A PRELIMINARY ESTIMATE OF TOTAL NITROGEN AND TOTAL PHOSPHORUS LOADING TO STREAMS IN MANITOBA, CANADA

By Alexandra Bourne, Nicole Armstrong, and Geoff Jones

Water Quality Management Section

Water Branch

November 2002

Manitoba Conservation Report No. 2002 - 04

Manitoba Building for the Future

Manitoba Conservation Report No. 2002 - 04

November 2002

A PRELIMINARY ESTIMATE OF TOTAL NITROGEN AND TOTAL PHOSPHORUS LOADING TO STREAMS IN MANITOBA, CANADA

Alexandra Bourne, Nicole Armstrong, and Geoff Jones

Water Quality Management Section
Water Branch

Printed on Recycled Paper

Building for the Future

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

EXECUTIVE SUMMARY

Enrichment of surface waters with plant nutrients such as phosphorus (P) and nitrogen (N) is one of the largest water quality issues facing not only Manitoba but also many other jurisdictions in Canada, the United States, Europe, and elsewhere in the world. Artificial enrichment with N and P can lead to the increased frequency and severity of nuisance blooms of algae. Nuisance blooms of algae can impair fish and wildlife habitat, cause taste and odour problems in drinking water, and increase the potential for generation of toxins from some species of algae that can subsequently affect humans, livestock, pets, aquatic life, and wildlife.

Nitrogen and P are essential components of healthy ecosystems and are naturally widespread in the environment. However, virtually all human activities can introduce new sources of nutrients to aquatic systems, can increase the rate of loss of nutrients from the landscape, or can increase the rate at which nutrients become available to support nuisance algal growth.

Manitoba Conservation began work towards a nutrient management strategy in 2000 (Manitoba Conservation 2000). The principal tasks of the nutrient management strategy include undertaking work to better identify the scope of the nutrient enrichment issue in Manitoba, to develop scientifically sound water quality objectives for N and P in both prairie streams and lakes, and in particular Lake Winnipeg, then to develop a comprehensive implementation plan. In an earlier report, available nutrient data were rigorously analyzed to identify whether total nitrogen (TN) and total phosphorus (TP) concentrations had changed in Manitoba over the past three decades (Jones and Armstrong 2001). In the following report, a preliminary estimate is made of TN and TP loading to streams in Manitoba to better understand the magnitude of the nutrient enrichment issue and wherever possible, to identify the major sources of nutrients. Focus is placed on the Assiniboine River and Red River watersheds.

Long-term water quality data and stream discharge data were used to compute flow-weighted estimates of nutrient loads, termed "total measured stream nutrient loads" (TMSNL), transported downstream from 41 monitoring stations. An attempt was then made to partition TMSNL between specific sources. Total measured stream nutrient loads are contributed from two general sources: (1) nutrients arising from within-stream processes including direct effluent discharge from point sources, release from stream bed and bank sediments, atmospheric deposition to surface water, and infiltration of ground water to streams and lakes; and (2) nutrients arising from watershed processes including atmospheric deposition to land surface, application of animal manure, nutrient release from soils and vegetation, increased nutrient transport due to enhanced drainage and removal of riparian vegetation, and application of inorganic fertilizer.

While an attempt was made to compute nutrient losses from watershed processes through the use of land use information and nutrient loss coefficients, these estimates appeared subject to a number of significant errors. Although subject to other errors, it was assumed that nutrient losses from watershed processes could also be calculated as the difference between TMSNL and within-stream loads, and it was assumed that the majority of within-stream loads were comprised of effluent discharges from point sources such as municipal and industrial effluents. Hence, while both methods were used, most summary information to describe general loading patterns was derived from the latter method.

Throughout this report, water quality data and stream discharge data from 1994 to 2001 were used. While data are available for a much longer period of time, this period reflected contemporary inputs, but more importantly, uncertainties in TN data at transboundary stations prior to 1994 precluded the use of a consistent data-set for a basin wide approach. It is important to note that nutrient loads are a function of both concentration and stream discharge, with stream discharge often being the pre-dominant factor. Consequently, average loads described in the following report for 1994 to 2001 may vary somewhat among other years but it is thought that the general patterns identified will remain similar.

In the Red River watershed, nutrient loading from watershed processes as estimated from land use and nutrient export coefficients provided similar estimates to those derived by subtracting within-stream loads from the TMSNL. In contrast, for the Assiniboine River, TN and TP loads from watershed processes were 13 and 7 times higher, respectively, than those derived by subtraction. Clearly, nutrient export coefficients found in the literature were more appropriate for use in the Red River watershed. The error associated with use of the export coefficients in the Assiniboine River watershed could be attributed to three main factors. First, the nutrient export coefficients used in this report were not specific to Manitoba. Second, land use information was only divided into four general categories (pasture, cropland, forest, and waterbodies) for the entire province. Finally, calculations could not account for nutrient retention by Lake of the Prairies and the Portage Reservoir, or uptake by large periphyton communities found near Brandon.

On average from 1994 to 2001, it was found that approximately 3,682 t/yr of TN was transported by the Assiniboine River in the vicinity of Headingley, Manitoba. Approximately 1,102 t/yr (30 %) of this was contributed from the headwaters of the Assiniboine and Qu'Appelle rivers in Saskatchewan, 1,130 t/yr (31 %) was contributed from the United States via the Souris River, 831 (23 %) was contributed from the Manitoba portion of the three main tributaries (Cypress, Souris, Little Saskatchewan rivers), and the remaining 619 t/yr (17 %) was contributed by either within-stream or watershed processes from other tributaries or directly to the mainstem within Manitoba. Total contribution from Manitoba was 1,450 t/yr. Of the 1,450 t/yr, 423 t/yr (29 %) could be attributed to direct discharges of municipal and industrial effluents while the remaining 1,027 t/yr (71 %) was attributed to various watershed processes including runoff from agricultural fields. It was estimated that TN load at the Headingley monitoring station had increased by 863 t/y between 1973 and 1999.

For the same period, it was found that approximately 637 t/yr of TP was transported by the Assiniboine River at Headingley, Manitoba. Approximately 130 t/yr (20 %) of this was contributed from the headwaters in Saskatchewan from both the Assiniboine River and the Qu'Appelle River, 209 t/yr (33 %) was contributed from the United States via the Souris River, 135 t/yr (21 %) was contributed from the Manitoba portion of the three main tributaries, with the remaining 163 t/yr (26 %) contributed from either within-stream or watershed processes within Manitoba. The total contribution from Manitoba was 298 t/yr. Twenty-five percent (75 t/yr) originated from the direct discharge of municipal and industrial effluents, while the remaining 75

% (223 t/yr) was attributed to watershed processes including agricultural activities. It was estimated that the TP load at the Headingley monitoring station had increased by 133 t/yr between 1973 and 1999.

The Red River in the vicinity of Selkirk transported an estimated average of 32,765 t/yr of TN from 1994 to 2001. Approximately 18,983 t/yr (58 %) of this was contributed to Manitoba from the Red River basin in the United States, 3,682 t/yr (11 %) was contributed from the Assiniboine River, 2,395 t/yr (7 %) was contributed from eight other tributaries in Manitoba (Pembina, Roseau, Rat, Boyne, Seine, and La Salle rivers), and the remaining 7,705 t/yr (24 %) was contributed from either within-stream or watershed processes to the mainstem within Manitoba. Additional contributions would occur from the United States from the international portion of the Pembina and Roseau river basins. However, lack of data from 1994 to 2001 precluded their quantification and therefore, these additional contributions were assumed to be relatively small in comparison to contributions from the Manitoba portion of these basins. When contributions of TN were excluded from the Assiniboine River and from the United States' portion of the basin, it was estimated that 4,176 t/yr (41 %) of the remaining 10,100 t/yr was added to the Manitoba portion of the basin through within-stream processes, including the direct discharge of effluents. The majority (86 % or 3,591 t/yr) of this 4,176 t/yr was estimated to have been contributed from the city of Winnipeg's three principle wastewater treatment facilities and sewers. The remaining 5,924 t/yr (59 %) was added to the basin by watershed processes including run-off from agricultural fields. Overall, the three wastewater treatment facilities in Winnipeg were estimated to have contributed 11 % of the TN load transported by the Red River at this station. The city of Winnipeg is the largest urban centre in the basin. It was estimated that the TN load in the Red River at Selkirk increased by 7,955 t/yr between 1978 and 1999, with 863 t/yr of this arising from the Assiniboine River basin. Due to analytical uncertainties in the TN data-set at Emerson, it was not possible to determine whether N loading had changed over time from the United States' portion of the basin.

The Red River at Selkirk transported an average of 4,905 t/yr of TP during 1994 to 2001. About 2,537 t/yr (52 %) of this originated from the United States' portion of the basin and 637 t/yr (13 %) originated from the Assiniboine River basin. Tributaries within Manitoba (Pembina, Roseau, Rat, Boyne, Seine, and La Salle rivers) contributed another 333 t/yr (7 %), while the remaining 1,398 t/yr (29 %) was estimated to have been contributed to either the mainstem or to smaller tributaries within Manitoba. Excluding contributions from the United States' portion of the basin and from the Assiniboine River basin, it was estimated that 470 t/yr (27 %) of the remaining 1,731 t/yr was contributed from within-stream processes included the direct discharge of effluents. The remaining 1,260 t/yr (73 %) was estimated to be contributed from watershed processes within the Manitoba portion of the basin. It was estimated that the three wastewater treatment facilities in Winnipeg contributed 390 t/yr (83 %) of the 470 t/yr arising from within-stream processes. Overall, it was estimated that Winnipeg's three wastewater treatment facilities contributed 8 % of the TP load transported by the Red River at Selkirk.

It is clear that within Manitoba, watershed processes such as run-off of nutrients from diffuse agricultural sources and from natural processes contributed the largest mass of nutrients to both the Assiniboine and Red rivers. Within the Assiniboine River basin, 71 % of TN and 76 % of TP were contributed from watershed processes, while in the Red River basin, 59 % of TN and 73 % of TP were similarly contributed from watershed processes.

Based upon the loading estimates from 1994 to 2001, Lake Winnipeg received approximately 63,207 t/yr of TN and 5,838 t/yr of TP. Forty-six percent of the TN and 73 % of the TP were contributed from the Red River basin during this period. The Winnipeg River was a significant contributor of both TN (27 %) and TP (13 %) while the Saskatchewan River (12 %) and atmospheric deposition (15 %) contributed a significant load of TP to Lake Winnipeg. Clearly, the largest contributor of nutrients to Lake Winnipeg was from the Red River basin.

It was estimated that 30 % of TN load and 43 % of the TP load contributed to Lake Winnipeg originated within the United States portion of the basin. Based upon the work of Jones and Armstrong (2001), it was estimated that TN and TP loads to Lake Winnipeg increased by 13 % and 10 % respectively, over the last three decades, due to increases measured in the Red River.

Accurately estimating nutrient loading to Manitoba's aquatic ecosystem is an extremely complex process that relies on the availability of a large amount of data specific to Manitoba. While the TMSNL are thought to be reasonably accurate estimates since they were based upon generally high quality monitoring data, partitioning these loads among the various contributing sources or processes is subject to more uncertainty. Unfortunately, while some data are available, many estimates were made based upon limited studies done in Manitoba and on studies done elsewhere. It is expected that further refinement of these preliminary estimates will occur in the future once additional research has been undertaken in Manitoba. Nevertheless, these preliminary estimates provide a valuable base of knowledge that is helpful to understand the magnitude of the nutrient management issue in Manitoba and to understand the general sources of nutrient contributions.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

TABLE OF CONTENTS vii

LIST OF FIGURES viii

LIST OF TABLES ix

INTRODUCTION 1

TOTAL MEASURED STREAM NUTRIENT LOAD 5

- Calculating the TMSNL and Nutrient Accrual Rates in Manitoba Streams 8
- Total Measured Nutrient Loads in Major Manitoba Streams 10
- Nutrient Loads and Accrual Rates in the Assiniboine River Watershed 15
- Nutrient Loads and Accrual Rates in the Red River Watershed 17

NUTRIENT LOADS FROM WITHIN-STREAM PROCESSES 20

- Direct Effluent Discharge to the Assiniboine River Watershed 28
- Direct Effluent Discharge to the Red River Watershed 29

NUTRIENT LOADING FROM WATERSHED PROCESSES 29

COMPARISON BETWEEN NUTRIENT LOADING FROM WATERSHED AND WITHIN-STREAM PROCESSES 34

NUTRIENT LOADING TO LAKE WINNIPEG 37

CHANGES IN TOTAL MEASURED NUTRIENT LOADING TO MANITOBA STREAMS DURING THE LAST THREE DECADES 39

CONCLUSIONS 42

REFERENCES 47

PERSONAL COMMUNICATION 49

LIST OF FIGURES

Figure 1. Map showing major drainage basins (watersheds) in Manitoba.................................... 3

Figure 2. Long-term stream water quality monitoring stations in Manitoba. 8

Figure 3. Schematic diagram of mean annual TN load (t/yr) in streams at long-term monitoring stations in Manitoba (1994 to 2001). Diagram not to scale. 13

Figure 4. Schematic diagram of mean annual TP load (t/yr) in streams at long-term monitoring stations in Manitoba (1994 to 2001). Diagram not to scale. 14

Figure 5. Map of the Assiniboine River watershed showing main tributaries and water quality monitoring stations (■).. 15

Figure 6. Map of the Red River watershed showing main tributaries (in Manitoba) and water quality monitoring stations (■). 18

Figure 7. Schematic diagram showing TN (t/yr) discharged from WWTF in Manitoba............ 25

Figure 8. Schematic diagram showing TP (t/yr) discharged from WWTF in Manitoba. 26

LIST OF TABLES

Table 1. Agricultural land use in Manitoba in 1996 (Manitoba Agriculture 2000). 4

Table 2. Total measured stream TN load (t/yr) at water quality monitoring stations in Manitoba.. 11

Table 3. Total measured stream TP load (t/yr) at water quality monitoring stations in Manitoba.. 12

Table 4. Percent contribution of TN to the Assiniboine River from four tributary streams. 16

Table 5. Percent contribution of TP to the Assiniboine River from four tributary streams. 16

Table 6. Rates of TN and TP accrual (mg/m^3/km/yr) on five reaches of the Assiniboine River between Kamsack and Headingley. 17

Table 7. Percent contribution of TN load to the Red River from tributary streams.................... 19

Table 8. Percent contribution of TP load to the Red River from tributary streams. 19

Table 9. Rates of TN and TP accrual (mg/m^3/km/yr) along two reaches of the Red River within Manitoba.. 20

Table 10. Average annual nutrient loads (t/yr) from direct effluent discharge to surface waters in Manitoba.. 24

Table 11. Total nitrogen (t/yr) and TP (t/yr) loading rates for industries that monitor discharge 24

Table 12. Comparison of estimated domestic contributions to total measured TN and TP loads from the cities of Winnipeg and Portage la Prairie. 27

Table 13. Measured and estimated non-industrial TN and TP loads (t/yr) discharged to the Assiniboine River from Brandon. 28

Table 14. Average annual nutrient loads (t/yr) from direct effluent discharge to the Assiniboine River and tributaries. 29

Table 15. Average annual nutrient loads from direct effluent discharge to the Red River and its tributaries.. 30

Table 16. Mean and range of TN and TP export coefficients (kg/ha/yr,) for specific land uses. 31

Table 17. Total nitrogen (t/yr) and TP loading (t/yr) in Manitoba based on land use export coefficients. 33

Table 18. Total nitrogen (t/yr) and TP loading (t/yr) from watershed processes in the Assiniboine River watershed in Manitoba. 33

Table 19. Total nitrogen (t/yr) and TP (t/yr) loading from watershed processes in the Red River watershed in Manitoba. 34

Table 20. Summary of mean nutrient loading (t/yr.) in Manitoba. Ranges are in parentheses... 35

Table 21. Summary of nutrient loading (t/yr) in the Assiniboine River watershed in Manitoba. 36

Table 22. Summary of nutrient loading (t/yr) in the Red River watershed in Manitoba. 37

Table 23. Contributions to the nutrient load in Lake Winnipeg from the three main tributaries and atmospheric deposition (1994 to 2001). 38

Table 24. Comparison of nutrient loads (t/yr) to Lake Winnipeg from portion of the Red River watershed in the United States and in Manitoba. 39

Table 25. Subdivision of nutrient loads to Lake Winnipeg from Manitoba's portion of the Red River watershed. 39

Table 26. Total change in TN and TP load (t) at several water quality monitoring stations in Manitoba over the reporting period. 41

INTRODUCTION

The nutrient enrichment or eutrophication of streams and rivers is one of the most important surface water quality issues in Manitoba. While plant nutrients are naturally present and are an integral part in all healthy aquatic systems, an over-abundance can result in excessive algae and aquatic plant growth. This in turn can lead to problems such as oxygen depletion and fish kills, decreased biodiversity, taste and odour concerns, increased water treatment costs, and production of toxins from blue-green algae.

