canada 2001). Prior to each sampling episode, predicted river discharge values were obtained from Manitoba Conservation Water Resources Branch, and the hydraulic model was used to estimate appropriate sampling times. During data analysis, river travel times were regenerated, using revised daily river discharges, to account for any differences between predicted and measured river discharge values.

3.3 OTHER MEASUREMENTS

3.3.1 Light Extinction

Light extinction coefficients, a measure of the light penetration in a water column, were derived from measurements of light intensity taken at varying depths in the river with a Li-Cor Model LI-185 quantum/radiometer/photometer, connected to a Li-Cor Model 192S underwater light sensor. Site-specific light extinction coefficients were obtained by plotting the linear regression of the natural logarithm of the percentage of surface radiation remaining at each depth interval, versus water depth. These measurements were obtained from selected sites in July and August 2002; equipment malfunction prevented collection of measurements in June 2002.

3.3.2 Attached Algae

The growth of attached algae was monitored during the intensive sampling periods in the open-water season 2002 through qualitative (observation) and quantitative (analysis of biomass and chlorophyll *a*) approaches. Attached algae were collected from natural cobble in June, July, and August 2002 and were submitted for analysis of chlorophyll *a* and dry weight to Enviro-Test Laboratory.

Additionally, a periphyton survey was conducted in August 2002 to evaluate the presence and distribution of attached algae in areas of the river not typically accessed during the intensive (and other) sampling periods. The survey was prompted by the need to determine the presence of suitable substrata and growing conditions in areas outside of the mixing zone and the colonization and densities of periphyton in these areas. This information was identified as important towards the assessment of the potential effects of effluent discharges from an upgraded

IWWTF (with respect to second shift operation of the Maple Leaf plant) on the growth of algae. Detailed results of this survey are presented in Appendix 2.

3.3.3 Sediment Oxygen Demand (SOD)

Sediment cores were collected from Sites 12R, 13R, 7L, and at Treesbank (between Site 8 and the Souris River) in September 2002 for analysis of SOD. Detailed methods of the collection of the cores and SOD analysis are provided in Toews (2002).

3.4 DEVELOPMENT OF A WATER QUALITY MODEL

Appendix 1 presents the results of model calibration exercises for the June, July, and August/September 2002 sampling periods. Model calibration was conducted using QUAL2E modelling software. Several water quality models were developed to address the need to account for varying conditions across the open-water season. A detailed description of model development is provided in Appendix 1.

4.0 AMMONIA

Considerable attention has been directed towards studying the effects of ammonia on aquatic biota because at high concentrations, ammonia may be toxic to aquatic life. In aqueous solutions, ammonia exists in equilibrium between the ammonium ion (NH_4^+) and un-ionized ammonia (NH_3). The toxicity of ammonia to aquatic biota is related primarily to the concentration of un-ionized ammonia. The relative concentrations of ammonium ion and un-ionized ammonia are largely dependent on pH and water temperature, with the fraction of un-ionized ammonia increasing as a function of pH and temperature. Additionally, the acute toxicity of un-ionized ammonia may be affected by several factors, including pH, temperature, dissolved oxygen concentration, carbon dioxide concentration, fluctuating or intermittent exposure regimes, salinity, and the presence of other toxic substances (USEPA 1998).

4.1 REGULATION OF AMMONIA LEVELS

The proposed Manitoba Surface Water Quality Standards, Objectives, and Guidelines (MWQSOGs) for ammonia are based on total ammonia nitrogen and vary according to the duration of exposure, the presence of early or mature life stages of aquatic life, and the presence of cool- or cold-water species (Williamson 2002). Short-term criteria (i.e., the 'acute' objectives) apply to mixing zones as no part of an effluent plume should be toxic to aquatic life, whereas longer-term objectives (i.e., chronic) apply downstream of mixing zones.

Furthermore, objectives for ammonia are both temperature- and pH-dependent. In general, ammonia toxicity increases with pH and temperature; thus, the objectives for ammonia are most restrictive in alkaline, warm environments. Calculated site-specific objectives for the study area, according to the range of observed pH and temperature, for the sampling periods in June, July, and August/September 2002 are presented in Table 15. In general, the most stringent values are associated with river conditions encountered in July 2002 (high pH and temperature). The lowest objective for a 1-hour averaging duration was 1.58 mg/L, which would apply to the mixing zone. The lowest objectives for a 4-day and 30-day averaging duration were 0.55 mg/L and 0.22 mg/L, respectively, and would apply downstream of the mixing zone.

The current operating licences for the City of Brandon Municipal WWTF (Environment Act Licence # 2351 S2 R) and Maple Leaf IWWTF (Environment Act Licence #2367 S2) do not specify limits for ammonia discharges. Rather, the licences specify that the combined effluents should not cause, or contribute to, the unionized ammonia concentration[1] in the Assiniboine River, at the nearest downstream model-predicted fully-mixed river monitoring station, to rise above the MWQSOG when river discharge is greater than 7Q10 levels[2].

4.2 DISCHARGES OF AMMONIA FROM THE MAPLE LEAF IWWTF

The Maple Leaf IWWTF entered the commissioning period in September, 1999. Concentrations and loads of ammonia, measured during intensive monitoring, discharged by the Maple Leaf WWTF in June, July, and August/September 2002 are presented in Tables 7 through 12. Concentrations and loads of ammonia discharged from May through September 2002, as reported by the City of Brandon, are presented in Table 14.

In general, the loads of ammonia discharged from the IWWTF in the open-water season of 2002 were low (less than 1 kg/day) and similar to those observed during earlier intensive monitoring periods (Cooley et al. 2001a). One relatively higher load of ammonia (13.2 kg/day) was measured on July 10, 2002, as reported by the City of Brandon (Table 14). Overall, loads of ammonia discharged from the ML IWWTF in the open-water season of 2002 were approximately one to two orders of magnitude lower than upstream loads measured in the Assiniboine River (i.e., Sites 1 and 2).

For comparison, the load of ammonia discharged from the Municipal WWTF in June (Figure 5), July (Figure 6), and August 2002 (Figure 7), during the monitoring studies was 75.5 kg/day, 465 kg/day, and 184 kg/day, respectively (Table 16). The load of ammonia discharged from the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was 23.7 kg/day, 1.5 kg/day, and 29.9 kg/day in June, July, and August 2002, respectively (Table 16). Therefore, in general, the ammonia loads from the Maple Leaf IWWTF were small relative to other sources and background conditions in the river.

Overall, concentrations of ammonia discharged in the Maple Leaf IWWTF effluent were relatively low (< 1 mg/L), but higher than upstream 'background' concentrations in the Assiniboine River (i.e., upstream of effluent discharges) during the intensive monitoring periods in 2002.

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[1] The licences were developed when Manitoba Water Quality Objectives (Williamson 1988) still referred to unionized ammonia. Current MWQSOGs refer to total ammonia (Williamson 2002).

[2] The licences were developed when Manitoba Water Quality Objectives (Williamson 1988) still referred to 7Q10 flows only. Current MWQSOGs apply to 1Q10, 7Q10, and 30Q10 flow scenarios (Williamson 2002).

4.3 OTHER INPUTS OF AMMONIA

The largest loads of ammonia to the study area during the monitoring periods in 2002 were consistently contributed by the Brandon Municipal WWTF (Figures 5-7). In June and August 2002, the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was the second largest source of ammonia. In July, this source was less significant. The Cypress River was also a major source of ammonia to the Assiniboine River in June 2002, contributing an estimated load of 11.5 kg/day at that time (Figure 5). For comparison, this load is comparable to the in-stream load of ammonia estimated for Site 9 (downstream of the Souris River) and two orders of magnitude higher than the load discharged from the ML IWWTF.

Loads of ammonia discharged by the Brandon Municipal WWTF in July were considerably higher than at other monitoring periods. The load discharged on July 16, 2002, which discharged to the parcel of water that was being tracked during the monitoring period in July, was 465 kg/day. Discharge from small tributaries in the study area was considerably lower in July than in June and with the exception of Epinette Creek where the ammonia load was estimated at 4.6 kg/day, small tributaries contributed considerably less than 1 kg/day of ammonia to the Assiniboine River (Figure 6).

In August/September 2002, the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was the second highest contributor of ammonia to the study area and loads were two to four orders of magnitude higher than all other sources to the study area, with the exception of the Brandon Municipal WWTF (Figure 7). Discharge from tributaries, including the Souris River, was also less significant in August/September 2002 than in June or July and loads of ammonia from these sources were consistently less than 1 kg/day.

4.4 AMMONIA DYNAMICS DURING SUMMER

Ammonia nitrogen is an intermediate between the conversion of organic nitrogen to nitrates (via nitrites). The main sources of ammonia to surface waters are from the decay of organic nitrogen, excretion from aquatic organisms, and inputs from point and non-point sources (e.g., effluents, runoff from agricultural land). In the aquatic environment, ammonia is taken up by plants and algae and is broken down (in a process known as nitrification) to nitrites and nitrates by nitrifying bacteria. Studies have demonstrated that nitrification occurs in the water and sediments, and that nitrifying bacteria are very sensitive to environmental conditions (Bowie et al. 1985). For example, scouring of sediments caused by flooding can significantly reduce nitrification until the bacterial flora becomes re-established (Bowie et al. 1985). The importance of processes related to the sediments varies with the size of the water body - in large rivers and lakes processes in the water column are relatively more important, while in small rivers sediment processes may have a large influence on water quality (Ambrose et al. 1991). Aquatic plants and algae can use nitrogen in the form of either nitrates or ammonia, although the latter is preferentially accumulated (Bowie et al. 1985).

4.5 AMMONIA IN THE ASSINIBOINE RIVER

Ammonia measurements were collected at fourteen sites from Brandon to Portage la Prairie from June, July, and August/September 2002. Water samples were also collected at limited sites (Sites 3C, 8C, and 12C) during weekly monitoring conducted from July through September 2002. Concentrations of ammonia measured during the intensive monitoring periods in June, July, and August/September, 2002 are presented in Figures 8 to 10.

The upstream ammonia concentrations in the Assiniboine River (Sites 1 and 2) in June (0.004 and 0.012 mg/L), July (0.065 and 0.014 mg/L), and August 2002 (0.005 and 0.006 mg/L) were well within the range of concentrations observed at MB Conservation water quality monitoring station at the Brandon 18th Street Bridge for the respective months, over approximately the last 10 years (Tables 17-19). Upstream concentrations were also similar to those observed in 1999 and 2000 during intensive monitoring.

Inputs of ammonia at Brandon caused ammonia concentrations to rise in the Assiniboine River; however, as with previous years, levels dropped rapidly to near background concentrations by the end or shortly downstream of the mixing zone (i.e., by Site 9). These rapid declines, which were replicated in model simulations (Appendix 1), likely reflect uptake by algae (phytoplankton) and nitrification processes. Comparison between calculated site-specific MWQSOGs for ammonia (Table 15) and observed concentrations in the Assiniboine River indicate that all measurements of in-stream ammonia were below ammonia objectives.

Comparison between the sum of upstream loads of ammonia together with all effluent and tributary loads of ammonia between Site 2 and 8 and the measured loads of ammonia at Site 8 indicate that a substantive quantity of ammonia is lost in the mixing zone (Table 16). Comparison of these data indicate that 27.5 kg/day, 446.2 kg/day, and 213.8 kg/day were lost in the mixing zone in July, July, and August/September 2002. Model simulation results for ammonia for these months were in reasonably good agreement with observed concentrations of ammonia in the mixing zone and downstream, although the model overpredicted ammonia in August, 2002. In the models, sinks for ammonia include conversion to nitrate (i.e., nitrification) and uptake by phytoplankton. It should be noted, however, that the model for July 2002 did not appear to accurately represent actual conditions with respect to nitrogen (i.e., loads and discharges), because the loads from the Brandon Municipal WWTF for the appropriate sampling day appear to be overestimates of nitrogen discharged into the parcel of water that was sampled along the length of river (see Appendix 1 for details). As discussed in Toews (2002), sampling in July coincided with the tail end of a 'crest' in river discharge, which may have contributed to difficulties associated with the accurate representation of river discharge conditions and loading.

5.0 DISSOLVED OXYGEN

Dissolved oxygen is essential for the survival of most aquatic life and is one of the basic parameters used to assess aquatic ecosystem integrity. The amount of oxygen that can be dissolved in water varies with temperature; colder water holds more oxygen than warmer water. Therefore, oxygen values may be reported as absolute concentrations (i.e., mg oxygen/L of water), or as percent saturation (the concentration of oxygen in the water relative to the concentration at equilibrium with air at that temperature).

5.1 REGULATION OF OXYGEN LEVELS

Because of its importance to aquatic life, suitable levels of oxygen are specified in guidelines and objectives for the aquatic environment. Current MWQSOGs indicate several criteria for dissolved oxygen for the protection of aquatic life, based on the averaging duration, temperature, and on the presence of mature or early life stages of fish. Objectives are also specific to waters containing cool-water fish (such as walleye and pike) or cold-water species (such as whitefish and trout). With the exception of burbot, which is typically considered a cold-water species, the Assiniboine River is inhabited by cool-water species. Therefore, the cool-water objectives were applied[3].

In the open-water season when sampling was conducted in 2002 (June - September) water temperature was in excess of 5°C. Under these conditions, two objectives for DO apply for the protection of cool-water species (Williamson 2002):

(1) 7-day averaging duration - 6.0 mg/L:	may not be exceeded more than once every 3 years (on average), under a design flow of 7-day, 3-year, or 7Q10; and,
(2) Instantaneous minimum - 5.0 mg/L:	may not be exceeded more than once every 3 years (on average), under a design flow of 1-day, 3-year, or 1Q10.

The potential oxygen demand of effluents discharged to surface waters is also regulated through specification of allowable inputs of BOD. Treated wastewater from municipal facilities contains

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[3] Cold-water objectives are not considered here because the system is a 'cool-water' system. However, it should be noted that burbot have been identified in this system and burbot is typically considered a cold-water species.

organic compounds that are broken down by bacteria. Many of these decomposition processes require oxygen; organic substances containing carbon are decomposed by bacteria that consume oxygen and release carbon dioxide, while nitrogen-containing substances, including ammonia, are converted to nitrites and ultimately nitrates by nitrifying bacteria in processes that also consume oxygen. Furthermore, mineralization of organic nitrogen to ammonia, although an anaerobic process, contributes to DO consumption indirectly through generation of ammonia. The BOD of a wastewater is a measure of the amount of oxygen that is consumed over a specified period (usually five days) and is, therefore, an indication of the amount of oxygen that substance would remove from the aquatic environment once released. The BOD is a composite measure of the oxygen used to decompose organic carbon-containing substances (carbonaceous BOD or CBOD) and the oxygen used in the nitrification of ammonia and oxidation of nitrite to nitrate (NBOD).

The 5-day BOD in the effluents discharged by the City of Brandon Municipal WWTF and the Maple Leaf IWWTF are each limited by their Environment Act licences to 30 mg/L. The licences also stipulate that effluents should not cause, or contribute to, the reduction of DO concentration in the water column of the Assiniboine River, at the nearest downstream model-predicted location of lowest DO, to less than 5.0 mg/L. The operating licence for Simplot Canada Ltd. does not specify restrictions for the release of BOD or effects of effluent discharge on DO concentrations in the river.

5.2 OXYGEN DYNAMICS DURING THE GROWING SEASON

The following are important in considering the oxygen balance during the growing season:

- Water temperature. The amount of oxygen that water can carry is inversely related to the temperature.

- Oxygen input by re-aeration. Re-aeration is the process whereby water with oxygen concentrations below saturation can become re-saturated with oxygen. Re-aeration rates are affected by characteristics of the river channel such as velocity and depth. Water turbulence, such as that produced by rapids or as water passes over weirs, increases the rate of re-aeration.

- Oxygen use by organisms within the water column. The oxygen demand exerted by large organisms such as invertebrates and fish is insignificant in larger, flowing rivers.

However, the activity of bacteria in the water column may use significant quantities of oxygen, in particular where there is a large amount of organic material available (e.g., high BOD load). Decomposition of organic matter occurs more rapidly at higher temperatures. Therefore, oxygen depletion in the river as a result of BOD decay in the warmer summer months would occur more rapidly than during cooler periods.

- Plants and algae (both in the water column and attached periphyton) produce oxygen during photosynthesis. The rate of photosynthesis depends on light (including photoperiod), nutrients, temperature, and other environmental factors. Therefore, DO may fluctuate significantly over a 24-hour period. This diurnal fluctuation arises from the production of oxygen by photosynthetic organisms in daylight and the consumption of oxygen by these organisms in darkness (i.e., respiration). Development of algal blooms or dense growth of periphyton may lead to wide diurnal DO fluctuations. The relative balance between photosynthesis and respiration determines the net effect of algae on DO (i.e., if respiration is greater than photosynthesis, algae would create an oxygen deficit).

- Oxygen use by organisms in the sediments. Organisms in the sediments, in particular bacteria that decompose organic matter and ammonia, can use a significant amount of oxygen, resulting in a flux of oxygen from the water column to the sediments. Use of oxygen by organisms in the sediments is expressed as sediment oxygen demand, or SOD. As in the water column, the rate of oxygen consumption is temperature-dependent.

- Settling and decay of phytoplankton and other aquatic plants can create a sediment oxygen demand (Thomann and Mueller 1987).

- Oxygen use by nitrifying bacteria and in the conversion of nitrite to nitrate. The breakdown of ammonia by nitrifying bacteria requires oxygen. The initial product is nitrite, which is then rapidly converted to nitrate. These bacteria are most abundant in the sediments, and their activity contributes to SOD.

- River discharge may be critical to meeting minimum DO requirements for the protection of aquatic life. The inter-relationship between river discharge and DO is complex and relates to the relative effect of SOD under varying river travel times and volumes of water, as well as to re-aeration.

5.3 OXYGEN IN THE ASSINIBOINE RIVER

5.3.1 Oxygen Concentrations

To evaluate the effect of effluent discharges on DO concentrations in the river and to monitor conditions in the study area, DO was measured during collection of water samples during intensive monitoring periods in June (Figure 11), July (Figure 12), and August/September (Figure 13) 2002. In addition, to evaluate potential for diurnal oxygen swings (i.e., nocturnal depletion), DO was measured at limited sites using a continuous dissolved oxygen monitoring system (Toews 2002).

In general, DO concentrations during daylight hours were high in the study area during the intensive monitoring periods and were typically in excess of 80% saturation. Several exceptions to this generalization were observed however in June and July 2002. In June, DO concentrations dropped in the mixing zone, reaching a minimum at Site 8 (6.02 mg/L along the left channel and 6.86 mg/L along the right channel).

In July 2002, DO concentrations were also lowest in the mixing zone at Sites 6 and 7, averaging 5.12 and 5.22 mg/L, respectively. DO concentrations in the mixing zone in July 2002 (Figure 12) were lower than observed in previous years (Cooley et al. 2001a) or in June (Figure 11) and August 2002 (Figure 13). Of the sites examined, Site 7L (i.e., left channel at Site 7) and a site at Treesbank (just downstream of Site 8) exhibited higher values for sediment oxygen demand, relative to more downstream locations in September 2002. These observations indicate potentially higher oxygen demand in the mixing zone, relative to downstream locations.

Several individual measurements obtained during the July 2002 intensive monitoring period fell below the chronic objective (7 day average) of 6 mg/L (Sites 1, 2, 6, and 7), and DO concentrations at Sites 6 (left and centre channel) and 7 (right channel) fell below the acute objective of 5 mg/L. Low background concentrations of DO at Sites 1 (site mean = 5.86 mg/L) and 2 (site mean = 5.71 mg/L), high water temperatures (which contributes to lower concentrations due to the reduced ability of water to carry oxygen at high temperatures and which accelerates microbial processes), loads of CBOD discharged from effluents (July 16, 371 kg/day of CBOD were discharged from the Municipal WWTF), and high ammonia loading rates from the Municipal WWTF (July 16, 465 kg/day of ammonia were discharged from the Municipal WWTF) contributed to low DO concentrations observed in July 2002. All daytime DO concentrations observed in June and August 2002 met or exceeded the chronic DO objective of 6 mg/L.

Model simulations were not generated for dissolved oxygen in the open-water season due to the complexities associated with diurnal fluctuations in DO and the inability to incorporate periphyton in the QUAL2E models.

5.3.2 Diurnal DO Fluctuations

High algal productivity associated with nutrient enrichment may lead to wide DO fluctuations in response to oxygen production by photosynthesis in the day and oxygen consumption by respiration at night. Preliminary assessments of the potential for DO "sags" in the Assiniboine River were conducted in August 1999 and June 2000 by comparing DO concentrations measured in the early morning to those measured later in the day at the same site (Cooley et al. 2001a). Evidence of diurnal DO fluctuations, in particular, overnight concentrations falling below the chronic DO objective, was observed at Site 8 in June 2000. In order to obtain detailed diurnal DO measurements, a datalogger capable of continuous dissolved oxygen monitoring was used at several sites during the 2002 monitoring program (Toews 2002).

Manitoba Conservation (2002) also installed a DO logger at various sites in the Assiniboine River in the open-water season of 2002. Data provided by MB Conservation (2002), indicated that early-morning dissolved oxygen concentrations measured at Site 8 in late June (approximately 3 weeks after the June sampling period) were well below the acute DO objective of 5 mg/L, with a minimum of 3.58 mg/L (46% saturation) measured on 29 June. From 25 June until mid-July, DO at Site 8 was less than 5 mg/L for approximately 7 to 8½ hours each night. Despite daytime maximum DO concentrations up to 12.10 mg/L (154% saturation), daily average DO concentrations were below saturation.

Results obtained the August/September intensive monitoring period, as reported in Toews (2002) were:

- Declines in DO were observed overnight at all sites examined, including Sites 5, 6, 8, 9, 12, and 14.
- Wide diurnal fluctuations in DO were observed in the mixing zone. For example, DO dropped by approximately 8 mg/L overnight at Site 6 in August. This was thought to reflect the effect of dense periphyton growth in this area.
- During some periods, daytime DO concentrations fell below the chronic water quality objective (6 mg/L) overnight at Site 8 (August 2002).

Collectively, dissolved oxygen data collected in 2000 and 2002 indicate that photosynthesis and respiration by periphyton and phytoplankton within the mixing zone contribute to wide fluctuations in daily dissolved oxygen concentrations, under lower flow conditions. The distribution of periphyton and phytoplankton is discussed in Section 6.0. Low overnight DO concentrations were observed as far downstream as Site 8 and during some time periods, these instantaneous minima fell below the acute DO objective of 5 mg/L (Williamson 2002).

6.0 NUTRIENTS AND ALGAE

One of the major tasks of the Assiniboine River Monitoring Study was to evaluate effects of effluent discharges near the City of Brandon on nutrients and algae, in particular phytoplankton, in the Assiniboine River. Aquatic primary production is, in general, carried out by three groups of organisms: phytoplankton, periphyton, and aquatic macrophytes. Phytoplankton are microscopic algae entrained in the water column of rivers, lakes, and other aquatic habitats. Within the water column, phytoplankton include algae that originate from upstream lakes, those that are washed off of substrata, and algae entrained and originating in the river current itself. As with lake phytoplankton, there is a seasonal succession of dominant taxa as growing conditions change.

Periphyton, or attached/benthic algae, grow in association with various types of substrata including rocks, submersed aquatic vegetation, mud, sand, and animals. Microscopic periphyton form coatings on mud or rock bottoms and large aquatic plants, while extensive mats of filamentous algae may develop in shallow, rocky areas. Periphyton are characterized by a distinct growth habit that follows a succession from initial adnate forms (small diatoms and bacteria) that colonize underwater surfaces. Once a biofilm is established, larger species of diatoms followed by stalked forms and filamentous green algae form an overstory layer. Filamentous periphyton can form extensive growths that are macroscopic. As growing conditions in the lower layers decline (i.e., the overstory causes light limitation and restricts nutrient diffusion), they die, detach, and the periphyton mat is sloughed off. In riverine habitats, this sloughed periphyton may contribute to loading of nutrients (and BOD) downstream.

Aquatic macrophytes (submersed plants) generally are restricted to areas where sufficient light penetrates to the sediments to allow seed germination; in rivers, they are also limited by water velocity. Although not directly quantified in the Assiniboine River Monitoring Study, aquatic plants were observed within the mixing zone.

Algal growth in riverine environments is determined by the interaction of many factors, including:

- Light availability. Light is required for photosynthesis, the process whereby algae use carbon dioxide to form organic compounds required for growth and division. Light requirements vary among groups of algae and with growing conditions, as cells can adapt to prolonged low light levels. Light availability in rivers depends on water depth, turbidity, and total hours of sunlight per day. Periphyton is restricted to areas where sufficient light reaches the bottom, or the euphotic zone.

- Water temperature. As with light, optimum temperatures for growth vary among groups of algae. Growth rate generally increases with warmer temperatures up to a point where heat disrupts enzyme-based processes.
- Flow/discharge. As the growth of algae is a time-dependent process, low flows or long residence times create the potential for greater accumulation of phytoplankton biomass in the water column under conditions where net growth occurs. Conversely, where net growth does not occur, algal biomass decreases further downstream of sources such as lakes and backwater areas. Current also influences the accrual of benthic algal biomass. Biomass may be greatest at intermediate water velocities due to the balance between scouring of benthic algae at high velocities, and decreased growth rates attributed to the effect of boundary layers which limit nutrient diffusion at low velocities.
- Substratum type. The growth of benthic algae is closely related to substratum type and water depth, with various groups being adapted to different substrata. Dense mats of algae in riverine environments generally form on rocky substrata only.
- Nutrient availability. Algae and plants require specific inorganic nutrients for growth. In fresh water, overall algal biomass is usually limited by either or both of the major nutrients: nitrogen and phosphorus. Certain types of bluegreen algae can obtain nitrogen by fixing atmospheric nitrogen; therefore, phosphorus may be the limiting nutrient. Diatoms may be limited by silica, required for formation of their cell wall, or frustule. Nutrients are limiting only if other growing conditions are suitable.

6.1 OBSERVED LEVELS OF ALGAE

6.1.1 Phytoplankton

6.1.1.1 Chlorophyll a

Chlorophyll concentrations in June 2002 were greater than observed in previous years and throughout the remainder of 2002, ranging from 11 µg/L to over 46 µg/L (Figure 14). Chlorophyll concentrations immediately downstream of wastewater inputs, at Sites 4 and 5 (28 to 40 µg/L), were higher than upstream values (i.e., 15 - 20 µg/L at sites 1, 2, and 3), but declined by Site 6. This increase in chlorophyll downstream of effluent outfalls likely did not originate entirely from growth within the river current, as river travel time between sites 3 and 5 was less than 24 hours. Algal growth rates are variable depending on species and/or environmental conditions, ranging from several hours to several days (Reynolds 1984); however, doubling times are thought to average out at approximately one day. Higher levels of chlorophyll *a* observed downstream of the effluent sources (i.e., Sites 4 and 5) reflected algae discharged in effluents, which ranged from 120 to 270 µg/L (average 2.6 kg/day, or approximately 10% of background chlorophyll loading), and sloughed benthic algae, and not solely algae (i.e., phytoplankton) that were reproducing in the river. The phytoplankton community was dominated by diatoms in June 2002, of which benthic pennate diatoms were a significant fraction at most sites (the exception was Site 14 in the reservoir). These benthic algae are believed to have been dislodged from substrata and were not thought to represent a reproducing population (Appendix 3).

Due to differences in environmental tolerances, algal cells originating in the treatment lagoon were not likely reproducing phytoplankton populations, resulting in high mortality rates as they moved downstream of Site 5 and a decline in chlorophyll *a* concentrations to 12 µg/L by Site 9. Beyond the mixing zone, phytoplankton chlorophyll *a* increased as the parcel of water moved downstream, from approximately 12 µg/L at Site 9 to 40 µg/L at Site 13; however, this may be an artefact of rainfall at the latter end of the June monitoring period. As discussed in Section 6.4.1.1, concentrations of total suspended solids and organic phosphorus also increased at these sites, during the June sampling, which may indicate an unidentified source in the downstream end of the study area.

Chlorophyll *a* concentrations measured in July (Figure 15) and August (Figure 16) 2002 were similar to those observed in July and August 1999, ranging from <5 to 15 µg/L at most sites. It was suggested that low chlorophyll *a* concentrations observed in July and August 1999 may have been a reflection of high turbidities and short travel times. However, similar to previous years of the Assiniboine River Monitoring Study, there was no evidence of increased phytoplankton chlorophyll *a* between Brandon and Portage la Prairie in July and August of 2002, despite longer river travel times and improved light conditions associated with low river discharge.

Weekly monitoring was also conducted at Sites 3C, 8C, and 13C from July through September 2002. Concentrations were generally below 15 µg/L at these three sites across the sampling period (Toews 2002). The most notable exception occurred on the third of September when concentrations ranged from 10 to 36 µg/L (Toews 2002). It should be noted, however, that chlorophyll *a* was not found to be strongly correlated to algal biomass (Appendix 3). On the basis of biomass and species composition, data collected indicate that 'blooms' of algae developed in late August and early September with a relatively larger fraction of cyanophytes (Appendix 3).

Chlorophyll *a* concentrations in the Assiniboine River were similar to those reported for turbid rivers in Alberta (e.g., South Saskatchewan River, Carr and Chambers 1998). In comparison, historical annual mean concentrations recorded for the Elbow River, Alberta, a system with low turbidity (mean turbidity of 4.2 NTU), ranged from 100 to 200 µg/L (Carr and Chambers 1998). Concentrations of chlorophyll *a* in excess of 15 µg/L have been deemed the 'nuisance phytoplankton growth goal' by some jurisdictions (e.g., State of Oregon, Rounds and Wood 2001).

Overall, chlorophyll *a* concentrations observed in June would be considered 'nuisance' levels by some jurisdictions, although a portion of the observed chlorophyll *a* was derived from sewage lagoon effluents and from benthic algal populations that had sloughed off. Levels observed in July and August/September were low and consistent with levels observed under high flow conditions (i.e., open-water season of 1999).

6.1.1.2 Phytoplankton Community

Phytoplankton communities typically change over the growing season, as a result of changing environmental conditions and subsequent shifts in the dominance among major groups. Phytoplankton biomass and relative species composition were measured at select sites in the open-water season of 2002, as discussed below. Detailed data are provided in Appendix 3.

Algal biomass in the Assiniboine River was generally between 1,000 mg/m^3 and 4,000 mg/m^3, during the intensive monitoring periods (Appendix 3). However, a disproportionately high biomass was observed at Site 13R in July and August 2002. Biomass generally increased from early summer, peaking in late August and early September, as measured during the weekly sampling. Sites 8 and 13 exhibited 'blooms' of cyanophytes on September 11, 2002.

Phytoplankton species composition observed under low flows in 2002 was similar to that observed in 1999 and 2000, characterized by diatoms and green algae in early summer and increasing relative abundance of bluegreens in late summer (Toews 2002). The seasonal succession of dominant algal groups follows patterns observed in many north temperate aquatic systems (Wetzel 1983). A summary description of seasonal changes in phytoplankton species composition among sites is provided in Appendix 3.

In general, samples of phytoplankton collected in the upstream end of the study area in June, July, and August 2002, contained benthic algae, which were believed to have sloughed off of substrata and were not believed to be reproducing populations (Appendix 3). Benthic diatoms were less abundant at Sites 13 and 14.

Bluegreen algae (i.e., cyanophytes) became more abundant in July and August, relative to June, 2002 (Appendix 3). In July, cyanophytes were more abundant at Sites 13 and 14 than the upstream sampling sites. In August/September, the relative abundance of cyanophytes was similar across sampling locations. Weekly sampling also indicated a notable increase in the relative abundance of cyanophytes in late August and September 2002. Heterocysts of nitrogen-fixing bluegreen algae were observed in large numbers in late summer, suggesting that available N:P ratios had shifted in favour of nitrogen fixers.

Some of the bluegreens found in the river have been responsible for blooms that have been found to produce algal toxins (H. Kling 2001 in Cooley et al. 2001a); however, the algal toxin microcystin was not measured in samples collected on September 11, 2002 when cyanophytes dominated. Data collected from intensive and weekly monitoring from June through early September 2002 indicated concentrations in the Assiniboine River consistently below the MWQSOG for microcystin of 1.5 µg/L (Williamson 2002). Low concentrations were also measured in June 2000 (Toews and Schneider-Vieira 2000).

6.1.2 PERIPHYTON

Nutrient-rich effluent discharges, particularly municipal effluents, may substantively stimulate growth of periphyton in lotic systems (Chambers et al. 1997). Although it is accepted that nutrient enrichment in streams can lead to excessive periphyton growth, the relationship between nutrient concentrations and periphyton biomass is anything but clear (Carr and Chambers 1998).

High densities of periphyton were measured at several sites on the Assiniboine River in the open-water season of 2002, as had been previously observed in earlier surveys (i.e., 2000). In addition, the macrophyte *Potamogeton pectinatus* grew prolifically in the riffle areas within the mixing zone downstream of Brandon in September 2000 and the summer of 2002.

During the intensive monitoring in the open-water season of 2002, relatively high densities of periphyton were observed in the mixing zone (Table 20), as had been observed in 2000. These densities were consistent with productive, nutrient-rich waters. In June, July, and August of

2002, mean periphyton chlorophyll (expressed as the sum of chlorophyll *a* and pheophytin) ranged from 492 to 1,138 mg/m^2 at Sites 5, 7, and 8 (Table 20, Toews 2002).

A periphyton survey was also conducted in early August 2002 to evaluate the presence of suitable substrata and the presence and abundance of periphyton in areas downstream of the mixing zone that are not accessed during the intensive monitoring periods (Appendix 2). In general, periphyton was observed to have colonized all 'suitable' substrata within the areas accessed in the Assiniboine River in August 2002. These substrata included cobble, the typical substrata for periphyton in the Assiniboine River, and all other available substrata such as woody debris and clams. Attached algae was also observed growing on sandy substrata (i.e., epipsammon) in some areas and small pebbles. The presence of attached algae on unstable substrata (i.e., sand) in August 2002 was likely possible owing to the low river discharges and subsequent low river velocities which permit growth of periphyton on unstable substrata. Filamentous algae were abundant throughout areas accessed, and, at some locations surveyed, large mats had sloughed off.

Mean densities of chlorophyll *a* and percentage composition of pheophytin measured in periphyton sampled during the periphyton survey are presented in Table 21. Densities were fairly similar at all sites examined, indicating that suitable growing conditions extended at least as far downstream as Site 11 (approximately 185 km downstream of Brandon), where suitable substrata were present.

Major findings of the survey were as follows:

- Suitable substrata for periphyton is present and may be relatively abundant in some reaches of the river, downstream of the mixing zone. The abundance of cobble is lower under low river discharges because areas of cobble along the banks are dewatered. Conversely, low water conditions may increase the extent of suitable habitat for periphyton growth due to relatively higher light penetration (i.e., reduced depths and increased availability of areas where the photic zone extends to the bottom) and/or reduced velocities, which allow colonization of typically unstable substrata.

- Under the conditions that occurred in August 2002, periphyton were able to colonize all types of substrata in the areas accessed, including cobble, small pebbles, clams, debris, and sand.

- Densities of periphyton measured at several locations downstream of the mixing zone were comparable and were similar to those observed at Site 8 (i.e., the end of the mixing zone) at the time of the survey.

High densities of periphyton may be associated with large diurnal fluctuations in oxygen, and the occurrence of critically low oxygen levels at nighttime, which may adversely affect aquatic life. Although no numeric water quality criteria or guidelines for periphytic algae have been proposed for the Province of Manitoba, the B.C. Ministry of the Environment has adopted a maximum criterion of 100 mg chlorophyll *a*/m^2 for the protection of aquatic life in streams and a criterion of 50 mg/m^2 for preservation of recreational use of streams (BC Ministry of Environment, Lands, and Parks 2001). In addition, Carr and Chambers (1998) recommended a guideline of 100 mg/m^2 (seasonal mean) for maintenance of 'intermediate water quality' and 50 mg/m^2 for high water quality, in Alberta, based on the occurrence of densities measured upstream of major point sources of nutrient input. Similarly, Dodds et al. (1998) reported that periphyton densities between 70 and > 200 mg/m^2 were indicative of eutrophication in streams. Periphyton chlorophyll *a* densities measured at and downstream of Brandon in the open-water season of 2002 were well above 100 mg/m^2, and thus above suggested criteria for protection of water quality. Continuous dissolved oxygen monitoring at several sites colonized by periphyton in 2002 confirmed the occurrence of overnight declines in dissolved oxygen (Section 5.0, Toews 2002).

Studies in other areas have linked excessive periphyton growth to phosphorus enrichment. Based on *in situ* measurements in streams, total phosphorus concentrations ranging from 0.10 mg/L to 0.20 mg/L were associated with a benthic chlorophyll *a* density of 450 mg chlorophyll *a*/m^2 (Dodds et al. 1998, Lohman et al. 1992). Concentrations of total phosphorus measured in the Assiniboine River in June, July, and August/September 2002 (Tables 22 to 24) were generally in this range (i.e., 0.1-0.2 mg/L); periphyton density (expressed as chlorophyll *a* only) ranged from 332 mg chlorophyll *a* /m^2 to 892 mg chlorophyll *a* /m^2 (Table 20).

Carr and Chambers (1998) demonstrated an association between phosphorus and periphyton for Alberta rivers. Specifically, excessive periphyton growth (150 mg/m^2) was predicted at total phosphorus concentrations averaging 0.033 mg/L in fall, when total dissolved phosphorus concentrations averaged 0.14 mg/L over all seasons, or when total dissolved phosphorus instantaneously exceeded 0.093 mg/L (Carr and Chambers 1998). However, as the Alberta rivers were considered to be primarily phosphorus-limited, the potential role of phosphorus in stimulating the growth of periphyton in the Assiniboine River is less clear, as this river is more likely nitrogen-limited (Section 6.5.1).

6.2 NUTRIENTS IN EFFLUENTS AND TRIBUTARIES

From May to September 2002, the Brandon Municipal WWTF contributed total phosphorus loads ranging from 13.1 kg/day (May 15) to 110 kg/day (July 10), as reported by the City of Brandon (Table 13). Loads were generally greatest in July and the beginning of August. The Maple Leaf IWWTF effluent discharged similar loads of total phosphorus ranging from 29 kg/day (May 22 and July 03) to 80 kg/day (September 11) (Table 14). The Maple Leaf IWWTF effluent (Table 14) generally contributed higher loads of total nitrogen to the Assiniboine River, ranging from 215 kg/day (May 22) to 388 kg/day (August 28), for the period of May through September 2002, than the Brandon Municipal WWTF (Table 13), where loads ranged from 106 kg/day (August 28) to 462 kg/day (July 10).

Calculated loads of total phosphorus discharged to the Assiniboine River via effluents and tributaries for the June, July, and August/September 2002 intensive monitoring periods are illustrated in Figures 17-19, respectively. The Brandon Municipal WWTF and the Maple Leaf IWWTF contributed similar loads of total phosphorus (ranging from approximately 31 kg/day to 70 kg/day) in June and August/September 2002, during the intensive monitoring periods (Tables 8 and 12). In July, loads were higher in the Municipal WWTF effluent on two of the days sampled. These two point sources were the highest sources of total phosphorus to the study area during the monitoring periods. The municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon contributed only small loads of phosphorus during the sampling periods.

Tributary streams were of varying significance with respect to contributions of phosphorus to the Assiniboine River. In June, the Cypress River carried a load of total phosphorus in excess of that discharged by the Brandon Municipal WWTF and similar to the ML IWWTF (Figure 17). Conversely, the load of TP in the Cypress River was less than 1 kg/day in July, but the Souris River contributed an estimated load of 169 kg/day at this time (the highest load in the study area). Similarly, the Souris River contributed the highest load of TP of all the tributaries sampled in August/September, which was approximately one half the loads from the ML IWWTF and the Brandon Municipal WWTF.

Calculated loads of total nitrogen discharged to the Assiniboine River via effluents and tributaries for the June, July, and August/September 2002 intensive monitoring periods are illustrated in Figures 20-22, respectively. During the June and August/September 2002 monitoring periods, the highest loads of total nitrogen were discharged from the Maple Leaf

IWWTF (ranging between approximately 310 kg/day to 398 kg/day) (Tables 8 and 12). Loads from the Brandon Municipal WWTF ranged from 123 kg/day to 277 kg/day.

On July 16, 2002, which corresponded to the effluents discharged to the parcel of water that was being tracked in the river, the Brandon Municipal WWTF discharged a load of 582 kg/day of total nitrogen, while the ML IWWTF discharged 349 kg/day (Figure 21). The municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon at times contributed higher loads of nitrogen than either effluent source. For example, on June 6 the load from the ditch was approximately 1.7 times higher than the load from ML and almost five times higher than the Brandon WWTF discharge (Figure 20). The load from this source varied considerably over and between the sampling periods, contributing as little as 22 kg/day (July 17) and as much as 602 kg/day (June 6) (Tables 8, 10, and 12).

Tributary streams/drains contributed significant quantities of total nitrogen to the Assiniboine River during all three intensive monitoring periods. In June, the Cypress River contributed a higher load of TN (249 kg/day) than the Brandon Municipal WWTF and approximately 70% of the load discharged from the ML IWWTF (Figure 20). The Souris River was also a major contributor at an estimated 156 kg/day, which was slightly higher than the Brandon Municipal WWTF and just under half the load discharged by the ML IWWTF. In July, the Souris River was an even greater contributor of TN, relative to the effluents; the total nitrogen load at this time was 1142 kg/day, equivalent to approximately two times the load discharged from the Municipal WWTF and over three times the load discharged from the IWWTF (Figure 21). Conversely, tributaries discharged relatively lower loads of total nitrogen in August/September, in comparison to the WWTF and IWWTF (Figure 22).

Overall, during the sampling periods in June, July, and August/September 2002, the City of Brandon Municipal WWTF and Maple Leaf IWWTF collectively increased the total phosphorus load carried by the Assiniboine River at Brandon by 141%, 129%, and 146%, respectively. The combined discharge of the effluents from the City of Brandon Municipal WWTF, the Maple Leaf IWWTF, and the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon increased the total nitrogen load in the Assiniboine River at Brandon by 84%, 98%, and 103% during the June, July, and August/September 2002 sampling periods, respectively. Tributary streams, most notably the Cypress and Souris rivers, were also major sources of total nitrogen and phosphorus to the Assiniboine River, with the relative contributions varying somewhat over the sampling periods.

6.3 OBSERVED LEVELS OF NUTRIENTS: ASSINIBOINE RIVER

Nitrogen and phosphorus dynamics in the Assiniboine River were previously evaluated using data collected in the open-water season of 1999 and in May and June 2000 (Cooley et al. 2001a). In general, due to unusually high river discharge in the open-water season of 1999, background concentrations and loads of phosphorus were greatly elevated over typical mean or median concentrations, and loads of phosphorus discharged in the effluent from the Brandon Municipal WWTF during June, July, and August 1999 did not notably elevate phosphorus or nitrogen concentrations in the Assiniboine River (Toews et al. 1999). The Maple Leaf IWWTF was not operating at this time.

Phosphorus and nitrogen loads discharged from both the Maple Leaf and Municipal WWTFs in September 1999, when the ML IWWTF was in the commissioning period, were still overshadowed by background loads in the Assiniboine River; phosphorus and nitrogen loads discharged from the Maple Leaf WWTF in September comprised less than 1% the background load in the river, as measured at Site 1.

Under the lower flow conditions in the spring of 2000, phosphorus and nitrogen inputs at Brandon significantly increased the phosphorus and nitrogen loads in the Assiniboine River. At that time, the largest single point source of nitrogen in the study area was the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon (there was no discharge from the ash lagoon during these sampling periods).

Nutrient dynamics were evaluated in the open-water season of 2002 (June, July, and August/September) through intensive monitoring programs and through water quality modelling. In general, discharges of effluents from the Brandon Municipal WWTF and the ML IWWTF caused measurable increases in nutrient concentrations in the mixing zone of the Assiniboine River, most notably for dissolved forms of nitrogen and phosphorus (Figures 23-46). Conversely, silica was not notably elevated in the Assiniboine River as a result of effluent discharges (Figures 47-49). The following sections (Section 6.4 and 6.5) provide discussions of the major findings pertaining to nutrient loads and dynamics in the Assiniboine River based on data collected during these sampling periods and results of water quality modelling.

6.4 RESULTS OF WATER QUALITY MODELLING

Preliminary water quality models for the open-water season were developed for data collected in May and June 2000 (data gathered in 1999 were not suitable for model calibration as high loads within the river masked the effects of inputs and processes within the river), although it was not possible to calibrate the model for all parameters (Cooley et al. 2001a). In general, results for May and June 2000 indicated that downstream of effluent discharges, concentrations of bioavailable nutrients (i.e., ammonia, nitrite/nitrate, orthophosphate, and dissolved reactive silica) declined sharply. Subsequent simulations indicated that the concentration of chlorophyll *a*, which is used as an indicator of phytoplankton, was too low to account for these nutrient losses. In conjunction with additional observations regarding the benthic algae community, these findings were interpreted to be indicative of the role of periphyton in nutrient removal, particularly in the mixing zone. QUAL2E does not contain a component for periphyton (attached algae); therefore, as periphyton appeared to be critical to nutrient dynamics, it was concluded that it was not possible to develop a fully calibrated model for the Assiniboine River in the growing season (Cooley et al. 2001a).

As presented in Appendix 1, models for the open-water season were also developed based on water quality data collected in June, July, and August/September 2002, during a season of low river discharge. Calibration exercises for the monitoring periods of June, July, and August/September 2002 were reasonably successful, in particular for the June 2002 period. There are a number of possible reasons for the inability to fully calibrate the July and August models for some parameters including:

- Lack of a sink for nutrients in the mixing zone: all modeling exercises for the 2002 period, particularly for the July and August/September periods, indicated the presence of a sink for nutrients in the mixing zone. The QUAL2E model does not incorporate a sink for uptake of nutrients by periphyton or aquatic macrophytes; the only ‘sinks’ are uptake by phytoplankton and subsequent settling of phytoplankton or settling of organic forms of nutrients.

