LONG-TERM TRENDS IN TOTAL NITROGEN AND TOTAL PHOSPHORUS CONCENTRATIONS IN MANITOBA STREAMS

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Water Quality Management Section,
Water Branch

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EXECUTIVE SUMMARY

Eutrophication is the nutrient enrichment of a surface waterbody (lake, stream, reservoir) from natural and human sources. The major nutrients contributing to eutrophication are nitrogen and phosphorus. Nutrient enrichment can result in excessive growth of algae and macrophytes in surface waters leading to oxygen depletion and fish kills, decreased biodiversity, taste and odour problems, increased water treatment costs, and blue-green algae toxin production (if blue-green algae are present). Nuisance blooms of algae periodically occur in many waterbodies in Manitoba. Combined with relatively high concentrations of nitrogen and phosphorus this is one of the most important water quality issues requiring assessment at the present time.

Manitoba Conservation recently drafted a Nutrient Management Strategy that outlines steps for establishing a long-term strategy to manage nutrients in Manitoba surface waters. The document identified a number of key items and issues that require consideration during the strategy development process. One of the items called for was a comprehensive analysis of existing water quality data to detect temporal trends in nutrient concentrations in provincial waterways. Results from this analysis will help to describe the present nutrient status of streams within the province and will aid in prioritizing waterways and regions that require more immediate attention in terms of future nutrient management.

Although algae and other aquatic plants generally utilize nutrients such as phosphorus and nitrogen in their dissolved inorganic forms (*e.g.*, phosphates for phosphorus, nitrate and ammonia for nitrogen), this report was restricted to identifying trends in total nitrogen (TN) and total phosphorus (TP) concentrations. Data sets for TN and TP were more extensive in terms of sample size and time frame, and had fewer censured values (*i.e.*, values less than detection) than data sets for ammonia, nitrate, dissolved phosphorus, and ortho-phosphorus. Furthermore, derivation of water quality objectives and criteria for nitrogen and phosphorus in other jurisdictions has focussed primarily on total values rather than inorganic or dissolved fractions.

Trend analysis was conducted on data from 46 long-term water quality monitoring stations representing 33 different waterways in Manitoba. Stations were selected on the basis of sample size, period of reporting, and availability of flow data. Thirty-three of the stations are maintained by Manitoba Conservation, while the remainder are operated by Environment Canada. Trend analyses were performed with two separate statistical methods depending on the extent of the data set involved. *QWTrend*, a computer program developed by the United States Geological Survey to analyze trends in water quality data, was used on data sets with over 60 data points and more than 15 years of data. The program uses relatively complex statistical methods to identify trends in concentration data after accounting for variation due to flow (or discharge). Trends in TN and TP data at water quality stations with fewer than 60 samples or less than 15 years of data were identified with a series of simple linear regressions on log-transformed data.

Analysis indicated great variability in long-term trends in TN and TP concentrations between streams and within streams in Manitoba. Nineteen water quality stations from 13 different streams had trends of increasing TN concentrations, while TP concentrations exhibited positive trends at 18 stations from 15 streams. Eleven monitoring sites, representing 9 different streams, had trends of increasing concentrations for both TN and TP. Most of these streams were in the southern portion of the province in the Assiniboine and Red River watersheds. The majority of streams in these watersheds are susceptible to anthropogenic nutrient loading because human population densities are high and agricultural land-use is intensive.

Four monitoring stations from four separate streams were found to have trends of decreasing TN concentration, while trends of decreasing TP were found in data from seven monitoring stations representing seven streams. Streams with trends of decrease were found in the northern and west-central regions of the province. Only two monitoring stations, one on the Swan River and the other on the Burntwood River, had decreasing trends for both TN and TP.

Ten monitoring stations from 10 streams and 20 stations from 15 streams showed no detectable trends in TN or TP, respectively. Seven monitoring stations, each from a different stream, showed no detectable trend in both TN and TP concentrations. Streams with stations that showed no trend in either TN or TP or both variables, although found in all areas of the province, tended to be located in the western portion of the Province north of the Assiniboine River and Boggy Creek-Whitemud River watersheds. Watersheds in this region of the province are generally less dominated by agricultural land-use (on a proportional land basis) than watersheds in the south. Several of these monitoring sites had relatively small data sets. Small sample size and a short period of record, coupled with high variability in the data may have made detection of statistically significant trends difficult. Trend detection may increase as more data is collected at these sites.

Results of the analysis of long-term trends in TN and TP in Manitoba waterways were interpreted in terms of there having been an increase, a decrease, or no detectable change in concentration over the period of record. A positive trend at a monitoring station could be attributed to an increase in nutrient additions to the waterway. However, further study, as identified in the Nutrient Management Strategy, is required to determine the potential source of nutrient addition (*i.e.* point or non-point source, anthropogenic or natural). Also trend results did not indicate whether such an increase was ecologically significant. Assessment of the potential impact of an increase in nutrients on an aquatic system depends on the magnitude of the increase and the actual recorded concentrations present. In addition, monitoring stations where trends were not detected may still be subject to anthropogenic nutrient additions leading to eutrophication. For example, TP concentrations at site WQ0201 on Boggy Creek fluctuated between 0.05 and 0.15 mg/L suggesting significant variation in nutrient loading over the period of record. Further study is required to determine what magnitude of fluctuation in TP or TN concentration will trigger the negative impacts associated with nutrient enrichment.

Jones, G., et N. Armstrong, 2001. *Long-term trends in total nitrogen and total phosphorus concentrations in Manitoba streams* (« Tendances à long terme des concentrations d'azote total et de phosphore total dans les cours d'eau du Manitoba »). Section de la gestion de la qualité de l'eau, Direction des eaux, Conservation Manitoba, Winnipeg (Manitoba). Rapport de Conservation Manitoba n^{o} 2001-07. 154pp.

SOMMAIRE

L'eutrophisation est l'enrichissement d'un cours d'eau ou d'une étendue d'eau de surface (lac, ruisseau, réservoir) par des nutriments de source humaine ou naturelle, dont les principaux sont l'azote et le phosphore. Cet enrichissement peut causer une croissance excessive d'algues et de macrophytes dans les eaux de surface, d'où un épuisement d'oxygène, une mortalité massive de poissons, une réduction de la biodiversité, un goût et des odeurs désagréables, une augmentation du coût de traitement des eaux, et la production de toxines par des algues bleues lorsque ces dernières sont présentes. Au Manitoba, bon nombre d'étendues d'eau et de cours d'eau présentent périodiquement une prolifération nocive d'algues. Étant donné l'association de ce problème à celui d'une concentration relativement élevée d'azote et de phosphore, cet élément du dossier de la qualité de l'eau est l'un de ceux qu'il importe le plus d'étudier à l'heure actuelle.

Un récent document du ministère de la Conservation décrit les étapes qui mèneront à l'établissement de la Stratégie de gestion des nutriments du Manitoba, un plan à long terme de contrôle des nutriments dans les eaux de surface de la province. On y précise certains éléments clés à envisager au cours de l'élaboration de la Stratégie, dont une analyse complète des données actuelles relatives à la qualité de l'eau afin d'y déceler les tendances temporelles des concentrations de nutriments. Les résultats de cette analyse permettront de dresser un meilleur tableau de l'état nutritif actuel des cours d'eau et d'établir un ordre de priorité afin de déterminer, parmi ces cours d'eau et parmi les régions, ceux qui nécessiteront une attention plus immédiate.

Bien que les algues et autres plantes aquatiques utilisent généralement des nutriments tels l'azote et le phosphore sous leur forme inorganique dissoute (p.ex., phosphates dans le cas du phosphore, nitrates et ammoniac dans le cas de l'azote), le présent rapport devait s'en tenir à l'identification des tendances des concentrations d'azote total (NT) et de phosphore total (PT). Les ensembles de données se rapportant au NT et au PT étaient plus considérables, en ce qui concerne la taille de l'échantillon et la période de référence, et comportaient moins de valeurs censurées (i.e. moindres que les valeurs décelables) que les ensembles se rapportant à l'ammoniac, aux nitrates, au phosphore dissous et à l'orthophosphore. De plus, la détermination des objectifs et des critères de qualité de l'eau relatifs à l'azote et au phosphore qui a été faite sous l'égide d'autres gouvernements s'appuyait principalement sur la valeur totale plutôt que sur la valeur de fractions inorganiques ou dissoutes.

L'analyse des tendances a porté sur des données provenant de 46 stations de surveillance à long terme de la qualité de l'eau, représentant 33 voies d'eau du Manitoba et choisies en tenant compte de la taille de l'échantillon, la période couverte et la disponibilité des données sur l'écoulement de l'eau. De ces stations, 33 sont gérées par Conservation Manitoba et les autres par Environnement Canada. Deux méthodes statistiques différentes ont été utilisées, selon la portée de l'ensemble en cause. Pour les ensembles échelonnés sur plus de 15 ans et se rapportant à plus de 60 points, l'outil d'analyse des tendances des données sur la qualité de l'eau était *QWTrend*, un logiciel du *United States Geological*

Survey. Les méthodes statistiques relativement complexes qu'utilise ce logiciel lui permettent d'identifier les tendances des données de concentration, après inclusion dans les calculs de la variation causée par l'écoulement de l'eau. Dans le cas des stations où les données étaient échelonnés sur moins de 15 ans ou se rapportaient à moins de 60 échantillons, l'identification des tendances relatives au NT et au PT s'est faite au moyen d'une série de régressions linéaires simples après normalisation logarithmique des données.

Les résultats de l'analyse révèlent une grande fluctuation dans les tendances à long terme des concentrations en NT et PT au Manitoba, tant d'un cours d'eau à l'autre qu'au sein du même cours d'eau. 19 stations représentant 13 cours d'eau indiquaient une tendance à la hausse des concentrations en NT, alors que la concentration en PT démontrait une tendance positive à 18 stations représentant 15 voies d'eau. 11 sites de surveillance représentant 9 cours d'eau indiquaient une tendance à la hausse des deux concentrations (NT et PT). La plupart de ces cours d'eau sont dans la partie sud de la province, soit le bassin hydrographique des rivières Assiniboine et Rouge. La majorité des cours d'eau de ce bassin sont exposés au risque d'un apport de nutriments d'origine humaine, étant donné la forte densité de peuplement et l'utilisation intensive des terres agricoles dans cette région.

Les données de quatre stations de surveillance, fournies par les échantillons de quatre cours d'eau, indiquaient une tendance à la baisse des concentrations en NT, alors que la tendance à la baisse des concentrations en PT était décelée dans les données de sept stations, fournies par les échantillons de sept cours d'eau. Les voies d'eau où se manifestait une tendance à la baisse sont dans les régions nord et centre-ouest de la province. Deux stations seulement indiquaient une tendance à la baisse pour les deux concentrations (NT et PT), soit une station de surveillance des eaux de la rivière Swan et une des eaux de la rivière Burntwood.

Dix stations recueillant les échantillons de 10 cours d'eau et 20 stations recueillant ceux de 15 cours d'eau ne présentaient aucune tendance décelable dans les concentrations de NT et de PT, respectivement. Sept stations, représentant chacune un cours d'eau différent, n'indiquaient aucune tendance décelable des deux concentrations (NT et PT). Les cours d'eau n'indiquant aucune tendance dans un cas (NT) ou l'autre (PT) ou les deux (NT et PT), se retrouvent dans toutes les régions de la province mais principalement dans l'Ouest, au nord du bassin hydrographique de la rivière Assiniboine et de celui de la rivière Whitemud et du ruisseau Boggy. En règle générale, les bassins de cette région sont, proportionnellement, moins soumis à l'utilisation des terres à des fins agricoles que ceux du Sud. Les ensembles de données de plusieurs de ces sites étaient relativement petits. Il se peut que la petite taille de l'échantillon et la brève période couverte, auxquelles s'ajoute la grande fluctuation des données, aient rendu difficile la détection de tendances statistiquement significatives. Une collecte plus importante de données sur ces sites pourrait permettre de déceler plus facilement les tendances.

Les tendances à long terme des concentrations en NT et en PT dans les cours d'eau du Manitoba ont été analysés. On a interprété les résultats de l'analyse comme une hausse ou une baisse, ou l'absence de tout changement décelable, pour la période couverte. Une tendance positive à une station de surveillance pourrait être attribuée à une augmentation des apports en nutriments au cours d'eau. Toutefois, comme l'indique la Stratégie de gestion des nutriments, il faut poursuivre les études si l'on veut déterminer la source de ces apports (p. ex., d'origine naturelle ou humaine, de source ponctuelle ou non). De plus, les résultats n'indiquaient pas si une hausse était significative ou non sur le plan écologique. L'évaluation des répercussions éventuelles d'une augmentation de la présence de nutriments dans un système aquatique dépend de l'ampleur de la hausse et des concentrations dont on a réellement noté la présence. De plus, les stations de surveillance où nulle tendance n'a été décelée peuvent quand même être sujettes à un apport de nutriments d'origine humaine qui entraînerait l'eutrophisation. À titre d'exemple, les concentrations en PT au site WQ0201 (ruisseau Boggy) ont fluctué entre 0,05 et 0,15 mg/l, ce qui suggère une variation importante en apport de nutriments au cours de la période couverte. Des études plus poussées seront requises pour évaluer quelle ampleur doit atteindre la fluctuation des concentrations en NT ou PT pour déclencher les répercussions négatives que l'on associe à l'apport en nutriments.

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INTRODUCTION

Nutrient enrichment or eutrophication is one of the most serious water quality issues in western Canada. Results from monitoring studies in the three prairie provinces suggest that most of the large rivers that transverse the prairie, parkland, and southern boreal regions contain high concentrations of plant nutrients, particularly nitrogen and phosphorus (Wood 1999). The main nutrient sources to streams in western Canada include erosion of naturally fertile soils, surface run-off of fertilizers from cultivated fields, run-off from livestock pasture and feedlots, urban run-off and storm sewer discharges, and agricultural, industrial, and urban sewage effluent discharges. Monitoring results from a number of water quality monitoring stations in Manitoba indicate that excessive nutrient loading may be an important concern with many large and small streams throughout the province.

The increasing awareness of eutrophication and its negative effects on water quality has prompted government agencies both nationally and internationally to develop nutrient management strategies aimed at controlling excessive inputs of nutrients to surface waters. Manitoba Conservation recently drafted a document outlining the direction it intends to take towards establishing a long-term nutrient management strategy for surface waters in Manitoba (Manitoba Conservation 2000). The document identified a number of key items and issues that require consideration during the strategy development process. One of these items called for a comprehensive trend analysis using existing water quality data in order to detect temporal trends in nutrient concentrations in provincial streams and rivers. This report presents the results of this trend analysis exercise. The results of this analysis will help to describe the present nutrient status of streams within the province and will aid in prioritizing waterways and regions that require more immediate attention in terms of nutrient management in the future.

Nutrient enrichment can have a number of direct and indirect impacts on surface waters (Carpenter *et al.* 1998, Smith *et al.* 1999). Perhaps the most observable direct impact of nutrient enrichment is the tendency for excessive growth of algae and other aquatic plants. This high productivity can radically alter the structure and function of aquatic ecosystems and negatively impact the overall water quality of the system, in turn limiting present and future uses of the resource. Eutrophication can result in an increase in the occurrence and extent of algal blooms, corresponding with an overall decrease in aquatic biodiversity. The presence of an algal bloom in a drinking water source can clog treatment plant filters, and often imparts an unpleasant taste and odour, as well as an unsightly appearance to the finished water. Treatment of such water for drinking purposes can be very expensive and may prove to be cost prohibitive for some water utilities. Blooms of blue-green algae species, many of which produce potent nerve and liver toxins, may become more common under eutrophic conditions, and consumption of waters during and following such blooms presents a health risk for humans, household pets, and livestock (Carmichael 1991). There is also evidence that the toxins produced by blue-green algae can bioaccumulate and thus be transferred through the aquatic food web (Kotak 1995). Algal blooms and extensive macrophyte growth are also considered aesthetically unappealing and can detract from the recreational use of a surface water. A decline in the aesthetic quality of the water can adversely affect tourism and recreation, and lead to decreased land and cottage values. The die-off and subsequent decay of algal blooms and macrophyte vegetation consumes dissolved oxygen, leading to extensive fish kills. As well, anoxic conditions promote the release of phosphorus from the sediments to the water column, where it is available for algal growth.

The growth of algae and macrophytes in rivers and streams is dependent on a number of environmental variables including light, temperature, water clarity, flow regime, grazing, the presence of toxic pollutants, and nutrient content (UK Environment Agency 1998, USEPA 1999). Although a number of nutrients are required for the growth and development of aquatic plants, it is widely believed that concentrations of phosphorus and nitrogen are the most limiting for plant growth, and excessive inputs of these two nutrients are the greatest contributors to eutrophication in aquatic environments (Elsier *et al.* 1990, USEPA 1998, Wood 1999, Smitth *et al.* 1999, Conley 2000).

Phosphorus (P) is generally considered more limiting than nitrogen in freshwater ecosystems (see Elsier *et al.* 1990, Conley 2000). It is required in the photosynthesis process in plants, and in energy transfer pathways in both plants and animals. Because phosphorus 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 organic and inorganic compounds. The total phosphorus concentration (TP) in a waterbody is a summation of dissolved and particulate compounds, and as such is not a measure of the amount that is immediately available to plants, but rather is an indication of the amount that is potentially available for plants. Particulate forms of phosphorus include phosphorus that is adsorbed to sediment particles and phosphorus compounds contained in the tissues of aquatic plants and animals. The total dissolved phosphorus content (DP) of water refers to that portion of the TP content that is present in the water after filtration through a 0.45 micron filter. In general these are phosphate ions that are not bound to particulate matter or tied-up in living organisms. The most common ionic forms of phosphate found in water include simple phosphate ($P0_4^{-3}$), monohydrogen phosphate ($HP0_4^{-2}$), and dihydrogen phosphate ($H_2P0_4^-$) (CCME 1987). These forms of phosphate are often referred to as orthophosphates, and are readily taken in and assimilated by plants. Determination of the soluble reactive phosphorus (SRP) content of a water sample is often used to indicate the portion of DP that is available for plant uptake. The concentration of dissolved phosphate ions in water is influenced by water pH and oxygen content, the activities of fungi, bacteria, algae, and invertebrates, and the concentration and composition of trace metals, organic compounds, and other particulate matter (CCME 1987).

Although nitrogen (N) is considered the main limiting nutrient in marine and some estuarine ecosystems, it is also very important in determining the primary productivity in freshwater systems (Smith *et al.* 1999, Conley 2000), and can become limiting in freshwater systems when its concentration, especially in proportion to phosphorus, is low. All living organisms require an adequate supply of the element nitrogen. Nitrogen is present in amino acids, nucleotides, and chlorophyll molecules, and as such is very important in cellular function, reproduction, and energy transfer in both plants and animals. 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 and nitrate) are available for plant uptake and assimilation.

Ammonia is found in water as NH_3 (its un-ionized form) and as NH_4^+ (its ionized form called ammonium). In water the two forms (NH_3 and NH_4^+) exist in equilibrium and their combined concentration is referred to as total ammonia. This equilibrium is dependent on water pH and temperature, with high pH and temperature causing a shift from $NH_4^+ \dashrightarrow NH_3$, and low pH and temperature favoring a shift from $NH_3 \dashrightarrow NH_4^+$. This equilibrium is important since ammonia in its un-ionized form is toxic to fish (Williamson 1988). Nitrate (NO_3^-) is the other major inorganic form of nitrogen that is most readily available for plant up-take. Generally nitrate levels in aquatic systems in western Canada rarely exceed 5 mg/L, and are usually below 1 mg/L (CCME 1987). 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.

STATISTICAL METHODS

As mentioned in the previous section, plants generally take in P and N as dissolved inorganic ions (*e.g.* phosphates, nitrate, and ammonia). However, for the purposes of this report, the trend analysis was limited to only TN and TP data, because the data sets for these variables tended to be the most extensive in terms of sample size and time frame. As well, the TP and TN data had few censured values (*i.e.* expressed as "< detection"), while, depending on the stream in question, a significant proportion of the ammonia, nitrate, dissolved phosphorus, and ortho-phosphorus data were reported as less than detection. Finally, the establishment of water quality objectives and criteria for N and P has primarily focussed on total values rather than the inorganic or dissolved fractions.

Trend analysis was performed using the *QWTrend* program developed by the USGS (Vecchia 2000). The *QWTrend* program performs a trend analysis on the concentration data after accounting for the variation in concentration that is due to the variation in flow (or discharge). The program employs a periodic auto-regressive moving average model (PARMA model) to determine linear trends in the flow-adjusted concentration data. The result is a trend in the concentration data that reflects what the trend in the data would be if flow were constant (*i.e.* variation due to flow is minimized). The program requires a minimum of a 15-year span in the concentration data. However, it is not a requirement for the data to be evenly distributed over this time span, and relatively large intervals between data points, from weeks to months and even years, are acceptable (but large gaps may detract from the overall confidence in the analysis results). Another requirement of the program is that there has to be at least 60 sample points in the concentration data. These sample size and time span minimum requirements are necessary for the PARMA model to identify trends in the data. A final requirement of the program is that no more than 10% of the concentration data can be censured data.

The *QWTrend* program offers a number of analysis options such as the ability to insert step trends and to identify multiple linear trends in the data. Insertion of a step trend into the analysis is called for when there is a distinct change in the monitoring protocol, such as a change in location or laboratory methodology, that may have an effect on the concentration data reported (Vecchia 2000). If a step trend is significant, then one can conclude that the change in protocol had a significant influence on the concentration data. According to Vecchia (2000) most trends in environmental data are actually a series of smaller monotonic trends. The *QWTrend* program also allows one to delineate the time intervals for linear trends in the data. Thus, one can request the program to identify a single trend across the entire data set for a variable at a given site, or to identify several shorter trends in the data. For this report we were only interested in assessing the single trend in the data over the entire time span of the data set.

The *QWTrend* program output includes a series of points representing the single linear trend in flow-adjusted concentration over the period of reporting. The program indicates the level of significance of the trend line with a p-value. Trends in flow adjusted concentrations were deemed statistically significant if $p<0.05$. The program also provides an indication of the annual and total percent change in the median of the flow-adjusted concentration trend line over the period of reporting. (Note that because the trend is derived from log10 transformed data, the percent change in the median is used rather than a percent change in the mean).

All PARMA model residuals were tested for normality using the Shapiro-Wilcox W test, where a value > 0.05 indicated that the residuals were normally distributed. In cases where the residuals were not normally distributed the raw data were examined and extreme outliers were removed systematically until the residuals became normal. In most instances this only required the removal of one or two outliers from the data set, and did not appear to affect the overall outcome of the trend analysis.

At some of the water quality monitoring stations the data record was less than 15 years or consisted of less than 60 data points. In such instances trend analysis with the *QWTrend* program was not possible. Instead, trends in data at these stations were identified using a series of simple linear regressions. This involved first regressing log-transformed concentration data with log-transformed flow data, and then taking the residual scores from this regression and regressing them with time. This process helped to minimize the influence of the correlation between concentration and flow in determining the overall trend in the concentration data. A positive slope in the regression line between time and the residual scores indicated a trend of increasing concentration, while a negative slope indicated a trend of decreasing concentration. Trends were considered significant if $p<0.05$. The Shapiro-Wilcox W test was used to test that the regression residuals were normally distributed.

A significant positive trend in flow-adjusted concentration (arrived at from either statistical method) suggests that the concentration of nutrients in the river is being augmented by additions from artificial or anthropogenic sources. Such sources could include surface run-off from fertilized fields and livestock holding areas, urban storm-water run-off, and effluent discharges from wastewater lagoons, sewage treatment plants, or industrial facilities. Nutrient additions can also result from increased erosion of stream banks due to stream channelization and drainage development projects within the watershed. A non-significant trend in flow-adjusted concentration indicates that additions of nutrient from anthropogenic sources, if present at all, are not significantly influencing the overall concentration of nutrients in the river. This characterizes situations in which the volume of flow in the river is very high relative to the volume of effluent or run-off waters entering the system from the watershed. A significant decreasing trend in flow-adjusted concentration suggests that the loading of nutrients to the system from anthropogenic sources is decreasing. A decreasing trend in concentration can reflect changes in land-use practices within the surrounding watershed, the implementation of nutrient reduction processes in wastewater treatment, or the recovery of a waterway following a major disturbance or perturbation such as flooding and stream bank erosion.

SITE SELECTION

Trend analysis was conducted on TN and TP data collected from 46 long-term water quality monitoring stations on 33 different waterways in Manitoba. The stations are listed in Table 1 and their locations displayed in Figure 1. Stations were selected on the basis of sample size, period of reporting, and availability of flow data. The majority (33) of the selected stations are located on streams and rivers in the southern half of the province and are maintained by Manitoba Conservation. Twelve of the stations are maintained by Environment Canada and are mainly located on trans-boundary waterways such as the Assiniboine, Saskatchewan, and Red Rivers, while a single site on the Souris River at Westhope is maintained by the North Dakota U.S. Geological Survey (USGS). Up until the end of 1993, the analytical method for determining dissolved nitrogen at the Environment Canada stations did not fully recover nitrogen associated with urea and ammonium compounds (Lee 2001, personal communication). As a result, much of the TN concentration (sum of dissolved and particulate nitrogen) reported prior to the end of 1993 (when the method was changed) actually underestimated the amount of nitrogen in the water. Therefore, trend analysis at these sites was limited to only the TP data.

RESULTS AND DISCUSSION

Graphs of the trend analysis results presented in this section show the actual recorded concentration values for TN and TP, as well as the flow-adjusted trend in concentration as determined by the *QWTrend* program. The level of significance of each trend is indicated by the p-value associated with each graph. All flow-adjusted trends, whether significant or not, were illustrated graphically along with the actual reported concentrations. The overall percent change in the annual median of the flow-adjusted trend from the beginning to the end of the reporting period is also provided.

Table 1. Water quality sampling stations included in the trend analysis of TN and TP data.

Station	Location	Reporting Period and Sample Size (n)	
		TN	TP
MA05OC0001	Red River, at Emerson, MB	N/A	1978-1999 (402)
WQ0367	Red River, at south gate of Winnipeg floodway, east of PTH #75.	1978-1999 (241)	1978-1999 (240)
WQ0142	Red River, at PR #204 bridge, Selkirk, MB	1978-1999 (241)	1978-1999 (240)
WQ0068	La Salle River, near bridge upstream of PTH #75 in St. Norbert, Winnipeg, MB	1974-1999 (87)	1974-1999 (87)
WQ0029	Boyne River, at bridge one block west of PTH#13, Carman, MB	1973-1996 (46)	1973-1996 (48)
MA05OB0001	Pembina River, at Windygates, MB	N/A	1974-1999 (275)
WQ0153	Roseau River, at dam near PR #200, Dominion City, MB	1973-1999 (60)	1973-1999 (60)
WQ0131	Rat River, at PR #303 bridge, Otterburne, MB	1973-1999 (51)	1973-1999 (54)
WQ0365	Marsh River, at PR #303, west of Otterburne, MB	1978-1999 (84)	1978-1999 (86)
WQ0166	Seine River, at south Perimeter Highway, Winnipeg, MB	1973-1999 (118)	1973-1999 (119)
WQ0644	Cooks creek, on municipal road 1 km south of Millbrook, MB	1990-1999 (50)	1990-1999 (50)
WQ0643	Cooks creek, at the boundary between R. M. of Springfield and R. M. of St. Clements	1990-1999 (50)	1990-1999 (50)
SA05MD0001	Assiniboine River, at Kamsack, SK	N/A	1974-1999 (318)
WQ0009	Assiniboine River, at 18th St. bridge, Brandon, MB	1974-1999 (274)	1970-1999 (320)
WQ0012/WQ0636 *	Assiniboine River, at PR #340 upstream of Treesbank, MB	1973-1999 (201)	1970-1999 (236)
WQ0014	Assiniboine River, downstream of WTP reservoir at Spillway Park, Portage la Prairie, MB	1973-1999 (179)	1971-1999 (212)
WQ0015	Assiniboine River, at Trans-Canada Hwy bridge east of Portage la Prairie, MB	1973-1999 (257)	1971-1999 (289)
WQ0018	Assiniboine River, at PR #334 bridge, Headingley, MB	1973-1999 (163)	1970-1999 (190)
WQ0105	Little Saskatchewan River (Minnedosa River), at PTH #25 bridge, near Rivers, MB	1973-1996 (126)	1973-1996 (126)
WQ0398	Cypress River, on municipal road east of town of Cypress River, MB	1978-1999 (70)	1978-1999 (70)
MA05NF0001/US05NFH0001 *	Souris River, at Coulter, MB/at Westhope, ND	N/A	1973-1999 (391)
WQ0371	Souris River, at PTH #22 bridge in town of Souris, MB	1978-1997 (150)	1978-1997 (150)
WQ0350	Souris River, at PR #530 bridge near Treesbank, MB	1973-1999 (182)	1970-1999 (215)
SA05JM0014	Qu' Appelle River, near Welby, SK	N/A	1975-1999 (270)
WQ0038	Brokenhead River, at PTH #59 bridge, southeast of Scanterbury, MB	1973-1999 (61)	1973-1999 (61)
MA05PF0022	Winnipeg River, at Point du Bois, MB	N/A	1972-1999 (265)
WQ0201	Boggy Creek (Whitemud River), at PTH #16, Neepawa, MB	1973-1991 (102)	1973-1991 (107)
WQ0197	Whitemud River, at PTH #16 bridge, Westbourne, MB	1973-1999 (176)	1973-1999 (179)
WQ0245	Turtle River, at PTH #5, Ste. Rose du Lac, MB	1988-1999 (102)	1988-1999 (102)
WQ0227	Ochre River, at PTH #5, near town of Ochre River, MB	1988-1999 (70)	1988-1999 (70)
WQ0252	Vermillion River, at PTH #20, north of Dauphin, MB	1974-1999 (79)	1974-1999 (78)
WQ0255	Wilson River, at PTH #20, north of Dauphin, MB	1979-1999 (74)	1979-1999 (73)
WQ0250	Valley River, at PTH #20, north of Dauphin, MB	1978-1999 (78)	1978-1999 (75)
WQ0390	Mossy River, at PR #273, approximately 3.2 km east of PTH #20	1978-1999 (114)	1978-1999 (114)
WQ0217	North Duck River, at PTH #10, near Cowan, MB	1988-1999 (34)	1988-1999 (34)
WQ0244	Swan River, at PR #268 bridge near Lenswood, MB	1988-1999 (33)	1988-1999 (34)
WQ0259	Woody River, at PR #268, near Bowsman, MB	N/A	1988-1999 (34)
SA05LC0001	Red Deer River, near Erwood, SK	N/A	1974-1999 (260)
WQ0561	Waterhen River, at PR #328 near community of Waterhen, MB	1981-1999 (60)	1981-1999 (60)
WQ0404/MA05LM0005 **	Dauphin River, near community of Dauphin River,MB/ Upstream of Anama Bay, MB	N/A	1978-1996 (178)
MA05KH0001	Saskatchewan River, above Carrot River in MB	N/A	1974-1999 (268)
WQ0163/MA05SH0001**	Saskatchewan River, below Grand Rapids, MB	N/A	1973-1997 (176)
MA05KH0002	Carrot River, near Turnberry, SK	N/A	1974-1999 (278)
WQ0049	Nelson River, at Norway House, MB	1978-1999 (102)	1975-1999 (121)
WQ0093	Burntwood River, at PTH #6 bridge, Thompson, MB	1975-1999 (112)	1975-1999 (120)

* combined data from two stations

** name change as a result of a change in the agency responsible for maintaining the station

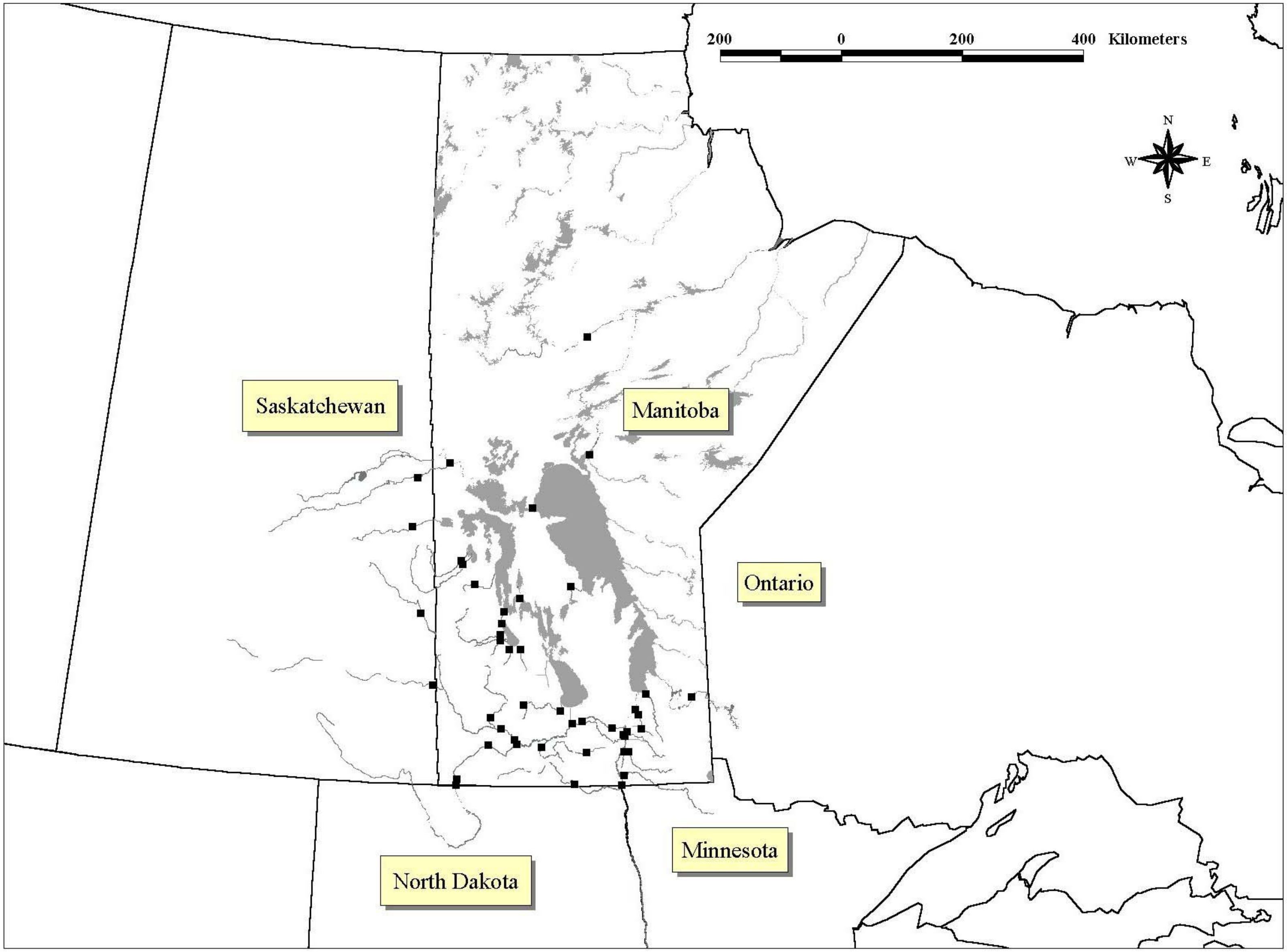


Figure 1. Locations of water quality monitoring stations used in the trend analyses.

The watershed boundaries shown in the Figures and referred to in the text of this section are based primarily on the Prairie Farm Rehabilitation Agency *Gross Watershed Boundaries, Version 2* (PFRA 1999). The PFRA watershed boundaries are delineated to represent the area that is tributary to the hydrometric stations along a river (Cherneski and Ackerman 1999). Thus, the entire watershed of a given river is sequentially delineated from it furthest upstream hydrometric station to its furthest downstream hydrometric station. Because, in most case, the furthest downstream station is upstream of the mouth of the river, the watershed appears to be truncated or incomplete. In such instances, information from Fedoruk (1970), Manitoba Department of Mines, Resources and Environmental Management (various dates 1960's - 1980's), and Natural Resources Canada (1999) was used to approximate the remainder of the watershed boundary. Please note that these boundaries represent the gross drainage area and include the effective drainage area as well as areas of poor or "dead" drainage within the watershed.

The land-use information presented in this section was obtained from several sources; including the Atlas of Manitoba (Weir 1983), the Atlas of Saskatchewan (Richards and Fung 1969), the Canadian Land Inventory (www.geogratis.cgdi.gc.ca/cgi-bin/geogratis/cli/landuse), the Canadian Soil Information System (www.sis.agr.gc.ca/cansis/intro), the Prairie Farm Rehabilitation Administration (PFRA 2000), and from land-use map layers created from 1993 - 1994 Landsat TM imagery and provided by the Manitoba Land Information Division of Manitoba Conservation.

RED RIVER

The Red River (Figure 2) is one of the primary waterways of southern Manitoba. The headwaters of the Red River are found at the convergence of the Ottertail and Boise de Sioux Rivers near Wahpeton, North Dakota (EMD 1980). From this origin the river flows a direct line distance of 460 km (reach = 885 km) to empty into Lake Winnipeg in Manitoba (EMD 1980). Important tributaries to the Red River in the United States include the Sheyenne, Pembina, Park, Wild Rice, Buffalo, Two Rivers, and Red Lake Rivers, while those in Manitoba include the Roseau, Seine, LaSalle, Rat, and Morris Rivers. The Assiniboine River also flows into the Red River (at Winnipeg), but is generally considered a separate watershed division from the Red River (EMD 1980).

The Red River watershed occupies a land area of approximately 127000 km^2. About 20% (26000 km^2) of this total is located within Manitoba, with most of the remaining 80% shared

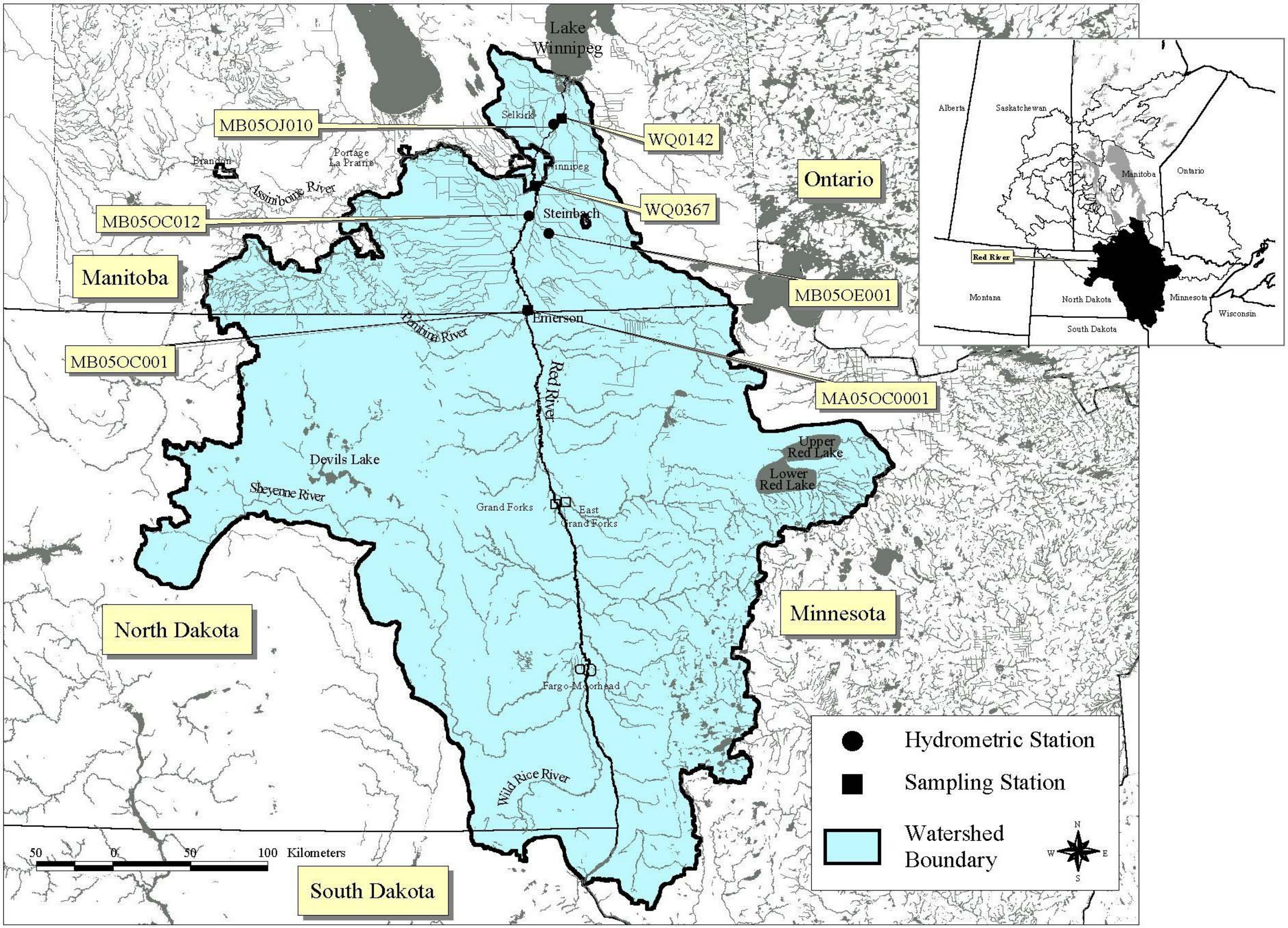


Figure 2. Red River watershed showing the location of water quality sampling sites and hydrometric stations on the Red River in Manitoba.

between the northern states of Minnesota and North Dakota (a relatively small portion of the watershed is also found in South Dakota) (EMD 1980). Water quality monitoring stations within the watershed are located on the Red River itself as well as on a number of smaller streams that are tributary to the Red. Results of the trend analysis conducted on the Red River stations are dealt with in this section, while the results from stations on tributary streams are presented in subsequent sections.

The vast majority of the land within the Red River watershed is used for cereal and feed crop production (EMD 1980). The application of agricultural fertilizers is strongly associated with this type of land use, and as a result there is a high potential for nutrient loading into the river system via land surface run-off during heavy rainfall and spring melt. Major nutrient point sources along the Red include effluent discharges from the cities of Fargo and Grand Forks in North Dakota, Moorhead and East Grand Forks in Minnesota, and Winnipeg in Manitoba (Goodman 1997). As well, a number of smaller communities in both Manitoba and North Dakota discharge secondary effluent directly into the Red River or into one of its many tributaries (a partial list of effluent discharge points in the Manitoba portion of the watershed can be found in EMO 1980).

Nutrient data from three long-term water quality sampling stations were used to assess trends in TN and TP in the Red River. This included an Environment Canada station at Emerson, MB (MA05OC0001) and two Manitoba Conservation stations located upstream (WQ0367 at the floodway gates at St. Norbert) and downstream of Winnipeg (WQ0142 at Selkirk). The trend analysis was limited to the period 1978 to 1999 (inclusive) because TN data were not available from station WQ0367 prior to 1978. Flow data for the analysis at station MA05OC0001 were obtained from hydrometric station MB05OC001, which is located in close proximity to the water quality sampling station. Flow data for the Red River at St. Norbert was insufficient for the trend analysis program. Therefore, flows for the analysis of WQ0367 were calculated by summing the flow data from the Red River at Ste. Agathe (hydrometric station MB05OC008) with those from the Rat River at Otterburne (hydrometric station MB05OE009). Flow data for the trend analysis of station WQ0142 were obtained from hydrometric station MB05OJ010, located approximately 9 km upstream at Lockport.

Data from 402 water samples were used in the trend analysis of TP at station MA05OC0001. Results of the trend analysis performed on the TP data show that there has been a significant (p=0.0108) trend of increasing flow-adjusted TP concentration (22.5% increase in median concentration) in the river at Emerson over the period 1978 to 1999 (Figure 3).

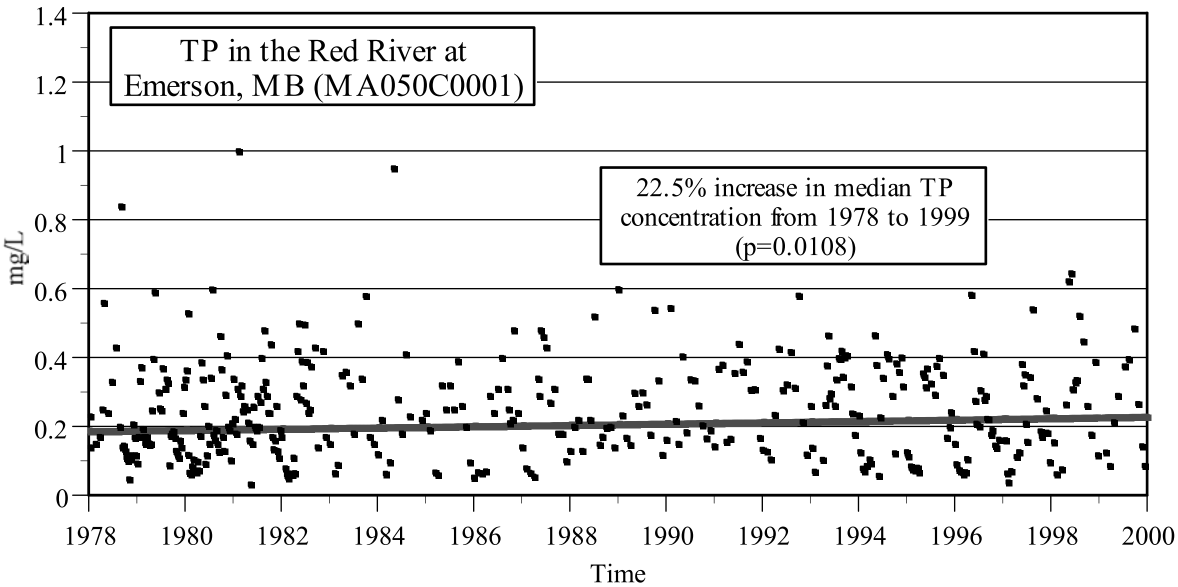


Figure 3. Trend in TP concentration in the Red River at Emerson, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

Data from 241 water samples were used in the trend analysis for TN at stations WQ0367 and WQ0142, while 240 data points were used for the analysis of TP at each site. It should be noted that, for the most part, the two sites have been sampled simultaneously since 1978.

Results of the analysis of the data from WQ0367 indicated that flow-adjusted TN concentrations at the site increased significantly ($p<0.0001$) since 1978 (Figure 4). The results of the analysis of TP data indicated that, unlike the results for TN, there was no significant trend ($p=0.1487$) in flow-adjusted concentrations of TP at the site over the 1978 to 1999 period (Figure5). Reported concentrations in TP varied considerably during this period, however, the lack of a significant trend in flow-adjusted concentrations suggested that most of this variation was related to changes in the flow regime at the site, rather than anthropogenic inputs to the system.