The two main nutrients associated with eutrophication are nitrogen (N) and phosphorus (P). Phosphorus is required in the photosynthesis process in plants, and in energy transfer pathways in both plants and animals and is generally considered more limiting than N in freshwater ecosystems (see Elsier *et al.* 1990, Conley 2000). Since P is highly reactive it normally does not exist in its elemental form in nature, but rather is found in combination with other elements in a wide variety of dissolved and particulate organic and inorganic compounds. The total phosphorus (TP) concentration of surface water is the sum of the dissolved and particulate forms of P. Dissolved P is that portion of the TP that can pass through a 0.45 micron filter, while particulate P is that portion that is adsorbed to sediment particles and incorporated in plant and animal tissue. Phosphorus is most readily taken up and assimilated by plants as inorganic ionic compounds. These ionic compounds (also called orthophosphates) are a fraction of the dissolved portion of TP and include simple phosphate ($P0_4^{-3}$), monohydrogen phosphate ($HP0_4^{-2}$), and dihydrogen phosphate ($H_2P0_4^-$) (CCME 1987). Thus, the TP of a waterbody is not a measure of the specific amount of P that is immediately available to plants, but is an indication of the amount that is potentially available for plants.

Nitrogen is present in amino acids (components of proteins), nucleotides, and chlorophyll molecules, and as such is a necessary nutrient for all living organisms. There is increasing evidence to suggest that nitrogen may be as important as phosphorus in limiting algal growth in rich prairie systems. As with phosphorus, nitrogen does not occur in its elemental form in water, but rather is present as nitrogenous inorganic and organic compounds (CCME 1987). Only inorganic forms of nitrogen--predominantly ammonia (in its ionized form NH_4^+) and nitrate

(NO_3^-) are available for plant uptake and assimilation. Nitrite (NO_2^-) is another inorganic form of nitrogen that is available to plants. However, because nitrite is rapidly converted to either ammonia or nitrate, the concentration of nitrite under natural conditions is usually below 0.001 mg/L (CCME 1987) and thus the overall contribution of nitrite to the available nitrogen content in aquatic systems is negligible.

The total nitrogen concentration (TN) in a water sample is a combination of both the total inorganic nitrogen (TIN) and the total organic nitrogen (TON) in the water. Summing the concentrations of ammonia (as mg/L N) and nitrate-nitrite (as mg/L N) in a sample can be used to determine the TIN content of a water sample. The TON of a water sample is determined by first measuring the total kjeldahl (pronounced 'kell-dall') nitrogen (TKN) content of the water sample. The TKN content (as mg/L N) is a measure of both the TON and the ammonia concentrations in the water. Therefore, by simply subtracting the concentration of ammonia from the TKN concentration one can calculate the TON content of a water sample. Furthermore, the TN content of a sample can be determined by adding the nitrate-nitrite concentration to the TKN concentration. Analytical methods can also be used to determine the total dissolved nitrogen and the total particulate nitrogen in a water sample. In this case, the TN of the water sample is calculated by summing the total dissolved and total particulate portions.

Anthropogenic sources of N and P to surface waters include surface run-off of fertilizer and animal manure from cultivated fields, run-off from livestock pastures and feedlots, and industrial and urban sewage effluent discharges. Surface run-off from non-fertilized lands in southern Manitoba can also be considered a source of nutrients simply because of the naturally high soil fertility in this region of the province. Furthermore, soil erosion (both naturally occurring and anthropogenic in origin) plays an important role in the movement of nutrients to the aquatic environment, and this process is often accelerated through poor or inappropriate land use practices.

The province of Manitoba occupies a total area of approximately 650,000 km^2. Surface waters account for approximately 102,300 km^2 or about 16 % of this total. Nine major watersheds or drainage basins are partially or entirely contained within the south half of the province (Figure 1). These include portions of the Lake Winnipegosis basin, along with the

Saskatchewan, Assiniboine, Qu'Appelle, Souris, Red, and Winnipeg River watersheds, and the entire area of the Dauphin Lake and Lake Manitoba drainage basins. Lake Winnipeg is the recipient of much of the drainage from these watersheds. Water exits from the north end of the lake to flow northeastward to Hudson Bay via the Nelson River. The aforementioned watersheds plus that of the Nelson River itself constitute the lower portion of the larger Nelson River drainage basin that extends westward from northwestern Ontario across Manitoba and the south half of Saskatchewan to the Rocky Mountains on the Alberta-British Columbia boundary.

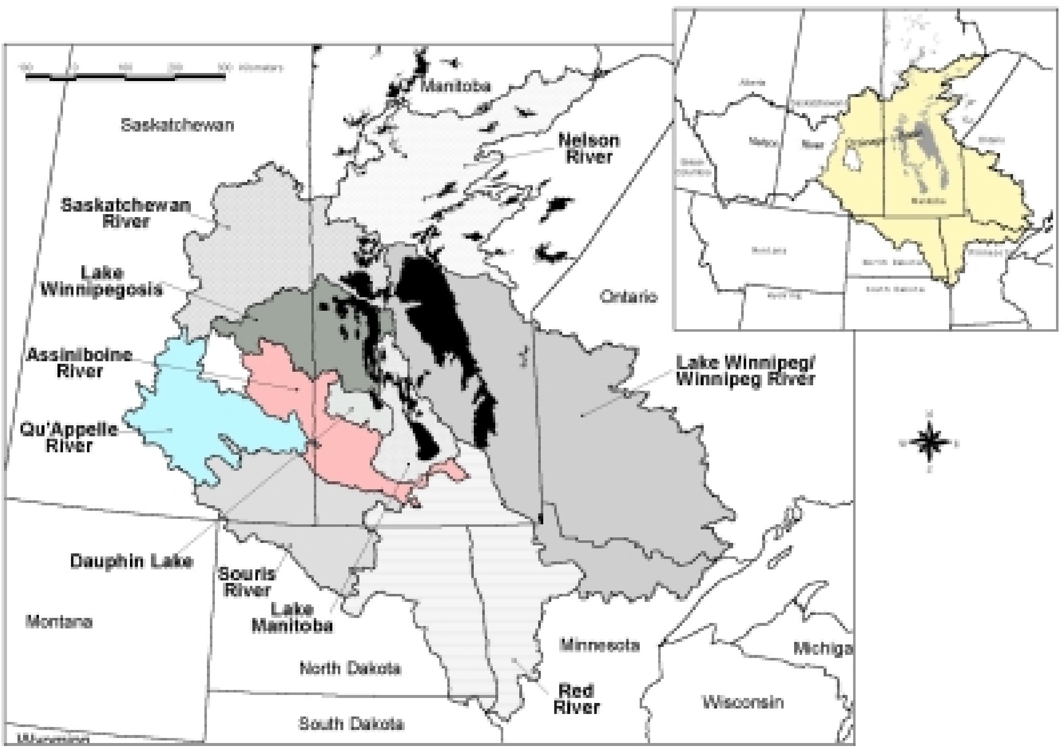

Figure 1. Map showing major drainage basins (watersheds) in Manitoba.

Approximately 15 % of the land base in Manitoba is used directly for agriculture (Table 1). Most of the agricultural activity takes place in the southern third of the province and is most intensive in the Assiniboine, Souris, and Red River watersheds. Agricultural activities in the province are varied and include cereal, feed, and specialty crop production, as well as range, pastureland, feedlot, and intensive hog operations. Fertilizer is commonly used on cultivated fields, and thus, there is a high potential for nutrient loading to surface waters within the region. There are also over 400 licensed wastewater facilities and 76 industries that discharge effluent to surface waters in Manitoba. Most of these are concentrated in the southern half of the province and many of the streams in this region are the recipients of effluent from these treatment facilities and industrial operations.

Table 1. Agricultural land use in Manitoba in 1996 (Manitoba Agriculture and Food 2000).

Land Use	Area (1000 ha)
Total area:	65,001
Surface water	10,230
Land area:	54,771
Non-Agricultural (includes urban areas, forests, and peatlands)	47,039
Agricultural:	7,732
Cropland	4,699
Summer-fallow	324
Pasture	356
Unimproved pasture and hayland	1,654
Other agricultural land	699

Nutrient enrichment of surface waters is not only an important water quality issue in Manitoba, but is also a major concern in other regions of Canada, North America, Europe, and elsewhere. Manitoba Conservation recently released a nutrient management strategy document that outlines the main steps required to gain the additional scientific knowledge to better manage plant nutrients in Manitoba (Manitoba Conservation 2000). One of the first tasks outlined in the strategy was the need to identify long-term trends in total nitrogen (TN) and total phosphorus (TP) concentrations in Manitoba waterways. The results of this assessment are available in Jones and Armstrong (2001).

The next major task in the strategy, and the purpose of this report, is the identification and quantification of the major sources of N and P to surface waters in the province. Nitrogen and P loads in Manitoba streams will be assessed, and the relative contribution from various sources including direct effluent discharge and runoff from watersheds will be calculated. Since the data sets for TN and TP are more extensive and have fewer censured values than data sets for ammonia, nitrate, dissolved phosphorus, and ortho-phosphorus, the total values rather than the inorganic or dissolved fractions of N and P were used in the loading estimations in this report. Furthermore, although this report presents information regarding nutrient loading to streams across the entire province, it focuses primarily on loading within the Assiniboine and Red river watersheds. Particular emphasis will also be placed on nutrient loading to Lake Winnipeg. Finally, change in the measured TN and TP load in Manitoba streams over the past 3 decades will be calculated based on the percent change in concentration calculated by Jones and Armstrong (2001).

TOTAL MEASURED STREAM NUTRIENT LOAD

The amount of nutrients present in a stream at a given time is referred to in this report as the total measured stream nutrient load (TMSNL). The TMSNL of a particular stream is dependent on both the nutrient concentration and the volume of water flowing within the stream. Thus, a stream with a very low nutrient concentration, but a high volume of flow may have the same or similar nutrient load as a stream that has a high concentration of nutrients and a relatively low volume of flow. The TMSNL is calculated by multiplying the nutrient concentration by the discharge or flow rate at a specific location in the stream. This yields a product that is a measure of the mass of nutrients moving past a certain point during a specified time period.

Several natural and anthropogenic processes contribute to the TMSNL in any given stream. Processes that directly influence the TMSNL of a stream are referred to as within-stream processes, while those that have a somewhat indirect, but no less significant, impact on the TMSNL are referred to as watershed processes. These processes and their calculation are briefly introduced below:

Within-Stream Processes: Two of the three general within-stream processes have both anthropogenic and natural components, while the direct discharge of liquid effluent is considered to be solely anthropogenic in origin.

1. Direct Effluent Discharge: The direct discharge of liquid effluents to surface water is a significant anthropogenic source of nutrients to aquatic systems in Manitoba and elsewhere. The quantity of nutrients contributed from direct or point source discharges of effluents were estimated using several methods, including calculations derived from available wastewater effluent discharge data and population census data.

2. Release from Stream Bed and Stream Bank Sediments: Nitrogen and P are often associated with sediment particles in streams. Depending on the flow and inherent energy in the stream, these particles can be scoured from the stream bed or stream bank and redistributed further downstream where the nutrients can be released to the water column. Although this is largely a natural process, it may have an anthropogenic component since land use activities can lead to increased flow rates in streams, and subsequently, increased scouring of stream bed and bank sediments. An estimation of nutrients released to Manitoba streams from this process is beyond the scope of this report.

3. Infiltration of Ground Water: Infiltration of ground water via the stream bed often provides a majority of the base flow in some streams during periods of low flow such as fall and winter. Ground water usually contains only trace amounts of N and P. However, under certain circumstances it can contain elevated levels of nitrogen. For example, the downward leaching of nitrates and nitrites from animal manure and inorganic fertilizer applications, and leakage of municipal sewage lagoons and private septic systems can add nitrogen to ground water. The contributions of N and P to streams from ground water infiltration were not estimated for this report.

Watershed Processes: Two of the five general watershed processes have both anthropogenic and natural components while the remaining three have only anthropogenic components.

1. Atmospheric Deposition: Nitrogen and P can be deposited directly to land and water through rainfall and particulate deposition. Nutrients can be deposited directly to surface waters as well

as onto the land surface and then transported to surface waters. Estimates were made of this source of nutrients. Losses to the atmosphere were not included. Although it is likely that atmospheric deposition of nutrients at least at the local scale can be significantly affected by human activity, there was no attempt to discriminate between anthropogenic and natural contributions in this report.

2. <u>Animal Manure:</u> The application of livestock manure to agricultural land, lawns, and gardens is a potential source of nutrients since N and P in the manure can be transported to surface waters during periods of heavy rainfall and spring run-off. This anthropogenic source of nutrients was estimated using several methods that will be discussed later in this report.

3. <u>Release from Soils and Vegetation:</u> Nutrients are released from soils and decaying vegetation and may be available for transport to surface water with rainfall or snowmelt. While largely a natural phenomenon, land use practices can alter the amount of soil exposed to erosion or the mass of vegetation that may be available for decomposition. It was not possible to estimate the contribution by this source to surface water.

4. <u>Enhanced Drainage and Reduced Riparian Vegetation:</u> Enhanced drainage networks and the drainage of wetlands causes nutrients to be transported more quickly from land surfaces to adjacent bodies of water. Loss of riparian vegetation also allows nutrients to be more readily moved directly into surface water. Loss of riparian vegetation also may cause stream banks to become less stable and more prone to erosion of nutrient-rich sediments. It was not possible to estimate the contribution by this source to surface water.

5. <u>Inorganic Fertilizer:</u> The application of inorganic fertilizer to agricultural lands, lawns, and gardens can also provide a source of nutrients that may later be transported with rainfall or snowmelt to surface water. This anthropogenic source of nutrients to surface water was estimated with nutrient export from agricultural land.