- In the case of nitrogen, nitrates may be lost to the atmosphere through denitrification (a process that requires anaerobic conditions). This process may be highly significant in thick river biofilms, where localized oxygen depletion may develop at night and, in some biofilms, in the daylight hours (e.g., Teissier et al. 2002). However, QUAL2E does not incorporate the process of denitrification; model simulations for each month evaluated in 2002 overestimated nitrate/nitrite nitrogen.

- Inappropriate/inaccurate hydraulic data and river discharges: if river discharges were not accurately represented, incoming loads of substances would be inaccurately represented, as would dilution processes.

- Inaccurate river travel time estimates: if river travel times were not accurate, the sampling program would not have been conducted such that the same parcel of water were tracked down the length of the study area. Subsequently, measured concentrations at various sites would reflect different river discharges and effluent and tributary loads.

- Sampling variability and analytical error associated with analysis of water quality and stream discharge measurements.

- Inaccurate representation of point and non-point sources: underestimation of loads of nutrients in the downstream end of the study area may reflect either underestimation of tributaries that were sampled during the monitoring periods or the presence of other point or non-point sources not sampled at those times.

Model calibration for the open-water seasons of 2000 and 2002 indicated that nutrients may be lost in the mixing zone to a larger extent than could be accounted for by the model. Specifically, model simulations calibrated to the concentrations of chlorophyll *a* (i.e., phytoplankton) that were measured in May and June 2000 and July and August/September 2002 indicated the levels of phytoplankton were insufficient to account for the decrease in bioavailable nutrients that was observed in the river, most substantively immediately downstream of effluent outfalls.

Periphyton may be very significant in reducing nutrients in small streams, partly due to its fixed position, which facilitates effective removal of dissolved nutrients that continually flow by (Thomann and Mueller 1987). However, as Scrimgeour and Chambers (2000) recently stated, while there has been substantive effort directed at research on effects of eutrophication in and development of water quality models for lakes, the ability to predict effects of nutrient additions on streams and rivers is extremely limited. These deficiencies are illustrated by the limited availability of water quality models that are applicable to nutrient-rich streams.

6.4.1 Nutrient Removal: Mass-Balance Modelling

QUAL2E was used to simulate total nitrogen and phosphorus as mass balance relationships for the Assiniboine River in the open-water season of 2002 (Appendix 1). As the model simulations represent mass-balance conditions (i.e., total nitrogen and phosphorus are a function of loads and dilution only), any discrepancies between model simulation results and observed values are due to removal of nutrients in the water column by passive or active processes and/or introduction of nutrients from point sources and runoff. In general, these simulations indicated that substantive quantities of nitrogen and phosphorus were removed from surface water in June, July, and August/September 2002. A similar finding was observed during model calibration exercises for data collected in May and June 2000.

It is noted that any error associated with effluent loads, hydraulics (i.e., river discharge), or sampling times may affect model simulation results and subsequently comparisons to observed data. However, given the large discrepancies between simulated and observed loads of nitrogen and phosphorus, it is evident that significant nutrient removal occurred.

Possible sinks for nutrients include: (1) phytoplankton uptake and settling; (2) periphyton uptake; and, (3) settling of particulate matter. Additional sources of nutrients include: (1) release of nutrients from sediments; (2) point sources not sampled during the monitoring program; and, (3) non-point sources, such as runoff from agricultural land and water discharged from the aquifer. Periphyton, which is known to be quite dense in the mixing zone, is a likely candidate for phosphorus and nitrogen removal in the upper portion of the study area where it is abundant. Mesocosm studies have reported that removal of nutrients by periphyton can result in measurable declines in the concentrations of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus in water (Perrin and Richardson 1997). It should also be noted, however, that nitrogen may be lost from the system through the process of denitrification, which is not incorporated into QUAl2E.

6.4.1.1 June 2002

Results of simulations of total nitrogen and phosphorus as a mass-balance approach depart from measured concentrations (and loads) immediately downstream of effluent discharges, indicating that conditions in this area of the river are conducive to nutrient removal (Figures 50 and 51). This occurrence was also observed for June 2000 (Cooley et al. 2001a).

A substantive load of nitrogen (186 kg/day) and phosphorus (31 kg/day) is lost between Site 2 and Site 8 (the end of the mixing zone, upstream of the Souris River). At the lower end of the study area, comparison between mass balance simulations and observed data indicated a potential source of total nitrogen and phosphorus, as well as TSS (Figure 52), as model simulations underestimated observed concentrations (Appendix 1). Potential sources may include sediment resuspension, erosion, a point source not captured in the sampling program, or non-point sources. Because the loads from this unidentified source are not known, it is not possible to determine the total loss of nutrients in the study area. A similar observation was made in June 2000, when there also appeared to be a source of nitrogen and phosphorus (organic forms) beyond Site 9 (Cooley et al. 2001a). Consistent with the June 2002 sampling period, sampling of downstream sites in June 2000 proceeded a period of heavy rains.

Inclusion of a chlorophyll *a* component in the model, as well as settling of organic forms of nitrogen and phosphorus, was sufficient to reduce simulated nutrient concentrations to levels that were similar to observed concentrations for June 2002. However, the model continued to overestimate nitrate/nitrite nitrogen in the mixing zone, indicating that accumulation by phytoplankton was insufficient to account for the observed losses. Possible ‘sinks’ for nitrate which are not incorporated into the QUAl2E model are denitrification, which may be very significant in streams with thick biofilm (Teissier et al. 2002), and accumulation by periphyton and macrophytes.

For this time period, inclusion of algal and settling processes were adequate to result in a reasonably well calibrated model for most parameters. As discussed below, during other sampling periods in the open-water season of 2002 (i.e., July and August/September), losses of nutrients in the mixing zone could not be accounted for by phytoplankton and settling of organic forms of nutrients (see Appendix 1).

6.4.1.2 July 2002

In general, concentrations and loads of total nitrogen and phosphorus measured in the Assiniboine River, downstream of point source discharges, were lower than simulated concentrations (Figures 53 and 54). Overall, mass balance model simulations indicated that approximately 77 kg/day of total phosphorus and 561 kg/day of total nitrogen were lost in the mixing zone by Site 8. Even assuming that nitrogen loads in the effluent sources were overestimated in the model, the magnitude of the difference between simulated and observed nitrogen concentrations in the mixing zone strongly suggests a nutrient sink.

Inclusion of phytoplankton and settling of organic nutrients served to reduce the discrepancies between simulated and observed concentrations of total nitrogen and phosphorus but did not solely account for the observed declines. Inclusion of phytoplankton and nutrient settling reduced the discrepancy between modelled and observed concentrations of total nitrogen and phosphorus to 58.5 kg/day and 467.9 kg/day, respectively, by Site 8. As observed in June, TSS was significantly underestimated in the lower end of the study area (Figure 55).

Collectively these observations indicate: (1) a substantive load of nitrogen and phosphorus was removed from the surface water, particularly within and immediately downstream of the mixing zone; and, (2) a potential source of TSS in the downstream end of the study area.

6.4.1.3 August 2002

As observed for June and July 2002, results of simulations of total nitrogen and phosphorus as a mass-balance approach depart from measured concentrations (and loads) immediately downstream of effluent discharges, indicating that conditions in this area of the river are conducive to nutrient removal (Figures 56 and 57).

A substantive load of nitrogen (678 kg/day) and phosphorus (64 kg/day) is lost between Site 2 and Site 8 (the end of the mixing zone, upstream of the Souris River), as indicated by discrepancies between observed concentrations and those simulated as a mass balance relationship (Appendix 1). At the lower end of the study area, comparison between mass balance simulations and observed data indicated a potential source of total nitrogen and phosphorus, as well as TSS (Figure 58), as model simulations indicated that in-stream loads of both substances should have remained relatively constant in the downstream end of the study area but observed data indicate a substantive increase in in-stream loads downstream of Site 10 (Figures 56 and 57). Mass balance simulations for TSS support this contention; simulated TSS concentrations grossly underestimated observed TSS concentrations at Sites 10 to 13, indicating a potential source (Figure 58). Potential sources of nutrients (and TSS) may include sediment resuspension, a point source not captured in the sampling program, or non-point sources. Due to this unknown source, it is not possible to determine the total loss of nutrients in the study area because the loads from this source are not known.

Inclusion of a phytoplankton component and settling of organic nitrogen and phosphorus in the model, served to reduce the discrepancy between observed and simulated total nitrogen at Site 8 to 646 kg/day. Incorporation of these components had no effect on the discrepancy between observed and simulated concentrations of total phosphorus at Site 8.

In general, these simulations indicated that substantive quantities of nitrogen and phosphorus were removed from surface water in the upper portion of the study area in June, July, and August/September 2002 (see Appendix 1 for details). Periphyton, which is known to be quite dense in the mixing zone (see Section 6.1.2), is a likely candidate for phosphorus and nitrogen removal. Denitrification may also play a role in the loss of nitrogen, but the magnitude of this process is not known.

6.5 FACTORS AFFECTING ALGAL GROWTH

A number of factors may affect, or limit, algal growth in surface waters including nutrients (phosphorus, nitrogen, and silica), light, and temperature. In addition, in lotic systems algal growth, or more appropriately algal biomass, may also be limited by water residence time (i.e., river travel times). Concentrations of phytoplankton will also be affected, to varying degrees, by river velocity (low velocities may lead to settling).

In general, algal growth is limited in winter due to low irradiance and temperature. In spring and summer, algae are limited by light, high sediment loads (i.e., turbidity), and high discharge (Scrimgeour and Chambers 2000). Nutrient limitation likely varies seasonally, although it also varies according to ambient conditions such as river discharge.

Although all algal species are affected by these basic requirements, there are notable differences in nutrient uptake rates, growth rates, and temperature preference ranges between algal species. Thus, the phytoplankton community and relative species abundance undergo a marked seasonal succession in response to varying ambient conditions (i.e., light levels, river discharge, nutrient concentrations, temperature) (Bowie et al. 1985). It is for this reason that multiple water quality models are often developed over the open-water season. The following is a brief discussion of the potential factors that may limit phytoplankton growth in the Assiniboine River.

6.5.1 Nutrients

Although the total concentration of nutrients is of relevance to nutrient availability for algal growth, it has been argued that a more appropriate measure is the bioavailable fraction of nutrients (i.e., ammonia, nitrate, and orthophosphate). Consequently, nutrient limitation is often described in terms of concentrations of DIN, equivalent to the sum of dissolved ammonia-N and nitrate/nitrite-N, and soluble reactive phosphorus (SRP), or dissolved orthophosphate (DOP) (which approximates SRP). Although Michaelis-Menten half-saturation constants (K_m), the concentration of a nutrient at which the algal growth rate is equal to one half the maximum, vary with the species and community of algae, in general, constants for phytoplankton fall in the following ranges: nitrogen 10 - 20 µg/L; phosphorus 1- 5 µg/L; and, silica 20 - 80 µg/L (Thomann and Mueller 1987). It should be noted that these values do not apply to all groups of algae. For example, silica is limiting to diatoms, while certain species of bluegreen algae can fix atmospheric nitrogen, and thus tend to proliferate when other species are nitrogen-limited. Concentrations of 55 µg/L of DIN and 5 µg/L of SRP are reportedly adequate to support ‘moderately dense mats’ of epilithic algae (Scrimgeour and Chambers 2000).

Some jurisdictions have proposed nutrient guidelines, as presented in Cooley et al. (2001a), based on levels of nutrients which limit algal growth. Manitoba Conservation indicates a narrative water quality guideline for nitrogen, phosphorus, carbon, and contributing trace elements to prevent nuisance plant and algal growth (Williamson 2002). In the case of phosphorus, a general guideline of 50 µg/L for total phosphorus in streams is applied. A guideline of 25 µg/L has been proposed for lakes, reservoirs, or ponds and tributaries at the point of entry to these bodies of water. However, the MWQSOGs further indicate that where it can be demonstrated that phosphorus is not a limiting factor, these objectives are not applicable. All measurements of total phosphorus collected in the Assiniboine River exceeded the MWQSOG for streams, generally by a large margin (Tables 22 to 24). Most tributary streams, drains, and all effluents also contained total phosphorus at concentrations exceeding this guideline. However, as discussed below, phosphorus may not be a limiting factor in the river.

As indicated in Tables 22 to 24, concentrations of total nitrogen and phosphorus in the Assiniboine River in June, July, and August/September 2002 were substantively greater than the values for K_m for phytoplankton listed above and those considered adequate for moderate periphyton growth at most sites. During the intensive monitoring periods in the open-water season of 2002, concentrations of total nitrogen were one to two orders of magnitude greater than the range of K_m for phytoplankton.

In June 2002, concentrations of DIN were between 3.5 to 10.5 times the concentration considered adequate for moderate epilithic algal growth at Sites 3 through 8. Concentrations of DOP in the Assiniboine River were one to two orders of magnitude greater than the typical K_m for phytoplankton and above those required for moderate periphyton growth at all sampling sites in the Assiniboine River. Concentrations of phosphorus and nitrogen did not appear to be low enough to be limiting in most tributaries sampled in June 2002. The exceptions were the Souris River and Five Mile Creek, where low concentrations of DIN were observed. The municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Little Souris River and an unnamed drain located upstream of Site 13 were significant sources of TN and DIN in June.

In July, nitrogen and phosphorus concentrations were high at most sites in the Assiniboine River, including upstream locations, and elevated above concentrations observed in June or August/September 2002. Total nitrogen was 1.0 mg/L or higher throughout the Assiniboine River study area and DIN exceeded 55 µg/L at Sites 1 through 8. Total phosphorus was consistently greater than 0.1 mg/L at all sites and DOP was notably elevated from Sites 4 through 11. All concentrations of DOP were well above the concentration of phosphorus considered adequate to support moderate growth of periphyton and concentrations did not appear to be low enough to limit algal growth. Most tributaries sampled in July contained sufficiently high concentrations of nitrogen and phosphorus such that nutrient limiting conditions did not appear to occur. Exceptions included Willow Creek and the Souris and Cypress rivers where DIN concentrations were below 55 µg/L. Lower concentrations of nitrogen were observed in most tributaries, relative to the June sampling period.

In August/September 2002, concentrations of total phosphorus and DOP were elevated throughout the study area, exceeding the threshold concentration of 5 µg/L at all sites. Total nitrogen concentrations were highest at Sites 1 through 9 (i.e., > 1 mg/L) and concentrations observed at upstream locations (Sites 1 and 2) were the highest of the three sampling periods. However, DIN comprised a relatively lower fraction of total nitrogen than had been observed in June or July sampling periods. Nonetheless, notably elevated concentrations of DIN were observed in the mixing zone from Sites 3 through 8 as observed in previous monitoring periods. Fewer tributaries were flowing at this time but several of them contained low concentrations of DIN, including the Souris and Cypress rivers and Epinette Creek. In addition, water chemistry measured in samples of spring water indicated that emergent springs may contribute substantive quantities of nutrients to the Assiniboine River. Concentrations of total nitrogen were higher in the two spring samples than observed in the river.

Overall, nutrient concentrations were similar to those observed in May and June 2000, although DOP concentrations measured in 2002 were sometimes lower than those measured in 2000. Concentrations of total nitrogen, DIN, and DOP were highest at upstream sites in July 2002. All measurements of DOP in the Assiniboine River exceeded 5 µg/L and were not likely limiting to algal growth at any site in the river during the monitoring periods.

Conversely, in June and August/September, concentrations of DIN were below typical K_m values for phytoplankton and below 55 µg/L (concentration considered adequate for moderate periphyton growth) at sites upstream of effluent discharges and downstream of the mixing zone (i.e., downstream of Site 8). Within the mixing zone, additions of nitrogen from point sources resulted in more than adequate nitrogen for algal growth and neither phosphorus nor nitrogen was limiting. Losses of nitrogen, and dilution of nitrogen loads in the Assiniboine River from groundwater inputs and the Souris River, caused DIN concentrations to drop below 55 µg/L downstream of the mixing zone, thus re-creating a condition of nitrogen limitation, as had occurred upstream of effluent outfalls.

High upstream concentrations of nitrogen and phosphorus in the river in July 2002 were sufficient to avoid nutrient limitation upstream of the mixing zone. However, DIN concentrations dropped below 55 µg/L by Site 9 in July, similar to what was observed for the other sampling periods.

This spatial pattern of nutrient limitation and enrichment in the Assiniboine River was also observed in May and June 2000 but not in the open-water season of 1999. Nutrient limiting conditions did not occur in 1999 due to the occurrence of flood conditions in the study area and subsequent high background nutrient loading (Cooley et al. 2001a).

While phosphorus is typically the limiting nutrient in lakes, nitrogen limitation is not uncommon in streams, particularly in watersheds that are heavily agriculturalized or where there is a rich geological source of phosphorus (Scrimgeour and Chambers 2000). In general, recent research has indicated that nitrogen limitation is more frequent than once believed and is more frequent in streams than lakes (Scrimgeour and Chambers 2000). Point source effluent discharges affected the nutrient balance and limitation in the Assiniboine River for a distance of approximately 37.4 to 67.9 km in June and August/September 2002. Due to high upstream concentrations of nutrients in July 2002, the distance of the river affected by nutrient discharges can not be readily discerned.

6.5.1.1 Nitrogen to Phosphorus Ratios in the River

To evaluate the possible role of nutrient limitation on algal growth, the various concentrations of nitrogen and phosphorus forms were evaluated, in conjunction with calculated nitrogen to phosphorus (N:P) ratios. N:P ratios are frequently used as indicators of nutrient status in aquatic systems, specifically with respect to interactions between nutrients and algal growth. Although the precise derivation, expression, and interpretation of N:P ratios vary considerably, in general it is widely accepted that a low N:P ratio (< 10) is indicative of nitrogen limitation and a high ratio (> 20) indicates phosphorus limitation. Values in between 10 and 20 are generally interpreted to indicate co-limitation.

Values for the N:P ratios were derived from nutrient data collected in June, July, and August/September 2002 (Tables 22 to 24). Because N:P ratios are derived by different means in the literature, ratios for this study were expressed using several approaches. The DIN:DOP ratio may be most appropriate as it considers only the bioavailable fraction of nutrients, which are the most relevant to algal growth. As discussed in Section 6.5.1, nutrient limiting conditions were observed at some sites and times in the open-water season of 2002. Specifically, low DIN:DOP ratios were observed at Sites 1 and 2 and Sites 9 through 14 in June and August/September 2002, indicating nitrogen-limiting conditions. This pattern was also observed in May and June 2000 and reflects the effects of nitrogenous effluent additions to the mixing zone. In July, low N:P ratios occurred at all sites in the Assiniboine River but because of high background DIN and nitrogen additions from effluents, nitrogen limitation only occurred in the downstream end of the study area, from Sites 10 to 14.

Based on N:P ratios and concentrations of nitrogen and phosphorus, some of the tributary streams were also nitrogen-limited in the open-water season of 2002, although this occurrence varied across sampling periods. The Souris River was consistently nitrogen-limited at the sampling times in the open-water season of 2002. As a major tributary to the study area, this would contribute to shifting conditions from a non-limiting nutrient status to nitrogen-limiting conditions in the Assiniboine River, downstream of the mixing zone and the confluence with the Souris River. In June, nitrogen-limiting conditions also occurred in Five Mile Creek, in July they occurred in Willow Creek and the Cypress River, and in August/September they occurred in the Cypress River and Epinette Creek. Conversely, some tributaries exhibited very high N:P ratios, reflecting the disproportionately high loads of nitrogen, relative to phosphorus. Nutrient ratios for the municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon were 3,865, 68, and 1,549 for the June, July, and August/September sampling periods, respectively. These indications of disproportionately high nitrogen loading from this source were also observed in earlier studies (Cooley et al. 2001a) and reflect the fact that this ditch is a rich source of nitrogen to the study area. The Little Souris River and the unnamed drain upstream of Site 13 also exhibited high N:P ratios in June.

6.5.1.2 Nitrogen to Phosphorus Ratios in Effluents

The nitrogen to phosphorus ratio of effluents is directly relevant to the potential effects on nutrient limitation in the receiving environment. For example, addition of an effluent with a low N:P may shift a P-limiting environment to nitrogen limitation (Scrimgeour and Chambers 2000). In the Assiniboine River at Brandon, effluents add sufficient nitrogen to suppress background conditions of nitrogen limitation for a number of kilometres downstream. Collectively, the sources of nutrients to the Assiniboine River resulted in ambient conditions where neither nitrogen nor phosphorus were limiting to algal growth for a considerable distance downstream.

The Maple Leaf IWWTF effluent was characterized by a relatively low nutrient ratio in June (8), July (14), and August/September (16). These values indicate a general ‘balance’ between phosphorus and nitrogen loads discharged from this source, with respect to nutrient limitation for algal growth (i.e., the loads of nitrogen and phosphorus discharged from the IWWTF did not skew the nutrient balance, in terms of requirements for algal growth). Conversely, ratios for the Municipal WWTF were low (consistently less than 10), indicating a higher proportion of phosphorus in the discharge.

Results of previous studies and those discussed in this report have determined that, with the exceptions of May 2000 and June 2002, at which times relatively greater loads of phosphorus were released, nutrients occurred in a ratio indicating co-limitation in the ML IWWTF effluent (Cooley et al. 2001a). The observations in 2002, with the notable exception of June 2002, are consistent with these earlier observations.

6.5.2 Light and Turbidity

In general, turbid river systems are considered to exhibit some degree of light limitation, depending upon the depth of the water. As the Assiniboine River is characterized as a turbid system, it was expected that phytoplankton and periphyton growth would be limited to some degree by light. Light extinction was measured at various sites along the Assiniboine River in July and August, 2002 (Table 25). Light extinction may be expressed as a light extinction coefficient (K_e), which is a measure of the rate at which light is absorbed and scattered (i.e., extinction) over the depth of a water column, and as z_1, which is the depth of the euphotic zone (i.e., depth at which 1% of the surface radiation remains). If the value for z_1 is equal to or greater than the depth of the surface water, then the euphotic zone extends over the full depth of the water column.

Values for the light extinction coefficient ranged from 1.59 m^{-1} to 7.50 m^{-1} (Table 25). The depth of the euphotic zone, expressed by z_1, extended the entire depth of the water column at most sites evaluated in both months. Exceptions included Site 14 in both July and August/September, Sites 4C and 5C in August (not measured in July), and Sites 13L in July and 13C in August. Therefore, ambient conditions encountered during the July and August monitoring periods were generally not light-limiting at the sites examined, with the exceptions noted above. However, in general, the data indicated that, as expected, light limiting conditions likely occurred to a varying extent in the centre channel of the Assiniboine River and/or other deeper areas of the river channel. In general, little to no light limitation occurred in the right and left channels or shallow areas of the river. Ultimately, these data indicate that light-rich areas exist in the Assiniboine River, particularly adjacent to the banks, but that light may be limiting at deeper sites and at certain locations with higher turbidity.

A good relationship was found between TSS and light extinction (Figure 59) as well as between turbidity and light extinction (Figure 60), using data gathered in July and August/September 2002. A weaker correlation between turbidity and light extinction was observed using data collected in the open-water season of 1999 and June 2000 (Cooley et al. 2001a). Turbidity was generally higher in June, July, and August/September 2002 than May and June 2000, but considerably lower than observed in the open-water season of 1999. Collectively, these data indicate that strong light-limiting conditions occur in the Assiniboine River under high flows (as observed in 1999) and varying levels of light limitation occur along the study area under low flow conditions (as observed in 2000 and 2002). It is also recognized that the overall light availability for growth of algae and plants varies among seasons, as the number of daylight hours decreases from June through September. Of the sampling periods, the highest total daily radiation occur in the month of July, with slightly lower levels in June, and the lowest in August followed by September (Environment Canada 2001). This is a reflection of the total number of daylight hours and the intensity of the solar radiation, which vary by month.

6.5.3 Temperature

Biochemical processes that affect nutrient and algal dynamics are temperature-dependent; generally, processes proceed at a greater rate at high temperatures (e.g., algal growth rate, ammonia nitrification). Low water temperature in spring and fall may limit algal growth in the Assiniboine River.

6.5.4 Hydraulics

Hydraulic conditions of a stream may affect (or limit) phytoplankton growth in a number of ways. Firstly, velocity affects algal settling rate, which subsequently directly affects the quantity of phytoplankton in the water column. Velocity may also affect phytoplankton in conjunction with light extinction and turbidity, by influencing the maintenance of phytoplankton in the photic zone of the water column.

River discharge affects phytoplankton biomass at any given time due to varying travel times; travel time may be an important variable in determining the algal biomass that develops in a given reach of a river (Thomann and Mueller 1987). Travel times for the Assiniboine River in June, July, and August/September 2002 from Brandon (at Site 2) to Portage La Prairie 9 (at Site 14) were estimated at approximately 11, 12, and 14 days, respectively (Appendix 1).

7.0 SYNTHESIS

Data collected during open-water season 2002 improved our understanding of ammonia and oxygen dynamics during the growing season, as well as providing insights into the relationship between nutrient inputs at Brandon and algal growth. These data were particularly important because they provided information on the conditions in the river under low flow conditions, as well as the effects of effluents on water quality under these low discharges.

The following points synthesize our current understanding of conditions in the Assiniboine River during the growing season and the effects of effluents on water quality in the study area, based primarily on information gathered during June, July, and August/September 2002, and to a lesser extent, data collected in May and June 2000.

Ammonia

- The largest point source of ammonia to the study area was the Brandon Municipal wastewater treatment facility (WWTF) effluent during the monitoring periods in 2002. The municipal drainage ditch that receives discharge from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon also contributed a significant load of ammonia, most notably in June 2002. The ML IWWTF discharged less than 1 kg/day of ammonia during the conduct of the intensive monitoring programs, which was one to two orders of magnitude lower than upstream loads in the river.

- Some tributary streams and drains also contributed significant loads of ammonia at certain times in the open-water season 2002 (e.g., the Cypress River contributed 11.5 kg/day of ammonia in June 2002). These loads were often higher than those originating from the ML IWWTF.

- Effluents caused a measurable increase in the in-stream concentrations of ammonia within the mixing zone.

- All ammonia concentrations measured in the study area in 2002 were within the proposed MWQSOGs (Williamson 2002), as observed in earlier studies.

- Ammonia loads in effluents were rapidly removed from the water column, likely as a result of biological processes (e.g., uptake by algae, nitrification).

- Large declines in ammonia concentrations within the mixing zone were observed in the open-water season of 2002, as observed in May and June 2000.

- As the relative contributions of algae (i.e., phytoplankton and periphyton) and bacteria (i.e., nitrification) to the observed reduction in ammonia in the river were not determined, the extent to which ammonia dynamics would be affected by conditions not favourable for algal growth (e.g., low light) is not known.

- Accumulation of ammonia by periphyton is believed to play a role in reducing ammonia concentrations in the water column, notably in the mixing zone where periphyton are abundant. However, the relative magnitude of this route compared to other factors that may reduce ammonia loads is not known.

Oxygen

- In general, DO was high in the study area and was typically in excess of 80% saturation.

- In June and July 2002, lower DO concentrations were observed in the mixing zone around Sites 6 and 7.

- DO concentrations at Sites 6 and 7 in July 2002 were below the acute (and chronic) water quality objective. These low concentrations were believed to reflect high water temperatures, low upstream DO concentrations, and effects of effluents (i.e., biological activity).

- Declines in DO were observed overnight at all sites examined, including Sites 5, 6, 8, 9, 12, and 14.

- Wide diurnal fluctuations in DO were observed in the mixing zone. For example, DO dropped by approximately 8 mg/L overnight at Site 6 in August. This was thought to largely reflect the effect of dense periphyton growth in this area, and to a lesser extent, phytoplankton.

- During some periods, DO concentrations fell below the acute water quality objective (5 mg/L) overnight at Site 8.

- High densities of periphyton may be associated with extreme fluctuations in oxygen concentrations, and the occurrence of critically low levels overnight, in the growing season.

- Sloughing and die-off of periphyton in fall would also contribute to oxygen depletion through decay.

Nutrients and Algae

- Algal growth is potentially limited by many factors, including flow, light, temperature, and nutrients. Site-specific characteristics (e.g., appropriate substrata for attached algae) are also important.

- Examination of nutrient concentrations and ratios indicated that, in instances where other factors do not limit growth, nitrogen was the nutrient which would limit algal production in much of the Assiniboine River under low flow conditions. It should be noted that a few species of bluegreen algae are able to fix atmospheric nitrogen; these groups may become relatively more abundant and form large blooms in nitrogen-limited water if other factors (e.g., temperature) are favourable. Typically, nitrogen limitation occurs at Sites 1 and 2, upstream of effluent sources, and downstream of the mixing zone. In July 2002, upstream concentrations were high and nitrogen limitation did not occur in this area.

- In June, July, and August/September 2002, phosphorus concentrations were well above the levels where algal growth would be limited and consistently above MWQSOGs for phosphorus in streams at all sites in the study area (i.e., upstream and downstream of effluent inputs at Brandon).

- Data and modelling exercises indicate that there may be an unidentified source of nutrients, algae, and total suspended solids beyond Site 9 or 10. Loads of these substances notably increased at Sites 11, 12, and 13 in June, July, and August 2002 in the river, although modelling predictions indicated that in-stream loads/concentrations should have remained quite constant.

- Effluents increased the concentrations of nitrogen and phosphorus in the mixing zone. In general, the largest sources of nitrogen and phosphorus to the river were the Brandon Municipal WWTF and the ML IWWTF. At times the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon was a large source of nitrogen.

- Nitrogen and phosphorus concentrations and loads declined markedly in the mixing zone. Comparisons between mass-balance model simulations and observed loads of nitrogen and phosphorus indicated a substantive loss of nutrients was occurring in the study area, notably in the mixing zone. Similar observations were reported previously (Cooley et al. 2001a).

- Tributary streams, most notably the Cypress and Souris rivers, were also major sources of total nitrogen and phosphorus to the Assiniboine River, with the relative contributions varying somewhat over the sampling periods.

- Chlorophyll *a* concentrations in June 2002 were markedly greater (ranging from 11 µg/L to 46 µg/L) than in previous years, and those observed in July and August/September 2002. Most measurements were above what are considered ‘nuisance levels’ by some jurisdictions (Rounds and Wood 2001).

- Chlorophyll *a* concentrations in July and August/September ranged from <5 to 15 µg/L, similar to previous studies.

- High chlorophyll *a* concentrations observed in the mixing zone reflected algae discharged in effluents and sloughed benthic algae and not solely algae (i.e., phytoplankton) that were reproducing in the river.

- Conversely, as in 2000, high densities of periphyton were observed in the mixing zone, during the intensive monitoring periods. Densities, which ranged from 492 mg/m^2 to 1138 mg/m^2, in the mixing zone (Sites 5, 7, and 8) were consistently and notably above numeric criteria (50 mg/m^2 or 100 mg/m^2) proposed by other jurisdictions for the protection of aquatic life (Carr and Chambers 1998).

- Observed chlorophyll *a* concentrations and nutrient concentrations, in conjunction with model simulations, indicate that the observed decline in nutrients in the mixing zone was not solely due to phytoplankton growth. Removal of nutrients by periphyton likely plays a role in this decline.

- The proportion of the biomass of periphyton in the mixing zone which can be attributed to nutrient input from the Maple Leaf IWWTF and the Municipal WWTF has not been determined. The flux of nutrients from the water column indicates that these substances may be taken up by the attached algae in this area; however, high densities of periphyton were also found on suitable substrata upstream of the nutrient inputs at Brandon, as well as at sites downstream of the mixing zone.

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TABLES AND FIGURES

Table 1. River segmentation, location of effluent inputs, weirs, tributaries, and sampling sites.

Model reach	Reach distance		Number of computational elements	Sampling sites, effluent outfalls, and weirs	Distance downstream (km) [1]	Computational element	Cumulative Computational element
	start km	end km					
1	0	1	1	18th Street Bridge; Sampling Site 1	250 m upstream of reach 1	-	-
2	1	5	4	18th Street Weir	4.9	4	5
3	5	6	1				
4	6	10	4				
5	10	12	2				
6	12	13	1	Hydro Weir	12.7	1	13
				Sampling Site 2	12.8	1	12
7	13	14	1	Manitoba Hydro Ash Lagoon / Simplot Canada ditch; Sampling Site 2A	13.6	1	14
8	14	15	1	Sampling Site 3	14.4	1	15
9	15	16	1	Willow Creek	15.2	1	16
10	16	17	1	Brandon Municipal Cell 5 outfall	16.6	1	17
11	17	18	1	Maple Leaf Meats WWTF Effluent Discharge	17.1	1	18
				Brandon Municipal Cell 3 outfall	17.8	1	18
12	18	19	1				
13	19	20	1	Sampling Site 4	20.0	1	20
14	20	21	1				
15	21	22	1				
16	22	23	1				
17	23	24	1	Sampling Site 5	23.8	1	24
18	24	25	1				
19	25	27	2				
20	27	35	8	Sampling Site 6	27.8	1	28
				Little Souris River	30.8	5	32
21	35	51	16	Sampling Site 7	37.2	3	38
22	51	61	10	Drain from southwest upstream of Site 8	51.6	1	52
				Sampling Site 8	51.8	1	52
				Five-Mile Creek	55.1	5	56
				Junction with the Souris River	60.9	10	61

Table 1. - continued –

Model reach	Reach distance		Number of computational elements	Sampling sites, effluent outfalls, and weirs	Distance downstream (km) [1]	Computational element	Cumulative Computational element
	start km	end km					
Souris:							
23	3	0	3	Sampling Site 8A		3	3
24	61	80	19				
25	80	90	10	Sampling Site 9	80.7	1	81
26	90	94	4				
27	94	108	14				
28	108	115	7				
29	115	135	20	Sampling Site 10	115.3	1	116
				Epinette Creek	132.9	9	124
30	135	144	9				
31	144	163	19				
32	163	171	8				
33	171	191	20	Cypress River	183	12	183
				Sampling Site 11	185.0	14	185
34	191	202	11				
35	202	209	7				
36	209	223	14				
37	223	224	1				
38	224	244	20	Sampling Site 12	224.7	1	225
39	244	264	20				
40	264	266	2	Drain from south	265.5	2	266
41	266	274	8	Sampling Site 13	266.1	1	267
42	274	283	9				
43	283	286	3				
44	286	287	1	Sampling Site 14: Portage Reservoir	287.0	1	287

[1] Distance refers to distance downstream of the starting point of the model study area. The model begins approximately 250 m downstream of the 18th Street Bridge in the City of Brandon.

Table 2. Assiniboine and Souris river median discharges for the open-water season (April - November). Median discharge was derived from single-day data for the period 1970 - 1999.

Month	Date	Median, single-day, discharge (m^3/s)		
		Assiniboine River near Brandon[1]	Assiniboine River at Holland	Souris River at Wawanesa
April	12	66.13	94.96	14.7
May	17	50.19	83	22.16
June	14	33.84	56.9	7.18
July	12	26.24	36.16	6.12
August	16	11.23	22.3	3.36
September	13	9.91	15.21	2.82
October	18	14.7	22.99	2.4
November	15	17.5	23.19	2.18

[1] Brandon data period: 1974-1999.

Table 3. Assiniboine and Souris river 1Q10 discharge for the open-water season (April - November).

Month	1Q10 discharge (m^3/s)		
	Assiniboine River near Brandon	Assiniboine River at Holland	Souris River at Wawanesa
April	3.96	6.12	0.12
May	5.27	12.63	0.43
June	4.51	10.96	0.10
July	4.02	7.93	0.03
August	3.83	7.50	0
September	2.83	7.50	0
October	2.83	7.45	0.06
November	3.65	6.12	0.15

Table 4. Assiniboine and Souris river 7Q10 discharge for the open-water season (April - November).

Month	7Q10 discharge (m^3/s)		
	Assiniboine River near Brandon	Assiniboine River at Holland	Souris River at Wawanesa
April	6.04	9.91	0.31
May	5.78	13.39	0.43
June	4.92	11.30	0.18
July	4.43	8.50	0.10
August	3.92	7.50	0
September	3.00	7.50	0
October	3.00	7.08	0.07
November	4.60	7.50	0.06

Table 5. Assiniboine and Souris river 30Q10 discharges for the open-water season (April - November).

Month	30Q10 discharge (m^3/s)		
	Assiniboine River near Brandon	Assiniboine River at Holland	Souris River at Wawanesa
April	9.65	19.43	0.99
May	6.55	13.73	0.43
June	5.78	11.50	0.21
July	5.56	8.98	0.13
August	3.79	8.07	0.01
September	3.34	7.65	0.06
October	4.32	8.86	0.17
November	5.77	8.38	0.04

Table 6. Discharge and estimated proportion of total discharge, in parentheses, in the Assiniboine River near Portage la Prairie provided by the Assiniboine River near Brandon, by the Souris River, and by additional flows between Brandon and Portage la Prairie during the sample collection periods in the open-water season in 2002.

Sampling Period	Discharge (m^3/s)					
	Assiniboine River Portage la Prairie [1]	Assiniboine River at Brandon [2]	Assiniboine River at Holland [2]	Souris River at Wawanesa [2]	Measured Tributaries [3]	Other Flows [4]
June 2002	23.82	9.9 (42%)	23.12 (97%)	1.16 (5%)	2.71 (11%)	10.02 (42%)
July 2002	20.86	10.52 (50%)	19.52 (94%)	6.09 (29%)	0.70 (3.4%)	3.46 (17%)
August 2002	16.65	8.44 (51%)	16.08 (97%)	1.42 (8.5%)	0.50 (3.0%)	6.29 (38%)

[1] Simulated discharges (see Appendix 1).

[2] Measured discharge.

[3] Tributary flows other than the Souris River were measured during the monitoring programs based on average velocity and cross-sectional area measurements obtained *in situ*.

[4] Refers collectively to flow contributions from groundwater and any other point or non-point sources that contributed to river discharge in the study area for the corresponding sampling period.

Table 7. Effluent quality for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the June 2002 sampling period. DO = dissolved oxygen; CBOD = carbonaceous biochemical oxygen demand; TSS = total suspended solids; TN = total nitrogen; TKN = total kjeldahl nitrogen; and, DIN = dissolved inorganic nitrogen.

											Chlorophyll a	
			Temperature	pH	Specific Conductance	Turbidity	DO	DO	CBOD	TSS	Chlorophyll *a*	Pheophytin
Site#	Date	Time	(°C)		(mS/cm)	(NTU)	(mg/L)	(% SATURATION)	(mg/L)	(mg/L)	(µg/L)	(µg/L)
Simplot/ash lagoon municipal drainage ditch												
2A	3-Jun-02	2010	13.2	7.31	3.32	5	4.82	47.25	1.0	3	7	1
2A	4-Jun-02	1630	20.1	7.25	3.48	5	5.39	60.78	2.0	3	38	1
2A	5-Jun-02	1610	19.2	7.40	3.26	7	5.75	63.67	1.0	9	16	1
2A	6-Jun-02	1625	20.3	7.46	3.70	20	6.31	71.45	4.0	30	47	1
Maple Leaf WWTF effluent grab sample												
MLEG	3-Jun-02	1600	28.5	7.11	2.61	3	5.36	71.8	1	<5	<1	<1
MLEG	4-Jun-02	1610	28.7	7.01	2.51	3	5.21	70.1	1	<5	15	<1
MLEG	5-Jun-02	1540	29.2	7.14	2.29	5	3.31	45.0				
MLEG	6-Jun-02	1600	29.4	7.24	2.32	6	5.06	69.1				
Maple Leaf WWTF effluent grab sample (from the river at end-of-pipe)												
MLEG	5-Jun-02	1550	28.8	7.14	2.29	15	6.71	90.3	2	14	170	<1
MLEG	6-Jun-02	1605	29.0	7.24	2.32	8	6.66	90.0	2	<5	2	<1
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample												
BSE5G	3-Jun-02	1945	17.2	8.91	1.04	66	8.02	85.27	7.0	37	170	1
BSE5G	4-Jun-02	1540	18.1	8.58	1.03	86	7.63	82.62	20.0	67	200	1
BSE5G	5-Jun-02	1645	17.6	8.59	1.67	0	7.35	78.79	10.0	50	120	1
BSE5G	6-Jun-02	1700	20.2	8.63	1.06	139	7.55	85.32	6.0	46	270	1

Table 7. - continued –

		Phosphorus					Nitrogen						
		Total	Dissolved Orthophosphate	Dissolved	Particulate [1]	Dissolved Reactive Silica	TN [2]	Dissolved Nitrate/ Nitrite	Dissolved Ammonia	Total TKN	Dissolved TKN	Organic Nitrogen [3]	DIN [4]
Site#	Date	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L SiO_2)	(mg/L)	(mg/L N)	(mg/L N)	(mg/L N)	(mg/L N)	(mg/L)	(mg/L)
Simplot/ash lagoon municipal drainage ditch													
2A	3-Jun-02	0.147	0.097	0.125	0.050	11.8	324.0	248	71.5	76	76	4.5	319.5
2A	4-Jun-02	0.162	0.078	0.107	0.084	10.1	336.0	249	98.4	87	86	-11.4	347.4
2A	5-Jun-02	0.162	0.100	0.128	0.062	11.8	297.0	227	75.8	70	89	-5.8	302.8
2A	6-Jun-02	0.480	0.144	0.238	0.336	20.5	359.0	268	118.0	91	89	-27.0	386.0
Maple Leaf WWTF effluent grab sample													
MLEG	3-Jun-02	10.7	10.4	10.5	0.3	13.6	105.0	103	0.06	<4	<4	1.9	103.1
MLEG	4-Jun-02	16.0	15.4	15.8	0.6	12.3	115.0	113	0.05	<4	<4	2.0	113.1
MLEG	5-Jun-02	-	-	-	-	-	-	-	-	-	-	-	-
MLEG	6-Jun-02	-	-	-	-	-	-	-	-	-	-	-	-
Maple Leaf WWTF effluent grab sample (from the river at end-of-pipe)													
MLEG	5-Jun-02	17.6	17.9	17.4	-0.3	11.7	109.0	107	0.06	<4	<4	1.9	107.1
MLEG	6-Jun-02	16.6	12.1	16.2	4.5	12.2	104.0	102	0.06	<4	<4	1.9	102.1
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample													
BSE5G	3-Jun-02	2.35	1.88	1.93	0.47	10.1	9.02	0.32	4.53	8.7	7.3	4.17	4.9
BSE5G	4-Jun-02	2.84	2.09	2.15	0.75	10.2	10.96	0.26	5.25	10.7	8.1	5.45	5.5
BSE5G	5-Jun-02	2.82	2.25	2.33	0.57	10.9	10.70	0.20	5.37	10.5	8.4	5.13	5.6
BSE5G	6-Jun-02	2.96	1.57	2.52	1.39	11.4	9.25	0.15	5.80	9.1	8.6	3.30	6.0

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[1] Calculated as the difference between total and dissolved phosphorus.

[2] TN (total nitrogen) calculated as the sum of TKN (total) and dissolved nitrate/nitrite.

[3] Organic nitrogen calculated as the difference between total TKN and ammonia.

[4] Dissolved inorganic nitrogen (DIN) calculated from the sum of dissolved nitrate/nitrite and ammonia.

Table 8. Effluent loading for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the June 2002 sampling period.

							Chorophyll		Phosphorus			
Site#	Date	Time	Discharge (m^3/s)	DO (kg/day)	CBOD (kg/day)	TSS (kg/day)	Chlorophyll *a* (kg/day)	Pheophytin (kg/day)	Total (kg/day P)	Dissolved Orthophosphate (kg/day P)	Dissolved (kg/day P)	Particulate (kg/day P)
Simplot/ash lagoon municipal drainage ditch[1]												
2A	3-Jun-02	2010	0.00716	2.98	0.62	1.55	0.00	0.00	0.09	0.06	0.08	0.03
2A	4-Jun-02	1630	0.00412	1.92	0.71	0.89	0.01	0.00	0.06	0.03	0.04	0.03
2A	5-Jun-02	1610	0.00362	1.80	0.31	2.81	0.01	0.00	0.05	0.03	0.04	0.02
2A	6-Jun-02	1625	0.0194	10.58	6.70	50.28	0.08	0.00	0.80	0.24	0.40	0.56
Maple Leaf IWWTF effluent [2]												
MLEG	3-Jun-02	1600	0.03398	15.74	2.94	7.34	0.00	0.00	31.41	30.53	30.83	0.88
MLEG	4-Jun-02	1610	0.03579	16.11	3.09	7.73	0.05	0.00	49.47	47.62	48.85	1.86
MLEG	5-Jun-02	1540	0.03753	21.76	6.49	45.40	0.55	0.00	57.08	58.05	56.43	-0.97
MLEG	6-Jun-02	1600	0.03860	22.21	6.67	8.34	0.01	0.00	55.36	40.35	54.03	15.01
Brandon Municipal WWTF sewage lagoon Cell 5 effluent [2]												
BSE5G	3-Jun-02	1945	0.1631	112.98	98.61	521.24	2.39	0.01	33.11	26.48	27.19	6.62
BSE5G	4-Jun-02	1540	0.1666	109.80	287.82	964.18	2.88	0.01	40.87	30.08	30.94	10.79
BSE5G	5-Jun-02	1645	0.1628	103.37	140.63	703.17	1.69	0.01	39.66	31.64	32.77	8.02
BSE5G	6-Jun-02	1700	0.1541	100.54	79.90	612.57	3.60	0.01	39.42	20.91	33.56	18.51

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 8. - continued –

					Nitrogen							
Site#	Date	Time	Discharge (m^3/s)	Dissolved Reactive Silica (kg/day SiO$_2$)	TN (kg/day)	Dissolved Nitrate/Nitrite (kg/day N)	Dissolved Ammonia (kg/day N)	Total TKN (kg/day N)	Dissolved TKN (kg/day N)	Organic Nitrogen (kg/day)	DIN (kg/day)
Simplot/ash lagoon municipal drainage ditch [1]											
2A	3-Jun-02	2010	0.00716	7.30	200.5	153.48	44.25	47.04	47.04	2.78	197.7
2A	4-Jun-02	1630	0.00412	3.59	119.5	88.59	35.01	30.95	30.60	-4.06	123.6
2A	5-Jun-02	1610	0.00362	3.69	92.9	70.98	23.70	21.89	27.83	-1.81	94.7
2A	6-Jun-02	1625	0.0194	34.36	601.7	449.21	197.79	152.53	149.18	-45.26	647.0
Maple Leaf IWWTF effluent [2]											
MLEG	3-Jun-02	1600	0.03398	39.93	308.3	302.40	0.18	5.87	5.87	5.70	302.6
MLEG	4-Jun-02	1610	0.03579	38.03	355.6	349.40	0.15	6.18	6.18	6.03	349.6
MLEG	5-Jun-02	1540	0.03753	37.94	353.5	346.99	0.19	6.49	6.49	6.29	347.2
MLEG	6-Jun-02	1600	0.03860	40.69	346.8	340.17	0.20	6.67	6.67	6.47	340.4
Brandon Municipal WWTF sewage lagoon Cell 5 effluent [2]											
BSE5G	3-Jun-02	1945	0.1631	142.28	127.1	4.51	63.82	122.56	102.84	58.7	68.3
BSE5G	4-Jun-02	1540	0.1666	146.79	157.7	3.74	75.55	153.98	116.57	78.4	79.3
BSE5G	5-Jun-02	1645	0.1628	153.29	150.5	2.81	75.52	147.66	118.13	72.1	78.3
BSE5G	6-Jun-02	1700	0.1541	151.81	123.2	2.00	77.24	121.18	114.52	43.9	79.2

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 9. Effluent quality for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the July 2002 sampling period. DO = dissolved oxygen; CBOD = carbonaceous biochemical oxygen demand; TSS = total suspended solids; TN = total nitrogen; TKN = total kjeldahl nitrogen; and, DIN = dissolved inorganic nitrogen.