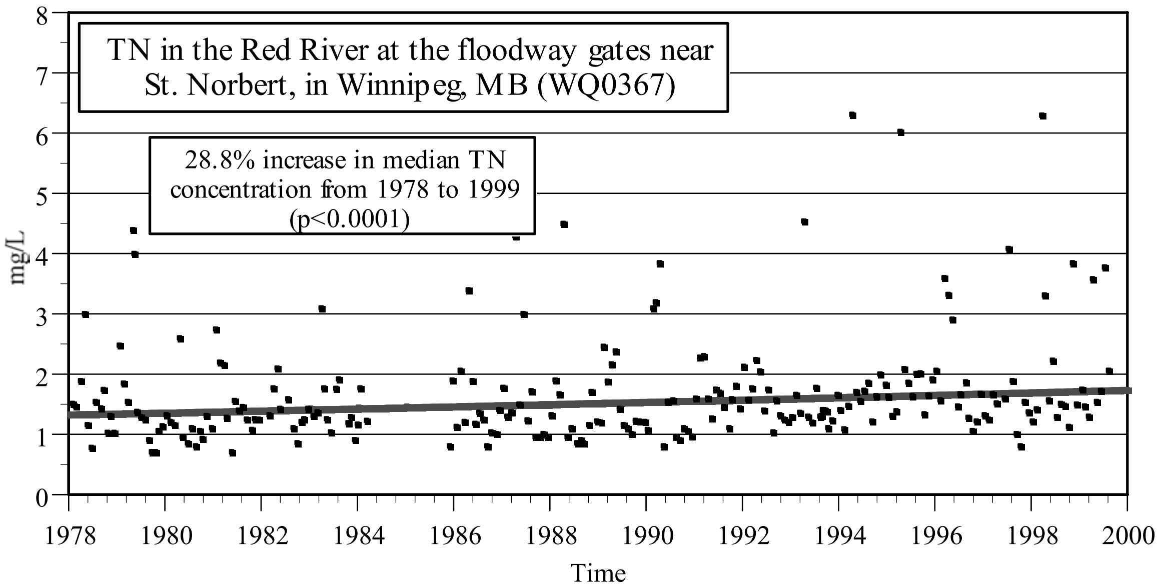


Figure 4. Trend in TN concentration in the Red River at the south floodway gates near St. Norbert, Winnipeg, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

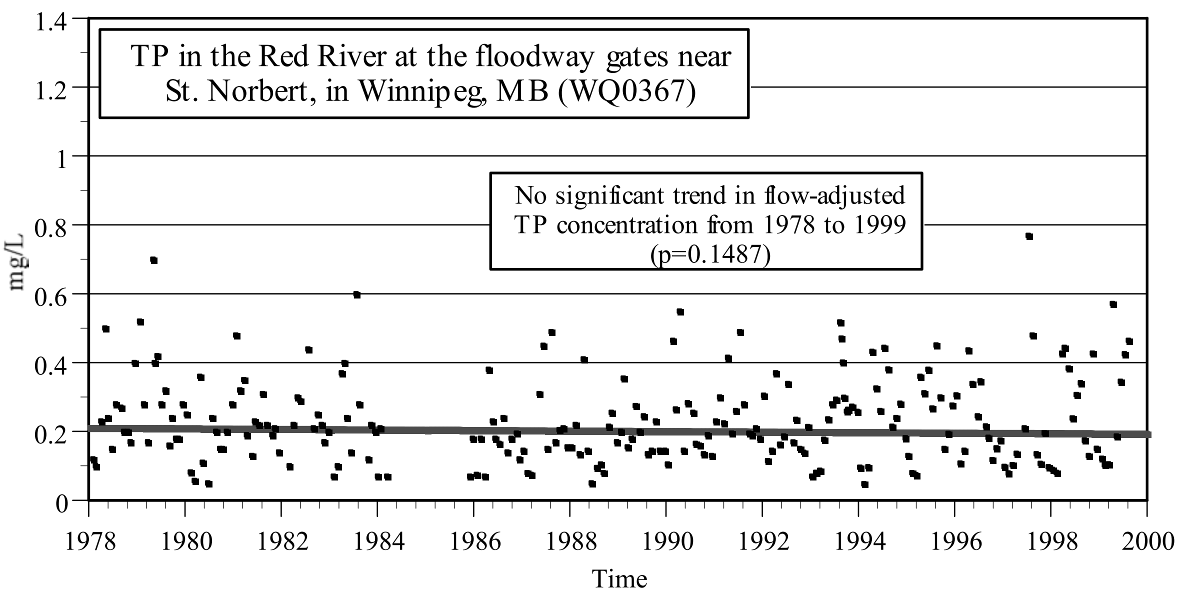


Figure 5. Trend in TP concentration in the Red River at the south floodway gates near St. Norbert, Winnipeg, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Trend analysis results for TN data at site WQ0142 indicated that flow adjusted TN concentrations increased quite dramatically over the 22-year period from 1978 to 1999. The trend in

TN at the site was highly significant ($p<0.0001$) with an increase in median TN concentrations of almost 60% (Figure 6). Similarly, TP at WQ0142 also showed a significant ($p=0.0003$), although less dramatic, trend of increasing flow-adjusted concentrations (28.8% increase in median concentration) (Figure 7). This was unlike the results reported for TP at WQ0367, which indicated that there was no significant trend for TP in the river. Comparison of the trends in TP and TN at WQ0367 with those at WQ0142 indicated that as the river passed through the Winnipeg region over the period of record, the concentration of nutrients in the river increased substantially. This increase in concentrations may be due to nutrient contributions from the Assiniboine, La Salle, and Seine Rivers, and numerous small creeks and drainage ditches, along with inputs from urban storm water run-off and treated effluent discharges from the City of Winnipeg and surrounding municipalities.

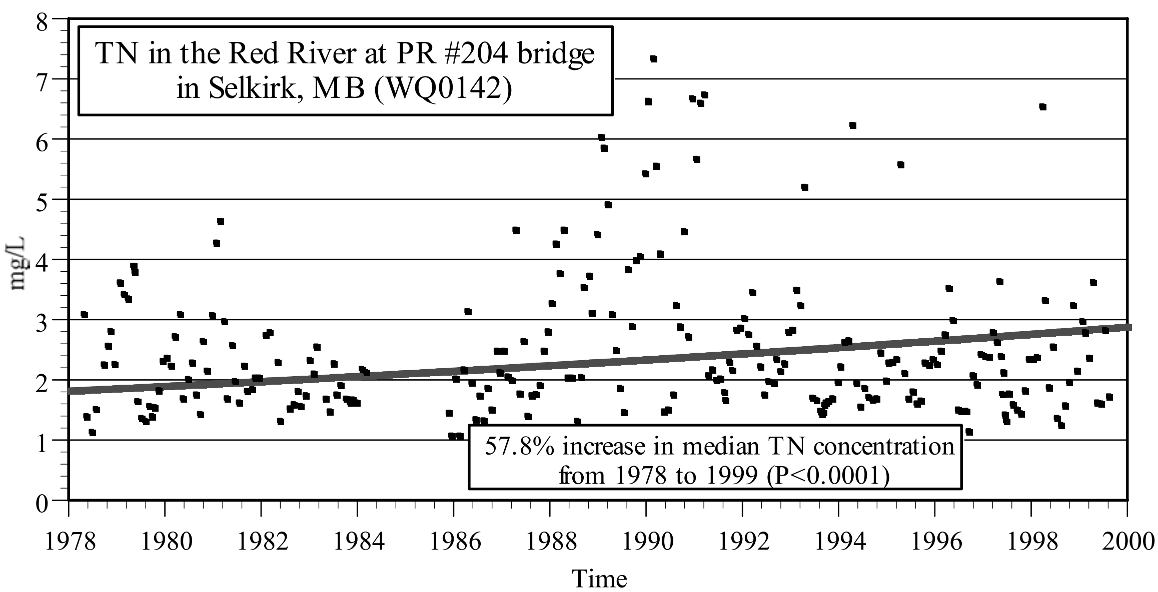


Figure 6. Trend in TN concentration in the Red River at the PR #204 bridge in Selkirk, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

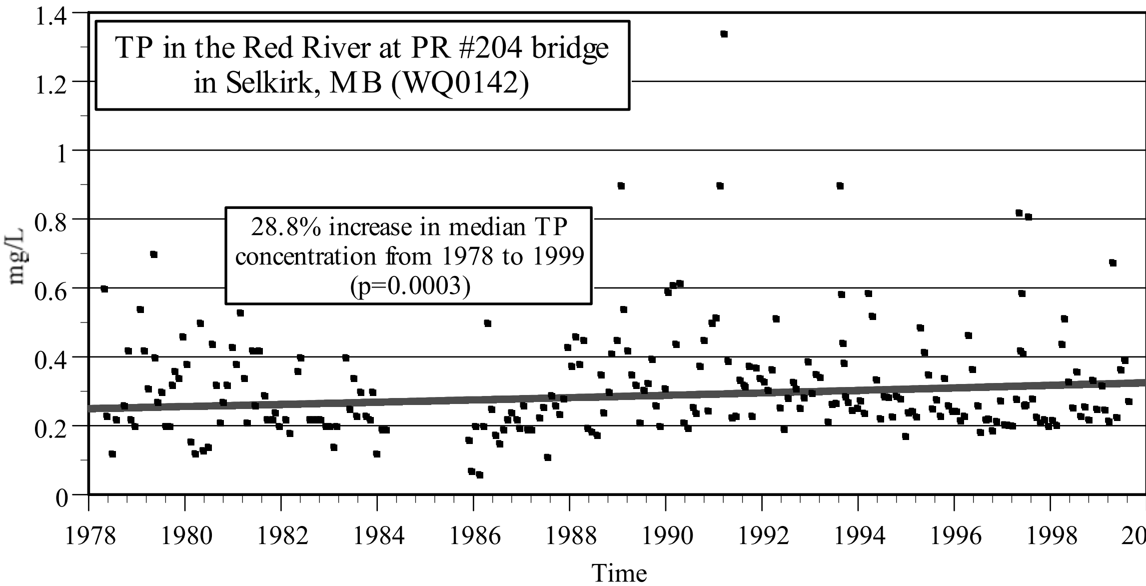


Figure 7. Trend in TP concentration in the Red River at the PR #204 bridge in Selkirk, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

Data collected at these long-term monitoring stations, and from numerous short-term monitoring stations along the Red River in Manitoba, indicate that TP and TN concentrations in the river are more than adequate to support the growth of algae (EMD 1980, Gregor and Chacko 1987, Chacko and Ronmark 1990, Goodman 1997). However, there have been few instances of excessive algal growth reported in the river. This may be due to the fact that the river is very turbid, which restricts light penetration into the water, and thus limits the amount of algal growth that can take place even though there is a readily available supply of nutrients (Goodman 1997). However, as the river empties into Lake Winnipeg the flow velocity declines and sediment particles settle, resulting in improved water clarity and an increased potential for algal bloom formation and macrophyte growth in the lake.

LA SALLE RIVER

The La Salle River is a tributary of the Red River and has its headwaters in a marshy area located about 10 km southeast of the City of Portage la Prairie (Figure 8). The river flows essentially eastward along a meandering course from its source to eventually converge with the Red River in St.

Norbert, at the south end of Winnipeg. The direct line distance from source to outlet is approximately 77 km, while the reach of the river is close to 140 km. The river drains a relatively large area (approximately 2460 km^2) of intensively cultivated agricultural land (Williamson 1984, Cowan and Therrien-Richards 1986). A number of livestock operations are also found throughout the watershed. As well, several municipal wastewater lagoons discharge secondary effluent into the river (EMD 1980). Thus, there is a high potential for nutrient inputs into the river from both point and non-point sources throughout the watershed.

The La Salle River is a multi-use waterway. It supports a number of fish species and is used recreationally for fishing and canoeing. In addition, it is used to some extent for agricultural livestock watering and irrigation purposes, and is also the source of raw water for several communities in the watershed.

The long-term water quality sampling station on the La Salle River (WQ0068) is located approximately 1.5 km upstream of the confluence with the Red River, near St. Norbert at the south end of Winnipeg. Trend analysis of TN and TP at the La Salle River site used data from 87 water samples collected from 1974 to 1999 (inclusive). Note that no samples were collected from 1978 to mid-1988. The flow data for the trend analysis were obtained from a hydrometric station (MB05OG001) located approximately 44 km upstream of the site near the community of Sanford.

The trend analysis results showed that TN and TP concentrations increased quite dramatically at the site over the period of reporting (Figures 9 and 10). The trends in flow-adjusted concentrations for both variables were highly significant ($P<0.0001$ for TN and $p=0.0043$ for TP). According to the analysis, the median flow-adjusted trend for TN increased 145.5% from 1974 to 1999, while the median of the trend in TP increased 193.8%.

The results from WQ0068 are of concern since they suggest that anthropogenic loading to the river has increased substantially over the last quarter century. However, the relatively wide gap in the data and the large distance between the flow station and the water quality sampling site decreases the degree of confidence in the results. A more detailed investigation to assess the nutrient loading within the watershed is warranted, particularly since the La Salle River provides fish habitat, and is an important water source for livestock and domestic consumption.

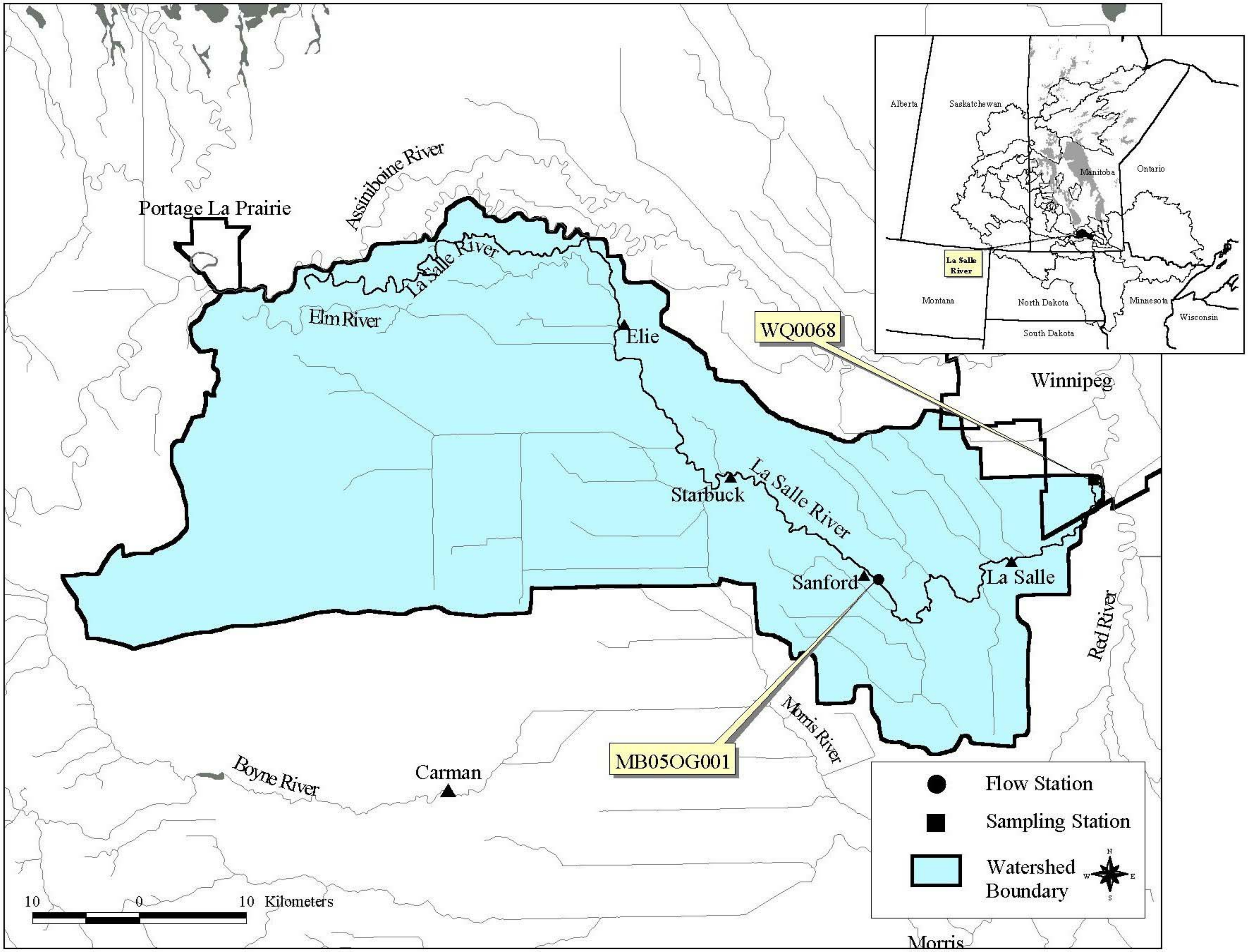


Figure 8. La Salle River watershed showing the location of water quality sampling site WQ0068 and hydrometric station MB05OG001 on the La Salle River.

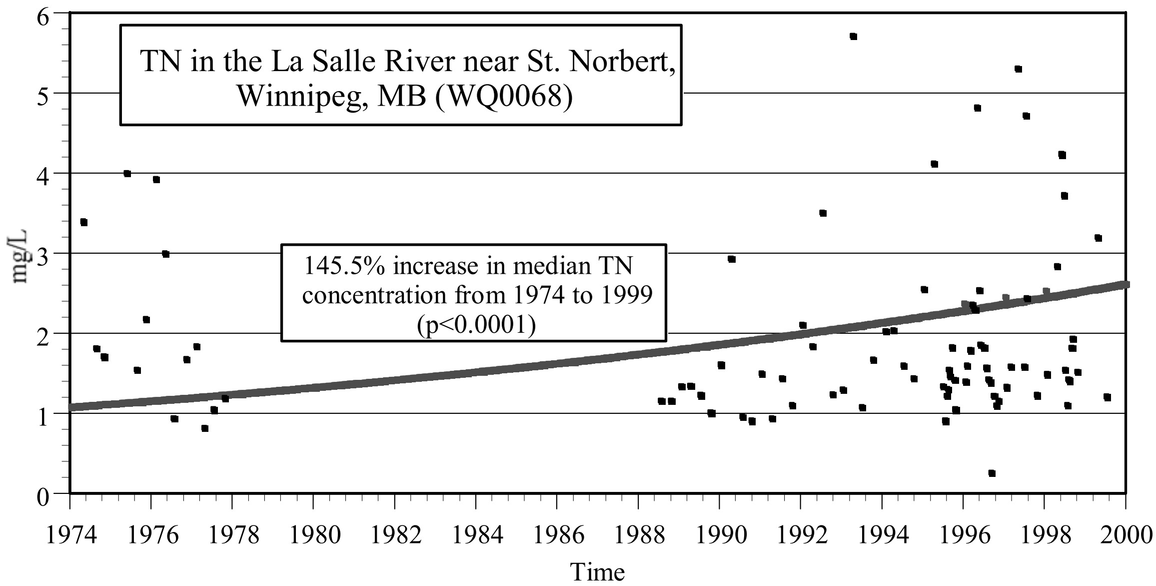


Figure 9. Trend in TN concentration in the La Salle River near St. Norbert, Winnipeg, MB, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

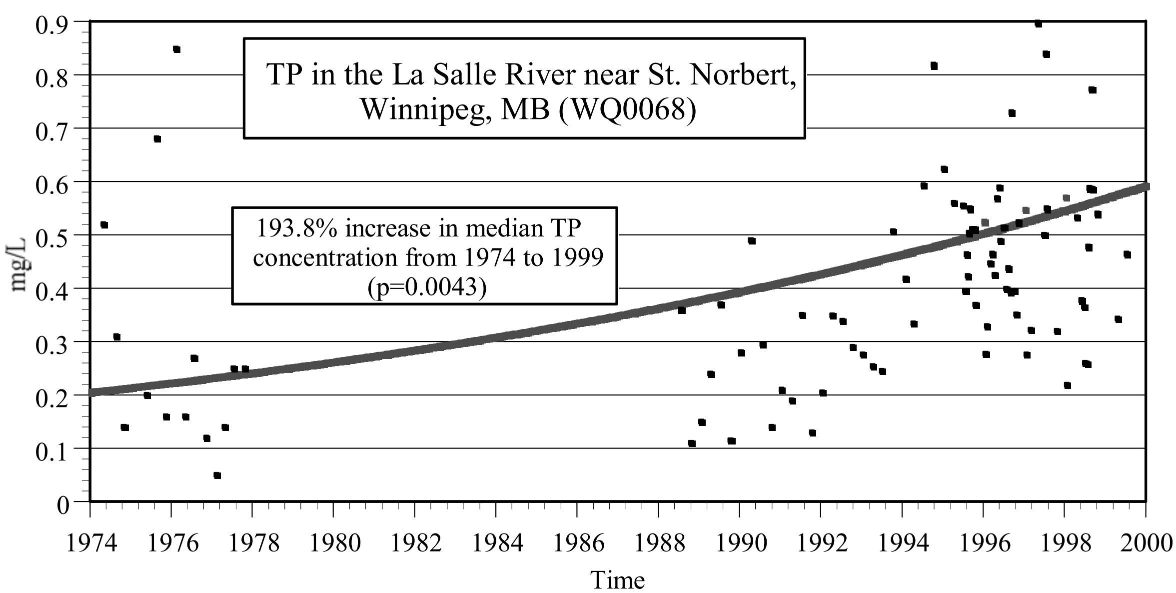


Figure 10. Trend in TP concentration in the La Salle River near St. Norbert, Winnipeg, MB, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

BOYNE RIVER

The headwaters of the Boyne River are located on the northeastern edge of the Pembina Hills region (portion of the Manitoba Escarpment) in southern Manitoba (Figure 11). From its headwaters the Boyne flows about 60 km before entering Stephenfield Reservoir – an impoundment created in 1963 to provide a dependable source of water for the agricultural industry in the area (Beck *et al.* 1992). The river exits the reservoir and flows approximately 33 km to a point east of the town of Carman where it is diverted from its natural course and channeled via the Norquay Channel a further 25km to empty into the Morris River. The Morris River flows southeastward for another 32 km to its confluence with the Red River. The Boyne River, including the Norquay Channel, drains an area of approximately 1325 km^2.

Much of the land in the river's watershed, particularly the portion east of the escarpment, is used for crop production. Treated effluent discharges along the course of the river include several Hutterite colony lagoons as well as a number of municipal lagoons (*e.g.* Treherne and Carman). Both the river and the reservoir are used extensively for agricultural purposes such as irrigation and livestock watering, as well as for recreational activities such as fishing, boating, canoeing, and swimming (Beck *et al.* 1992). The river is also the drinking water source for the town of Carman.

Data from water quality monitoring station WQ0029, located in the town of Carman, were used for the trend analysis of TN and TP concentrations in the Boyne River. Water quality sampling of the Boyne River has been carried-out by Manitoba Conservation at a number of monitoring stations over the past three decades. However, much of this sampling has been driven by issue-specific studies and long term data for a single station is lacking. Site WQ0029 was chosen for analysis because it has one of the longest available records of data collection for the river and is in close proximity to a hydrometric station (MB05OF003, approximately 6 km upstream of WQ0029). Flow data collection at the hydrometric station ceased at the end of 1996, which limited the TN and TP sample size for the trend analysis to 46 and 48 data points respectively. This is an inadequate sample size for the *QWTrend* program, which calls for a minimum of 60 data points. Therefore, the alternative analysis technique involving simple linear regression analysis of $\log_{10}$ nutrient and flow data was used to identify trends in the river (see Statistical Methods section for details).

The TN and TP data used in the trend analysis at WQ0029 extend from 1973 to the end of

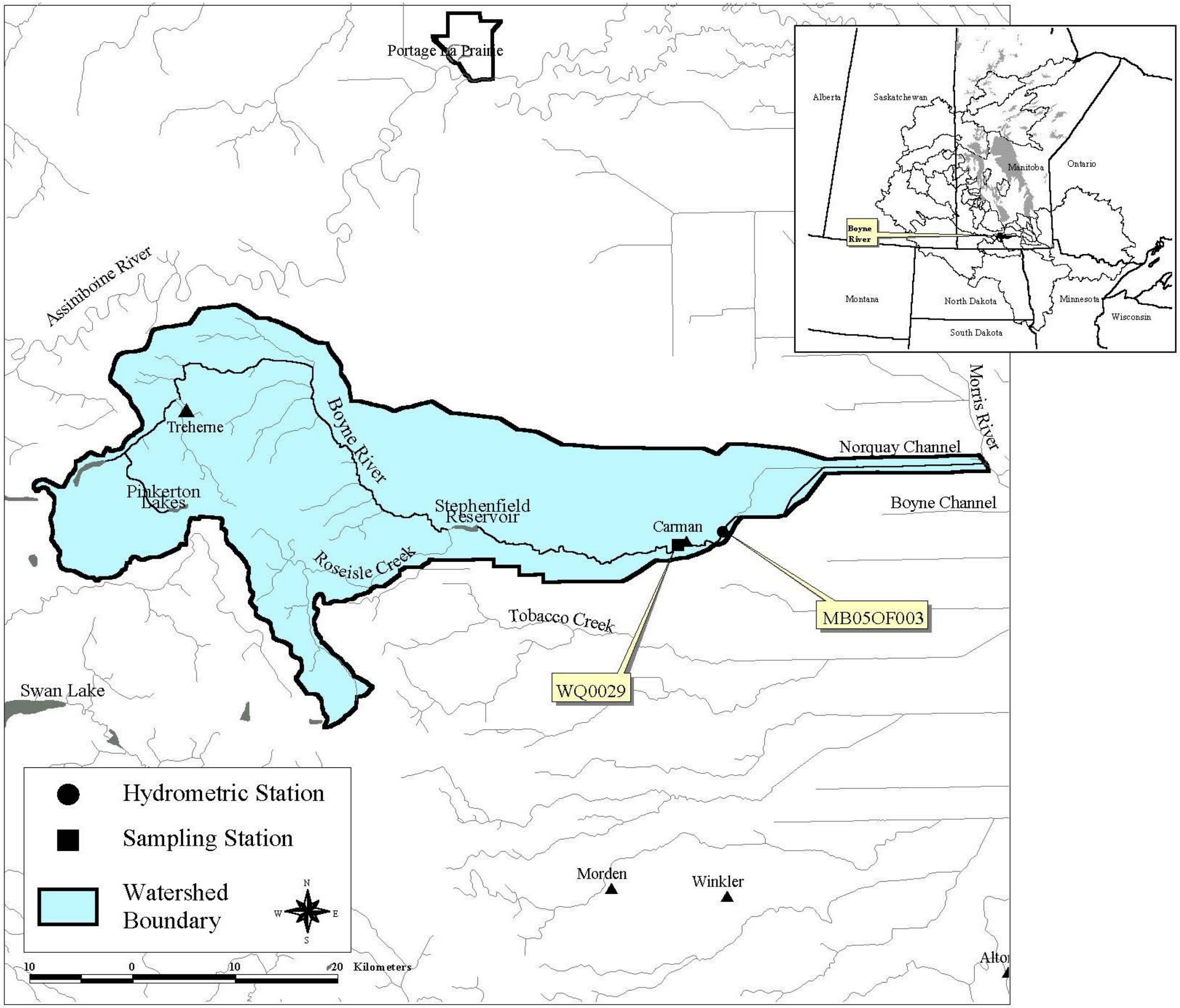


Figure 11. Boyne River watershed showing the location of water quality sampling site WQ0029 and hydrometric station MB05OF003 on the Boyne River.

1996, with a relatively large gap from 1979 through to 1989. The results of the trend analysis at the site indicated that concentrations of both variables increased over the reporting period (Figures 12 and 13). However, the p-values from the regression suggested that while the trend in increasing TP concentration was significant (p=0.0016), that of TN was not significant (p=0.0940).

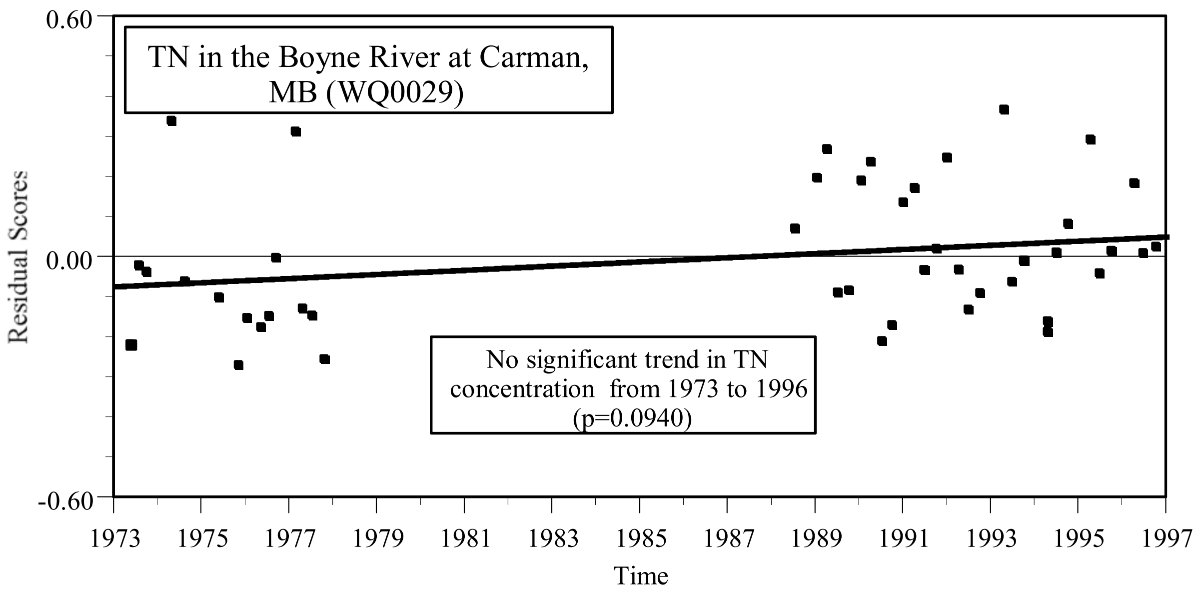


Figure 12. Trend in TN concentration in the Boyne River at Carman, MB, 1973 to 1996 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, which represents the trend in TN after accounting for variation due to flow.

PEMBINA RIVER

The Pembina River originates in the Turtle Mountains approximately 16 km south of the town of Boissevain near the border between Manitoba and North Dakota (Figure 14). The river flows in an easterly direction about half of its length from its headwaters across Southern Manitoba. It then veers south into North Dakota and meanders eastward to eventually empty in to the Red River just south of the international border near Pembina, North Dakota. Much of the river's approximately 390 km long course follows a deep, wide valley originally carved by the glacial Souris River following the most recent ice-age (CEC 1990). Alluvial deposits at a number of locations along the valley caused natural damming of the river, which resulted in the formation of a number of shallow lakes (International Pembina River Engineering Board 1964), the largest of which are Pelican, Rock, and Swan Lakes. The main tributaries of the Pembina River include Badger Creek and the Long River in

Manitoba, and the Little Pembina River and Tongue River in North Dakota. There are also numerous minor tributaries, including Pilot, Mary Jane, Crystal, and Snow Flake Creeks.

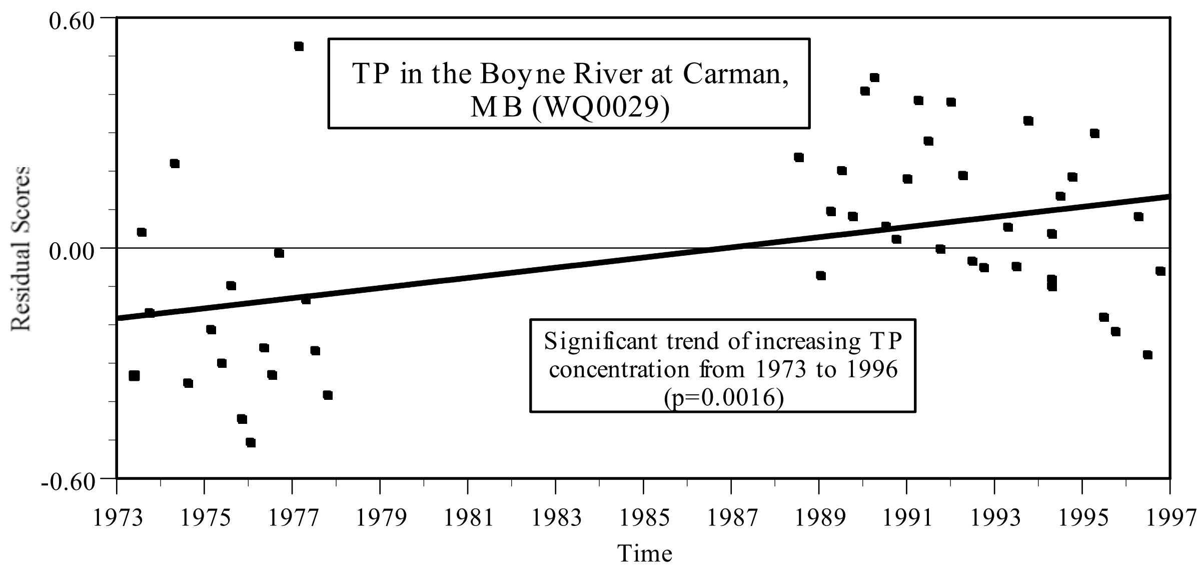


Figure 13. Trend in TP concentration in the Boyne River at Carman, MB, 1973 to 1996 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, which represents the trend in TP after accounting for the variation due to flow.

The Pembina River watershed covers approximately 9900 km^2. Roughly half of the watershed is in Manitoba with the other half in North Dakota. The area has long been recognized for its rich soils, and the land within the watershed has a lengthy history of agricultural use, including livestock production and crop cultivation (International Pembina River Engineering Board 1964). Thus, there is a high potential for non-point source nutrient loading to the rivers and lakes within the watershed. As well, several municipal lagoons discharge treated effluent directly to the river, or indirectly via one of its many tributaries. This is a concern since the river is a multi-use waterway. Water is drawn from the river for livestock watering, crop irrigation, and domestic consumption and the river and many of the lakes within the watershed are used for swimming, fishing, canoeing, and boating. Cottage development on some of the lakes, in particular Pelican and Rock Lakes, is quite extensive.

Data for the trend analysis TP in the Pembina River were obtained from Environment Canada water quality monitoring station MA05OB0001 located near Windygates, MB. Flow data for the analysis were obtained from hydrometric station MB05OB007, also located near Windygates, MB.

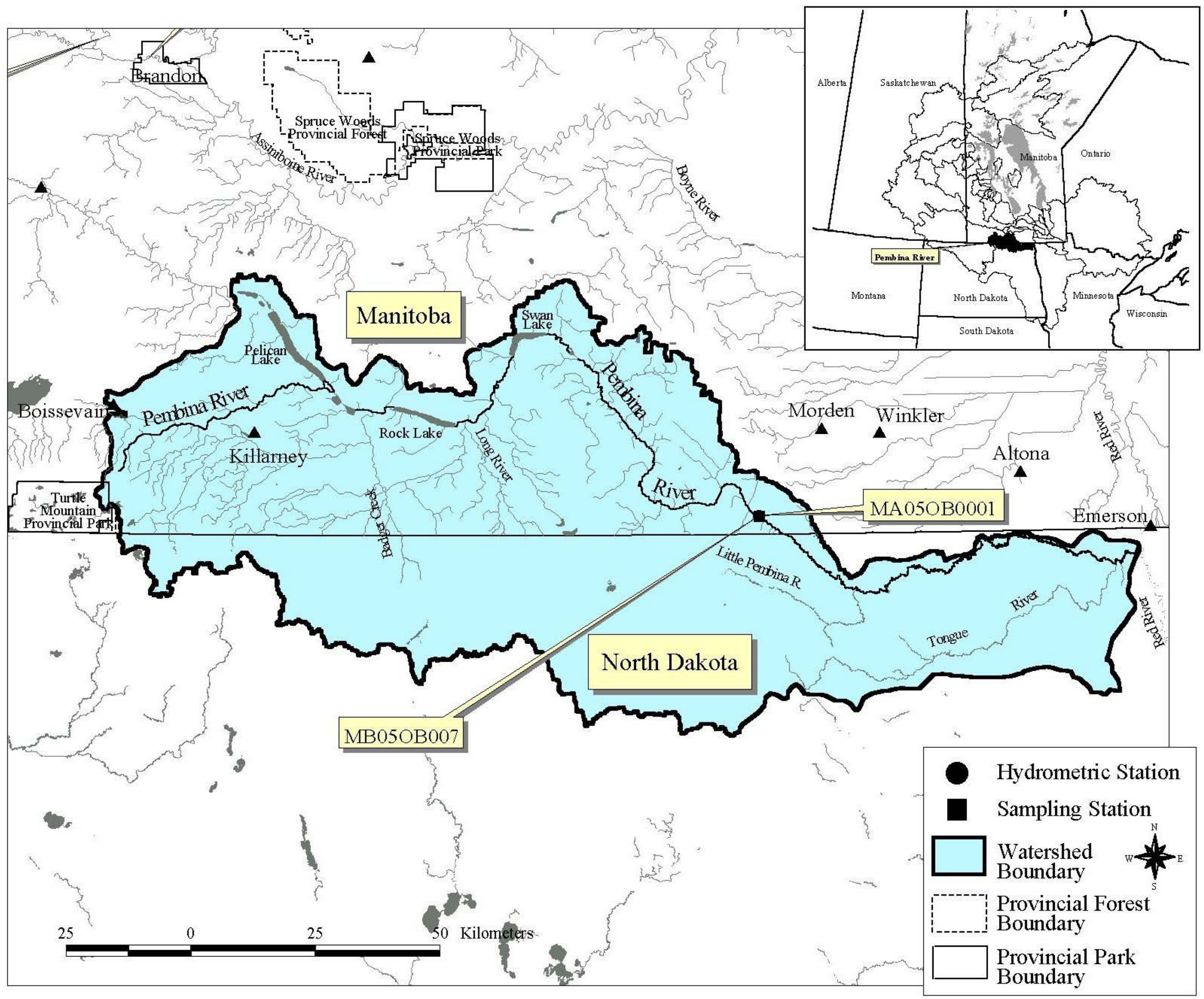


Figure 14. Pembina River watershed showing the location of water quality sampling site MA05OB0001 and hydrometric station MB05OB007 on the Pembina River.

Trend analysis for TP used data from 275 water samples collected from 1974 through 1999. Initial runs of the *QWTrend* program found that the PARMA model residuals were not normally distributed. Four outliers in the TP data were sequentially removed from the analysis in order to obtain normality in the residuals.

Results of the analysis showed a significant ($p<0.0001$) trend of increase in the flow-adjusted concentrations of TP in the river, with a calculated increase in the median of the flow-adjusted trend of some 52% for the entire period (Figure 15). The results suggested that anthropogenic loading of phosphorus to the river system has increased substantially over the past quarter century. The increasing trend in TP concentration is of concern since it helps promote excessive algal growth and in particular the development of blue-green algal blooms—which have been a fairly regular occurrence in many of the lakes and streams of the Pembina River system.

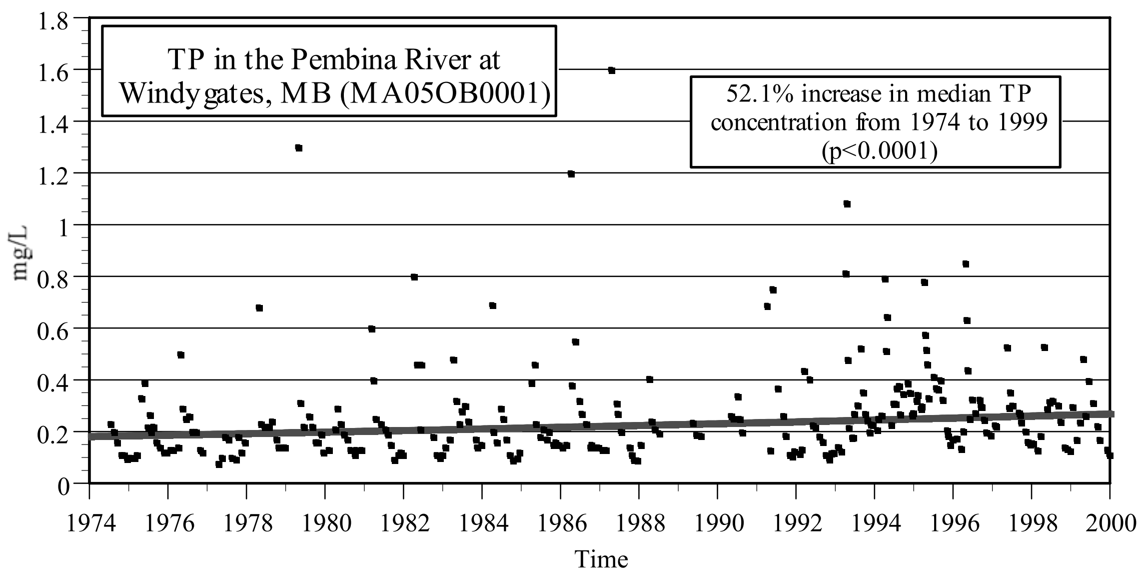


Figure 15. Trend in TP concentration in the Pembina River near Windygates, MB, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

ROSEAU RIVER

The Roseau River is an international waterway that originates in the Betrami Island Uplands area of northwestern Minnesota (Figure 16). The river flows north and then west by northwest through Minnesota and enters Manitoba north of the community of Caribou, MN. The river continues to meander in a westerly direction until its confluence with the Red River west of Dominion City, MB. Total length of the river is approximately 275 km, with roughly 175 km in Minnesota and 100 km in Manitoba. Important tributaries to the river include the South Fork Roseau River, the Hay River, Sprague Creek, and the Pine River. All these waterways join the Roseau in Minnesota, however, the Pine River and Sprague Creek have their headwaters in the Sandilands Provincial Forest region in Manitoba.

The Roseau River catchment area is a sub-unit of the much larger Red River watershed. The Roseau River watershed covers a land area of approximately 5850 km^2, almost 60% of which is located in Minnesota. Drainage within the watershed is generally poor and the river and immediate watershed area are subject to flooding. Numerous control structures and diversion channels have been constructed to control drainage within the watershed (International Roseau River Engineering Board 1975, Mills *et al.* 1977). Agricultural production is concentrated in the western half of the watershed because of the predominance of poorly drained depressions and forested uplands in the eastern portion of the watershed. Agricultural activities include livestock husbandry and cereal crop cultivation, with hay crop production to the east. Point sources of nutrients to the Roseau River include discharges of treated wastewater effluent from Roseau, MN and Dominion City, MB.

The water quality of the Roseau River has been monitored on a periodic basis at various locations since the 1960s (Chacko and Ronmark 1990, Ralley 1998, unpublished data in the Manitoba Conservation water quality database). These sources indicate that the water quality in the Roseau is similar to other streams in southern Manitoba, and that plant nutrient concentrations are high enough that a potential has existed for the growth and development of algal blooms in the river (International Roseau River Engineering Board 1975). This is cause for some concern since the river provides habitat for fish and associated riparian wildlife species, supports recreational activities such as sport fishing and canoeing, and is used for agricultural watering (Stepaniuk 1994).

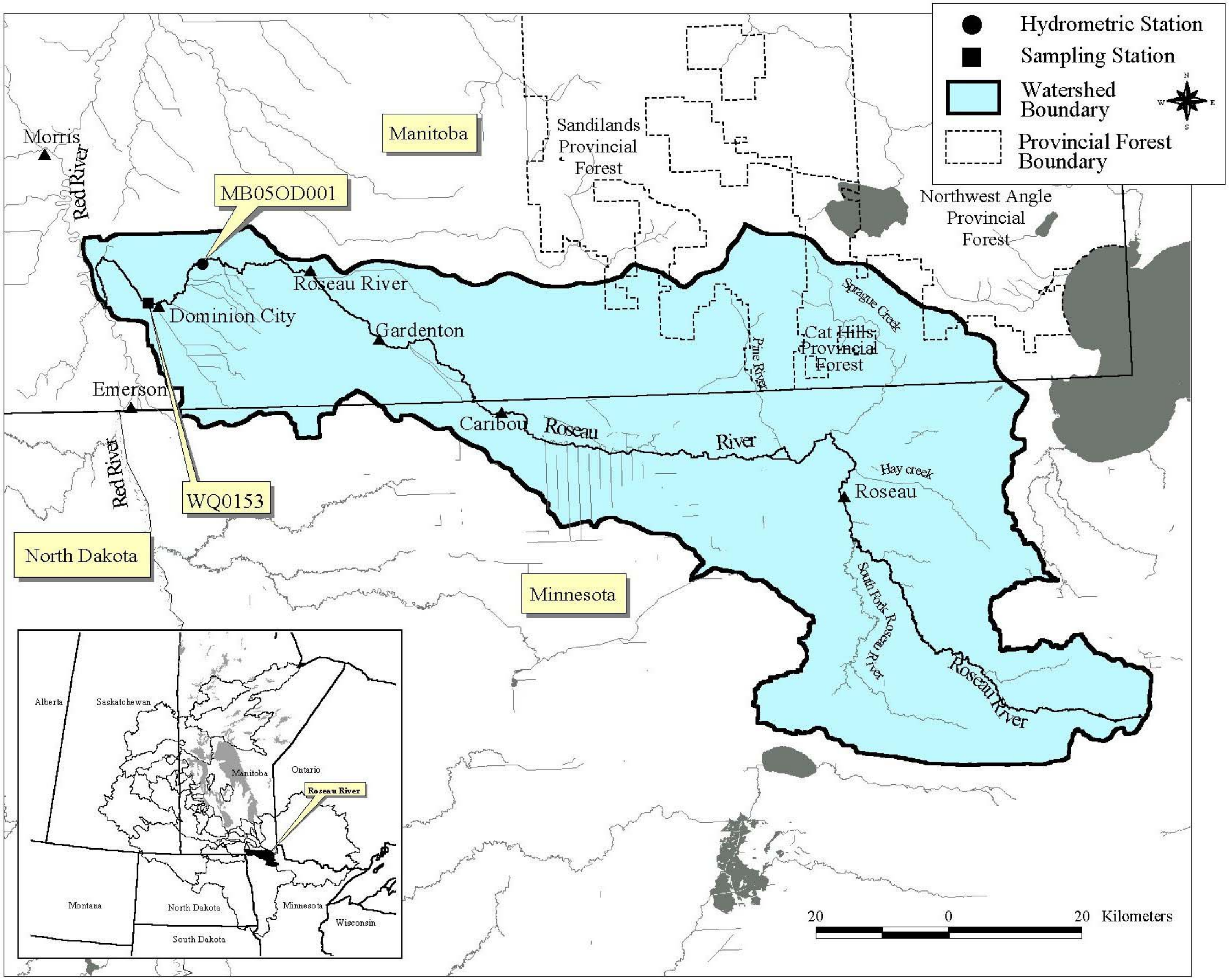


Figure 16. Roseau River watershed showing the location of water quality sampling site WQ0153 and hydrometric station MB05OD001 on the Roseau River.

Trend analysis of TN and TP in the Roseau River was conducted on data collected from water quality station WQ0153, located at the dam near PR #200, immediately downstream of Dominion City (but upstream of the community's lagoon discharge). Flow data for the analysis were obtained from hydrometric station MB05OD001, which is located approximately 15 km upstream of the water quality monitoring site. Total nitrogen and TP data from 60 water samples collected from 1973 through 1999 were used in the analysis. Note that there was a gap in the collection of TN and TP data from 1978 to 1988.

The results of the trend analysis showed that concentrations of TN and TP, when adjusted for river flow, increased significantly ($p<0.0001$) over the period of reporting (Figures 17 and 18). Furthermore, an overall rise of over 45% in the median value of the flow-adjusted trend indicated that this increase was quite substantial. There was concern that the relatively large gap in reported data and the small number of samples available for the analysis would detract from the validity of the analysis results. However, even though the data set was small, the calculated PARMA model residuals were normally distributed, which provided some assurance as to the legitimacy of the results.

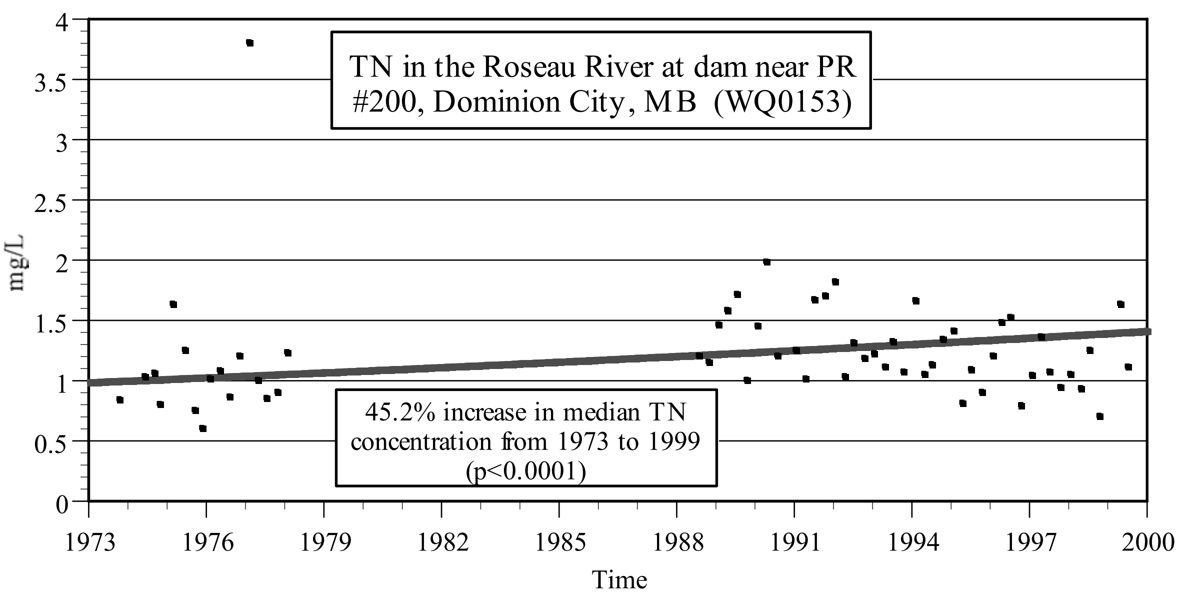


Figure 17. Trend in TN concentration in the Roseau River at the dam near PR #200 Dominion City, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

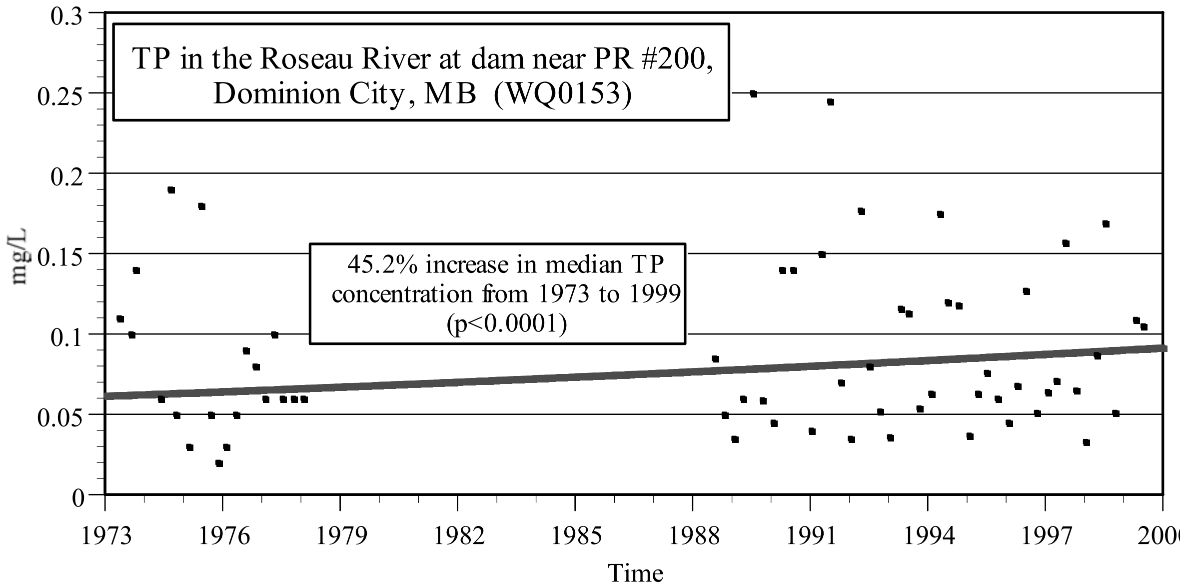


Figure 18. Trend in TP concentration in the Roseau River at the dam near PR #200 Dominion City, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

RAT RIVER

The headwaters of the Rat River are located in the Sandilands Provincial Forest region of southeastern Manitoba (Figure 19). The river flows westward and northwestward from its headwaters for a total distance of approximately 130 km before emptying into the Red River. Major tributaries of the river include the Sand River, Joubert Creek, and the Marsh River. The river is dammed at St. Malo to form an impoundment (St. Malo Reservoir) that is used as a source of drinking water for the community. The river also provides fish and wildlife habitat, and is used for recreational activities and livestock watering.