The processes contributing to the TMSNL can be summarized as follows:

		Within-Stream Processes						**Watershed Processes**								
TMSNL	=	Direct Effluent Discharge	+	Release from from Sediments	+	Infiltration of Groundwater	+	Atmospheric Deposition	+	Livestock Manure	+	Release from Soils and Vegetation	+	Enhanced Drainage and Reduced Riparian Vegetation	+	Inorganic Fertilizer

Calculating the TMSNL and Nutrient Accrual Rates in Manitoba Streams

The TMSNL for streams in Manitoba was calculated with TN and TP data from a total of 41 water quality stations representing 32 separate streams in Manitoba (Figure 2). Most of the flow data for calculating TMSNL at each water quality station were obtained from the Water Survey of Canada, which maintains a network of hydrometric stations across the province. Flow data for the Nelson River were obtained from Manitoba Hydro. The majority of water quality stations were located on streams and rivers in the southern half of the province, and most were monitored by Manitoba Conservation. Several water quality stations located on transboundary streams such as the Carrot, Saskatchewan, Winnipeg, Red Deer, Red, Pembina, and Assiniboine rivers were maintained by Environment Canada, while the station on the Souris River at Westhope was maintained by the North Dakota USGS. The water quality monitoring interval often differed between stations such that TN and TP concentrations (mg/L) were recorded at approximately monthly, quarterly, or only three times per year. Stream discharge or flow (m^3/s) was generally measured on a daily basis.

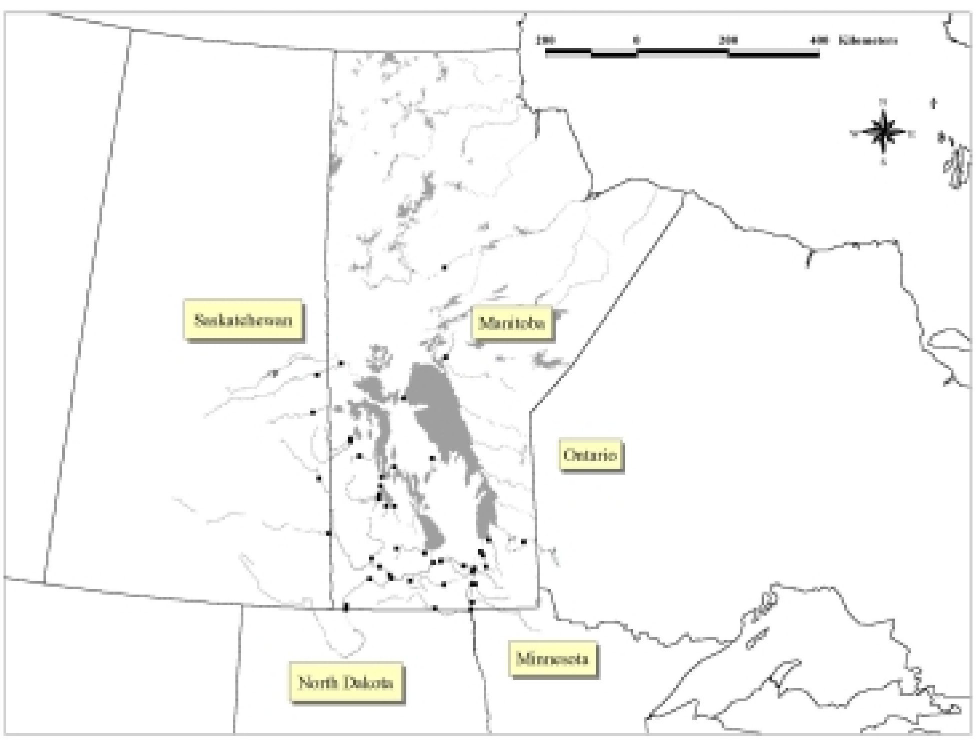

Figure 2. Long-term stream water quality monitoring stations in Manitoba.

Prior to 1994, the analytical method for determining dissolved nitrogen at the stations maintained by Environment Canada did not account for all the nitrogen associated with urea and ammonium compounds (pers. comm. Lee 2001). Since this resulted in underestimated values for TN in samples collected before 1994, the calculations of stream TN and TP load in this report were limited to the period from 1994 to 2001 (inclusive) at all stations.

Mean monthly stream discharge was calculated for stations with monthly records for TN and TP concentration. These mean values were then multiplied by the monthly TN and TP concentrations to yield a TMSNL for TN and TP for each month. The months were summed for each year to provide an estimate of annual TMSNL. Occasionally, water quality data were not available for a particular month. In such instances, nutrient concentrations from the previous and subsequent month were averaged to determine TN and TP concentrations for the missing month. Annual averages for TN, TP and discharge were calculated and then multiplied to determine the annual TMSNL for stations that were sampled only three times per year or on a quarterly basis. Discharge data for the months of November through February was lacking for some small streams. Discharge during this period for these streams was estimated by calculating an average of the discharge measured at the end of October with that measured at the beginning of March.

The annual and average (1994 to 2001) percent contribution of each major tributary within the Assiniboine and Red River watersheds to TMSNL of the Assiniboine River (at Headingley) and the Red River (at Selkirk) were calculated. Estimates of nutrient loads from the Little Saskatchewan River to the Assiniboine River were not available for 1997 to 1999. Similarly, nutrient loads were not available for the Boyne or Seine rivers for 1997 to 2001. Since TMSNL was not available for the Morris River (a main tributary to the Red River), it could not be included in the analyses. Cooks Creek was excluded from the analysis as the confluence with the Red River occurs downstream of the Selkirk sampling station.

Downstream increases in TMSNL are primarily due to increases in discharge rather than increases in concentration (Chambers and Dale 1997). The rate at which a stream accumulates nutrients within a specific reach is called the nutrient accrual rate. The annual nutrient accrual rate is arrived at by calculating the change in flow weighted mean TN or TP concentration

(Cooke *et al.* 2002) over a specific river reach for any given year ($mg/m^3/km/yr$). Annual flow weighted mean TN and TP concentrations (mg/m^3) for the period 1994 to 2001 were derived for each station on the Assiniboine and Red rivers (as in Cooke *et al.* 2002). Rates of nutrient accrual were calculated for reaches of the Assiniboine River (*i.e.*, between Kamsack, Brandon, Treesbank, Portage Spillway, East of Portage and Headingley) and the Red River (*i.e.*, between Emerson, St. Norbert and Selkirk) by dividing the change in annual flow weighted mean TN or TP concentrations by the length of the river reach (Chambers and Dale 1997). Nutrient accrual rates for each year of analysis were averaged to provide an overall estimate of TN and TP accrual in each river for the 1994 to 2001 period.

Total Measured Nutrient Loads in Major Manitoba Streams

Total nitrogen and TP loads (expressed in metric tons per year or t/yr) varied considerably between streams in Manitoba (Tables 2 and 3). Total nitrogen loads ranged from a low of 7 t/yr in the Cypress River in 2000, to a high of 37,871 t/yr in the Red River at Selkirk in 1997 (Table 2). Total phosphorus loads ranged from a low of 1.1 t/yr in the North Duck River in 2000, to a high of 8,176 t/yr in the Red River at Selkirk in 1997 (Table 3). The load of TN and TP also varied considerably between years within the same stream. For example, the respective load of TN and TP in the Assiniboine River at Kamsack ranged from a low of 148 t/yr and 19 t/yr in 2000 to a high of 1,712 t/yr and 176 t/yr in 1995. The influence of discharge on TMSNL was evident with high discharge years resulting in relatively high TMSNL. This was particularly apparent in the Red River and its tributaries in 1997, and in several streams in the Dauphin Lake and Lake Manitoba watersheds in 2001. The TN and TP loads appeared to be well correlated with each other and with flow or discharge. The Red River consistently had the highest TN and TP loads each year, while the lowest loads were usually recorded in the Turtle, Ochre, and North Duck rivers. Mean TMSNL for TN and TP in each stream (from Tables 2 and 3) are illustrated schematically in Figures 3 and 4.

Table 2. Total measured stream TN load (t/yr) at water quality monitoring stations in Manitoba.

Stream	1994	1995	1996	1997	1998	1999	2000	2001	Mean
Assiniboine River									
At Kamsack	222	1,712	630	561	189	290	148	502	532
At Brandon	1,275	4,119	2,977	1,892	1,100	3,433	871	3,177	2,355
At Treesbank	1,387	4,545	3,162	2,046	1,349	3,985	1,306	3,642	2,678
At Portage Spillway	1,518	4,638	3,357	2,664	2,532	4,957	2,229	4,484	3,297
East of Portage	1,668	4,840	3,551	2,641	2,905	5,661	2,374	4,119	3,470
At Headingley	1,740	4,444	3,575	3,440	3,619	5,535	2,465	4,638	3,682
Assiniboine River Tributaries									
Qu'Appelle River	509	631	1,004	738	227	793	158	507	571
Little Saskatchewan	188	440	233	n/a	n/a	n/a	173	371	281
Souris River, Westhope	n/a	n/a	949	680	327	2,563	n/a	n/a	1,130
Souris River, Treesbank	334	1,688	2,380	1,244	861	4,144	527	1,811	1,624
Cypress River	20	65	56	74	102	22	7	101	56
Red River									
At Emerson	14,020	19,200	18,058	23,206	19,628	21,869	15,085	20,801	18,983
At St. Norbert	17,128	27,298	25,716	24,329	25,273	26,601	16,522	25,785	23,582
At Selkirk	22,121	36,370	34,558	37,871	35,303	33,681	24,459	37,755	32,765
Red River Tributaries									
LaSalle River	54	152	344	436	183	51	111	565	237
Roseau River	478	418	899	869	549	969	569	1,008	720
Rat River	76	107	235	438	294	118	184	309	220
Boyne River	43	145	107	n/a	n/a	n/a	n/a	n/a	98
Cooks Creek, RM boundary	16	15	33	n/a	n/a	n/a	n/a	n/a	21
Pembina River	719	1,623	1,509	1,268	1,456	623	66	1,032	1,037
Seine River	84	61	101	n/a	n/a	n/a	n/a	n/a	82
Other Streams									
Brokenhead River	251	111	173	197	192	81	346	507	232
Burntwood River	7,603	8,527	12,304	17,633	13,549	7,423	12,260	10,103	11,175
Carrot River	502	804	920	850	296	336	379	75	520
Dauphin River	1,144	3,637	5,102	n/a	n/a	n/a	n/a	n/a	3,294
Mossy River	231	777	571	279	347	378	195	930	463
Nelson River	4,474	4,663	5,707	7,144	6,191	4,642	7,129	6,624	5,822
North Duck River	27	24	22	19	24	22	12	25	22
Ochre River	28	40	30	12	24	28	51	80	37
Red Deer River	493	922	1,112	724	229	286	214	64	506
Saskatchewan River, above Carrot River	9,098	11,110	14,284	16,320	10,440	9,863	7,317	4,981	10,427
Saskatchewan River, at Grand Rapids	6,938	7,016	9,467	n/a	n/a	n/a	n/a	n/a	7,807
Swan River	325	957	538	389	176	160	194	247	373
Turtle River	20	66	64	14	33	49	43	213	63
Valley River	135	492	358	180	146	148	74	226	220
Vermillion River	67	422	46	38	45	40	39	131	103
Waterhen River	2,922	2,031	2,723	2,811	3,879	2,420	2,075	2,029	2,611
Whitemud River	74	470	449	113	280	392	277	1,292	418
Wilson River	62	200	70	30	97	n/a	n/a	n/a	92
Winnipeg River	14,021	15,613	19,663	18,731	8,491	16,259	17,639	24,118	16,817
Woody River	201	326	223	213	98	104	97	120	173

n/a = data not available

Table 3. Total measured stream TP load (t/yr) at water quality monitoring stations in Manitoba.

Stream	1994	1995	1996	1997	1998	1999	2000	2001	Mean
Assiniboine River									
At Kamsack	30	176	54	32	35	29	19	38	52
At Brandon	185	649	400	330	186	540	97	453	355
At Treesbank	219	691	427	351	247	412	118	577	380
At Portage Spillway	247	899	499	408	558	810	210	701	542
East of Portage	252	947	531	455	631	964	267	788	604
At Headingley	310	811	634	551	875	989	285	642	637
Assiniboine River Tributaries									
Qu'Appelle River	74	75	124	107	26	129	19	68	78
Little Saskatchewan	21	43	24	n/a	n/a	n/a	16	41	29
Souris River, Coulter	n/a	n/a	244	88	57	449	n/a	n/a	209
Souris River, Treesbank	64	294	470	236	165	674	72	477	307
Cypress River	2.9	10	9.0	9.1	21	2.8	1.2	18	9.3
Red River									
At Emerson	1,708	1,981	2,430	3,666	2,710	2,896	1,874	3,029	2,537
At St. Norbert	2,037	2,347	3,226	3,235	2,947	3,757	1,749	5,524	3,103
At Selkirk	2,661	4,165	4,418	8,176	4,266	5,425	2,782	7,344	4,905
Red River Tributaries									
LaSalle River	16	47	88	89	40	10	28	97	52
Roseau River	43	23	52	70	47	69	45	86	54
Rat River	8.0	13	28	57	32	11	23	23	24
Boyne River	5.8	13	7.9	n/a	n/a	n/a	n/a	n/a	9.0
Cooks Creek, RM boundary	2.1	1.8	4.6	n/a	n/a	n/a	n/a	n/a	2.8
Pembina River	107	356	221	252	228	144	9.3	130	181
Seine River	12	10	15	n/a	n/a	n/a	n/a	n/a	12
Other Streams									
Brokenhead River	15	5.6	10	14	13	4.7	16	20	12
Burntwood River	897	643	926	1,182	1,240	886	1,325	1,203	1,038
Carrot River	49	55	136	59	26	40	28	12	51
Dauphin River	19	53	78	n/a	n/a	n/a	n/a	n/a	50
Mossy River	23	100	72	32	23	26	12	57	43
Nelson River	264	249	258	260	386	278	339	373	301
North Duck River	1.4	1.4	2.3	4.9	1.9	1.7	1.1	1.5	2.0
Ochre River	2.7	6.1	2.7	1.5	1.2	1.6	5.1	6.1	3.4
Red Deer River	45	38	71	15	10	17	8.7	2.3	26
Saskatchewan River, above Carrot River	741	1,031	883	1,052	1,078	807	581	438	827
Saskatchewan River, at Grand Rapids	289	271	362	n/a	n/a	n/a	n/a	n/a	307
Swan River	70	123	45	102	32	13	13	29	53
Turtle River	1.4	6.1	6.3	1.4	2.1	4.1	3.2	22	5.8
Valley River	6.3	45	18	16	11	6.4	1.8	23	16
Vermillion River	6.5	106	6.2	15	4.1	4.0	2.8	18	20
Waterhen River	44	41	126	118	101	59	48	50	73
Whitemud River	6.1	37	33	9.2	31	33	22	70	30
Wilson River	16	26	5.9	6.6	9.0	n/a	n/a	n/a	13
Winnipeg River	618	682	848	879	428	844	883	1,121	788
Woody River	30	42	17	41	11	8.0	11	4.3	20