											Chlorophyll	
			Temperature	pH	Specific Conductance	Turbidity	DO	DO	CBOD	TSS	Chlorophyll *a*	Pheophytin
Site#	Date	Time	(°C)		(mS/cm)	(NTU)	(mg/L)	(% Saturation)	(mg/L)	(mg/L)	(µg/L)	(µg/L)
Simplot/ash lagoon municipal drainage ditch												
2A	15-Jul-02	1725	30.7	9.05	1.72	23	7.51	105.03	2.0	16	4	8
2A	16-Jul-02	1800	30.0	8.95	1.85	134	7.27	100.23	2.0	12	2	5
2A	17-Jul-02	1710	26.2	9.01	1.94	22	7.98	101.86	2.0	14	8	5
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building)												
MLEG	15-Jul-02	1550	32.1	7.20	2.64	5	5.17	74.39	1.0	3	4	2
MLEG	16-Jul-02	1610	32.0	7.25	2.72	7	4.90	70.36	2.0	3	8	1
Maple Leaf IWWTF effluent grab sample (from the river at end-of-pipe)												
MLEG	17-Jul-02	1645	30.8	7.26	2.70	133	6.34	88.84	2.0	8	5	1
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample												
BSE5G	15-Jul-02	1820	28.3	8.06	1.24	74	5.70	75.92	7.0	15	17	9
BSE5G	16-Jul-02	1640	29.8	8.08	1.25	120	6.13	84.17	13.0	12	17	21
BSE5G	17-Jul-02	1740	27.0	7.98	1.22	0	5.74	74.46	12.0	20	36	13

Table 9. - continued –

			Phosphorus					Nitrogen						
			Total	Dissolved Orthophosphate	Dissolved	Particulate [1]	Dissolved Reactive Silica	TN [2]	Dissolved Nitrate/ Nitrite	Dissolved Ammonia	Total TKN	Dissolved TKN	Organic Nitrogen [3]	DIN [4]
Site#	Date	Time	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L SiO_2)	(mg/L)	(mg/L N)	(mg/L N)	(mg/L N)	(mg/L N)	(mg/L N)	(mg/L N)
Simplot/ash lagoon municipal drainage ditch														
2A	15-Jul-02	1725	0.136	0.062	0.090	0.046	12.3	6.70	5	0.5	1.8	1.40	1.280	5.420
2A	16-Jul-02	1800	0.164	0.099	0.129	0.035	12.3	6.33	4	0.3	2.3	1.20	2.030	4.300
2A	17-Jul-02	1710	0.150	0.106	0.108	0.042	10.6	4.92	4	0.4	1.4	1.20	1.040	3.880
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building)														
MLEG	15-Jul-02	1550	19.8	19.4	19.3	0.500	12.1	136.0	134	0.230	2.5	2.50	2.270	134.230
MLEG	16-Jul-02	1610	18.2	19.3	18.4	-0.200	12.1	123.0	121	0.100	2.0	2.00	1.900	121.100
Maple Leaf IWWTF effluent grab sample (from the river at end-of-pipe)														
MLEG	17-Jul-02	1645	18.9	19.9	19.2	10.7	10.7	112.1	112	0.090	0.1	0.10	0.010	112.090
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample														
BSE5G	15-Jul-02	1820	4.55	4.25	4.33	0.220	15.6	18.71	0.11	15.30	18.6	17.80	3.300	15.410
BSE5G	16-Jul-02	1640	4.59	4.23	4.31	0.280	15.4	20.38	0.08	16.30	20.3	18.00	4.000	16.380
BSE5G	17-Jul-02	1740	4.55	4.13	4.32	0.230	15.2	19.35	0.05	16.30	19.3	18.30	3.000	16.350

[1] Calculated as the difference between total and dissolved phosphorus.

[2] TN (total nitrogen) calculated as the sum of TKN (total) and dissolved nitrate/nitrite.

[3] Organic nitrogen calculated as the difference between total TKN and ammonia.

[4] Dissolved inorganic nitrogen (DIN) calculated from the sum of dissolved nitrate/nitrite and ammonia.

Table 10. Effluent loading for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the July 2002 sampling period.

							Chlorophyll		Phosphorus			
			Discharge	DO	CBOD	TSS	Chlorophyll *a*	Pheophytin	Total	Dissolved Orthophosphate	Dissolved	Particulate
Site#	Date	Time	(m^3/s)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day P)	(kg/day P)	(kg/day P)	(kg/day P)
Simplot/ash lagoon municipal drainage ditch[1]												
2Ab	15-Jul-02	1725	0.0675	43.78	11.66	93.28	0.02	0.05	0.79	0.36	0.52	0.43
2Ab	16-Jul-02	1800	0.0655	41.13	11.31	67.88	0.01	0.03	0.93	0.56	0.73	0.37
2Ab	17-Jul-02	1710	0.0520	35.86	8.99	62.91	0.04	0.02	0.67	0.48	0.49	0.20
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building) [2]												
MLEGc	15-Jul-02	1550	0.03381	15.10	2.92	7.30	0.01	0.01	57.84	56.67	56.38	1.17
MLEGc	16-Jul-02	1610	0.03281	13.89	5.67	7.09	0.02	0.00	51.60	54.72	52.16	-3.12
MLEGd	17-Jul-02	1645	0.03450	18.90	5.96	23.85	0.01	0.00	56.34	59.32	57.23	-2.98
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample [2]												
BSE5Gc	15-Jul-02	1820	0.32287	159.01	195.27	418.44	0.47	0.25	126.93	118.56	120.79	8.37
BSE5Gc	16-Jul-02	1640	0.33034	174.96	371.03	342.49	0.49	0.60	131.00	120.73	123.01	10.27
BSE5Gc	17-Jul-02	1740	0.10688	53.00	110.81	184.68	0.33	0.12	42.01	38.14	39.89	3.88

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 10. - continued -

					Nitrogen						
			Discharge	Dissolved Reactive Silica	Total N	Nitrate/Nitrite	Ammonia	Total TKN	Dissolved TKN	Organic N	DIN
Site#	Date	Time	(m^3/s)	(kg/day SiO_2)	(kg/day)	(kg/day N)	(kg/day N)	(kg/day N)	(kg/day N)	(kg/day)	(kg/day)
Simplot/ash lagoon municipal drainage ditch[1]											
2A	15-Jul-02	1725	0.0675	71.71	39.06	28.57	3.03	10.49	8.16	7.46	31.60
2A	16-Jul-02	1800	0.0655	69.58	35.81	22.80	1.53	13.01	6.79	11.48	24.33
2A	17-Jul-02	1710	0.0520	47.63	22.11	15.82	1.62	6.29	5.39	4.67	17.44
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building) [2]											
MLEG	15-Jul-02	1550	0.03381	35.34	398.72	391.42	0.67	7.30	7.30	6.63	392.09
MLEG	16-Jul-02	1610	0.03281	34.30	348.71	343.04	0.28	5.67	5.67	5.39	343.32
MLEG	17-Jul-02	1645	0.03450	31.90	334.17	333.87	0.27	0.30	0.30	0.03	334.14
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample [2]											
BSE5G	15-Jul-02	1820	0.32287	435.18	521.93	3.07	426.81	518.87	496.55	92.06	429.88
BSE5G	16-Jul-02	1640	0.33034	439.53	581.67	2.28	465.22	579.38	513.74	114.16	467.50
BSE5G	17-Jul-02	1740	0.10688	140.36	178.68	0.46	150.51	178.22	168.98	27.70	150.98

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 11. Effluent quality for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon , the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the August 2002 sampling period. DO = dissolved oxygen; CBOD = carbonaceous biochemical oxygen demand; TSS = total suspended solids; TN = total nitrogen; TKN = total kjeldahl nitrogen; and, DIN = dissolved inorganic nitrogen.

											Chlorophyll	
Site#	Date	Time	Temperature (°C)	pH	Specific Conductance (mS/cm)	Turbidity (NTU)	DO (mg/L)	DO (% Saturation)	CBOD (mg/L)	TSS (mg/L)	Chlorophyll *a* (µg/L)	Pheophytin (µg/L)
Simplot/ash lagoon municipal drainage ditch												
2A	20-Aug-02	1935	17.7	7.42	1.75	7	3.78	40.70	0.5	8	4	1
2A	21-Aug-02	1855	15.5	7.57	3.33	5	4.30	44.28	5.0	6	3	<1
2A	22-Aug-02	1835	17.4	7.53	3.02	36	3.72	39.81	4.0	9	3	<1
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building)												
MLEG	20-Aug-02	2005	28.2	7.76	2.80	7	6.69	89.15	1.0	6.0	2	<1
MLEG	21-Aug-02	1925	28.6	7.57	2.69	14	7.13	95.74	2.0	2.5	3	<1
MLEG	22-Aug-02	1815	29.5	7.39	2.65	15	6.62	90.53	0.5	13.0	2	<1
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample												
BSE5G	20-Aug-02	2030	20.2	7.65	1.33	18	5.59	63.29	6.0	30	9	27
BSE5G	21-Aug-02	1735	18.7	7.75	1.33	13	6.94	76.22	8.0	31	6	16
BSE5G	22-Aug-02	1910	18.2	7.73	1.34	21	6.31	68.60	4.0	15	4	15

Table 11. - continued –

			Phosphorus				Dissolved Reactive Silica	Nitrogen						
			Total	Dissolved Orthophosphate	Dissolve	Particulate [1]		TN [2]	Dissolved Nitrate/ Nitrite	Dissolved Ammonia	Total TKN	Dissolved TKN	Organic Nitrogen [3]	DIN [4]
Site#	Date	Time	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L P)	(mg/L SiO_2)	(mg/L)	(mg/L N)	(mg/L N)	mg/L N)	(mg/L N)	(mg/L N)	(mg/L N
Simplot/ash lagoon municipal drainage ditch														
2A	20-Aug-02	1935	0.197	0.153	0.186	0.011	16.2	80	65	15.6	15.0	15.8	-0.6	80.7
2A	21-Aug-02	1855	0.328	0.270	0.311	0.017	27.4	289	213	71.9	76.0	75.0	4.1	284.9
2A	22-Aug-02	1835	0.297	0.226	0.261	0.036	25.6	241	186	58.4	55.0	44.0	-3.4	244.4
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building)														
MLEG	20-Aug-02	2005	10.4	9.4	9.5	0.900	18.0	104	102	0.05	2.0	2.0	2.0	102.1
MLEG	21-Aug-02	1925	16.2	16.4	16.0	0.200	16.8	106	104	0.08	2.0	2.0	1.9	104.1
MLEG	22-Aug-02	1815	18.7	19.1	18.7	0.000	15.9	106	104	0.12	2.0	2.0	1.9	104.1
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample														
BSE5G	20-Aug-02	2030	4.93	4.23	4.53	0.400	11.4	20.8	0.10	17.70	20.7	20.4	3.0	17.8
BSE5G	21-Aug-02	1735	4.99	4.29	4.51	0.480	11.4	21.8	0.13	18.00	21.7	20.0	3.7	18.1
BSE5G	22-Aug-02	1910	4.75	4.35	4.60	0.150	11.7	19.1	0.13	18.50	19.0	19.7	0.5	18.6

[1] Calculated as the difference between total and dissolved phosphorus.
[2] TN (total nitrogen) calculated as the sum of TKN (total) and dissolved nitrate/nitrite.
[3] Organic nitrogen calculated as the difference between total TKN and ammonia.
[4] Dissolved inorganic nitrogen (DIN) calculated from the sum of dissolved nitrate/nitrite and ammonia.

Table 12. Effluent loading for the municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon, the Maple Leaf IWWTF, and the Brandon Municipal Cell 5 measured during the August 2002 sampling period.

							Chlorophyll		Phosphorus			
			Discharge	DO	CBOD	TSS	Chlorophyll *a*	Pheophytin	Dissolved Orthophosphate	Total	Dissolved	Particulate
Site#	Date	Time	(m^3/s)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day P)	(kg/day P)	(kg/day P)	(kg/day P)
Simplot/ash lagoon municipal drainage ditch[1]												
2A	20-Aug-02	1935	0.00371	1.21	0.16	2.56	0.0013	0.0003	0.05	0.06	0.06	0.00
2A	21-Aug-02	1855	0.00482	1.79	2.08	2.50	0.0012	0.0002	0.11	0.14	0.13	0.01
2A	22-Aug-02	1835	0.00292	0.94	1.01	2.27	0.0008	0.0001	0.06	0.07	0.07	0.01
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building) [2]												
MLEG	20-Aug-02	2005	0.04233	24.47	3.66	21.94	0.0073	0.0018	34.30	38.03	34.74	3.29
MLEG	21-Aug-02	1925	0.04325	26.64	7.47	9.34	0.0112	0.0019	61.29	60.54	59.79	0.75
MLEG	22-Aug-02	1815	0.04350	24.88	1.88	48.85	0.0075	0.0019	71.78	70.27	70.27	0.00
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample [2]												
BSE5G	20-Aug-02	2030	0.1542	74.49	79.96	399.78	0.1199	0.3598	56.37	65.70	60.37	5.33
BSE5G	21-Aug-02	1735	0.1183	70.96	81.80	316.98	0.0614	0.1636	43.87	51.02	46.11	4.91
BSE5G	22-Aug-02	1910	0.1049	57.17	36.24	135.91	0.0362	0.1359	39.41	43.04	41.68	1.36

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 12. - continued -

					Nitrogen						
			Discharge	Dissolved Reactive Silica	TN	Nitrate/Nitrite	Ammonia	Total TKN	Dissolved TKN	Organic N	DIN
Site#	Date	Time	(m^3/s)	(kg/day SiO_2)	(kg/day)	(kg/day N)	(kg/day N)	(kg/day N)	(kg/day N)	(kg/day)	(kg/day)
Simplot/ash lagoon municipal drainage ditch [1]											
2A	20-Aug-02	1935	0.00371	5.19	25.64	20.84	4.99	4.80	5.06	-0.19	25.83
2A	21-Aug-02	1855	0.00482	11.40	120.28	88.65	29.92	31.63	31.21	1.71	118.57
2A	22-Aug-02	1835	0.00292	6.45	60.72	46.86	14.71	13.86	11.09	-0.86	61.57
Maple Leaf IWWTF effluent grab sample (from within UV disinfection building) [2]											
MLEG	20-Aug-02	2005	0.04233	65.83	380.32	373.01	0.18	7.31	7.31	7.13	373.19
MLEG	21-Aug-02	1925	0.04325	62.78	396.12	388.65	0.30	7.47	7.47	7.17	388.94
MLEG	22-Aug-02	1815	0.04350	59.75	398.34	390.83	0.45	7.52	7.52	7.06	391.28
Brandon Municipal WWTF sewage lagoon Cell 5 effluent grab sample [2]											
BSE5G	20-Aug-02	2030	0.1542	151.92	277.18	1.33	235.87	275.85	271.85	39.98	237.20
BSE5G	21-Aug-02	1735	0.1183	116.57	223.21	1.33	184.05	221.88	204.50	37.83	185.38
BSE5G	22-Aug-02	1910	0.1049	106.01	173.33	1.18	167.62	172.15	178.50	4.53	168.80

[1] Discharge calculated from *in situ* measurements of cross-sectional area and average velocity.

[2] Discharge data derived from daily discharge data provided by the City of Brandon.

Table 13. Effluent quality for the Brandon Municipal Cell 5 outfall, open-water season 2002. Data provided by the City of Brandon.

	Sampling Date	24-hr Discharge	pH	TSS	5-day BOD	Ammonia-nitrogen		Total nitrogen		Total phosphorus	
		(m^3)		(mg/L)	(mg/L)	(mg/L)	(kg/d)	(mg/L)	(kg/d)	(mg/L)	(kg/d)
May	1-May-02	14,612	8.73	44	16	8.73	127.6	14.80	216.5	1.21	17.7
	8-May-02	13,920	8.18	67	14	6.52	90.8	14.90	207.4	1.25	17.4
	15-May-02	8,217	8.74	98	32	4.63	38.0	16.50	135.5	1.60	13.1
June	5-Jun-02	14,063	7.87	43	12	5.19	73.0	12.20	172.1	2.89	40.6
	12-Jun-02	15,895	7.83	48	14	9.38	149.1	13.00	207.1	3.10	49.3
	19-Jun-02	9,405	7.88	23	8	13.70	128.8	18.70	175.5	3.77	35.5
	26-Jun-02	9,160	7.95	14	12	16.10	147.5	19.00	173.9	4.08	37.4
July	3-Jul-02	15,071	8.06	43	19	17.50	263.7	21.50	324.3	4.54	68.4
	10-Jul-02	25,415	8.32	21	19	13.80	350.7	18.20	461.8	4.32	109.8
	17-Jul-02	9,234	7.74	23	12	15.50	143.1	16.90	155.8	4.76	44.0
	24-Jul-02	10,823	7.87	63	16	14.10	152.6	21.50	232.7	5.36	58.0
	31-Jul-02	11,717	8.35	68	15	9.99	117.1	17.40	204.2	4.54	53.2
August	7-Aug-02	12,360	7.86	35	19	11.40	140.9	16.50	203.7	4.79	59.2
	14-Aug-02	13,779	7.66	24	12	12.60	173.6	18.90	260.0	4.95	68.2
	21-Aug-02	10,225	7.60	30	28	17.60	180.0	28.80	294.1	4.96	50.7
	28-Aug-02	4,336	7.74	10	6	19.50	84.6	24.50	106.1	4.88	21.2
September	4-Sep-02	5,589	7.98	21	8	19.30	107.9	32.10	179.6	4.71	26.3
	11-Sep-02	18,072	8.22	14	6	17.80	321.7	21.50	389.3	4.37	79.0
	18-Sep-02	6,828	8.45	25	10	13.40	91.5	18.70	127.4	3.64	24.9
	25-Sep-02	11,115	8.60	16	10	11.10	123.4	14.90	165.8	2.86	31.8

Table 14. Effluent quality for the Maple Leaf IWWTF, open-water season 2002. Data provided by the City of Brandon.

	Sampling Date	24-hr Discharge	pH	TSS	5-day BOD	Ammonia-nitrogen		Total nitrogen		Total phosphorus	
		(m^3)		(mg/L)	(mg/L)	(mg/L)	(kg/d)	(mg/L)	(kg/d)	(mg/L)	(kg/d)
May	01-May-02	2,519	7.70	7	<6	0.13	0.3	85.7	215.9	14.10	35.5
	08-May-02	3,190	7.82	10	<6	0.14	0.4	119.0	379.6	13.40	42.7
	15-May-02	3,178	7.45	7	6	0.23	0.7	86.9	276.2	16.30	51.8
	22-May-02	2,274	7.70	17	10	0.21	0.5	94.7	215.3	12.90	29.3
	29-May-02	3,281	7.50	7	<6	0.19	0.6	97.5	319.9	18.00	59.1
June	5-Jun-02	3,243	7.51	6	<6	0.16	0.5	97.9	317.5	16.20	52.5
	12-Jun-02	3,156	7.77	6	<6	0.05	0.2	99.2	313.1	10.80	34.1
	19-Jun-02	3,217	7.63	5	<6	0.12	0.4	97.2	312.7	10.20	32.8
	26-Jun-02	3,160	7.58	5	<5	0.08	0.3	103.0	325.5	15.10	47.7
July	3-Jul-02	2,551	7.70	5	<6	0.18	0.5	112.0	285.7	11.50	29.3
	10-Jul-02	3,676	7.56	11	<6	3.58	13.2	102.0	375.0	17.60	64.7
	17-Jul-02	2,981	7.29	13	<6	0.12	0.4	107.0	319.0	20.00	59.6
	24-Jul-02	3,501	7.48	5	<6	0.14	0.5	106.0	371.1	17.20	60.2
	31-Jul-02	3,393	7.58	5	<6	0.12	0.4	105.0	356.3	14.10	47.8
August	7-Aug-02	3,114	7.54	5	<6	0.43	1.3	107.0	333.2	14.50	45.2
	14-Aug-02	3,192	7.71	6	<6	0.08	0.3	93.1	297.2	12.50	39.9
	21-Aug-02	3,737	7.53	9	<6	0.14	0.5	101.0	377.4	16.30	60.9
	28-Aug-02	3,497	7.32	8	<6	0.08	0.3	111.0	388.2	20.30	71.0
September	4-Sep-02	2,659	7.4	16	<6	0.53	1.4	111.0	295.1	16.40	43.6
	11-Sep-02	3,798	7.36	5	<6	0.14	0.5	96.9	368.0	21.00	79.8
	18-Sep-02	3,612	7.73	10	<6	0.08	0.3	101.0	364.8	15.30	55.3
	25-Sep-02	3,055	7.93	13	<6	0.05	0.2	106.0	323.8	11.40	34.8

Table 15. Calculated water quality objectives for ammonia, based on lowest and highest observed pH and temperature during the June, July, and August 2002 sampling periods. Calculations are presented in Williamson (2002).

Sampling Period	pH	Temperature (^{o}C)	Ammonia Objective (mg/L)		
			Averaging Period		
			30-day	4-day	1-hour
June	7.96	14.3	2.58	6.44	3.06
		20.8	1.72	4.30	3.06
	8.39	14.3	1.31	3.28	3.96
		20.8	0.88	2.19	3.96
July	8.26	22.9	0.95	2.37	5.10
		29.3	0.63	1.57	5.10
	8.89	22.9	0.33	0.84	1.58
		29.3	0.22	0.55	1.58
August/September	8.42	18.5	0.97	2.41	3.74
		24.7	0.65	1.62	3.74
	8.86	18.5	0.47	1.16	1.66
		24.7	0.31	0.78	1.66

Table 16. Loads of ammonia in the Assiniboine River and discharged from various sources in the open-water season, 2002.

Period	Source/Site	Ammonia Load (kg/day)
June 2002 [1]	Site 2	10.1
	Simplot/Ash Lagoon Municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon	23.7
	Willow Creek	0.14
	Brandon Municipal	75.5
	Maple Leaf IWWTF	0.19
	Little Souris River	0.32
	Total Loads to Site 8	109.95
	Site 8 Measured Loads	82.5
July 2002 [2]	Site 2	12
	Simplot/Ash Lagoon Municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon	1.5
	Willow Creek	0.2
	Brandon Municipal	465
	Maple Leaf IWWTF	0.3
	Little Souris River	0.01
	Total Loads to Site 8	479.01
	Site 8 Measured Loads	32.8
August 2002 [3]	Site 2	4.3
	Simplot/Ash Lagoon Municipal drainage ditch that receives effluent from the Simplot Canada Fertilizer Plant and the Manitoba Hydro Ash Lagoon	29.9
	Willow Creek	0
	Brandon Municipal	184
	Maple Leaf IWWTF	0.3
	Little Souris River	0
	Total Loads to Site 8	218.5
	Site 8 Measured Loads	4.7

[1] Effluent loads refer to those measured on June 06, 2002.
[2] Effluent loads refer to those measured on July 16, 2002.
[3] Effluent loads refer to those measured on August 21, 2002.

Table 17. Summary statistics for major water quality parameters measured in the Assiniboine River at the Brandon 18th Street Bridge during the month of June from 1993 to 2002. Data provided by Manitoba Conservation, Water Quality Management Section (Manitoba Conservation 2002).

	Units	Mean	S.E.	Median	Minimum	Maximum	n [8]
Temperature	°C	18.9	0.9	19.0	15.0	23.0	10
pH[1]		8.30	0.03	8.32	8.11	8.43	10
Field pH		8.32	0.05	8.30	8.10	8.50	9
Dissolved oxygen	mg/L	7.55	0.29	7.60	5.90	9.10	10
BOD[2]		1.9	1.0	1.0	<1.0	5.0	4
Fecal coliforms	CFU/100 mL	16.9	5.0	10.0	<10.0	40.0	8
Chlorophyll *a* [2]	mg/L	4.8	1.6	4.6	2.0	8.0	4
Nitrogen measurements							
Ammonia[3]	mg/L	0.034	0.006	0.039	<0.010	0.060	10
Nitrate/nitrite[4]	mg/L	0.050	0.019	0.030	<0.010	0.200	10
Total Kjeldahl nitrogen	mg/L	1.00	0.10	0.91	0.70	1.60	10
Total nitrogen (TN)[5]	mg/L	1.05	0.11	0.94	0.71	1.66	10
Dissolved inorganic nitrogen (DIN)[6]	mg/L	0.084	0.022	0.086	0.010	0.237	10
Organic nitrogen[7]	mg/L	0.97	0.09	0.88	0.66	1.55	10
Phosphorus measurements							
Total phosphorus (TP)	mg/L	0.151	0.020	0.139	0.085	0.260	10
Particulate phosphorus	mg/L	0.076	0.014	0.067	0.028	0.171	10
Dissolved phosphorus	mg/L	0.076	0.009	0.072	0.038	0.120	10
Total organic carbon	mg/L	11.3	0.9	11.0	7.5	15.0	10
Total suspended solids	mg/L	62	15	40	8	130	10
Turbidity	NTU	40	9	27	6	80	10
True color	TCU	24	4	18	10	50	10
Total alkalinity	mg/L $CaCO_3$	263	13	278	197	302	10
Conductivity	µS/cm	967	59	954	603	1360	10

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[1] Laboratory measurements.

[2] Data only available for 1999 - 2002.

[3] Reported as soluble, dissolved, or total. Values were combined to derive statistics.

[4] Reported as soluble or dissolved. Values were combined to derive statistics.

[5] Calculated as total Kjeldahl nitrogen + nitrate/nitrite.

[6] Calculated as ammonia + nitrate/nitrite.

[7] Estimated from total Kjeldahl nitrogen - ammonia.

[8] Unless indicated otherwise, n values less than 10 resulted from one or more measurements not having been taken in a given year(s).

Table 18. Summary statistics for major water quality parameters measured in the Assiniboine River at the Brandon 18th Street Bridge during the month of July from 1993 to 2002. Data provided by Manitoba Conservation, Water Quality Management Section (Manitoba Conservation 2002).

	Units	Mean	S.E.	Median	Minimum	Maximum	n[8]
Temperature	°C	19.9	0.5	19.8	18.0	22.5	10
pH[1]		8.20	0.06	8.29	7.80	8.46	10
Field pH		8.28	0.06	8.25	7.85	8.50	10
Dissolved oxygen	mg/L	7.16	0.32	7.10	5.50	8.37	10
BOD[2]		1.9	0.5	2.0	<1.0	3.0	4
Fecal coliforms	CFU/100 mL	74.3	26.9	40.0	<10.0	210.0	9
Chlorophyll *a*[2]	mg/L	8.9	2.57	7.1	5.0	16.3	4
Nitrogen measurements							
Ammonia[3]	mg/L	0.051	0.010	0.050	0.018	0.120	10
Nitrate/nitrite[4]	mg/L	0.144	0.031	0.155	0.010	0.300	10
Total Kjeldahl nitrogen	mg/L	0.87	0.09	0.90	<0.50	1.29	10
Total nitrogen (TN)[5]	mg/L	1.01	0.11	1.07	0.44	1.43	10
Dissolved inorganic nitrogen (DIN)[6]	mg/L	0.19	0.04	0.22	0.03	0.37	10
Organic nitrogen[7]	mg/L	0.82	0.09	0.87	0.20	1.23	10
Phosphorus measurements							
Total phosphorus (TP)	mg/L	0.223	0.023	0.219	0.114	0.340	10
Particulate phosphorus	mg/L	0.110	0.022	0.102	0.010	0.207	10
Dissolved phosphorus	mg/L	0.113	0.011	0.114	0.072	0.186	10
Total organic carbon	mg/L	12.0	1.1	11.8	8.0	18.0	10
Total suspended solids	mg/L	132	26	149	25	280	10
Turbidity	NTU	72	15	75	9	160	10
True color	TCU	26	3	25	10	40	10
Total alkalinity	mg/L $CaCO_3$	243	9	235	199	296	10
Conductivity	µS/cm	894	53	910	675	1240	10

[1] Laboratory measurements.
[2] Data only available for 1999 - 2002.
[3] Reported as soluble, dissolved, or total. Values were combined to derive statistics.
[4] Reported as soluble or dissolved. Values were combined to derive statistics.
[5] Calculated as total Kjeldahl nitrogen + nitrate/nitrite.
[6] Calculated as ammonia + nitrate/nitrite.
[7] Estimated from total Kjeldahl nitrogen - ammonia.
[8] Unless indicated otherwise, n values less than 10 resulted from one or more measurements not having been taken in a given year(s).

Table 19. Summary statistics for major water quality parameters measured in the Assiniboine River at the Brandon 18th Street Bridge during the month of August from 1992 to 2001. Data provided by Manitoba Conservation, Water Quality Management Section (Manitoba Conservation 2002).

	Units	Mean	S.E.	Median	Minimum	Maximum	n[8]
Temperature	°C	21.5	0.4	21.0	20.0	24.0	10
pH[1]		8.39	0.05	8.36	8.22	8.64	10
Field pH		8.38	0.08	8.30	8.01	8.80	10
Dissolved oxygen	mg/L	6.59	0.18	6.55	5.80	7.80	10
BOD[2]		0.8	0.2	1.0	<1.0	1.0	3
Fecal coliforms	CFU/100 mL	52.0	18.5	25.0	<10.0	170.0	10
Chlorophyll *a*[2]	mg/L	5.5	2.0	5.4	2.0	9.0	3
Nitrogen measurements							
Ammonia[3]	mg/L	0.032	0.006	0.027	<0.010	0.070	10
Nitrate/nitrite[4]	mg/L	0.205	0.045	0.185	0.030	0.450	10
Total Kjeldahl nitrogen	mg/L	1.09	0.05	1.04	0.90	1.50	10
Total nitrogen (TN)[5]	mg/L	1.30	0.07	1.26	0.93	1.74	10
Dissolved inorganic nitrogen (DIN)[6]	mg/L	0.24	0.05	0.21	0.04	0.49	10
Organic nitrogen[7]	mg/L	1.06	0.06	1.01	0.87	1.50	10
Phosphorus measurements							
Total phosphorus (TP)	mg/L	0.182	0.016	0.187	0.103	0.275	10
Particulate phosphorus	mg/L	0.079	0.010	0.081	0.035	0.150	10
Dissolved phosphorus	mg/L	0.103	0.010	0.110	0.043	0.153	10
Total organic carbon	mg/L	12.3	0.9	11.9	9.0	17.0	10
Total suspended solids	mg/L	77	17	71	11	160	10
Turbidity	NTU	45	11	42	5	98	10
True color	TCU	26	3	23	15	50	10
Total alkalinity	mg/L $CaCO_3$	247	9	242	215	313	10
Conductivity	µS/cm	886	41	872	703	1140	10

[1] Laboratory measurements.
[2] Data only available for 1999 - 2002.
[3] Reported as soluble, dissolved, or total. Values were combined to derive statistics.
[4] Reported as soluble or dissolved. Values were combined to derive statistics.
[5] Calculated as total Kjeldahl nitrogen + nitrate/nitrite.
[6] Calculated as ammonia + nitrate/nitrite.
[7] Estimated from total Kjeldahl nitrogen - ammonia.
[8] Unless indicated otherwise, n values less than 10 resulted from one or more measurements not having been taken in a given year(s).

Table 20. Summary of ash-free dry mass and chlorophyll densities in periphyton samples collected from the Assiniboine River, during intensive monitoring in June, July, and August 2002. Values represent site means of seven replicate samples.

	Date	AFDM / m^2 (g/m^2)	Chlorophyll *a* / m^2 (mg/m^2)	Pheophytin (mg/m^2)	(Chlorophyll +pheophytin) / m^2 (mg/m^2)	AFDM / Chlorophyll *a*	AFDM / (Chlorophyll+ pheophytin)
June 2002							
Curries Rapids [1]	4-Jun-02	71	464	290	753	154	286
Waggle Springs [2]	11-Jun-02	51	396	256	652	149	240
Site 8 (Treesbank Bridge) [3]	12-Jun-02	58	332	160	492	188	367
July 2002							
Curries Rapids [1]	18-Jul-02	118	348	235	583	344	507
Waggle Springs [2]	19-Jul-02	85	553	200	753	174	498
Site 8 (Treesbank Bridge) [3]	22-Jul-02	117	374	185	559	331	679
August 2002							
Curries Rapids [1]	24-Aug-02	63	432	167	599	149	402
Waggle Springs [2]	24-Aug-02	78	892	246	1138	100	331
Site 8 (Treesbank Bridge) [3]	28-Aug-02	78	603	152	755	144	609

[1] All samples were collected from the monitoring site just upstream of Site 5.
[2] All samples were collected from just upstream of the Waggle Springs area (upstream of Site 7).
[3] All samples were collected from Site 8.

Table 21. Summary of chlorophyll *a* densities in periphyton sampled during the August 2002 periphyton survey. Values represent site means of five replicates. Detailed data and site locations are presented in Appendix 2.

Site	Site ID	Date	Chlorophyll *a* (µg)	Pheophytin (µg)	Chlorophyll *a*/unit area (mg/m^2)	Pheophytin/unit area (mg/m^2)	Total Chlorophyll *a*/unit area (mg/m^2)	Pheophytin (%)
Site 8 (Treesbank Bridge) 1	8Per	7-Aug-02	736	570	285.2	220.9	506.1	42.8
Site 8a (downstream of Souris River) 2	8APer1R	7-Aug-02	690	442	267.4	171.3	438.7	36.6
Site 9a (upstream of Kiche Manitou) 3	9Per1L	8-Aug-02	572	302	221.7	117.0	338.7	33.7
Site 10 (PTH 5) 4	10Per1R	8-Aug-02	984	326	381.3	126.3	507.6	25.4
Site 11 (PTH 34) 5	11Per1R	9-Aug-02	704	369	272.8	143.1	415.9	32.5

Table 22. Concentrations of total nitrogen (TN) and dissolved inorganic nitrogen (DIN), total phosphorus (TP) and dissolved orthophosphate (DOP), TN: TP, DIN:DOP, and DIN: TP ratios, and nutrient limitation in the Assiniboine River, tributaries, and effluents, June 2002.

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation [1]
	(km)	Total (mg/L)	DIN (mg/L)	Total (mg/L)	DOP (mg/L)	TN:TP	DIN:DOP	DIN:TP	
Assiniboine River									
1	0	0.77	0.019	0.071	0.025	23.8	1.6	0.6	N limited
2	12.8	0.84	0.019	0.081	0.025	22.8	1.7	0.5	N limited
3	14.4	1.14	0.228	0.080	0.024	31.5	21.0	6.3	
4	20.0	1.58	0.577	0.168	0.097	20.8	13.1	7.6	
5	23.8	1.41	0.530	0.160	0.033	19.6	35.9	7.3	
6	27.8	1.26	0.413	0.138	0.036	20.2	25.2	6.6	
7	37.2	1.22	0.347	0.125	0.049	21.5	15.8	6.1	
8	51.8	1.11	0.190	0.130	0.039	19.0	10.8	3.2	
9	80.7	0.91	0.017	0.099	0.047	20.3	0.8	0.4	N limited
10	115.3	0.87	0.019	0.101	0.031	18.9	1.4	0.4	N limited
11	185.0	0.99	0.040	0.137	0.021	16.0	4.3	0.6	N limited
12	224.7	1.01	0.022	0.160	0.017	13.9	2.9	0.3	N limited
13	266.1	0.76	0.013	0.139	0.018	12.1	1.6	0.2	N limited
14	287.0	0.94	0.045	0.070	0.011	29.9	9.4	1.4	N limited
Tributaries									
Simplot/ash lagoon municipal drainage ditch[2]	13.6	329.0	338.9	0.238	0.105	3792	7439	3865	
Willow Creek	15.2	1.82	0.090	0.148	0.092	27.2	2.2	1.3	
Little Souris River	30.8	2.69	1.780	0.091	0.014	65.4	281.2	43.3	
Five Mile Creek	55.1	0.22	0.021	0.048	0.014	10.1	3.3	1.0	N limited
Souris River	60.9	1.56	0.010	0.102	0.020	33.8	1.1	0.2	N limited

Table 22. - continued –

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation [1]
	(km)	Total (mg/L)	DIN (mg/L)	Total (mg/L)	DOP (mg/L)	TN:TP	DIN:DOP	DIN:TP	
Epinette Creek	132.9	0.87	0.200	0.127	0.023	15.1	19.2	3.5	
Cypress River	183.0	1.57	0.240	0.292	0.062	11.9	8.6	1.8	
13Drain	266.1	11.27	9.240	0.368	0.219	67.7	93.3	55.5	
Effluents									
Brandon Municipal WWTF[2]	16.6	9.98	5.5	2.74	1.95	8.1	6.3	4.4	
Maple Leaf IWWTF[2]	17.1	164.3	165.3	12.6	11.4	8.5	8.0	6.8	

[1] Nutrient limitation was assumed to follow the following relationship: DIN:DOP < 10 = N limited; DIN:DOP > 20 = P limited; DIN:DOP 10 - 20 = N or P limited. Where [DOP] ≥ 5 µg/L, P is not limiting. Where [DIN] ≥ 55 µg/L, N is not limiting.

[2] Data presented represent the means of measurements collected from June 03 to 06, 2002.

Table 23. Concentrations of total nitrogen (TN) and dissolved inorganic nitrogen (DIN), total phosphorus (TP) and dissolved orthophosphate (DOP), TN: TP, DIN:DOP, and DIN: TP ratios, and nutrient limitation in the Assiniboine River, tributaries, and effluents, July 2002.

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation[1]
		Total	DIN	Total	DOP	TN:TP	DIN:DOP	DIN:TP	
	(km)	(mg/L)	(mg/L)	(mg/L)	(mg/L)				
Assiniboine River									
1	0	0.950	0.165	0.153	0.100	13.8	3.7	2.4	
2	12.8	1.120	0.134	0.161	0.099	15.4	3.0	1.8	
3	14.4	1.127	0.132	0.163	0.097	15.3	3.0	1.8	
4	20.0	1.767	0.689	0.306	0.230	12.8	6.6	5.0	
5	23.8	1.770	0.763	0.288	0.243	13.6	6.9	5.9	
6	27.8	1.620	0.790	0.273	0.230	13.1	7.6	6.4	
7	37.2	1.623	0.800	0.298	0.245	12.1	7.2	6.0	
8	51.8	1.530	0.615	0.278	0.230	12.2	5.9	4.9	
9	80.7	1.390	0.195	0.293	0.184	10.5	2.3	1.5	
10	115.3	1.425	0.036	0.255	0.175	12.4	0.5	0.3	N limited
11	185.0	1.315	0.026	0.227	0.113	12.8	0.5	0.3	N limited
12	224.7	1.163	0.014	0.207	0.079	12.4	0.4	0.1	N limited
13	266.1	1.208	0.011	0.218	0.059	12.3	0.4	0.1	N limited
14	287.0	1.225	0.115	0.213	0.102	12.7	2.5	1.2	N limited
Tributaries									
Simplot/ash lagoon municipal drainage ditch[2]	13.6	5.983	4.533	0.150	0.089	88.9	123.4	67.8	
Willow Creek	15.2	2.020	0.029	0.348	0.245	12.84	0.26	0.18	N limited
Little Souris River	30.8	2.350	0.362	0.331	0.134	15.70	5.97	2.42	
Five Mile Creek	55.1	0.440	0.170	0.088	0.044	11.06	8.54	4.27	
Souris River	60.9	2.170	0.025	0.321	0.144	14.95	0.38	0.17	N limited

Table 23. - continued -

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation [1]
		Total	DIN	Total	DOP	TN:TP	DIN:DOP	DIN:TP	
	(km)	(mg/L)	(mg/L)	(mg/L)	(mg/L)				
Epinette Creek	132.9	0.370	0.210	0.044	0.015	18.60	30.96	10.55	
Cypress River	183.0	0.820	0.027	0.087	0.040	20.84	1.49	0.69	N limited
Effluents									
Brandon Municipal WWTF[2]	16.6	19.480	16.047	4.56	4.20	9.44	8.45	7.78	
Maple Leaf IWWTF[2]	17.1	123.867	122.47	18.97	19.5	14.44	13.88	14.27	

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[1] Nutrient limitation was assumed to follow the following relationship: DIN:DOP < 10 = N limited; DIN:DOP > 20 = P limited; DIN:DOP 10 - 20 = N or P limited. Where [DOP] ≥ 5 µg/L, P is not limiting. Where [DIN] ≥ 55 µg/L, N is not limiting.

[2] Data presented represent the means of measurements collected from July 15-17, 2002.

Table 24. Concentrations of total nitrogen (TN) and dissolved inorganic nitrogen (DIN), total phosphorus (TP) and dissolved orthophosphate (DOP), TN: TP, DIN:DOP, and DIN: TP ratios, and nutrient limitation in the Assiniboine River, tributaries, and effluents, August/September 2002.

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation [1]
	(km)	Total (mg/L)	DIN (mg/L)	Total (mg/L)	DOP (mg/L)	TN:TP	DIN:DOP	DIN:TP	
Assiniboine River									
1	0	1.605	0.010	0.132	0.007	27.0	3.4	0.2	N limited
2	12.8	1.005	0.011	0.107	0.027	21.0	0.9	0.2	N limited
3	14.4	1.092	0.109	0.105	0.033	23.2	7.5	2.3	
4	20.0	1.613	0.757	0.230	0.177	15.5	9.3	7.2	
5	23.8	1.923	0.597	0.239	0.104	17.8	12.7	5.5	
6	27.8	1.830	0.621	0.234	0.119	17.3	11.6	5.9	
7	37.2	1.300	0.573	0.211	0.151	13.6	8.4	6.0	
8	51.8	1.010	0.266	0.159	0.094	14.0	6.3	3.7	
9	80.7	0.770	0.024	0.134	0.072	12.8	0.7	0.4	N limited
10	115.3	0.805	0.008	0.152	0.070	11.8	0.3	0.1	N limited
11	185.0	0.805	0.013	0.154	0.025	11.6	1.1	0.2	N limited
12	224.7	0.870	0.033	0.159	0.040	12.1	1.9	0.5	N limited
13	266.1	0.808	0.015	0.159	0.041	11.5	0.8	0.2	N limited
14	287.0	1.055	0.015	0.122	0.045	19.1	0.7	0.3	N limited
Tributaries									
Simplot/ash lagoon municipal drainage ditch[2]	13.6	203.4	203.3	0.274	0.216	1547	1964	1549	
Waggle Spring	Upstream of Site 7	2.520	0.530	0.031	0.015	179.8	78.1	37.8	
Souris Spring	Upstream of Souris River	2.020	0.035	0.032	0.006	139.6	12.9	2.4	Possibly co-limited

Table 24. - continued –

Site/Source	Distance downstream	Mean Nitrogen		Mean Phosphorus		Molar nutrient ratios			Nutrient Limitation [1]
		Total	DIN	Total	DOP	TN:TP	DIN:DOP	DIN:TP	
	(km)	(mg/L)	(mg/L)	(mg/L)	(mg/L)				
Souris River	60.9	1.405	0.009	0.227	0.126	13.7	0.1	0.1	N limited
Epinette Creek	132.9	0.220	0.023	0.037	0.006	13.1	8.5	1.4	N limited
Cypress River	183.0	0.505	0.011	0.062	0.005	18.0	4.9	0.4	N limited
Effluents									
Brandon Municipal WWTF[2]	16.6	20.59	18.19	4.89	4.29	9.3	9.4	8.2	
Maple Leaf IWWTF[2]	17.1	105.3	103.4	15.1	15.0	16.4	16.7	16.1	

[1] Nutrient limitation was assumed to follow the following relationship: DIN:DOP < 10 = N limited; DIN:DOP > 20 = P limited; DIN:DOP 10 - 20 = N or P limited. Where [DOP] ≥ 5 µg/L, P is not limiting. Where [DIN] ≥ 55 µg/L, N is not limiting.