The Rat River watershed is located immediately north of the Roseau River watershed and encompasses an area of approximately 1940 km^2. Forested uplands, marshes, and poorly drained peatlands characterize much of the eastern portion of the watershed, thus limiting agricultural uses in the east to pasture, rangeland, and hay crops, and restricting cereal and specialty crop cultivation to the western half of the catchment.

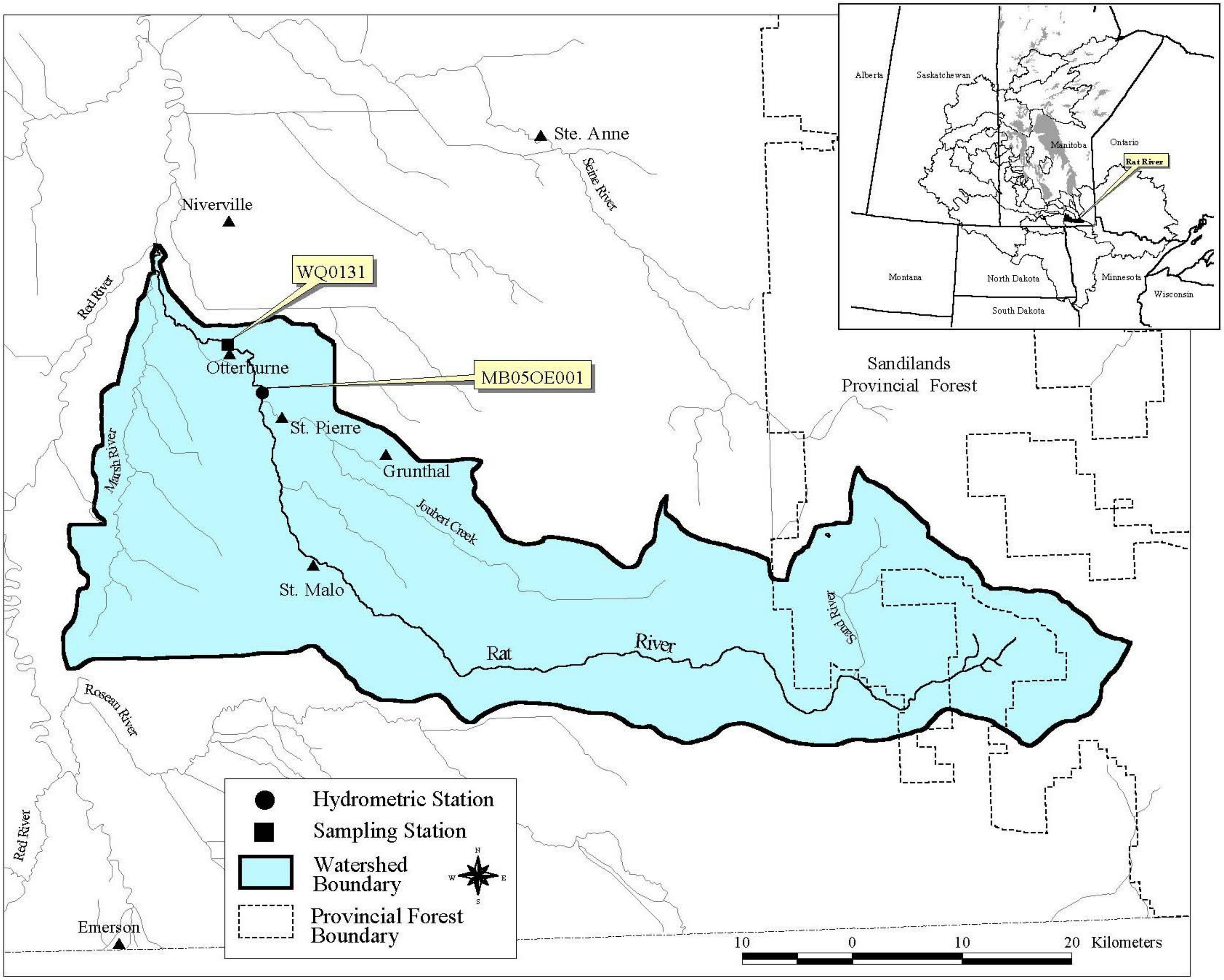


Figure 19. Rat River watershed showing the location of water quality sampling site WQ0131 and hydrometric station MB05OE001 on the Rat River.

Major point sources discharging treated effluent to the Rat River upstream of the water quality sampling station include wastewater treatment facilities at St. Pierre, St. Malo, St. Malo Provincial Park, the Winnipeg Bible College (located east of Otterburne), and Grunthal (via Joubert Creek).

Data from water quality sampling station WQ0131, at PR #303 near Otterburne, MB, were used in the trend analysis of TN and TP in the Rat River. Flow data for the trend analysis were obtained from hydrometric station MB05OE001, located approximately 7.5 km upstream of WQ0131 near the confluence of Joubert Creek. The data set at WQ0131 contained 51 data points for TN and 54 data points for TP. The data were collected over the period 1973 - 1999, with a 10-year gap in the data from 1978 to 1987. The *QWTrend* program could not be used to analyze the data because the sample size was too small. Therefore the alternate method of trend analysis involving simple linear regression was employed. The results of this analysis indicated that TN at site WQ0131 has remained fairly stable since 1973 (p=0.0785) (Figure 20). However, the results of the trend analysis of the TP data showed that concentrations of TP increased significantly (p=0.0026) over the same time period (Figure 21).

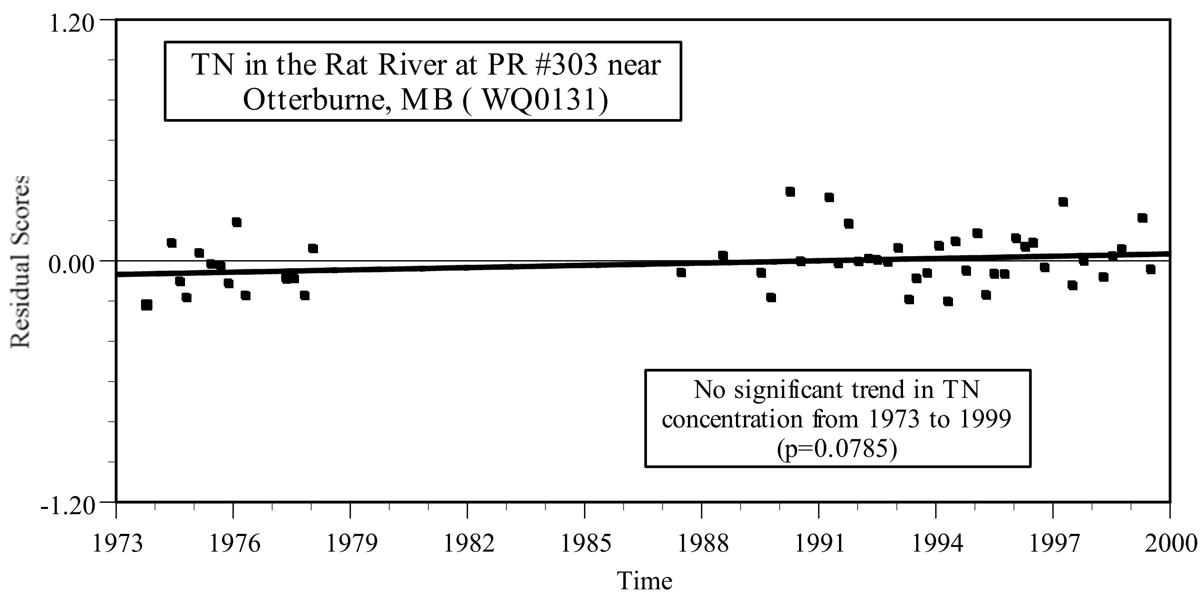


Figure 20. Trend in TN concentration in the Rat River at PR #303 near Otterburne, MB, 1973 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

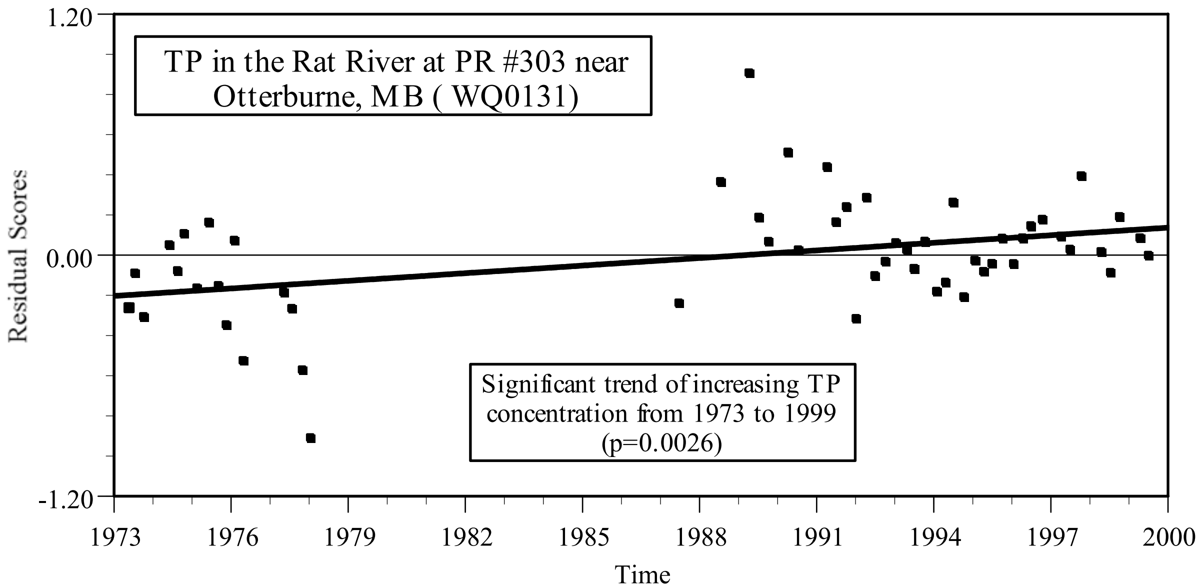


Figure 21. Trend in TP concentration in the Rat River at PR #303 near Otterburne, MB, 1973 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

MARSH RIVER

The Marsh River has its headwaters in a wetland area west of the small community of Arnaud, MB (Figure 22). The Marsh is a tributary of the Rat River and its confluence with the Rat River occurs approximately 4 km upstream of the Rat River's confluence with the Red River. The Marsh River flows northward from its origin for approximately 42 km before emptying into the Rat River. There are a few small creeks and coulees as well as numerous ditches and drains that flow into the Marsh River. The catchment area drained by the Marsh River is approximately 410 km^2. Most of the land within this catchment is intensively cultivated with cereal and specialty crops. Although no licensed wastewater facilities discharge effluent directly to the river, there are a number of settlements and agricultural operations within the watershed that use land application as a means of disposal of treated domestic and livestock wastes.

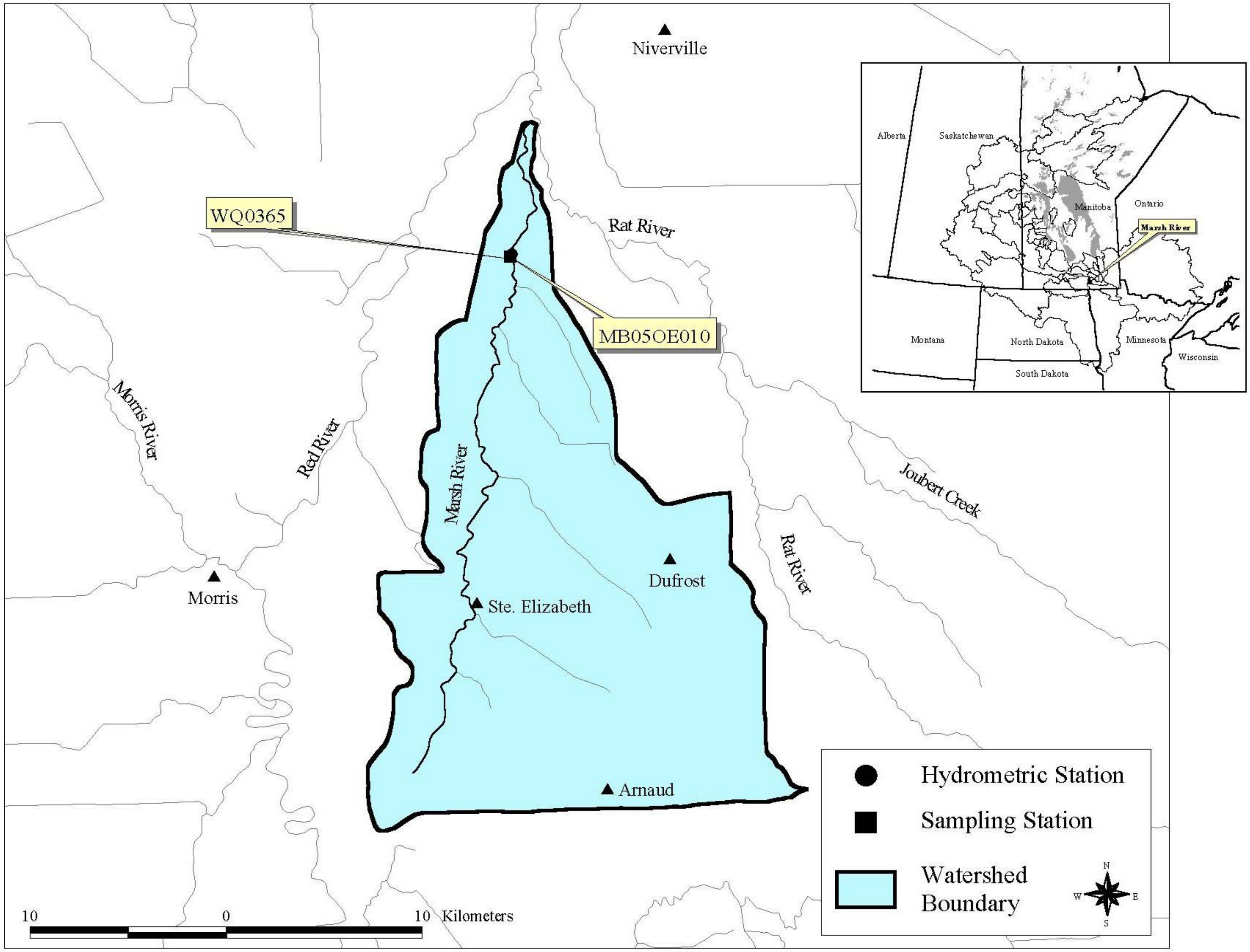


Figure 22. Marsh River watershed showing the location of water quality sampling site WQ0365 and hydrometric station MB05OE010 on the Marsh River.

Data for the trend analysis of TN and TP in the Marsh River were obtained from water quality sampling station WQ0365, located at PR #303 west of Otterburne, MB. Flow data for the trend analysis were obtained from hydrometric station MB05OE010, which is located in close proximity to the water quality sampling site. Total nitrogen and TP data were obtained from 84 and 86 water samples respectively, collected from 1978 to 1999. Note that there was a gap in the data collection from 1984 to mid-1988.

The results of the *QWTrend* analysis on the data revealed significant positive trends in flow-adjusted concentrations for both TN ($p<0.0001$) and TP ($p=0.0100$) over the period of reporting (Figures 23 and 24). The median value of the flow-adjusted trend in TN more than doubled from 1978 to 1999, while that of the TP trend line increased by almost 66%. Both trends were quite dramatic and, because point sources within the watershed are few, likely reflect an increase in non-point source loading, as well as the influence of periodic flooding and back up of water from the Red and Rat Rivers (Hughes 2001).

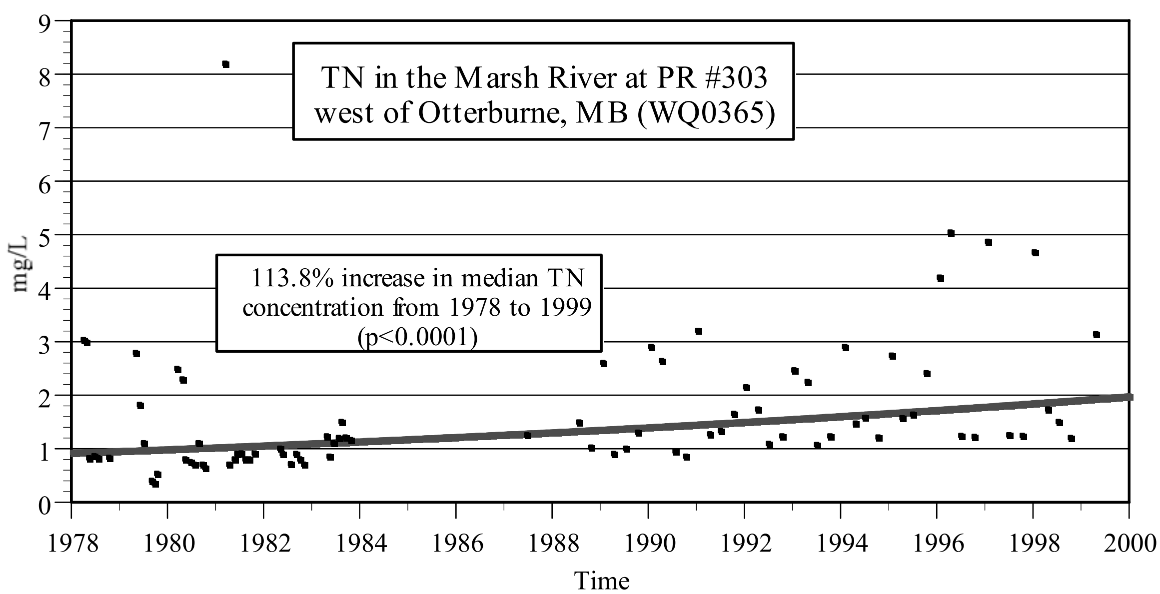


Figure 23. Trend in TN concentration in the Marsh River at PR #303 west of Otterburne, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

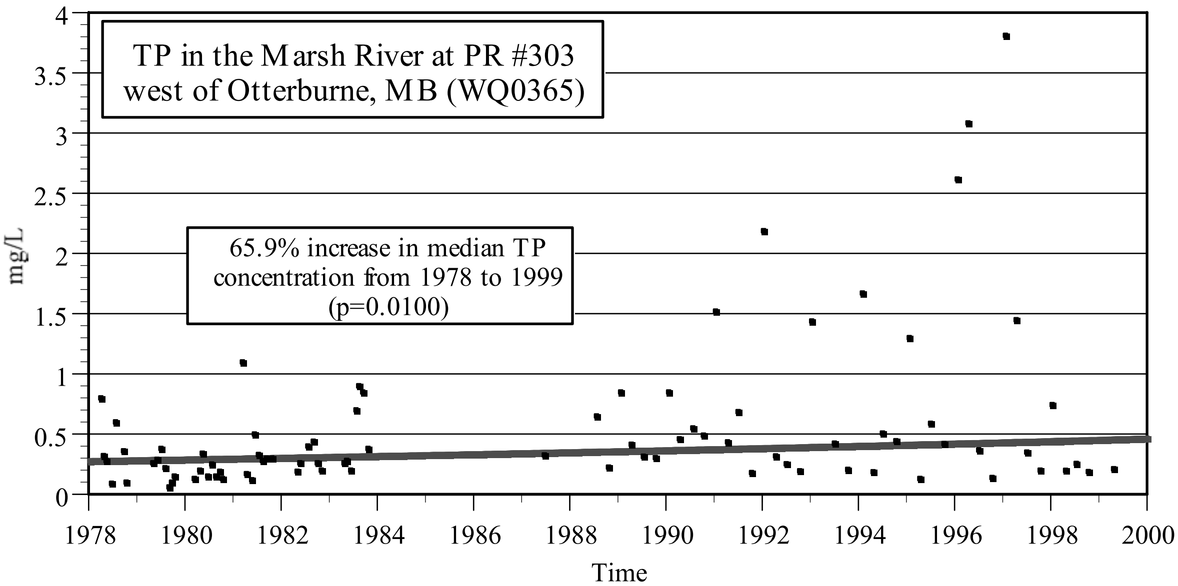


Figure 24. Trend in TP concentration in the Marsh River at PR #303 west of Otterburne, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

SEINE RIVER

The Seine River flows approximately 120 km from its headwaters in the Sandilands Provincial Forest to its confluence with the Red River in the city of Winnipeg (Figure 25). The river drains approximately 1600 km^2 of land, much of which is dedicated to intense cereal crop cultivation and livestock production, including beef and dairy cattle, chickens, and hogs. All of this agricultural activity creates a high potential for non-point source nutrient loading to the river. Municipal wastewater lagoons have discharged secondary treated effluent to the river in the past. These include lagoons at the communities of La Broquerie, Ste. Anne, and Lorette. The La Broquerie and Ste. Anne facilities continue to discharge to the river, while the lagoon at Lorette ceased operation at the end of 1999. A number of other wastewater facilities operate within the watershed, however, discharge from these facilities is either applied to land or is directed to the Red River via the Seine River Diversion.

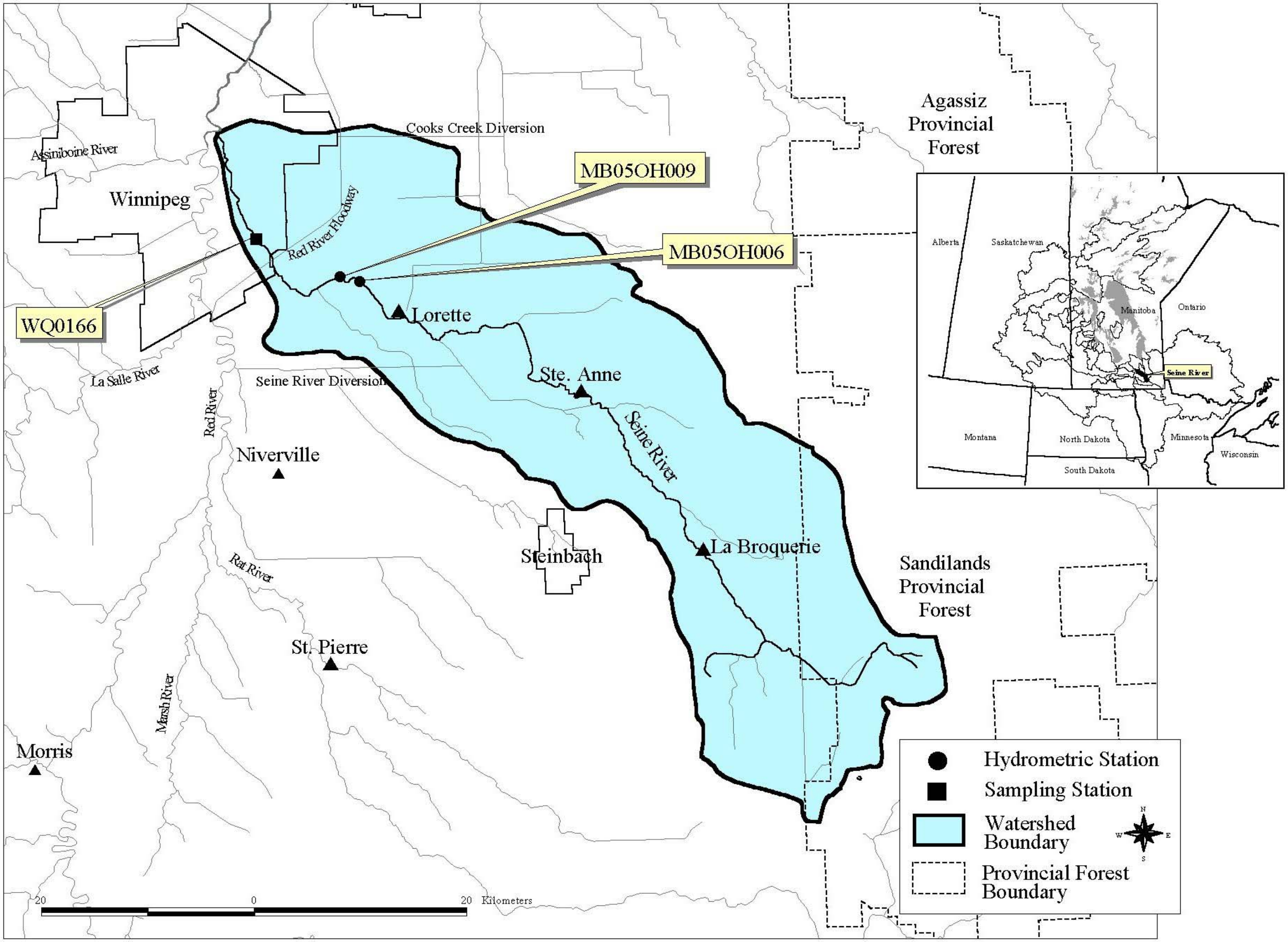


Figure 25. Seine River watershed showing the location of water quality sampling site WQ0166 and hydrometric stations MB05OH006 and MB05OH009 on the Seine River.

Trend analysis of TP and TN in the Seine River used water sample data collected from station WQ0166 located at the south perimeter highway in the southeast region of Winnipeg. Total phosphorus data from 119 water samples and TN data from 118 water samples collected from 1973 to 1999 (inclusive) were used in the analysis. Flow data for the analysis were obtained from two hydrometric stations (MB05OH006 and MB05OH009) located approximately 12 km upstream of WQ0166 near the small locality of Prairie Grove. Hydrometric station MB05OH006 provided flow data from 1973 through to mid-May 1986, while flow data to the end of 1999 were obtained from MB05OH009. Insertion of a step trend in the analysis was deemed unnecessary since the flow station locations are very close together along the river (within 2 km of each other).

Results of the trend analysis on TN indicated that there has been a significant ($p<0.0001$) increase in flow-adjusted TN in the Seine River at site WQ0166 since 1973 (Figure 26). The results from the analysis of the TP data showed that when adjusted for flow, concentrations of TP in the river at WQ0166 have increased dramatically ($P<0.0001$), with an overall increase in the median of the trend in excess of 187%, or almost 4% per year, since 1973 (Figure 27).

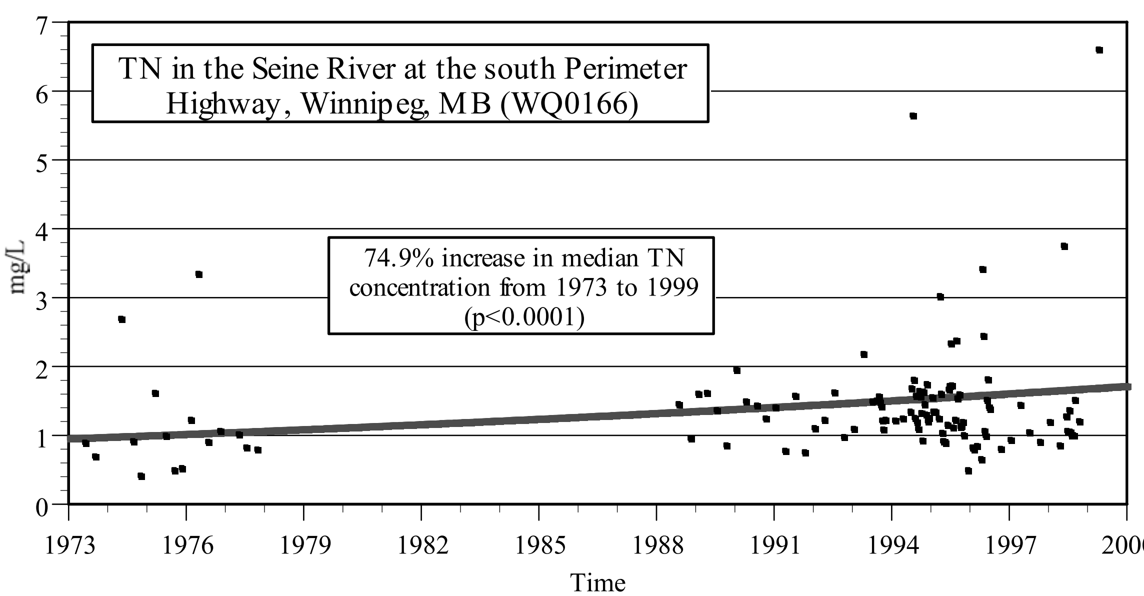


Figure 26. Trend in TN concentration in the Seine River at the south Perimeter Highway, Winnipeg, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

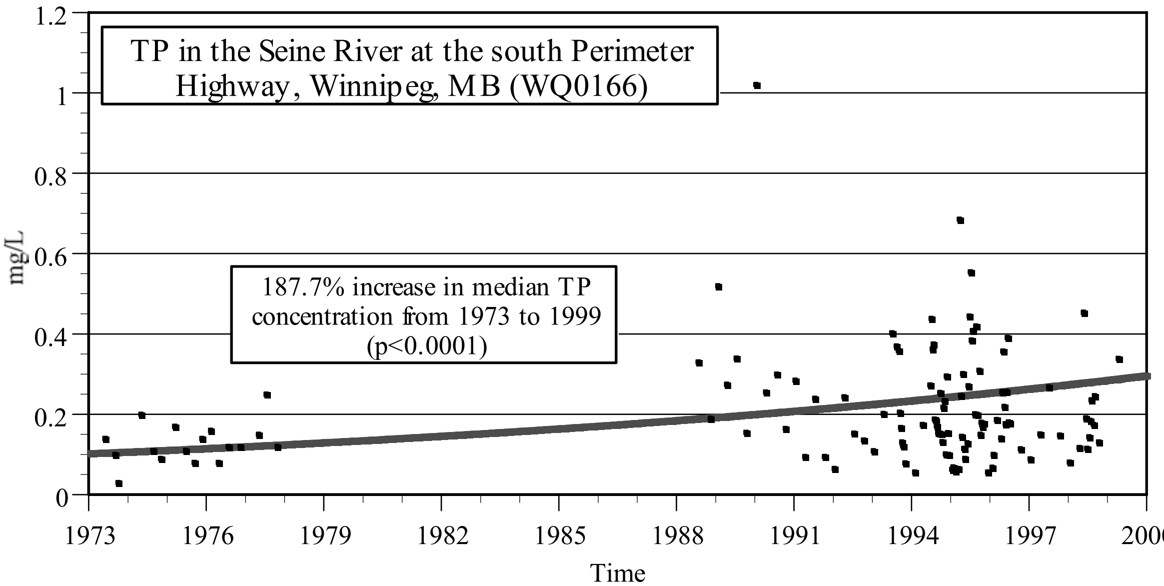


Figure 27. Trend in TP concentration in the Seine River at the south Perimeter Highway, Winnipeg, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

COOKS CREEK

Cooks Creek is a relatively small waterway that has its headwaters in a marshy peatland area east of Winnipeg, near Richer, Manitoba (Figure 28). The creek flows in a northerly direction for approximately 60 km before emptying into the Red River near the city of Selkirk. The catchment area of the creek is approximately 750 km^2. While the eastern and southern extremes of the watershed include forested uplands with limited agricultural activity, the majority of the watershed is relatively flat lowland and is subject to intense cultivation. Much of the creek upstream of the community of Cooks Creek has been dredged and channeled for purposes of flood control and agricultural use (Hughes 2000). During periods of high water, the flow in the upper reach of the creek is diverted westward to the Red River Floodway via the Cooks Creek Diversion.

Hughes (2000) found that although phosphorus levels tended to be highest in the lower reaches of the creek, they were generally more than adequate to support excessive primary production along the entire length of the creek. Inputs of nutrients (such as phosphorus) to the creek include non-point source run-off from fields and livestock operations, and effluent discharges from the municipal wastewater treatment facility at Oakbank (Hughes 2000).

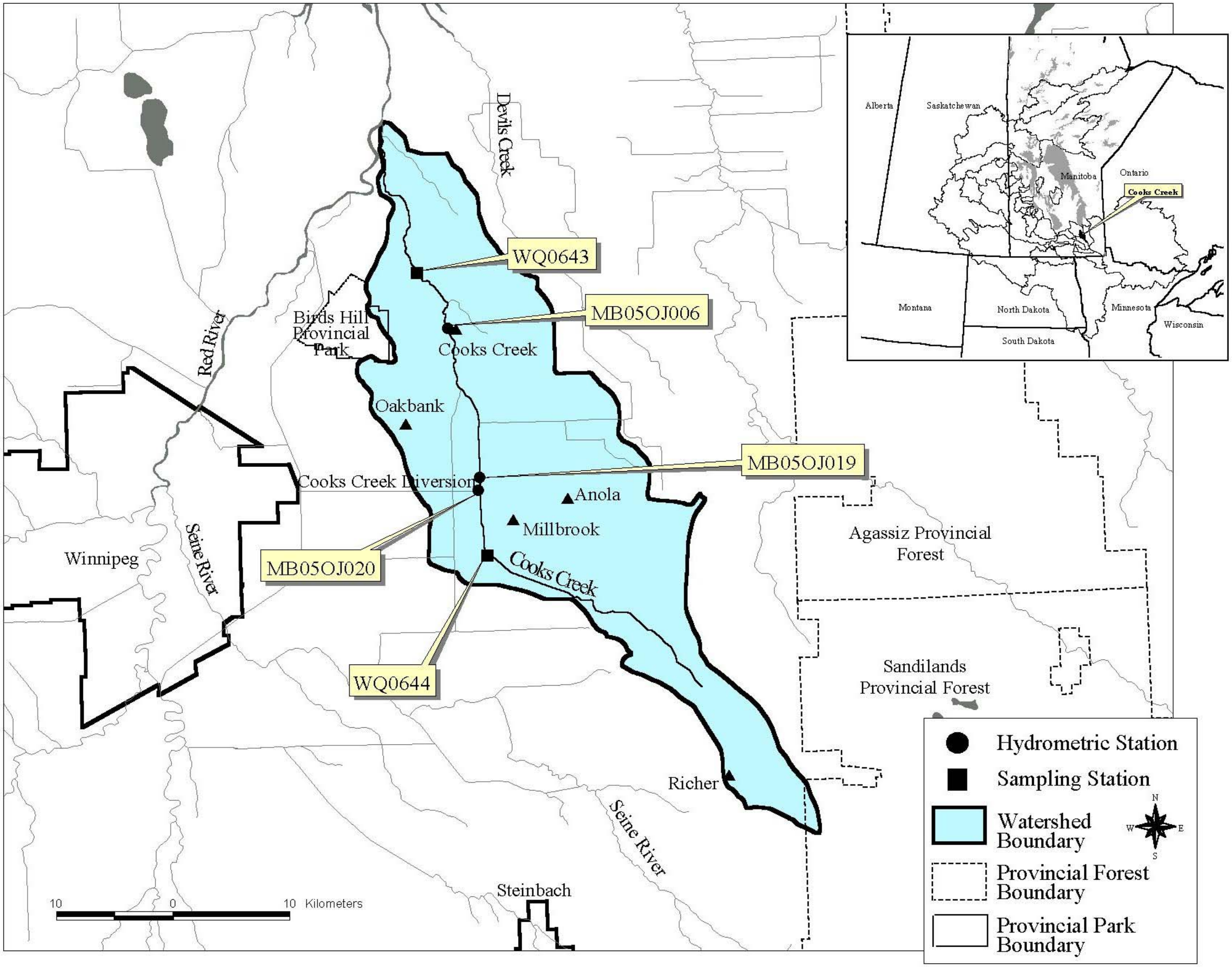


Figure 28. Cooks Creek watershed showing the location of water quality sampling sites and hydrometric stations on Cooks Creek and the Cooks Creek Diversion.

Data from two separate water quality monitoring stations -- WQ0644 and WQ0643 -- were used in the trend analysis of TN and TP in Cooks Creek. Station WQ0644 is located in the upstream portion of the watershed near the community of Millbrook, while station WQ0643 is located in the downstream portion of the watershed on the boundary between the Rural Municipalities of Springfield (south) and St. Clements (north). Data from 50 water samples collected at WQ0644 and 56 samples collected at WQ0643 during the period 1990 to 1999 (inclusive) were used for the trend analysis. The period of reporting was too short and the number of samples too few for the *QWTrend* program. Therefore, the alternate method of analysis using simple regression was used to identify trends in the data.

Stream flows for the trend analysis of data from WQ0644 were estimated by summing the flow data from hydrometric station MB05OJ019, located about 6.5 km downstream of WQ0644, with that of hydrometric station MB05OJ020, which is located in the Cooks Creek Diversion channel. Hydrometric station MB05OJ006 is the closest hydrometric station to WQ0643. However, because the flow data record at MB05OJ006 ended in 1994, we elected to use the more complete flow data record available from MB05OJ019 for the trend analysis of TN and TP at WQ0643.

The results of the statistical analysis at site WQ0644 indicated that there was a significant trend ($p=0.0219$) of decreasing TN concentration at the site during the 1990s (Figure 29). The same case cannot be made for TP concentrations, which fluctuated quite widely and did not exhibit a significant trend over the period of reporting ($p=0.0929$) (Figure 30). No significant trends were detected in either TN ($p=0.3659$) or TP ($p=0.2858$) at site WQ0643 (Figures 31 and 32). The decreasing trend in TN at WQ0644 and no detectable trend at WQ0643 implied that TN loading declined in the upper portion of the creek, but remained fairly constant in the downstream reaches of the creek over the period of reporting. Although a there was no significant trend in TP at either site, the switch from a negative slope in the regression line at WQ0644 to a positive slope at WQ0643 suggested that inputs of TP to the creek have been increasing downstream of WQ644. This is possible given that the portion of the creek downstream of WQ0644 has been more susceptible to nutrient inputs from agricultural run-off and wastewater effluent discharges.

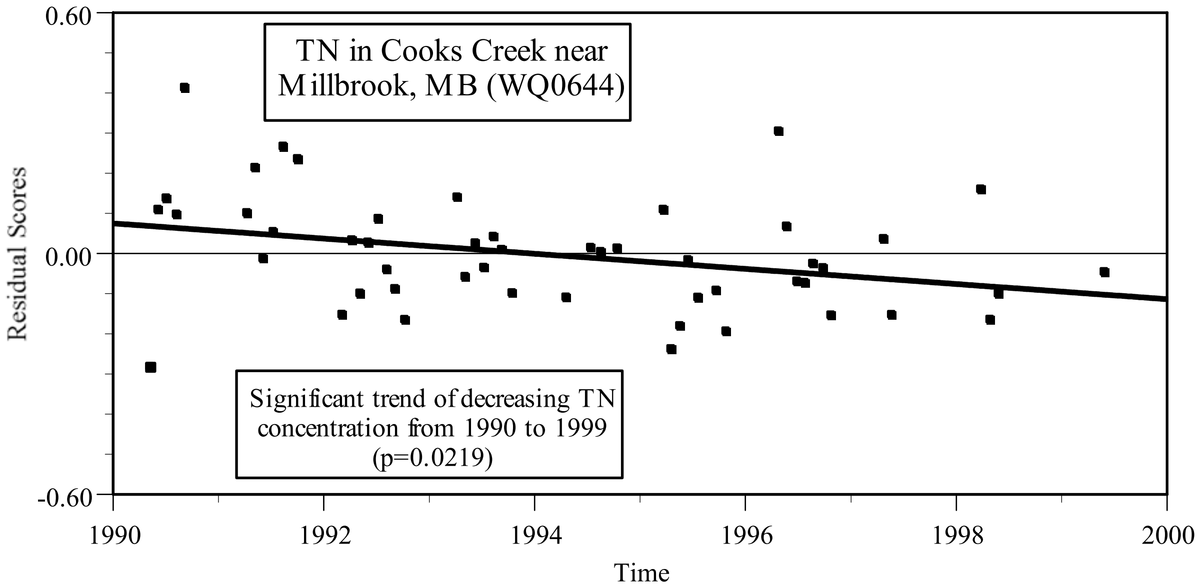


Figure 29. Trend in TN concentration in Cooks Creek near Millbrook, MB, 1990 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

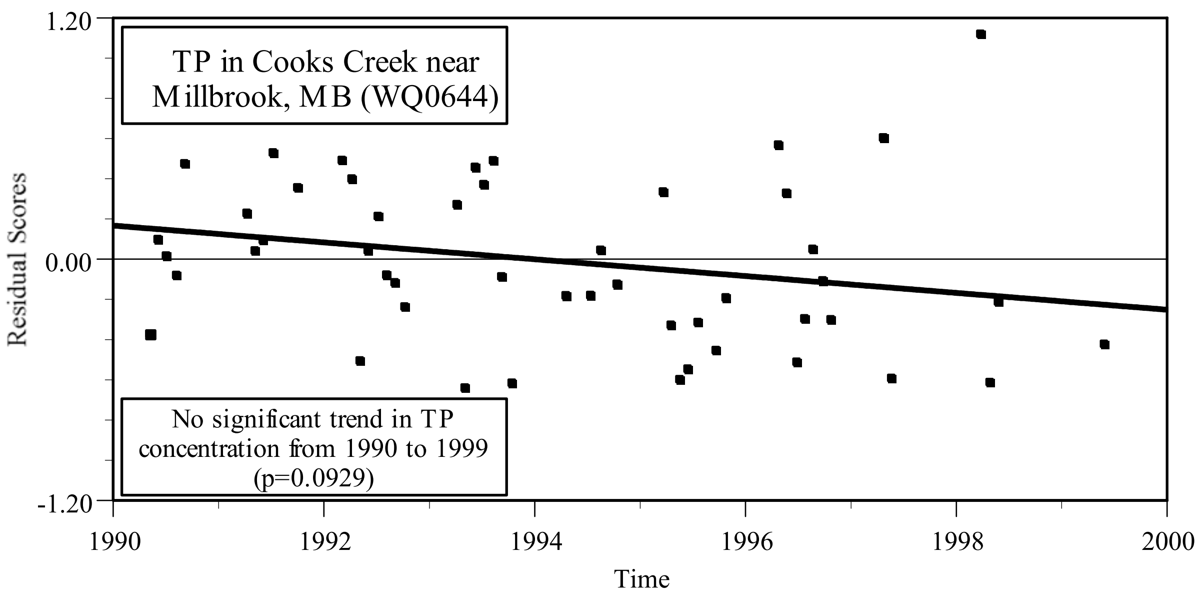


Figure 30. Trend in TP concentration in Cooks Creek near Millbrook, MB, 1990 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

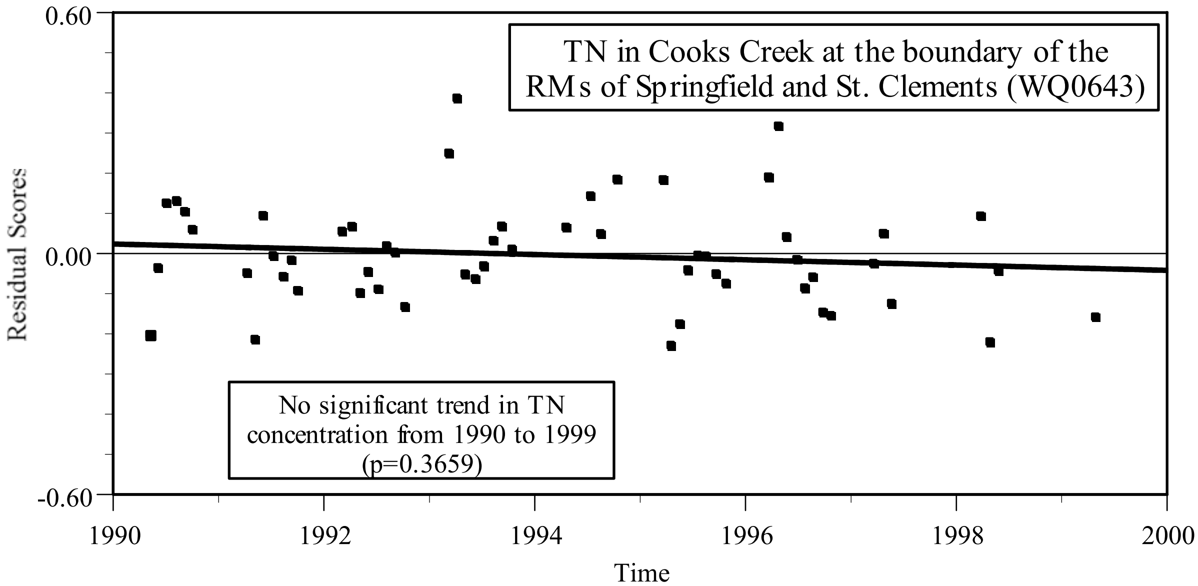


Figure 31. Trend in TN concentration in Cooks Creek at the boundary between the RM of Springfield and the RM of St. Clements, 1990 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

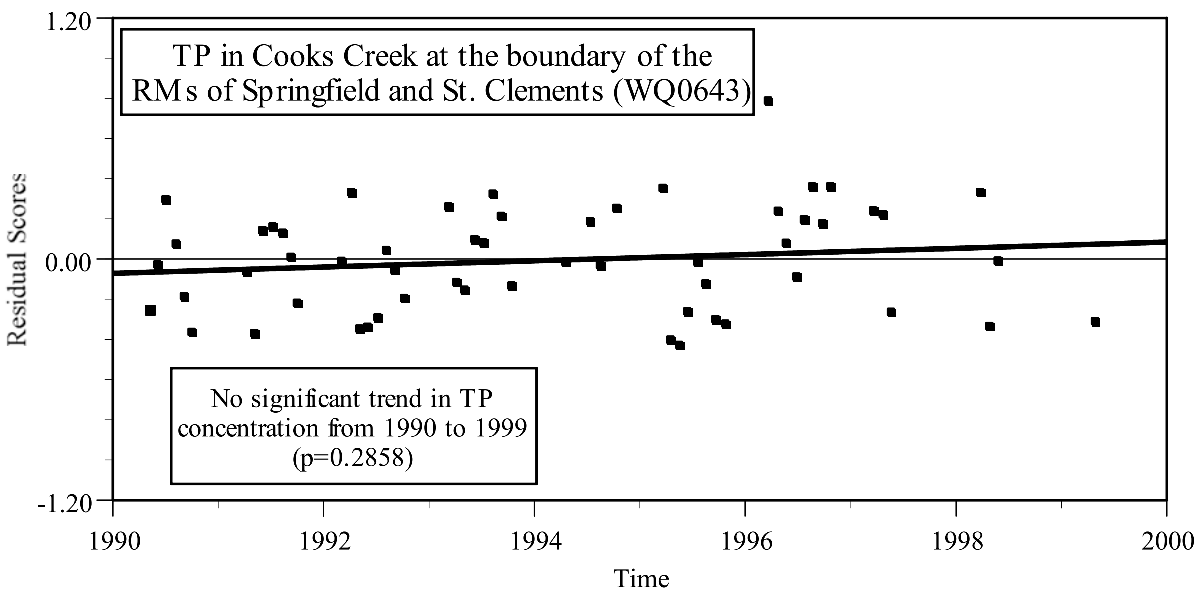


Figure 32. Trend in TP concentration in Cooks Creek at the boundary between the RM of Springfield and the RM of St. Clements, 1990 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

The Cooks Creek water quality monitoring stations continue to be sampled on a regular basis, and future analyses using larger data sets will help to better distinguish trends in nutrients in the creek.