n/a = data not available

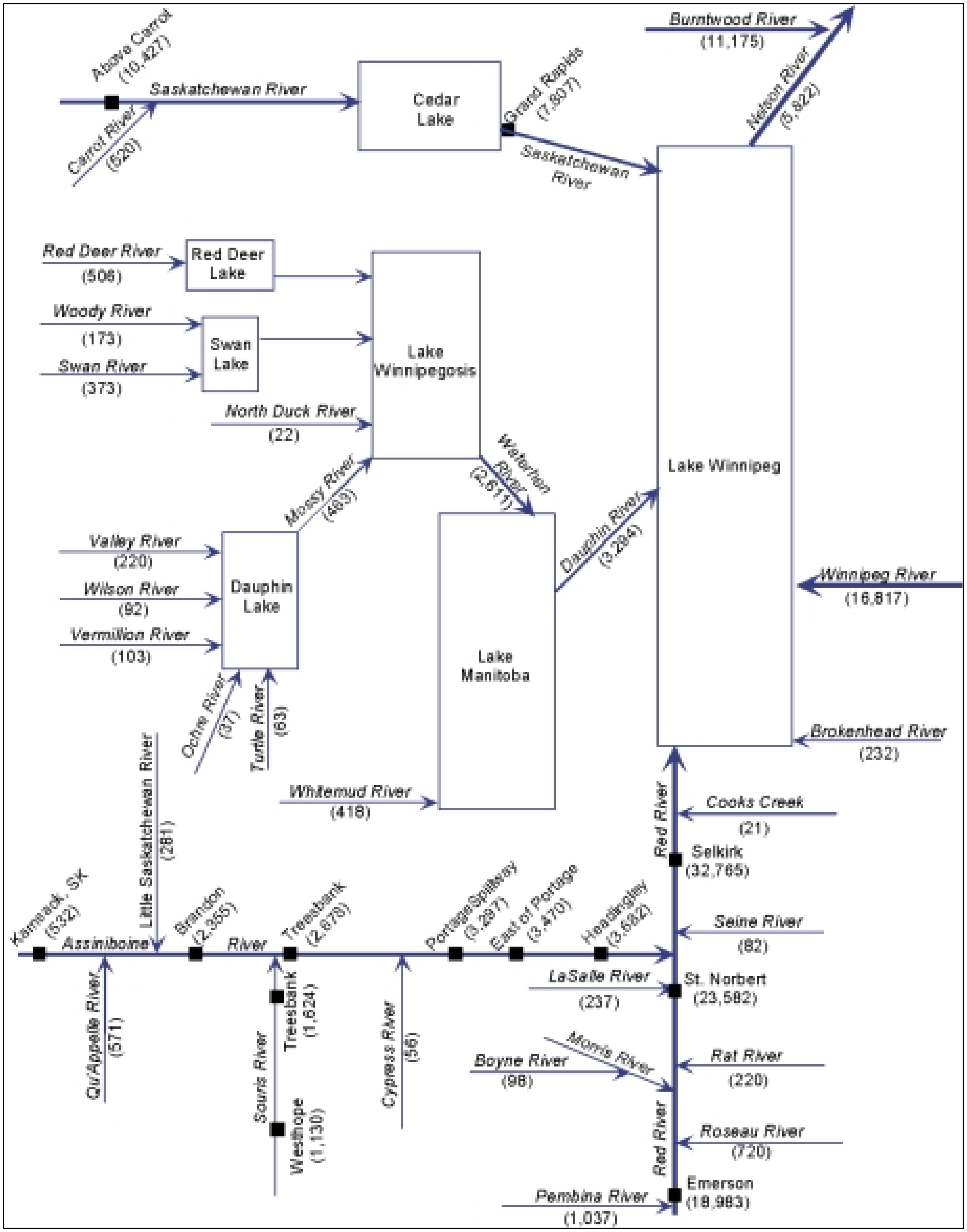

Figure 3. Schematic diagram of mean annual TN load (t/yr) in streams at long-term monitoring stations in Manitoba (1994 to 2001). Diagram not to scale.

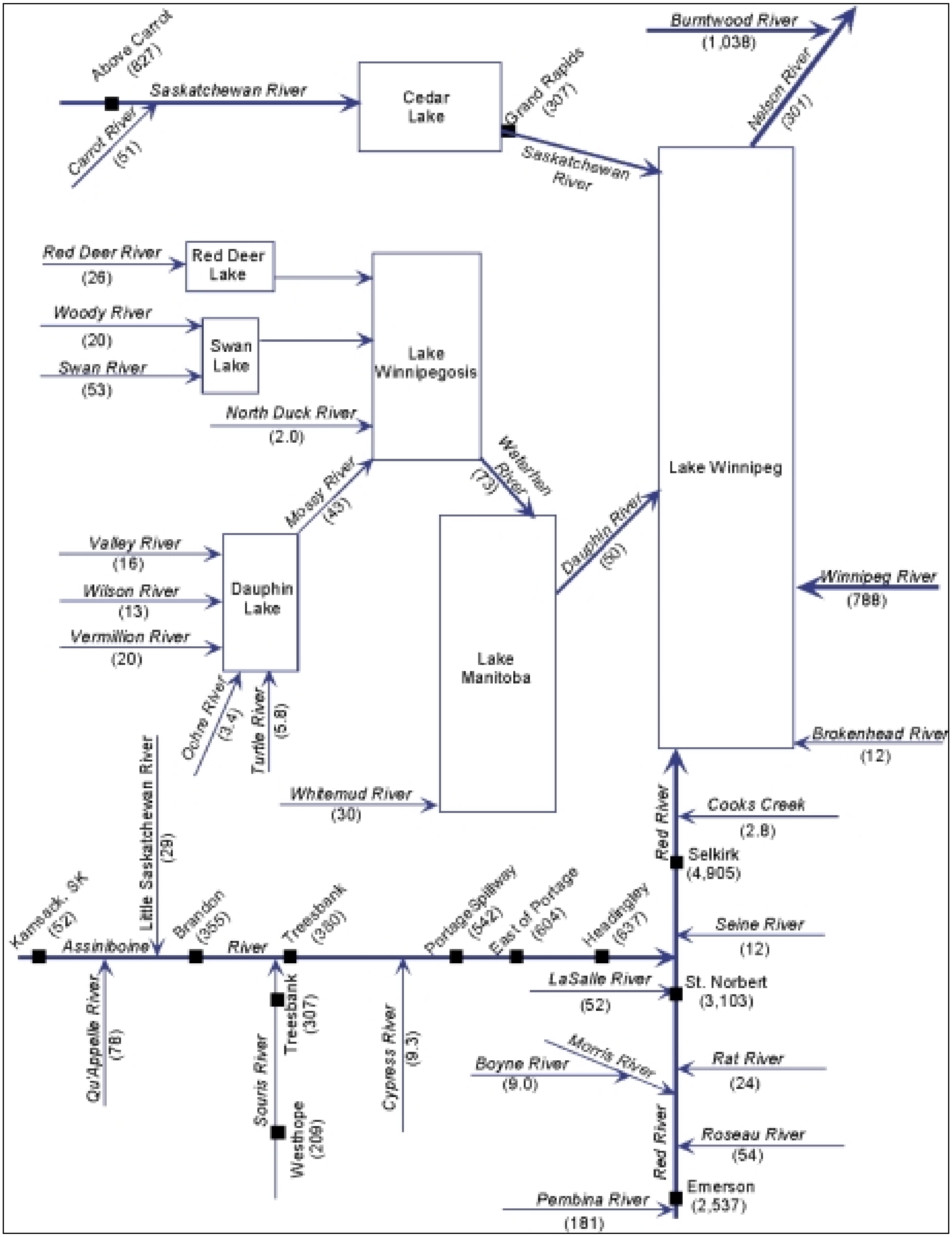

Figure 4. Schematic diagram of mean annual TP load (t/yr) in streams at long-term monitoring stations in Manitoba (1994 to 2001). Diagram not to scale.

Nutrient Loads and Accrual Rates in the Assiniboine River Watershed

The Assiniboine River rises near the community of Preeceville in eastern Saskatchewan and flows southeastward into Manitoba, and then eastward to eventually empty into the Red River at Winnipeg (Figure 5). The main tributaries of the Assiniboine River include the Qu'Appelle, Little Saskatchewan, Souris, and Cypress rivers. The Assiniboine River watershed, excluding the Qu'Appelle and Souris River watersheds, drains an area of approximately 41,500 km^2. About 60 % of the watershed is within Manitoba, while the rest is in Saskatchewan.

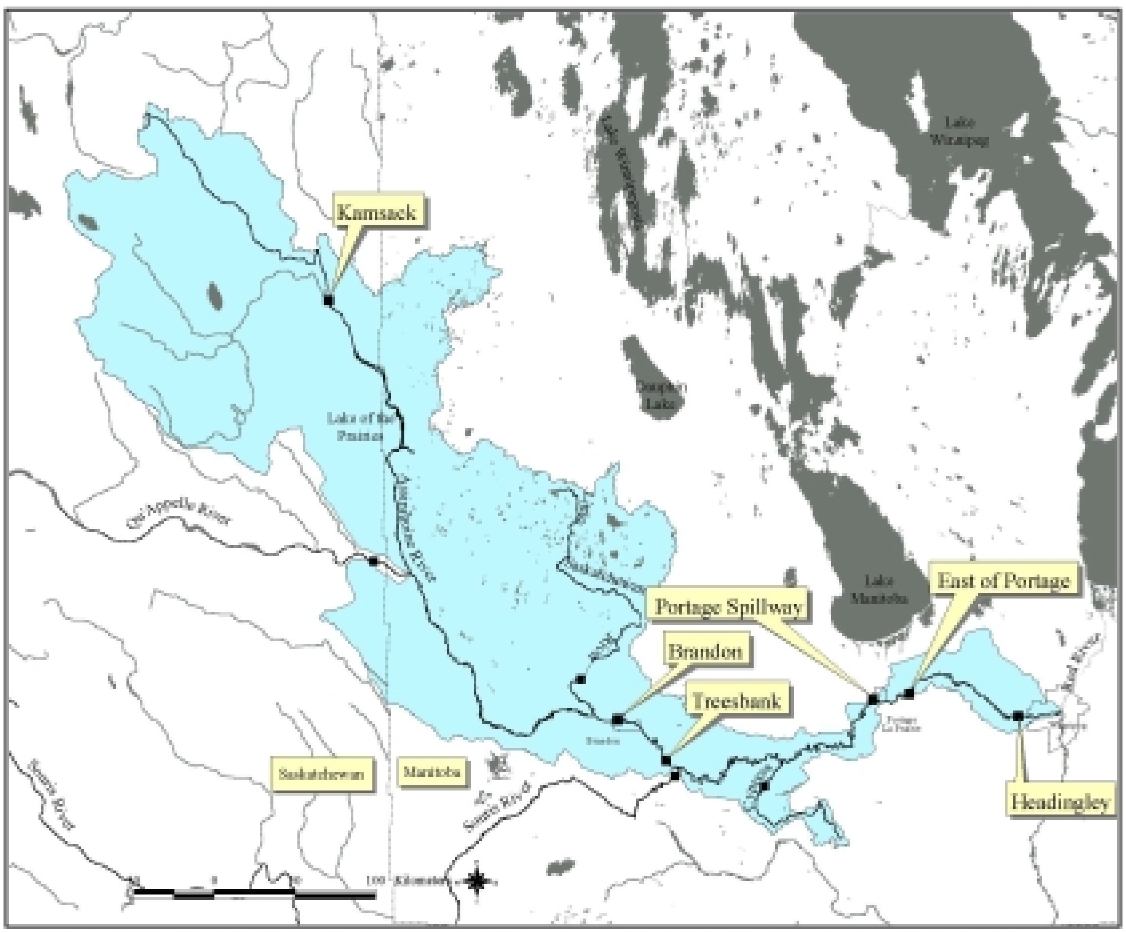

Figure 5. Map of the Assiniboine River watershed showing main tributaries and water quality monitoring stations (■).

Percent contributions from the four main tributary streams to the total in-stream TN and TP load in the Assiniboine River were quite variable both between streams and from year to year (Tables 4 and 5). The proportion of the TN load in the Assiniboine River contributed by these tributaries ranged from a low of 0.3 % from the Cypress River in 2000 to a high of 75 % from the Souris River in 1999. The proportion of the total TN contributed by the Souris River alone ranged from 19 % in 1994 to 75 % in 1999. The Cypress River also contributed the smallest proportion of TP to the total load in the Assiniboine River (0.3 % in 1999), while contributions from the Souris River accounted for 74 % of the load in 2001. In general, contributions from the Souris River made up the highest proportion of TN and TP load to the Assiniboine River in all years measured except for 1994, when the highest proportion of the load was contributed by the Qu'Appelle River. Averaged over the period from 1994 to 2001, the combined contributions from the four tributary streams accounted for 65 % of the TN load and 66 % of the TP load in the Assiniboine River.

Table 4. Percent contribution of TN to the Assiniboine River from four tributary streams.

Tributary	1994	1995	1996	1997	1998	1999	2000	2001
Qu'Appelle River	29	14	28	21	6.3	14	6.4	11
Little Saskatchewan River	11	10	6.5	n/a	n/a	n/a	7.0	8.0
Souris River, Treesbank	19	38	67	36	24	75	21	39
Cypress River	1.1	1.5	1.6	2.1	2.8	0.4	0.3	2.2

Table 5. Percent contribution of TP to the Assiniboine River from four tributary streams.

Tributary	1994	1995	1996	1997	1998	1999	2000	2001
Qu'Appelle River	24	9.3	20	19	3.0	13	6.6	11
Little Saskatchewan River	6.7	5.2	3.8	n/a	n/a	n/a	5.6	6.4
Souris River, Treesbank	21	36	74	43	19	68	25	74
Cypress River	0.9	1.2	1.4	1.7	2.4	0.3	0.4	2.8

Rates of TN and TP accrual varied dramatically both between years and between reaches on the Assiniboine River (Table 6). Annual TN and TP accrual rates varied by as much as 21.2 $mg/m^3/km/yr$, with some reaches having both positive and negative TN and TP accrual. A negative rate of nutrient accrual indicates that nutrient uptake within that particular reach exceeded input. However, years of high and low accrual in each reach were not correlated ($p > 0.06$) suggesting that parameters that are expected to vary consistently across the watershed, such as precipitation or runoff, did not have a dominant influence on nutrient accrual. Overall, TN and TP accrual on the Assiniboine River was highest in the reaches between the Brandon and Treesbank monitoring stations and between the Portage Spillway and East of Portage monitoring stations. The relative short river distances coupled with nutrient loads from the cities of Brandon and Portage la Prairie and their associated industries in these two reaches likely lead to the elevated accrual rates. Low rates of both TN and TP accrual observed in the most upstream reach of the Assiniboine River (between the stations at Kamsack and at Brandon) may be due to nutrient retention by Lake of the Prairies, along with limited agricultural and industrial development in close proximity to the river. Similarly, low rates of TN and TP accrual between Treesbank and the Portage Spillway may be in part due to nutrient retention by the Portage Reservoir, which is located immediately upstream of the spillway control structure.

Table 6. Rates of TN and TP accrual ($mg/m^3/km/yr$) on five reaches of the Assiniboine River between Kamsack and Headingley.

Reach	**TN**	**TP**
Kamsack to Brandon	-0.70	0.05
Brandon to Treesbank	4.48	0.39
Treesbank to Portage Spillway	-0.04	0.14
Portage Spillway to East of Portage	4.27	1.57
East of Portage to Headingley	0.52	0.11

Nutrient Loads and Accrual Rates in the Red River Watershed

The Red River watershed drains an area of approximately 127,000 km^2, about 20 % (25,400 km^2) of which is in Manitoba (Figure 6). The rest of the watershed is located mainly in

North Dakota and Minnesota. Major tributaries of the Red River within Manitoba include the Assiniboine, Roseau, Seine, LaSalle, Rat, Pembina, and Morris rivers. Total measured stream nutrient loads for TN and TP were calculated for each of these streams (see Tables 2 and 3) except the Morris River, which lacks a long-term water quality database. Instead, the TMSNL for TN and TP in the Boyne River, a tributary of the Morris River, were calculated and used in this report.