[2] Data presented represent the means of measurements collected from August 20-22, 2002.

Table 25. Values for light extinction (K_e), depth of the euphotic zone (z_1), turbidity, and total suspended solids (TSS) measured during monitoring of the Assiniboine River in the open-water season, 2002.

	June					July					August/September				
Site	z_1 [1]	K_e [1]	Total depth	Turbidity [2]	TSS	z_1 [1]	K_e [1]	Total depth	Turbidity [2]	TSS	z_1	K_e	Total depth	Turbidity [2]	TSS
	m	m^{-1}	m	NTU	mg/L	m	m^{-1}	m	NTU	mg/L	m	m^{-1}	m	NTU	mg/L
2L	-	-	1.4	55	35	-	-	1.4	58	39	1.91	2.41	1.5	43	28
3L	-	-	1.4	56	42	-	-	1.4	54	29	1.88	2.45	1.6	44	30
4C	-	-	1.9	41	22	-	-	2.4	60	50	1.87	2.47	2.5	38	47
5C	-	-	1.2	30	18	-	-	1.1	32	20	1.36	3.38	1.5	57	41
7C	-	-	2.2	11	< 5	-	-	1.8	29	20	2.52	1.83	2.3	22	23
9L	-	-	0.8	11	8	1.92	2.40	0.9	43	31	2.90	1.59	1.0	14	15
9R	-	-	0.8	11	8	1.87	2.46	1.0	42	36			0.9	16	17
12R	-	-	0.8	83	160	-	-	0.9	66	51	0.93	4.95	0.6	104	91
13L	-	-	2.5	108	120	0.77	5.98	1.9	167	140	-	-	0.7	155	150
13C	-	-	-	-	94	-	-	-			0.61	7.50			
14R	-	-	3.3	43	29	1.39	3.32	3.1	58	22	1.57	2.93	3.6	50	22

[1] Light meter was not functioning; new meter arrived in mid-July.

[2] Average of surface and bottom measurements where water depth exceeded 1 m.

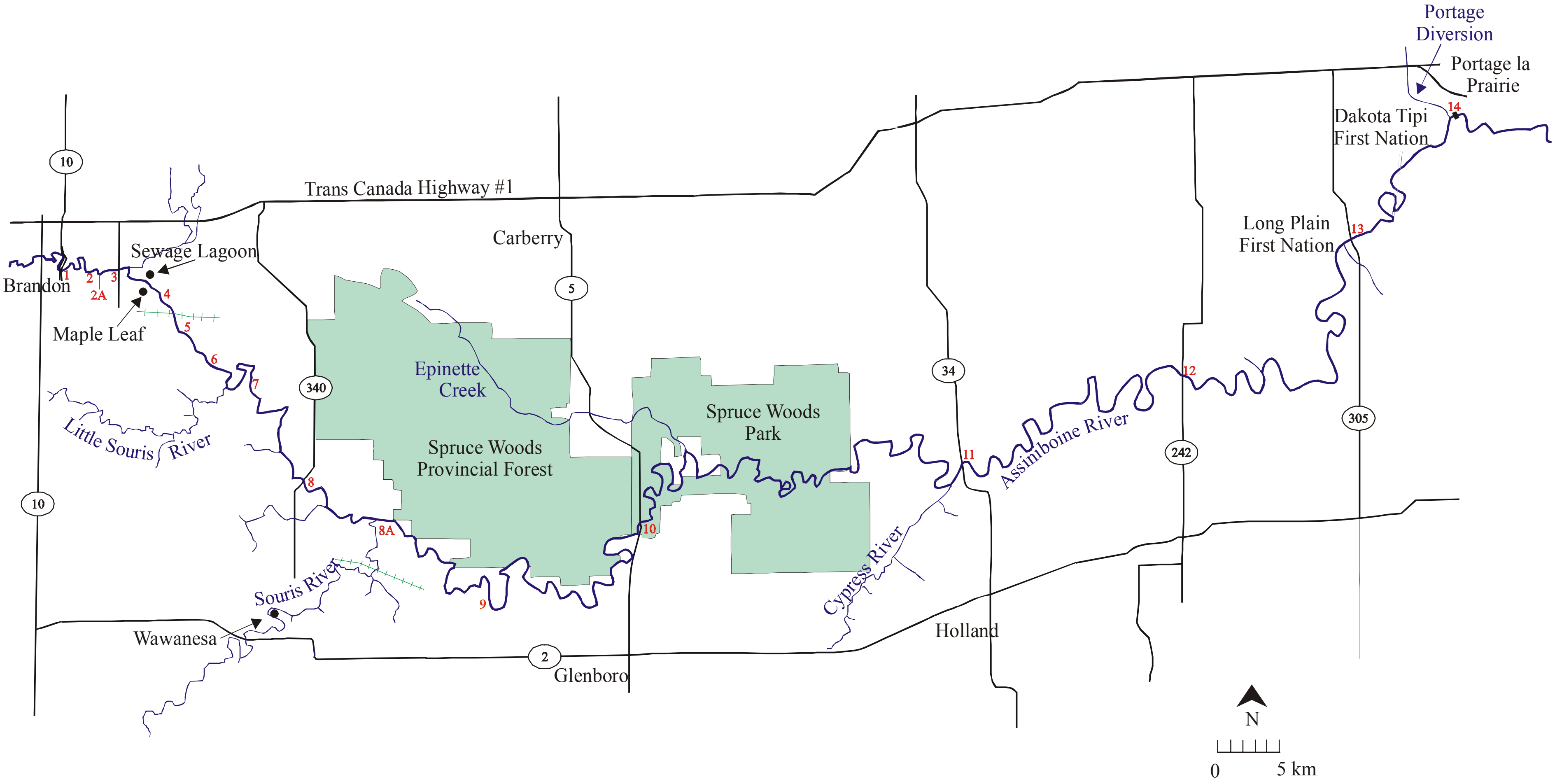

Figure 1. Study area of the Assiniboine River Monitoring Study (Brandon to Portage la Prairie), with sampling site locations.

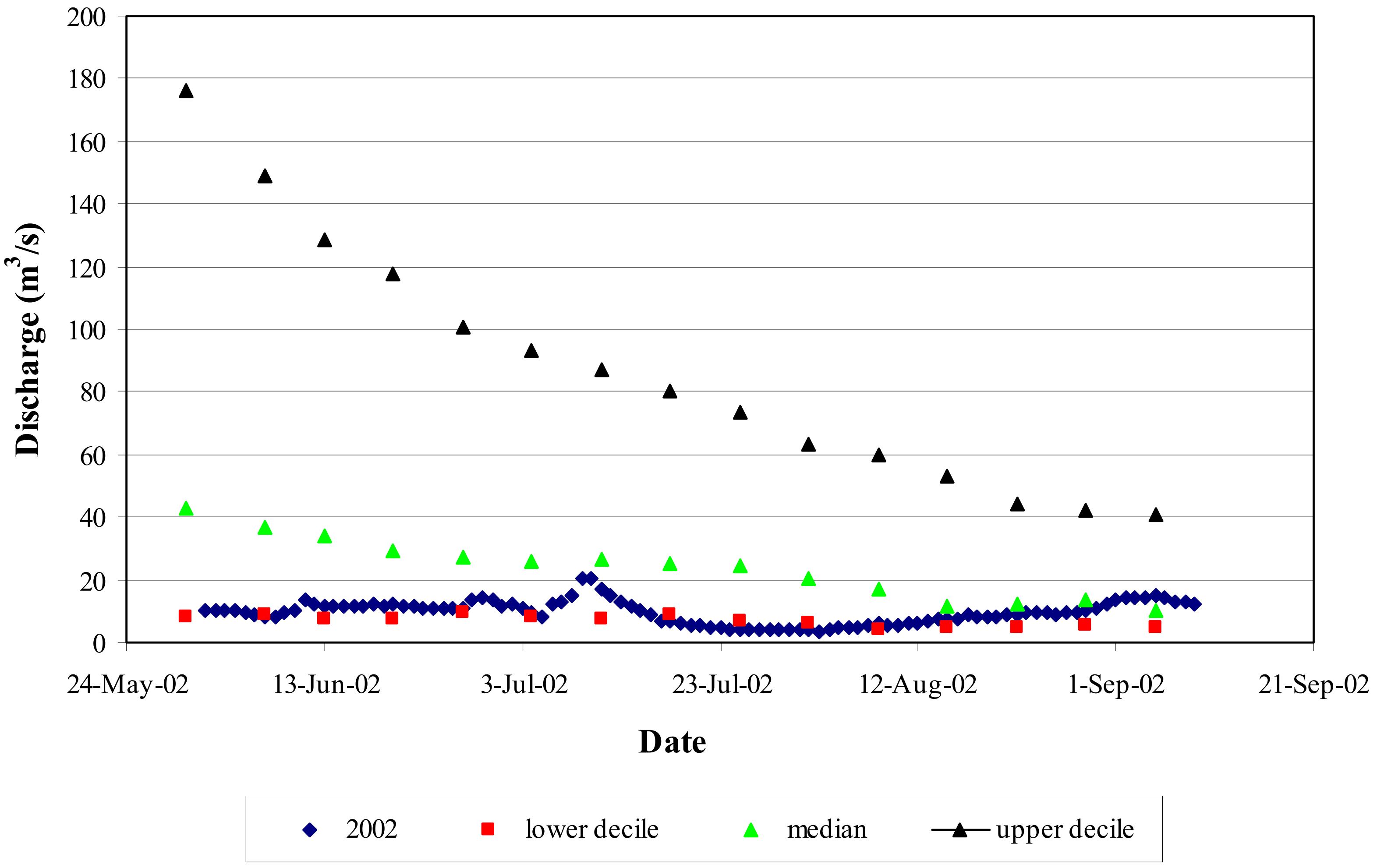

Figure 2. Assiniboine River discharge measured at Brandon for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

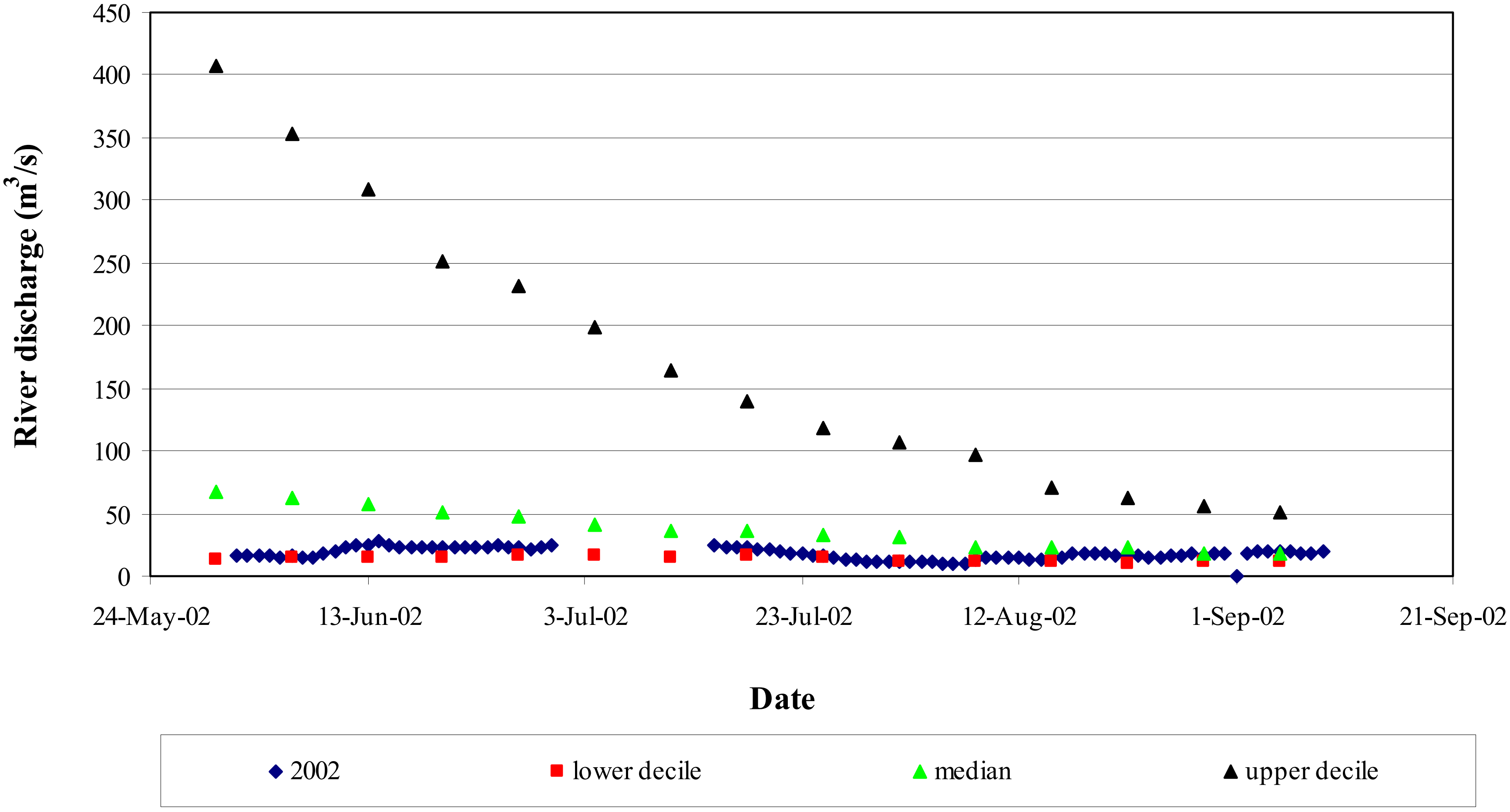

Figure 3. Assiniboine River discharge measured at Holland for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

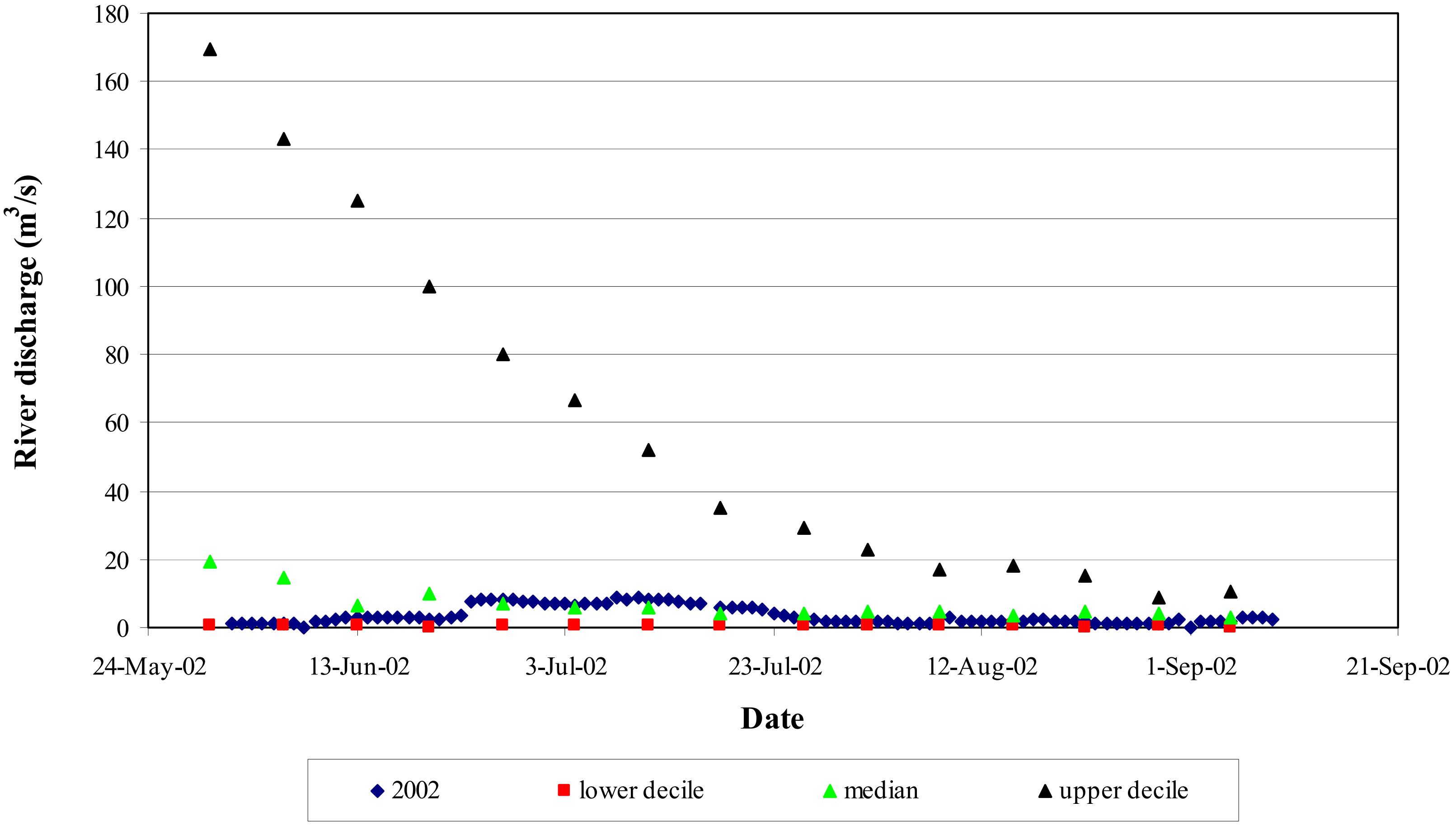

Figure 4. Souris River discharge measured at Brandon for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

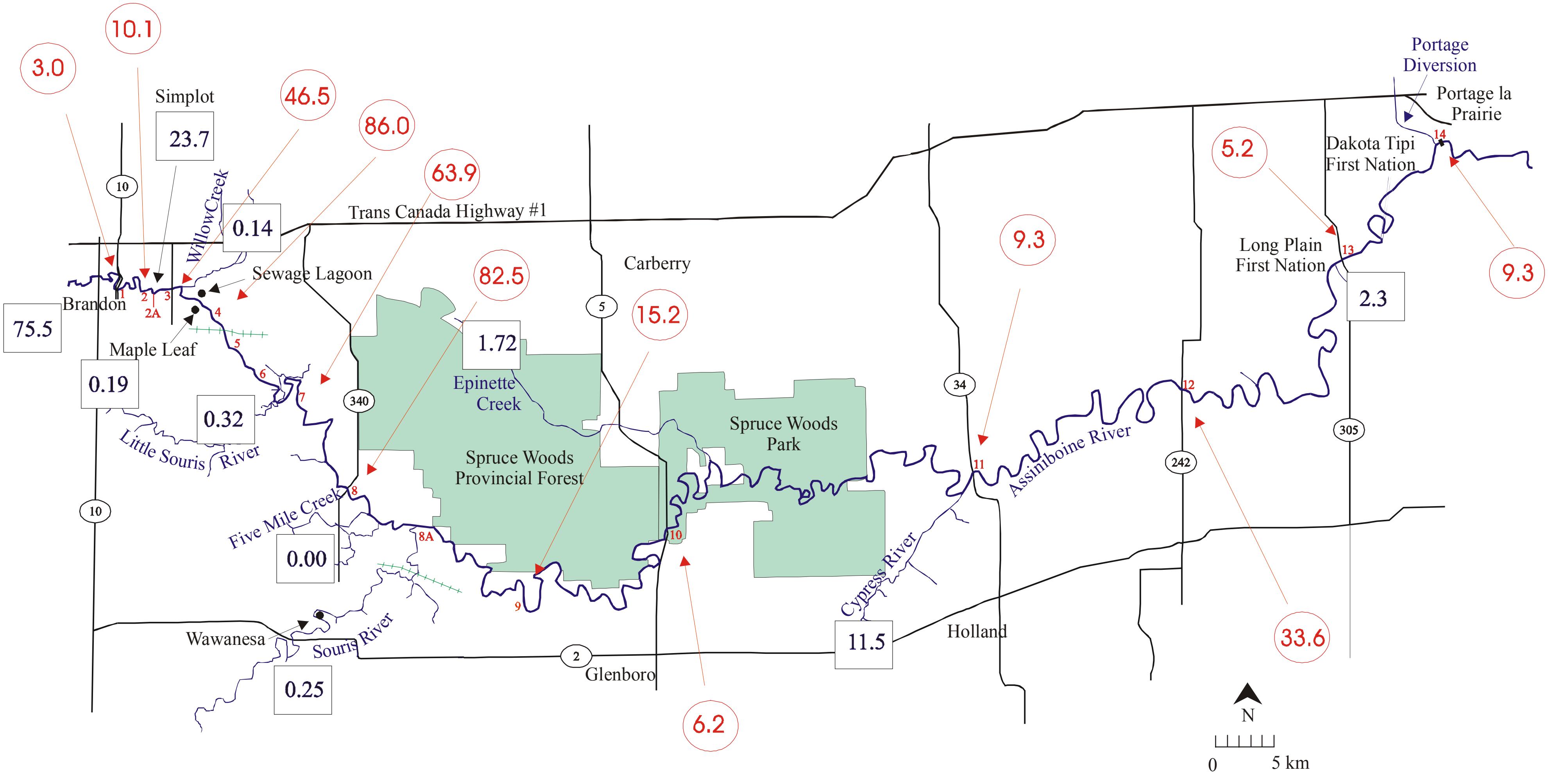

Figure 5. Ammonia- nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, June 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on June 06, 2002.

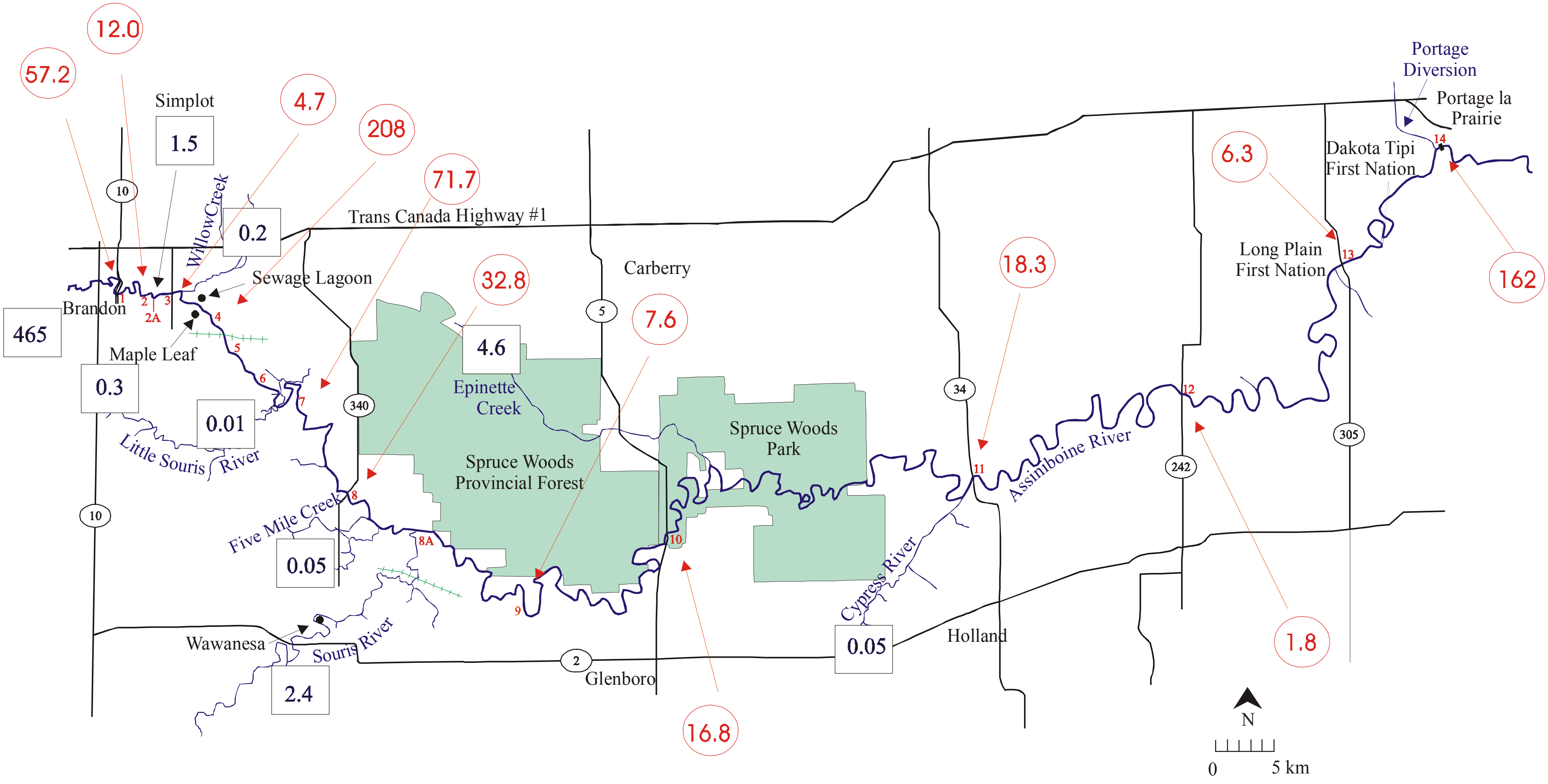

Figure 6. Ammonia- nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, July 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on July 16, 2002.

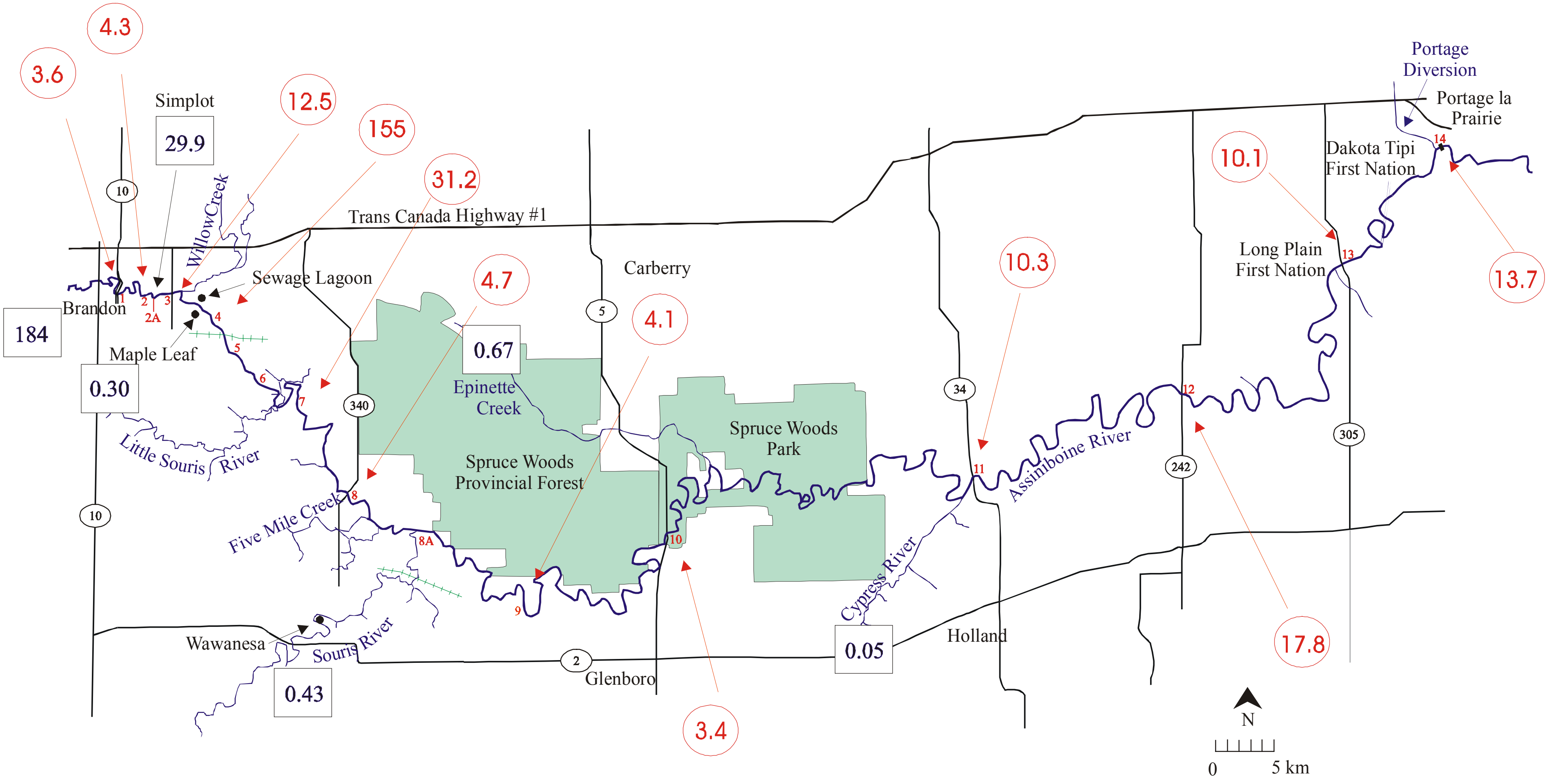

Figure 7. Ammonia- nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, August/September 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on August 21, 2002.

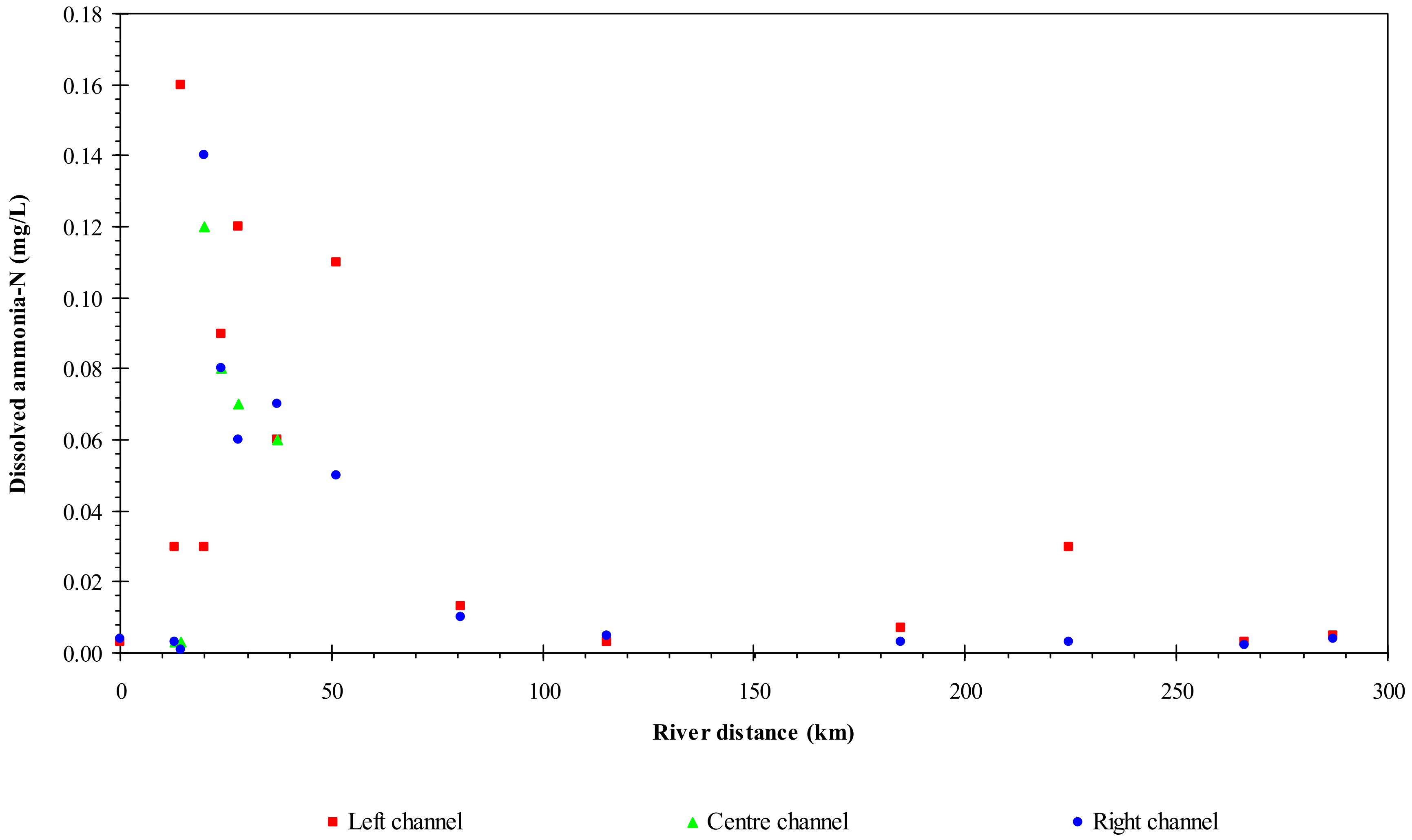

Figure 8. Dissolved ammonia nitrogen measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

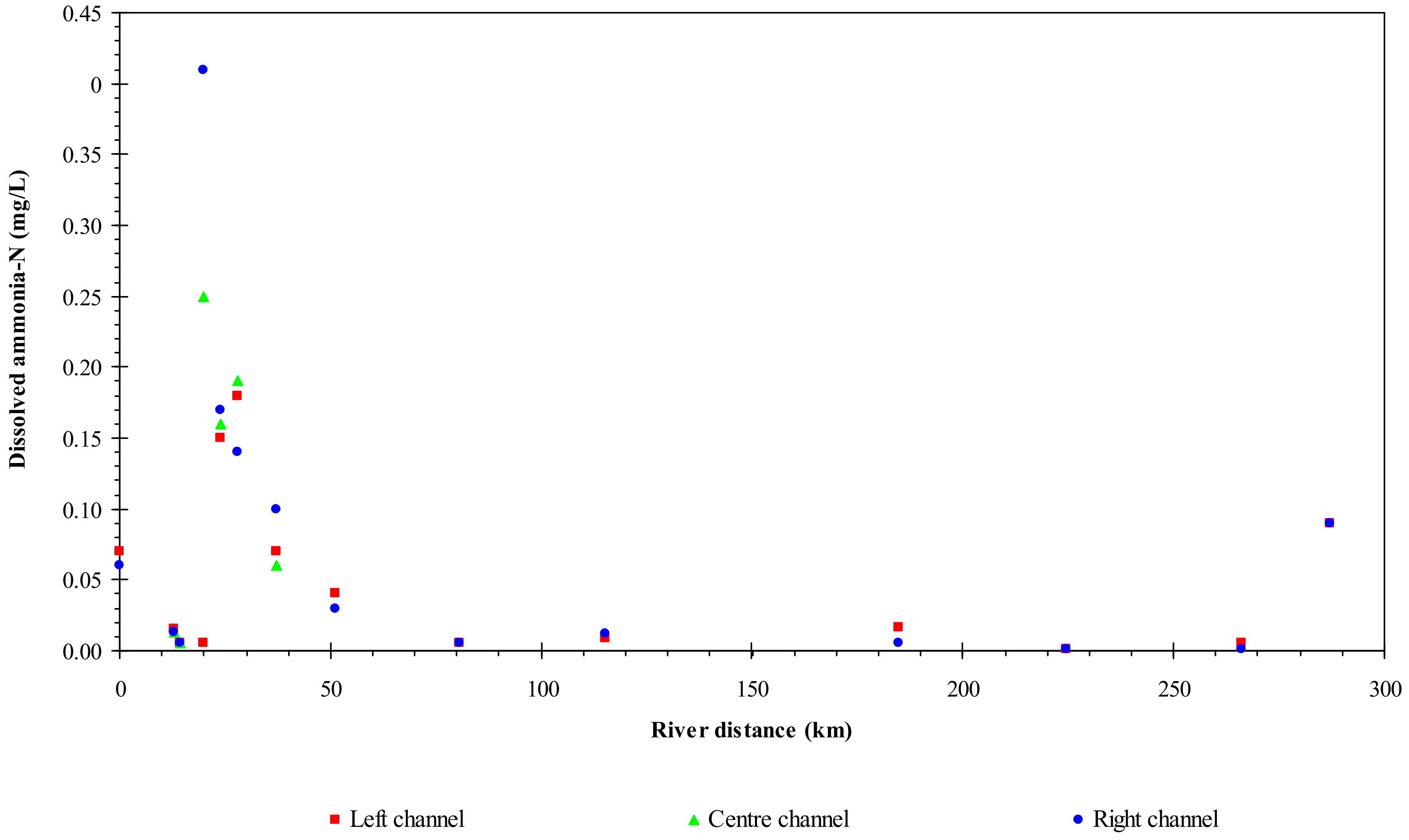

Figure 9. Dissolved ammonia nitrogen measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

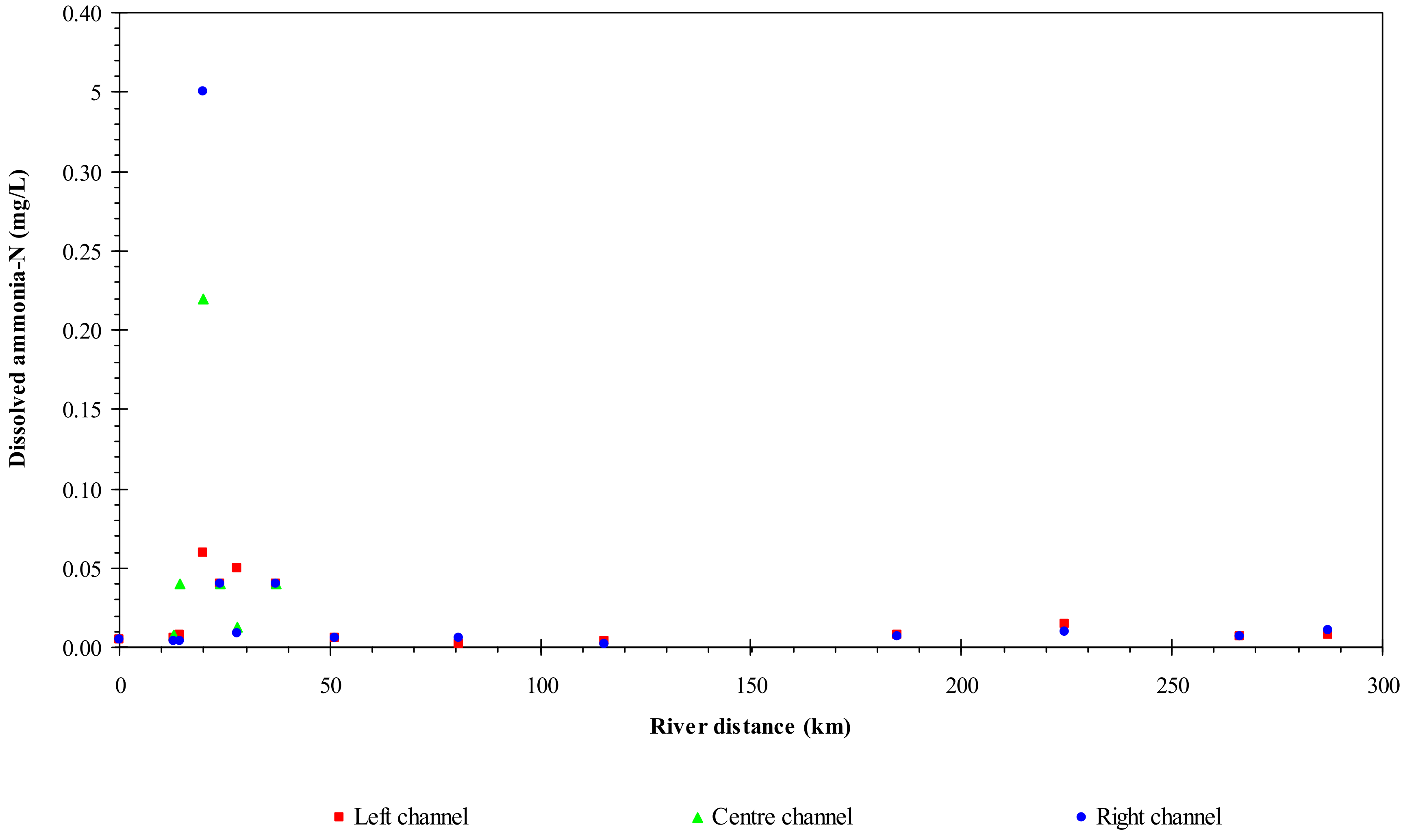

Figure 10. Dissolved ammonia nitrogen measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

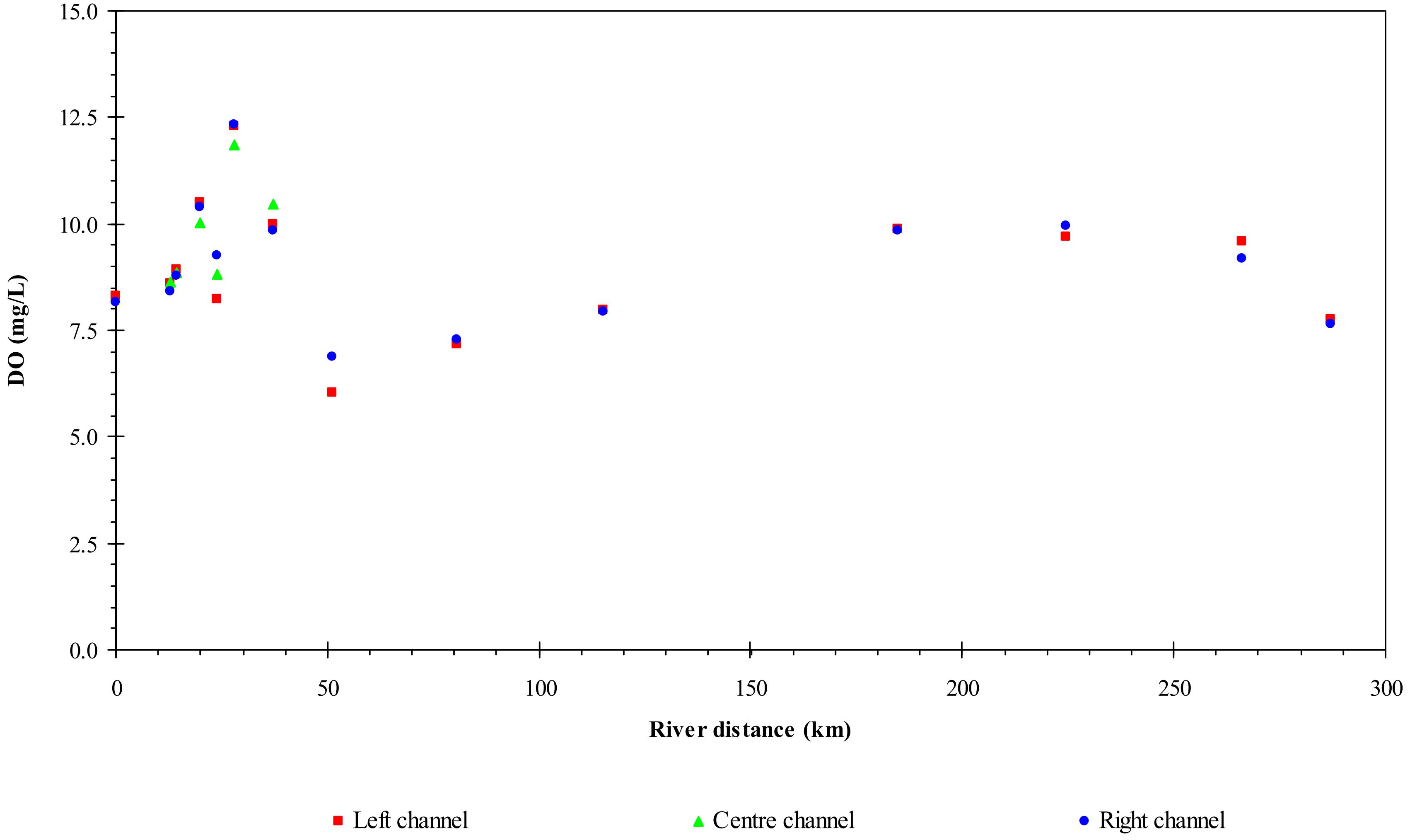

Figure 11. Dissolved oxygen measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