ASSINIBOINE RIVER

The Assiniboine River is an inter-provincial waterway with its headwaters located about 50 km northwest of the community of Preeceville in eastern Saskatchewan. The river flows in a southeast direction into Manitoba and then eastward to eventually meet the Red River at Winnipeg (Figure 33). Many streams of various sizes flow into the Assiniboine along its course. Two of the largest tributaries are the Qu'Appelle River and the Souris River, both of which originate in Saskatchewan, but empty into the Assiniboine in Manitoba. Smaller tributaries include the Little Saskatchewan River and the Cypress River.

The watershed or drainage basin of the Assiniboine River (excluding the Qu'Appelle and Souris Rivers, which are generally considered separate basins) is quite large, encompassing approximately 41500 km^2. Roughly 60%, (24900 km^2) of the watershed is within the boundaries of Manitoba, with the rest located in Saskatchewan. Agricultural activity within the watershed in both provinces is very intense (Upper Assiniboine River Basin Study Committee 2000). Land uses range from cereal, feed, and specialty crop production, to range and pasture lands, to cattle feedlot and hog barn operations. The river is also the recipient of treated effluent from a number of municipal and industrial wastewater treatment facilities such as the cities of Brandon and Portage La Prairie, and Maple Leaf Foods (east of Brandon).

Data from six water quality monitoring stations were used to analyze trends in TP and TN in the Assiniboine River (Figure 33). This included a single Environment Canada station (SA05MC0001) located upstream near the town of Kamsack, SK, and five Manitoba Conservation stations -- WQ0009, WQ0012/WQ0636, WQ0014, WQ0015, and WQ0018 -- all situated further downstream between Brandon and Winnipeg.

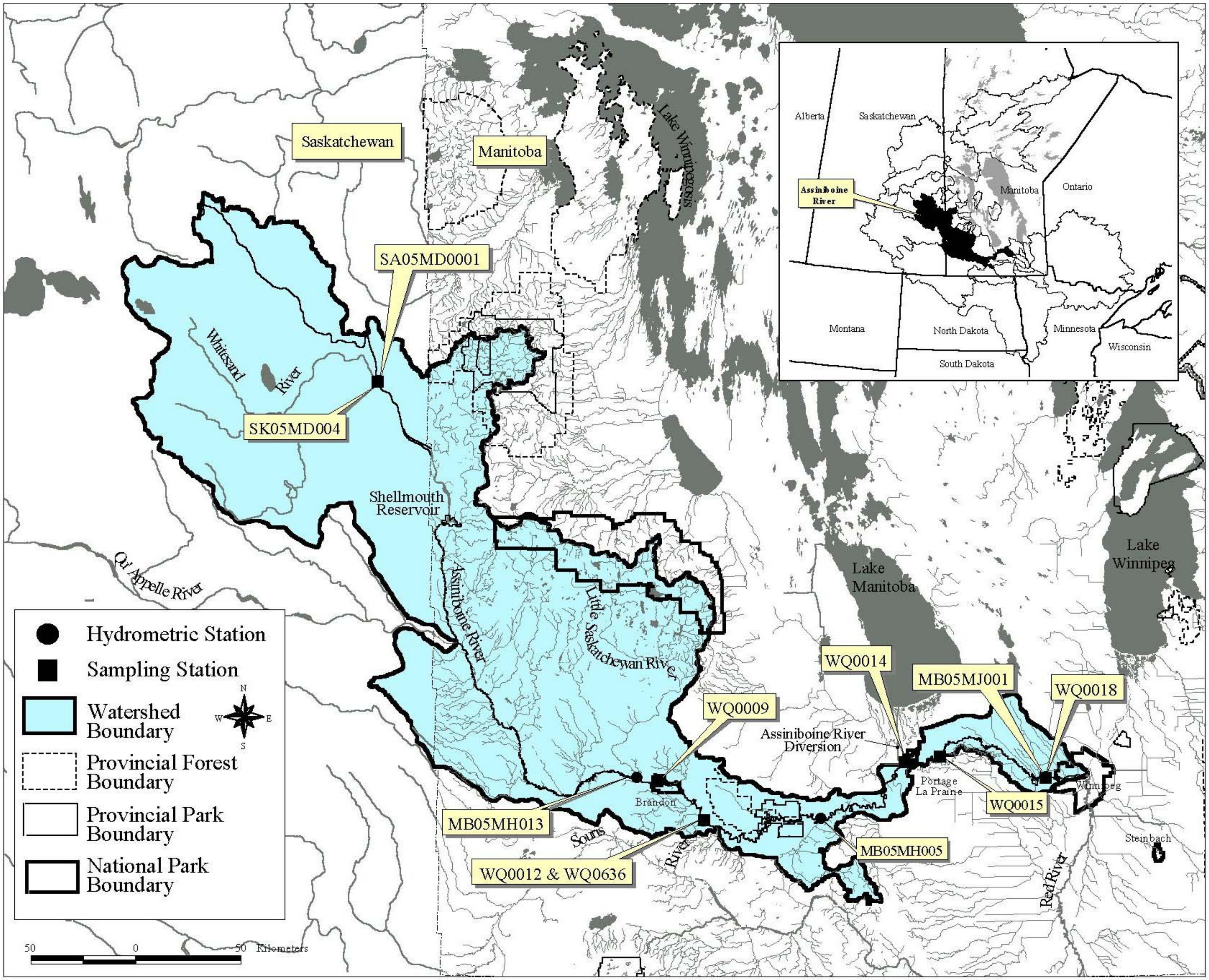


Figure 33. Assiniboine River watershed showing the location of water quality sampling sites and hydrometric stations on the Assiniboine River.

The flow data for the trend analysis at SA05MD0001 were obtained from hydrometric station SK05MD004, which is located in close proximity to the water quality sampling station. Trend analysis of TP at the site was conducted using data from 318 samples collected during the period 1974-1999 (inclusive).

The analysis results indicated that there was a trend of increasing flow-adjusted concentrations of TP since 1974 (Figure 34). However, this trend was not strong enough to be considered statistically significant (p=0.0777). Normality tests indicated that the residuals from the *QWTrend* output were not normal (Shapiro-Wilcox <0.0001), and re-running the program after removal of a number of extreme outliers in the TP data did not increase the normality of the residuals and did not result in a more significant trend. Vecchia (2000) states that the trend analysis program is robust enough that a certain degree of non-normality in the analysis residuals and thus outliers in the data are acceptable, especially if the data set is large. However, it has to be recognized that the non-normality of the residuals does diminish the overall confidence of the trend analysis results for TP at this site.

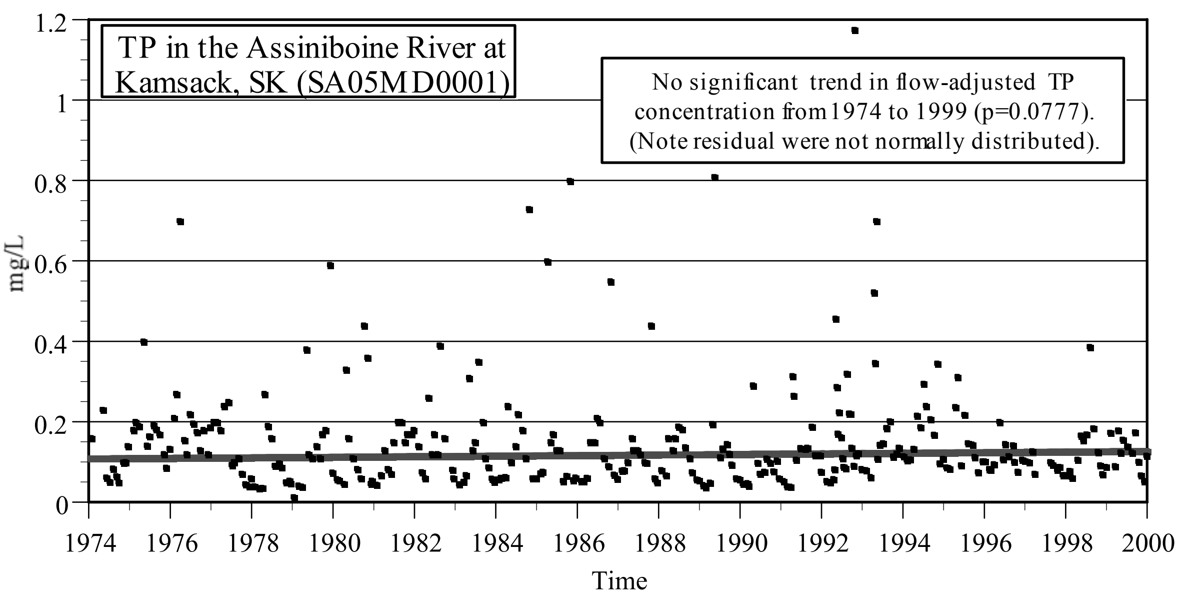


Figure 34. Trend in TP concentration in the Assiniboine River at Kamsack, SK, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Water quality monitoring station WQ0009 is located in the City of Brandon, MB. The river water has been monitored at this station for the past three decades. The trend analysis of TP at the site was conducted using data from 320 water samples collected from 1970 to 1999 (inclusive). Analysis of TN at the site was carried out using data from 274 samples collected over a period of 26 years from 1974 through 1999. Flow data for the analysis were obtained from a hydrometric station (MB05MH013), located approximately 10 km upstream of WQ0009.

The results of the statistical analysis showed that flow-adjusted TN concentrations increased significantly (p=0.0147) from 1974 to 1999 (Figure 35). However, as indicated by the low overall change in the median of the trend (12.7%), this increase in TN at WQ0009 was relatively small and very gradual. No significant trend (p=0.2290) in flow-adjusted TP concentrations was detected at the site (Figure 36).

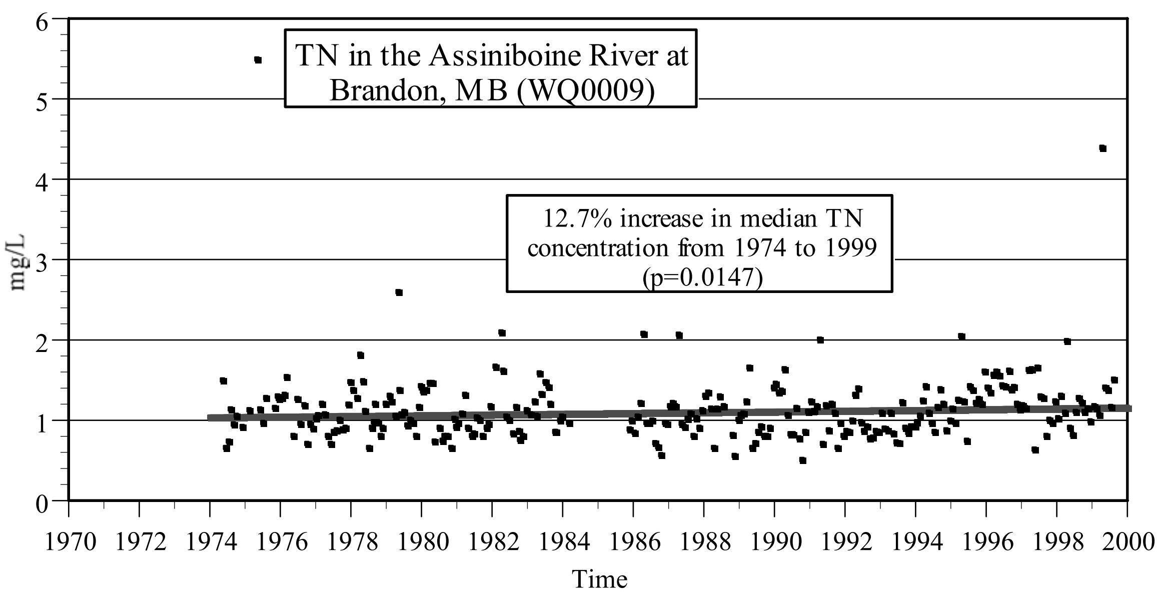


Figure 35. Trend in TN concentration in the Assiniboine River at Brandon, MB, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

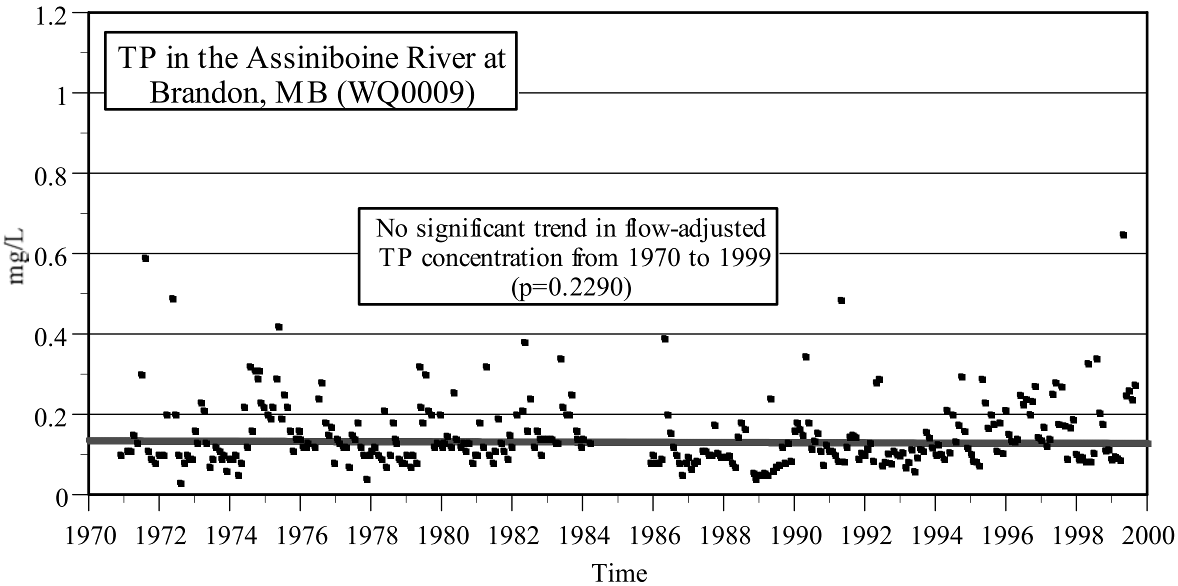


Figure 36. Trend in TP concentration in the Assiniboine River at Brandon, MB, 1970 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Water quality sample station WQ0636 is located approximately 45.5 km downstream of WQ0009 at PR #340, near Treesbank, MB. The sampling station was originally designated WQ0012 and was located downstream at the Treesbank Ferry crossing. Following the completion of the bridge on PR #340 in the early 1990s, the sampling station was moved to its present location and renamed WQ0636. A step trend was not inserted into the trend analysis since only 7.5 km of river separates the present location of the sampling station from its original location at the Treesbank Ferry site.

Data from 201 water samples collected from 1973 through 1999 were used in the trend analysis of TN, while 236 records collected from 1970 through 1999 were used in the analysis of TP at the site. Flow data for the analysis at WQ0636 were obtained from hydrometric station MB05MH013. Although MB05MH013 is located approximately 55 km upstream of WQ0636, it was chosen for the analysis because it had the closest, most complete record of river flow. No major tributaries enter the river between hydrometric station MB05MH013 and water quality sampling station WQ0636. Therefore, although the volume of flow at WQ0636 may differ somewhat due to overland contributions, the degree of fluctuation in flow volumes is likely similar to that recorded at the hydrometric station.

The trend analysis program did not detect a significant trend in either TN (p=0.0720) or TP (p=0.0654) at WQ0636 (Figures 37 and 38). It should be noted, however, that the trend lines generated by the program do have a positive slope and are close to being statistically significant. The Assiniboine River at WQ0636 continues to be monitored on a regular basis and future analysis on the TN and TP data may reveal that flow-adjusted concentrations of both variables are indeed increasing at the site.

The city of Portage la Prairie is located on the north side of the Assiniboine River, approximately 240 km downstream of Brandon (120 km straight line distance east). Like Brandon, Portage la Prairie also uses the Assiniboine River as a source of drinking water. The nutrient status of the river at water quality monitoring station WQ0014, located immediately downstream of the Portage la Prairie spillway and dam, has been monitored at fairly regular intervals for the past 30 years. During this period, TN and TP concentrations at station WQ0014 have mainly fluctuated between 0.5 to 1.5 mg/L and 0.1 to 0.2 mg/L, respectively.

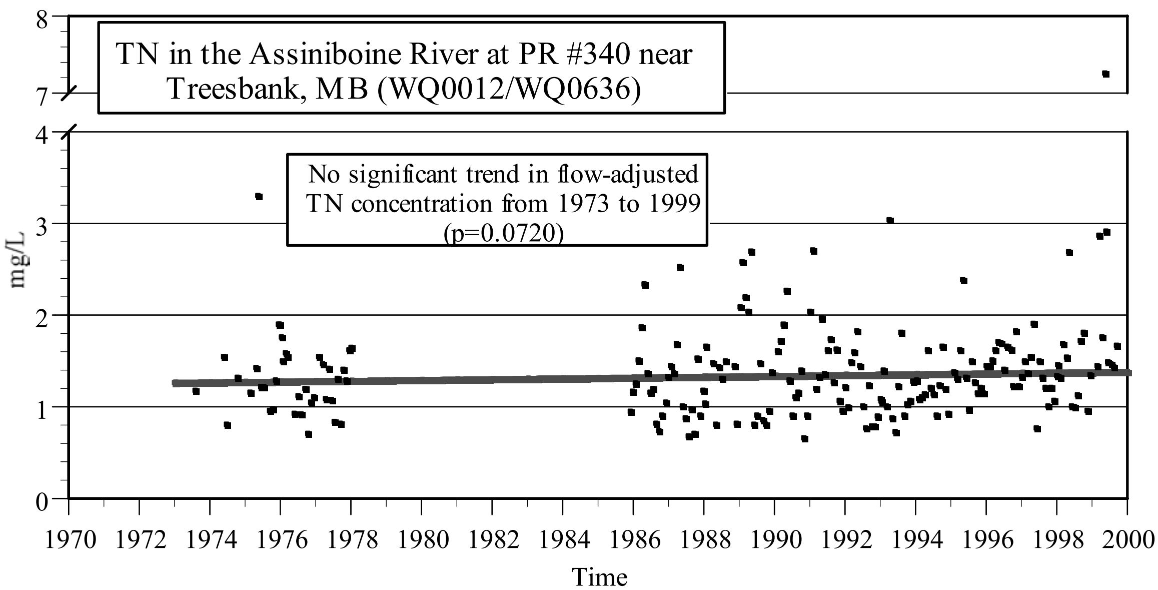


Figure 37. Trend in TN concentration in the Assiniboine River at PR #340 near Treesbank, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

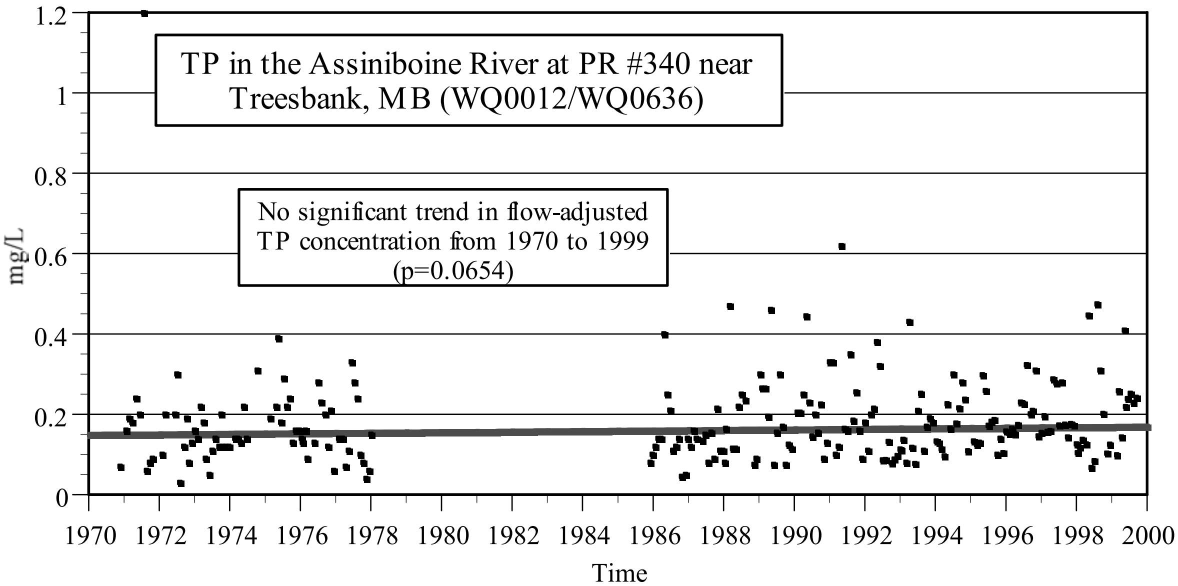


Figure 38. Trend in TP concentration in the Assiniboine River at PR #340 near Treesbank, MB, 1970 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

The Portage la Prairie spillway and dam is a flood control structure used to divert water from the Assiniboine River to the Assiniboine Diversion channel and into Lake Manitoba during periods of high water flow in the river. Construction of the spillway and dam was completed in 1970 (Environment Canada 2001). The establishment of the dam and spillway created a reservoir on the river that is the source of raw water for the city's drinking water treatment plant.

Total nitrogen data used in the trend analysis at WQ0014 were obtained from 179 water samples collected from 1973 through 1999. Total phosphorus concentrations used in the analysis included data from 212 water samples collected from 1971 through 1999. Note that there was a gap of approximately eight years in both data sets from 1978 to the beginning of 1986. Water flow data for the trend analysis were calculated by subtracting the flow in the Assiniboine River Diversion from the flow recorded at hydrometric station MB05MH005, which is located approximately 104 km upstream near Holland, MB.

The statistical analysis results indicated that there was a significant trend of increasing flow-adjusted concentrations of both TN ($p=0.003$) and TP ($p<0.0001$) in the river at site WQ0014 (Figures 39 and 40). These results were different than those obtained from the upstream site WQ0636. The results from both sites indicated that nutrient inputs along the reach of the river between WQ0636 and Portage la Prairie have gradually increased over time. It is likely that the concentration of TN and TP at WQ0014 were influenced to a significant degree by the reservoir located immediately upstream of the sample site. Water movement decreases considerably once a river enters a reservoir. This reduction in flow velocity allows for greater nutrient uptake by algae, and favors increased the denitrification and volatilization of nitrogen compounds and settling out of phosphorus to the sediments (Frick *et al.* 1996). Together these processes can lead to a reduced nutrient concentration in the water leaving the reservoir, thereby influencing the long-term trends in concentrations further downstream.

The next downstream water quality sampling station on the Assiniboine River is station WQ0015. This station is located approximately 27 km downstream of WQ0014 at the Trans Canada Highway (PTH #1) bridge east of Portage la Prairie. Water samples have been collected at fairly regular intervals at WQ0015 for the past three decades. As with WQ0014, flow data for the analysis of trends at site WQ0015 were obtained by subtracting the flow in the Assiniboine River Diversion from the flow at MB05MH005 located near Holland. Total nitrogen data for the analysis were obtained from 227 water samples collected from 1973 to 1999, while 259 water samples collected from 1971 through 1999 provided TP data for the trend analysis.

Trend analysis of the TN data indicated that there was a significant ($p<0.0001$) trend of increasing flow-adjusted concentrations from 1973 to 1999 at WQ0015 (Figure 41). With an overall increase of 36.5% in the median, the trend in TN at WQ0015 was somewhat more pronounced than that at site WQ0014, which recorded only a 20.5% increase in the median. The analysis also found a strong trend of increase in the flow-adjusted TP data ($p<0.0001$) (Figure 42), which suggested that anthropogenic inputs of TP to the river increased significantly from 1971 through 1999.

Water quality station WQ0015 is situated approximately 20 km downstream of the city of Portage la Prairie sewage treatment plant (STP), while site WQ0014 is located upstream of the STP. Sewage and wastewater are treated at the STP prior to being discharged to the Assiniboine River. The trend analysis results showed that discharging treated effluent to the river apparently has not resulted in an increase in the trend of flow-adjusted TP in the river downstream of the STP. In fact, the trend in TP downstream of the STP is of the same magnitude as the trend upstream. However, summary statistics of 209 samples collected on concurrent dates from the two sites indicated that

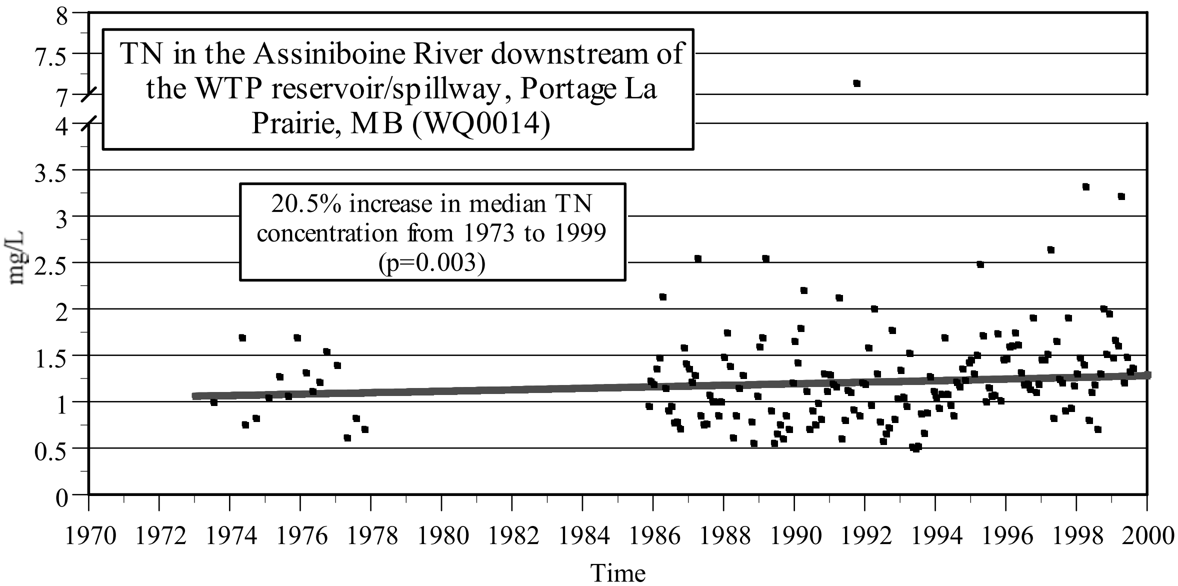


Figure 39. Trend in TN concentration in the Assiniboine River downstream of the WTP reservoir/spillway, Portage la Prairie, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line

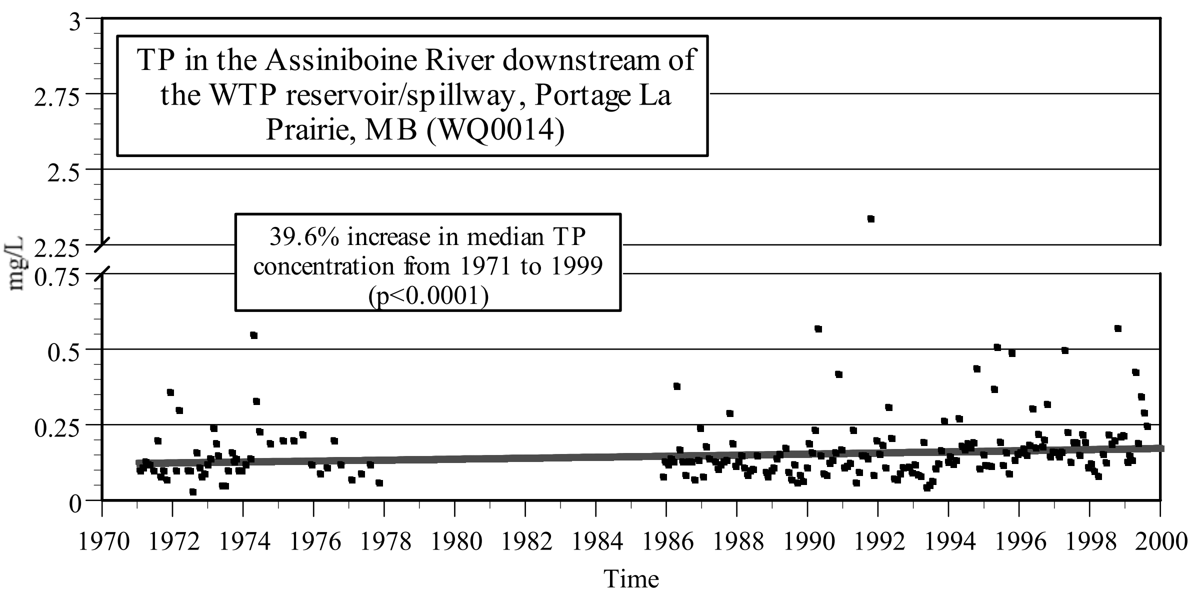


Figure 40. Trend in TP concentration in the Assiniboine River downstream of the WTP reservoir/spillway, Portage la Prairie, MB, 1971 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line

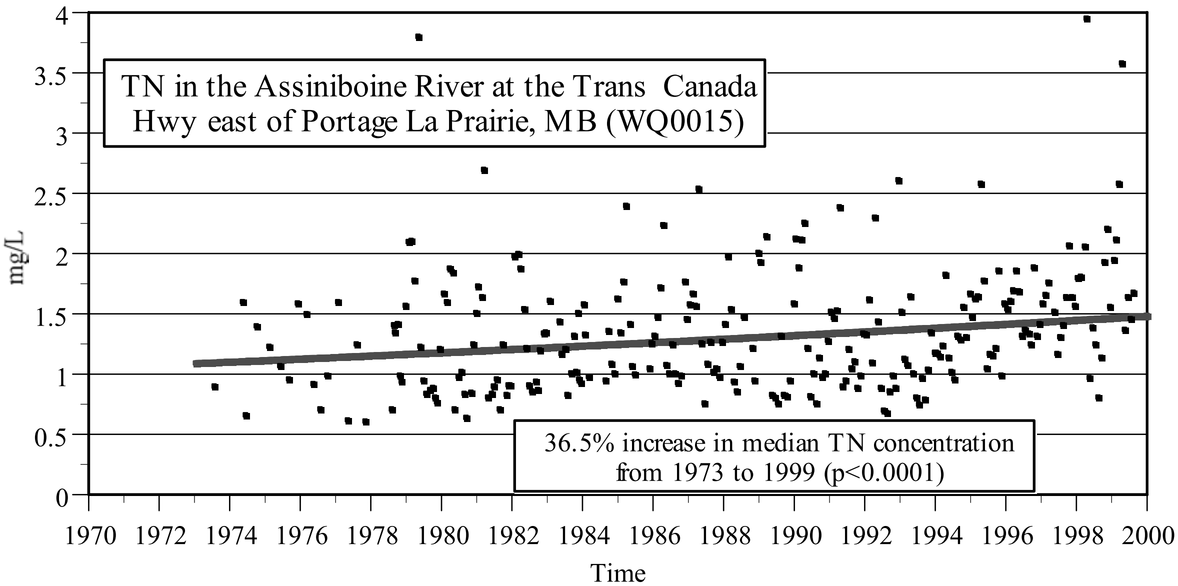


Figure 41. Trend in TN concentration in the Assiniboine River at the Trans Canada Hwy east of Portage la Prairie, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

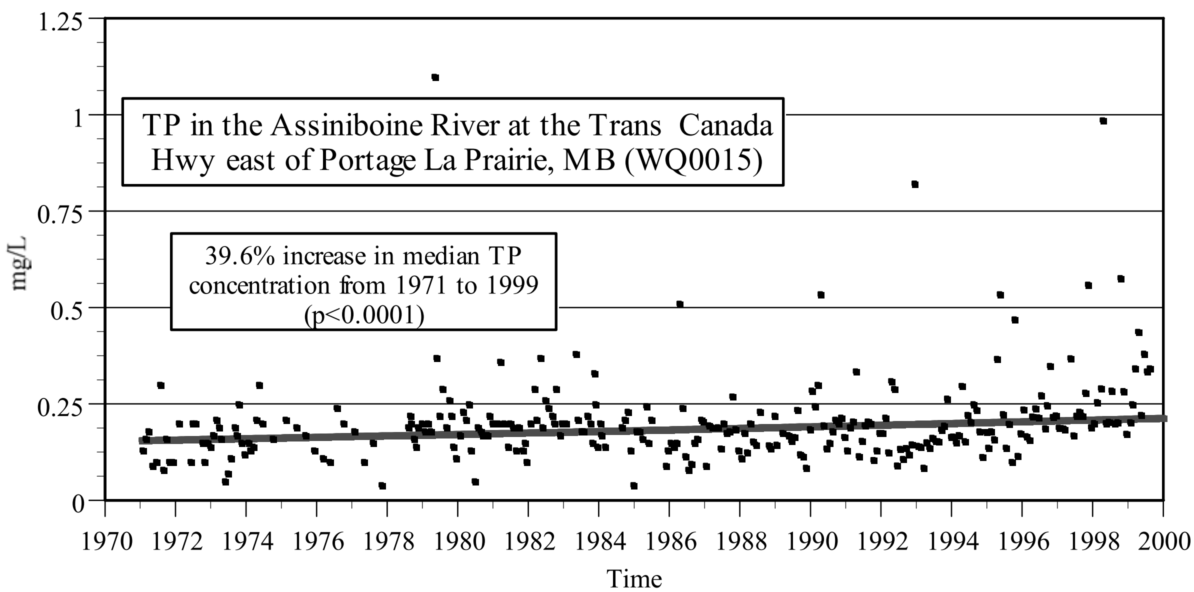


Figure 42. Trend in TP concentration in the Assiniboine River at the Trans Canada Hwy east of Portage la Prairie, MB, 1971 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line

the concentrations of TP at the downstream site tended to be higher than those concentrations at the upstream site (mean of 0.200 mg/L, median of 0.180 mg/L, and a 75% quartile of 0.220 mg/L for WQ0015 compared to a mean of 0.188 mg/L, median 0.135 mg/L, and a 75% quartile of 0.190 mg/L for WQ0015). The STP effluent may have also had an influence on the TN content in the river since the trend of increasing flow-adjusted TN concentrations was considerably stronger (steeper slope of the trend line) and concentrations of TN were generally higher at site WQ0015 than at site WQ0014. It should be noted that effluent is also discharged to the river from the Norquay Park STP, which is located immediately upstream of water quality site WQ0015. However, because only a relatively small amount of effluent is discharged on a periodic basis and since the discharge point is on the opposite side of the river, its influence on the nutrient data collected at water quality at station WQ0015 was likely negligible.

Water quality sampling station WQ0018 is the furthest downstream long-term water quality monitoring station on the Assiniboine River. It is located approximately 84 km downstream of WQ0015 at PR #334, west of Winnipeg, near Headingley, MB. Total nitrogen data from 163 water samples collected from 1973 to 1999 (inclusive) and TP data from 190 water samples collected over the 30-year period from 1970 through 1999 were used in the trend analysis at WQ0018. Flow data for the trend analysis were obtained from hydrometric station MB05MJ001, which is located in the immediate vicinity of the water quality sampling station.

The results of the analysis at WQ0018 indicated that, when adjusted for flow, concentrations of TN and TP have increased substantially over the last three decades (Figures 43 and 44). The TN results showed an overall increase in the median of the trend in excess of 54%, while an increase of over 62% was reported for the trend in TP. The PARMA model residuals following the initial running of the *QWTrend* program on the TP data were not normally distributed. Six outliers were sequentially removed from the original data set (n=196) in order to achieve normality in the model residuals. While the omission of this many data points may appear manipulative, their removal did not alter the significance or direction of the flow-adjusted trend. Their removal did, however, result in a lower reported percentage change in the median of the TP trend from 86.2% down to 62.2%.

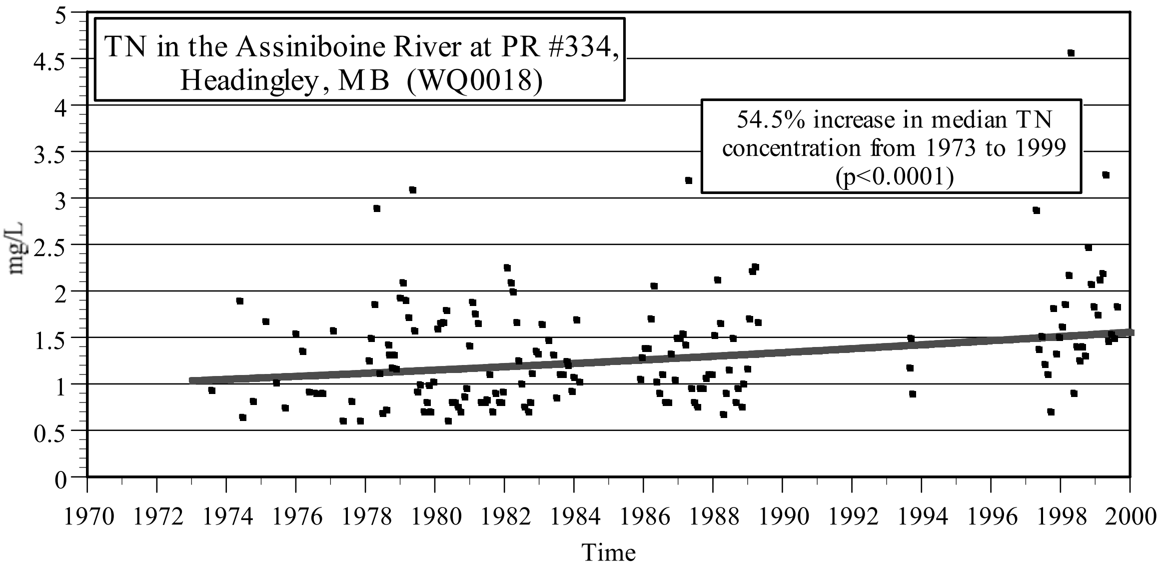


Figure 43. Trend in TN concentration in the Assiniboine River at PR #334, south of Headingley, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

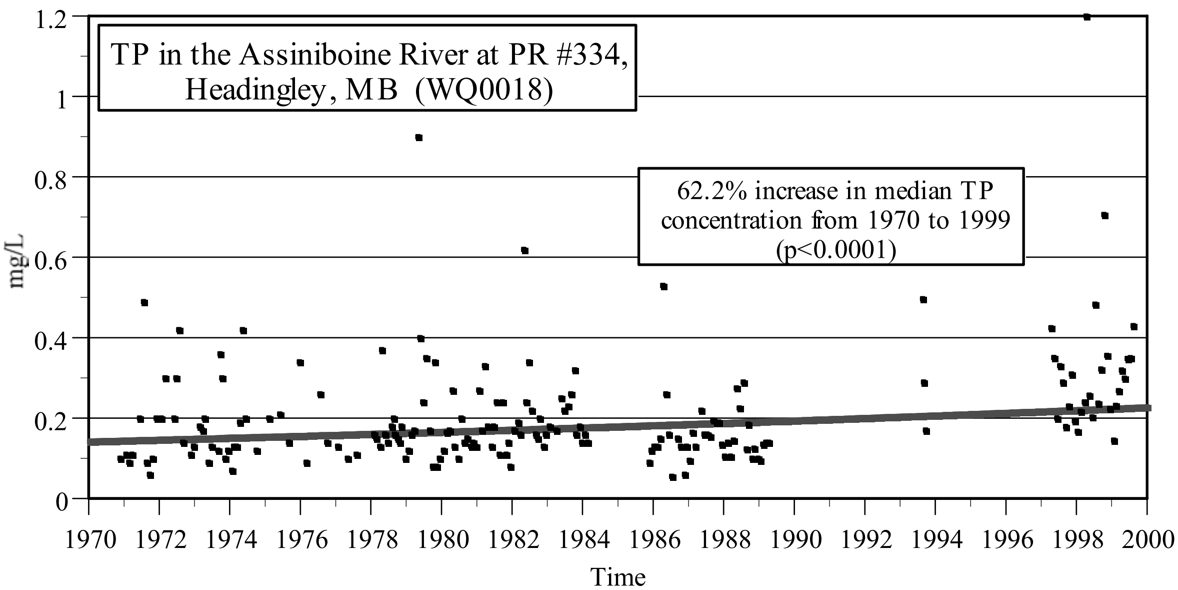


Figure 44. Trend in TP concentration in the Assiniboine River at PR #334, south of Headingley, MB, 1970 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

The lack of significant trends in flow-adjusted TP data from the site at Kamsack and the site at Brandon, indicated that most of the variation in TP concentration along this stretch of the river could be accounted for by variation in the flow regime. This suggested that, in general, inputs of nutrients from anthropogenic sources during the past three decades did not result in a corresponding trend of increasing concentrations in the river. On the other hand, the significant trends of increase in TP at sites WQ0014, WQ0015, and WQ0018 indicated that the variation in TP concentrations in this downstream portion of the river could not be totally accounted for by changes in the flow regime. This implied that phosphorus inputs from activities in the surrounding watershed have lead to an increase in TP in the downstream portion of the river. The analysis of the TN data indicated that concentrations in the river increased modestly at Brandon, which may reflect a gradual, and perhaps localized, increase in loading from this urban area. As with the TP results, the progressively stronger positive trends in flow-adjusted TN concentration at sites further downstream suggested that over the period of record there has been a substantial increase in nutrient loading along the portion of the river between Brandon and Headingley.

LITTLE SASKATCHEWAN RIVER

The Little Saskatchewan River (also called the Minnedosa River) has its headwaters in Whitewater Lake in Riding Mountain National Park (Figure 45). From its headwaters the river flows east and southward through the park for a distance of about 15 km before exiting the park south of Lake Audey. Outside the park the river meanders a further 120 km through agricultural lands (crops and pastureland) before emptying into Rivers Reservoir (Lake Wahtopanah), an impoundment constructed by PFRA in 1960 (Rounds 1990), near the town of Rivers, MB. The reservoir is used for recreation purposes and as a raw water source for the town of Rivers. The river flows from the reservoir a further 32 km to empty into the Assiniboine River, approximately 10 km west of Brandon. The river's watershed, which is actually a portion of the much larger Assiniboine River watershed, occupies an area of approximately 4300 km^2, the majority of which is located upstream of the Rivers Reservoir.

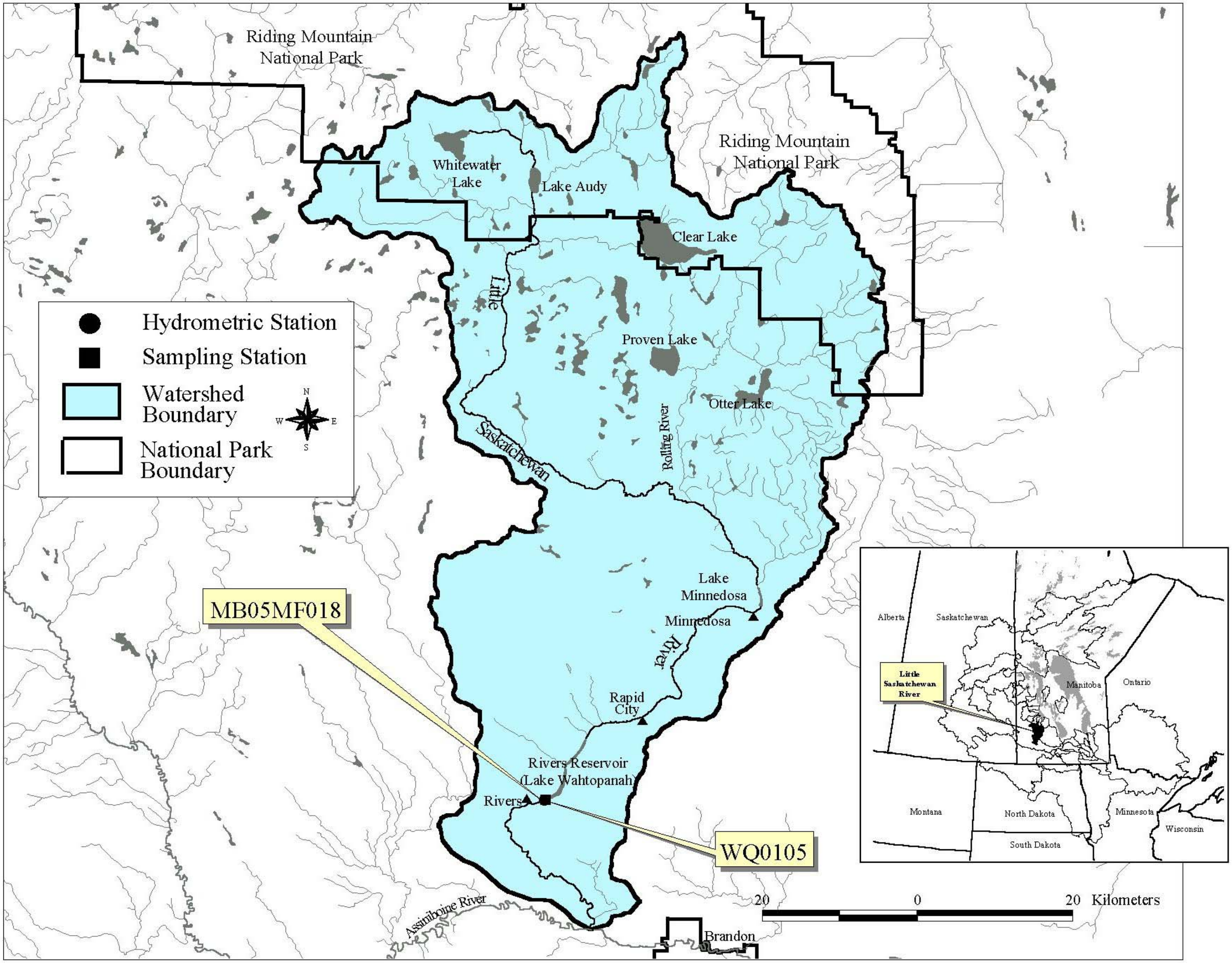


Figure 45. Little Saskatchewan River watershed showing the location of water quality sampling site WQ0105 and hydrometric station MB05MF012 on the Little Saskatchewan River.

A number of monitoring programs and water quality assessments have been conducted on the Little Saskatchewan River and Rivers Reservoir. Data collected at various sampling stations along the river from 1965 – 1996 and summarized in Green (1997a) suggests that the nutrient content of the river is quite adequate to support the growth of algae and macrophytes. A trophic status assessment of the reservoir by Hughes (1982) concluded that the reservoir was mesotrophic to eutrophic (moderately to highly nutrient enriched). This was supported by an unpublished report by Ralley (1990), who also noted that the nutrient content of the reservoir was high and suggested that productivity in the reservoir may be limited by water clarity (*i.e.* high turbidity and suspended solids), rather than by nutrient availability.

Long term water quality monitoring data of the Little Saskatchewan River are available from sampling station WQ0105, which is located just downstream of the reservoir on PTH #25 near Rivers. The station has been sampled on a fairly routine basis since 1973, except for a period of approximately 4 years in the 1980s. Flow data for the trend analysis were obtained from hydrometric station MB05MF018, located nearby WQ0105. Flow measurements at MB05MF018 were not recorded after 1996. Therefore, although TP and TN data are available up to the present, the trend analysis was only conducted using data from 1973 through 1996.

Nutrient data from 126 water samples were used in the trend analysis of TP and TN at WQ0105. The analysis revealed a significant trend ($p=0.0018$) of increasing flow-adjusted TP concentration over the 1973 - 1996 period, while the results for TN suggested that flow-adjusted concentrations declined significantly ($p<0.0001$) over the same period (Figures 46 and 47). The trend of increasing TP concentration could be attributable to increased non-point source and point source loading from agricultural activity and municipal wastewater lagoon effluent in the watershed. However, this does not explain why TN concentrations decreased while TP concentrations increased. It is entirely likely that the reservoir located immediately upstream of WQ0105 not only had a major influence on the downstream flow regime, but also had an effect on the concentration of nutrients reported at the site (Frick *et al.* 1996). This disruption of normal flow regime and alteration of nutrient concentrations may at least partly account for the apparent discrepancy between the trends for TN and TP.