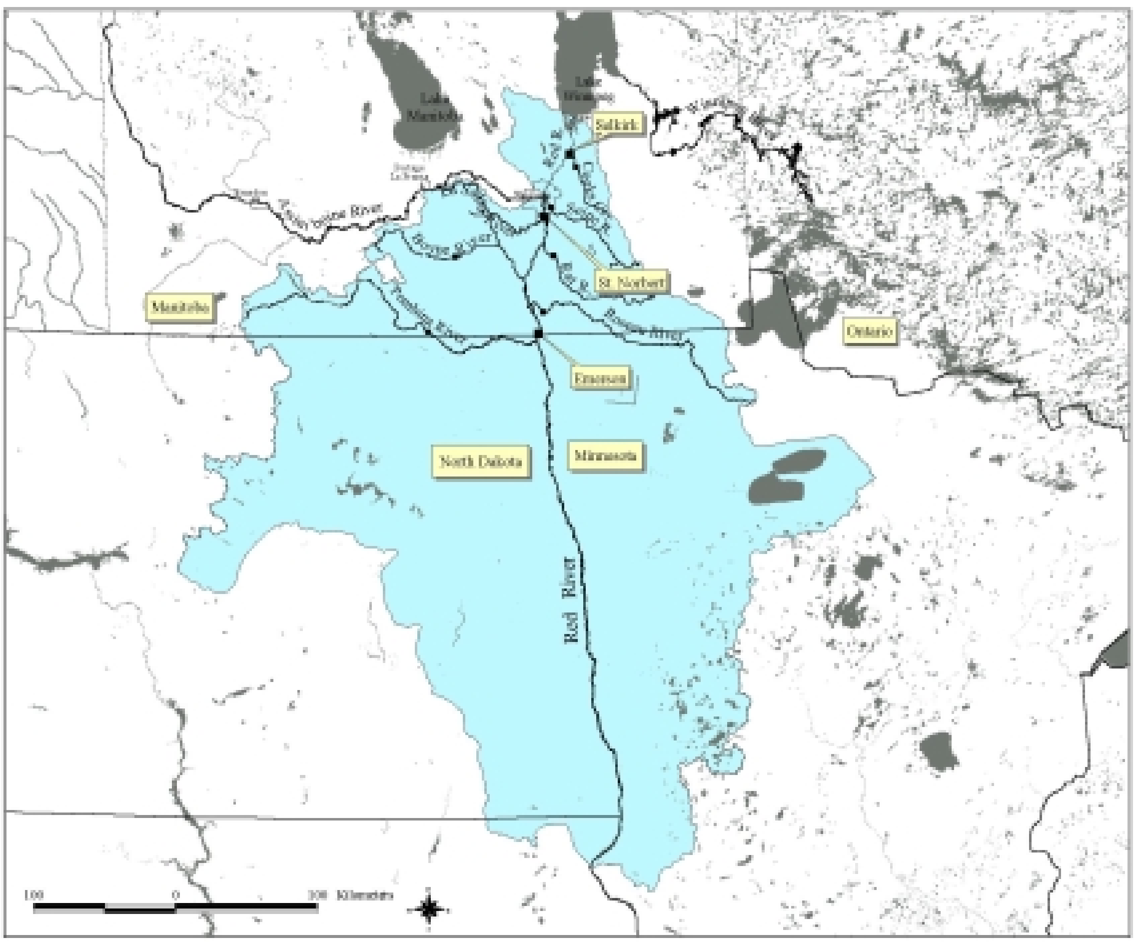

Figure 6. Map of the Red River watershed showing main tributaries (in Manitoba) and water quality monitoring stations (■).

The average percent contribution of tributary streams to the TN load in the Red River ranged between a low of 0.2 % from the La Salle, Seine, and Boyne rivers (various years) to a high of approximately 16 % from the Assiniboine River in 1999 (Table 7). Tributary contributions to the TP load in the Red River followed a similar pattern, ranging between 0.2 % (various years from several small tributary streams) to 21 % from the Assiniboine River in 1998 (Table 8). The Assiniboine River was consistently the largest single contributor to TN and TP loads in the Red River. The Assiniboine River annually contributed from 6.7 % to 21 % of the TP load and from 7.9 % to 19 % of the TN load in the Red River during 1994 to 2001. In contrast to the high inputs to the Assiniboine River from tributary streams, the mean percent contribution of all tributaries to the measured stream TN and TP load in the Red River was only about 18 % for TP and 20 % for TN. However, the absence of a TMSNL for the Morris River, and for the Seine and Boyne rivers during 1997 to 2001 and the considerably higher flow volumes in the Red River in comparison to its tributaries may account for some of the difference.

Table 7. Percent contribution of TN load to the Red River from tributary streams.

Tributaries	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
LaSalle River	0.2	0.4	1.0	1.2	0.5	0.2	0.5	1.5
Roseau River	2.2	1.1	2.6	2.3	1.6	2.9	2.3	2.7
Rat River	0.3	0.3	0.7	1.2	0.8	0.4	0.8	0.8
Boyne River	0.2	0.4	0.3	n/a	n/a	n/a	n/a	n/a
Pembina River	3.3	4.5	4.4	3.3	4.1	1.9	0.3	2.7
Seine River	0.4	0.2	0.3	n/a	n/a	n/a	n/a	n/a
Assiniboine at Headingley	7.9	12	10	9.1	10	16	10	12

Table 8. Percent contribution of TP load to the Red River from tributary streams.

Tributaries	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
LaSalle River	0.6	1.1	2.0	1.1	0.9	0.2	1.0	1.3
Roseau River	1.6	0.6	1.2	0.9	1.1	1.3	1.6	1.2
Rat River	0.3	0.3	0.6	0.7	0.7	0.2	0.8	0.3
Boyne River	0.2	0.3	0.2	n/a	n/a	n/a	n/a	n/a
Pembina River	4.0	8.6	5.0	3.1	5.4	2.7	0.3	1.8
Seine River	0.5	0.2	0.3	n/a	n/a	n/a	n/a	n/a
Assiniboine at Headingley	12	19	14	6.7	21	18	10	8.7

As with the Assiniboine River, rates of TN and TP accrual on the Red River varied dramatically between years and reaches, ranging from more than 5 $mg/m^3/km/yr$ to -1.5 $mg/m^3/km/yr$ (Table 9). While average rates of TN and TP accrual were usually higher between St. Norbert and Selkirk than between Emerson and St. Norbert, in some years the trend was reversed. Higher rates of TN and TP accrual between St. Norbert and Selkirk can be attributed to nutrient loads from the city of Winnipeg and contributions from tributaries to the Red River such as the Seine and Assiniboine rivers. Correspondingly high or low years of both TN and TP accrual did not occur for each reach suggesting, as with the Assiniboine River, that parameters expected to vary consistently across the watershed such as precipitation or runoff did not have a dominant influence on nutrient accrual rates.

Table 9. Rates of TN and TP accrual ($mg/m^3/km/yr$) along two reaches of the Red River within Manitoba.

	Emerson to St. Norbert		St. Norbert to Selkirk	
Year	**TN**	**TP**	**TN**	**TP**
1994	1.62	0.14	2.11	0.31
1995	4.07	0.04	-1.54	1.19
1996	2.40	0.17	0.54	0.16
1997	-0.92	-0.45	5.58	3.44
1998	2.54	-0.08	1.40	0.35
1999	1.76	0.38	-1.42	0.49
2000	-1.09	-0.43	1.75	0.48
2001	0.56	1.20	4.20	0.11
Mean	**1.37**	**0.12**	**1.58**	**0.82**

NUTRIENT LOADS FROM WITHIN-STREAM PROCESSES

Nutrient loading from within-stream processes in Manitoba includes direct effluent discharge, release from stream bed and bank sediments, and infiltration of ground water. Only the direct effluent discharges were quantified for this report. Effluent sources in Manitoba include discharge from industrial operations, domestic wastewater treatment facilities (WWTF –

includes wastewater treatment lagoons and wastewater treatment plants), and urban stormwater drains. These are important sources of nutrients to receiving waters because they often contain high concentrations of inorganic N and P, which can be readily taken up by algae and other aquatic plants (Chambers and Dale 1997). Most of the wastewater treatment facilities in Manitoba are not required to monitor effluent for N and P prior to discharge. This, coupled with the fact that many rural wastewater treatment lagoons are not discharged on a regular basis, and many discharge to municipal drains or to wetlands, makes quantifying the amount of N and P loading to surface water streams difficult. As well, since it is common to have wastewater from domestic and industrial sources combined, treated, and discharged from the same facility, distinguishing between industrial and domestic sources of N and P is usually not possible.

There are over 400 provincially licensed wastewater treatment facilities (WWTF) in Manitoba servicing towns, villages, Hutterite colonies, provincial parks, community centres, schools, and churches. Only those facilities that discharge to surface waters were included in the analyses for this section. Total nitrogen and TP loading from most of the facilities was estimated on the basis of population, typical per capita nutrient loading, and extent of treatment (Chambers *et al.* 2001). Federally regulated facilities that discharge to surface water (*e.g.*, First Nations, national parks) were not included in the analyses because data were insufficient to provide a reasonable estimation of loading from these sources.

The population serviced by each WWTF was obtained from community web sites, Statistics Canada (2001), and from Manitoba community profiles (Manitoba Intergovernmental Affairs 2002). Hutterite colonies were estimated at 100 people (a conservative estimate based on the assumption that most colonies subdivide at about 150 people). School populations were estimated at 50 and mobile home parks at 75. Population estimates for provincial parks were based on the number of cars visiting the park. Calculations were based on the assumption that an average of 3.5 people per car spent 4 hours in the park and one in 120 used the facilities. Hydraulic capacity of the facility (from Manitoba Conservation license application) and an estimated daily hydraulic load per person of 227 L (U.S. Environmental Protection Agency 1980) were used to estimate a population when no other data were available.

The influent TP and TN loads to WWTF were estimated at 3.38 g/capita/d for TP and 10 g/capita/d for TN (Chambers *et al.* 2001). The influent TP load was multiplied by the P removal efficiency (expressed as the percentage of P removed during treatment) to yield the effluent TP load. A P removal efficiency of 59 % was used for calculating the TP load from secondary treatment facilities and a removal efficiency of 65.5 % was used to calculate the TP load from wastewater treatment lagoons (Chambers *et al.* 2001). Effluent TN load was calculated based on a removal efficiency of 10 % regardless of facility type (Chambers *et al.* 2001).

Nitrogen and P loads in effluent discharge were available for the cities of Winnipeg (Szoke 2002) and Portage la Prairie (Manitoba Conservation 2002c). Winnipeg contributes N and P to the Red and Assiniboine rivers from three water pollution control centres (treatment plants), 76 combined sewer overflows, and 90 land drainage sewers. The North End Water Pollution Control Centre (NEWPCC), a conventional secondary treatment plant, is the largest of the three plants and accepts 70 % of the wastewater generated by the city. The South End Water Pollution Control Centre (SEWPCC) is a secondary treatment plant with an oxygen-based activated sludge treatment process that treats 20 % of the city's wastewater. Both the NEWPCC and the SEWPCC discharge into the Red River. The West End Water Pollution Control Centre (WEWPCC) uses both an extended aeration plant and a conventional facultative sewage lagoon to provide secondary treatment, prior to discharging to the Assiniboine River. Since discharges to the Assiniboine River within the city of Winnipeg occur downstream of the station at Headingley and are in close proximity to the Red River, they were considered discharges to the Red River watershed. Average TN and TP loads for the past 25 years were calculated for Winnipeg's three water pollution control centres, combined sewer overflows, land drainage sewers, and emergency sanitary overflows. The loads calculated from the pollution control centres included the TN and TP loads generated from domestic wastewater and from industrial facilities that discharge directly to the city's sewage collection system.

Wastewater from Portage la Prairie is treated at the city's Water Pollution Control Facility (WPCF) and treated effluent is discharged directly to the Assiniboine River. As was the case in Winnipeg, the TN and TP loads discharged from the WPCF in Portage la Prairie also include those from both domestic and industrial (e.g., McCain Foods Ltd.) sources. Measured nutrient loads for the cities of Winnipeg and Portage la Prairie were compared to the estimated loads to determine the approximate percent contribution from domestic and industrial sources.

Wastewater from the city of Brandon is treated and discharged to the Assiniboine River downstream (east) of the city. Unlike Winnipeg and Portage la Prairie, data for TN and TP loads in effluent from Brandon were available as separate measurements for industrial and domestic sources from 1999 to 2001 (Manitoba Conservation 2002). Estimates of nutrient loads for Brandon were also calculated based on population, typical per capita nutrient loading, and extent of treatment. These were then compared to the measured domestic loads for 1999 to 2001. However, to be consistent with estimates from other WWTF in the province, only the estimated loads from Brandon were used (rather than the measured loads) in the calculation of total within stream loads to surface waters in Manitoba and to the Assiniboine River.

Thirty-two industrial facilities are licensed to discharge to surface waters in Manitoba. However, the majority of these facilities do not monitor for effluent TN and TP, and, as mentioned previously, many industries discharge directly to municipal sewer systems and thus differentiating between industrial and non-industrial sources is difficult. Therefore, nutrient loads from industrial facilities were only determined for facilities that collect effluent nutrient data (Manitoba Conservation 2002c, Tembec 2002). These loads were summed to provide an estimate of total TN and TP loads to surface waters from industrial facilities within the province.

Total nitrogen and TP loads from WWTF, industrial facilities, combined sewer overflows, and land drainage sewers were summed to provide total loads of TN and TP to surface waters from within stream processes in Manitoba. Nutrient loads from facilities that discharge to the Assiniboine and Red rivers and their tributaries were also summed to provide an estimate of the within-stream TN and TP loads in their respective watershed. All discharges within the city of Winnipeg were included in total nutrient load to the Red River. Facilities that discharge to the Souris River and its tributaries were not included in the Assiniboine River watershed estimates because the Souris River watershed is generally considered a separate drainage basin.

Total nitrogen and TP loads to surface waters in Manitoba from all WWTF, estimated industrial facilities, and outflows were 5,170 and 667 t/yr, respectively (Table 10). Nutrient loads from municipal and industrial facilities in southern Manitoba's three largest cities (with a total of about 59 % of the provincial population) accounted for 76 % of the TN load and 68 % of the TP load to Manitoba surface waters. Nutrient loads from Winnipeg, Brandon, and Portage la Prairie account for more of the total load to surface waters than might be expected based on population. However, the inclusion of industrial loads likely accounts for the difference. In addition, industrial nutrient loads (Table 11) are likely considerably underestimated in other areas of Manitoba because of a lack of data. The discharge routes and estimated nutrient loads for wastewater treatment facilities in some of Manitoba's larger communities are represented schematically in Figures 7 and 8.

Table 10. Average annual nutrient loads (t/yr) from direct effluent discharge to surface waters in Manitoba.

Source	TN (t/yr)	TP (t/yr)
Winnipeg (includes industry)		
NEWPCC	2,569	232
SEWPCC	516	82
WEWPCC	226	40
Land drainage sewers	201	20
Combined overflow sewers	79	16
Winnipeg Total	**3,591**	**390**
Brandon (estimated)	129	17
Portage la Prairie (includes industry)	88	32
Other WWTF (estimated)	1,180	161
Other industrial facilities	181	67
Provincial Total	**5,170**	**667**

Table 11. Total nitrogen (t/yr) and TP (t/yr) loading rates for industries that monitor discharge.