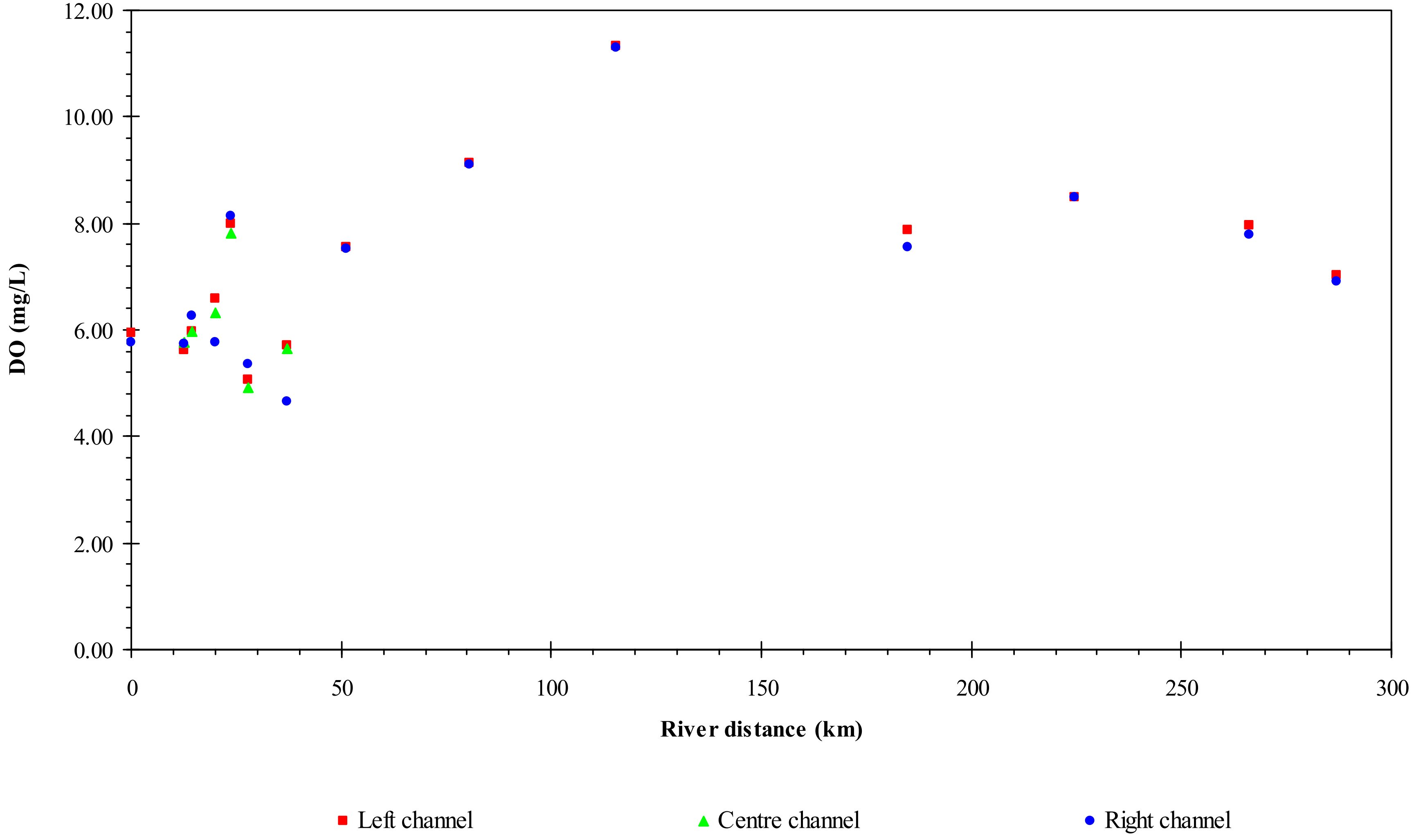

Figure 12. Dissolved oxygen (DO) measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

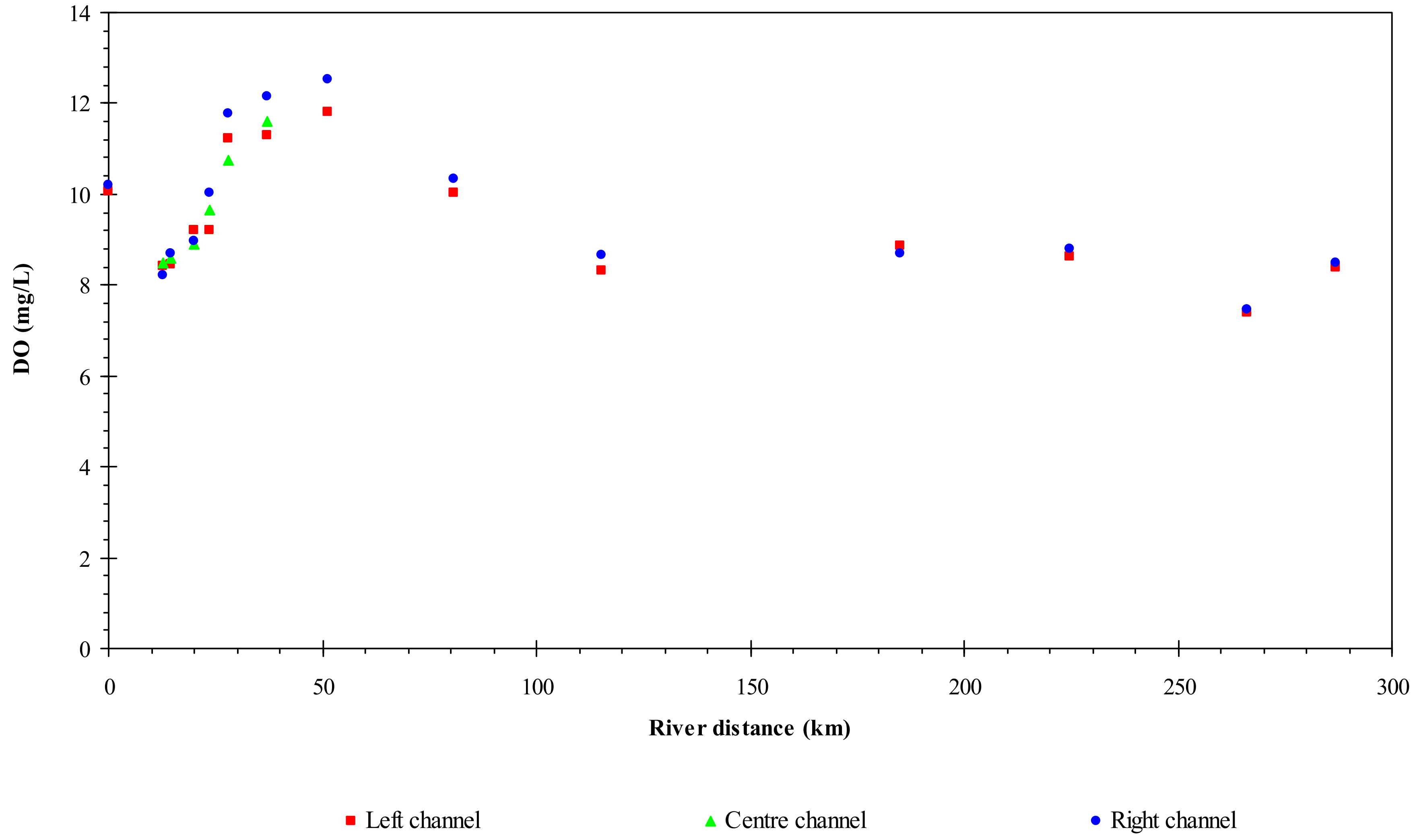

Figure 13. Dissolved oxygen measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

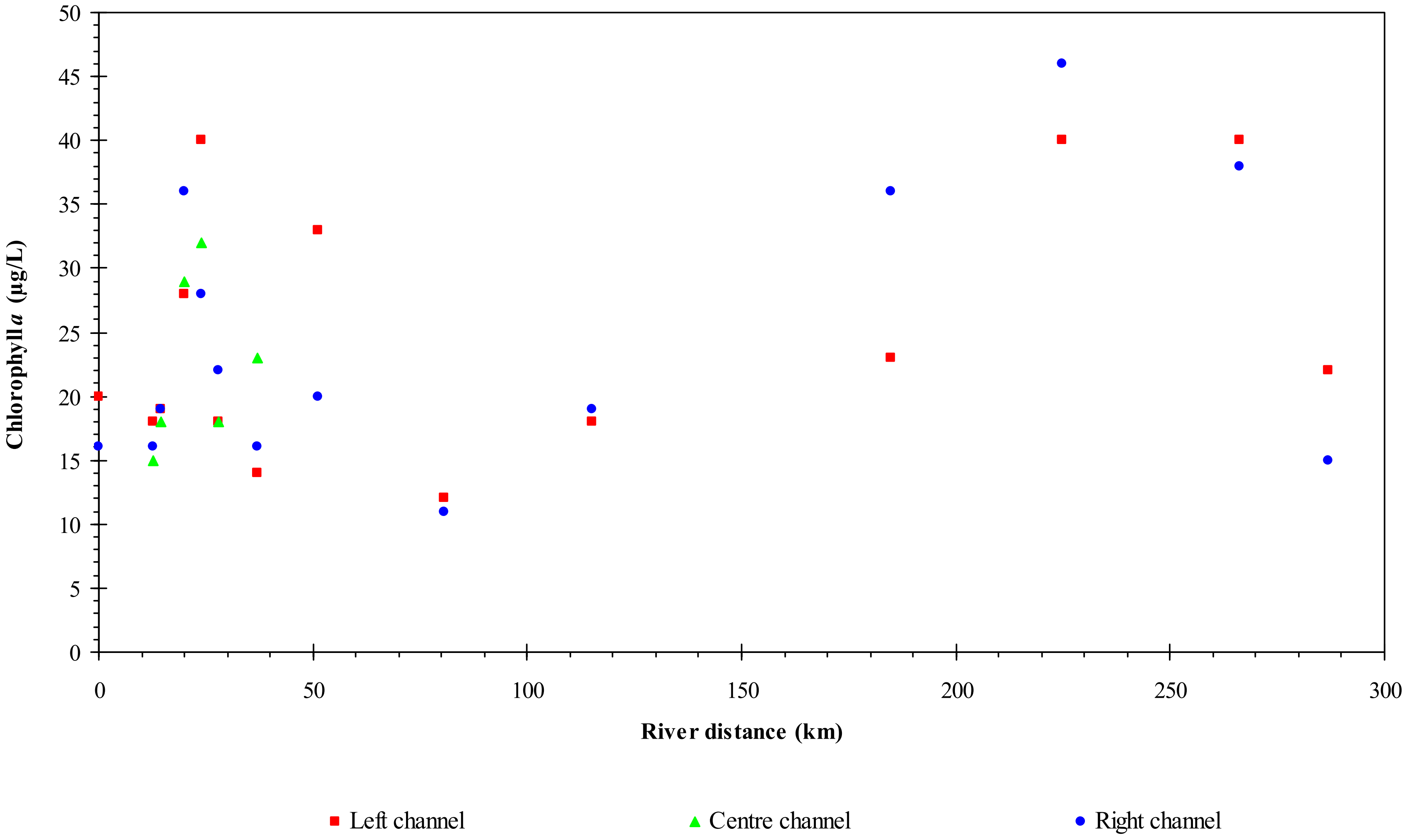

Figure 14. Chlorophyll *a* measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

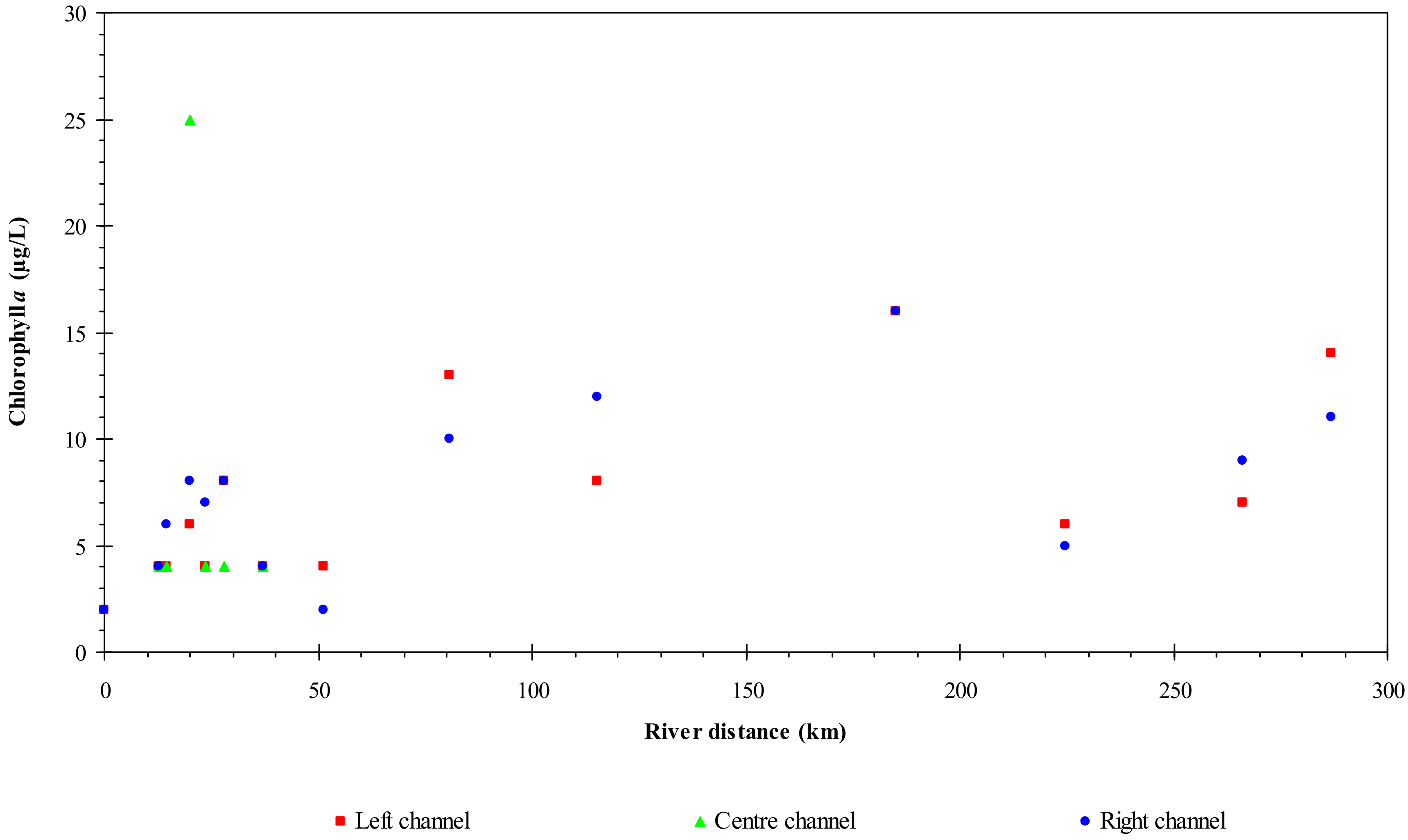

Figure 15. Chlorophyll *a* measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

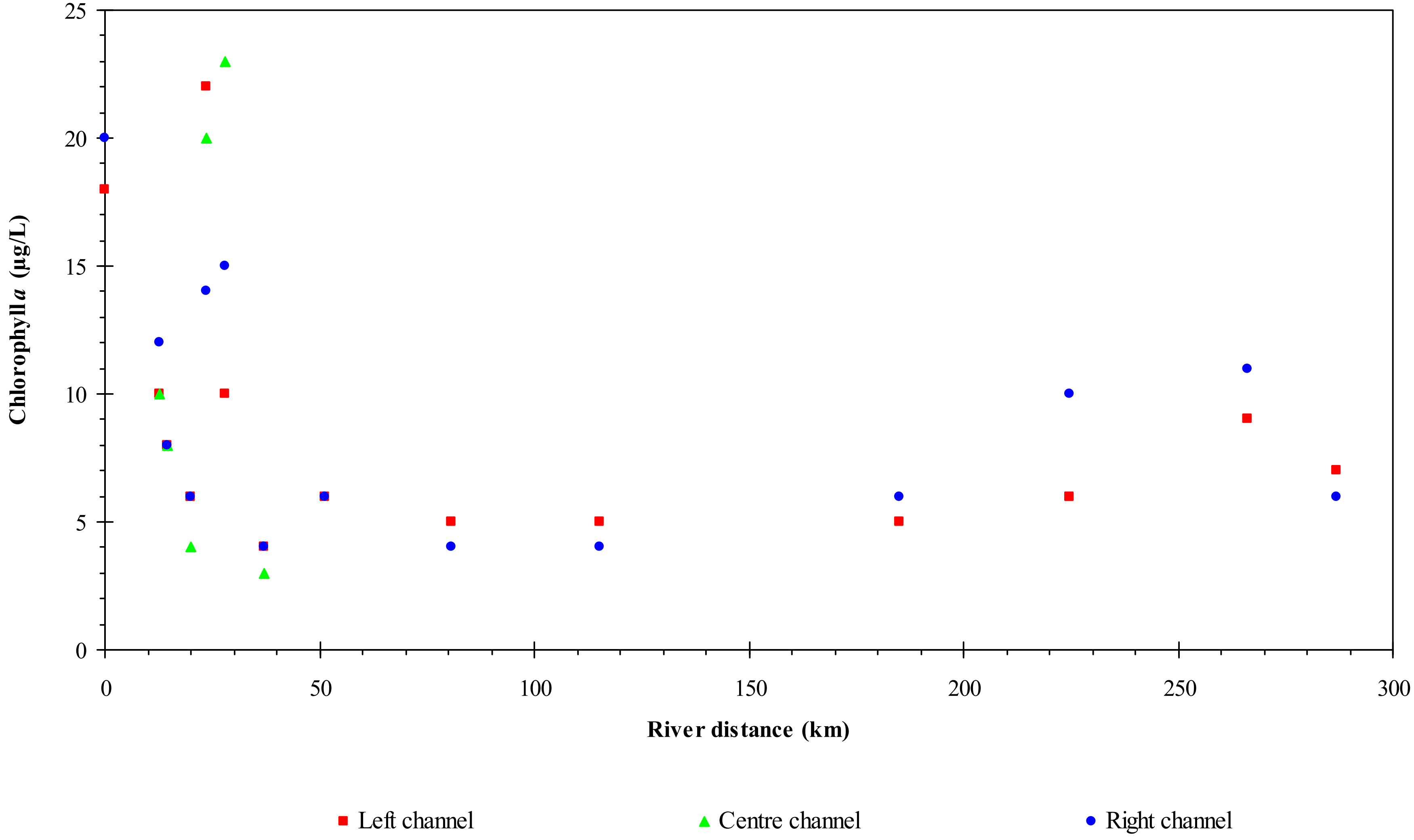

Figure 16. Chlorophyll *a* measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

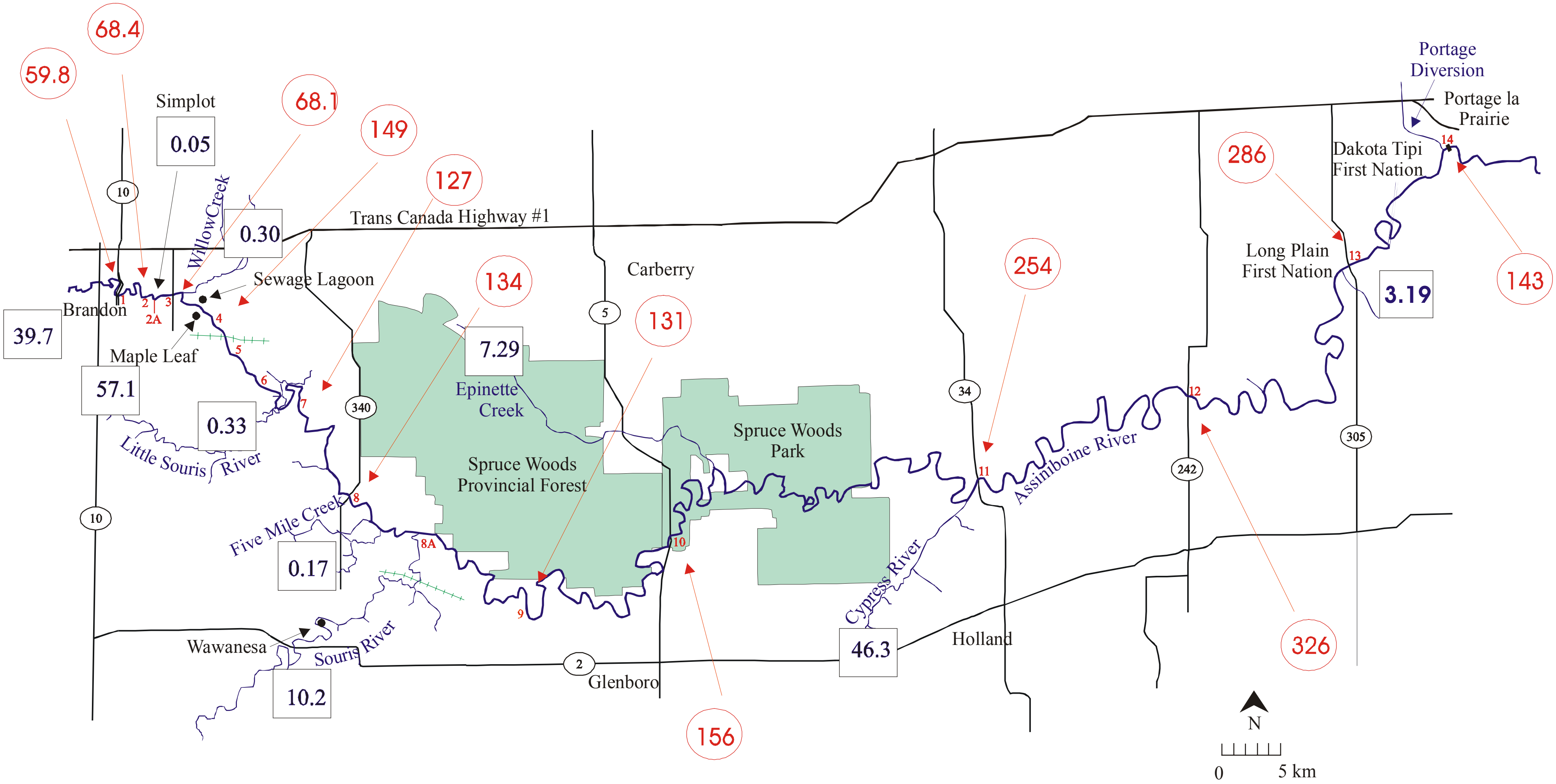

Figure 17. Total phosphorus loads (kg/day) in the Assiniboine River and various tributaries and effluents, June 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on June 06, 2002.

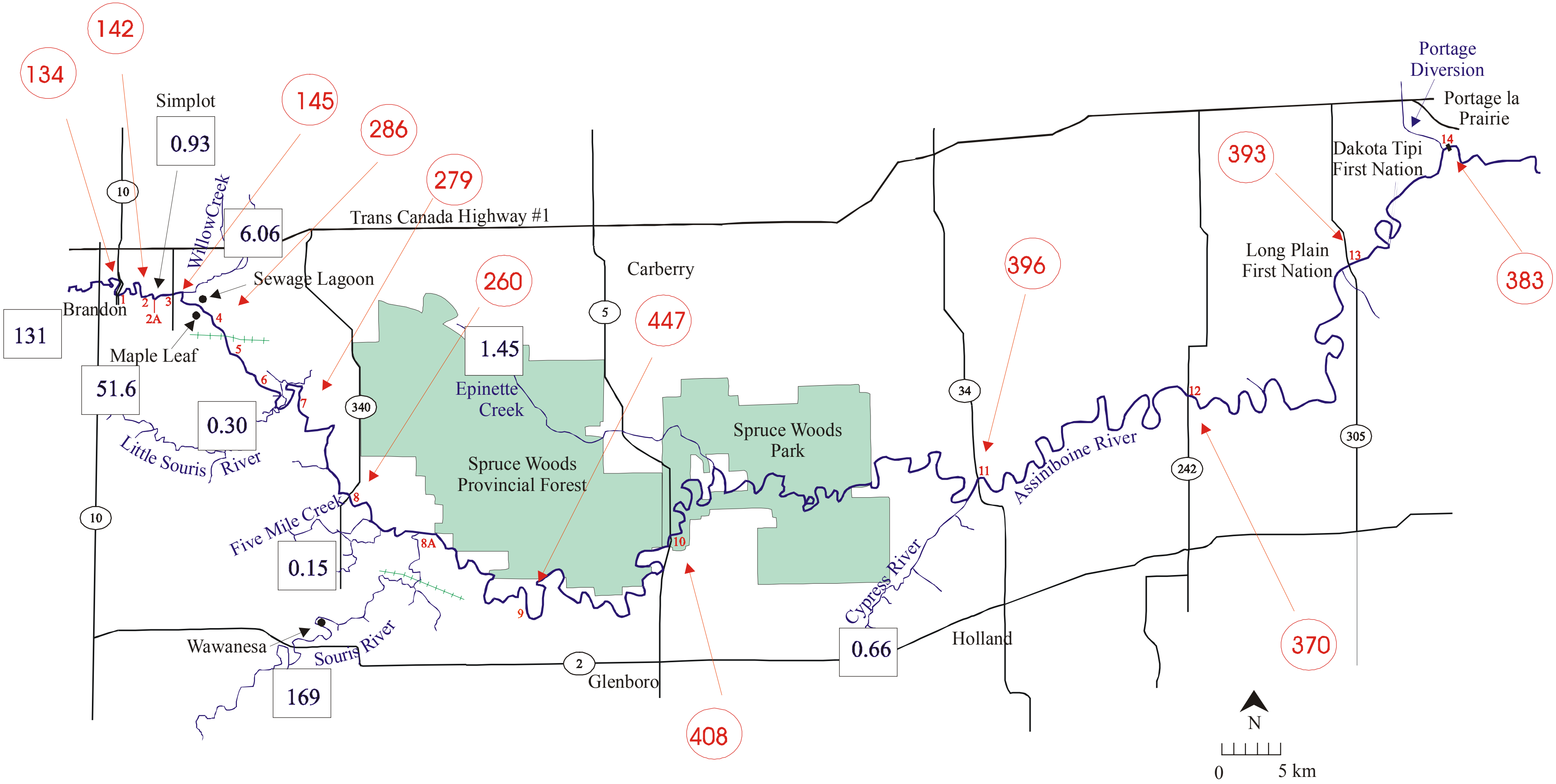

Figure 18. Total phosphorus loads (kg/day) in the Assiniboine River and various tributaries and effluents, July 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on July 16, 2002.

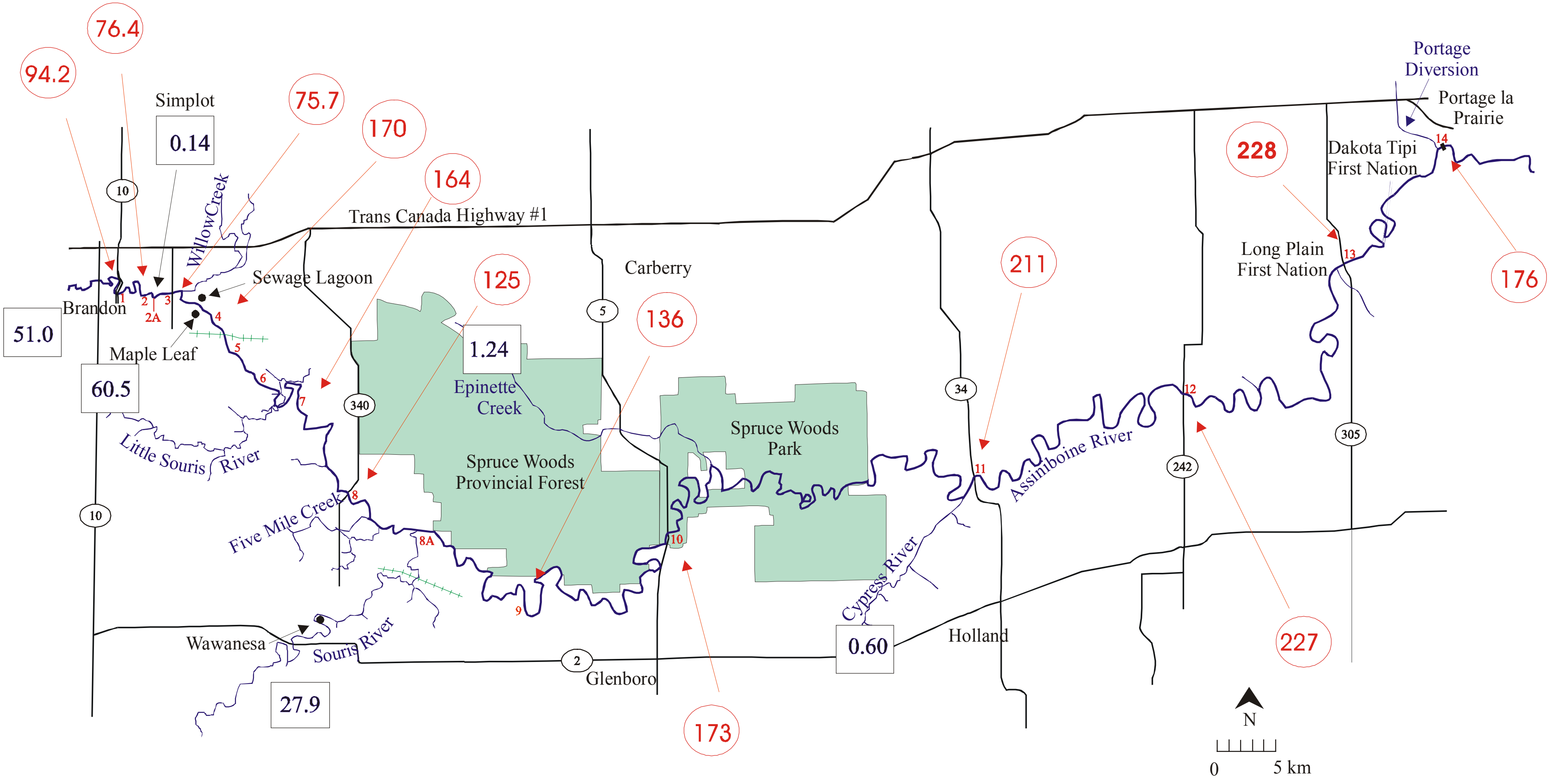

Figure 19. Total phosphorus loads (kg/day) in the Assiniboine River and various tributaries and effluents, August/September 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on August 21, 2002.

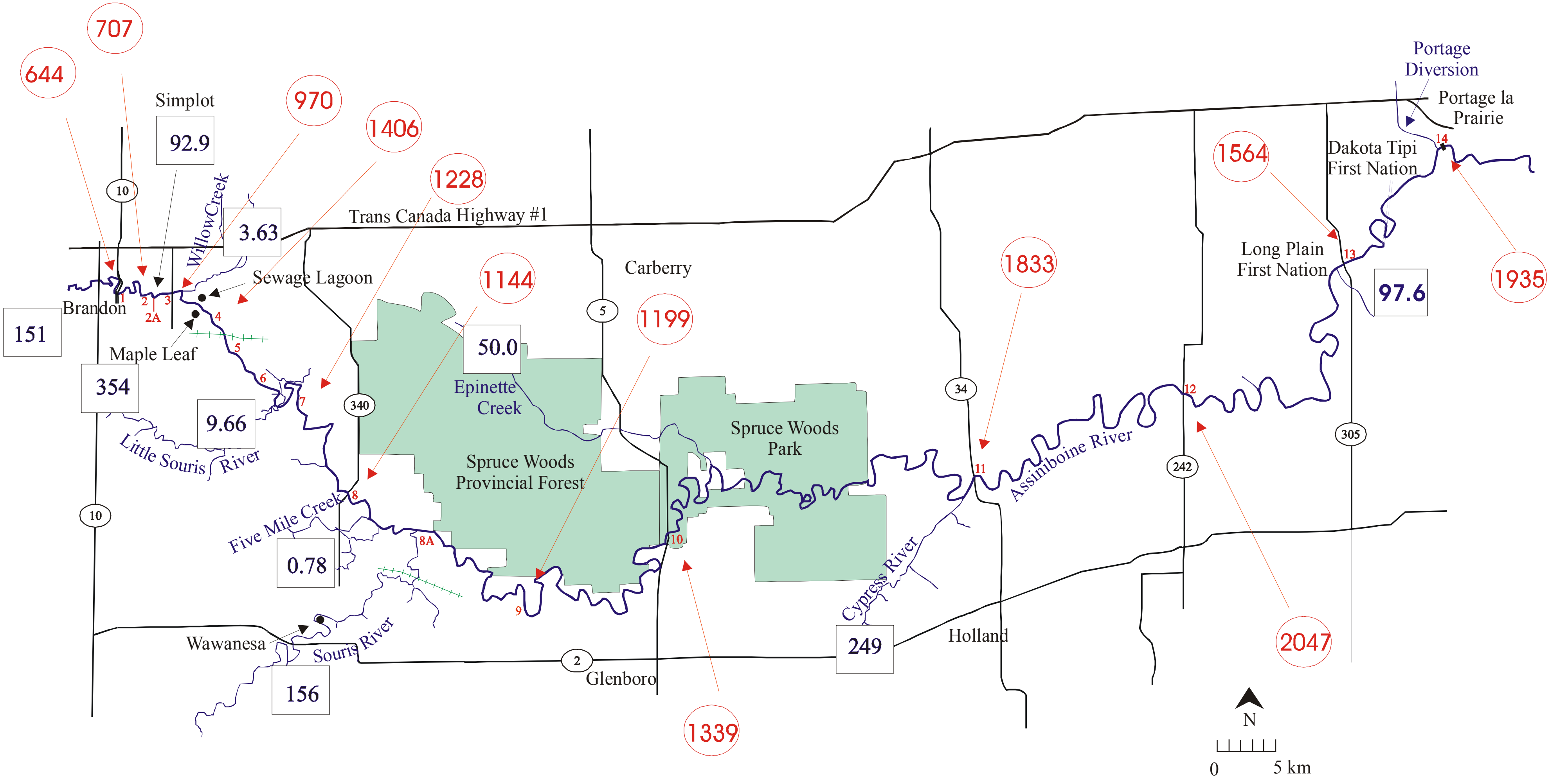

Figure 20. Total nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, June 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on June 06, 2002.

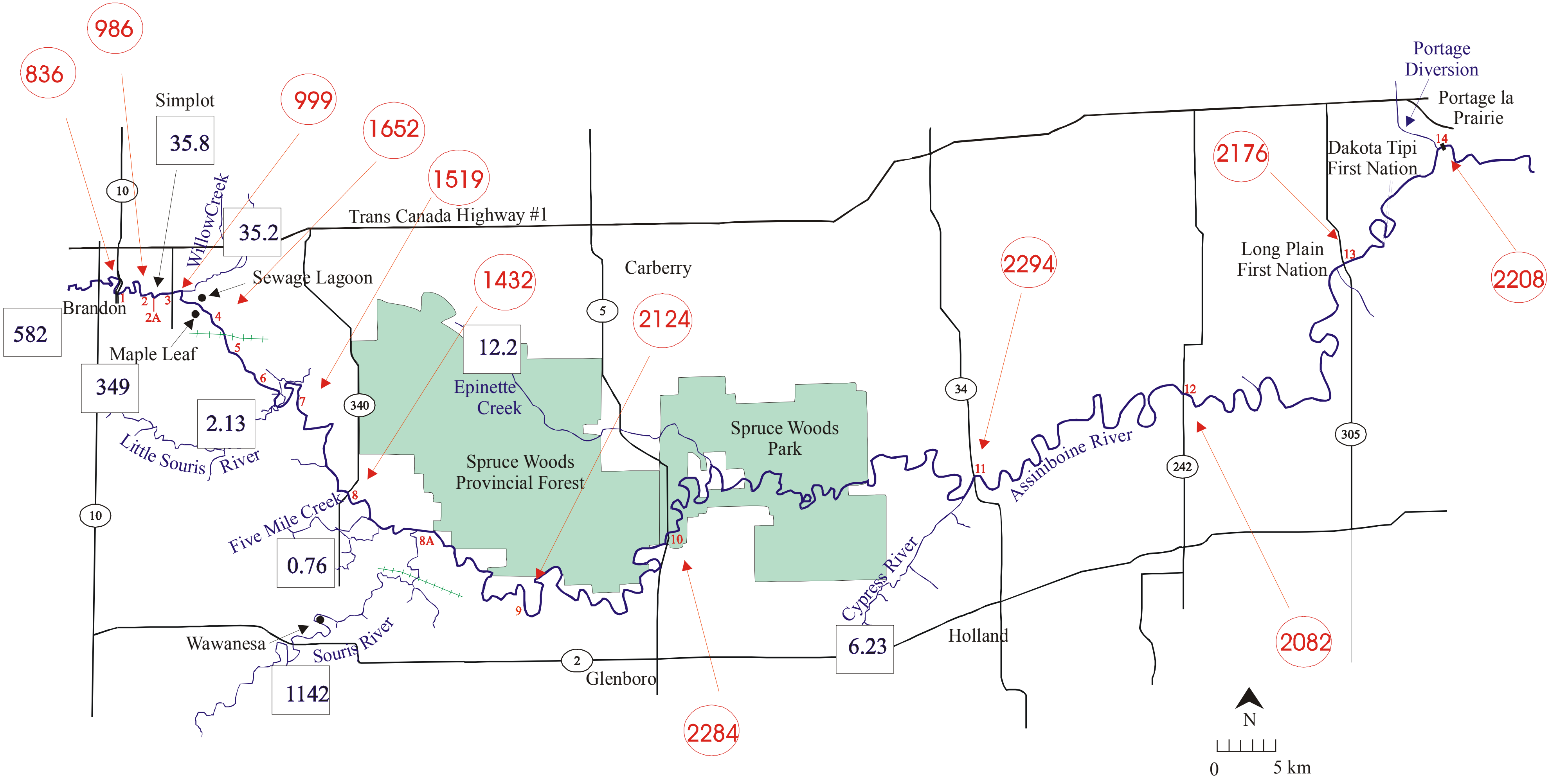

Figure 21. Total nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, July 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on July 16, 2002.

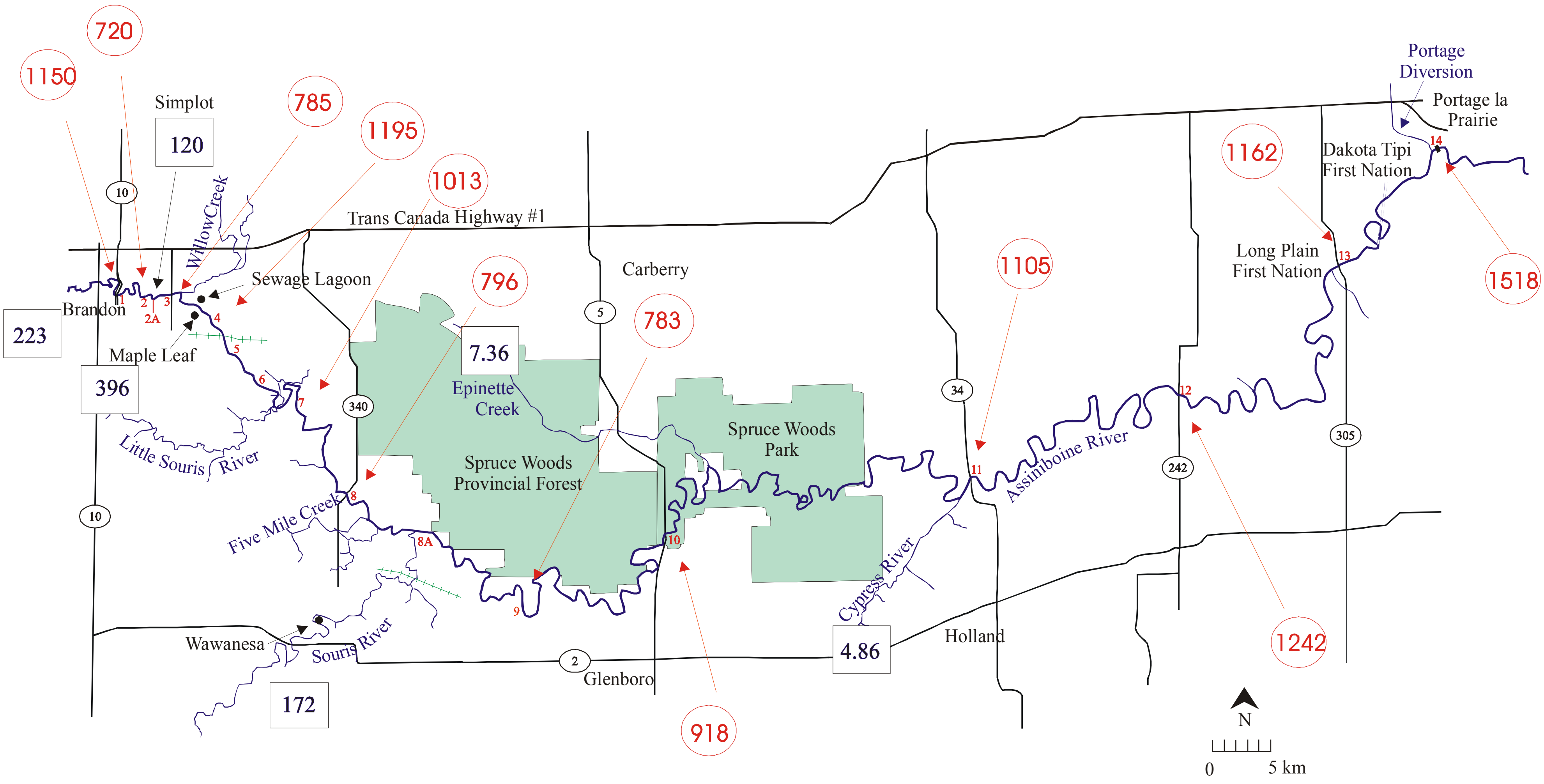

Figure 22. Total nitrogen loads (kg/day) in the Assiniboine River and various tributaries and effluents, August/September 2002. Numbers in red circles indicate calculated loads in the Assiniboine River and values in blue boxes indicate loads from tributaries and effluents. Effluent loads refer to measurements collected on August 21, 2002.