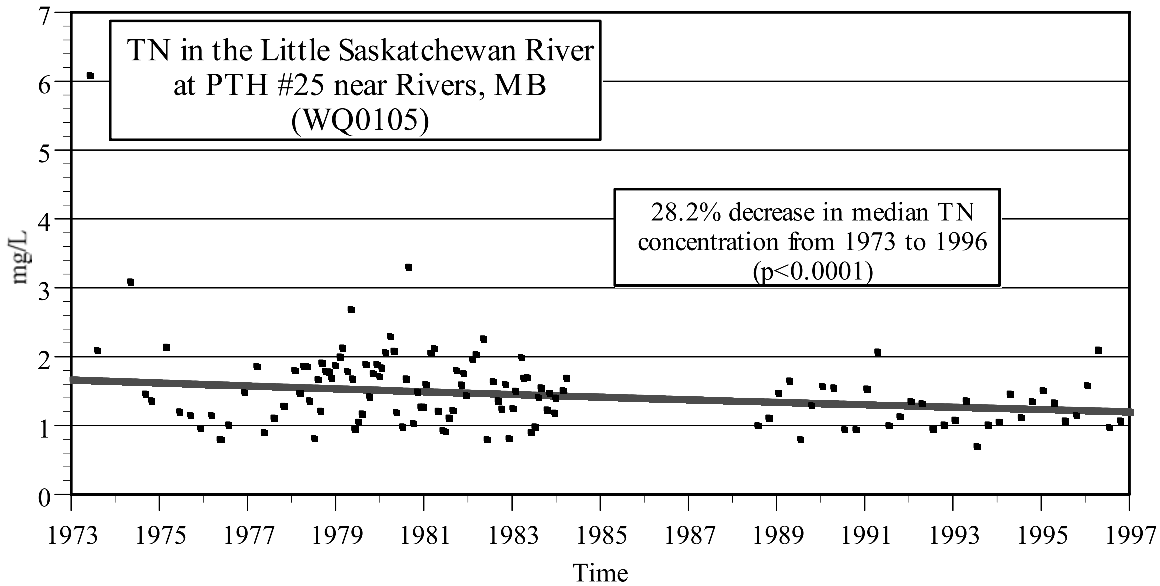


Figure 46. Trend in TN concentration in the Little Saskatchewan River at PTH #25 near Rivers, MB, 1973 to 1996 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

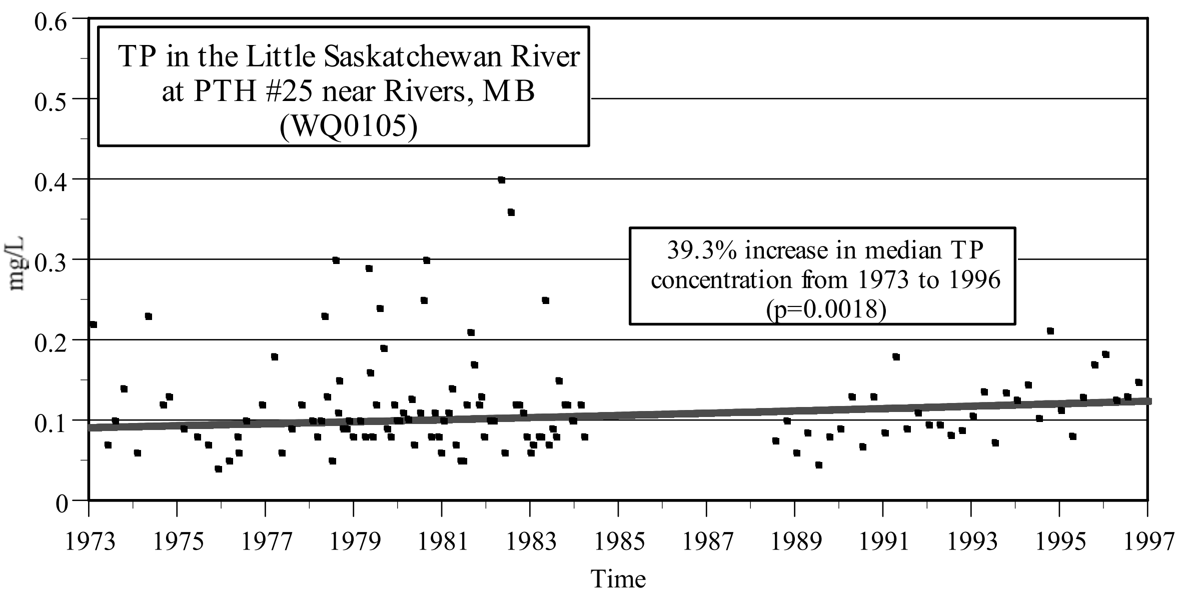


Figure 47. Trend in TP concentration in the Little Saskatchewan River at PTH #25 near Rivers, MB, 1973 to 1996 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

CYPRESS RIVER

The Cypress River originates in a wetland area along the eastern edge of the Manitoba Escarpment region near the village of Somerset (Figure 48). The river meanders north and westward from its headwaters to eventually empty into the Assiniboine River near PTH #34. The river distance from the headwaters to the confluence with the Assiniboine is approximately 94 km. Although flow volumes in the river can be quite low at times, some reaches, where the channel is cut deeper, do provide suitable habitat for fish. The river is also used for livestock watering and as a source of water for agricultural irrigation.

The Cypress River and its tributaries drain an area of approximately 815 km^2. Much of the land in the watershed is dedicated to agriculture, including livestock production and cereal crop cultivation. This, coupled with the rolling topography of the region, creates the potential for nutrient loading to the river from overland run-off. As well, the river is susceptible to nutrient loading from wastewater lagoons at Somerset, Cypress River, and Holland, all of which discharge to tributaries of the river.

Nutrient concentrations in the river have been monitored periodically at a number of sites since 1978. Concentrations of TN and TP at the long-term water quality monitoring station WQ0398, located northeast of the village of Cypress River, have ranged from 0.3 to 6.4 mg/L and from 0.04 to 1.06 mg/L, respectively. The highest TP and TN concentrations were usually recorded during spring sampling dates, and thus likely reflect inputs from melt-water run-off. Hughes (2001), using the Canadian Water Quality Index rankings, found that the water quality of the Cypress River ranged from good in 1995 and 1996, to fair in 1997, and marginal in 1998. He suggested that the downgrading of the water quality to fair and marginal rankings in 1997 and 1998 was due mainly to the elevated phosphorus and suspended solids concentrations recorded in these latter years.

Trend analysis of nutrient concentrations in the river was performed using TN and TP data from 70 water samples collected at site WQ0398 from 1978 to 1999. Flow data for the analysis were obtained from hydrometric station MB05MH008, which is located approximately 30 km upstream of the water quality monitoring station, near the village of Bruxelles.

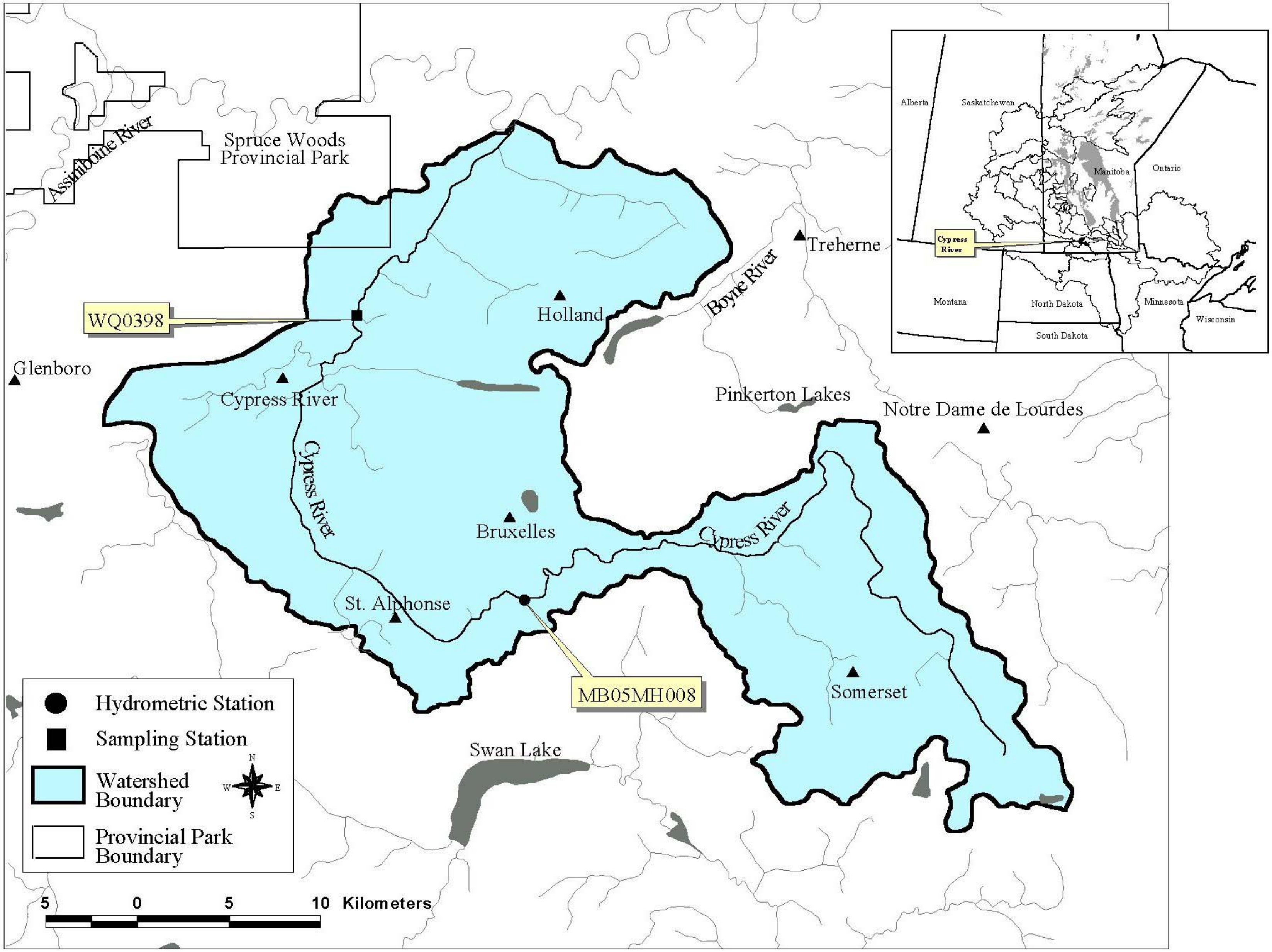


Figure 48. Cypress River watershed showing the location of water quality sampling site WQ0398 and hydrometric station MB05MH004 and MB05MH008 on the Cypress River.

The results of the trend analysis showed that the flow-adjusted concentrations of both TN and TP rose significantly ($p<0.0001$) over the period of reporting (Figures 49 and 50). The median of the flow-adjusted trend in TN increased by 66%, while the median for the TP trend almost tripled. The strong trends in flow-adjusted TP and TN concentrations indicated that over the last two decades there has been an increasingly higher amount of nutrient loading to the river from point and non-point sources within the watershed. Possible contributing factors to the trends in TN and TP observed at WQ0398 include increased soil erosion and application of manure and fertilizers to agricultural lands within the catchment, and perhaps a rise in the volume of municipal wastewater effluent reaching the river.

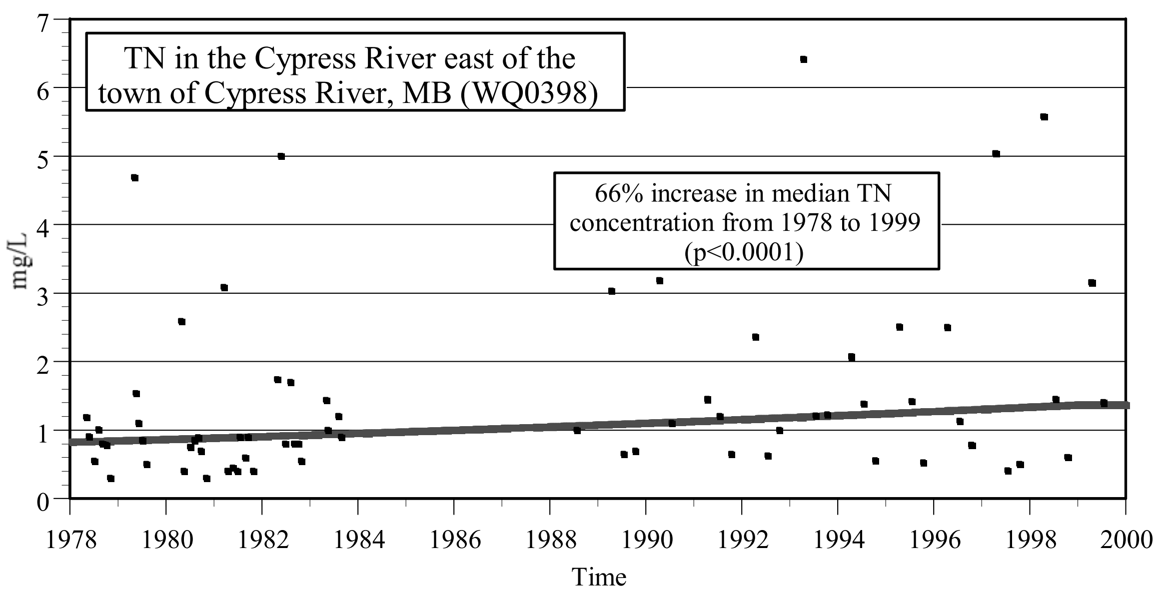


Figure 49. Trend in TN concentration in the Cypress River at municipal road 3.2 km east of Cypress River, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

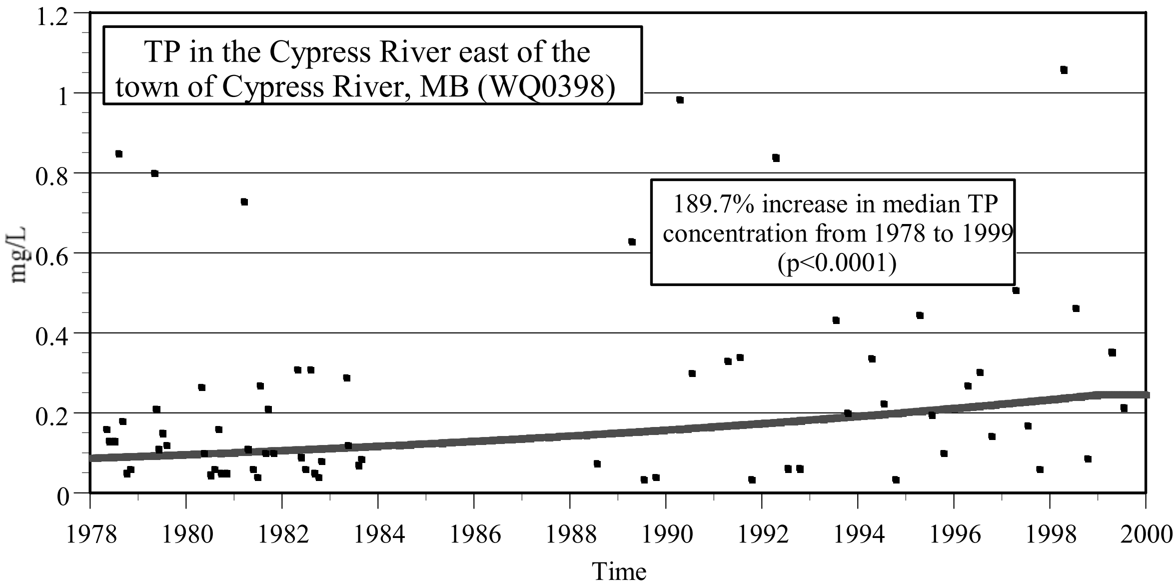


Figure 50. Trend in TP concentration in the Cypress River at municipal road 3.2 km east of Cypress River, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

SOURIS RIVER

The Souris River has the distinction of being both an inter-provincial and an international waterway (Figure 51). The Souris is a relatively long river, extending approximately 1175 km from its headwaters near Weyburn, SK to its confluence with the Assiniboine River in Manitoba. The river flows southeastward from its headwaters and enters North Dakota west of the community of Sherwood. The river continues its very meandering course southeastward through North Dakota for over 200 km then swings northward to eventually enter Manitoba near the small community of Coulter. It then proceeds in a north and northeast direction across southwestern Manitoba and empties into the Assiniboine River near Treesbank. Major tributaries to the Souris River include Long Creek and Moose Mountain Creek in Saskatchewan, the Des Lacs River in North Dakota, and the Antler River and Gainsborough Creek in Manitoba

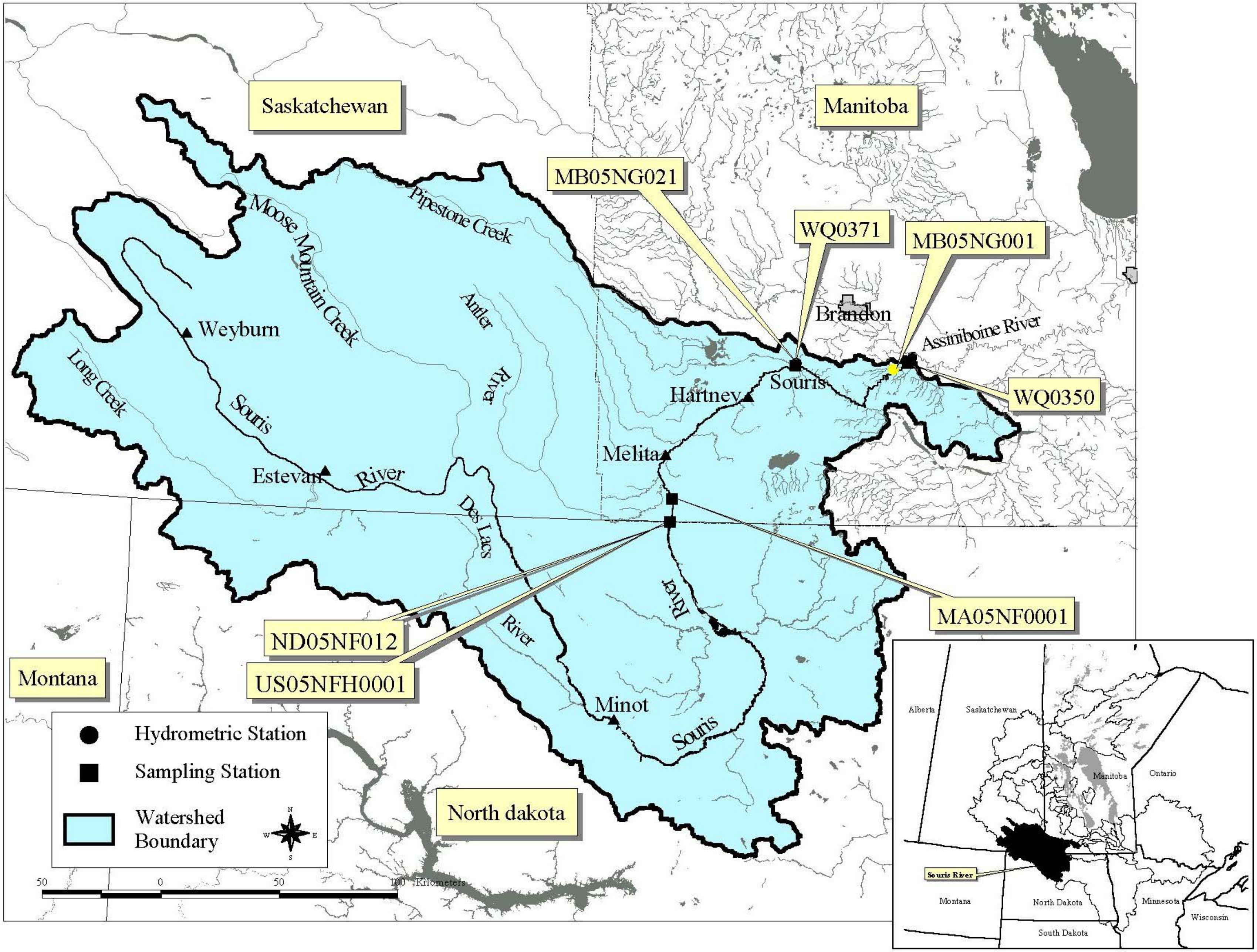


Figure 51. Souris River watershed showing the location of water quality sampling sites and hydrometric stations on the Souris River.

The Souris River drains a total land area of approximately 62500 km^2. Roughly 10000 km^2 of the watershed is within the boundaries of Manitoba. The majority of the land in the watershed is subject to intense agricultural usage (EMD 1979). However, because of the relatively steep valley walls and narrow valley floor, land use directly adjacent to the river in Manitoba is usually restricted to livestock pasture (Beck 1981). The river is a multi-use waterway and serves as a source of water for agricultural irrigation, livestock watering, and human consumption. The river also supports a diverse assemblage of aquatic life including fish, invertebrates, and waterfowl and is used extensively for recreation pursuits such as fishing, canoeing, and water-skiing (EMD 1979).

Like many rivers in the southern portion of Manitoba, activities within the Souris River watershed greatly affect the water quality of the river water. Numerous studies have investigated various aspects of the water quality and quantity in the Souris River and its surrounding drainage area (*e.g.* Environment Canada 1978, EMD 1979, Beck 1981, Chacko 1986, Blachford 1987, Beak Associates Consulting Ltd. 1991, Jones *et al.* 1998, Hughes 1999a). The general consensus of these studies is that the river and many of its tributaries contain high concentrations of nitrogen and phosphorus. Sources of these nutrients include wastewater discharges from communities in North Dakota, such as Minot, Velva, and Towner (Chako 1986), and several communities in Manitoba, including Melita, Souris, and Wawanesa (EMD 1979). As well, significant amounts of nutrients are believed to originate from non-point sources such as run-off from agricultural land (EMD 1979, Blachford 1987, Beak Associates Consulting Ltd. 1991). This abundance of nutrients has made the river highly susceptible to algal bloom development and excessive macrophyte growth (EMD 1979, Beck 1981).

Data from three sampling locations were used to assess trends in TN and TP in the Souris River in Manitoba. The furthest upstream sampling site is located near the international border where the river crosses into Canada from the United States. Over the years the United States Geological Survey (USGS) and Environment Canada have collected water samples on their respective side of the border -- the USGS with a station near Westhope, North Dakota, and Environment Canada with a station near Coulter, Manitoba. However, since neither agency has a complete long-term record of data for this section of the river, the data sets from both locations were combined to provide a longer period of record for the trend analysis. The combined data set consisted of Environment Canada data collected from 1973 to 1992 at Coulter and USGS data collected from

1993 to 1999 (inclusive) at Westhope. This amounted to 391 water samples with TP data. The flow data record for the Souris River at Coulter is incomplete (only 1977 to 1991); therefore only the flow data set from the hydrometric station near Westhope (ND05NF012), which provides a complete record of flow from 1973 to 1999, was used in the trend analysis.

The initial running of the trend analysis program involved inserting a step trend to account for the change in location and analytical method that occurred at the end of 1992. The step trend was not significant ($p=0.0775$), indicating that the change in location and analytical method did not significantly alter the data. The data were then analyzed again without the step trend. The analysis results indicated that there was no significant trend in flow-adjusted concentrations ($p=0.1147$) over the period of reporting (Figure 52).

Vecchia (2000) conducted a more detailed examination of a similar TP data set collected at Westhope and Coulter. Vecchia's data set spanned the period from 1977 to 1996. The majority of the data he used were obtained from the USGS water quality station at Westhope. Most of the TP data in our data set were obtained from the Environment Canada site at Coulter and spanned the period from 1973 through 1999. In his analysis, Vecchia divided the TP record into a compound monotonic trend (a series of simple monotonic trends) and found that TP increased significantly from 1977 to the end of 1991 and then decreased from 1992 through 1996. However, when Vecchia's data set was analyzed specifying a single linear trend from 1977 through 1996, the results revealed a significant ($p<0.0001$) overall trend of increasing flow-adjusted concentrations for the 1977 to 1996 period. This was quite different than the results we obtained from our data set, which showed no significant trend in TP from 1973 to 1999. The discrepancy between our results and those of Vecchia is likely due to the fact that the data set we analyzed was more extensive in terms of number of samples (391 as compared to 208) and in length of record. We investigated this further by performing the analysis on our TP data specifically for the period 1977 to 1996 (*i.e.* the same period of time covered by Vecchia's data). The results showed that, as with Vecchia's data, there was a significant increase in flow-adjusted concentrations of TP in our data set over the 1977 to 1996 period. Thus, it appears that the flow-adjusted TP concentrations in our data set from 1997 through 1999 were low enough to cause a decline in the slope of the trend line and make the overall trend in the data no longer significant.

The purpose of this report was to identify the overall long-term trend in nutrient data at each site. However, as stated by Vecchia (2000), water quality data often consists of a series of simple monotonic trends which reflect influences from other short-term trends in the environment such as periods of drought or above normal precipitation, or perhaps cyclical agricultural and economic activity in the watershed. Identification of short-term monotonic trends at each site is beyond the scope of the present report, but will be addressed in more detailed investigations in the future.

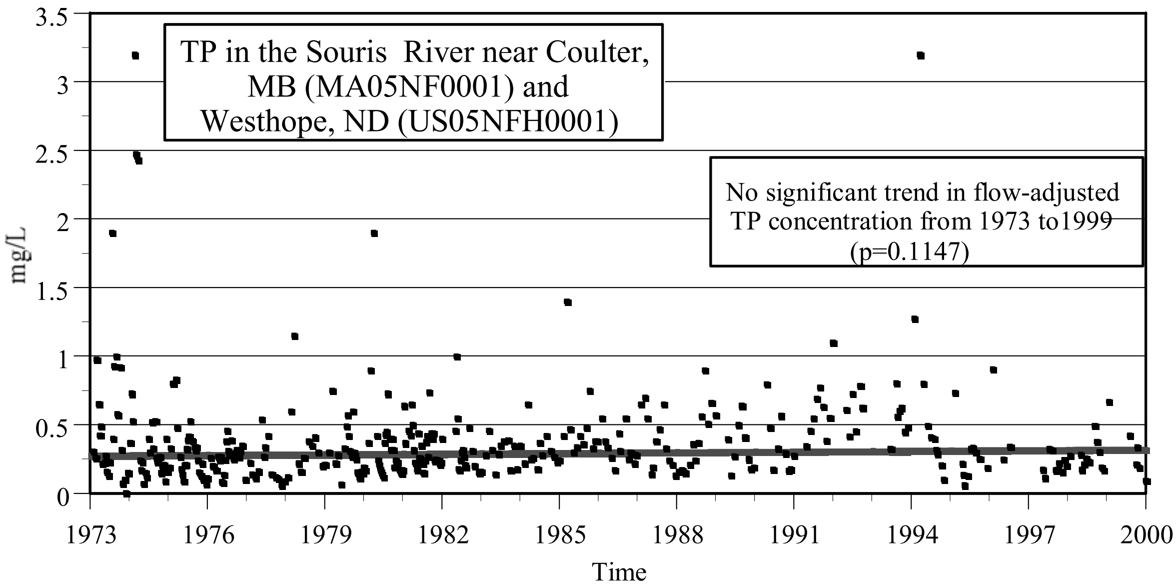


Figure 52. Trend in TP concentration in the Souris River near Coulter, MB, and Westhope, ND, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Water quality monitoring station WQ0371 is located in the town of Souris, approximately 105 km downstream of the Coulter station. Total nitrogen and TP data for the trend analysis at WQ0371 were obtained from 150 water samples collected from 1978 to 1997 (the site was not sampled beyond 1997). Flow data for the analysis of the TN and TP data were provided by hydrometric station MB05NG021, which is located in the immediate vicinity of WQ0371.

The analysis results showed that there was a significant (p=0.0024) trend of increasing flow-adjusted TN concentrations at the site from 1978 to 1997 (Figure 53). Although some relatively high TP concentrations were recorded in the latter half of the reporting period, these were highly positively correlated with flow volume, and no significant trend in the data (p=0.3351) was found once the influence of flow had been taken into account (Figure 54).

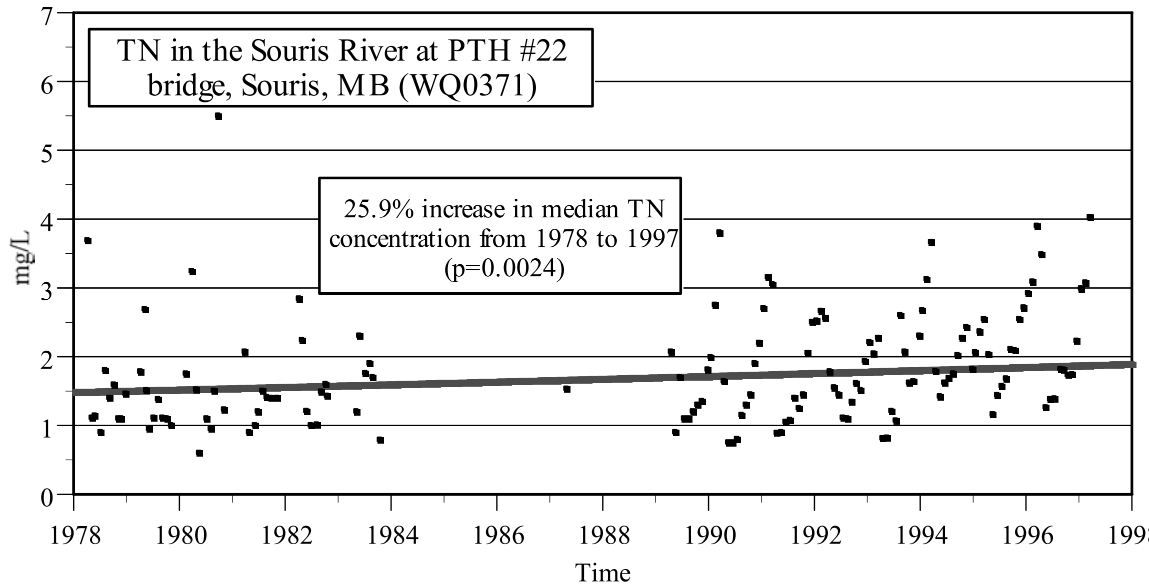


Figure 53. Trend in TN concentration in the Souris River at PTH #22, Souris, MB, 1978 to 1997 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

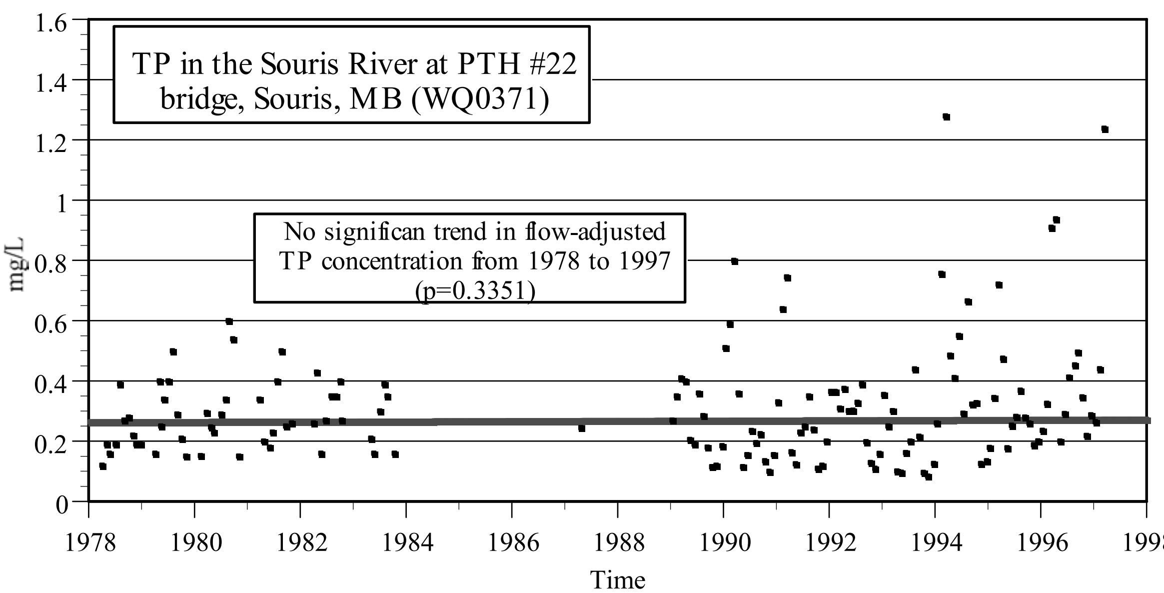


Figure 54. Trend in TP concentration in the Souris River at PTH #22, Souris, MB, 1978 to 1997 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Water quality station WQ0350 is located on the Souris River at PR #530, near the community of Treesbank. The site is approximately 70 km downstream of WQ0371 and about 8 km upstream of the river's confluence with the Assiniboine River. Water sampling at WQ0350 has been conducted on a periodic basis since the early 1970s, with an approximate seven-year gap in collection from 1978 to 1985. Total nitrogen data for the trend analysis at the site were obtained from 182 water samples collected from 1973 to 1999, while 215 water samples collected from 1970 to 1999 provided the TP data. Flow data for the analysis were supplied by hydrometric station MB05NG001 near Wawanesa, about 9 km upstream of the water quality monitoring station.

Results of the analysis showed that flow-adjusted concentrations of both TN and TP increased significantly ($p<0.0001$) over the period of reporting (Figures 55 and 56). The degree of increase for both variables over the entire period of record was relatively substantial, with the median of the trend increasing over 45% for TN, and over 50% for TP.

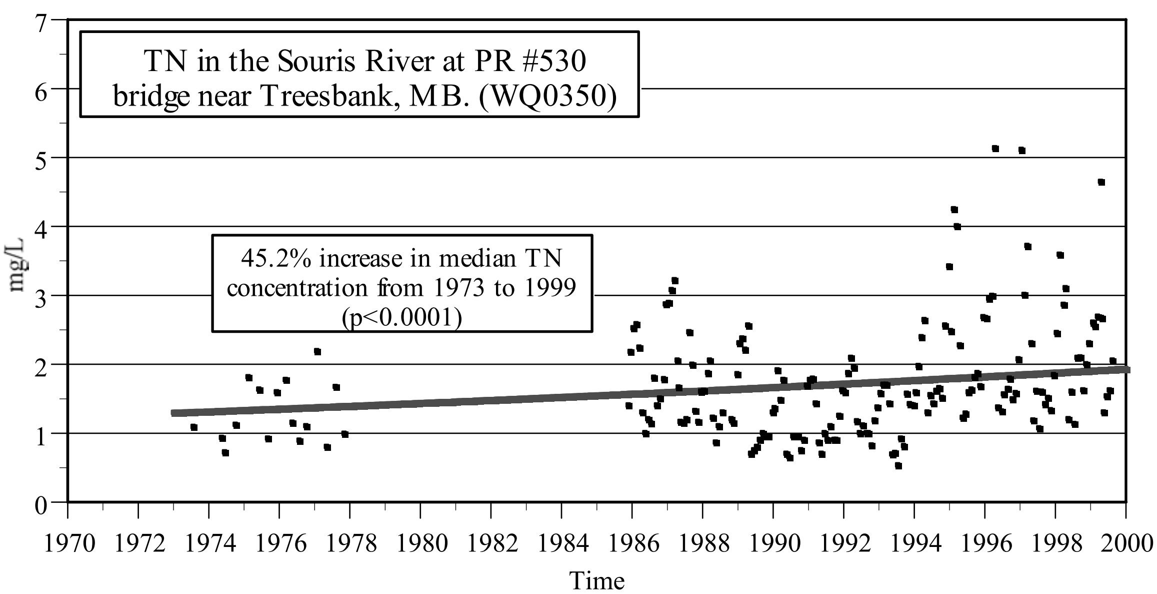


Figure 55. Trend in TN concentration in the Souris River at PR #530 near Treesbank, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

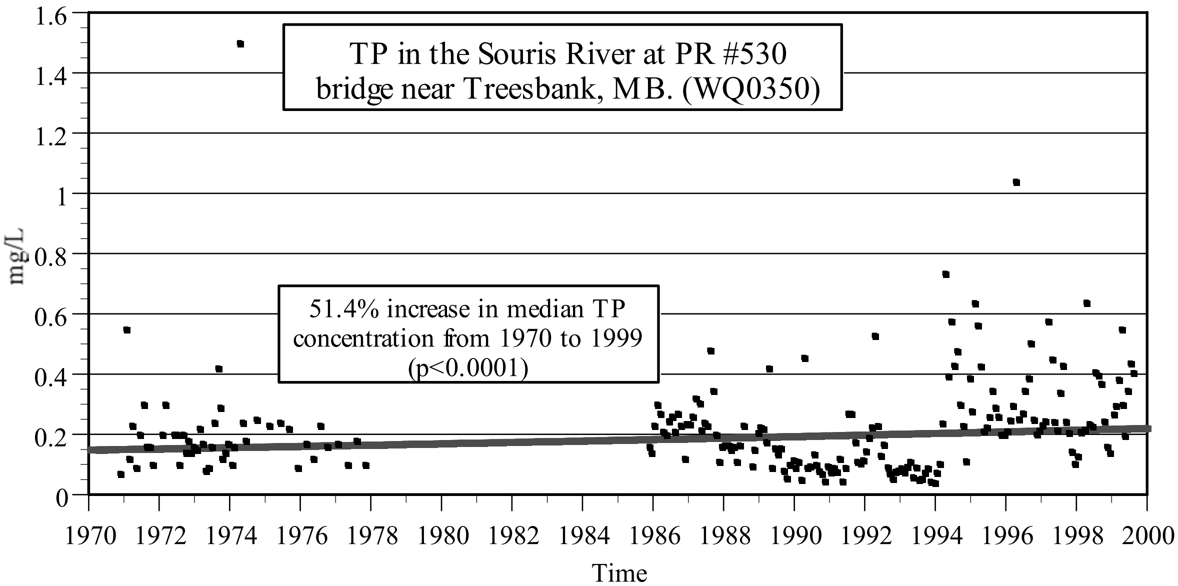


Figure 56. Trend in TP concentration in the Souris River at PR #530 near Treesbank, MB, 1970 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

QU'APPELLE RIVER

The Qu' Appelle River is an inter-provincial waterway with its headwaters at Lake Diefenbaker in south-central Saskatchewan, northwest of the city of Moose Jaw (Figure 57). The Qu' Appelle flows eastward from its origin for approximately 450 km and eventually discharges into the Assiniboine River near the village of St. Lazarre in Manitoba. The drainage basin of the Qu' Appelle River is approximately 50300 km^2. The vast majority of this basin is located in Saskatchewan, with only about 70 km^2 or 0.14% of the basin in Manitoba. The river's tributaries are numerous and include many small ephemeral streams (Water Survey of Canada 1975), as well as larger waterways such as the Moose Jaw River and Wascana, Pheasant, and Kaposvar Creeks.

Water movement and volume in the Qu' Appelle River is regulated by a series of control structures (Water Survey of Canada 1975). Flow into the river from Lake Diefenbaker is controlled via an outlet conduit at the Qu' Appelle Valley Dam at the southeast end of the lake. Control structures are also used to regulate water levels in several smaller lakes located along the course of

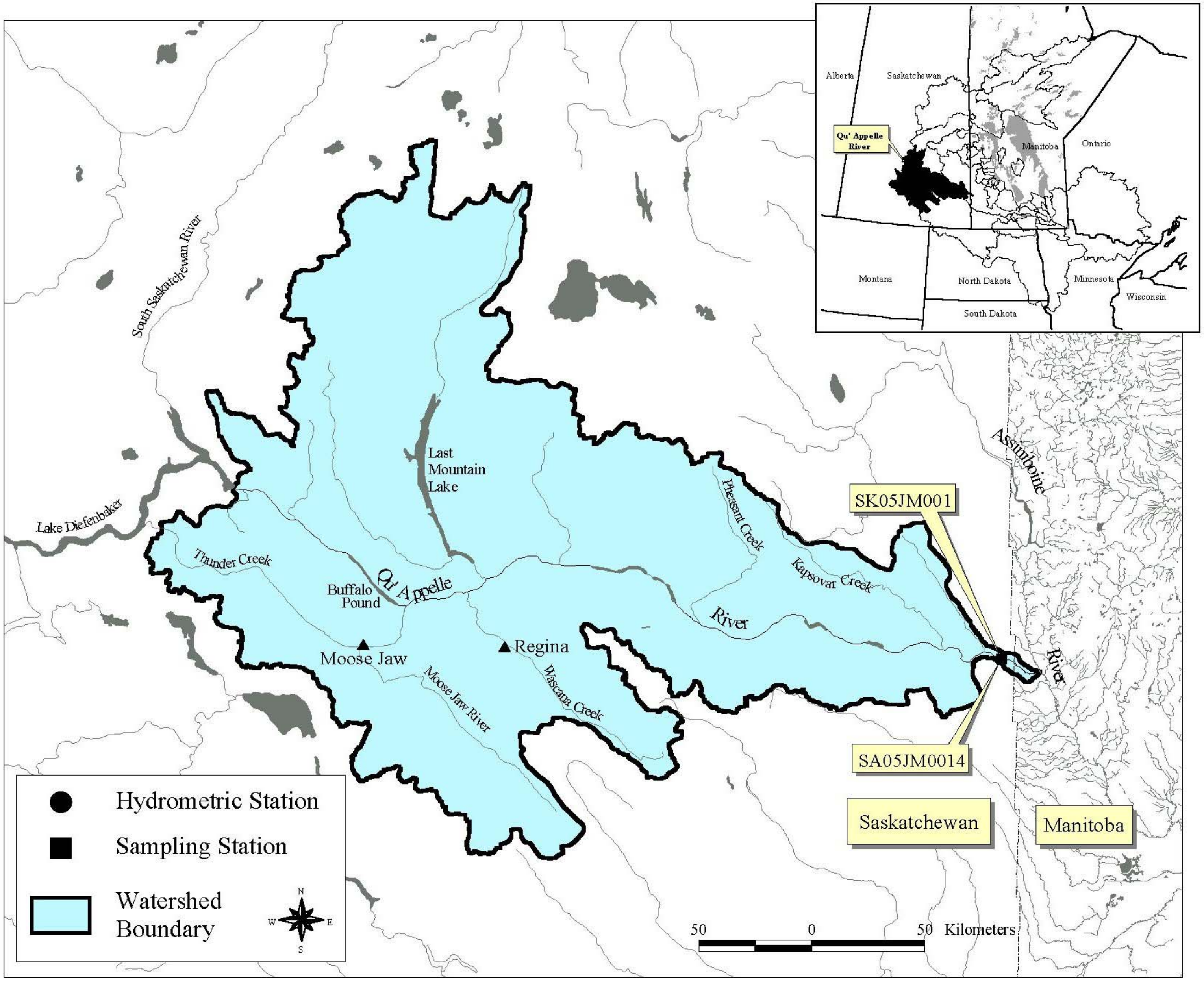


Figure 57. Qu' Appelle River watershed showing the location of water quality sampling site SA0JM0014 and hydrometric station SK05JM001 on the Qu' Appelle River.

the river. These include (moving eastward) Eyebrow, Buffalo Pound, Pasqua, Echo, Mission, Katepwa, Crooked, and Round Lakes. These impoundments are used for domestic and agricultural consumption and recreation purposes, and are important habitat for waterfowl, fish, and other aquatic organisms.

Land use within the Qu' Appelle River watershed is primarily agricultural with a strong emphasis on crop cultivation. Therefore, there is a high potential for non-point source loading of nutrients to the river especially following heavy rainfall or run-off events. As well, a number of population centres have the potential to impact the river system, including the city of Regina which discharges effluent to the Wascana Creek (a major tributary of the Qu' Appelle River) following secondary treatment and phosphorus reduction (Wristen 1999).

Data for the trend analysis of TP in the Qu' Appelle River were obtained from 270 water samples collected from 1975 through 1999 at Environment Canada water quality monitoring station SA05JM0014, located near Welby, SK. The flow data for the analysis were obtained from hydrometric station SK05JM001, also located near Welby.

Results of the trend analysis suggest that there was a trend of decreasing flow-adjusted TP concentrations during the period 1975 to 1999 (inclusive) (Figure 58). This trend was found to be highly significant ($p<0.0001$), with an overall reduction in the median of the trend line of approximately 40%. The reason behind this trend is not known, but it may be related to phosphorus retention in upstream lakes and impoundments, coupled with the implementation of phosphorus removal at Regina in 1989 and the switch to land application of effluent by the city of Moose Jaw in 1987 (Chambers *et al.* 2001). Note that although contributions of TP to the system appear to be declining, overall concentrations in the river remain quite high (generally > 0.1 mg/L).

BROKENHEAD RIVER

The Brokenhead River originates in a boggy wetland area in the northwest corner of the Sandilands Provincial Forest, east of Richer, MB (Figure 59). The river extends approximately 120 km north from its headwaters to eventually empty into Lake Winnipeg near the community of Scanterbury. Numerous small creeks and drainage ditches as well as fens and other wetland areas drain into the Brokenhead along its course northward.

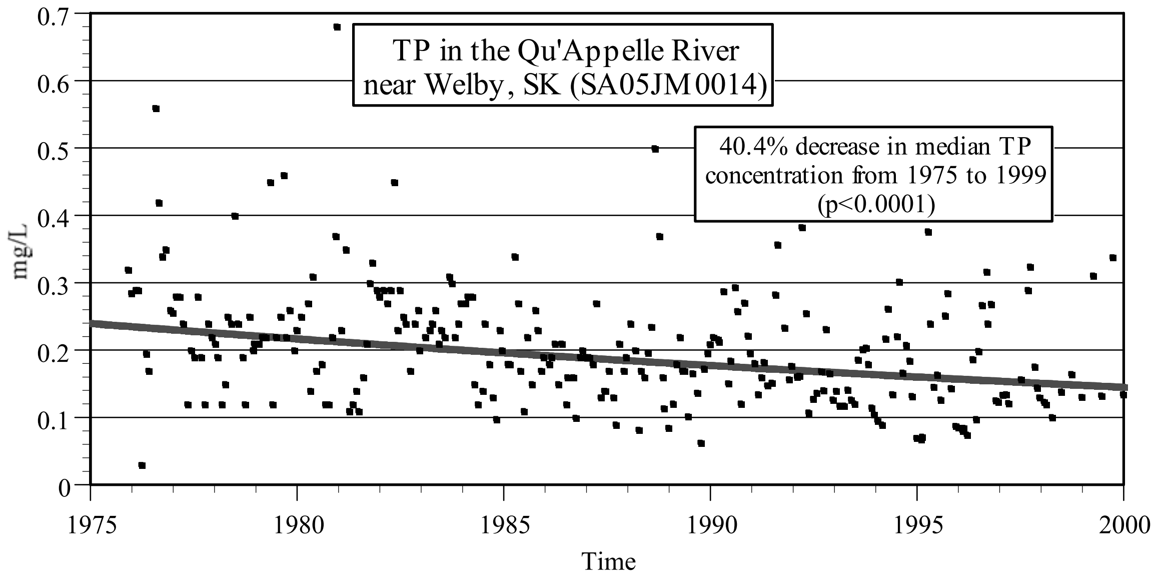


Figure 58. Trend in TP concentration in the Qu'Appelle River near Welby, SK, 1975 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

The Brokenhead River catchment area lies between two much larger drainage basins -- the Red River basin to the west and the Winnipeg River basin to the east. The watershed occupies approximately 2700 km^2 of land, of which about 23% or 642 km^2 is devoted to cereal and forage crop production (Brokenhead River Watershed Management Study 1995). Most of the agricultural activity occurs in the western portion of the watershed, while the eastern portion is primarily forested uplands and wetlands.

The water quality of the Brokenhead River was monitored sporadically in the 1970s and has been monitored on a quarterly basis from 1988 to the present. A recent assessment of the river's water quality using the Canadian Water Quality Index rankings concluded that the overall water quality was good (Hughes 2001). However, other investigations have found that reaches of the river are susceptible to nutrient loading from treated effluent discharges (*e.g.* from the community of Beausejour) and from overland run-off from agricultural lands following spring melt and heavy rainfall events (Green 1997b).