Facility	Type of Facility	TN (t/yr)	TP (t/yr)	Receiving Water
Simplot Canada, Brandon	Manufacturing	8.8	0.4	Assiniboine River
Maple Leaf Meats, Brandon	Meat processing	113.9	14.2	Assiniboine River
Springhill Farms, Neepawa	Meat processing	4.2	n/a	Whitemud River
Tembec, Pine Falls	Pulp and Paper	53.9	52.0	Winnipeg River
	Total	**180.8**	**66.6**	

n/a = data not available

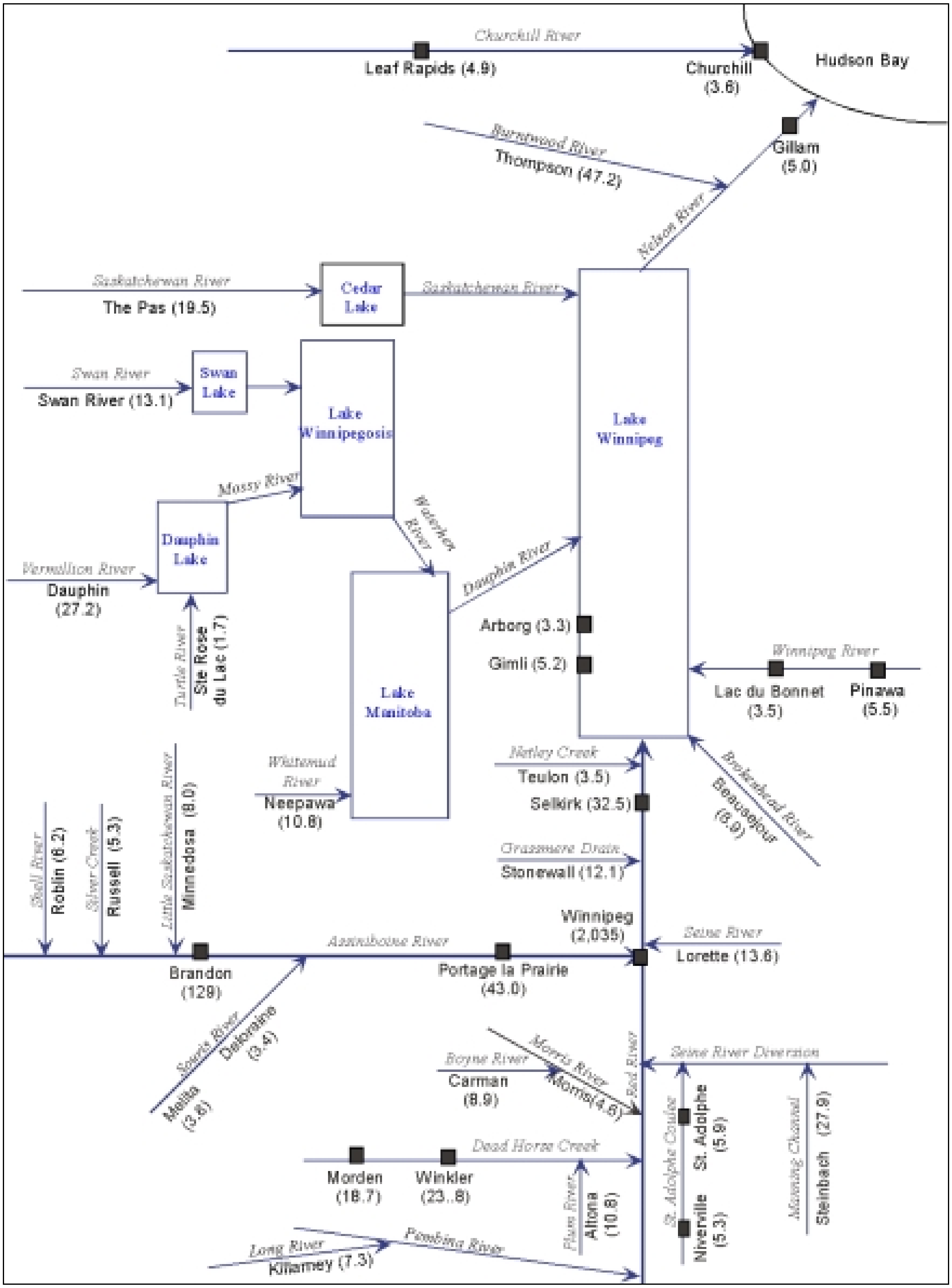

Figure 7. Schematic diagram showing TN (t/yr) discharged from WWTF in Manitoba.

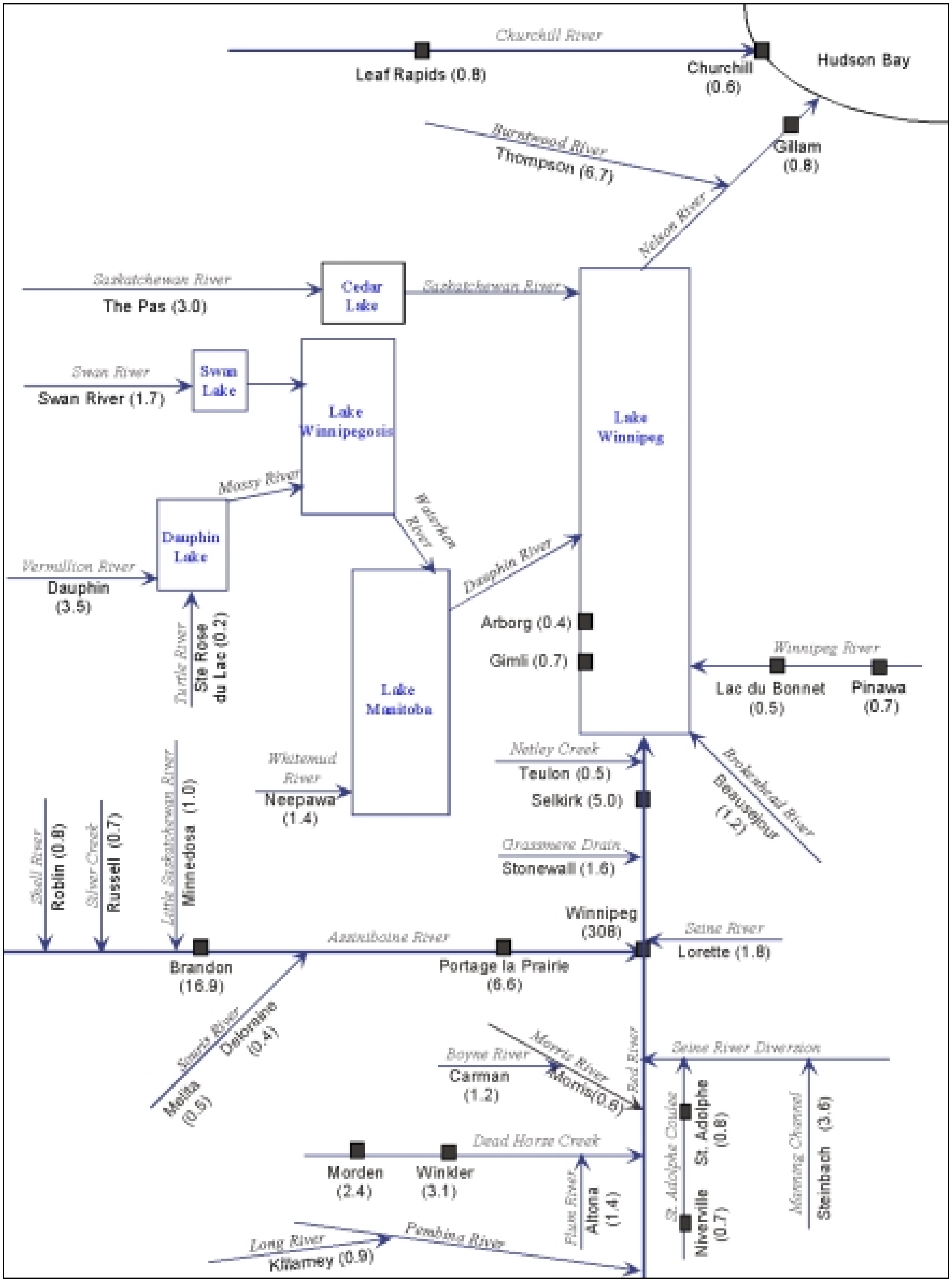

Figure 8. Schematic diagram showing TP (t/yr) discharged from WWTF in Manitoba.

Nutrient loads from Winnipeg and Portage la Prairie differed dramatically in their relative contributions from industrial and domestic wastewater sources (Table 12). Loads from domestic sources in Winnipeg were estimated to be approximately 61 % and 87 % of the total measured discharge load for TN and TP, respectively. In contrast, in Portage la Prairie, domestic contributions were only about 49 % of the total TN load and about 20 % of the total TP load. Industrial TN and TP loads dominated in Portage la Prairie because the population is small relative to the amount of industrial activity, whereas in Winnipeg, loads from the larger population were relatively more significant and greatly exceeded any inputs from industrial activity.

Table 12. Comparison of estimated domestic contributions to total measured TN and TP loads from the cities of Winnipeg and Portage la Prairie.

Contributing Source	**TN (t/yr)**	**% of Total**	**TP (t/yr)**	**% of Total**
Winnipeg				
Estimated domestic contribution	2,035	61	308	87
Total measured domestic and industrial contribution	3,311		354	
Portage la Prairie				
Estimated domestic contribution	43	49	6.6	20
Total measured domestic and industrial contribution	88		32	

Estimates of TN and TP loads for Brandon (based on population, extent of treatment, and per capita nutrient loading) were comparable to the loads measured during 1999 to 2001 (Table 13). Average measured load for 1999 to 2001 ranged from 91 to 198 t/yr for TN and between 14 and 32 t/yr for TP. Estimated TN and TP loads fell within this range at 130 and 17 t/yr, respectively.

Table 13. Measured and estimated non-industrial TN and TP loads (t/yr) discharged to the Assiniboine River from Brandon.

	TN (t/yr)	TP (t/yr)
Measured Loads (years)		
1999	198	22
2000	91	14
2001	137	32
Average	142	23
Estimated Annual Loads	129	17

Calculating the TN and TP loads for WWTF based on population, typical per capita nutrient loading, and the extent of treatment provided credible estimates. However, the inorganic forms of N and P that are responsible for increased aquatic plant growth are proportionately more abundant in municipal effluents than in natural waters. Therefore, calculations based on TN and TP load likely underestimate the contribution of WWTF to the bio-available nutrient load in surface waters (Chambers and Dale 1997).

Direct Effluent Discharge to the Assiniboine River Watershed

Fifty-two WWTF discharge to the Assiniboine River and its tributaries. Five major industrial facilities are licensed to discharge to the Assiniboine River, but measurements of TN and TP loads were only available from two of the facilities--Simplot Canada Ltd. and Maple Leaf Meats in Brandon. Nutrient loads from McCain Foods Ltd. were included with non-industrial contributions from Portage la Prairie. The WWTF contributing the greatest amount of TN and TP to the Assiniboine River was the facility in Brandon, followed secondly by the facility in Portage la Prairie (Table 14). Together these two facilities contributed roughly half of the total WWTF TN load and about 65 % of the total WWTF TP load within the Assiniboine River watershed.

Table 14. Average annual nutrient loads (t/yr) from direct effluent discharge to the Assiniboine River and tributaries.

Source	TN (t/yr)	TP (t/yr)
Brandon (estimated)	129	17
Portage (includes industry)	88	32
Other WWTF (estimated)	84	11
Other industrial facilities	123	15
Assiniboine River Watershed Total	**423**	**75**

Direct Effluent Discharge to the Red River Watershed

Eighty-six WWTF, including three large pollution control facilities in Winnipeg, discharge effluent to the Red River or its tributaries (this includes the WEWPCC which actually discharges to the Assiniboine River a short distance upstream of its confluence with the Red River). In addition, 76 combined sewer overflows, 90 land drainage sewers, and seven emergency sanitary overflows also discharge directly to the Red River in Winnipeg (this includes 31 combined sewer overflows and 50 land drainage sewers that actually discharge to the Assiniboine River along its course through the city of Winnipeg to its confluence with the Red River). The largest contributions of TN and TP from WWTF to the Red River were from the south and north end water pollution control centres (SEWPCC and NEWPCC, respectively) in Winnipeg (Table 15). Total contributions from the city of Winnipeg accounted for 85 % of the TN load and 82 % of the TP load in direct effluent discharges to the Red River watershed.

NUTRIENT LOADING FROM WATERSHED PROCESSES

Nutrient loading from watershed processes occurs through transport of nutrients from land to water. Watershed nutrient loads are more difficult to quantify than direct effluent discharges because they are often more diffuse, highly variable, and intermittent. The load of nutrients exported from land to surface water depends on soil type, vegetation cover, and precipitation. The type of land use practices or activities also heavily influences the movement of nutrients from land to surface waters. Rates of nutrient export can be lowered by the presence of riparian vegetation along stream channels and lake shores, while the development of drainage channels can have the opposite effect and result in increased nutrient export to surface waters. The amount of nutrient loading to land from atmospheric deposition and agricultural fertilizer and manure applications can also strongly influence the amount of nutrients that are available for export to surface waters.

Table 15. Average annual nutrient loads from direct effluent discharge to the Red River and its tributaries.

Source	**TN (t/yr)**	**TP (t/yr)**
Winnipeg (includes industry)		
WEWPCC	226	40
SEWPCC	516	82
NEWPCC	2,569	232
Land drainage sewers	201	20
Combined sewer overflows	79	16
Winnipeg Total	**3,591**	**390**
Other WWTF	642	88
Red River Watershed Total	**4,233**	**478**
Red River Upstream of Selkirk	4,176	470

Nutrient loads from watershed processes for specific land uses can be calculated from nutrient export coefficients. Nutrient export coefficients represent the quantity of nutrients generated per unit area per unit time (kg/ha/yr). The use of export coefficients is based on the assumption that a given land use activity (*e.g.*, cropland, pasture, or forest) will yield a specific quantity of nutrients (expressed on an aerial basis) to a downstream waterbody (McFarland and Hauck 2001). Total nitrogen and TP export coefficients are available for many different types of

North American land use practices (reviewed by Chambers and Dale 1997). Unfortunately, only one study in the literature is specific to Manitoba (South Tobacco Creek), and only cropland TN and TP export are quantified (Green and Turner 2002). Therefore, TN and TP export coefficients from South Dakota, North Dakota, Minnesota, and Wisconsin (those areas with the closest geology, hydrology, and land use to Manitoba) were calculated from the Chambers and Dale (1997) database to create Manitoba specific coefficients for pasture land and forests, while data from Green and Turner (2002) were used for cropland export. The maximum, minimum, and mean of available TN and TP export coefficients were calculated for these three land use categories (Table 16). A fourth land use category was derived to include the remaining land use types in Manitoba (*i.e.*, surface water, wetlands, urban areas, and barren land). It was anticipated that nutrient export from this latter category would approximately equal atmospheric loading from precipitation and dry fallout (as in Chambers and Dale 1997). Therefore, only the mean rate of export equal to atmospheric deposition and dry fallout was determined for this category.

Table 16. Mean and range of TN and TP export coefficients (kg/ha/yr,) for specific land uses.