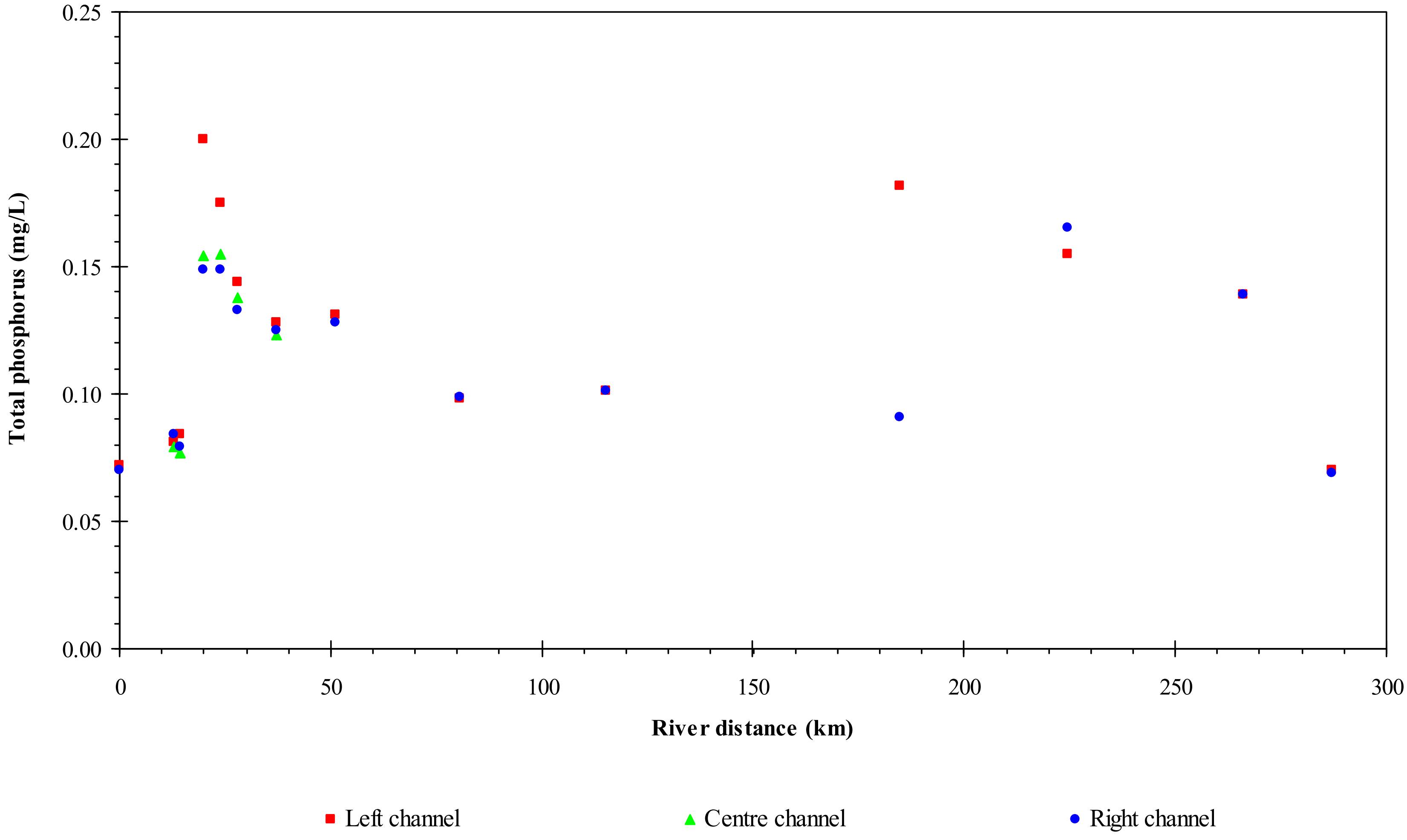

Figure 23. Total phosphorus concentrations measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

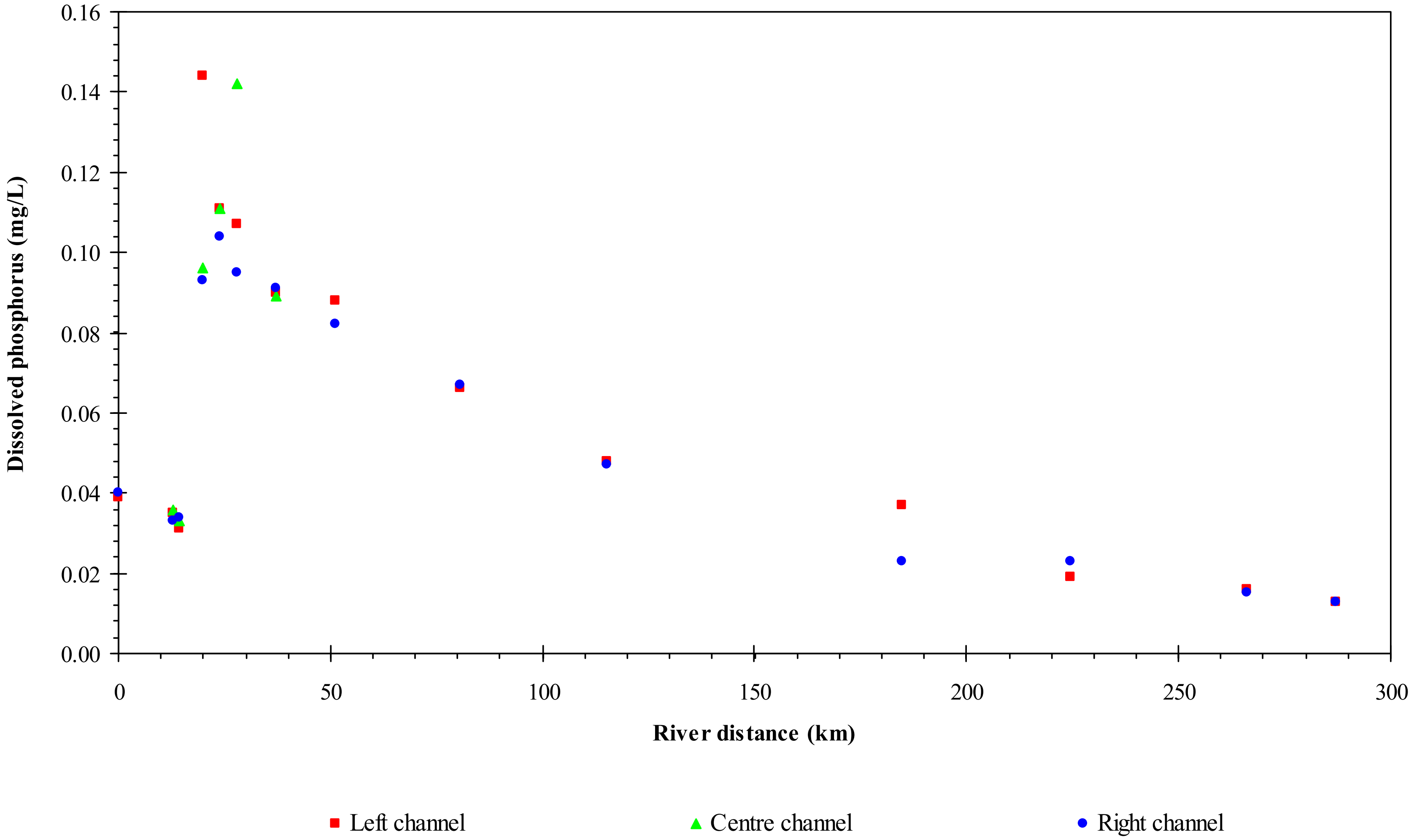

Figure 24. Dissolved phosphorus concentrations measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

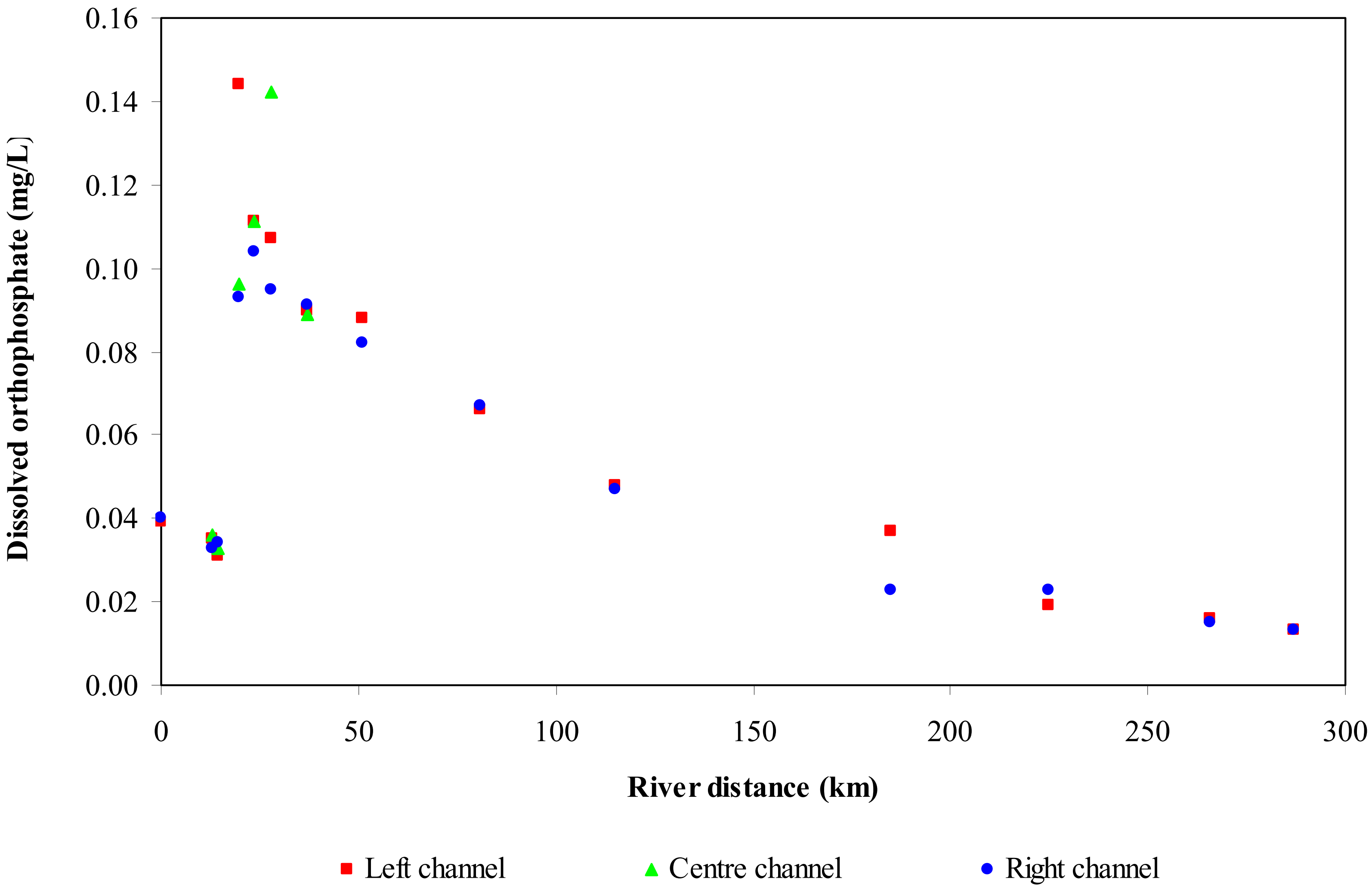

Figure 25. Dissolved orthophosphate concentrations measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

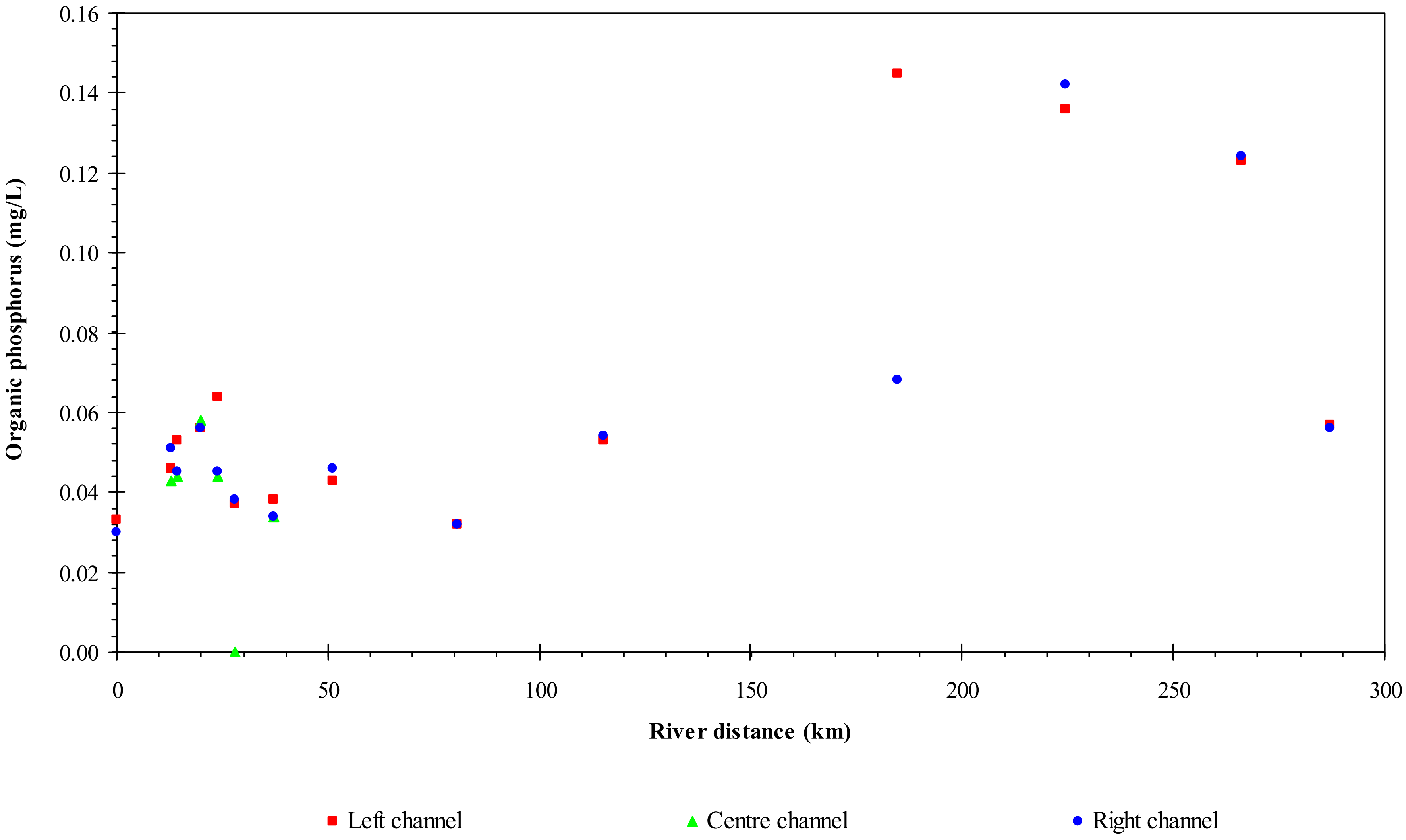

Figure 26. Organic phosphorus, estimated as the difference between total and dissolved phosphorus, in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

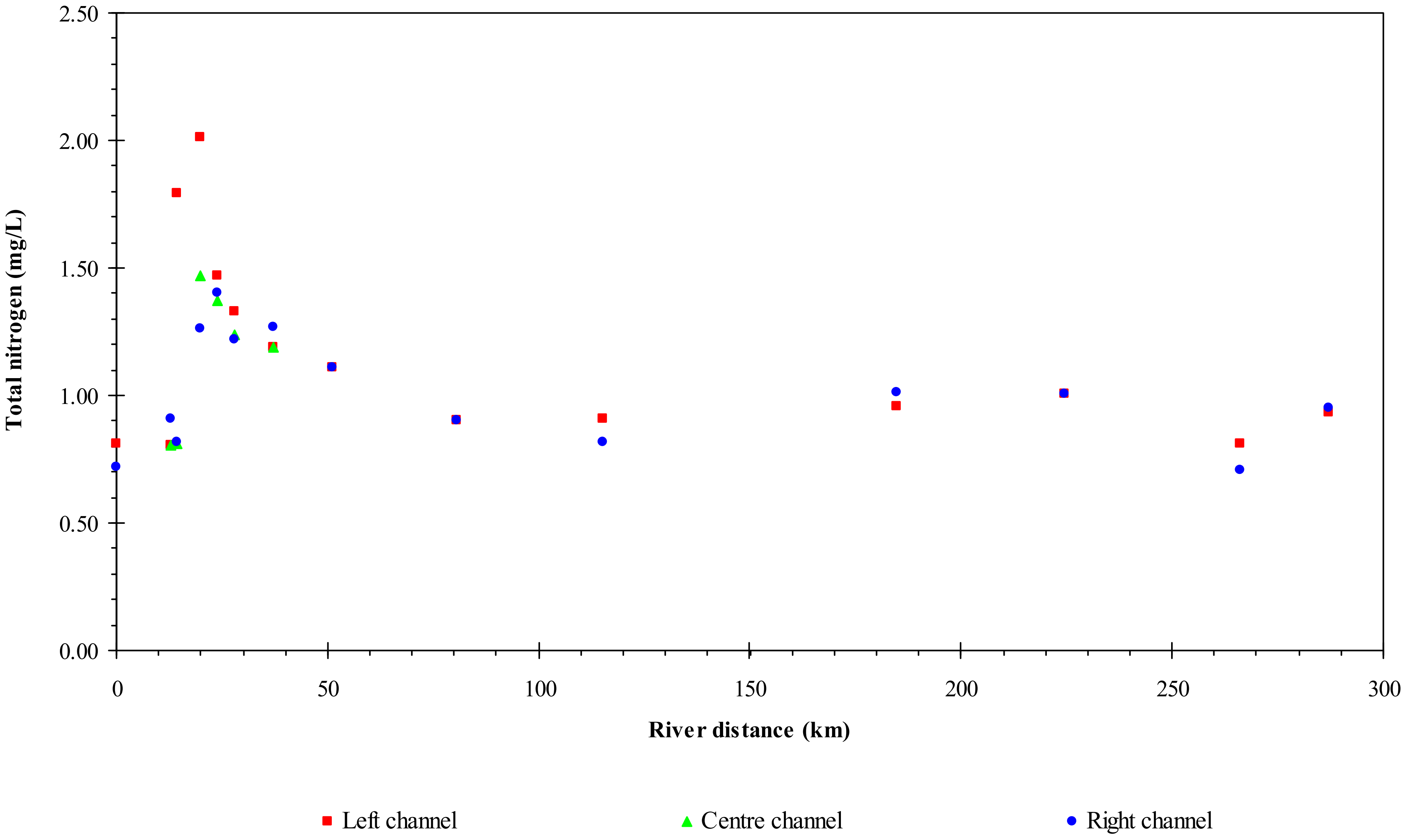

Figure 27. Total nitrogen, estimated as the sum of total kjeldahl nitrogen and dissolved nitrate/nitrite nitrogen measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

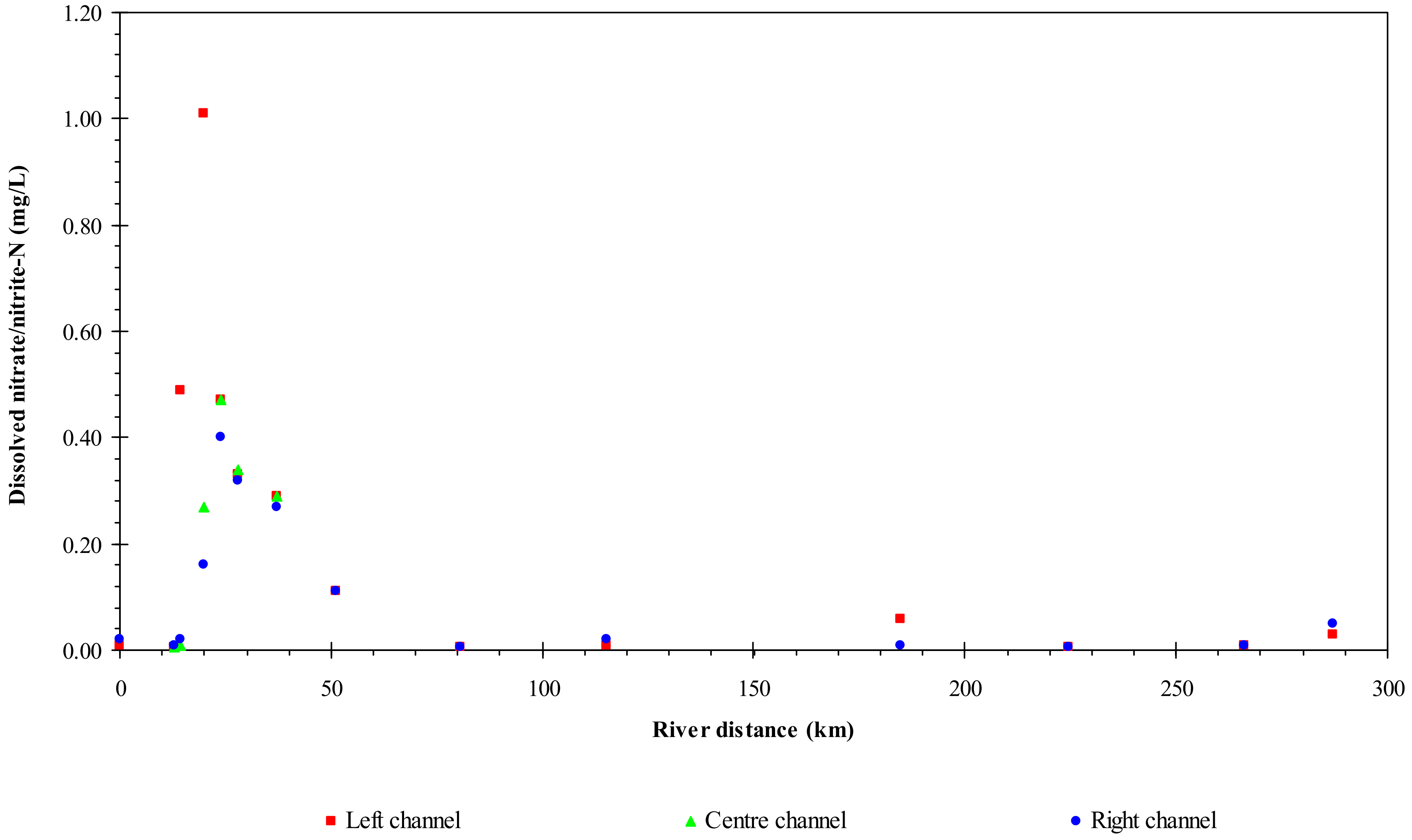

Figure 28. Dissolved nitrate/nitrite nitrogen measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

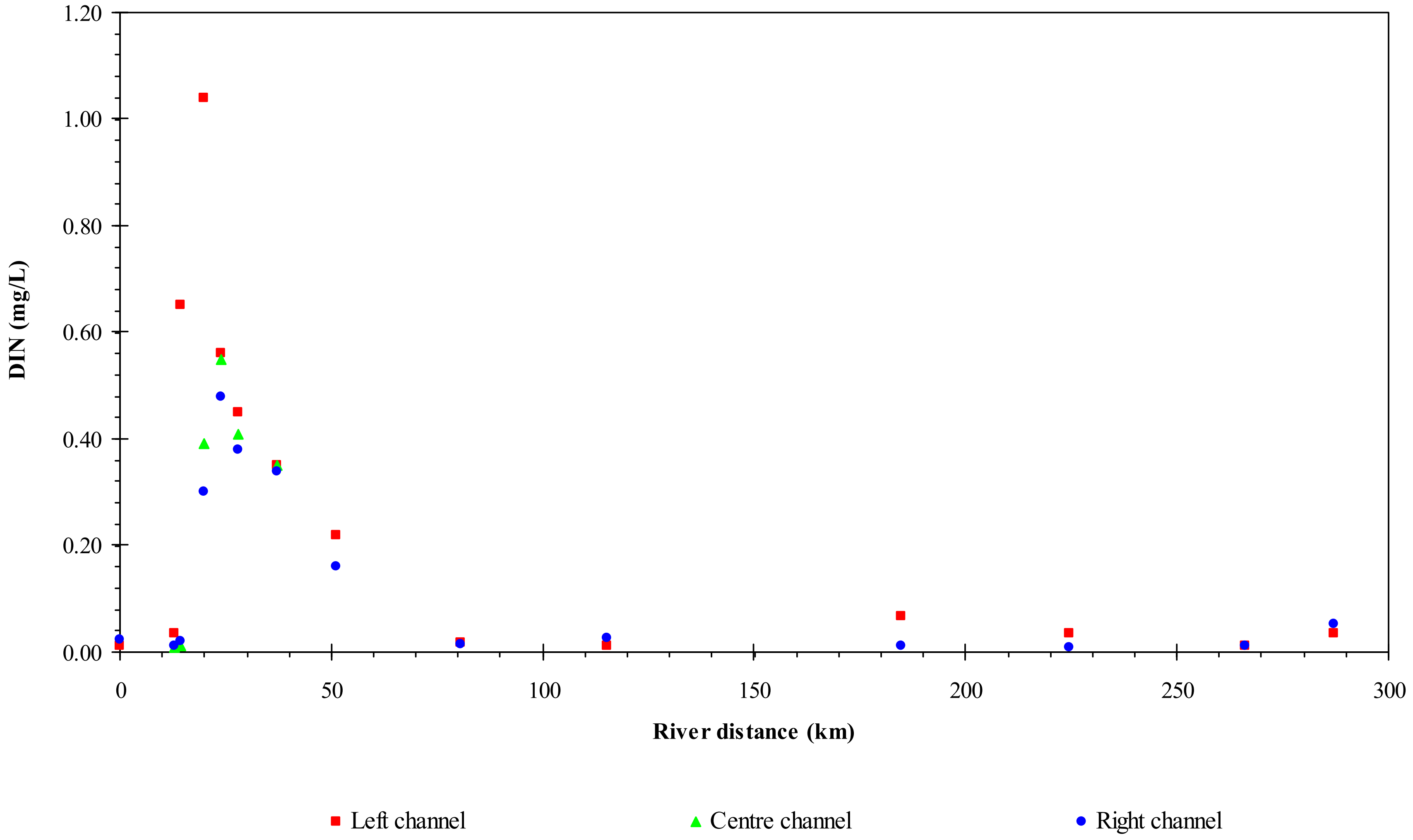

Figure 29. Dissolved inorganic nitrogen (DIN), estimated as the sum of dissolved nitrate/nitrite nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

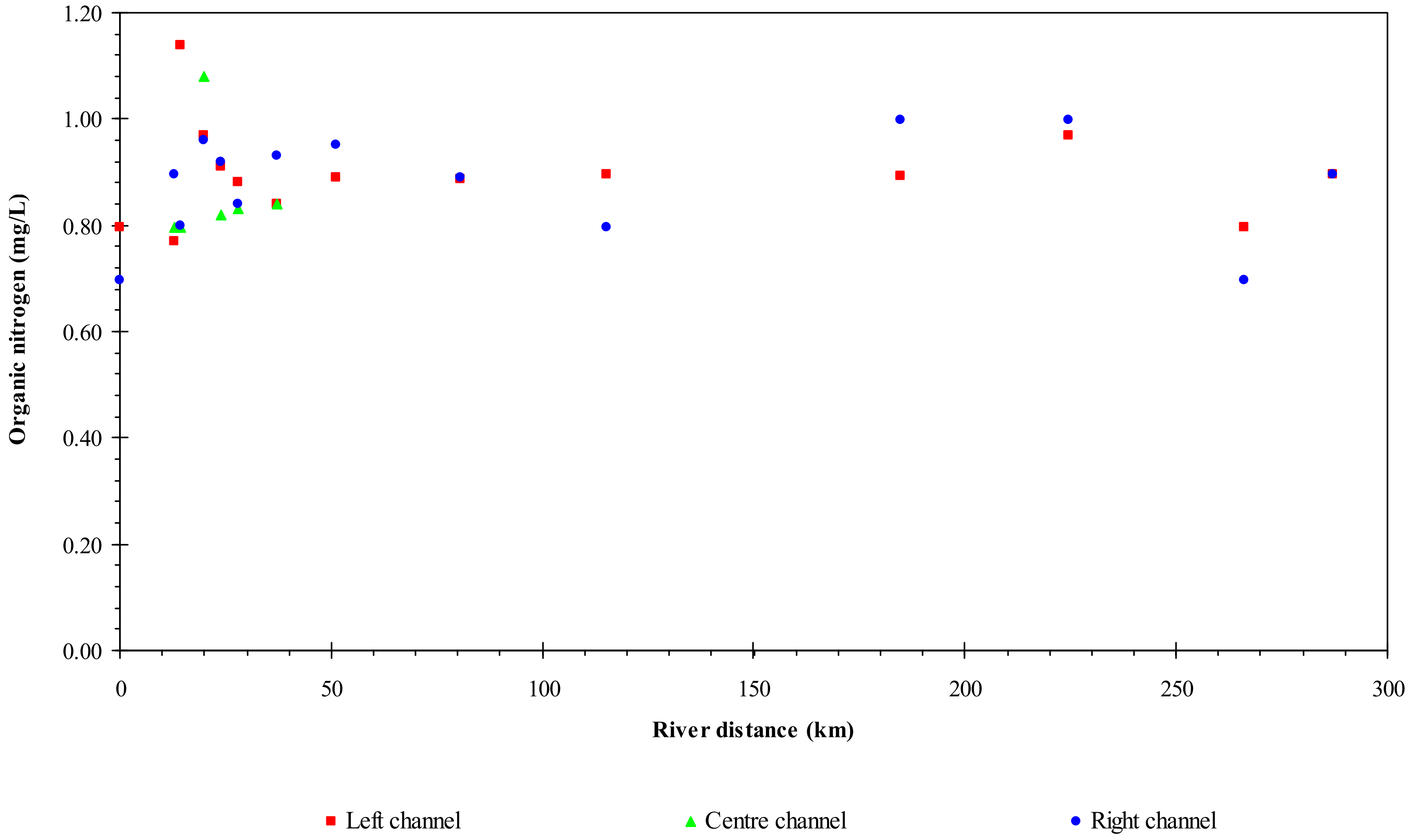

Figure 30. Organic nitrogen, estimated as the difference of total kjeldahl nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

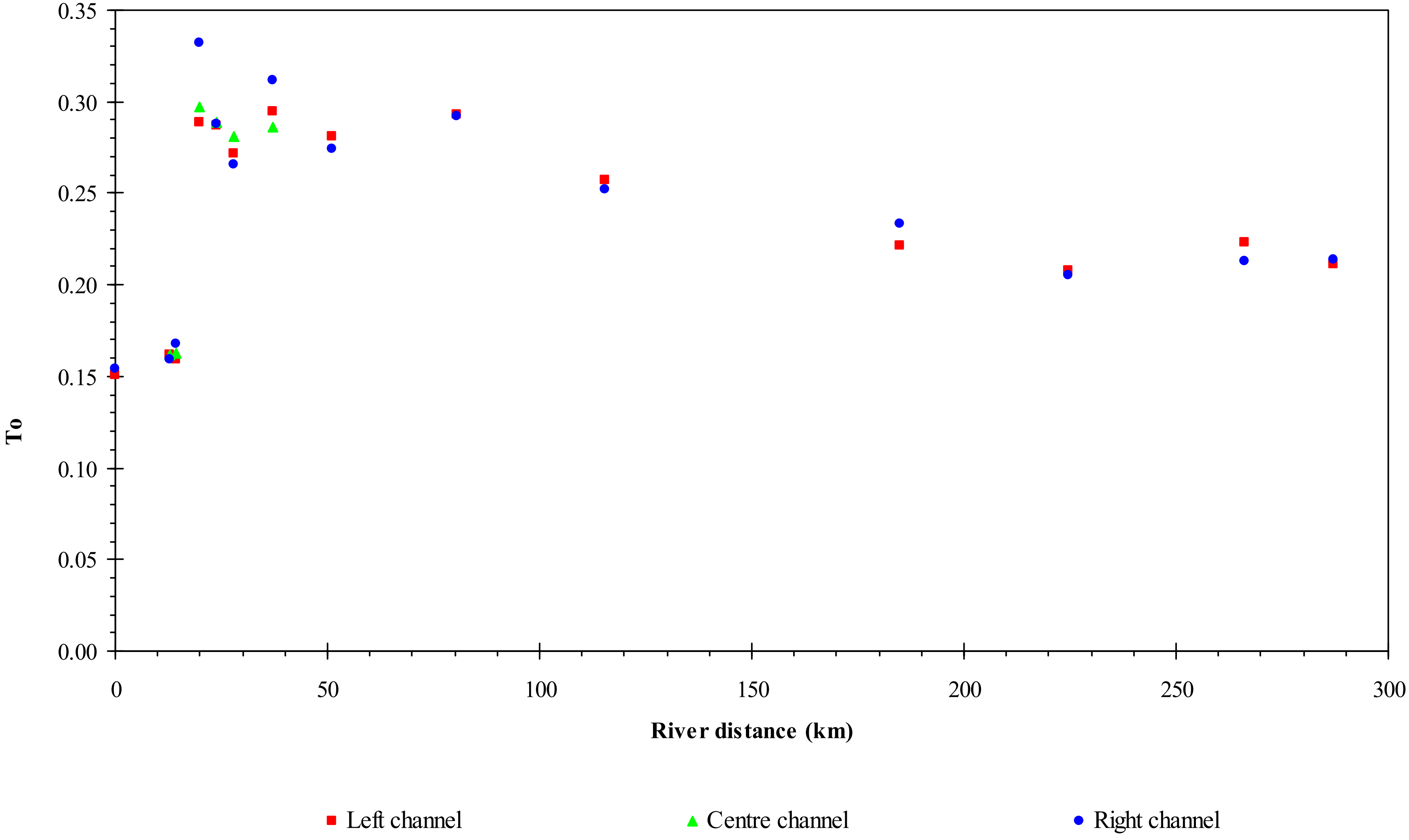

Figure 31. Total phosphorus concentrations measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

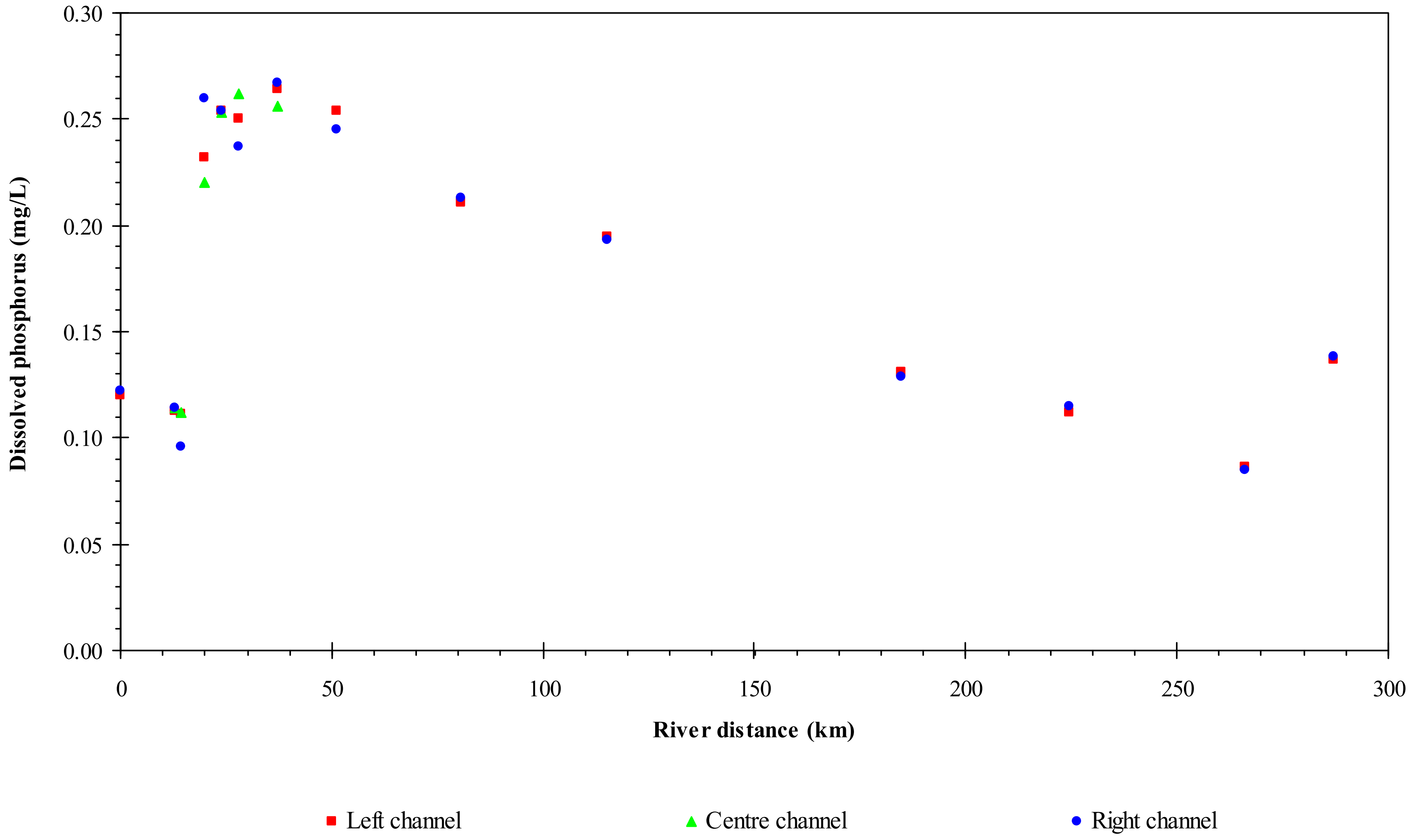

Figure 32. Dissolved phosphorus concentrations measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

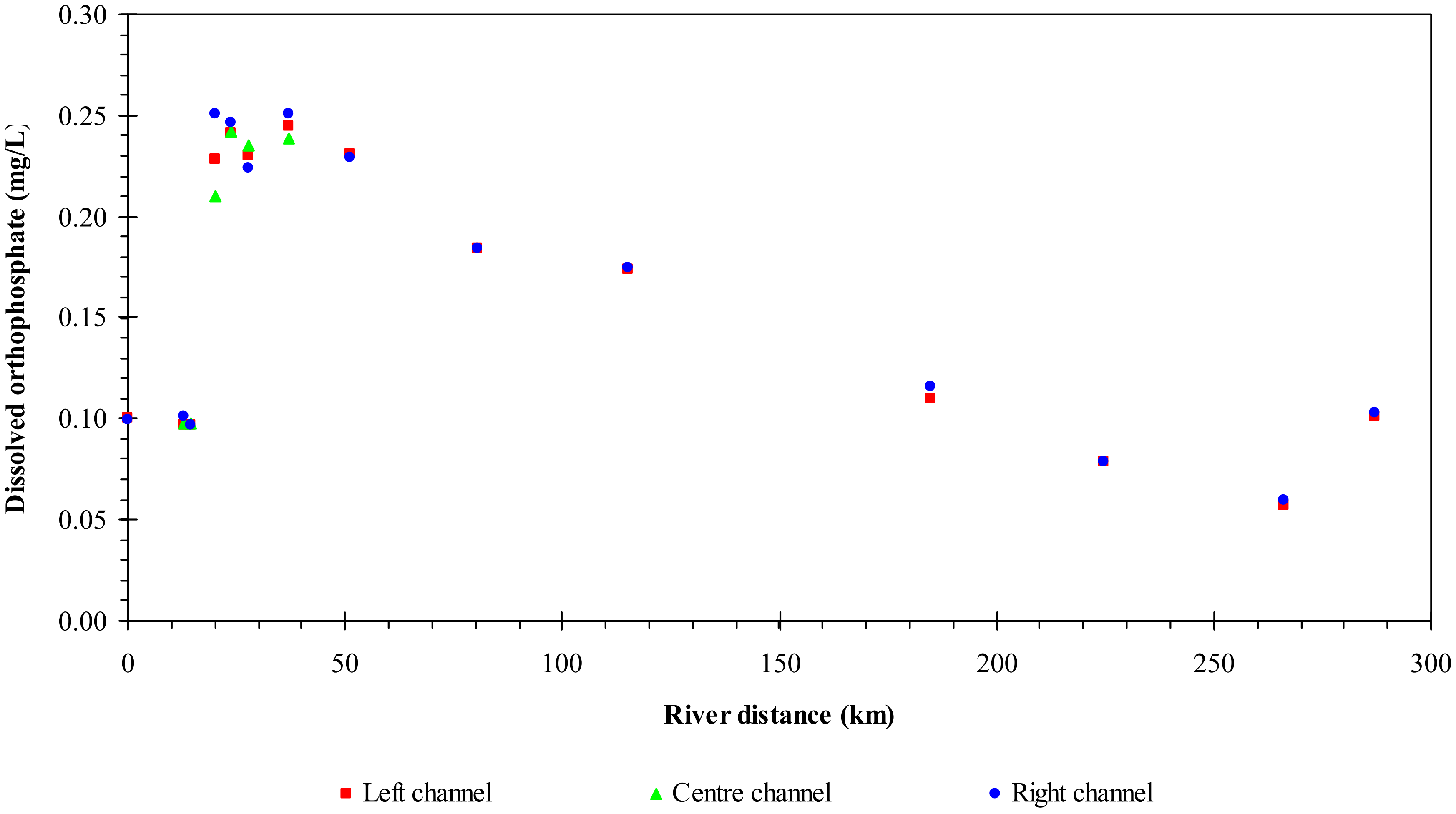

Figure 33. Dissolved orthophosphate concentrations measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

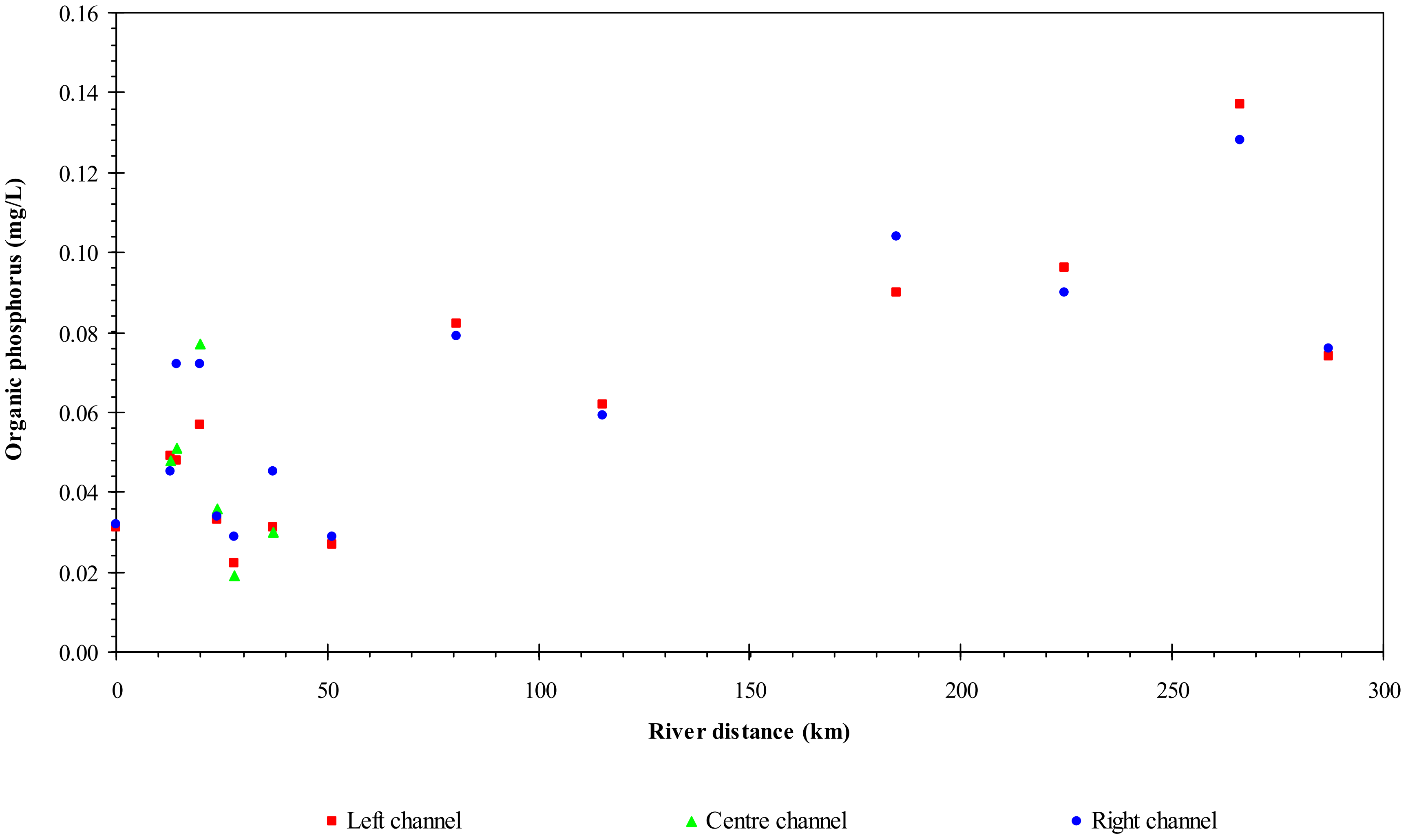

Figure 34. Organic phosphorus, estimated as the difference between total and dissolved phosphorus, in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

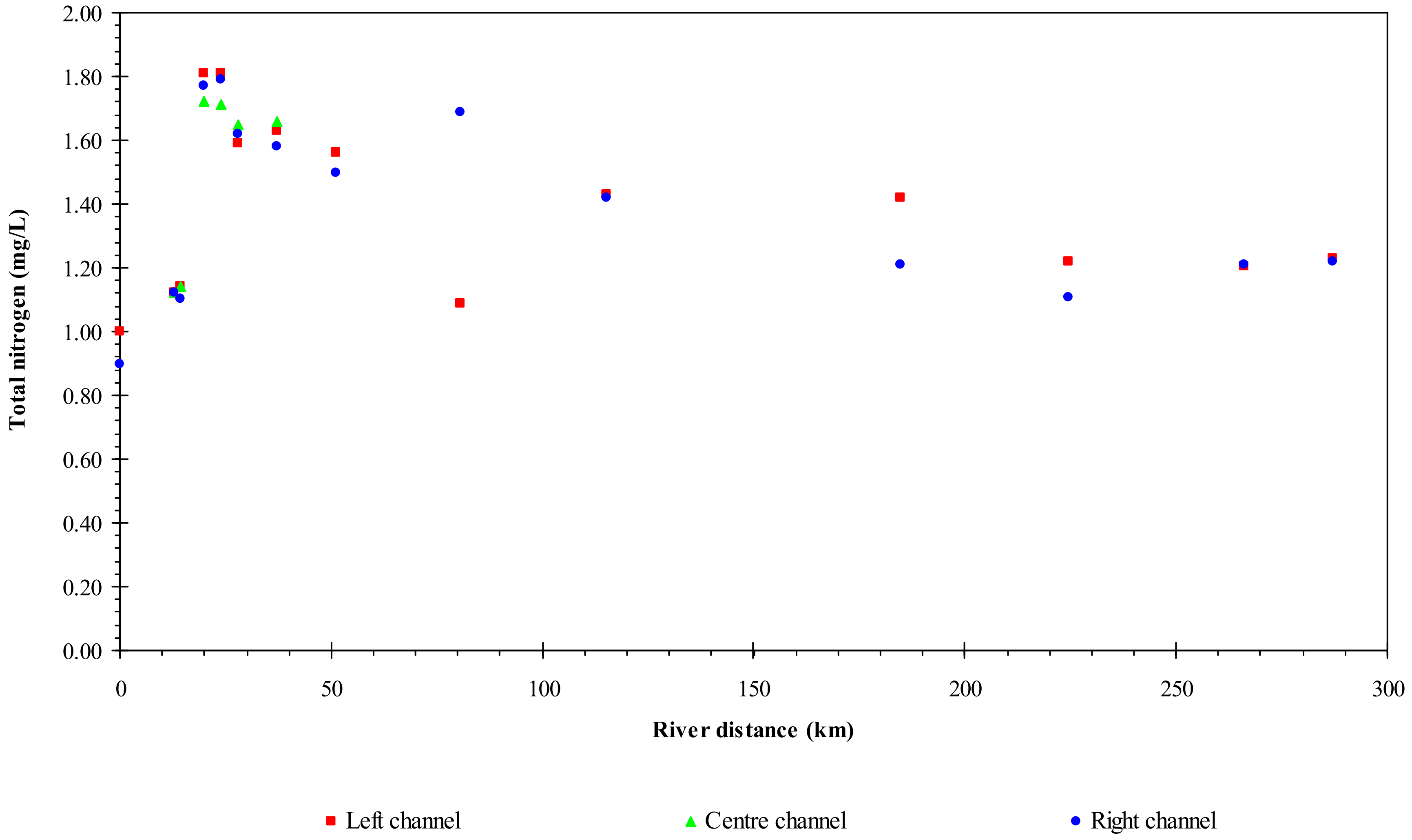

Figure 35. Total nitrogen, estimated as the sum of total kjeldahl nitrogen and dissolved nitrate/nitrite nitrogen, measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