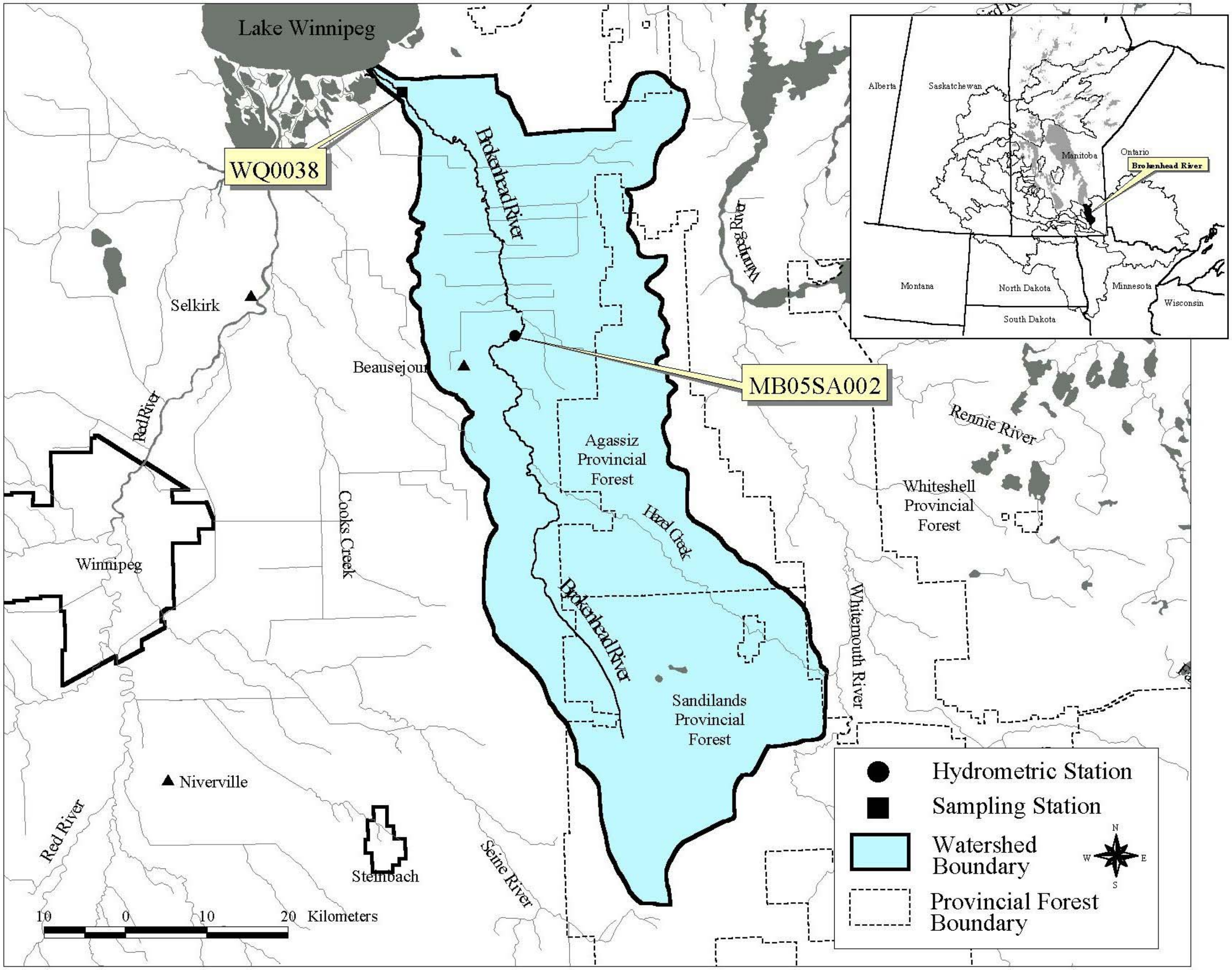


Figure 59. Brokenhead River watershed showing the location of water quality sampling site WQ0038 and hydrometric station MB05SA002 on the Brokenhead River.

Trend analysis of both TN and TP in the Brokenhead River was conducted using data from 61 water samples collected from 1973 to 1999. The samples were collected from station WQ0038, which is located at PTH #59, near Scanterbury, MB. Note that there was a gap in the data from 1978 to the middle of 1987. Flow data for the analysis were obtained from hydrometric station MB05SA002. Although approximately 46 km of river lies between the hydrometric station and the water quality station, MB05SA002 was selected for the analysis because it was the closest hydrometric station to water quality site WQ0038 with a complete record of flow data.

The trend analysis did not identify a significant trend in flow-adjusted TN or TP concentrations at station WQ0038 (Figures 60 and 61). The results suggested that the fluctuations in TN and TP concentrations in the river at site WQ0038 were highly correlated with flow, and that inputs from anthropogenic sources did not cause an increase in TN or TP concentrations at the site over the period of record. This is likely due to the fact that much of the drainage area of the Brokenhead River is lightly populated and consists of upland forest and natural wetlands, as opposed to densely populated, intensively cultivated agricultural lands.

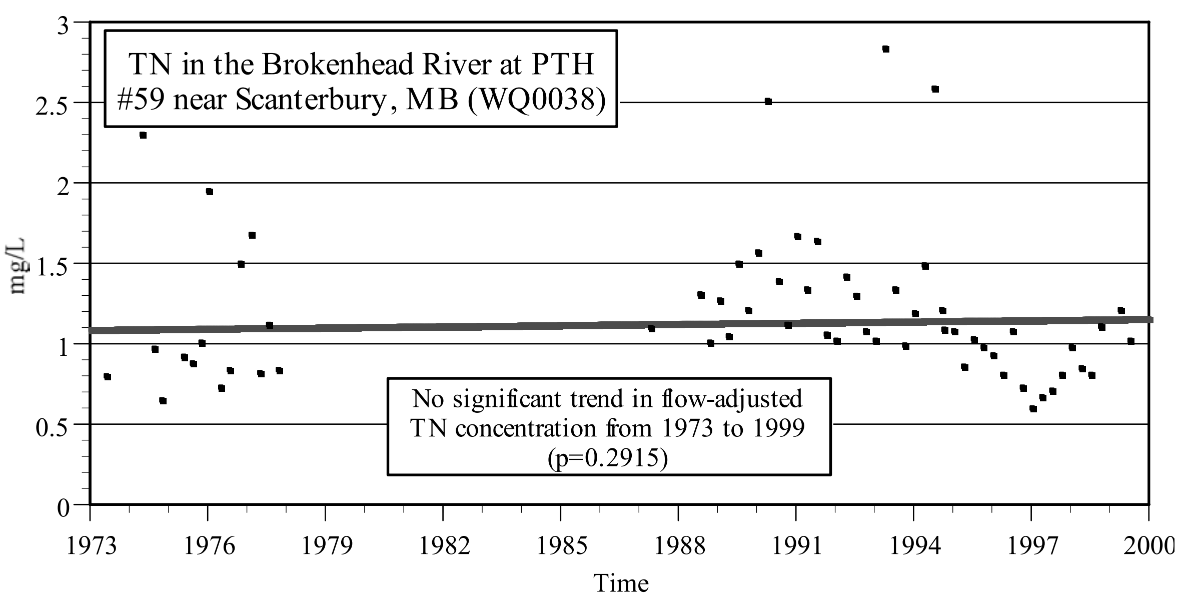


Figure 60. Trend in TN concentration in the Brokenhead River at PTH #59 near Scanterbury, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

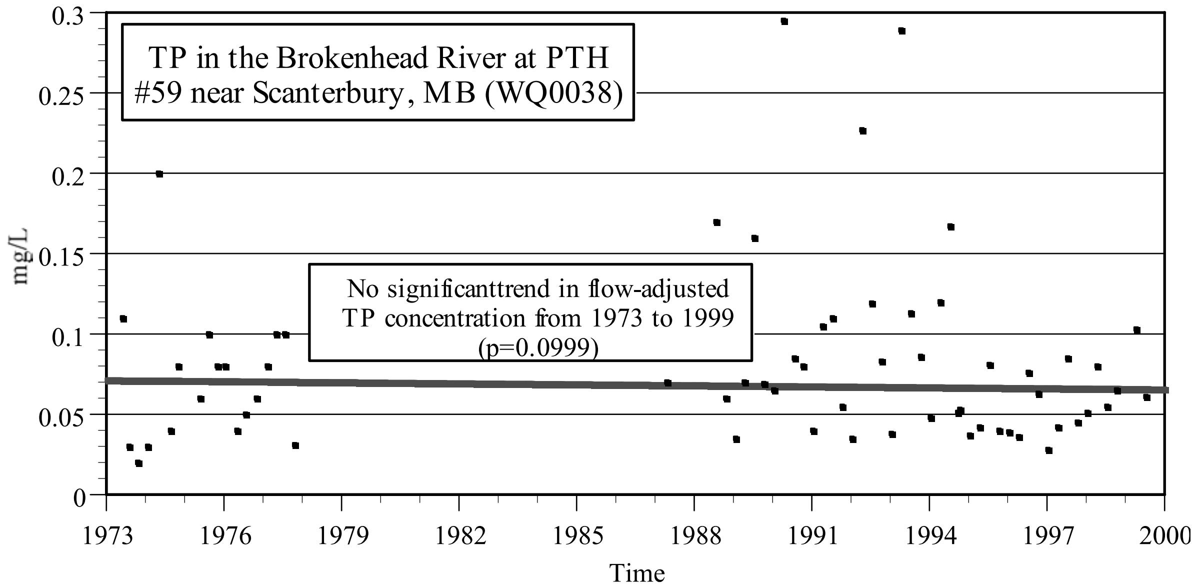


Figure 61. Trend in TP concentration in the Brokenhead River at PTH #59 near Scanterbury, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

WINNIPEG RIVER

The Winnipeg River originates as the outflow from the north end of Lake of the Woods, in northwestern Ontario (Figure 62). The river flows in a northwest direction for a river distance of about 260 km from its headwaters before emptying into Lake Winnipeg (Traverse Bay) west of Pine Falls, MB. The Winnipeg River is the largest waterway in southern Manitoba in terms of water volume discharge, and although flows vary somewhat from year to year, it generally contributes about 40% of the total influent volume to Lake Winnipeg (based on data in Brunskill *et al.* 1980). By comparison, the Red River contributes approximately 8% (varies from year to year) to the total inflow to the lake, or about 1/5 of the total volume contributed by the Winnipeg River (based on data in Brunskill *et al.*1980, Stoner *et al.*1998).

The watershed of the Winnipeg River is very large, encompassing an area of over 137000 km^2. Most of this drainage area (70%) is in northwestern Ontario, while approximately 21% is in Minnesota, and 9% is within the boundaries of Manitoba. Igneous and metamorphic bedrock of the Canadian Shield physiographic region underlie most of the watershed. Except for the occasional surface outcrop, the bedrock tends to be overlain by a variety of forest and peatland soil types

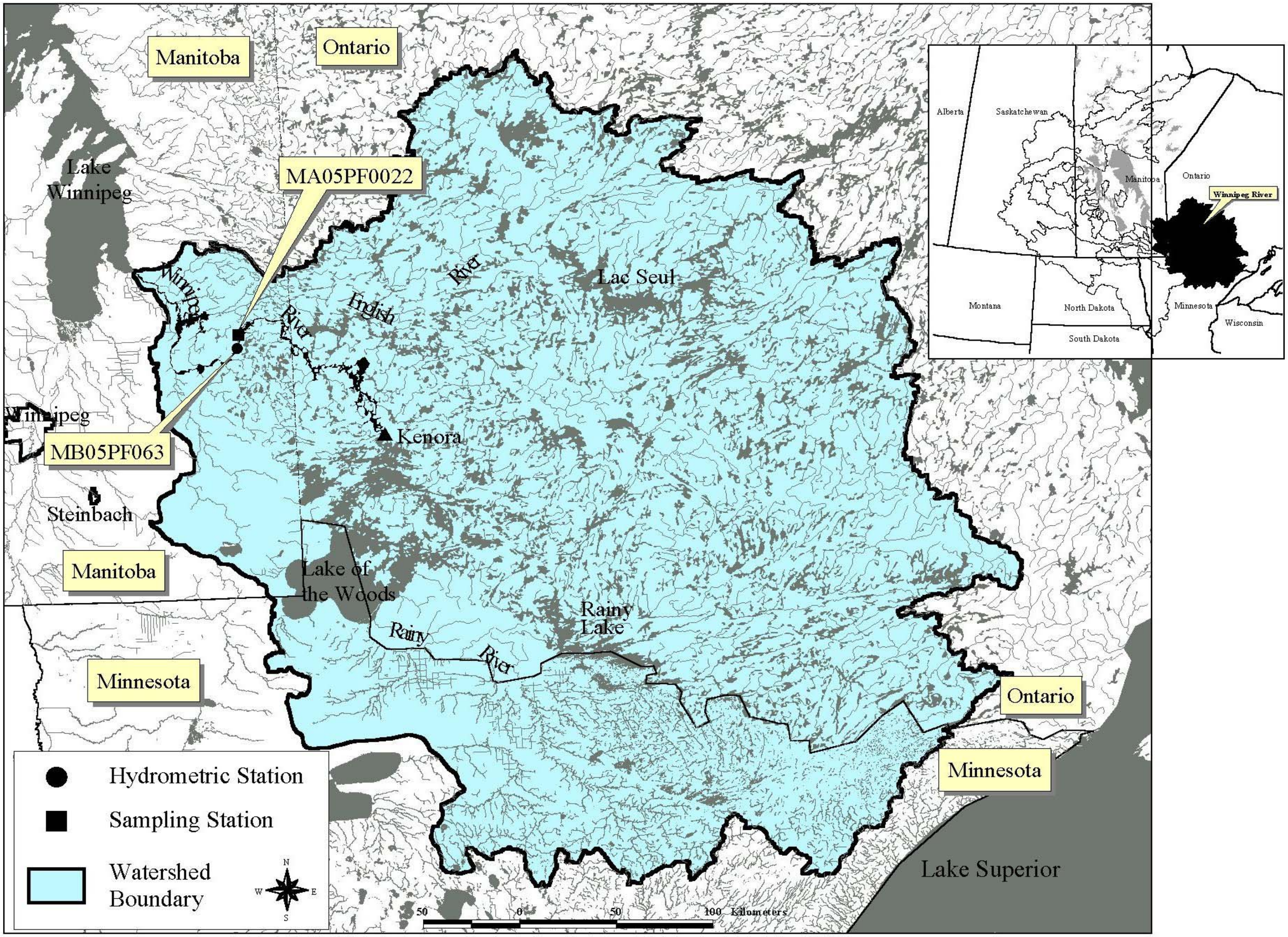


Figure 62. Winnipeg River watershed showing the location of water quality sampling site MA05PF0022 and hydrometric station MB05PF063 on the Winnipeg River.

ranging from thin, poorly developed regosols, to coarse and medium textured brunisols and finer textured luvisols and gleysols, to thick organic peat deposits (Smith *et al.* 1998). Vegetation cover in the watershed is characteristic of the boreal shield ecozone (Smith *et al.* 1998) and consists of extensive forest stands (spruce, pine, aspen, birch) in upland regions, and marsh and peatland vegetation (mosses, ericaceous shrubs, graminoids) in poorly drained lowlands and along lake shores. The soil and terrain within the watershed is not conducive to agriculture and land-use is restricted mainly to forestry, mining, and recreational uses (Patalas and Salki 1992, Smith *et al.*1998).

Major tributaries in the Winnipeg River system include the English and Rainy Rivers. The English River drains much of the northern portion of the watershed and joins the Winnipeg River near the Manitoba boundary. The Rainy River is located along the international border between Canada (Ontario) and the United States (Minnesota) and drains much of the southern portion of the watershed into the south end of Lake of the Woods. Tributaries of note within Manitoba include the Whitemouth, Whiteshell, Oiseau (Bird), and Maskwa Rivers.

The Winnipeg-English-Rainy River system has a long history of hydro-electric development dating back to the late 1880s (Manitoba Hydro-Electric Board 1958). Numerous control structures have been installed to regulate flow volumes in the river system as well as water levels in Lake of the Woods, Rainy Lake, and Lac Seul. This water level regulation is necessary for the operation of a number of hydro-electricity generating stations on the Winnipeg and English Rivers. Six generating stations are located on the Winnipeg River in Manitoba (Manitoba Hydro-Electric Board 1958). These include (moving downstream from the Manitoba-Ontario border towards Lake Winnipeg) Point du Bois, Slave Falls, Seven Sisters, McArthur, Great Falls, and Pine Falls. The oldest of these is Point du Bois, which began operation in 1911 and was completed in 1926, while the most recent is McArthur, which began operation in 1954 (Manitoba Hydro Electric Board 1958, Winnipeg Hydro 1998).

The trend analysis of the TP content in the Winnipeg River was carried out using TP data from 265 water samples collected from 1972 to 1999 at the Environment Canada water quality monitoring station at Point du Bois (MA05PF0022). Station MA05PF0022 was chosen for the analysis because it is the only water quality sampling station on the river with a long-term record of both TP data and flow data (hydrometric station MB05PF063 is located close by). The sampling site is approximately 130 km upstream of Lake Winnipeg, and thus, the results of the trend analysis do not represent conditions in the river between Point du Bois and Lake Winnipeg.

Results from the analysis indicated that there was a gradual trend of increasing flow-adjusted TP concentration at the Point du Bois site from 1978 through 1999 (Figure 63), which implied that TP inputs to the system have increased during the past quarter century. However, because the soils in the watershed tend to be nutrient poor and human development (other than hydro-electrical development) is relatively localized, the overall concentration of TP in the river has remained low (generally between 0.02 and 0.03 mg/L). Thus, the positive trend in flow adjusted TP, although statistically significant ($p<0.0001$), may not have any significant influence on the ecology of the river. However, the trend in increasing TP in the river is of concern since it suggests that loading to Lake Winnipeg from the Winnipeg River may be increasing.

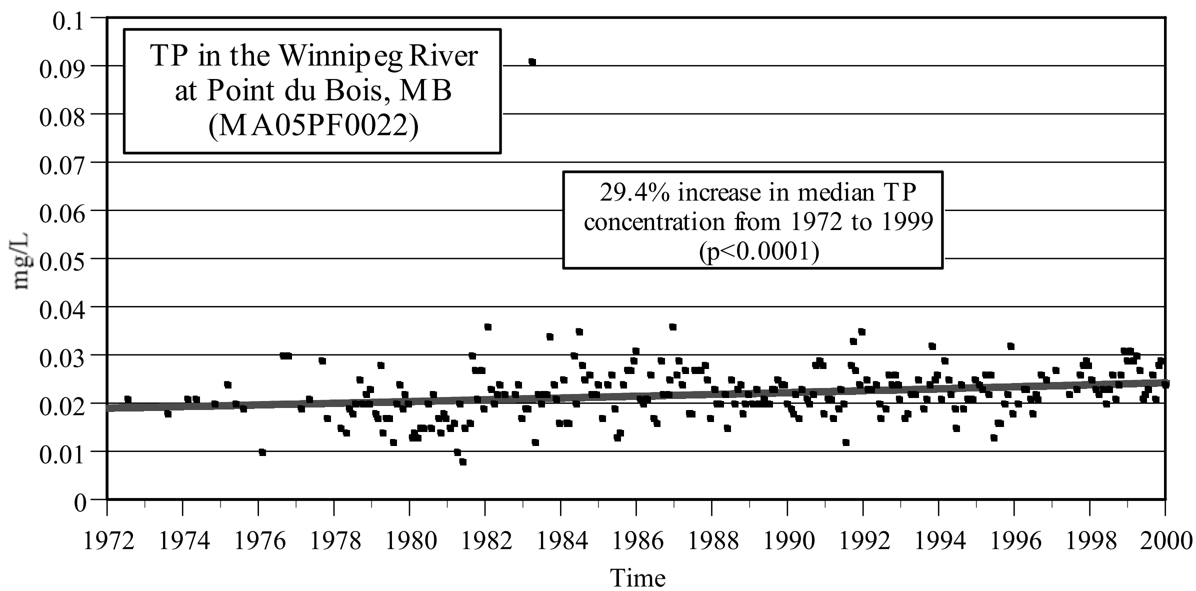


Figure 63. Trend in TP concentration in the Winnipeg River at Point du Bois, MB, 1972 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

BOGGY CREEK AND WHITEMUD RIVER

Boggy Creek meanders northward from its headwaters on the Manitoba Escarpment for a distance of approximately 23 km before widening into Lake Irwin, a reservoir created by PFRA in 1959 (Dickson 1964) (Figure 64). Like most river impoundments in southern Manitoba, the reservoir is narrow (approximately 3.2 km long and 400 m wide) and somewhat irregularly serpentine shaped. The reservoir is used as a source of drinking water for the nearby town of

Neepawa. The creek exits Lake Irwin and enters a low, marshy area immediately southeast of the town of Neepawa where it forms the headwaters of the Whitemud River[1]. The Whitemud River continues eastward from Neepawa for a river distance of approximately 120 km and empties into Lake Manitoba northeast of the village of Westbourne. Major tributaries of the Whitemud River include Pine, Squirrel, and Rat Creeks, as well as the Big Grass Drain, which originates in the Big Grass Marsh area (collectively Jackfish, Seagull, and Chandler Lakes).

The Boggy Creek-Whitemud River system drains a total area of approximately 7500 km^2. In general, drainage within the watershed is from the Manitoba Escarpment eastward to Lake Manitoba. Land use in the watershed is mainly agricultural and includes hog and cattle production, as well as crop cultivation. Streams within the watershed are susceptible to nutrient inputs from non-point sources such as run-off from fields and pasturelands, as well as inputs from point sources such as discharges from wastewater lagoons. Municipal wastewater lagoons at Neepawa and Gladstone discharge treated effluent directly to the Whitemud River, while lagoons at Austin and MacGregor discharge to tributaries of the river. Several Hutterite colony lagoons also discharge treated effluent to waterways within the watershed.

A recent water quality assessment of the Whitemud River-Boggy Creek system found that, although nutrient concentrations varied somewhat between sample dates and between sample locations along the waterway, they were generally more than adequate to support algal growth (Hughes 1999b). The survey was conducted during the ice-free period of 1996, 1997, and 1998. The lowest TP concentration recorded was 0.046 mg/L from a water sample collected near Westbourne in the fall of 1997, while the highest concentration of 0.52 mg/L was recorded in a sample collected near the community of Arden in June 1997. Concentrations of TN also varied

[1] Note that some sources and maps do not distinguish between the Boggy Creek and Whitemud River portions of the waterway, but rather refer to the entire waterway as the Whitemud River.

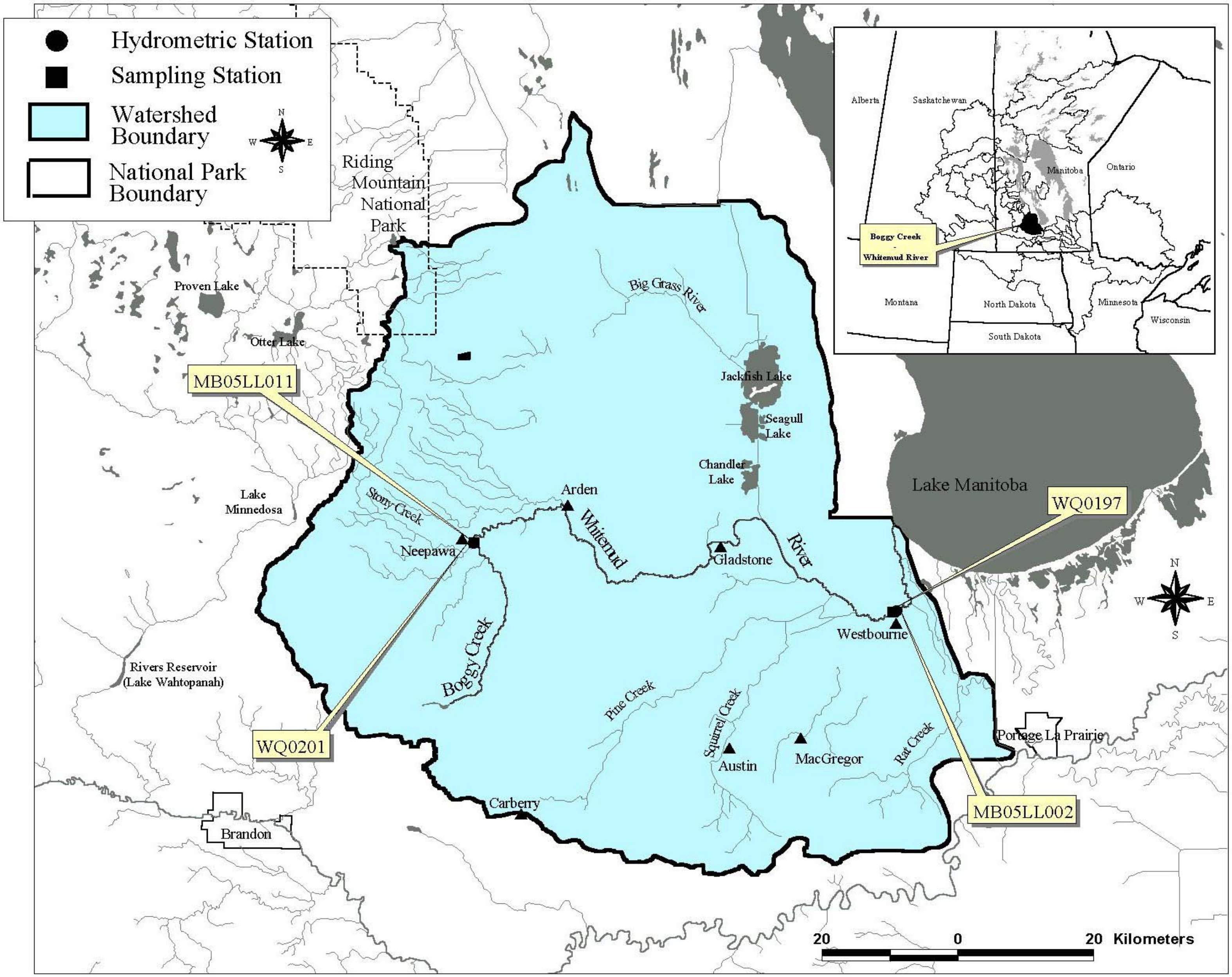


Figure 64. Boggy Creek - Whitemud River watershed showing the location of water quality sampling site WQ0201 and hydrometric station MB05LL011 on Boggy Creek and sampling site WQ0197 and hydrometric station MB05LL002 on the Whitemud River.

considerably during the survey period, from a low of 0.70 mg/L in the Whitemud near Westbourne in October 1997, to a high of 4.63 mg/L in Boggy Creek near Neepawa in early April 1998. Chlorophyll-*a* concentrations in the water remained relatively low over most of the survey period, which indicates that the high nutrient content of the water did not appear to result in excessive phytoplankton growth in the waterway (Hughes 1999b). However, field observations during the survey period and during subsequent growing seasons found that periphyton growth was quite prolific at a number of the sites sampled (Hughes 2001 pers. comm.).

TN and TP data collected at two water quality sampling stations were used to assess the trends in nutrients in the Boggy Creek – Whitemud River system. The first site, station WQ0201, is located on Boggy Creek immediately downstream of Lake Irwin near the southeast corner of Neepawa. Flow records for the trend analysis at WQ0201 were obtained from hydrometric station MB05LL011, located nearby. However, since the hydrometric station was abandoned at the end of 1994, and there were no nutrient data collected at WQ0201 from 1992 through 1995, the trend analysis was limited to data collected from 1973 through to the end of 1991. This amounted to 107 water samples with TP data and 102 water samples with TN data.

The second site, station WQ0197, is located on the Whitemud River near the bridge on PTH #16 at Westbourne. Flow data for the trend analysis of site WQ0197 were obtained from hydrometric station MB05LL002, which is located in close proximity to the water quality sampling station. Total nitrogen data from 176 water samples and TP data from 179 water samples collected from 1973 to 1999 were used in the trend analysis at site WQ0197.

The analysis indicated that while there was a significant ($p<0.0001$) trend of increasing flow-adjusted TN concentration at the Boggy Creek site from 1973 through 1991 (Figure 65), there was no significant ($p=0.2549$) long-term trend in TP concentration at the site over the same period (Figure 66). The trend in increasing TN concentration at WQ0201 may be due to increased artificial loading of nitrogen to the creek from agricultural run-off in the Boggy Creek portion of the watershed. The apparent lack of a trend in TP concentration suggests that phosphorus loading within the watershed did not change from 1973 to 1991. However, as mentioned in previous discussions, this may be due to retention of phosphorus in the Lake Irwin reservoir (Frick *et al.* 1996), and does not necessarily mean that artificial loading of phosphorus in the watershed upstream of the reservoir remained unchanged.

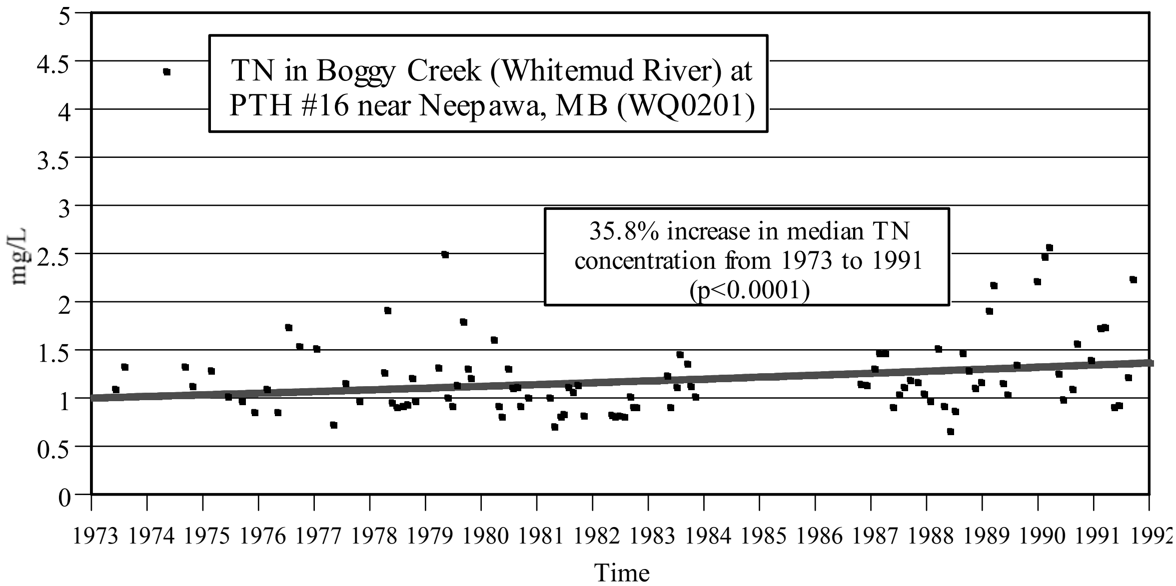


Figure 65. Trend in TN concentration in Boggy Creek (Whitemud River) at PTH #16 near Neepawa, MB, 1973 to 1991 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

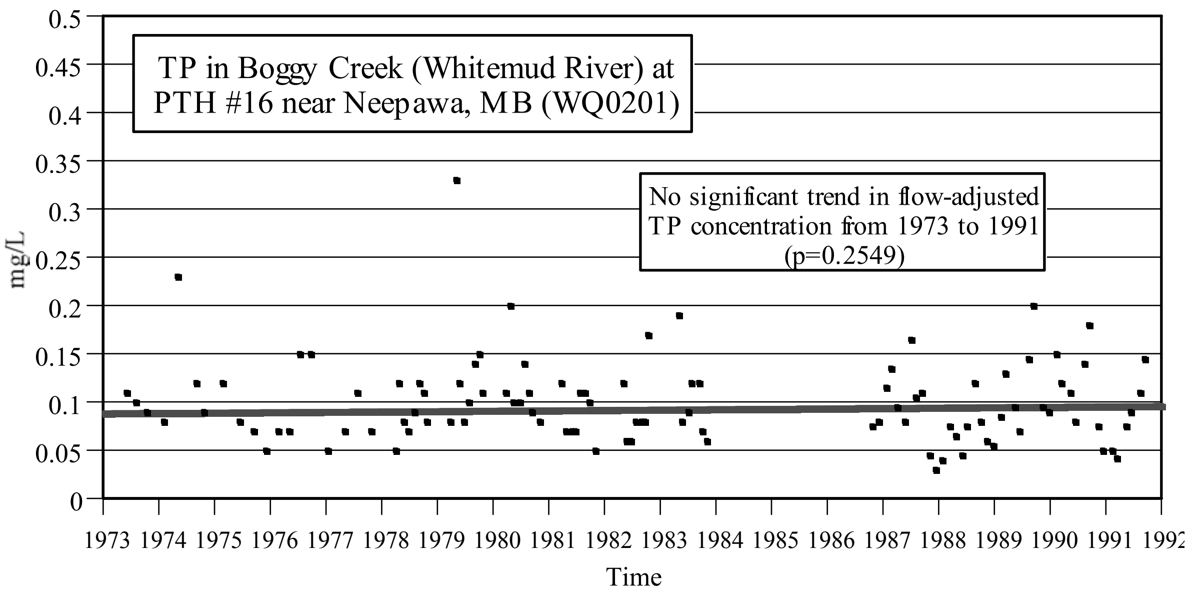


Figure 66. Trend in TP concentration in Boggy Creek (Whitemud River) at PTH #16 near Neepawa, MB, 1973 to 1991 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

The results of the analysis of data from site WQ0197 showed that there was a significant ($p<0.0001$) trend of increasing flow adjusted TN concentrations in the Whitemud River near Westbourne from 1973 through 1999 (Figure 67). Analysis of the TP data revealed that there was also an significant trend of increasing flow-adjusted TP concentration at the site over the same period (Figure 68). Because these are flow-adjusted trends, they suggest that anthropogenic inputs of nitrogen and phosphorus to the Whitemud River have increased over the last quarter century.

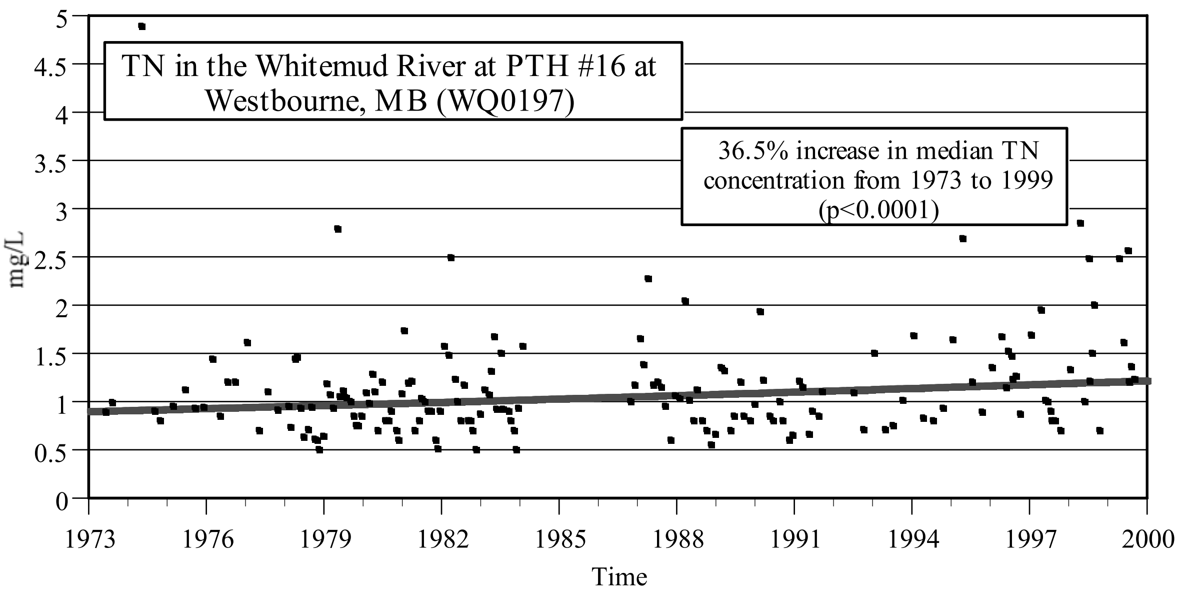


Figure 67. Trend in TN concentration in the Whitemud River at PTH #16 at Westbourne, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

In order to compare trends at the upstream site (WQ0201) with those of the downstream site (WQ0197) the *QWTrend* program was run using data from site WQ0197 for the period 1973 to 1991 (inclusive). The results of this analysis (see Appendix 1) suggest that there was a significant ($p=0.0335$) positive trend in flow-adjusted TN concentration at WQ0197 for the period 1973 through 1991. This trend was similar to, but somewhat less pronounced than that of site WQ0201. The analysis also found that, as with the site WQ0201, there was no significant ($p=0.1057$) trend in the flow-adjusted TP concentration at site WQ0197 from 1973 to 1991. Thus, the trend analysis results for TN and TP data from site WQ0201 were very similar to those from WQ0197 for the period 1973 through 1991. With this in mind, the fact that the trend in TP at WQ0197 was highly significant for the period 1973 to 1999 suggests that much of the increase in artificial loading of phosphorus to the river system occurred during the latter years of the reporting period.

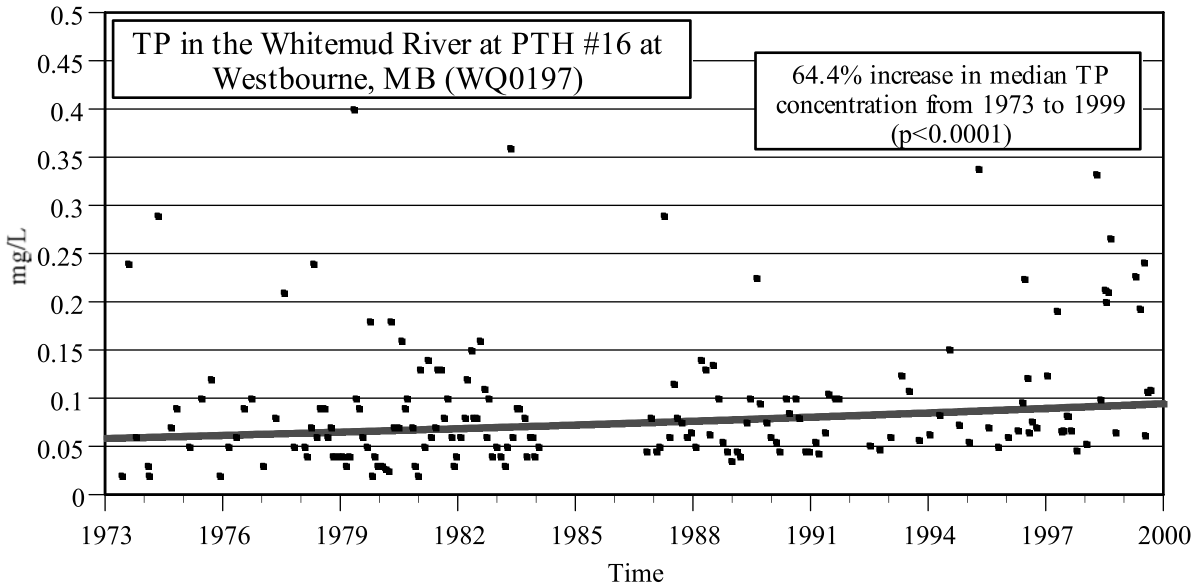


Figure 68. Trend in TP concentration in the Whitemud River at PTH #16 at Westbourne, MB, 1973 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

TURTLE RIVER

The Turtle River originates southeast of the community of McCreary approximately 8 km east of the Riding Mountain National Park (an extension of the Manitoba Escarpment) (Figure 69). The river runs northward for a distance of approximately 58 km and empties into Dauphin Lake north of the town of Ste. Rose Du Lac. The natural channel of the upper portion of the river has been altered considerably by dredging. However, the lower reaches of the river have not been changed to any great extent and much of the channel remains in a near-natural state (Williamson *et al.* 1992). Along its course, the river is fed by a number of small tributaries that flow eastward off of the escarpment. These include Wilson, McKinnon, Scott, and Henderson Creeks. Another contributor to the overall flow in Turtle River is Hansen Creek. The creek does not actually flow into the river itself, but rather flows into Turtle River marsh which then flows into the Turtle River just before it enters Dauphin Lake (Williamson *et al.* 1992). Rather than originating on the escarpment, Hanson

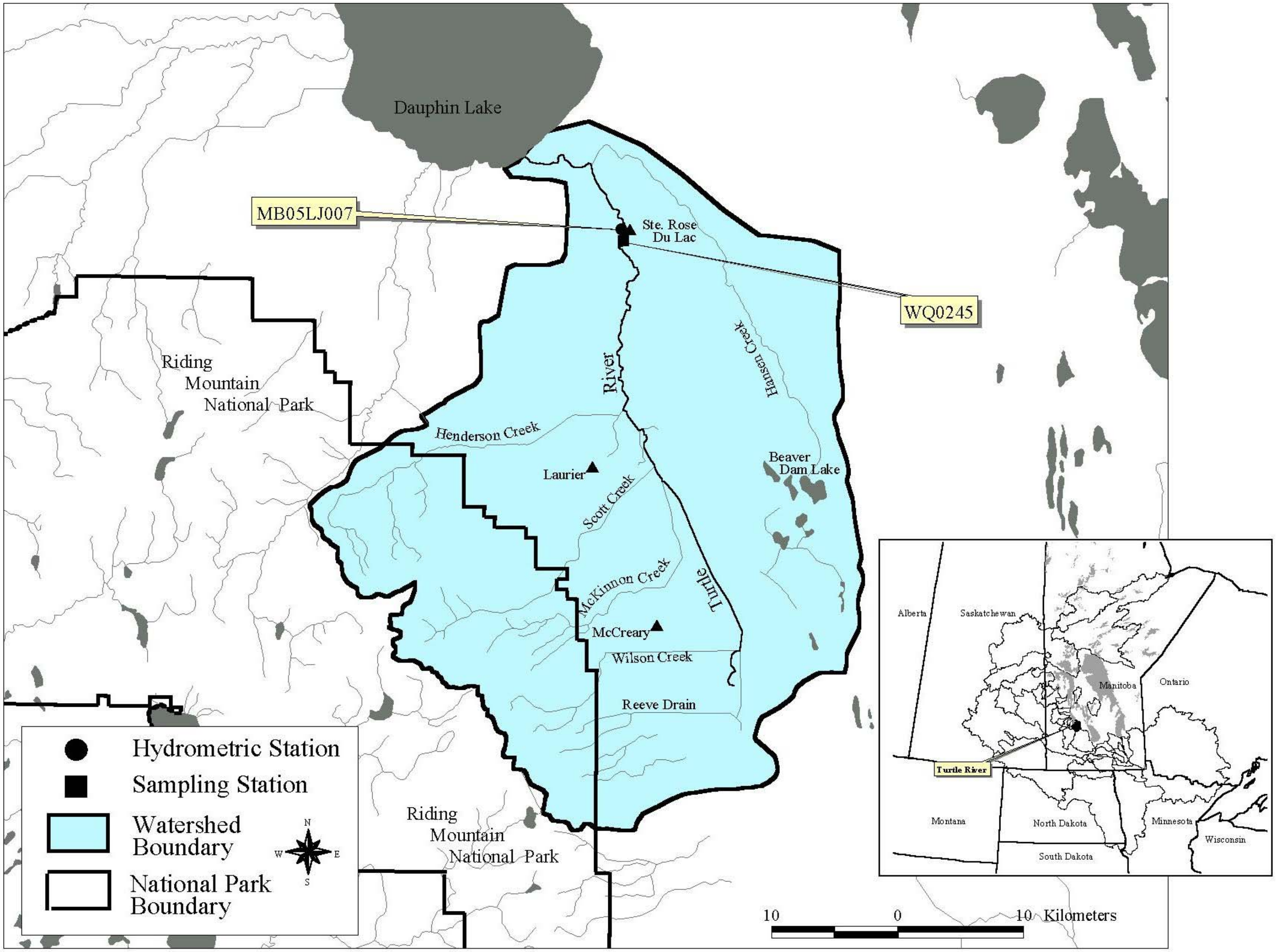


Figure 69. Turtle River watershed showing the location of water quality sampling site WQ0245 and hydrometric station MB05LJ007 on the Turtle River.

Creek is located east of the Turtle River and as such drains much of the eastern portion of the watershed. The Turtle River and its tributaries drain a land area of approximately 1500 km^2. About 20% of the watershed is within the boundary of Riding Mountain National Park. Forested uplands and narrows valleys that have been only minimally impacted by human activity characterize this portion of the watershed. The rest of the watershed consists of a narrow band of rolling terrain immediately outside the park followed by a rapid drop to level lowlands extending to the east and north. Agriculture is the main land use in the region of the watershed outside of the park, and most of this agricultural activity occurs in the lowland region. There is a long agricultural history in the area with cereal, oilseed, and forage crop cultivation, as well as cattle and hog production (Water Resources Branch 1979).

Except for recreational purposes, aquatic habitat, and some irrigation, the direct withdrawal of surface waters within the watershed has been minimal (Water Resources Branch 1979). Historically the main source of water for domestic use and livestock watering has been groundwater. The notable exception in terms of domestic water use is the village of Ste. Rose Du Lac, which, until recently, obtained its drinking water from a small reservoir created on the Turtle River immediately south of the community. As well, a small proportion of the water used for livestock watering within the watershed has been derived from surface waters in areas where groundwater is not potable (*i.e.* too saline or excessive hardness) (Water Resource Branch 1979).

Potential sources of nutrients within the watershed include non-point sources such as overland run-off from fertilized fields (chemical or manure applications) and pastures, and point sources such as municipal wastewater discharges. Municipal wastewater treatment lagoons at Laurier and Ste. Rose Du Lac discharge treated effluent to the river via drainage ditches, while the wastewater lagoon at McCreary discharges treated effluent to McKinnon Creek, which empties into the Turtle River. Williamson *et al.* (1992) conducted a water quality survey of the Turtle River from 1990 – 1992. One of the objectives of the survey was to differentiate between point source and non-point source loading of nutrients to the river. The study found evidence suggesting that phosphorus and nitrogen loading to the river upstream of Ste. Rose Du Lac was related to non-point sources such as overland run-off, while increases in these nutrients downstream of the village were the result of wastewater discharges from the local lagoon. The study also found that discharged effluent from the McCreary lagoon caused levels of phosphorus and nitrogen to increase in McKinnon Creek. However, once the creek entered the Turtle River, the level of dilution afforded by the river was such that the concentrations of phosphorus and nitrogen in the river were not significantly affected.

Data for assessing trends in TN and TP concentration in the Turtle River were collected from water quality sampling station WQ0245, located upstream of Ste. Rose Du Lac at PTH #5. Flow data for the analysis were provided by hydrometric station MB05LJ007, which is located just downstream of WQ0245 at Ste. Rose Du Lac. Total nitrogen and TP data from 102 water samples collected from 1988 through 1999 were used in the trend analysis. The data could not be analyzed using the *QWTrend* program because the period of record covered a span of less than 15 years. Instead, the data were analyzed using the alternate method employing a series of simple linear regression analyses. The results of the analysis showed that after factoring for variation in concentration due to flow, there was no significant trend in either TN (p=0.8014) or TP (P=0.3436) concentration from 1988 through 1999 (Figures 70 and 71). This suggested that loading of nutrients to the river from anthropogenic sources remained essentially unchanged over the period of record.