Land Use Category	**TN (kg/ha/yr)**	**Range**	**TP (kg/ha/yr)**	**Range**
Pasture	1.75	0.17 - 4.28	0.22	0.02 - 0.51
Cropland	3.15	0.30 - 6.70	0.65	0.03 - 1.10
Forest	1.68	0.23 - 3.93	0.12	0.01 - 0.38
Other - waterbodies, wetlands, urban areas, and barren land	4.0		0.20	

Manitoba land use data were obtained from Manitoba Agriculture and Food (2000) and Manitoba Conservation (2002b). The various land use types in Manitoba were matched with the appropriate land use category provided in Table 16 (*i.e.*, pastureland, cropland, forest, or other) to calculate nutrient exports for the province. Summer fallow and "other farmland" were grouped with pasture land; the agricultural land use with the lowest rate of export. The total area of each land use type (ha) was multiplied by the mean, minimum, and maximum TN and TP export coefficients (kg/ha/yr) to yield an estimated range of TN and TP loads (kg/yr). Total nitrogen and TP loads from each land use category were summed to provide an estimate of the TN and TP load from watershed processes to surface water in Manitoba.

More detailed land use data were used to calculate nutrient export in the Assiniboine River and Red River watersheds. Land use data were obtained from the Manitoba Remote Sensing Centre (1994) and consisted of 12 specific classes. The classes were merged into the four main land use categories presented in Table 16. The land use data were incorporated into a GIS program (*ArcView 3.2*) and the total area of land in each or the four categories was then calculated for both watersheds. The watersheds were based on drainage areas defined by Fedoruk (1970) that are available in digital format from www.geogratis.cgdi.gc.ca (Natural Resources Canada 1999). The total area of each land use type (ha) was multiplied by the maximum, minimum, and mean TN and TP export coefficients (kg/ha/yr) to provide an estimated range of TN and TP loads (t/yr) to each watershed. Total nitrogen and TP loads from each type of land use were summed to provide an estimate of the TN and TP load from watershed processes to both the Assiniboine and Red River watersheds (t/yr).

The mean nutrient load from watershed processes in Manitoba was estimated at approximately 188,170 t/yr of TN and 13,071 t/yr of TP (Table 17). Of the total nutrient load from watershed processes, loading from the land use category that included surface water, wetlands, urban areas, and barren land accounted for about 50 % of the TN and TP load to surface waters from watershed processes. While this wide category of land use does account for about 50 % of the land area in Manitoba, the nutrient load is likely overestimated since export coefficients were set to equal atmospheric deposition with no allowance for nutrient uptake. Quantifying nutrient uptake and/or release from wetlands and urban areas is beyond the scope of this report. Refined estimates of nutrient loads from land to surface water in Manitoba will depend on further research to estimate nutrient export coefficients.

Estimated nutrient export from the Assiniboine River and Red River watersheds within Manitoba were remarkable similar. An estimated 6,695 tonnes of TN and 1,039 tonnes of TP were exported from land to surface water in the Manitoba portion of the Assiniboine River watershed (Table 18). Similarly, an average of 7,229 tonnes of TN and 1,209 tonnes of TP were exported from land to surface water in the Red River watershed in Manitoba (Table 19). While the study areas of the two watersheds were similar (approximately 2.5 million ha each), land use differed slightly, with the Assiniboine River watershed having slightly more pasture and forested land, and the Red River watershed having relatively more cropland. However, total land area dedicated to roads, rail lines, urban communities, wetlands, and surface water were similar in the two watersheds. The use of average nutrient export coefficients results in watershed loading estimates based heavily on specific land use areas. Comparisons with actual measured nutrient loads and those from within stream processes are required to test the accuracy of averaged nutrient export coefficients.

Table 17. Total nitrogen (t/yr) and TP loading (t/yr) in Manitoba based on land use export coefficients.

Land Use Category	**Area**	**TN (t/yr)**			**TP (t/yr)**		
	(1000 ha)	Mean	Min	Max	Mean	Min	Max
Pasture	3,033	5,308	516	12,981	667	61	1,547
Cropland	4,699	14,802	1,410	31,483	3,054	1,410	5,169
Forest	26,300	44,184	6,049	103,359	3,156	263	9,994
Other	30,969	123,876			6,194		
Total	**65,001**	**188,170**	**131,850**	**271,700**	**13,071**	**7,927**	**22,904**

Table 18. Total nitrogen (t/yr) and TP loading (t/yr) from watershed processes in the Assiniboine River watershed in Manitoba.

Land Use Category	**Area**	**TN (t/yr)**			**TP (t/yr)**		
	(1000 ha)	Mean	Min	Max	Mean	Min	Max
Pasture	558	976	95	2,386	123	11	284
Cropland	1,244	3,918	373	8,333	808	373	1,368
Forest	490	822	113	1,924	59	5	186
Other	245	979			49		
Total	**2,536**	**6,695**	**1,560**	**13,622**	**1,039**	**438**	**1,887**

Table 19. Total nitrogen (t/yr) and TP (t/yr) loading from watershed processes in the Red River watershed in Manitoba.

Land Use Category	Area	TN (t/yr)			TP (t/yr)		
	(1000 ha)	Mean	Min	Max	Mean	Min	Max
Pasture	369	645	63	1,578	81	7	188
Cropland	1,596	5,027	479	10,693	1,037	479	1,756
Forest	356	598	82	1,399	43	4	135
Other	240	959			48		
Total	**2,560**	**7,229**	**1,582**	**14,628**	**1,209**	**538**	**2,127**

COMPARISON BETWEEN NUTRIENT LOADING FROM WATERSHED AND WITHIN-STREAM PROCESSES

In a closed and balanced system, the sum of within-stream and watershed processes should approximately equal the TMSNL such that:

$$\boxed{\text{Total Measured Stream Nutrient Load}} = \boxed{\text{Within-stream Processes}} + \boxed{\text{Watershed Processes}}$$

However, ecosystems are very complex and not all nutrients can be accounted for, particularly when assessments are done at large scales such as for an entire watershed. Nutrient loads from within-stream and watershed processes were summed for all of Manitoba and their relative contributions to nutrient loads examined. Total nitrogen and TP loads from within-stream and watershed processes within the Assiniboine and Red River watersheds were compared to the TMSNL loads at the most downstream station on the Assiniboine and Red river, respectively. Total measured stream TN and TP loads for the portion of the Assiniboine River in Manitoba were calculated as the TMSNL for the Assiniboine River at Headingley minus the TMSNL for the river at Kamsack, the Qu'Appelle River at Welby, and the Souris River at Treesbank (see Figure 5 for station locations). Total measured stream TN and TP loads for the portion of the

Red River in Manitoba were calculated as the TMSNL in the Red River at Selkirk minus the TMSNL in the Red River at Emerson and the TMSNL in the Assiniboine River at Headingley (see Figure 6 for station locations). Total nitrogen and TP loads from within-stream processes were subtracted from the TMSNL as derived above to provide a second estimate of loading from watershed process in the Assiniboine and Red River watersheds that is not dependent on general export coefficients.

When mean TN and TP loads from watershed processes in Manitoba were compared to those from within-stream processes, it was clear that the majority of the TN (97 %) and TP (95 %) in surface waters in Manitoba originated from watershed processes (Table 20). However, TN and TP loads from within-stream process were likely underestimated due to non-measured loads from industrial facilities. The underestimation due to a lack of industrial data may have been balanced since loads from WWTF were likely overestimated - it was assumed that all nutrients released to municipal drains and small creeks were eventually received by a major downstream waterbody. Despite potential errors associated with calculations of TN and TP loads from within-stream processes, loads from watershed processes clearly dominated nutrient loading to Manitoba surface waters.

Table 20. Summary of mean nutrient loading (t/yr.) in Manitoba. Ranges are in parentheses.

	Within-stream Processes	Watershed Processes
TN (t/yr)	5,170	188,170 (131,850 - 271,700)
TP (t/yr)	667	13,071 (7,927 - 22,904)

Estimates of TN and TP loads from watershed processes in the Assiniboine River watershed were about 16 and 14 times higher, respectively, than those calculated for within-stream processes (Table 21). However, TN and TP loads from watershed processes that were calculated as the difference between the TMSNL and the load from within-stream processes, were much lower than even the minimum loads that were calculated with export coefficients. Nutrient export from the Assiniboine River watershed was considerably lower than the values found in Chambers and Dale (1997). However, nutrient retention by Lake of the Prairies and the reservoir at Portage la Prairie were not subtracted from the watershed process nutrient loads. Total measured stream nutrient load on the Assiniboine River at Headingley may have been reduced due to nutrient retention in these upstream reservoirs. Total measured stream loads of TN and TP may have also been reduced through uptake by periphyton, which can be substantial in the Assiniboine River (Cooley *et al.* 2001). As such, while general nutrient export coefficients may provide an adequate estimate of the potential amount of nutrients entering the Assiniboine River, nutrient retention and uptake may reduce the actual nutrient load carried in the river.

Table 21. Summary of nutrient loading (t/yr) in the Assiniboine River watershed in Manitoba.

	Load from within-stream processes*	**Mean load from watershed processes (range)**	**TMSNL**	**TMSNL minus load from within-stream processes**
TN (t/yr)	423	6,695 (1,560-13,622)	953	531
TP (t/yr)	75	1,039 (438-1,887)	209	135

* Within-stream processes minus WEPCC contributions and loads to Sturgeon Creek since inputs occurred downstream of the Headingley sampling station.
**TMSNL is based on the 1994 to 2001 period for the Assiniboine River at Headingley minus Assiniboine River at Kamsack, SK, Qu'Appelle River at Welby, and Souris River at Treesbank.

Estimates of TN and TP loads from watershed processes within the Red River watershed were similar to those derived by calculating the difference between TMSNL and the load from within-stream processes (Table 22). Nutrient export from the Red River watershed was comparable to average rates found in the literature for South Dakota, North Dakota, Minnesota, and Wisconsin (Chambers and Dale 1997).

Table 22. Summary of nutrient loading (t/yr) in the Red River watershed in Manitoba.

	Load from within-stream processes*	Mean load from watershed processes (range)	TMSNL	TMSNL minus load from within-stream processes
TN (t/yr)	4,176	7,229 (1,582-14,628)	10,100	5,924
TP (t/yr)	470	1,209 (538-2,127)	1,731	1,260

*TMSNL is based on the 1994 to 2001 period from the Red River at Selkirk minus Red River at Emerson and the Assiniboine River at Headingley.

NUTRIENT LOADING TO LAKE WINNIPEG

Average percent contribution of TN and TP loads to Lake Winnipeg were calculated for the Red (at Selkirk), Saskatchewan (at Grand Rapids), and Winnipeg (at Point du Bois) rivers with the TMSNLs. Together the Red, Saskatchewan, and Winnipeg rivers contribute most of the flow to Lake Winnipeg (Brunskill *et al.* 1980). Remaining tributaries such as the Poplar, Berens, Bloodvein, and Dauphin rivers were not included in the analyses as either flow or nutrient data were not available for the period 1994 to 2001. However, given that many of these rivers drain undeveloped Precambrian Shield watersheds and their discharge is relatively small compared to the total volume of water entering the lake, it was assumed that their combined contribution to the TN and TP load to the lake was minor. To remove the influence of the Assiniboine River watershed, which has been considered separately for these analyses, TMSNL for the Assiniboine River at Headingley, was subtracted from TMSNL for the Red River at Selkirk. Data for the Saskatchewan River at Grand Rapids were only available for 1994 to 1996. Percent contribution of TN and TP load from atmospheric deposition was also estimated with surface area (23,750 km^2) and atmospheric deposition (20 kg TP/km^2/yr and 400 kg TN/km^2/yr) from Chambers and Dale (1997).

Contributions from Manitoba and the United States to the Red River watershed were identified and the Manitoba portion was further subdivided into contributions from within-stream process and contributions from watershed process. Total measured stream nutrient load in the Red River at Emerson was used to estimate the contributions from the United States to Lake Winnipeg. Nutrient loads to the Assiniboine River within Winnipeg (WEPCC and sewers) were also included as contributions to within-stream processes in the Red River as they were input downstream of the Headingley station and were not accounted for in the Assiniboine River loading estimates.

The Red River was the single largest contributor of TN and TP to Lake Winnipeg during the period of record (1994 to 2001). The Winnipeg River was the second largest contributor, followed by atmospheric deposition, and finally, the Saskatchewan River (Table 23). Since the United States contributed more than half of the nutrient load in the Red River, it follows that approximately 30 % of the TN, and 43 % of TP load to Lake Winnipeg originated in the United States (Table 24). Sixty-three percent of the TN and 72 % of the TP loads contributed from the Manitoba portion of the Red River watershed to Lake Winnipeg were derived from watershed processes (Table 25). Therefore, the contribution of within-stream processes in the Red River watershed to nutrient loads in Lake Winnipeg were 6.6 and 8.1 % of the TN and TP loads, respectively. More specifically, the city of Winnipeg, with associated WPCC and sewers, contributed approximately 5.7 % of the TN and 6.7 % of the TP loads to Lake Winnipeg over the period of record (1994 to 2001).

Table 23. Contributions to the nutrient load in Lake Winnipeg from the three main tributaries and atmospheric deposition (1994 to 2001).

Source	**Mean TN (t/yr)**	**Contribution %**	**Mean TP (t/yr)**	**Contribution %**
Red River	29,083	46	4,268	73
Saskatchewan River	7,807	12	307	5
Winnipeg River	16,817	27	788	13
Atmospheric Deposition	9,500	15	475	8
Total Lake Winnipeg Load	**63,207**		**5,838**	

Table 24. Comparison of nutrient loads (t/yr) to Lake Winnipeg from the portion of the Red River watershed in the United States and in Manitoba.

Source	**Mean TN (t/yr)**	**Contribution %**	**Mean TP (t/yr)**	**Contribution %**
United States	18,983	30	2,537	43
Manitoba	10,100	16	1,731	30
Total Lake Winnipeg Load	**63,207**		**5,838**	

Table 25. Subdivision of nutrient loads to Lake Winnipeg from Manitoba's portion of the Red River watershed.

Source	**Mean TN (t/yr)**	**Contribution %**	**Mean TP (t/yr)**	**Contribution %**
Within-Stream Processes	4,176	6.6	470	8.1
City of Winnipeg (includes WPCCs, combined sewer overflow and land drainage sewers)	3,591	5.7	390	6.7
Watershed Processes*	5,924	9.4	1,260	22
Contribution from the Manitoba portion of the Red River basin	10,100		1,731	
Total Lake Winnipeg Load	**63,207**		**5,838**	

* As estimated by the difference between TMSNL and within-stream processes.

CHANGES IN TOTAL MEASURED NUTRIENT LOADING TO MANITOBA STREAMS DURING THE LAST THREE DECADES

Trend analysis of TN and TP data from 45 long-term water quality monitoring stations indicated that the majority of streams in the Assiniboine River and Red River watersheds had increasing concentrations of both TN and TP between about 1970 and 1999 (Jones and Armstrong 2001). These trend analysis results were used to calculate the change in TMSNL for the period 1970 to 1999 at all stations where a significant increase or decrease in TN and TP was observed. Final and initial concentrations of TN and TP were extracted from the first and last point on the trend analysis regression line and multiplied by average annual flow (m^3/yr) for the reporting period such that,

Change in TMSNL = (final concentration – initial concentration) x average annual flow

Nineteen water quality sampling stations recorded an increase in TN load, while 17 stations recorded an increase in TP load (Table 26). Increases in TN load over the period of record ranged from 1.1 tonnes (Cypress River from 1978 to 1999) to 7,955 tonnes (Red River at Selkirk from 1978 to 1999). Increases in the TP load at the stations ranged from 0.3 tonnes to 567 tonnes (Cypress River and Red River at Selkirk, respectively). While the largest increase in TN and TP load was recorded in the Red River at Selkirk, the TN and/or TP loads were also estimated to have increased substantially at upstream stations on the Red River, and on tributary streams such the Assiniboine, Roseau, Seine, Marsh, Pembina, and La Salle rivers. Large increases in TMSNL were also estimated for stations on the Souris, Waterhen, and Winnipeg rivers. Rivers with high annual flows tended to show the largest potential increase in TMSNL. However, rivers with relatively low flows but large increases in median TN or TP concentration, such as the La Salle River, were estimated as having moderate increases in TMSNL. In rivers with more than one sampling station such as the Assiniboine, Red and Souris rivers, estimated increases in TMSNLs were largest at the most downstream stations. In general, both annual average discharge and the increase in TN or TP concentration over the period of analysis were highest at the most downstream station.