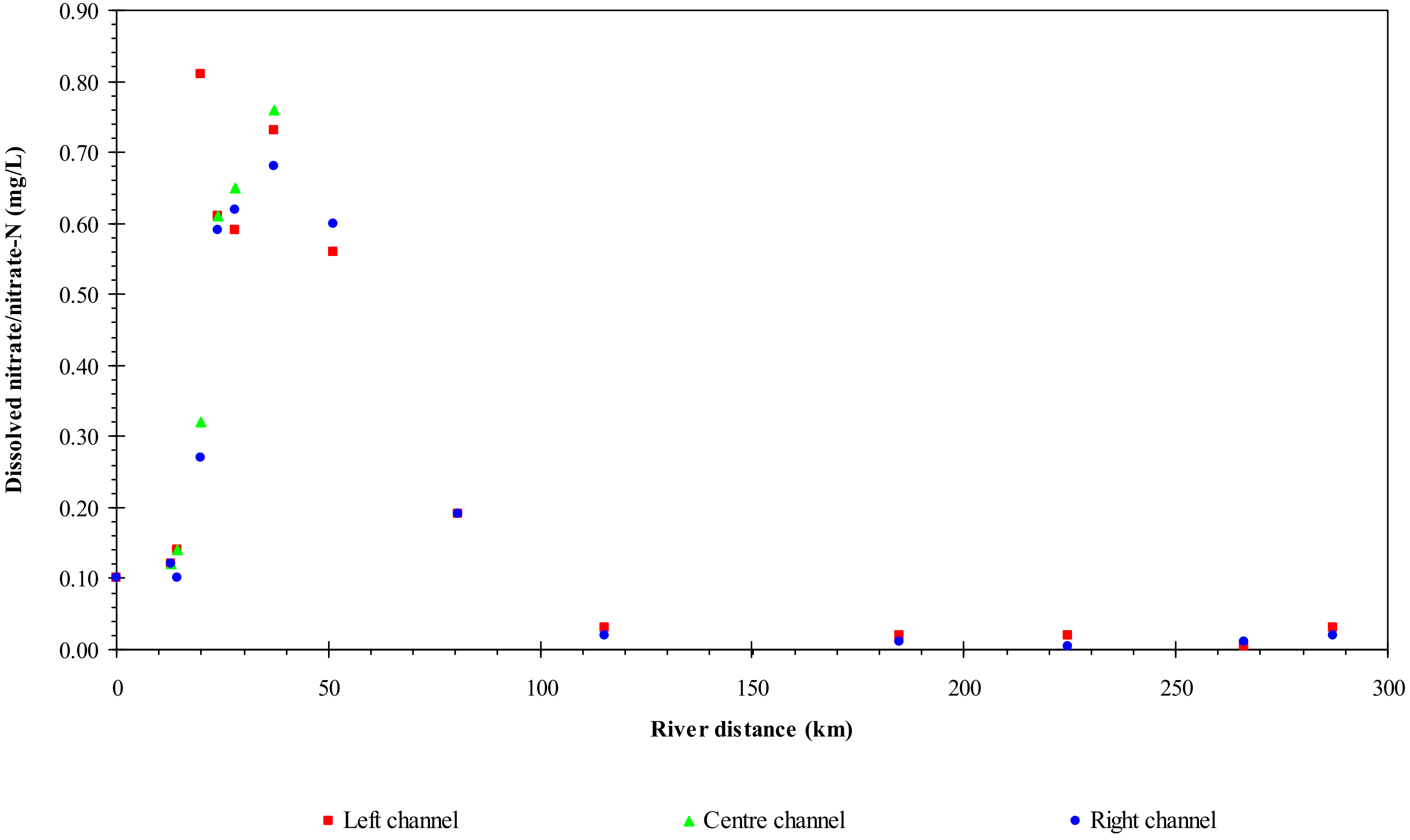

Figure 36. Dissolved nitrate/nitrite nitrogen measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

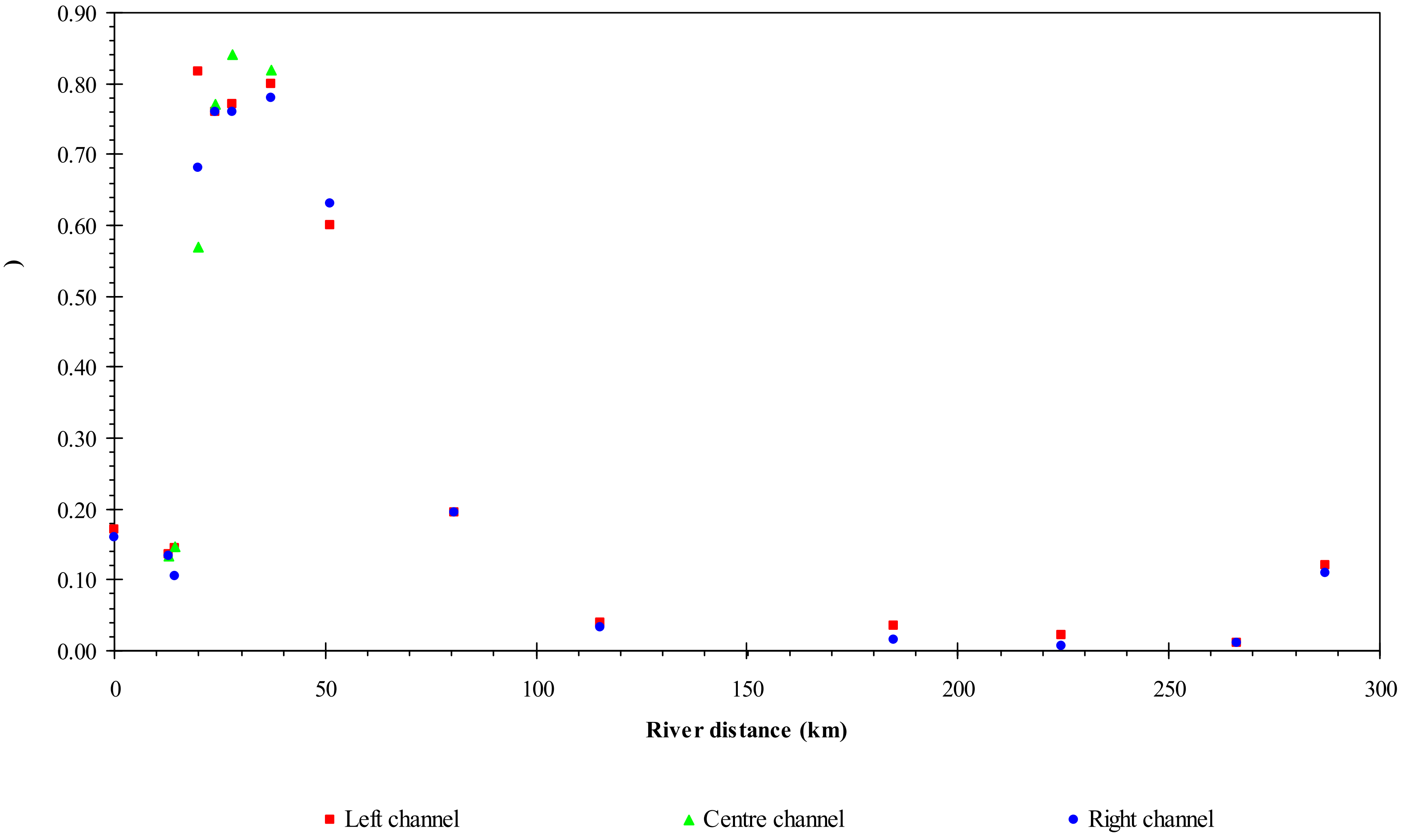

Figure 37. Dissolved inorganic nitrogen (DIN), estimated as the sum of dissolved nitrate/nitrite nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

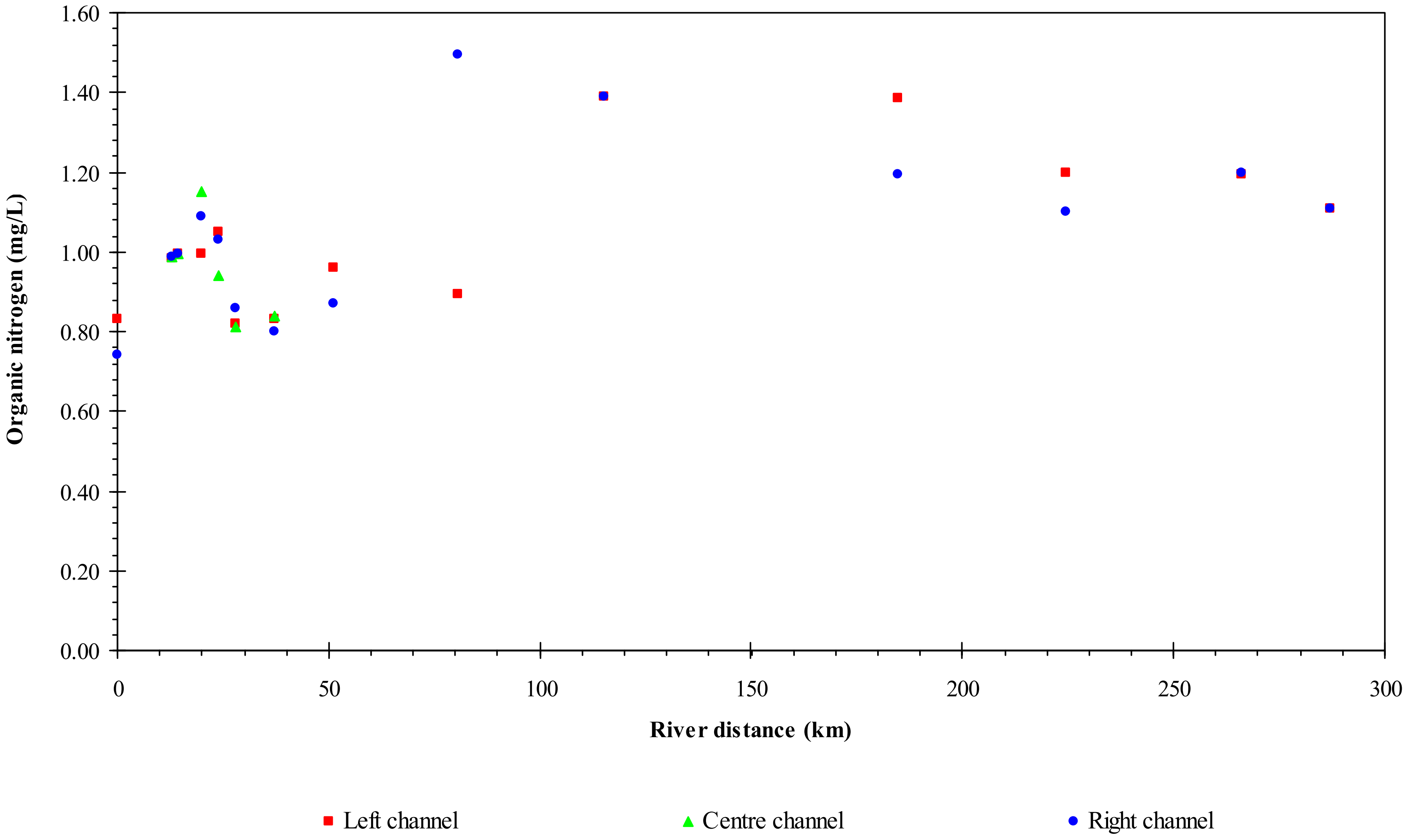

Figure 38. Organic nitrogen, estimated as the difference of total kjeldahl nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

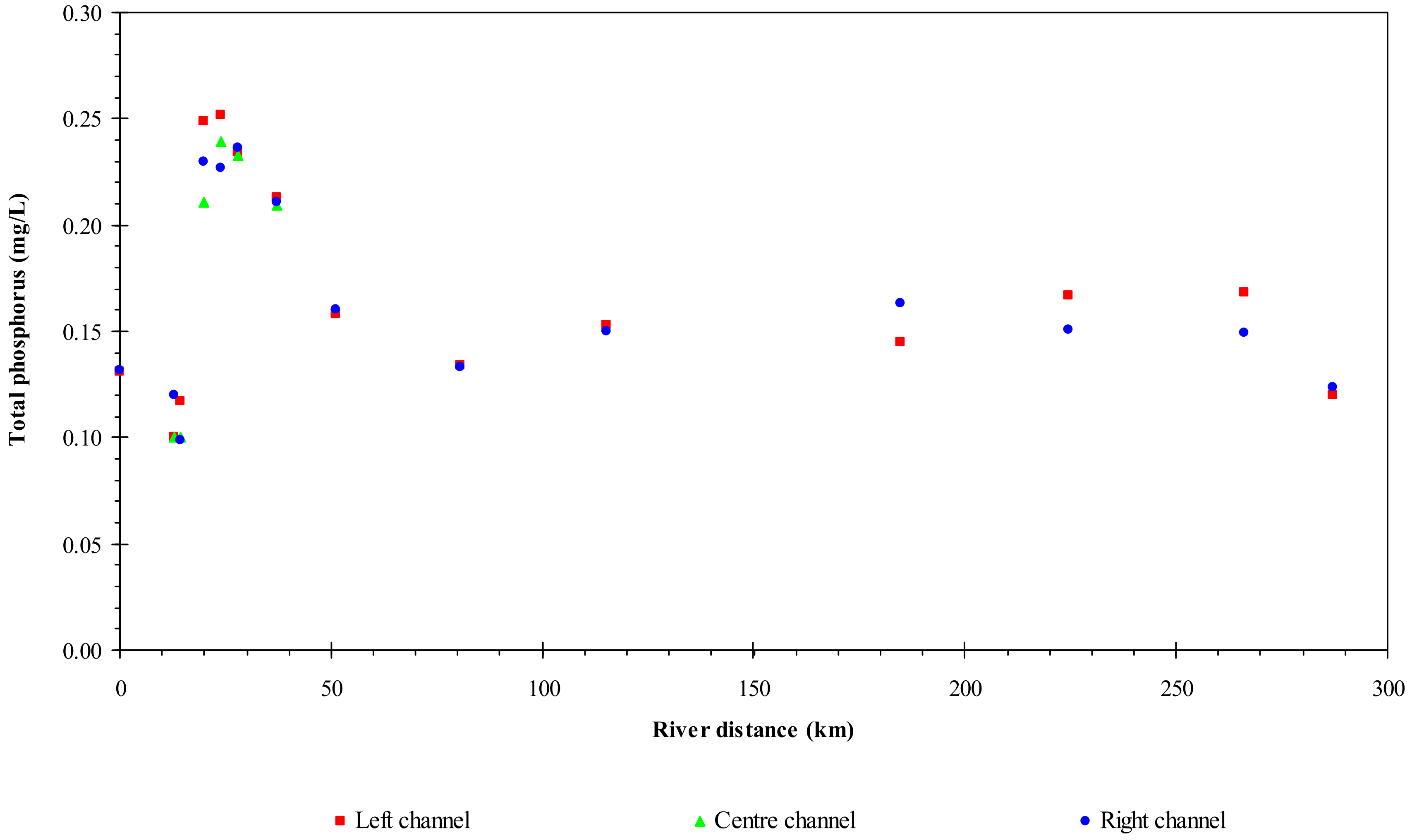

Figure 39. Total phosphorus concentrations measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

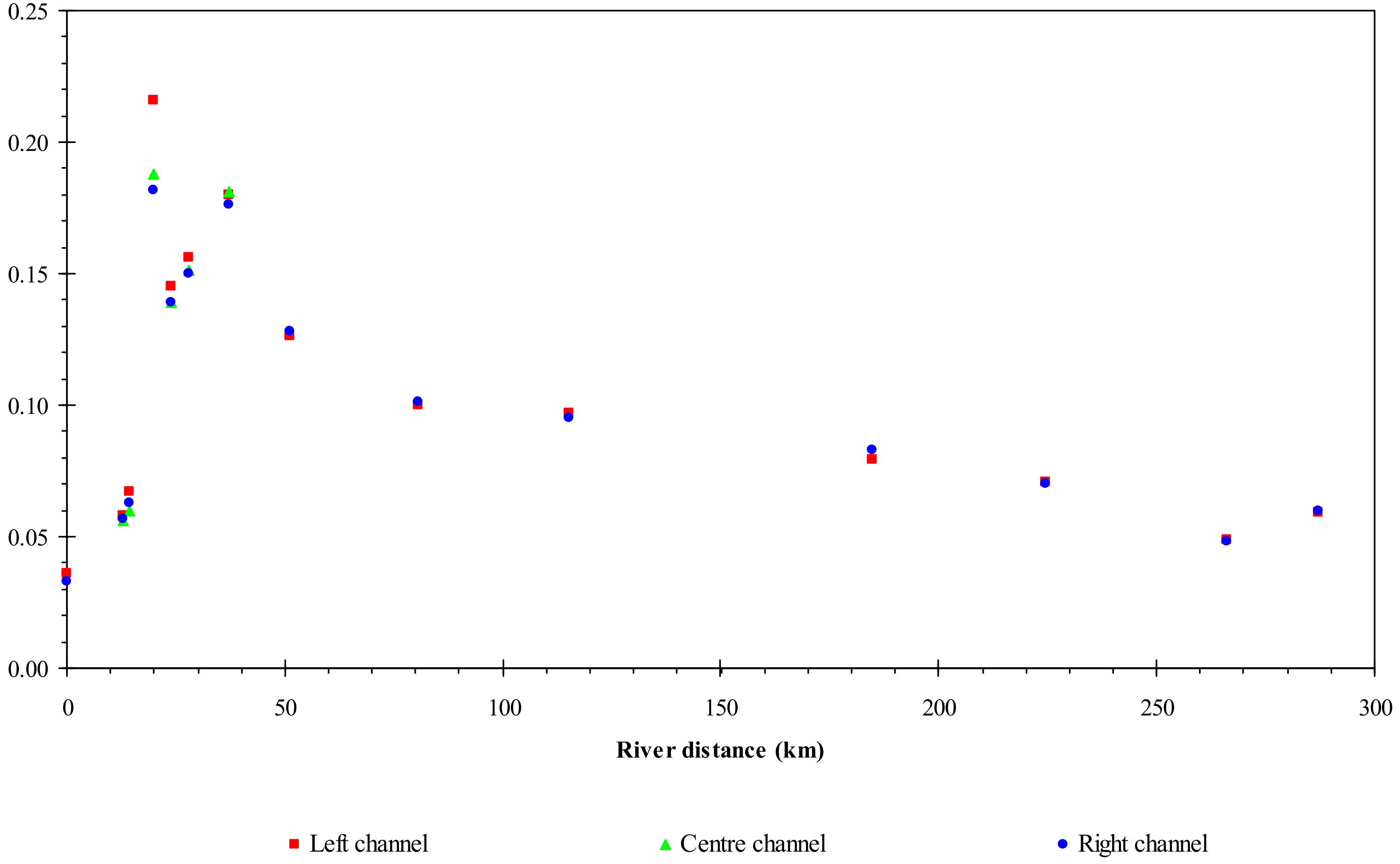

Figure 40. Dissolved phosphorus concentrations measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

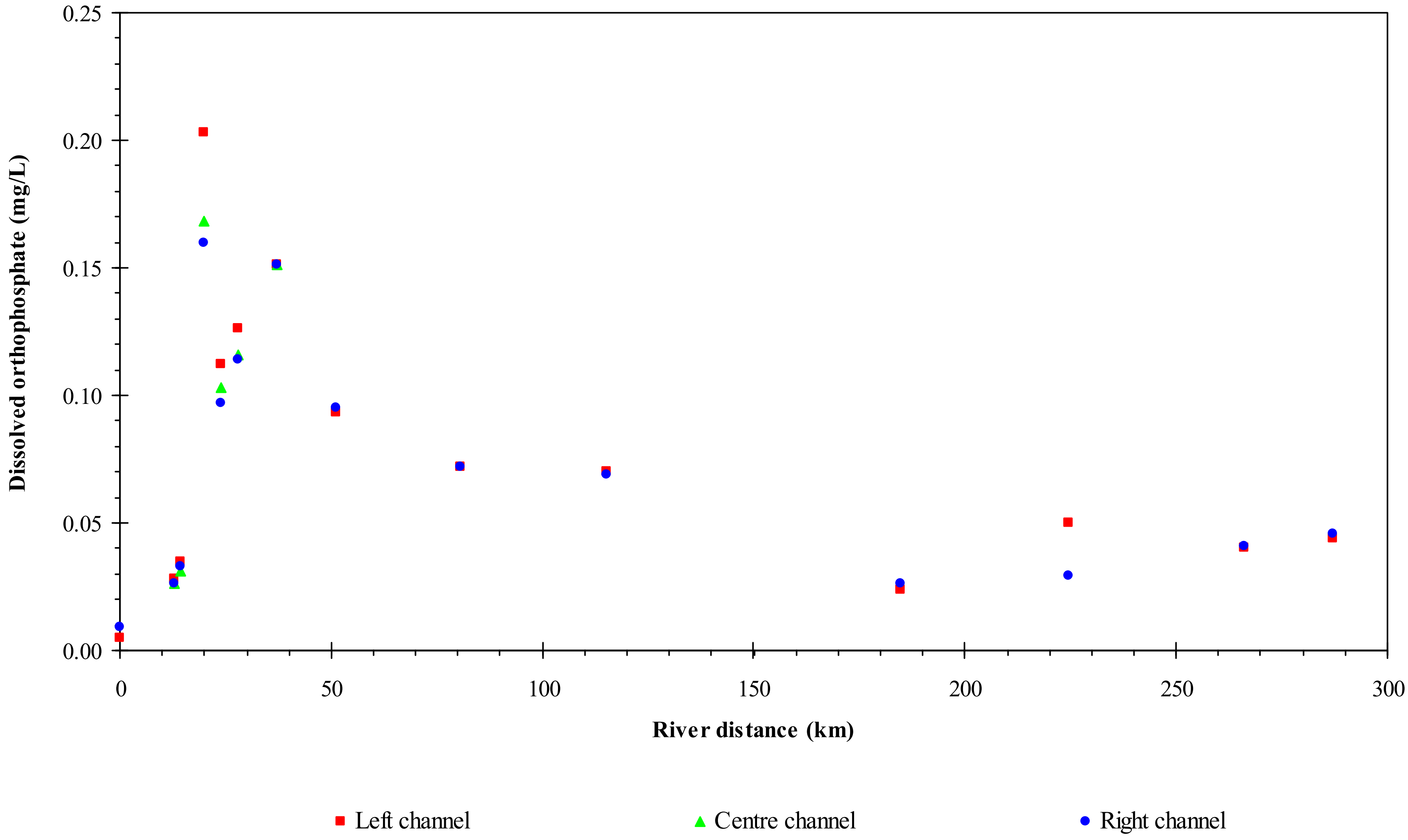

Figure 41. Dissolved orthophosphate concentrations measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

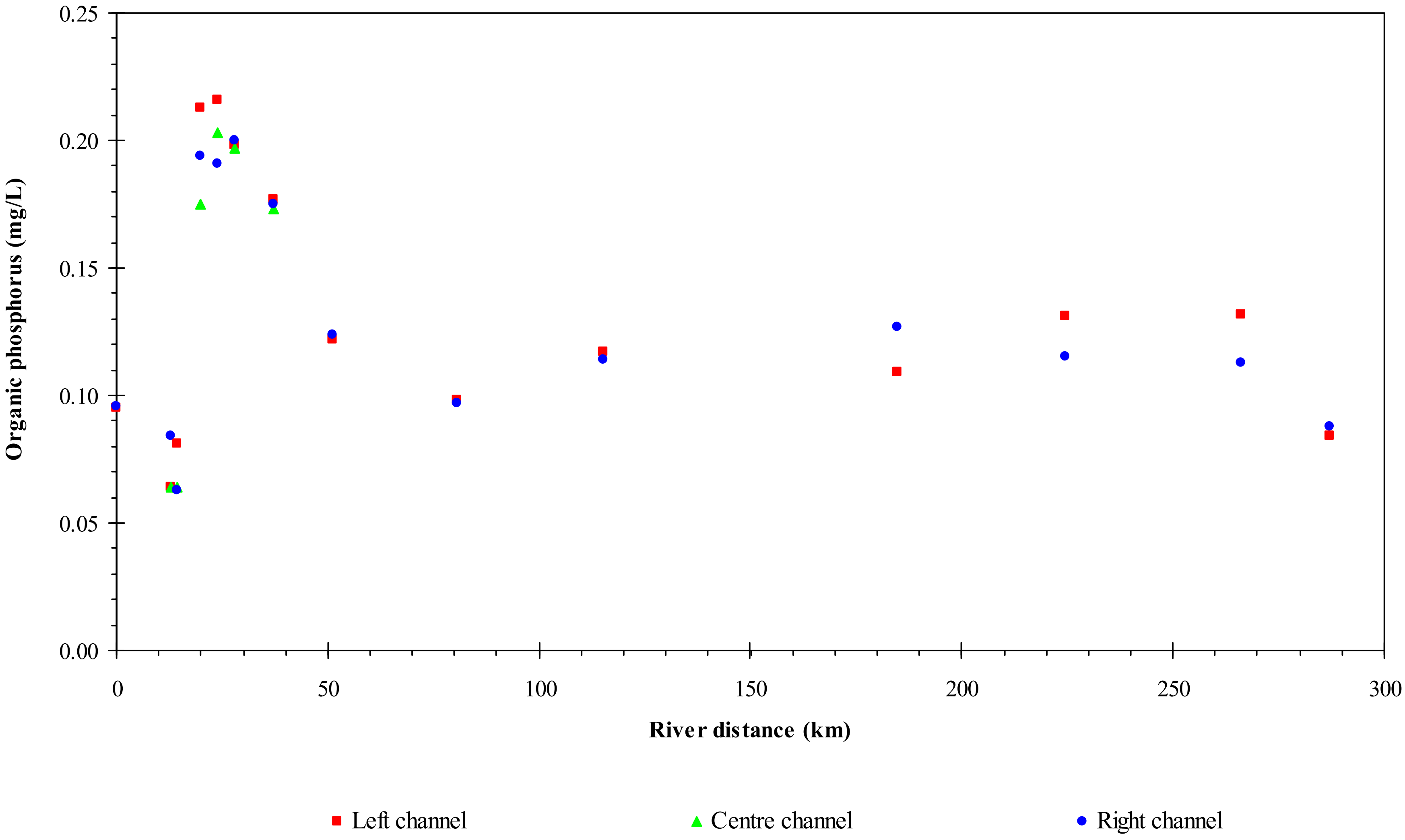

Figure 42. Organic phosphorus, estimated as the difference between total and dissolved phosphorus, in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

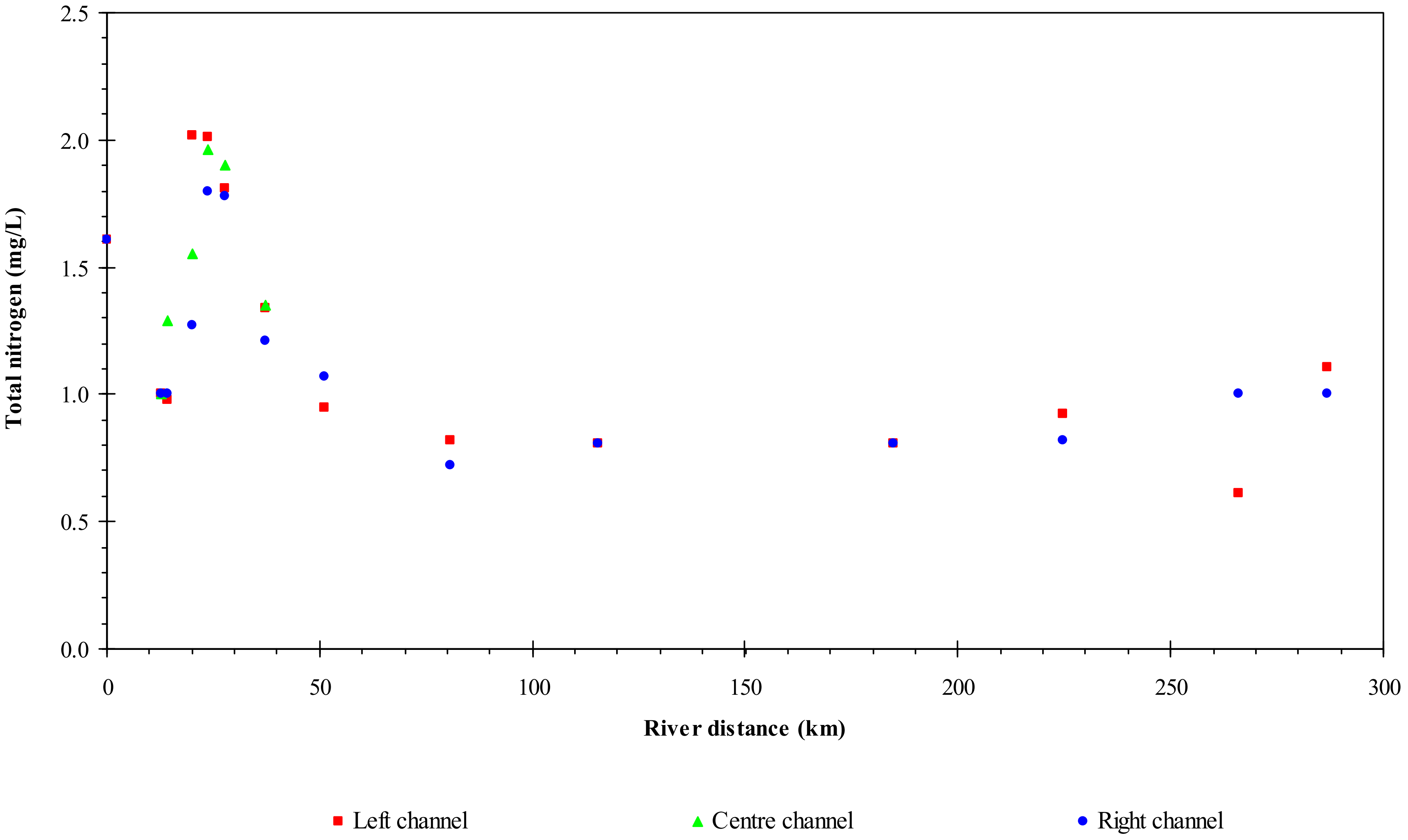

Figure 43. Total nitrogen, estimated as the sum of total kjeldahl nitrogen and dissolved nitrate/nitrite nitrogen, measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

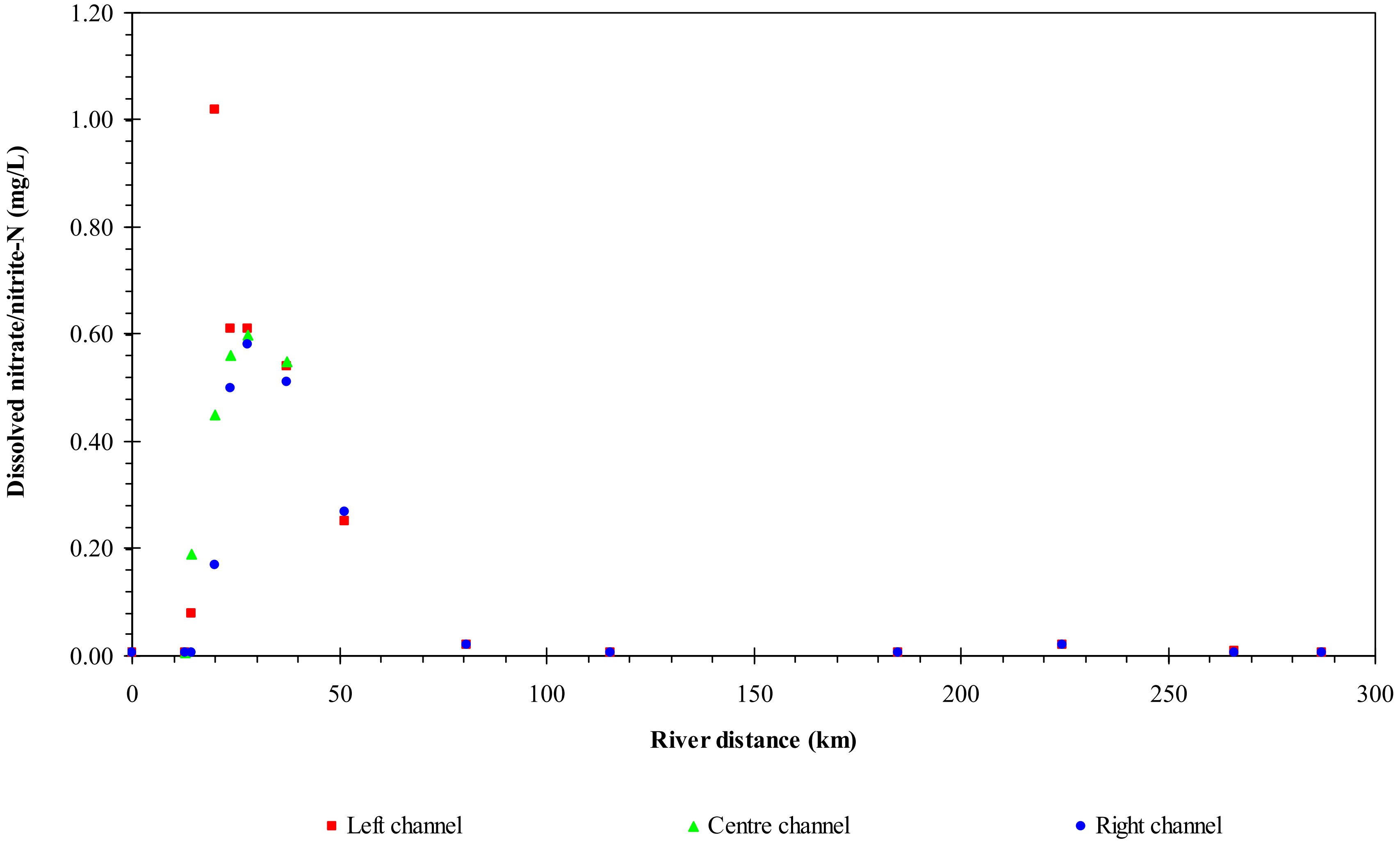

Figure 44. Dissolved nitrate/nitrite nitrogen measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

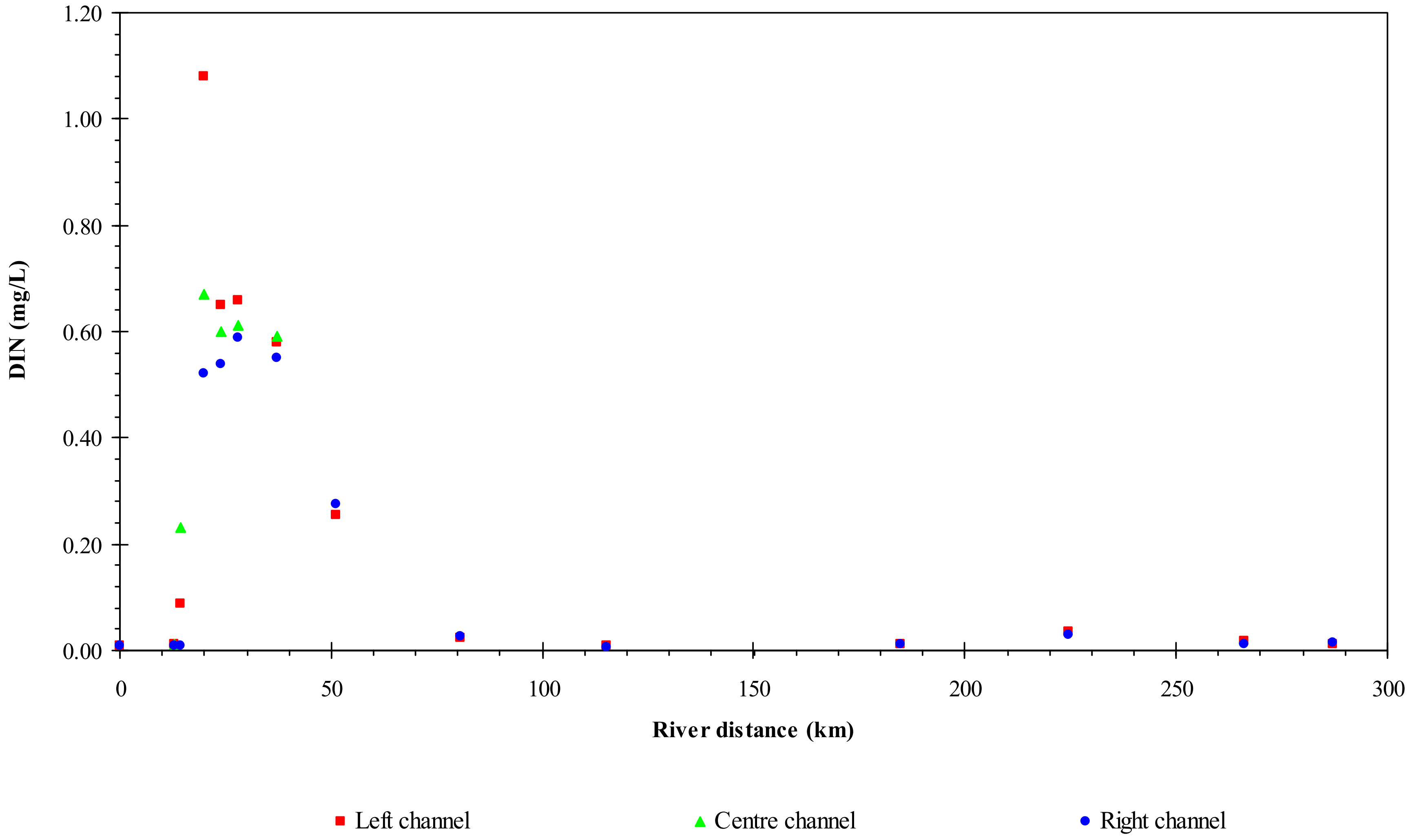

Figure 45. Dissolved inorganic nitrogen (DIN), estimated as the sum of dissolved nitrate/nitrite nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

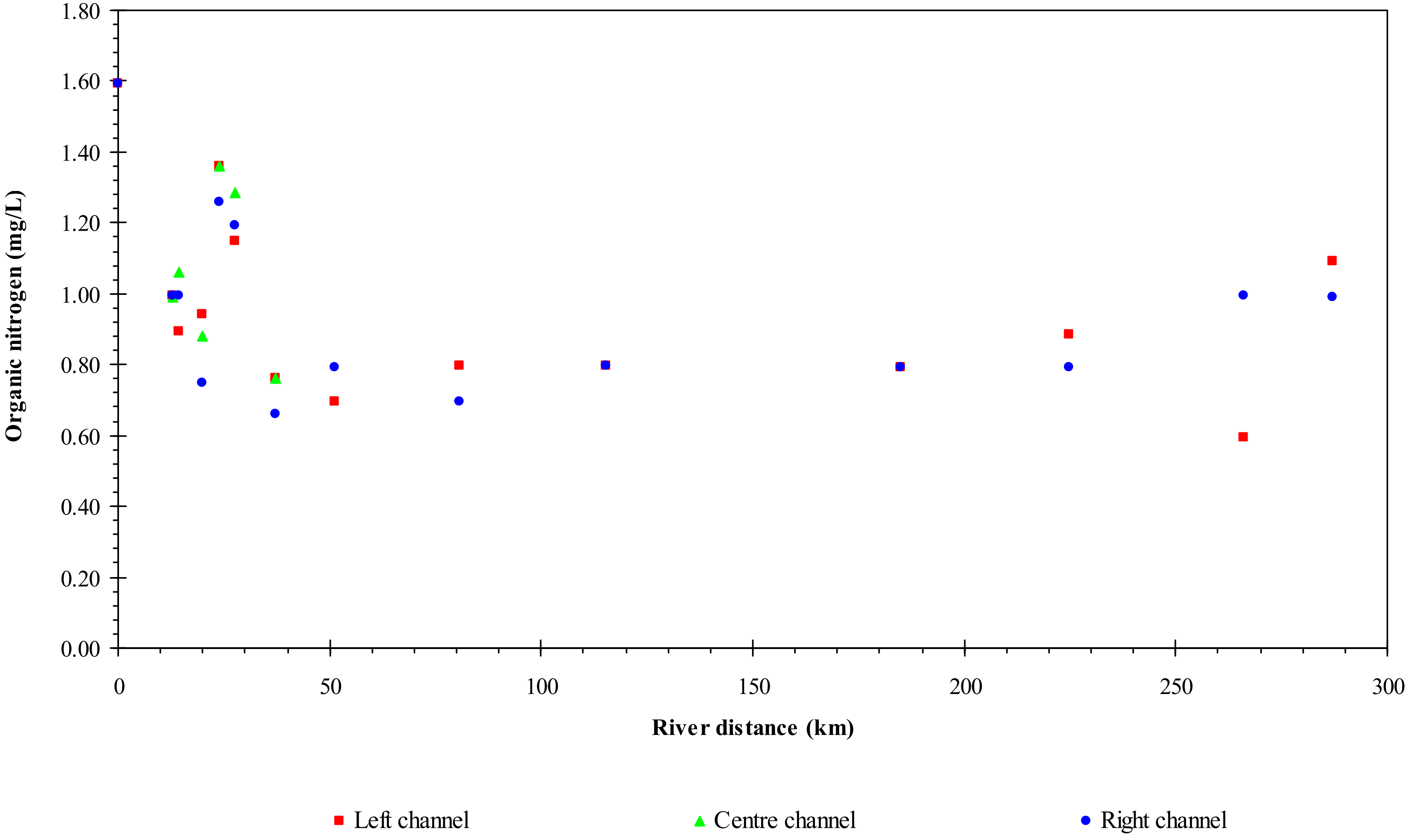

Figure 46. Organic nitrogen, estimated as the difference of total kjeldahl nitrogen and dissolved ammonia nitrogen, in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

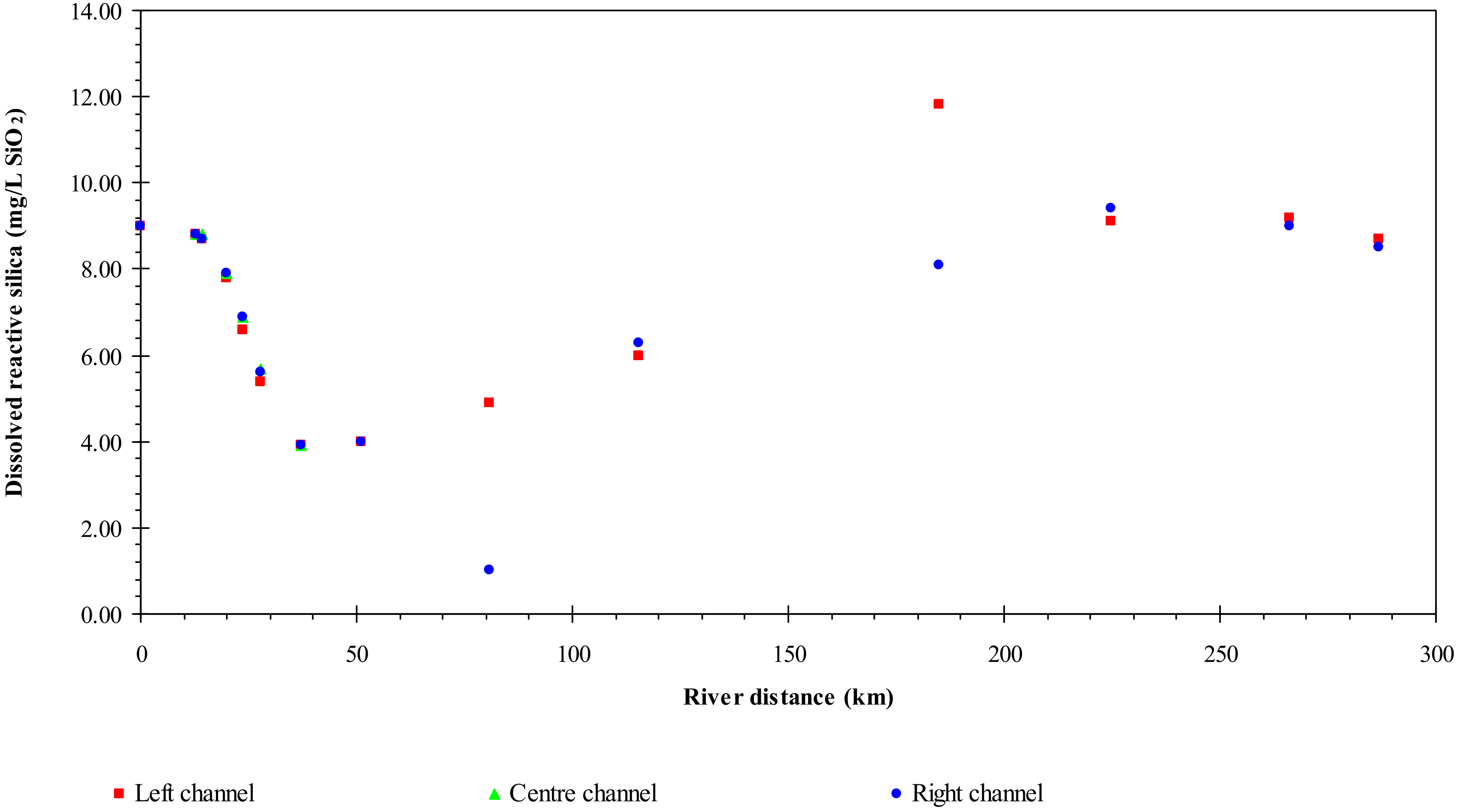

Figure 47. Dissolved reactive silica measured in the Assiniboine River in June 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

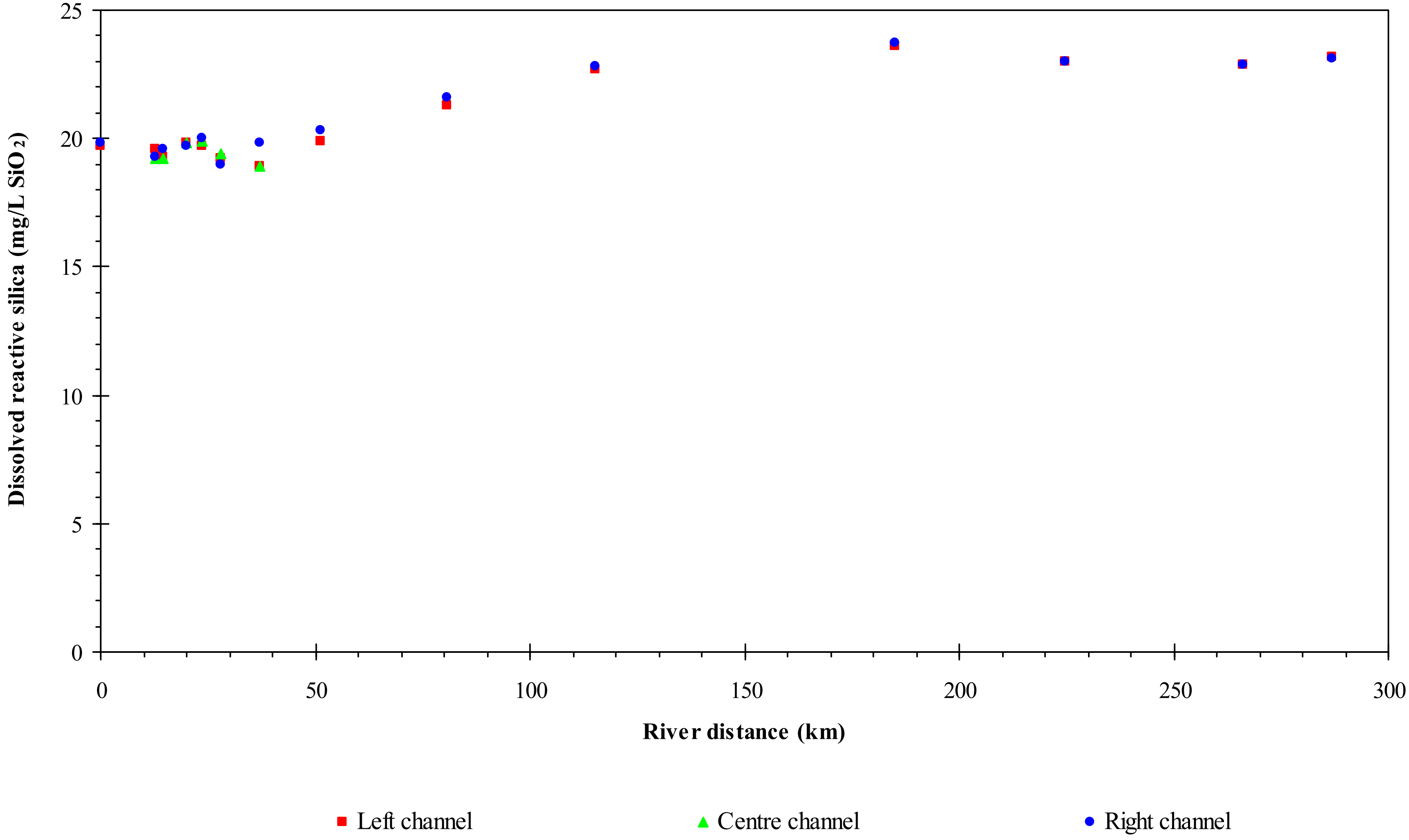

Figure 48. Dissolved reactive silica measured in the Assiniboine River in July 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

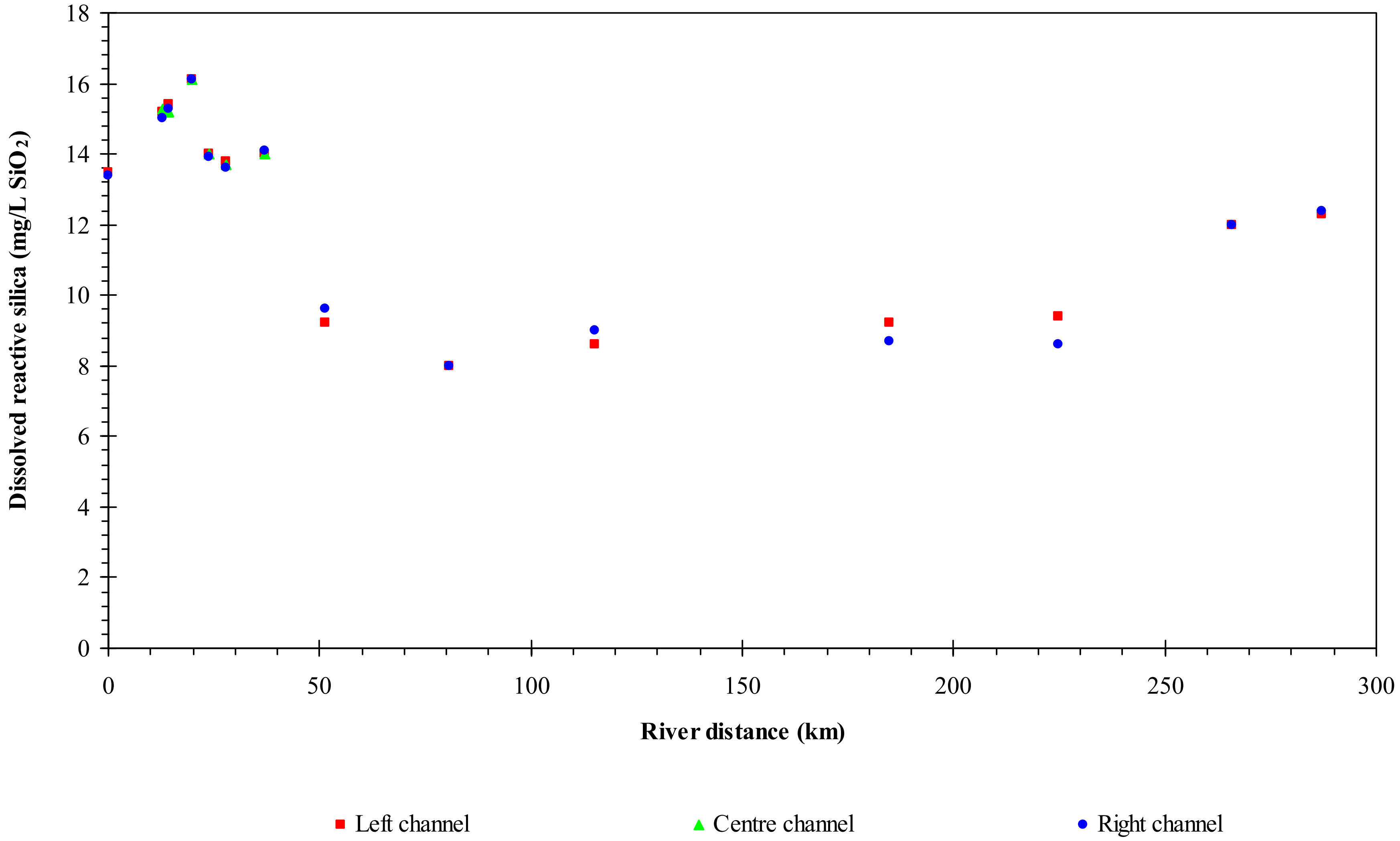

Figure 49. Dissolved reactive silica measured in the Assiniboine River in August/September 2002. Site 1 (0 km) is the Brandon 18th St. Bridge; Site 14 (287 km) is the Portage la Prairie Reservoir.