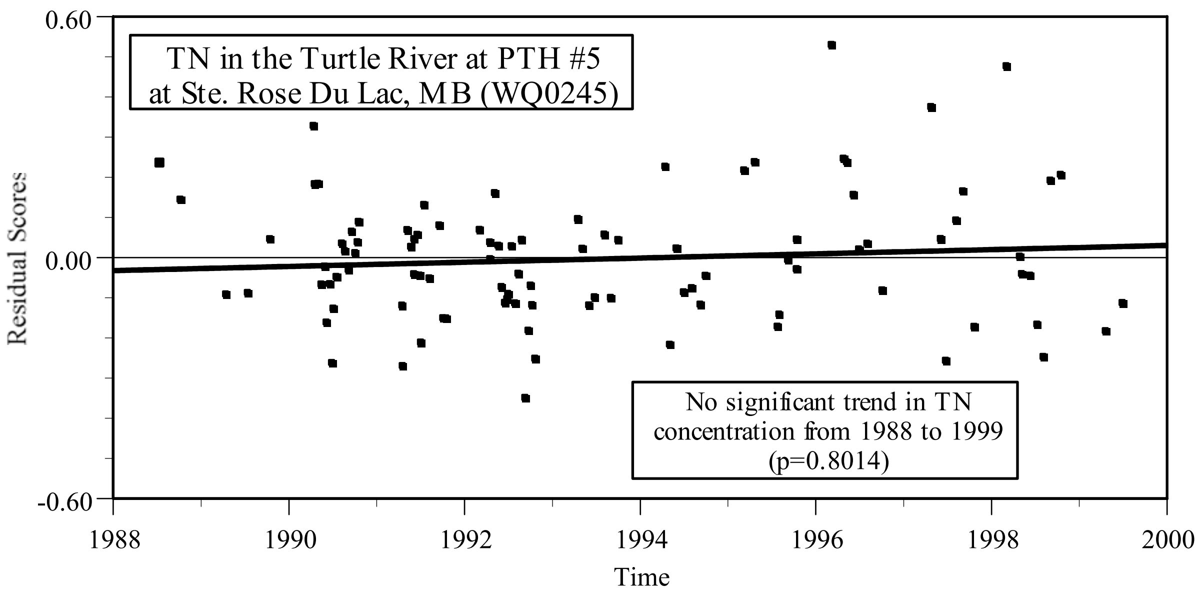


Figure 70. Trend in TN concentration in the Turtle River at PTH #5 at Ste. Rose Du Lac, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

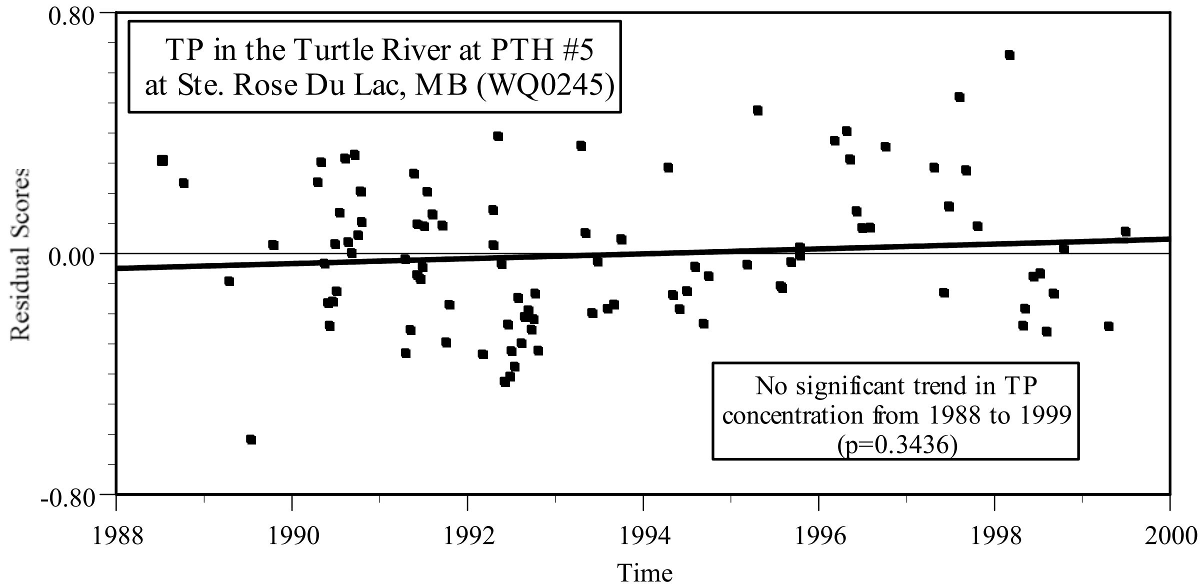


Figure 71. Trend in TP concentration in the Turtle River at PTH #5 at Ste. Rose Du Lac, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

OCHRE RIVER

The Ochre River originates at the confluence of two smaller streams deep within Riding Mountain National Park (Figure 72). From its headwaters in the park the river progresses northward for approximately 41 km before emptying into Dauphin Lake, about 5 km north of the community of Ochre River. The river is fed by several small, often intermittent, creeks and streams as it flows though the park and down the northeast face of the Manitoba Escarpment. Once off the escarpment, contributions to the river are mainly via overland flow and drainage ditches. Unlike much of the Turtle River to the east, the channel of the Ochre River has not been altered to any great extent and remains in a near-natural state.

The Ochre River and its tributaries drain an area of approximately 460 km^2. About 75% of the catchment is in Riding Mountain National Park and is characterized by relatively pristine forested uplands (aspen, birch, and conifers) and deep narrow valleys. The area of the watershed outside of the park consists of a mixture of cultivated fields, open and treed pasture and rangeland, and aspen

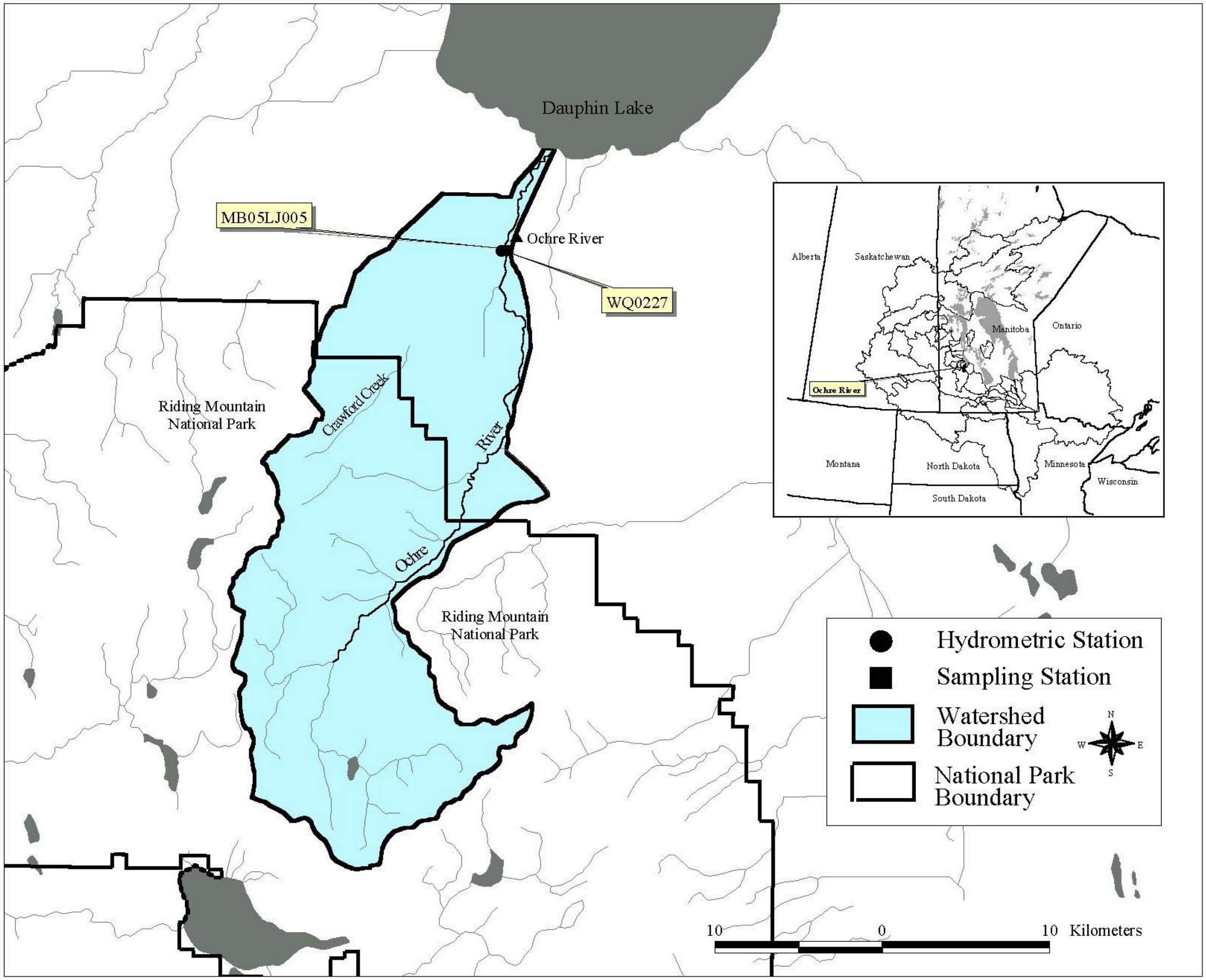


Figure 72. Ochre River watershed showing the location of water quality sampling site WQ0227 and hydrometric station MB05LJ005 on the Ochre River.

dominated deciduous forest stands. Sources of nutrients to the river include contributions from overland run-off and soil erosion as well as periodic discharges of treated effluent from the municipal wastewater treatment lagoon at the community of Ochre River.

The trend analysis of nitrogen and phosphorus in the Ochre River was carried out using data from 70 water samples collected at water quality monitoring station WQ0227 from 1988 to 1999 (inclusive). Station WQ0227 is located at PTH #5 near the community of Ochre River. Flow data for the analysis were obtained from hydrometric station MB05LJ005, which is also located at PTH #5. The period of record (12 years) negated using the *QWTrend* program. Instead, the analysis method using simple linear regressions was used to identify trends in the nutrient data.

The results of the analysis indicated that there was no significant trend in either TN ($p=0.6226$) or TP ($p=0.4483$) concentrations at the site from 1988 through 1999 (Figures 73 and 74). These results were similar to those obtained for the Turtle River. However, the actual concentrations of nutrients in the Turtle River tended to be higher than those recorded in the Ochre River. Over the 1988 – 1999 period there were 67 dates during which samples were collected concurrently from both sites. The Turtle River had higher TP and TN concentrations on 66% and 73% of these dates, respectively. The difference in TP and TN concentrations between the two rivers may be attributed to differences in land-use within the two watersheds. The Turtle River watershed has proportionally more land under agricultural production than the Ochre River watershed (Muir and Grift 1987), which is predominantly forest. As a consequence, the Turtle River is more susceptible to non-point source nutrient loading. Thus, although significant trends in TN and TP were not observed at either the Turtle River site or the Ochre River site, the rivers do differ with regard to their nutrient concentration and their susceptibility to eutrophication.

VERMILLION RIVER

The headwaters of the Vermillion River are formed by the convergence of several small streams (Buck Creek, Scott Creek, Kennis Creek, Robinson Creek, and Teepee Creek) near the northern boundary of Riding Mountain National Park in western Manitoba (Figure 75). The river flows

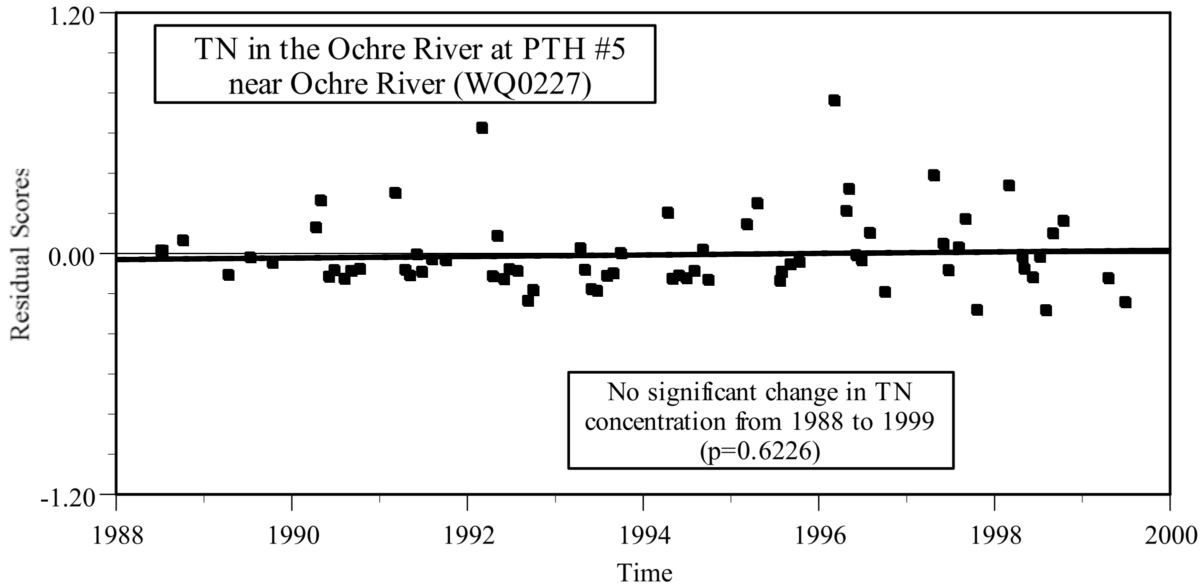


Figure 73. Trend in TN concentration in the Ochre River at PTH #5 near Ochre River, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

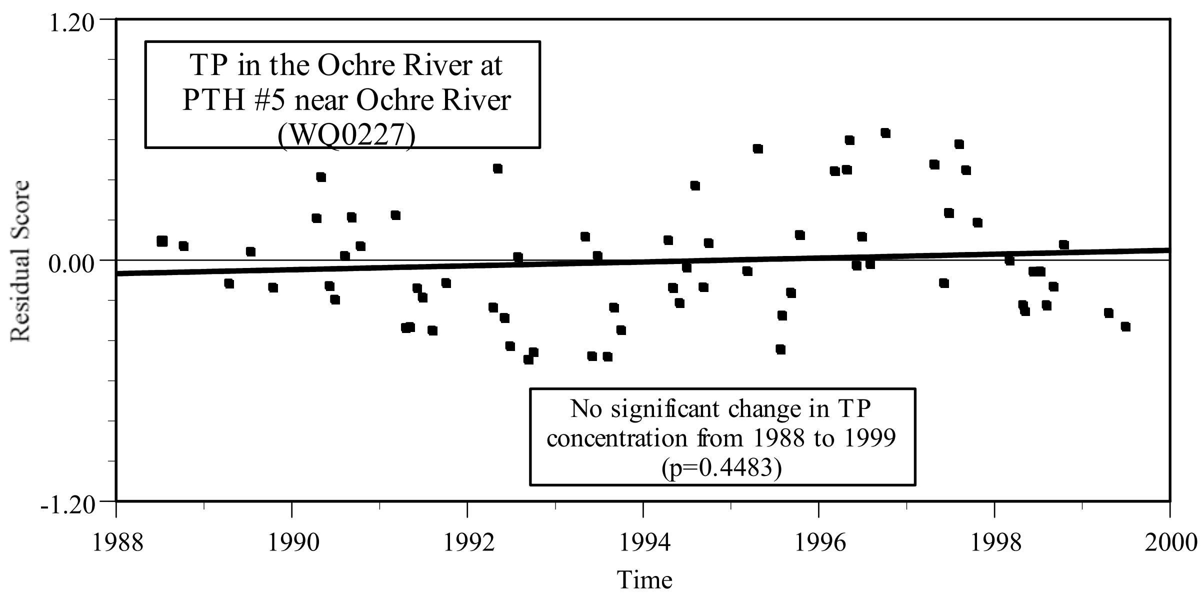


Figure 74. Trend in TP concentration in the Ochre River at PTH #5 near Ochre River, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

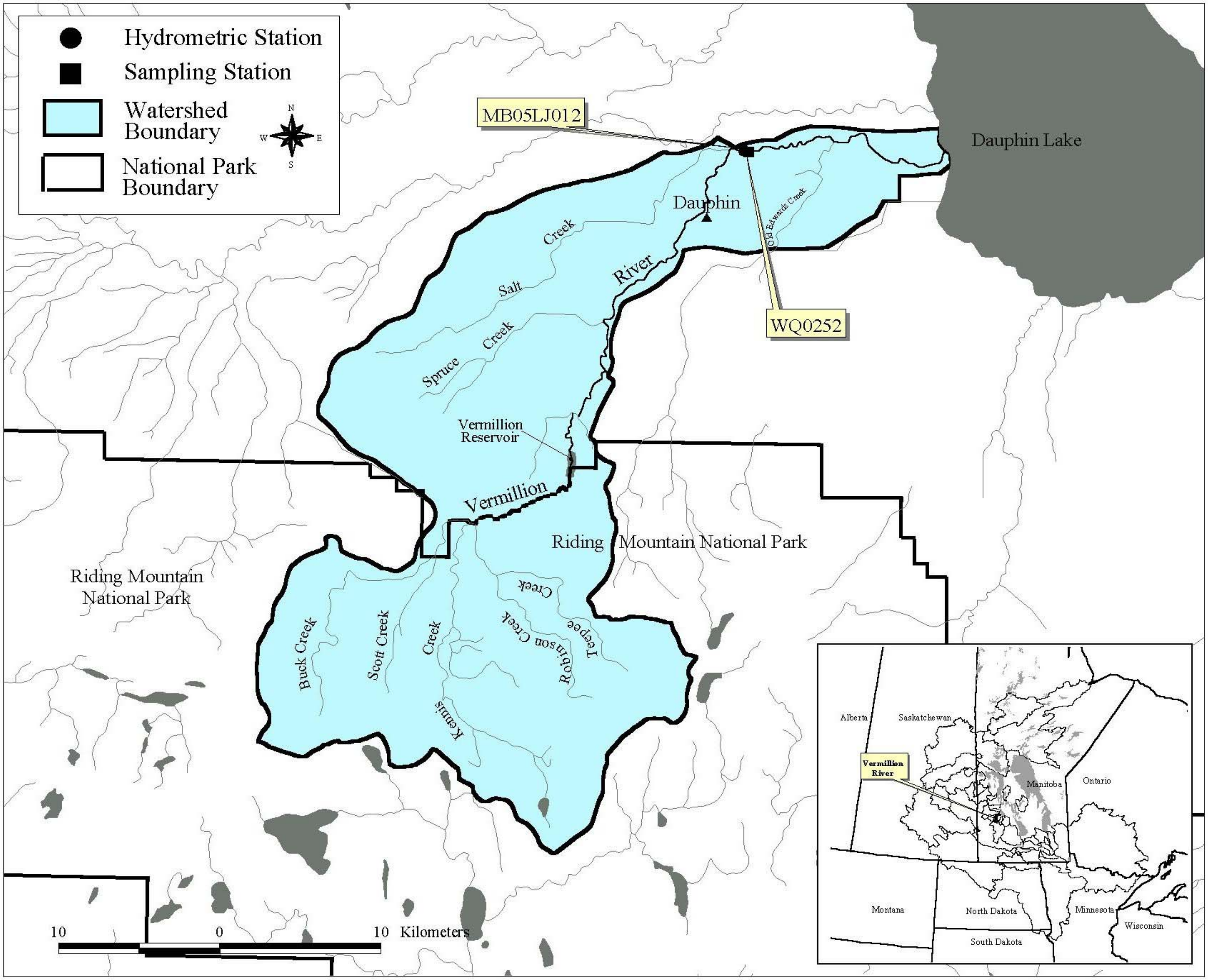


Figure 75. Vermillion River watershed showing the location of water quality sampling site WQ0252 and hydrometric station MB05LJ012 on the Vermillion River.

northeastward from the park for approximately 55 km before eventually emptying into Dauphin Lake northeast of the city of Dauphin. A reservoir was established on the river immediately south of the park boundary in the late 1970s. The reservoir is used as a source of raw water for the city of Dauphin. Major tributaries downstream of the reservoir include Spruce Creek and Salt Creek, and Old Edwards Creek (the original Edwards Creek channel running north from PTH #20). Besides being a source of domestic water, the river is also used for recreational purposes and has been recognized as an important spawning waterway for the Dauphin Lake fishery (Reid Crowther 1996).

The Vermillion River catchment area is roughly 750 km^2. Approximately half of the catchment is in Riding Mountain National Park, where land-use is restricted to recreation and wildlife habitat. Nutrient loading to this portion of the river system from human activity is likely negligible. However, north of the park the land is used for agricultural crops and livestock production, and the river is susceptible to non-point source nutrient loading as it winds its way through this portion of the watershed. The only major point source for nutrient loading to the river is the city of Dauphin, which periodically discharges treated effluent to the river at a point northeast of the community. It has been estimated that the effluent discharge accounts for about 25% of the total TP loading and about 30% of the total TN loading to the river (Tetres Consultants 1996), which implies that the majority of the nutrient inputs to the system are from non-point sources within the watershed.

Data for the trend analysis of TN and TP in the Vermillion River were obtained from water samples collected at the bridge on PTH #20, north of Dauphin (WQ0252). The data available from station WQ0252 spans the period from 1974 through 1999. However, data were only sporadically collected at the site before 1978. As well, prior to 1978 effluent from the wastewater treatment facility at Dauphin was discharged upstream of the water quality station. Since the data record before 1978 is lacking and the location of the effluent discharge was changed to a downstream site in 1978, only data collected from 1978 onward were used in the trend analysis. This amounted to 79 data points for TN and 78 data points for TP. Flow data for the analysis were obtained from hydrometric station MB05LJ012, which is also located at the bridge on PTH #20.

The trend analysis did not detect a significant trend in either TN ($p=0.1952$) or the TP ($p=0.0518$) at site WQ0252 (Figures 76 and 77). These results indicated that the variation in nutrient concentrations in the river was highly correlated with the flow volume of the river, which

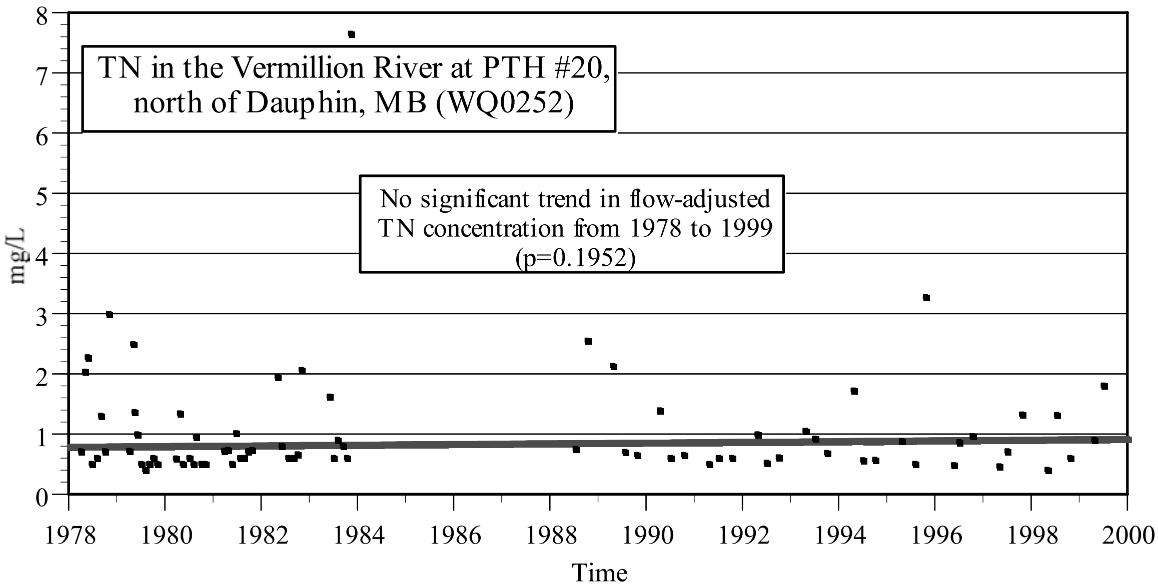


Figure 76. Trend in TN concentration in the Vermillion River at PTH #20, north of Dauphin, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

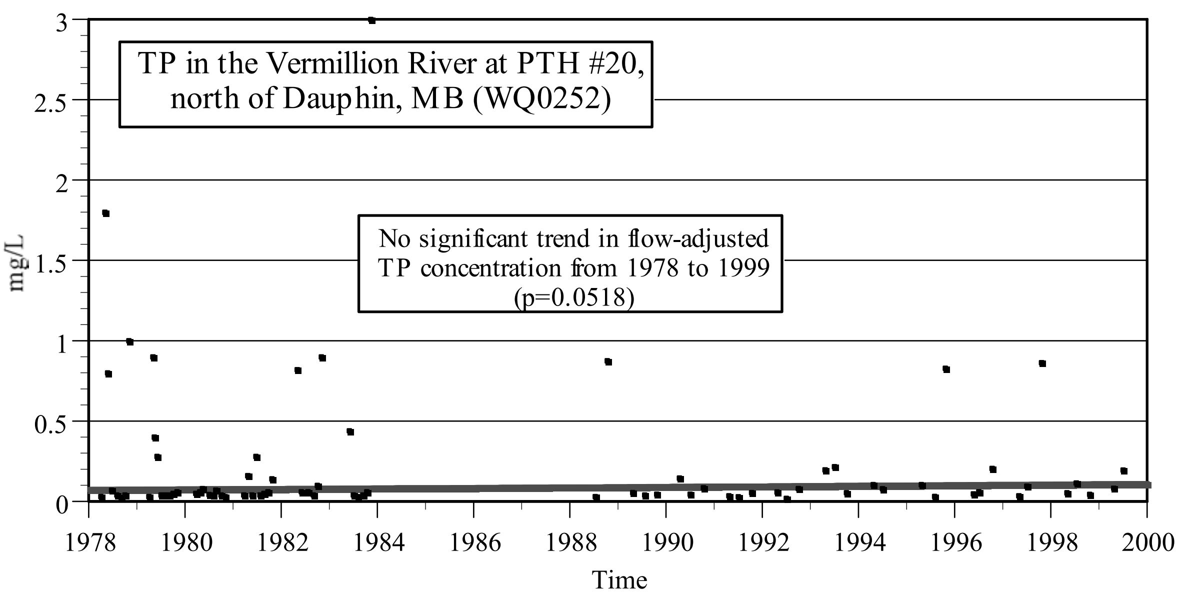


Figure 77. Trend in TP concentration in the Vermillion River at PTH #20, north of Dauphin, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

suggests that nutrient inputs from artificial sources, such as agricultural run-off, did not increase or decrease significantly over the past two decades. Note that the p-value for the TP results was close to significant (at α=0.05). As well, the slope of the trend line for TP was positive. The site on the Vermillion River continues to be monitored on a regular basis and analysis of the data in future years may yet reveal a more significant positive trend in the flow adjusted TP concentrations.

WILSON RIVER

The headwaters of the Wilson River form at the confluence of the East Wilson River and West Wilson River north of Riding Mountain National Park (Figure 78). The Wilson River flows eastward from this point for approximately 75 km before emptying into Dauphin Lake, northeast of the city of Dauphin. Most of the streams that feed into the Wilson River system originate within or near the northern boundary of Riding Mountain National Park. Examples of these include Mineral Creek, Ranch Creek, and Mitchell Creek.

The Wilson River watershed has a land area of approximately 950 km^2. The upper third of the watershed is located within Riding Mountain National Park. Nutrient inputs to the river system in this upper portion of the watershed are from natural sources such as natural stream channel erosion. Land-use in the bottom 2/3 of the watershed is almost exclusively agricultural, with crop cultivation the predominant activity. As such, the river system in the lower portion of the watershed is susceptible to artificial nutrient loading from agricultural run-off.

Data for the trend analysis of TN and TP in the Wilson River were obtained from water quality sampling station WQ0255, which is located in the lower portion of the watershed, approximately 15 km upstream of Dauphin Lake at PTH #20. Seventy-four water samples with TN data and 73 water samples with TP data, collected periodically from 1979 through 1999, were used in the analysis. Flow data for the trend analysis were obtained from hydrometric station MB05LJ045. Hydrometric station MB05LJ045 is located almost 30 km upstream of WQ0255. This relatively large distance between hydrometric station and water quality station presented some concern. However, the flow data set from hydrometric station MB05LJ045 is the only complete long-term record of flow for the Wilson River. Furthermore, most of the watershed drainage into the river occurs upstream of the

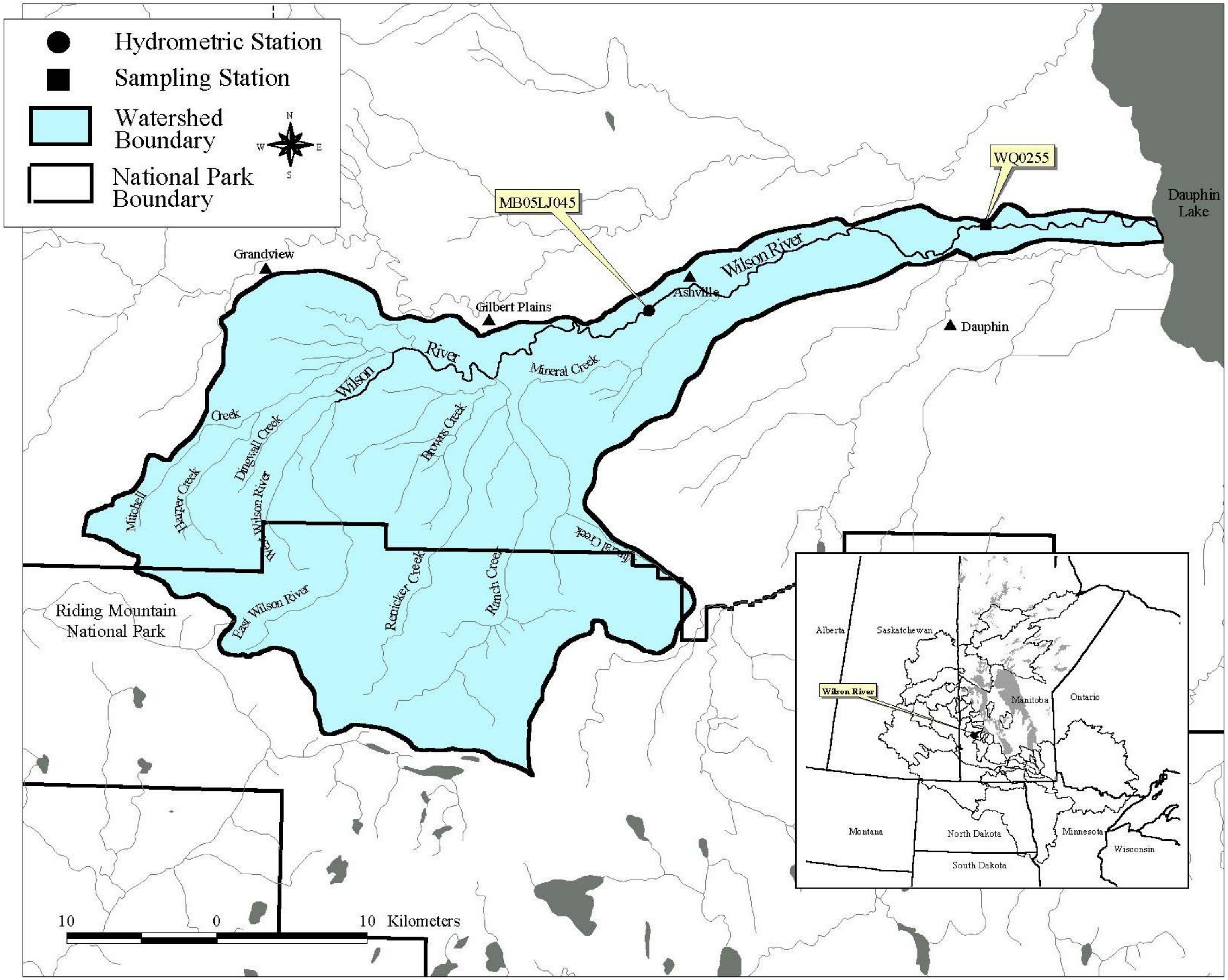


Figure 78. Wilson River watershed showing the location of water quality sampling site WQ0255 and hydrometric station MB05LJ045 on the Wilson River.

hydrometric station, therefore, flows at MB05LJ045 are likely very similar to the actual flows at the water quality sampling station downstream.

The results of the trend analysis on TN and TP in the Wilson River showed that there was a significant positive trend in flow-adjusted TN concentrations (p=0.0345), and a significant negative trend in flow-adjusted TP concentrations (p=0.0321) from 1979 through 1999 (Figures 80 and 81). Both trends were very gradual, with the median of the TN trend line increasing by 21.3% over the period of record, and that of the TP trend line decreasing by about 13.5%. The increase in TN may be due to the presence of nitrogen compounds in surface run-off from fertilized and manure-applied fields within the watershed. The fact that TN increased while TP appeared to decrease may be due in part to the composition of most agricultural fertilizers, which are generally more concentrated with nitrogen than with phosphorus.

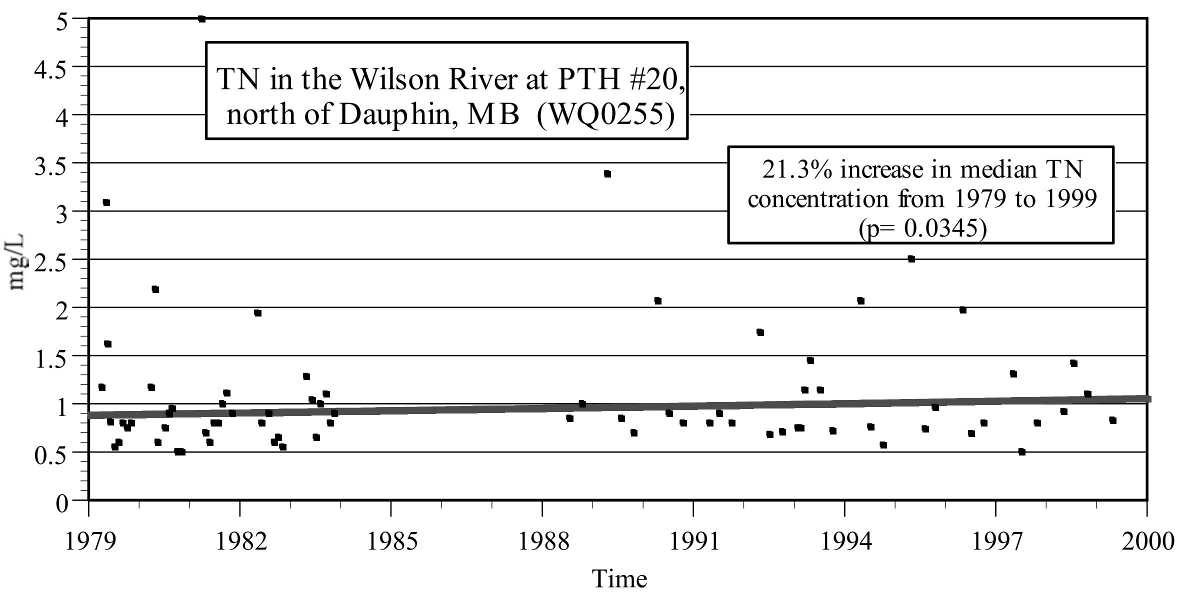


Figure 79. Trend in TN concentration in the Wilson River at PTH #20, north of Dauphin, MB, 1979 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

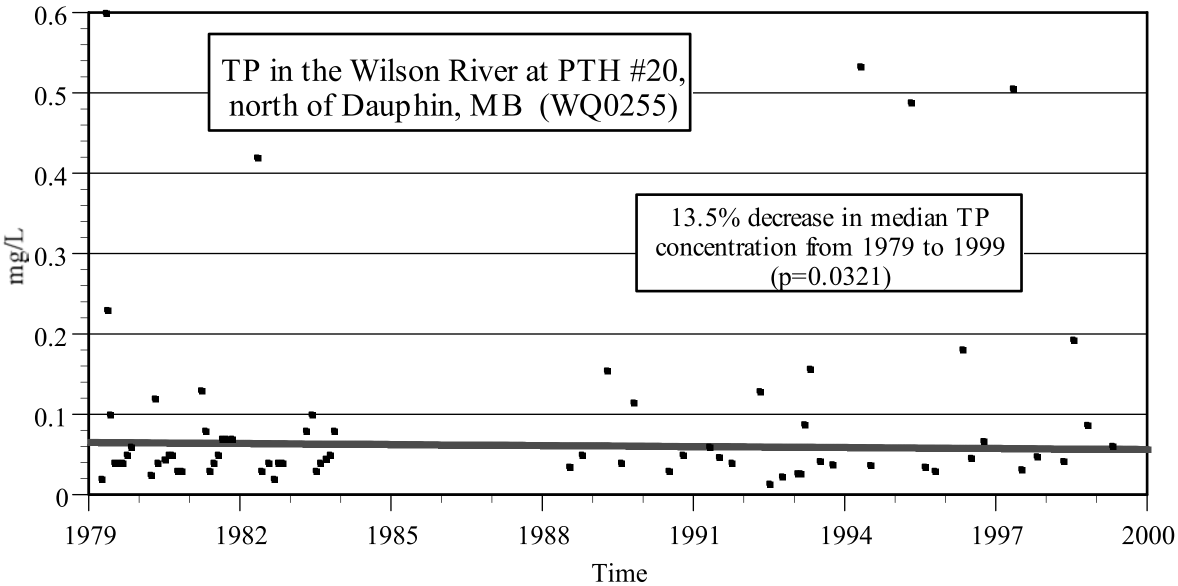


Figure 80. Trend in TP concentration in the Wilson River at PTH #20, north of Dauphin, MB, 1979 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

VALLEY RIVER

The Valley River rises at the confluence of several small streams in the southeastern corner of Duck Mountain Provincial Park (Figure 81). The river flows southward from its headwaters through the park for about 20 km and then enters the Duck Mountain Provincial Forest southwest of Whitemud Lake. It meanders a further 50 km southward and then, upon leaving the provincial forest, begins to arch in an east to northeast direction towards its discharge point approximately 130 km downstream at Dauphin Lake. Numerous tributaries, most of which drain southward from the Duck Mountain region, contribute to the flow volume in the Valley River. Some of the larger tributaries to the river include Short Creek, Gilbert Creek, Pleasant Valley Creek, Silver Creek, Dry Creek, Sulphurspring Creek, and Drifting River.

The Valley River and its tributaries drain an area of approximately 2940 km^2. About 45.5%, or 1335 km^2, of the watershed is found in the upland regions of the Duck Mountain Provincial Forest (36%), Duck Mountain Provincial Park (8%) and Riding Mountain National Park (1.5%). The rest of the watershed is situated between these two upland regions and is characterized by gently rolling

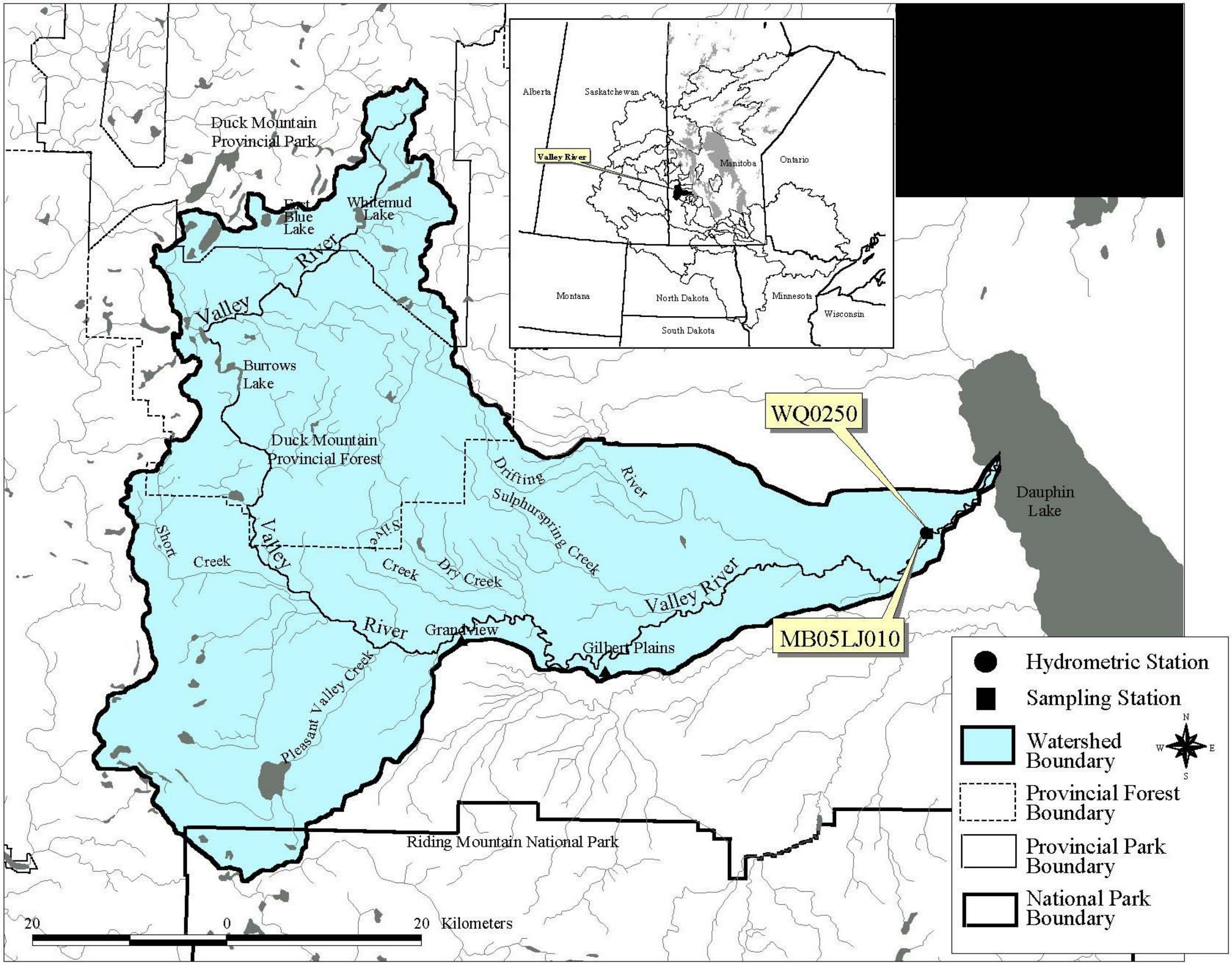


Figure 81. Valley River watershed showing the location of water quality sampling site WQ0250 and hydrometric station MB05LJ010 on the Valley River.

topography and rich, fertile soils. Land-use in this portion of the watershed is mainly agricultural and includes cereal and hay crop cultivation and livestock production. The higher elevations in the Duck Mountain and Riding Mountain upland regions provide important wildlife habitat and recreational opportunities such as camping and canoeing. Some logging also takes place in the Duck Mountain Provincial Forest portion of the watershed.

The Valley River is a multi-use waterway. It serves as a source of raw water for the communities of Grandview and Gilbert Plains, and has a history of being an important spawning river for a number of fish species (Gaboury 1985). The river also receives treated effluent from a provincially operated wastewater treatment lagoon at East Blue Lake in Duck Mountain Provincial Park, and from municipal facilities at Grandview and Gilbert Plains.

Trend analysis of TN and TP in the Valley River was performed using data collected at water quality sampling station WQ0250, which is located at PTH #20 north of Dauphin. The TN data were derived from 78 water samples, while 75 water samples provided the TP data for the analysis. The data were collected periodically from 1978 through 1999. Flow data for the analysis were obtained from hydrometric station MB05LJ010, which is situated at the same location as WQ0250.

The results of the analysis revealed a significant ($p=0.0027$) trend of increasing flow-adjusted TN concentration and a fairly weak, but significant ($p=0.035$) trend of decreasing flow-adjusted TP concentration at the site from 1978 to 1999 (Figures 82 and 83). As with the results from the Wilson River, the trend in TN concentration at in the Valley River may reflect a gradual increase in anthropogenic loading of nitrogen compounds from agricultural and municipal point and non-point sources within the watershed. However, one would have expected a similar trend in the TP concentration. The factors behind this apparent decline in TP concentrations are not known. The flow and nutrient data for the site fluctuated quite dramatically over the period of record, and the initial running of the *QWTrend* program suggested that there was no detectable trend in the TP data. However, the PARMA model residuals from this analysis were not normally distributed. In order to achieve normality in the residuals, three data outliers were removed from the TP data set prior to the final analysis. The removal of outliers helped to increase the normality in the residuals, but in doing so the confidence in the results was eroded somewhat given that the overall data set was relatively small. Site WQ0250 continues to be sampled on a periodic basis, and reanalysis of the TP data in future years may yield more statistically confident results.

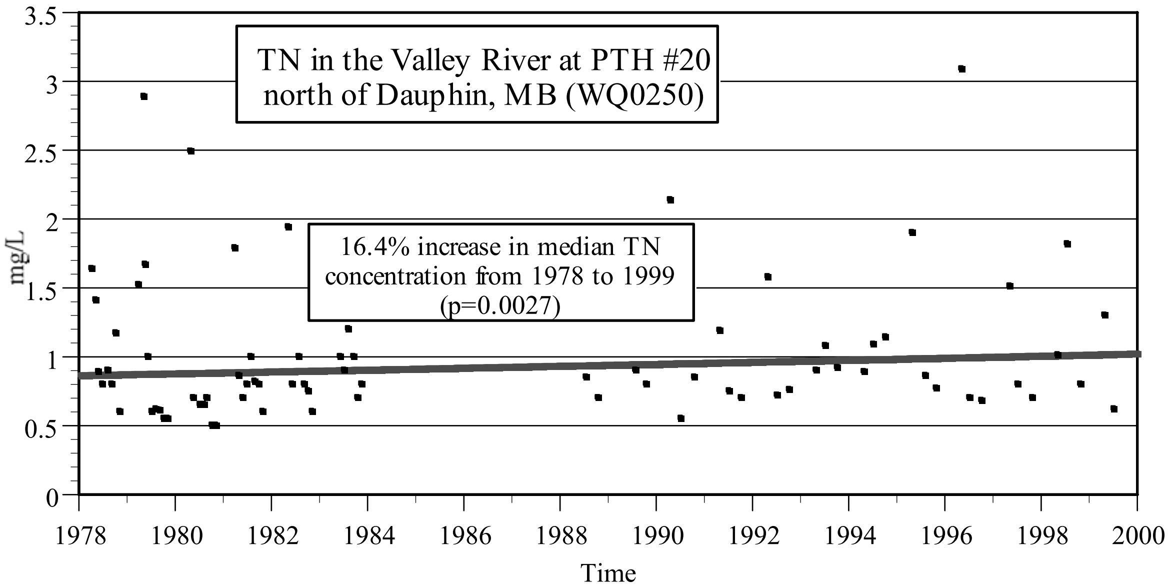


Figure 82. Trend in TN concentration in the Valley River at PTH #20, north of Dauphin, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

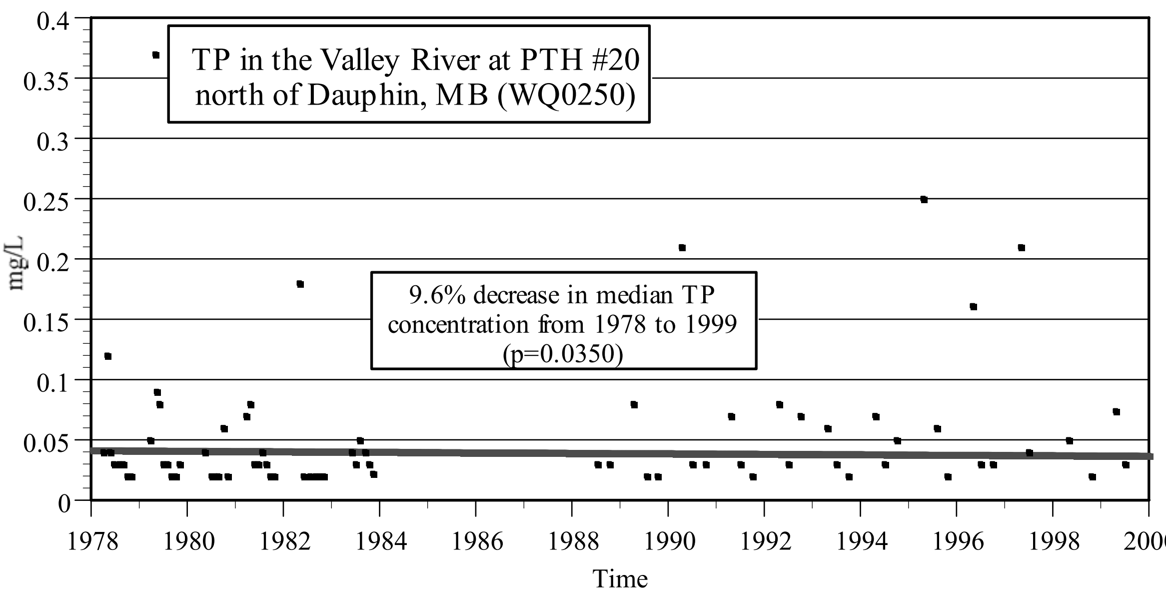


Figure 83. Trend in TP concentration in the Valley River at PTH #20, north of Dauphin, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

MOSSY RIVER

The Mossy River originates as the outflow from the north end of Dauphin Lake (Figure 84). The river courses northward from the lake for approximately 30 km before emptying into Lake Winnipegosis near the town of Winnipegosis. Along with the outflow from Dauphin Lake, tributaries such as the Fishing River and Fork River also contribute to the flow volume in the Mossy River.

Data from long-term water quality sampling station WQ0390 were used in the trend analysis of nutrients in the Mossy River. However, because WQ0390 is approximately 2.5 km downstream of Dauphin Lake, the trends detected relate to nutrient concentrations in water flowing from Dauphin Lake, and do not provide any information as to nutrient trends further downstream. Data for the trend analysis of TN and TP at the site were obtained from 114 water samples collected from 1978 to 1999. Flow data for the analysis were provided by hydrometric station MB05LJ025, which is located near WQ0390. Another water quality sampling station, WQ0226, is located on the Mossy River downstream of WQ0390 near the community of Winnipegosis. However, flow data for this reach of the river are lacking. An attempt was made to estimate flows for WQ0226 based on data from MB05LJ025 and contributions from the Fishing and Fork Rivers. However, since the flow records for the latter two rivers are incomplete, and the existing data were highly variable and not correlated with flow on the Mossy River at MB05JL025, estimating flows in the Mossy River at WQ0226 was not possible.