Table 26. Total change in TN and TP load (t) at several water quality monitoring stations in Manitoba over the reporting period.

Location	TN (t)	Reporting period	TP (t)	Reporting period
Assiniboine River				
At Kamsack	N/A	N/A	No change	1974-1999
At Brandon	+ 135	1974-1999	No change	1970-1999
At Treesbank	No change	1973-1999	No change	1970-1999
At Portage Spillway	+ 362	1973-1999	+ 85	1971-1999
East of Portage	+ 683	1973-1999	+ 99	1971-1999
At Headingley	+ 863	1973-1999	+ 133	1970-1999
Tributaries of the Assiniboine River				
Qu'Appelle River	N/A	N/A	- 27	1975-1999
Little Saskatchewan	- 63	1973-1996	+ 5	1973-1996
Souris River, Coulter	N/A	N/A	No change	1973-1999
Souris River, Treesbank	+ 337	1973-1999	+ 39	1970-1999
Cypress River	+1.1	1978-1999	+ 0.3	1978-1999
Red River				
At Emerson	N/A	N/A	+ 204	1978-1999
At St. Norbert	+ 2,231	1978-1999	No change	1978-1999
At Selkirk	+ 7,955	1978-1999	+ 567	1978-1999
Tributaries of the Red River				
LaSalle River	+ 118	1974-1999	+ 29	1974-1999
Roseau River	+ 149	1973-1999	+ 11	1973-1999
Rat River	No change	1973-1999	N/A	1973-1999
Boyne River	No change	1973-1996	+ 0.7	1973-1996
Cooks Creek, RM boundary	No change	1990-1999	No change	1990-1999
Marsh River	+ 73	1978-1999	+ 12.2	1978-1999
Pembina River	N/A	N/A	+ 21.1	1974-1999
Seine River	+ 22	1973-1999	+ 6	1973-1999
Other Manitoba Rivers				
Brokenhead River	No change	1973-1999	No change	1973-1996
Burntwood River	- 2,653	1975-1999	- 609	1975-1999
Carrot River	N/A	N/A	+ 5.9	1974-1999
Dauphin River	N/A	N/A	- 28	1978-1996
Mossy River	+76	1978-1999	No change	1978-1999
Nelson River	No change	1978-1999	-68	1975-1999
North Duck River	No change	1988-1999	No change	1988-1999
Ochre River	No change	1988-1999	No change	1988-1999
Red Deer River	N/A	N/A	No change	1974-1999
Saskatchewan River, Grand Rapids	N/A	N/A	No change	1973-1997
Saskatchewan River, Carrot River	N/A	N/A	No change	1974-1999
Turtle River	No change	1988-1999	No change	1988-1999
Valley River	+ 18	1978-1999	- 1.0	1978-1999
Vermillion River	No change	1974-1999	No change	1974-1999
Waterhen River	+ 466	1981-1999	No change	1981-1999
Whitemud River	+ 55	1973-1999	+ 6.2	1973-1999
Wilson River	+ 8	1979-1999	- 0.4	1979-1999
Winnipeg River	N/A	N/A	+ 143	1972-1999
Woody River	N/A	N/A	No change	1988-1999

CONCLUSIONS

It can be concluded that:

- Nutrient losses from watershed processes were estimated through the use of land use data and nutrient export coefficients. The estimates appeared subject to a number of significant errors. Although subject to other errors, it was assumed that nutrient losses from watershed processes could also be calculated as the difference between TMSNL and within-stream loads, and it was assumed that the majority of within-stream loads was comprised of effluent discharges from point sources such as municipal and industrial effluents. Hence, while both methods were used, most summary information to describe general loading patterns were derived from the latter method.

- Nutrient loads from watershed processes based on land use and export coefficients overestimated nutrient loading to the Assiniboine River but were similar to loads estimated by calculation in the Red River (TMSNL - within stream process loads). In the Assiniboine River, mean TN and TP loads were 92 % and 86 % greater than values calculated as the difference between TMSNL and within-stream loads. In contrast, in the Red River, the percent difference between the two methods was only about 4 % for TN and TP. General error associated with the use of export coefficients can be attributed to 1) use of coefficients that were not specific to Manitoba, and 2) general grouping of all of Manitoba's land into only four categories. More specifically, the use of export coefficients to estimate nutrient loading from watershed processes may have been poorly suited to the Assiniboine River due to nutrient retention by Lake of the Prairies and the Portage Reservoir, and nutrient uptake by attached algal communities.

- On average (1994 to 2001), the Assiniboine River at Headingley transported approximately 3,682 t/yr of TN. Of this:

  - 1,102 t/yr (30 %) was contributed from the headwaters in Saskatchewan from both the Assiniboine and Qu’Appelle rivers;

- 1,130 t/yr (31 %) was contributed from the headwaters of the Souris River in the United States;

- 831 t/yr (23 %) was contributed from the Manitoba portion of three main tributaries (Cypress, Souris, and Little Saskatchewan rivers); and

- 619 t/yr (17 %) was contributed by within-stream or watershed processes and/or from other small tributaries.

- The total contribution of TN load to the Assiniboine River from Manitoba was 1,450 t/yr. Of this:

  - 423 t/yr (29 %) was attributed to direct discharges of municipal and industrial effluents (excluding discharges downstream of the Headingley station such as Winnipeg's WEWPCC); and

  - 1,027 t/yr (71 %) was attributed to various watershed processes.

- It was estimated that TN load in the Assiniboine River at Headingley had increased by 863 t from 1973 to 1999.

- On average, from 1994 to 2001, approximately 637 t/yr of TP were transported by the Assiniboine River at the Headingley. Of this:

  - 130 t/yr (20 %) was contributed from the headwaters in Saskatchewan from both the Assiniboine River and the Qu'Appelle River;

  - 209 t/yr (33 %) was contributed from the headwaters of the Souris River in the United States;

  - 135 t/yr (21 %) was contributed from the Manitoba portions of three main tributaries; and

  - 163 t/yr (26 %) was contributed by within-stream or watershed processes and/or from other small tributaries.

- The total contribution of TP load to the Assiniboine River from Manitoba was 298 t/yr. Of this:
  - 75 t/yr (25 %) originated from the direct discharge of municipal and industrial effluents, and;
  - 223 t/yr (75 %) was attributed to watershed processes.
- It was estimated that TP load in the Assiniboine River at Headingley increased by 133 t between 1970 and 1999.
- On average (1994 to 2001), the Red River at Selkirk transported approximately 32,765 t/yr of TN. Of this:
  - 18,983 t/yr (58 %) was contributed from the Red River basin in the United States;
  - 3,682 t/yr (11 %) was contributed from the Assiniboine River;
  - 2,395 t/yr (7 %) was contributed from six other tributaries in Manitoba (Pembina, Roseau, Rat, Boyne, Seine, and La Salle rivers); and
  - 7,705 t/yr (24 %) was contributed by within-stream or watershed processes and/or from other small tributaries.
- When TN from the Assiniboine River was excluded, it was estimated that 10,100 t/yr of TN was contributed from Manitoba. Of this:
  - 3,591 t/yr (36 %) was contributed from the city of Winnipeg through the three WPCC, combined sewer overflow, and land drainage sewers;
  - 585 t/yr (6 %) was contributed by other direct discharges of municipal and industrial effluents; and
  - 5,924 t/yr (59 %) was added to the Red River by watershed processes.

- Overall, the city of Winnipeg contributed approximately 11 % of the TN load transported by the Red River at Selkirk.

- It was estimated that the TN load carried by the Red River at Selkirk increased by 7,955 t between 1978 and 1999, with 863 t of this arising from the Assiniboine River basin.

- The Red River at Selkirk transported an average of 4,905 t/yr of TP during 1994 to 2001. Of this:

  - 2,537 t/yr (52 %) originated from the United States' portion of the basin and 637 t/yr (13 %) originated from the Assiniboine River basin;

  - tributaries within Manitoba (Pembina, Roseau, Rat, Boyne, Seine, and La Salle rivers) contributed another 333 t/yr (7 %); and

  - 1,398 t/yr (29 %) was contributed by within-stream or watershed processes and/or from other small tributaries.

- Excluding contributions from the United States' portion of the basin and from the Assiniboine River basin, it was estimated that 1,731 t/yr of TP was contributed to the Red River from Manitoba. Of this:

  - 390 t/yr (23 %) was contributed from the city of Winnipeg through the three WPCC, combined sewer overflow, and land drainage sewers;

  - 80 t/yr (5 %) was contributed by other direct discharges of municipal and industrial effluents; and

  - 1,260 t/yr (73 %) was added to the Red River by watershed processes.

- Overall, the city of Winnipeg contributed approximately 8 % of the TP load transported by the Red River at Selkirk.

- It was estimated that the TP load carried by the Red River at Selkirk increased by 567 t between 1978 and 1999, with 133 t of this arising from the Assiniboine River basin and 204 t arising from the United States' portion of the basin.

- It is clear that within Manitoba, watershed processes such as run-off of nutrients from diffuse agricultural sources and from natural processes contributed the largest mass of nutrients to both the Assiniboine and Red rivers. Within the Assiniboine River basin, 71 % of TN and 76 % of TP was contributed from watershed processes, while in the Red River basin, 59 % of TN and 73 % of TP were similarly contributed from watershed processes.

- Based upon the nutrient load estimates from 1994 to 2001, Lake Winnipeg received approximately 63,207 t/yr of TN and 5,838 t/yr of TP. Of this:

  - the largest contribution was from the Red River watershed, with the Red River contributing 46 % of TN and 73 % of TP loads;

  - the Winnipeg River contributed approximately 27 % of the TN and 13 % of the TP;

  - the Saskatchewan River contributed a significant amount of the TP load (12 %);

  - approximately 15 % of the TP load was the result of atmospheric deposition; and

  - an estimated 30 % of the TN load (18,983 t/yr) and 43 % of the TP load (2,537 t/yr) contributed to Lake Winnipeg originated from within the United States portion of the Nelson River basin.

- Based upon the TN and TP trend analysis results for the Red River in Jones and Armstrong (2001), it was estimated that over the last three decades the TN and TP load to Lake Winnipeg has increased by 13 % and 10 %, respectively.

- It is expected that further refinement of these preliminary estimates will occur in the future once additional research has been undertaken in Manitoba. Nevertheless, these preliminary estimates provide a valuable base of knowledge that is helpful to understand the magnitude of the nutrient management issue in Manitoba and to understand the general sources of nutrient contributions.

REFERENCES

Brunskill, G. J., S. E. M. Elliott, and P. Campbell. 1980, Morphometry, hydrology, and watershed data pertinent to the limnology of Lake Winnipeg: Canadian Manuscript Report of Fisheries and Aquatic Sciences 1556, 32 p.

CCME. 1987 (plus updates to 1994). Canadian water quality guidelines. Canadian Council of Ministers of the Environment. Environment Canada and Health Canada. Ottawa, ON, Canada.

Chambers, P. A and A. R. Dale. 1997. Contribution of industrial, municipal, agricultural and groundwater sources to nutrient export, Athabasca, Wapiti and Smoky rivers, 1980 to 1993. Northern River Basins Study, Edmonton AB.

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

Conley, D. J. 2000. Biogeochemical nutrient cycles and nutrient management strategies. Hydrobiologia 410:87-96.

Cooke, S. E., S. M. Amhed, and N. D. MacAlpine. 2002. Introductory Guide to Surface Water Quality Monitoring in Agriculture. Alberta Agriculture, Food and Rural Development. Edmonton, Alberta. http://www.agric.gov.ab.ca/sustain/water/final_wq_guide.html

Cooley, M., F. Schneider-Vieira, and J. Towes. 2001. Assiniboine River monitoring study water quality component: water quality assessment and model for the open water season. North/South Consultants Inc. Winnipeg, MB. 156 pp. plus Appendices.

Elsier, J. J., E. R. Marzolf, and C. R. Goldman. 1990. Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: A review and critique of experimental enrichments. Canadian Journal of Fisheries and Aquatic Science 47:1468-1477.

Fedoruk, A. N. 1970. Proposed watershed divisions of Manitoba. Report #10. Manitoba Department of Mines and Natural resources, Canada Land Inventory Project. Winnipeg, MB. 89 pp.

Green, D.J and W. N. Turner. 2002. South Tobacco Creek manured watershed runoff study, 1998-2001. Manitoba Conservation and Deerwood Soil & Water Management Association. Manitoba Conservation Report No. 2002-02.

Jones, G. and N. Armstrong. 2001 Long-term trends in total nitrogen and total phosphorus concentrations in Manitoba Streams. Water Quality Management Section, Water Branch. Manitoba Conservation Branch Report No 2001-7. 154 pp.

Manitoba Agriculture and Food. 2000. Manitoba Agriculture Yearbook. Program and Policy Branch, Policy and Economics Division, Manitoba Agriculture and Food. 221 pp.

Manitoba Conservation. 2000a. Development of a nutrient management strategy for surface waters in southern Manitoba. Water Quality Management Section, Manitoba Conservation. Winnipeg, MB. Information Bulletin 2000-2E. Available at www.gov.mb.ca/natres/watres/nutrmgt.pdf.

Manitoba Conservation. 2002b. Introducing Manitoba's forests. Available at http://www.gov.mb.ca/conservation/forestry/forest-education/general.html

Manitoba Conservation. 2002c. Municipal and Industrial Approvals Section, Environmental Approvals Branch, Environmental Stewardship Division. Winnipeg, MB

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

McFarland, A.M.S. and L.M. Hauck. 2001. Determining nutrient export coefficients and source loading uncertainty using in-stream monitoring data. Journal of the American Water Resources Association. 37:223-236.

Natural Resources Canada. 1999 (updated 4 December 1999). Geogratis: The Canadian watershed maps. www.geogratis.cgdi.gc.ca .

Remote Sensing Centre. 1994. Land Use/Land Cover Data and Maps. Manitoba Conservation, Manitoba Land Initiatives. Winnipeg, MB.

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

Szoke, N. 2002. Nutrient characterization of discharges from Winnipeg to the Red and Assiniboine rivers. City of Winnipeg Waterworks, Waste and Disposal Department. Presentation at International Association of Great Lakes Research Conference, June 2002, University of Manitoba, Winnipeg, MB.

Tembec Paper Group. 2002. Monthly Effluent Data. Pine Falls Operation. Pine Falls, Manitoba.

U.S. Environmental Protection Agency (USEPA). 1980. Design manual: Onsite wastewater treatment and disposal systems. Office of Water Program Operations. EPA 625/1-80-012. Washington, D.C.

PERSONAL COMMUNICATION

Lee, G. P. 2001. National Hydrology Research Centre (NHRC), Environment Canada. Saskatoon, SK