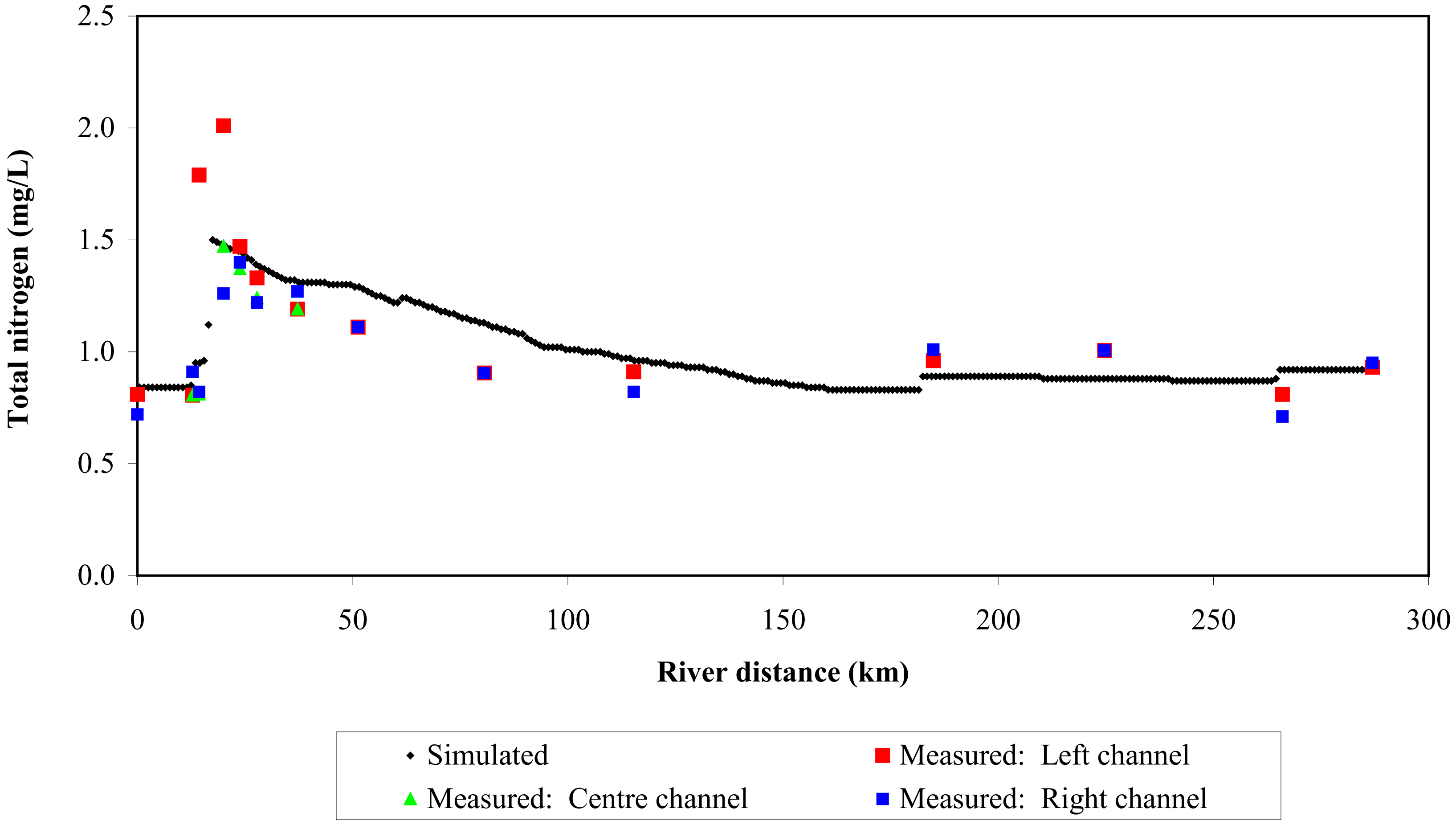

Figure 50. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: June 2002.

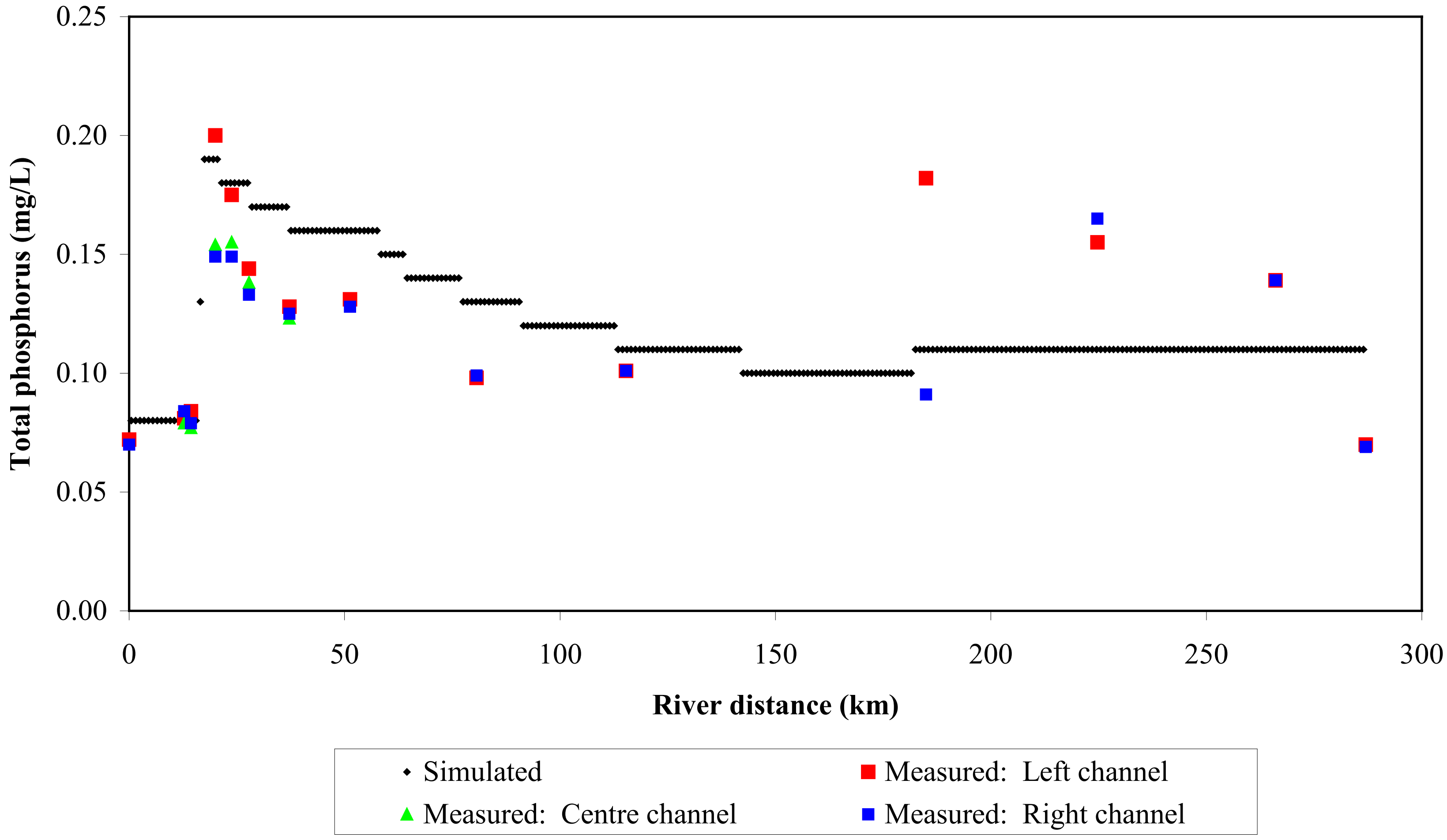

Figure 51. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: June 2002.

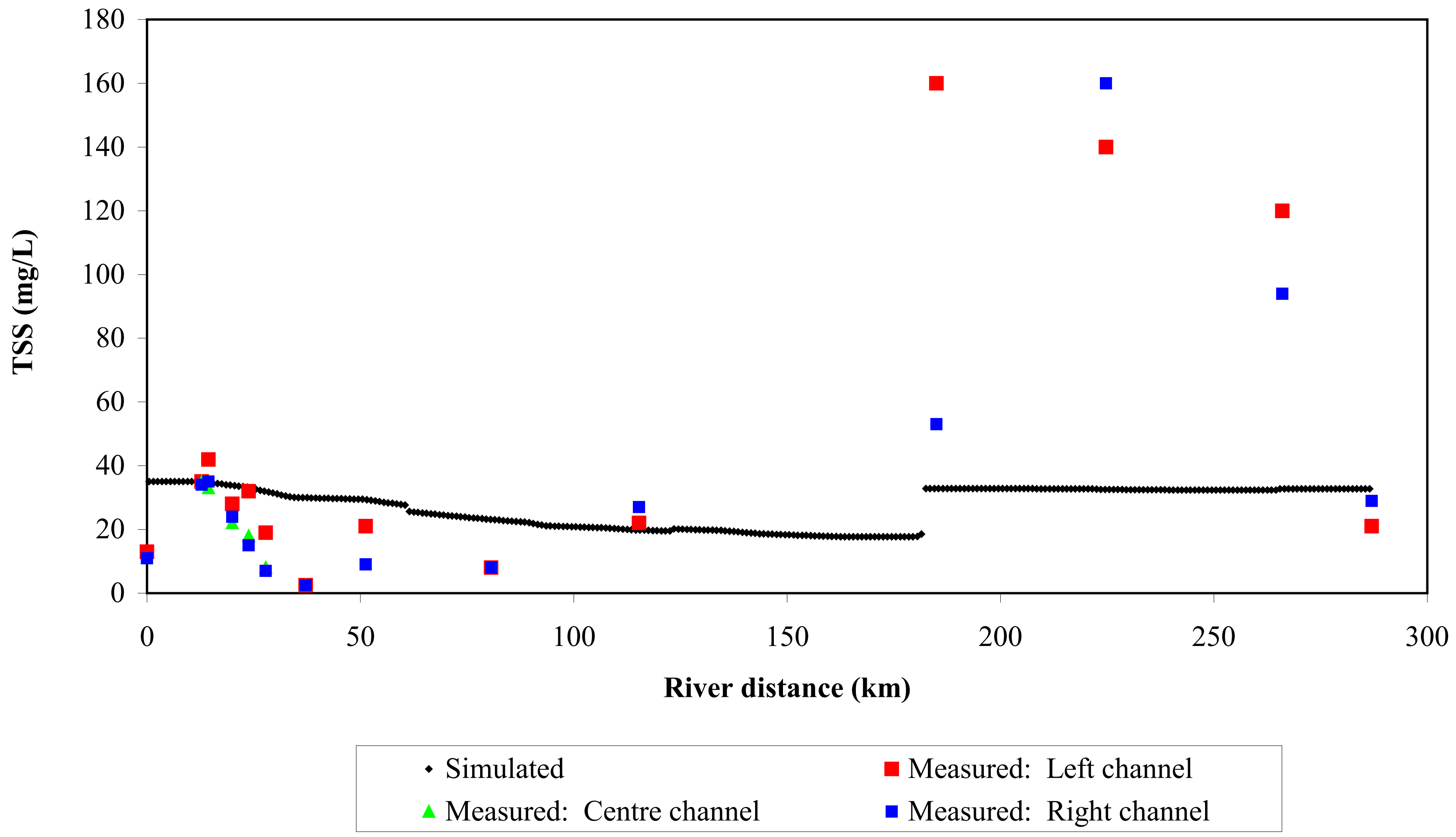

Figure 51. Results of a mass-balance simulation for total suspended solids (TSS), relative to measured values for the Assiniboine River: June 2002.

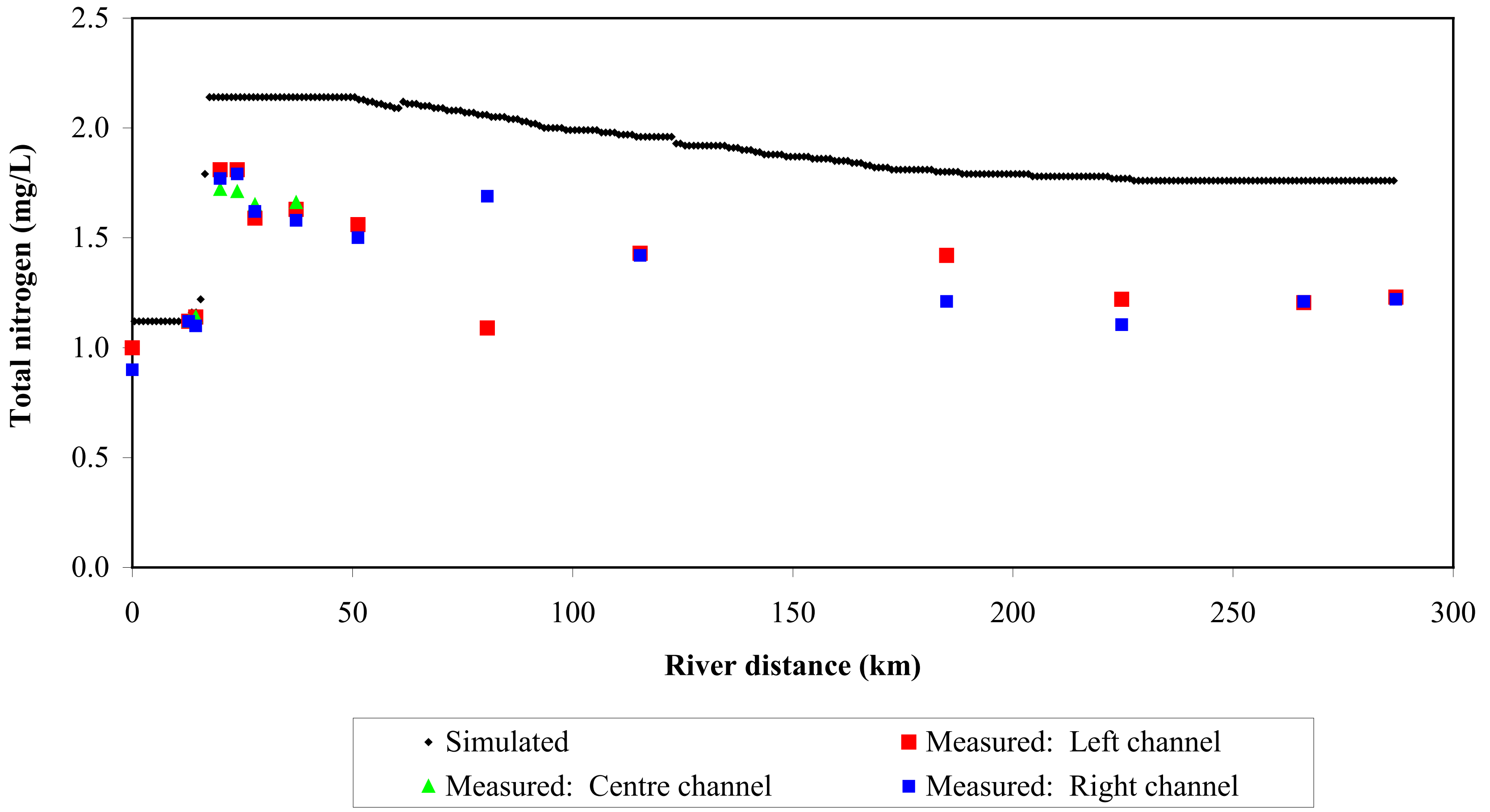

Figure 53. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: July 2002.

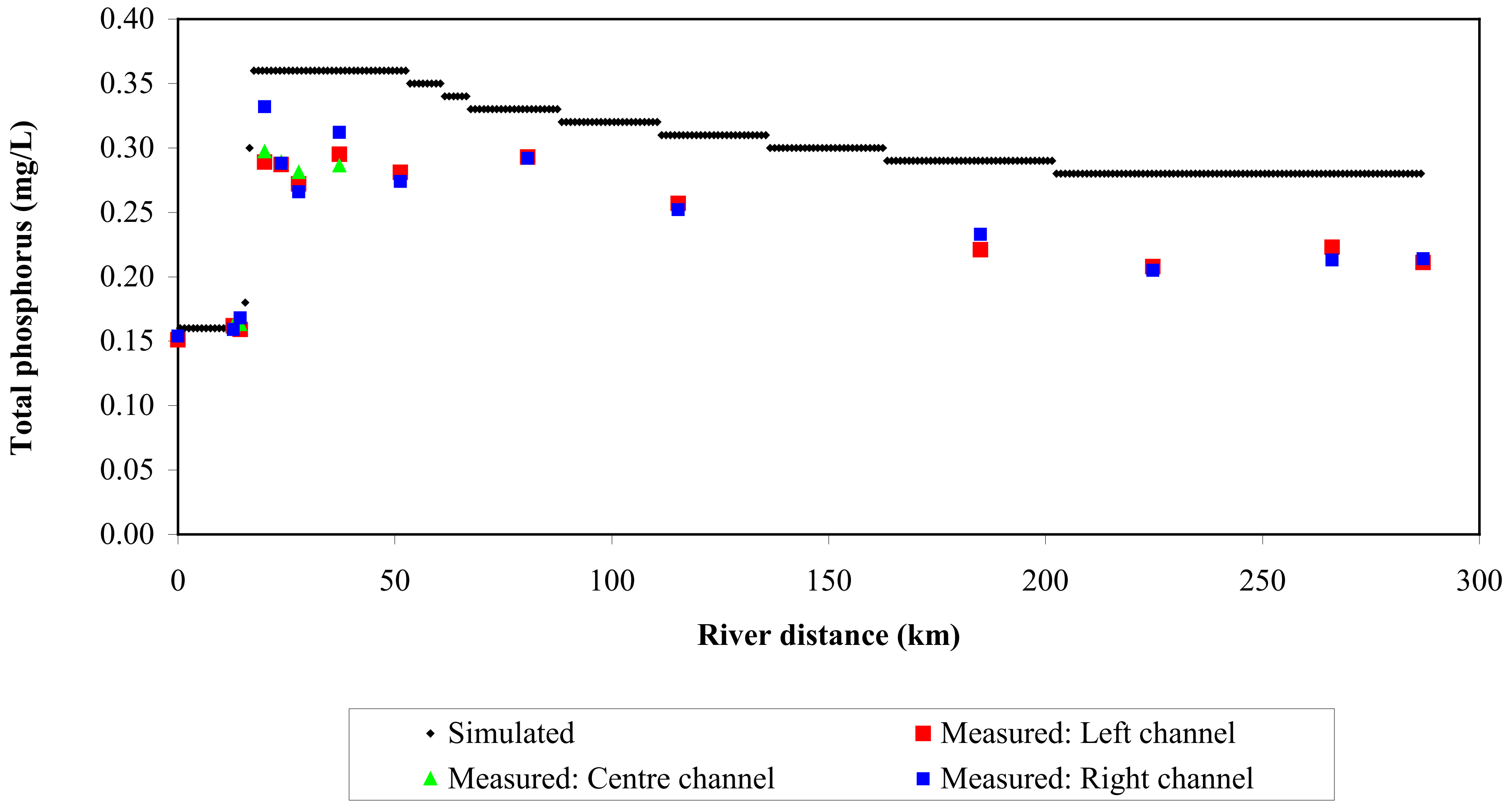

Figure 54. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: July 2002.

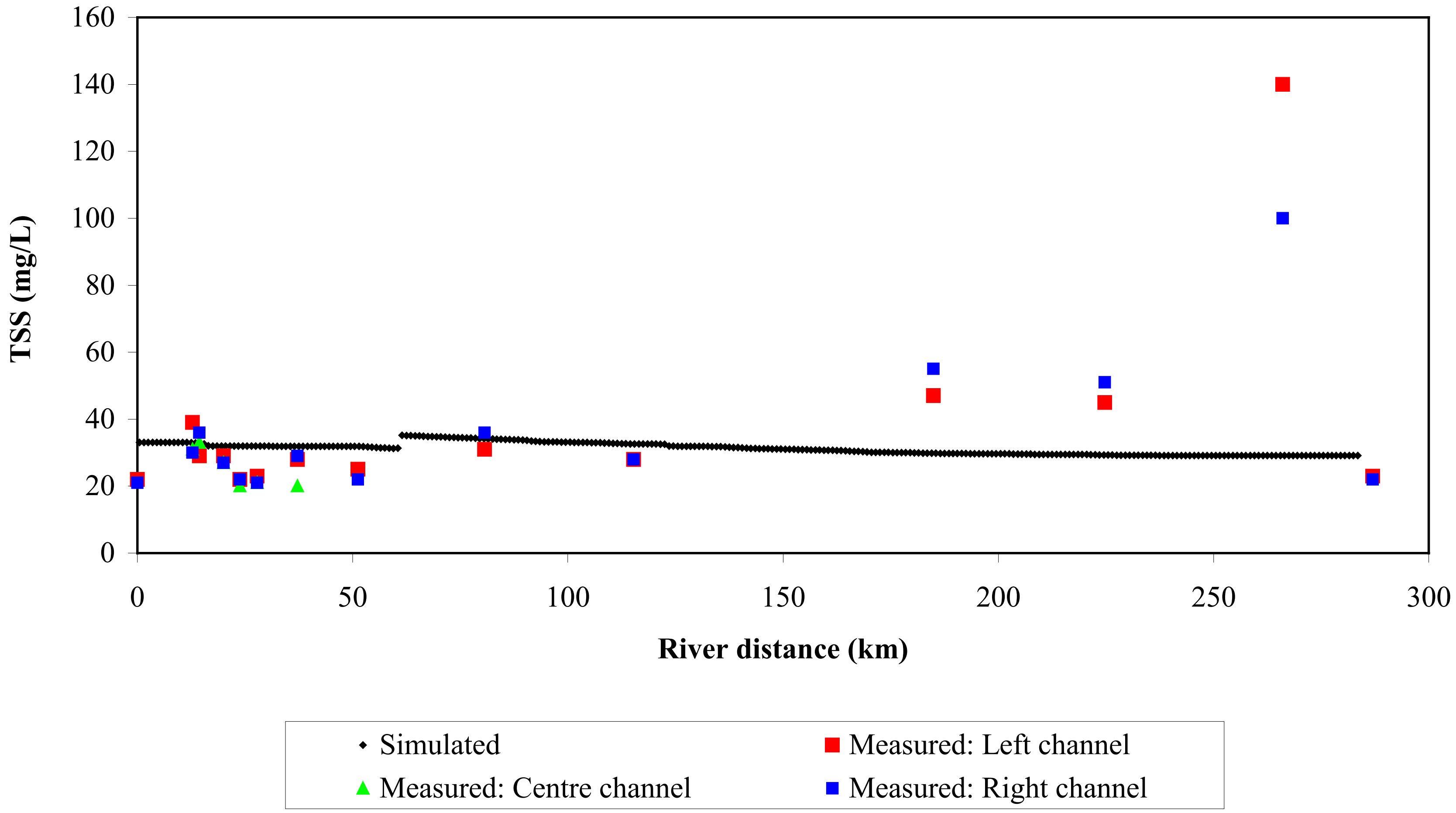

Figure 55. Results of a mass-balance simulation for total suspended solids (TSS), relative to measured values for the Assiniboine River: July 2002.

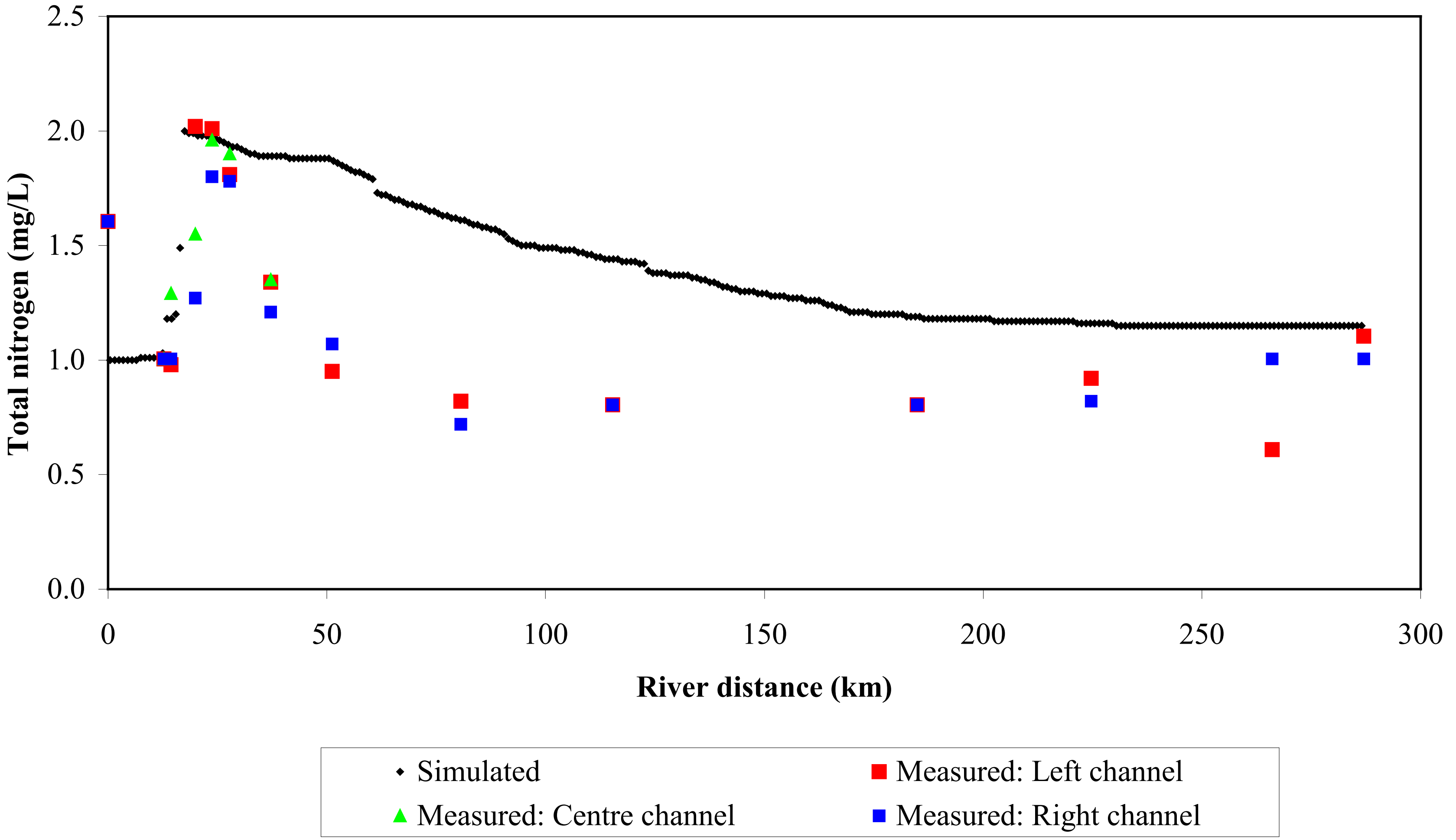

Figure 56. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: August/September 2002.

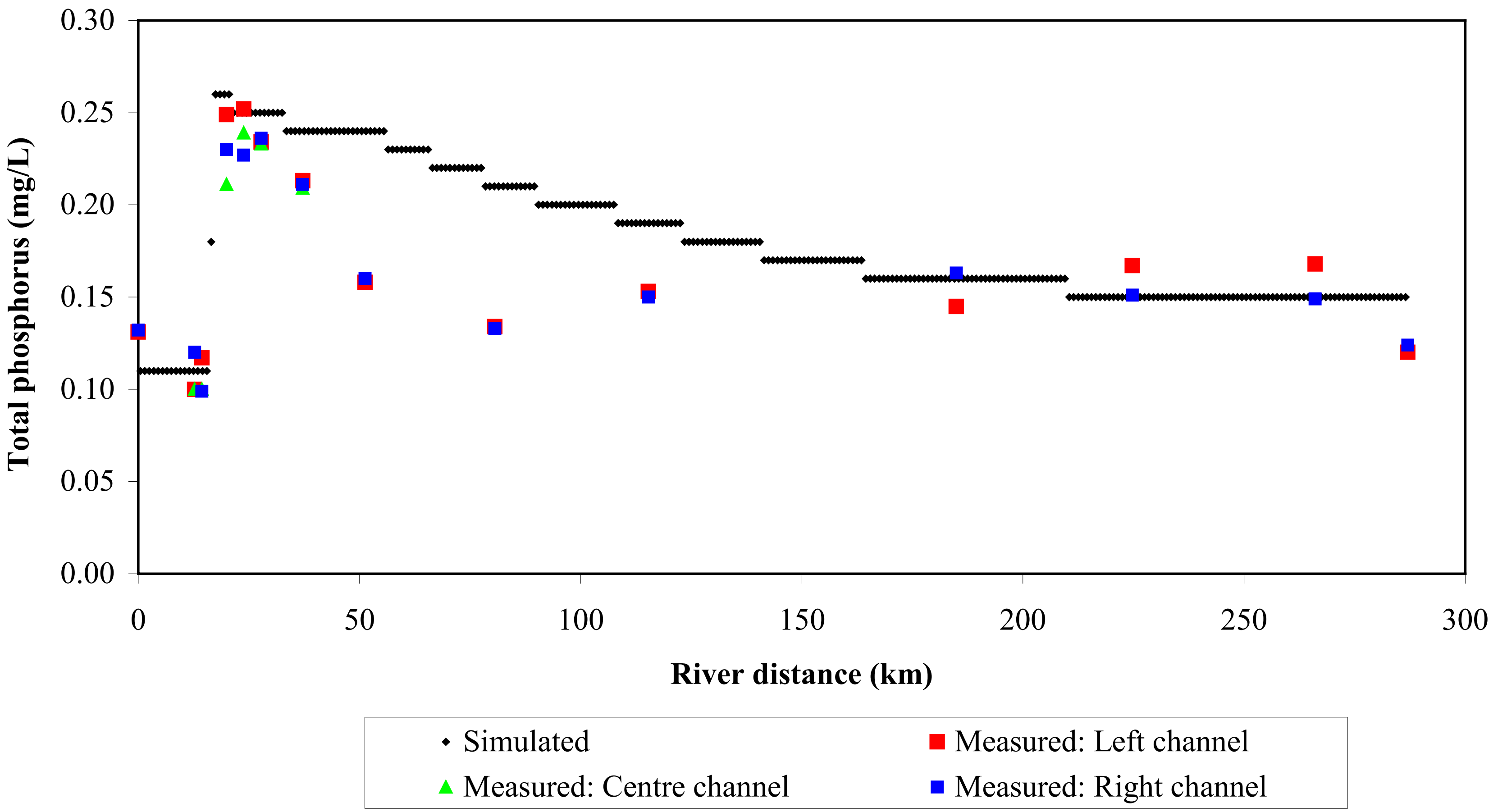

Figure 57. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: August/September 2002.

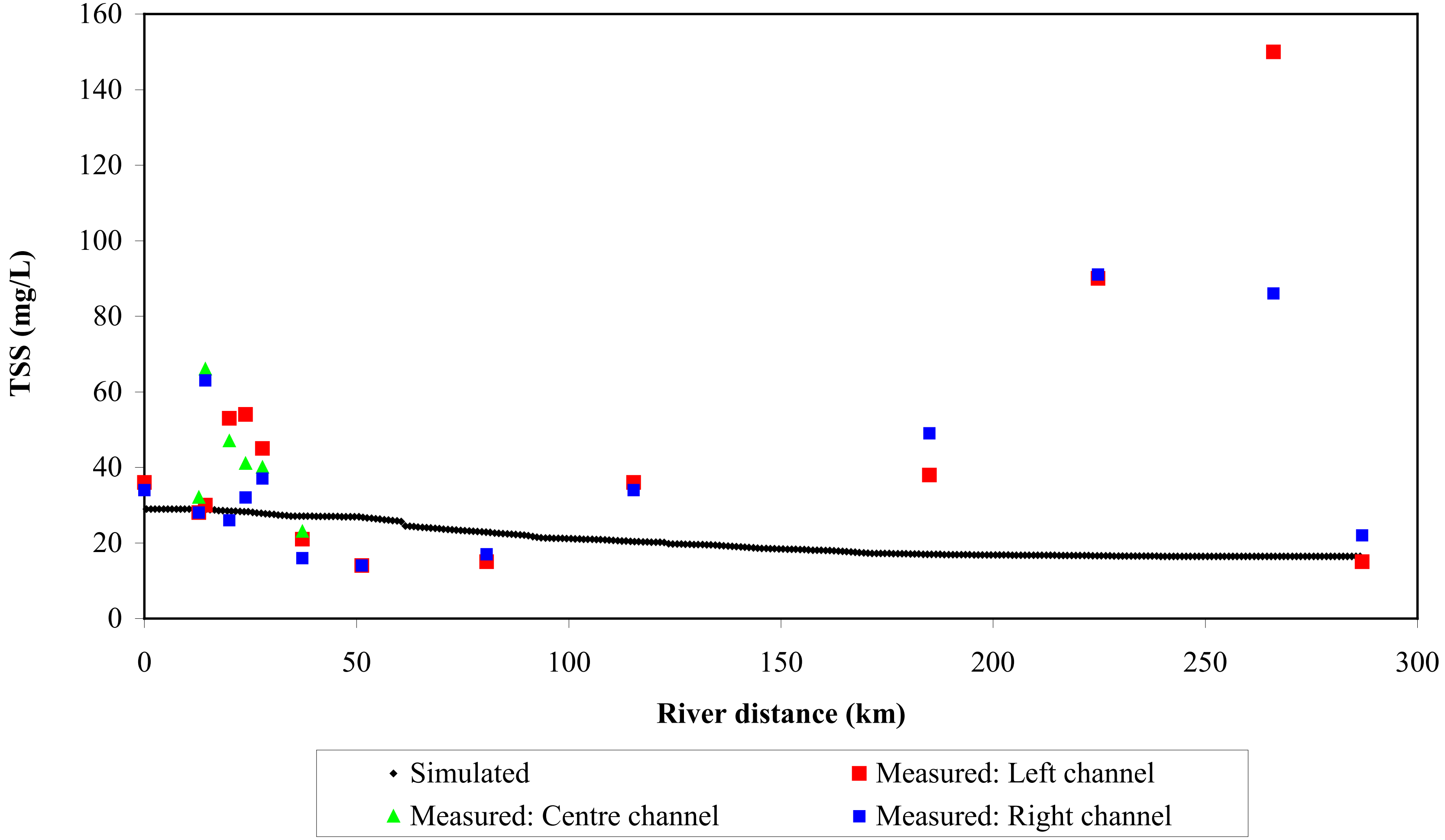

Figure 58. Results of a mass-balance simulation for total suspended solids (TSS), relative to measured values for the Assiniboine River: August/September 2002.

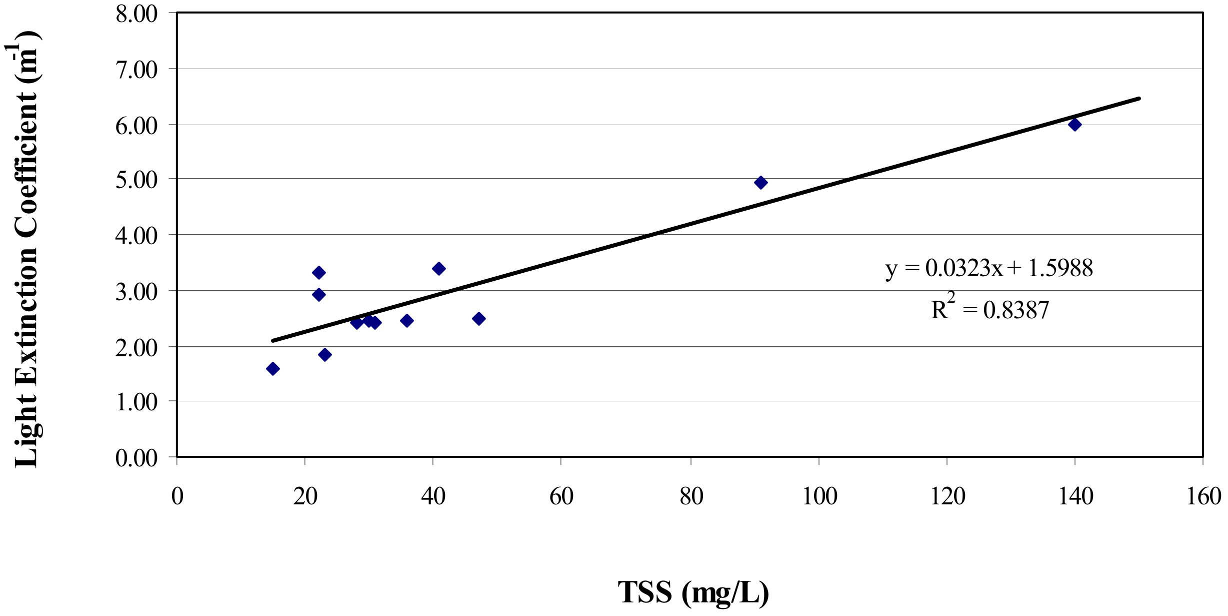

Figure 59. Relationship between total suspended solids (TSS) concentrations and light extinction coefficients measured in the Assiniboine River in July and August/September 2002. The line and formula represent a linear regression.

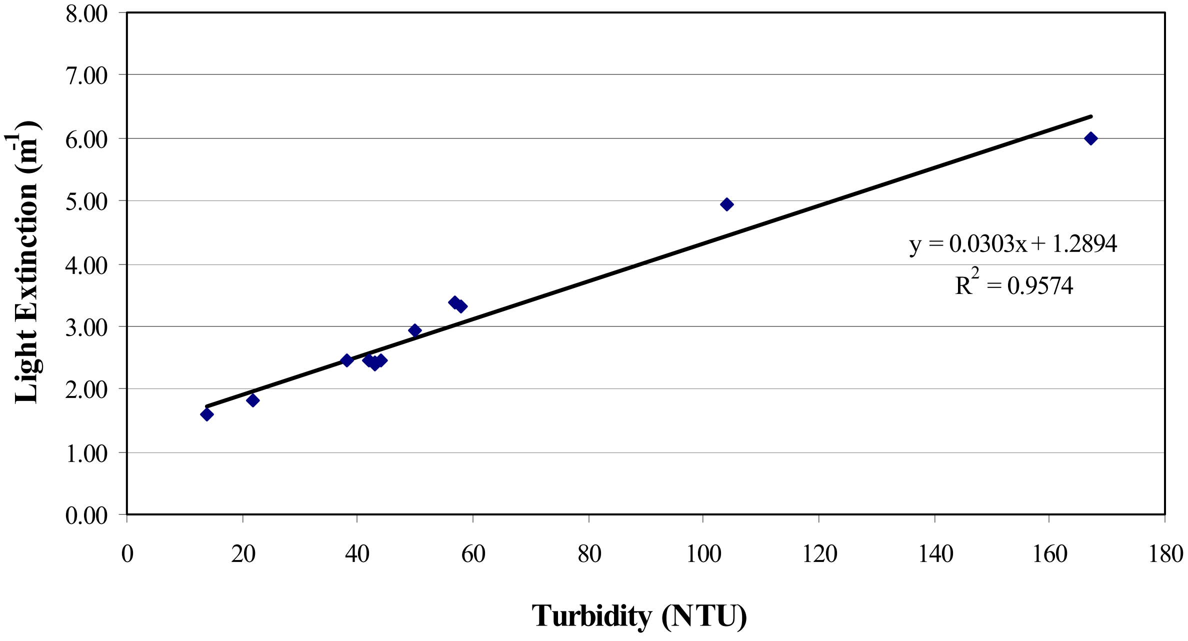

Figure 60. Relationship between turibidity and light extinction coefficients measured in the Assiniboine River in July and August/September 2002. The line and formula represent a linear regression.