The results of the statistical analysis showed that while there was a significant trend ($p<0.0001$) of increasing flow-adjusted concentrations of TN over the period of record (Figure 85), there was no detectable trend ($p=0.1423$) in the flow-adjusted TP data (Figure 86). As stated previously, the Mossy River is the outflow from Dauphin Lake. During the latter half of the last century soil erosion (due to increased stream channelization and land clearing), run-off from livestock wastes and cultivated fields, and sewage effluent discharges within the lake's drainage basin (see inset map Figure 83) have rapidly increased the rate of eutrophication within the lake (Manitoba Natural Resources 1989). The trend analysis suggested that there has been a significant increase in the concentration of TN discharged from Dauphin Lake into the Mossy River. This is in keeping with the overall increase in eutrophication within the lake–-that is, the loading of nitrogen to the lake from sources within the drainage basin is reflected in an increase in nitrogen concentration in the

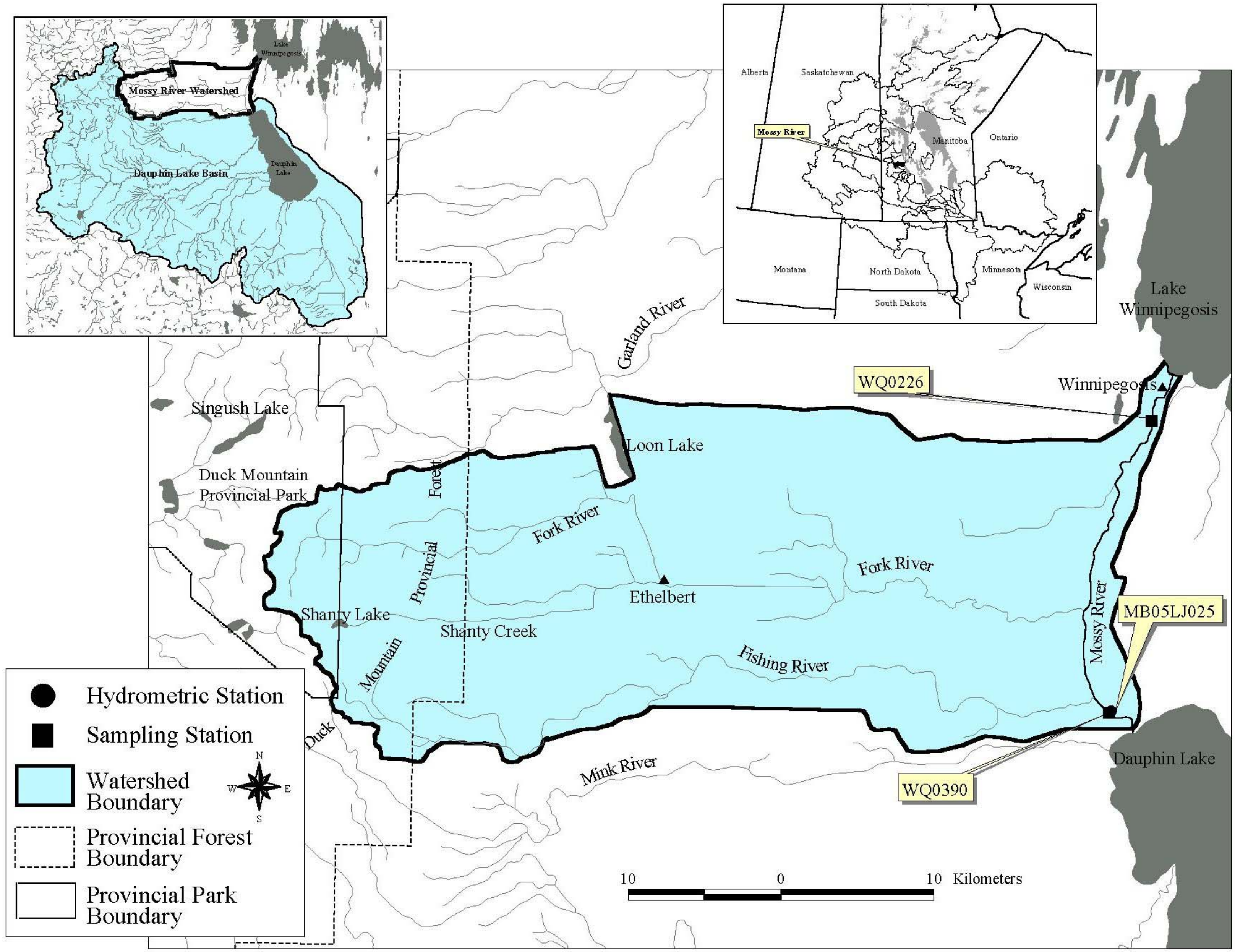


Figure 84. Mossy River watershed showing the location of water quality sampling sites WQ0390 and WQ0226, and hydrometric station MB05LJ025 on the Mossy River.

outflow from the lake. The trend analysis results for TP, however, indicate that the rate of release of phosphorus from the lake to the Mossy River has remained relatively unchanged since 1978. Since historic data indicates that phosphorus loading to the lake has increased, the lack of a significant trend in TP concentration in the outflow from the lake implies that much of the phosphorus entering the lake is being retained, likely through assimilation by algae and macrophytes, and adsorption to sediment particles.

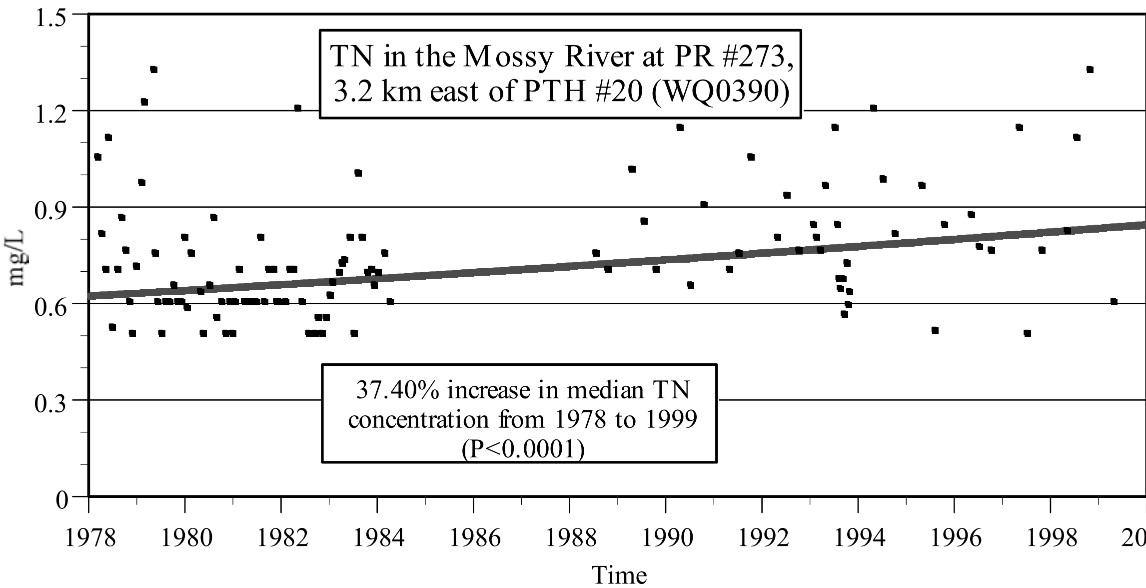


Figure 85. Trend in TN concentration in the Mossy River at PR #273, 3.2 km east of PTH#20, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

NORTH DUCK RIVER

The North Duck River originates in the northeastern corner of Duck Mountain Provincial Forest in west-central Manitoba (Figure 87). The river winds northeastward from the Provincial Forest for approximately 90 km before emptying into Lake Winnipegosis west of the community of Duck Bay. The largest tributary of the North Duck River is the Sclater River, which also originates in the Duck Mountain area. The Sclater River drains much of the southern portion of the watershed and joins the North Duck River just upstream of Lake Winnipegosis. Several smaller unnamed creeks, most of which originate in the Duck Mountain area, also feed into the North Duck River as it flows to Lake Winnipegosis.

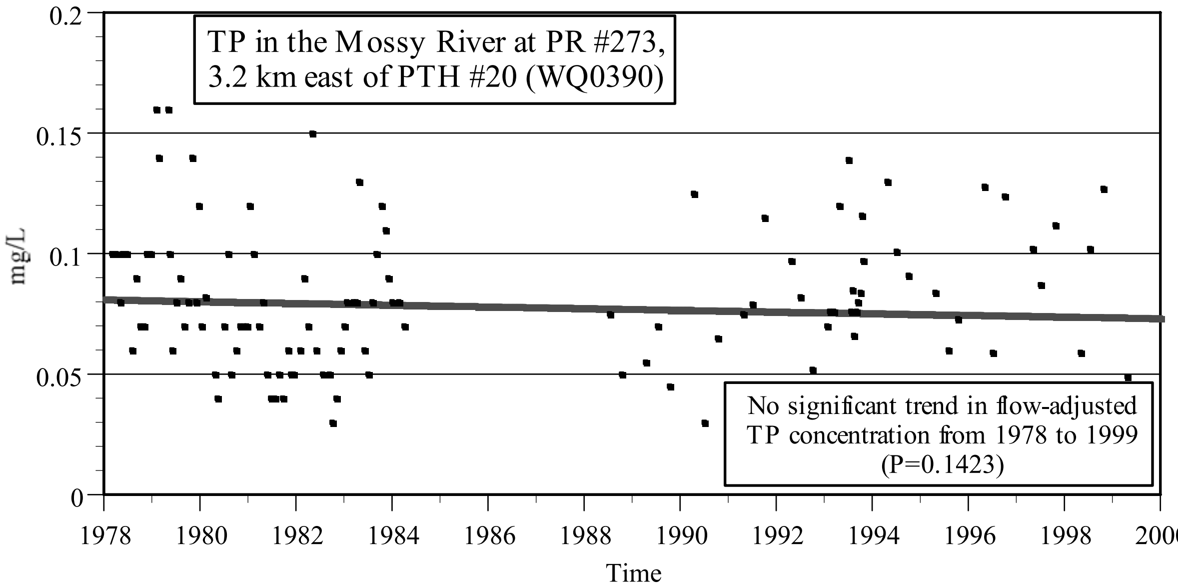


Figure 86. Trend in TP concentration in the Mossy River at PR #273, 3.2 km east of PTH#20, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

The North Duck River watershed encompasses an area of approximately 900 km^2. Agricultural land use within the catchment is somewhat limited due to topography, unsuitable soils, and poor drainage. Much of the watershed remains forested, with poplar and conifer species in pure and mixed stands. Non-agricultural land use within the catchment includes outdoor recreation, hunting and trapping, and forestry. Sources of nutrients to the North Duck River system include natural erosion of soils and contributions from agricultural activities.

The trend analysis of TN and TP in the North Duck River was conducted on data obtained from water quality monitoring station WQ0217, located at PTH #10 near Cowan. Total nitrogen and TP data were obtained from 34 water samples collected from 1988 to 1999 (inclusive). Flow data for the analysis were provided by hydrometric station MB05LG004, which is located in the immediate vicinity of the water quality site. Because of the small sample size and relatively short data record, trends in the data were analyzed using the linear regression method. Station WQ0217 is located in the upper region of the watershed, therefore, the trend analysis results only indicate conditions in this particular portion of the river system, and do not provide any information as to water quality conditions or trends in reaches further downstream.

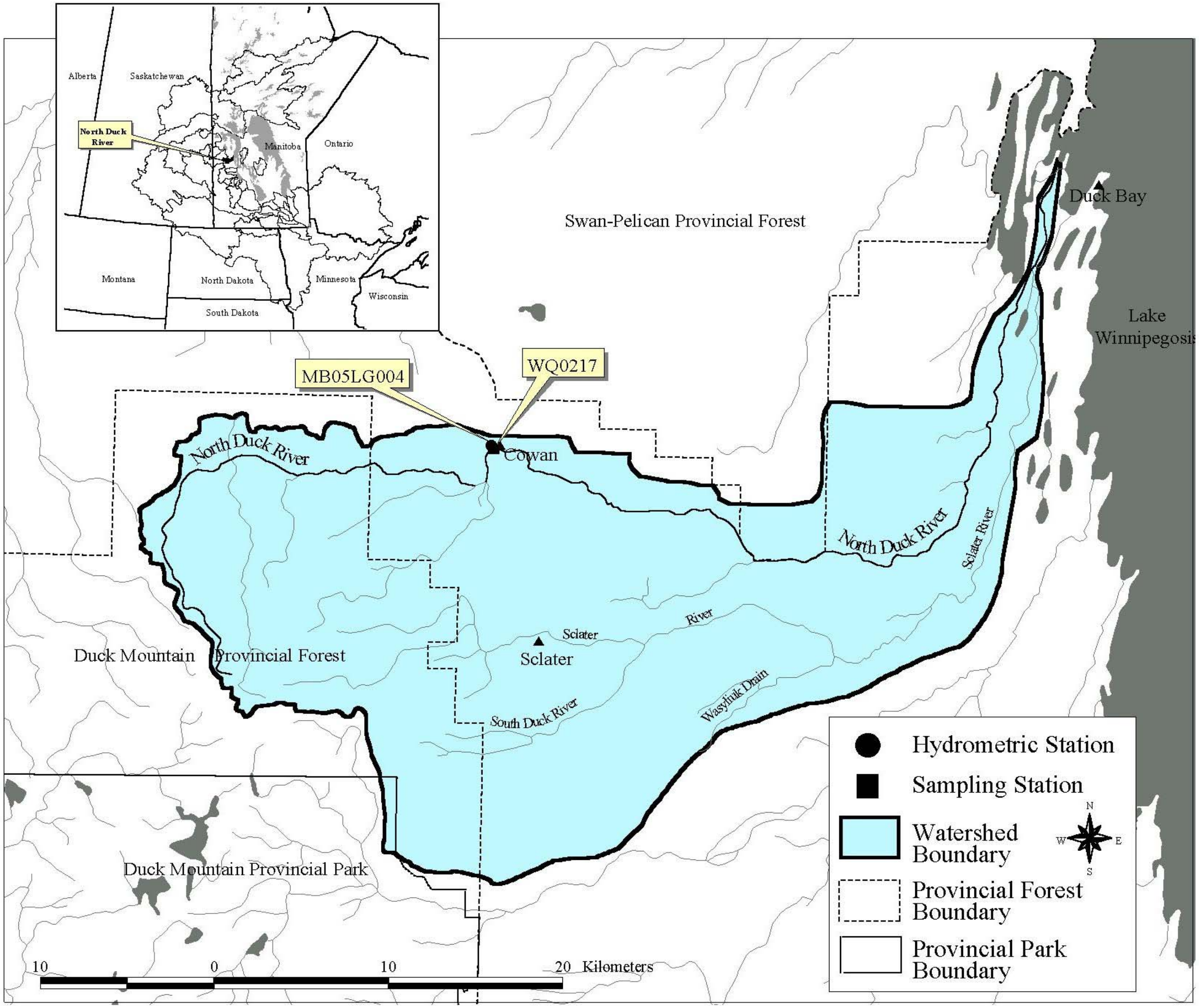


Figure 87. North Duck River watershed showing the location of water quality sampling site WQ0217 and hydrometric station MB05LG004 on the North Duck River.

The analysis did not detect a significant trend in either TN (p=0.2045) or TP (p= 0.4660) at site WQ0217 (Figures 88 and 89). These results were not surprising since land-use for agricultural purposes is limited and other anthropogenic sources of nutrients to the river system in this region of the watershed are negligible.

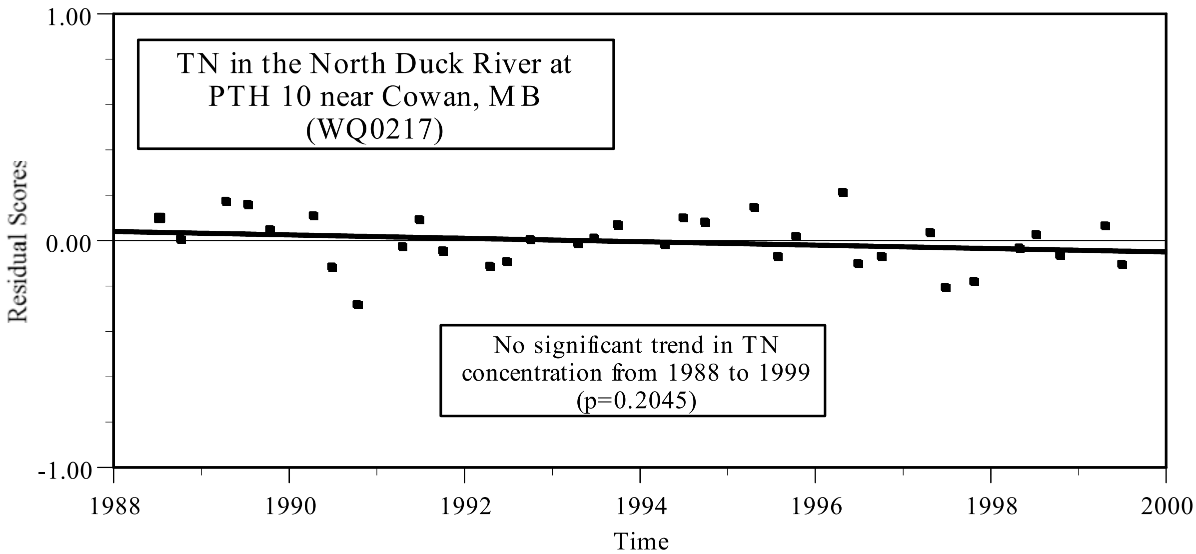


Figure 88. Trend in TN concentration in the North Duck River at PTH #10 near Cowan, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

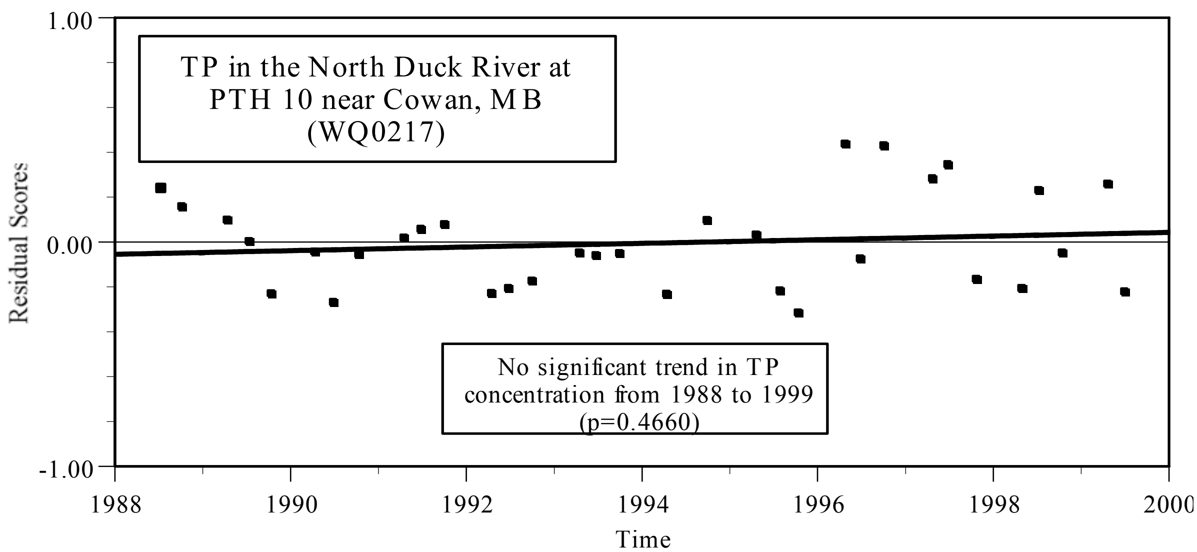


Figure 89. Trend in TP concentration in the North Duck River at PTH #10 near Cowan, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

SWAN RIVER

The Swan River rises on the west side of the Porcupine Hills east-central Saskatchewan (Figure 90). The Porcupine Hills straddle the Manitoba-Saskatchewan border and are an extension of the Manitoba Escarpment upland region. The river flows south from its headwaters for approximately 90 km and then curves to the east, crosses the border into Manitoba, and then continues in a northeast direction to empty into Swan Lake. Swan Lake then drains, via the Shoal River, into Dawson Bay at the northern end of Lake Winnipegosis. The total running length of the Swan River is approximately 250 km, about half of which is in Manitoba.

The Swan River watershed encompasses a land area of 6200 km^2, roughly evenly split between Saskatchewan and Manitoba. Drainage within the watershed is generally very good (PFRA 1985), with run-off waters from the Porcupine Hills area in the northwest and the Duck Mountains in the south contributing to the bulk of the flow in the river. Major tributaries in Manitoba include Lobstick Creek, and the Roaring and Sinclair Rivers.

Land use within the watershed varies depending on topography. The gap between the Porcupine Hills and the Duck Mountain regions is characterized by level to gently rolling terrain, and most of the land in this area has been developed for agriculture. Much of the upland areas, particularly in the Porcupine Hills and Duck Mountain regions, are unsuitable for agriculture and remain forested with aspen and conifers in pure and mixed stands. Along with providing wildlife habitat and recreational opportunity, portions of these areas are also harvested for timber and wood fibre.

Water-use along the river is limited to agricultural irrigation and domestic consumption by a small number of residents (PFRA 1985). The river is also used to dispose of treated effluent from the town of Swan River wastewater treatment lagoon. Effluent discharge from the lagoon usually takes place in the spring and fall of each year. Other wastewater treatment facilities that discharge to the Swan River system include the lagoons at the villages of Benito (Lobstick Creek) and Minitonas (East Favel River, which flows into the Roaring River).

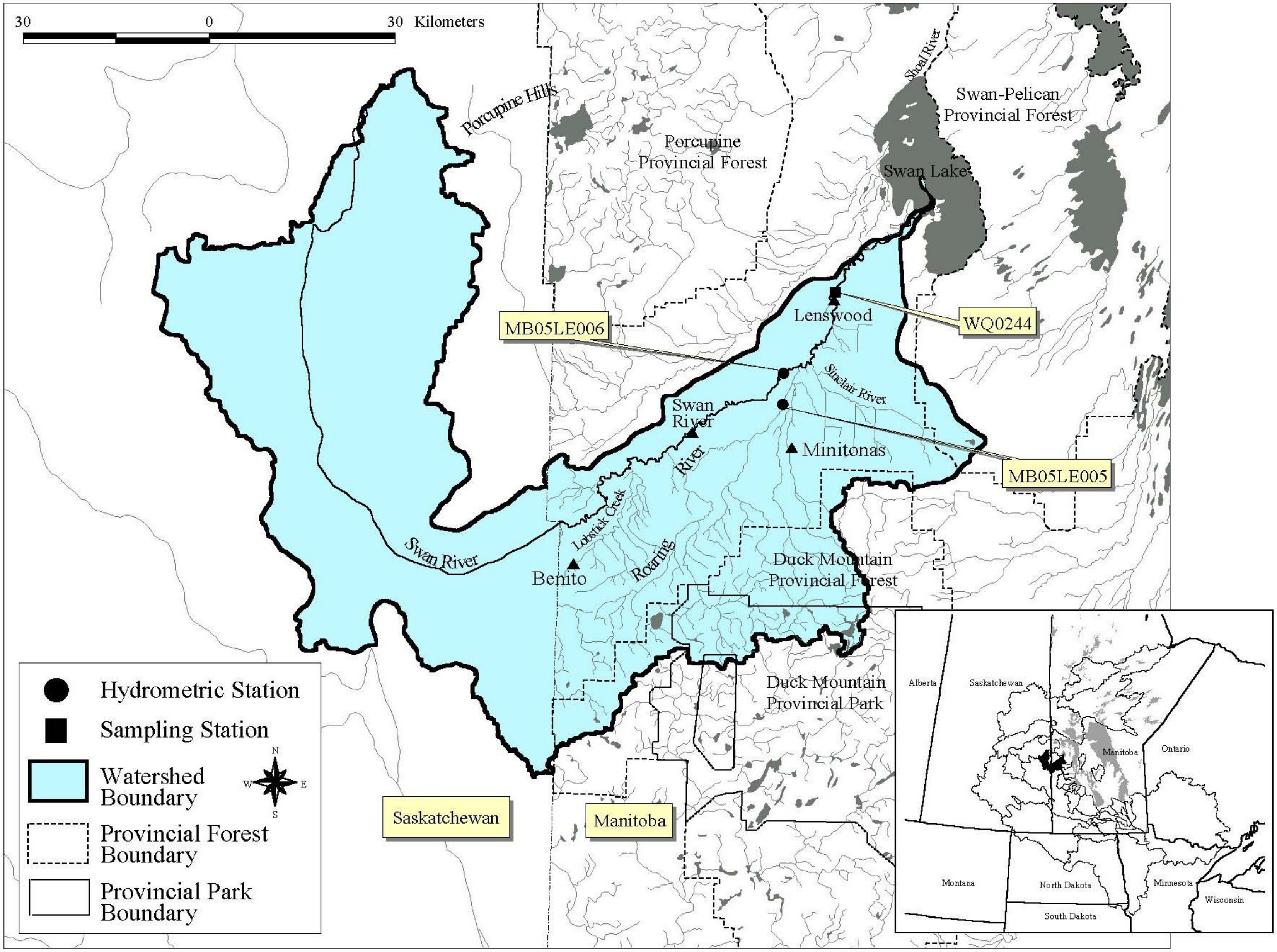


Figure 90. Swan River watershed showing the location of water quality sampling site WQ0244, and hydrometric stations MB05LE006 on the Swan River and MB05LE005 on the Roaring River.

Water quality data for the trend analysis of TN and TP in the Swan River were obtained from sampling station WQ0244, which is located approximately 45 km downstream of the town of Swan River near Lenswood, MB. Sample station WQ0244 is located downstream of the confluence of the Swan and Roaring Rivers. The closest hydrometric station to WQ0244 is MB05LE006, which is located upstream of this confluence. Therefore, for the analysis, the flow at WQ0244 was calculated by summing the flow values from the Swan River station (MB05LE006) with those of the Roaring River (hydrometric station MB05LE005). The data record for station WQ0244 is insufficient in terms of sample size and length to be analyzed using the *QWTrend* program. Therefore the alternative statistical analysis using simple linear regression was used to identify trends in the data.

TN data from 33 water samples and TP data from 34 water samples collected from 1988 through 1999 were used in the analysis. The analysis detected significant trends of decreasing concentration of TN (p=0.0309) and TP (p=0.0268) at station WQ0244 from 1988 to 1999 (Figure 91 and 92). These results suggest that artificial loading of TN and TP to the river system has declined over the period of record. The reasons behind these decreasing trends remain unclear at this time.

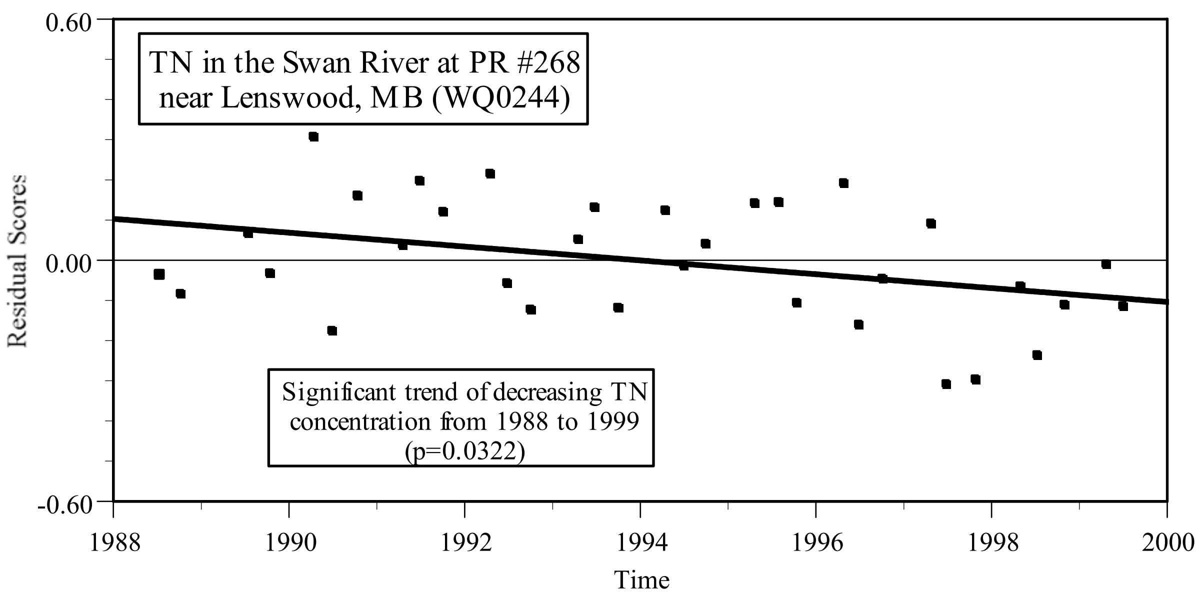


Figure 91. Trend in TN concentration in the Swan River at PR #268 near Lenswood, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TN with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TN after accounting for variation due to flow.

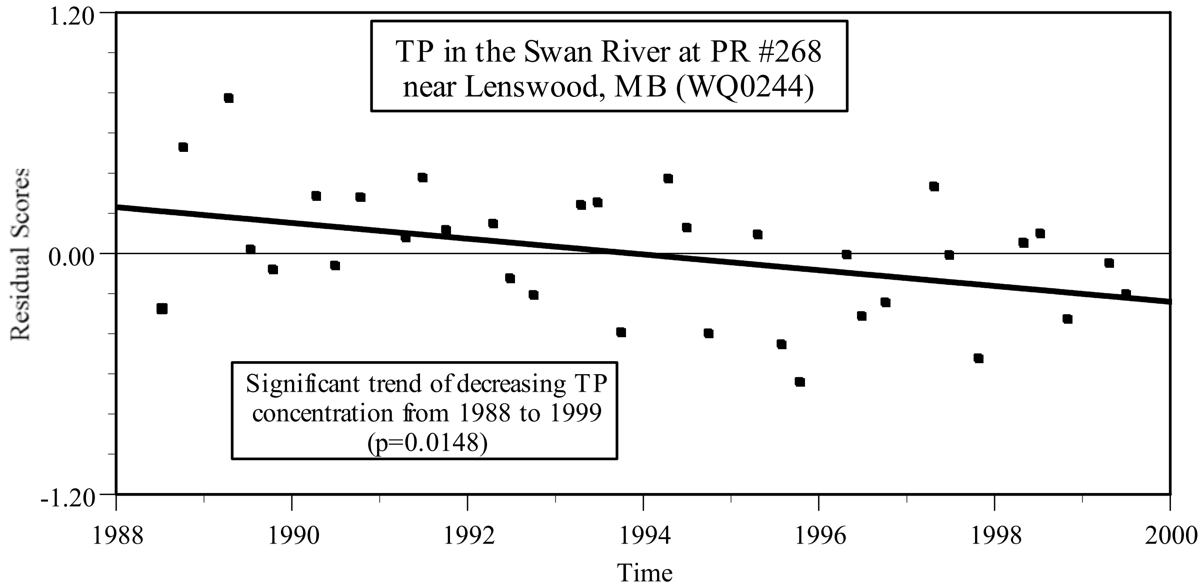


Figure 92. Trend in TP concentration in the Swan River at PR #268 near Lenswood, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

WOODY RIVER

The Woody River originates from a collection of small lakes and marshes in the Porcupine Hills area of east-central Saskatchewan near the provincial border with Manitoba (Figure 93). The course of the Woody closely parallels that of the Swan River to the south. It travels south-southeast from its headwaters for a distance of some 60 km and then enters Manitoba and curves to flow in a northeast direction for approximately 90 km to eventually empty into Swan Lake. Numerous small tributaries, most of which also originate in the Porcupine Hills region, feed the river along its course. Some of the largest of these include the Bowsman River and the Birch River.

The Woody River drains an area of approximately 2560 km^2. Much of the catchment is forested slopes and uplands (poplar and conifers in mixed and pure stands), and agricultural activity is generally confined to land along the river in the southern and eastern portions of the watershed. Some logging has been carried out in the watershed, but much of the natural vegetation in the forested areas remains undisturbed.

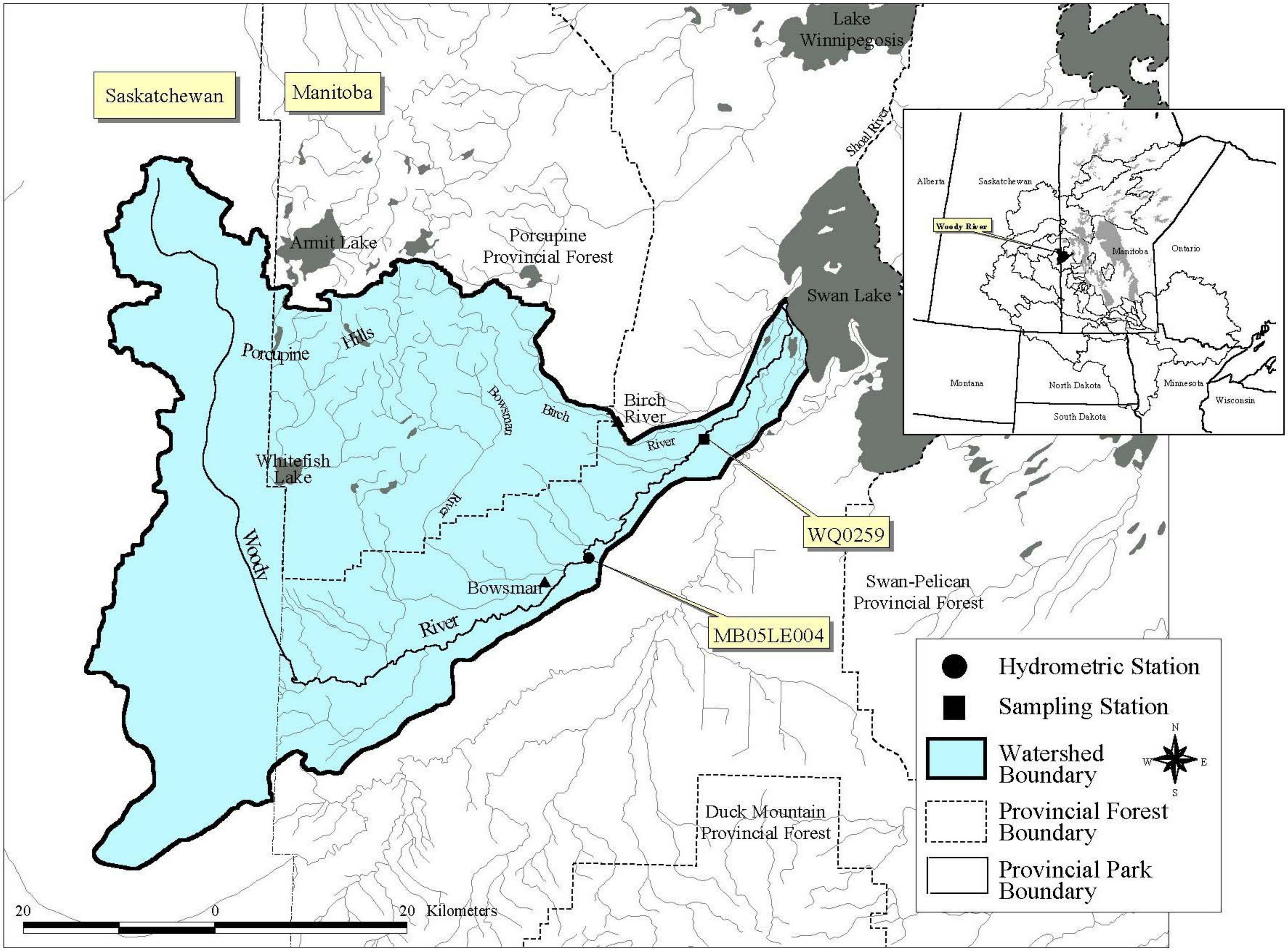


Figure 93. Woody River watershed showing the location of water quality sampling site WQ0245 and hydrometric station MB05LE004 on the Woody River.

Data for the trend analysis of TN and TP in the Woody River were obtained from 34 water samples collected from 1988 through 1999 at water quality station WQ0245, located at PR #268, northeast of the village of Bowsman, MB. Flow data for the analysis were obtained from hydrometric station MB05LE004, which is located 22 km upstream of WQ0245 near Bowsman. Because the period of record was relatively short and the sample size was small, the *QWTrend* program was not used to identify trends in the data. Instead, the alternate method of simple linear regression of log-transformed data was used.

The results of the analysis on the TP data indicated that once the effect of flow was removed from the data, the TP concentrations remained essentially unchanged over the period of record ($p=0.3065$) (Figure 94). The lack of a trend in the TP data is likely due to the fact that much of the watershed is sparsely populated and remains largely undisturbed by agriculture.

The results from the analysis of the TN data suggested that there was a significant decrease in flow-adjusted concentrations from 1988 through 1999. However, because the regression residuals were not normally distributed (even after the removal of several outliers in the data), the results of this analysis were very questionable, and as such, are not presented in this report.

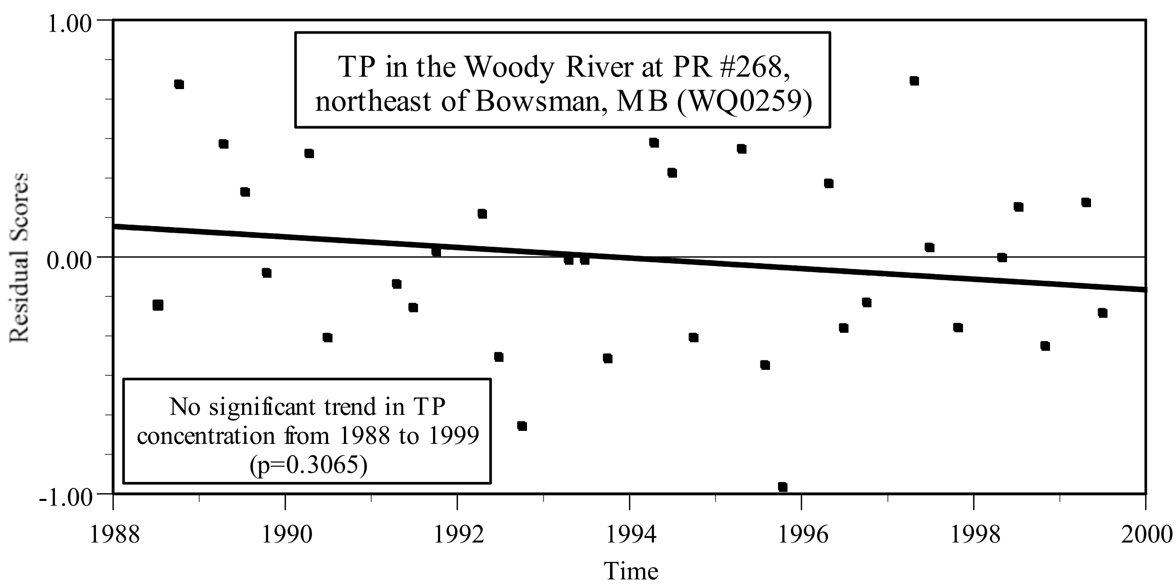


Figure 94. Trend in TP concentration in the Woody River at PR #268, northeast of Bowsman, MB, 1988 to 1999 (inclusive). Dots are residual scores from the regression of TP with flow, while the solid line is the regression line of the residual scores with time, and represents the trend in TP after accounting for variation due to flow.

RED DEER RIVER

The Red Deer River originates at the confluence of the Barrier River and Pipestone Creek in east-central Saskatchewan (Figure 95). The River flows eastward across Saskatchewan for approximately 175 km before crossing the border into Manitoba. Shortly after entering Manitoba the River widens to form Red Deer Lake. The river exits the lake and travels a further 20 km to eventually empty into Dawson Bay at the northwest end of Lake Winnipegosis. Total length of the river from headwaters to mouth (including across Red Deer Lake) is about 240 km. Major tributaries to the Red Deer River include the Etomani River, which runs northward from the Porcupine Uplands region, and the Fir River, which flows southward from the Pasquia Hills. Numerous smaller streams originating in the Porcupine Uplands (in Saskatchewan), the Porcupine Hills, and the Pasquia Hills also contribute to the Red Deer River as it flows towards Lake Winnipegosis.

The Red Deer River watershed encompasses approximately 14500 km^2. Agricultural land-use is concentrated in the western half of the catchment and in the immediate vicinity of the river eastward to the Hudson Bay area. Forestry related activities such as logging are more prevalent in the eastern portion of the watershed where the topography and soil conditions are less favorable for agricultural use.

The trend analysis of TP in the Red Deer River was conducted using data obtained from the Environment Canada water quality monitoring station near Erwood, SK (SA05LC0001). Two hundred sixty data points for TP, collected from 1974 through 1999, were used in the analysis. Flow data for the Red Deer River were obtained from hydrometric station SK05LC001, which is located near the water quality monitoring station.

Results of the analysis showed that there was no significant trend ($p=0.1443$) in flow-adjusted TP concentration over the period of record (Figure 96). This suggested that nutrient input to the river from artificial sources such as agriculture run-off and treated effluent discharges have not caused a significant change in the TP concentration in the river over the last quarter century.

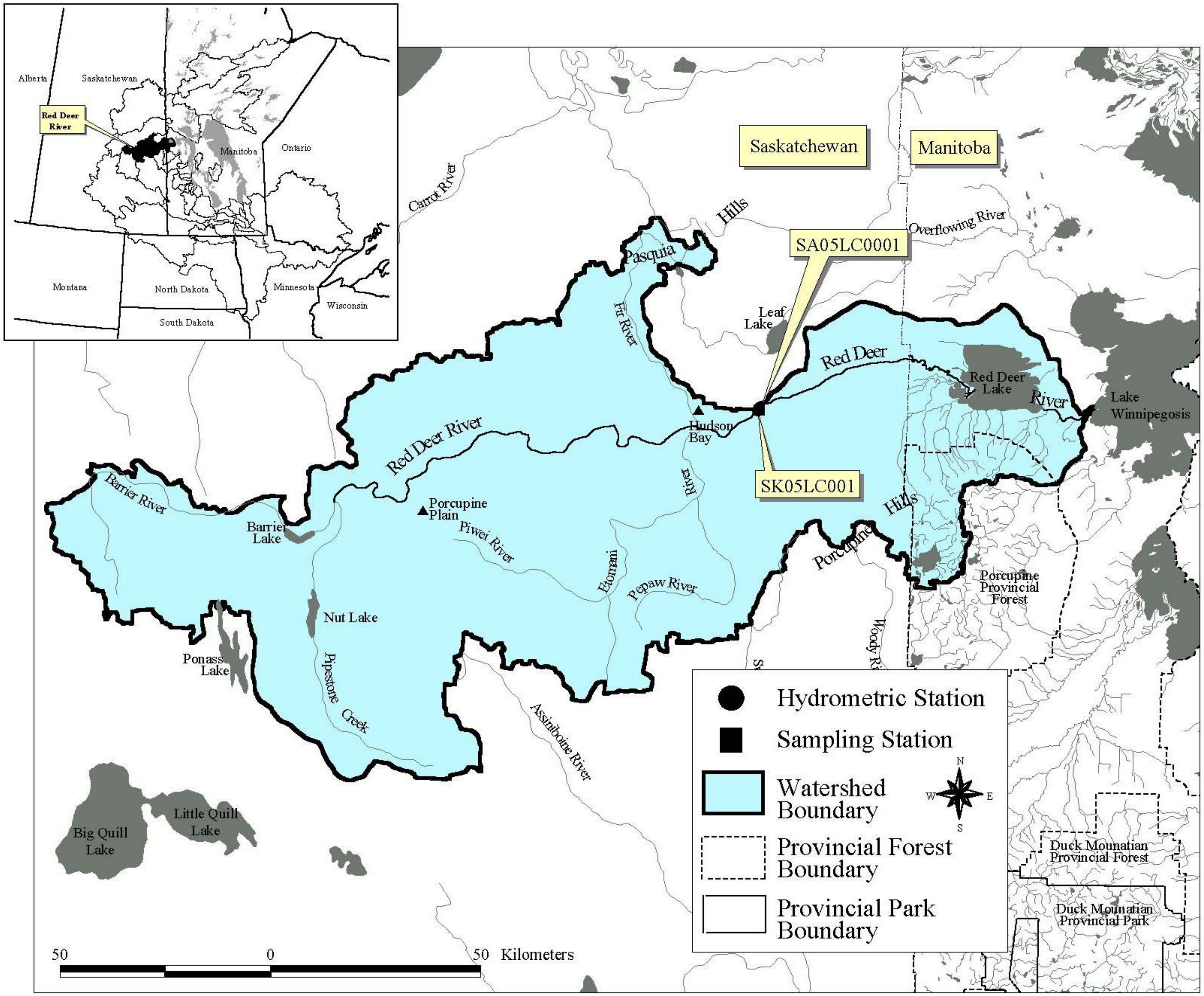


Figure 95. Red Deer River watershed showing the location of water quality sampling site SA05LC0001 and hydrometric station SK05LC001 on the Red Deer River.

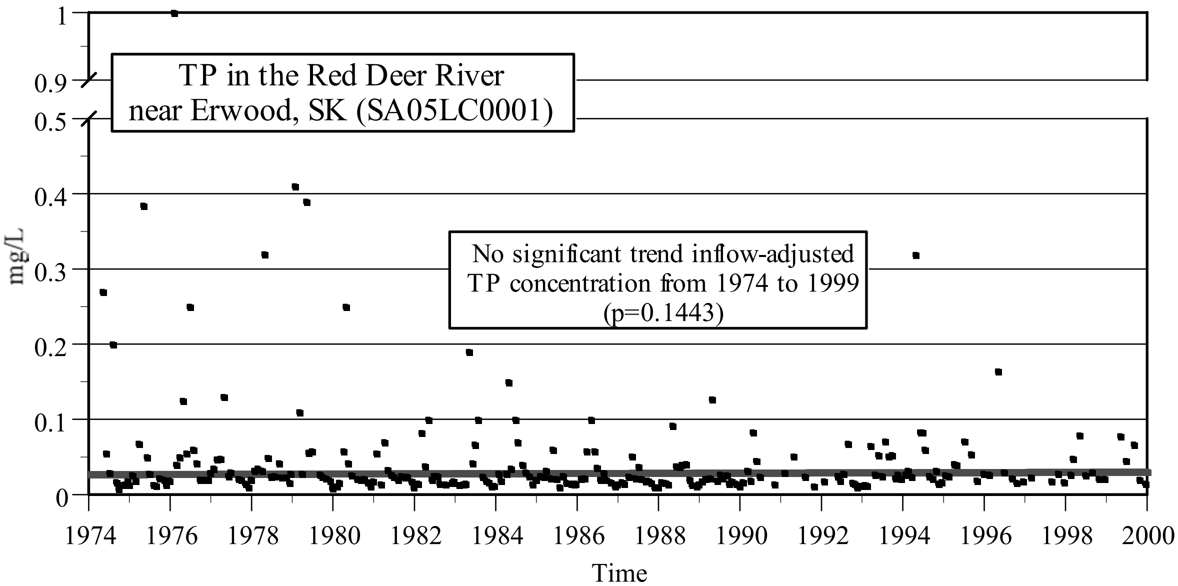


Figure 96. Trend in TP concentration in the Red Deer River near Erwood, SK, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

WATERHEN RIVER

The Waterhen River system drains water from Lake Winnipegosis into Lake Manitoba (Figure 97). Water flows from the south end of Lake Winnipegosis northward into Waterhen Lake by way of the West Waterhen River and the Little Waterhen River. Water then moves southward out of Waterhen Lake and into Lake Manitoba via the Waterhen River. The Waterhen River itself is less than 25 km in length, however, it is fairly wide, and the volume of water discharged via the river is relatively high.

The immediate catchment area of Waterhen River is approximately 1600 km^2. Lakes, marshes, and peatland occupy much of the watershed area, with mixed-forest stands of white spruce and poplar in drier sites (Smith *et al.*1998). The watershed is sparsely populated and the wet conditions and poor soils (generally nutrient deficient, and in some areas, very saline) are not conducive to agricultural use. Some logging and traditional hunting and trapping occurs, but this is generally very limited. Rivers and lakes within the watershed provide habitat for aquatic and semi-aquatic wildlife, and are important for the fisheries of both Lake Winnipegosis and Lake Manitoba.

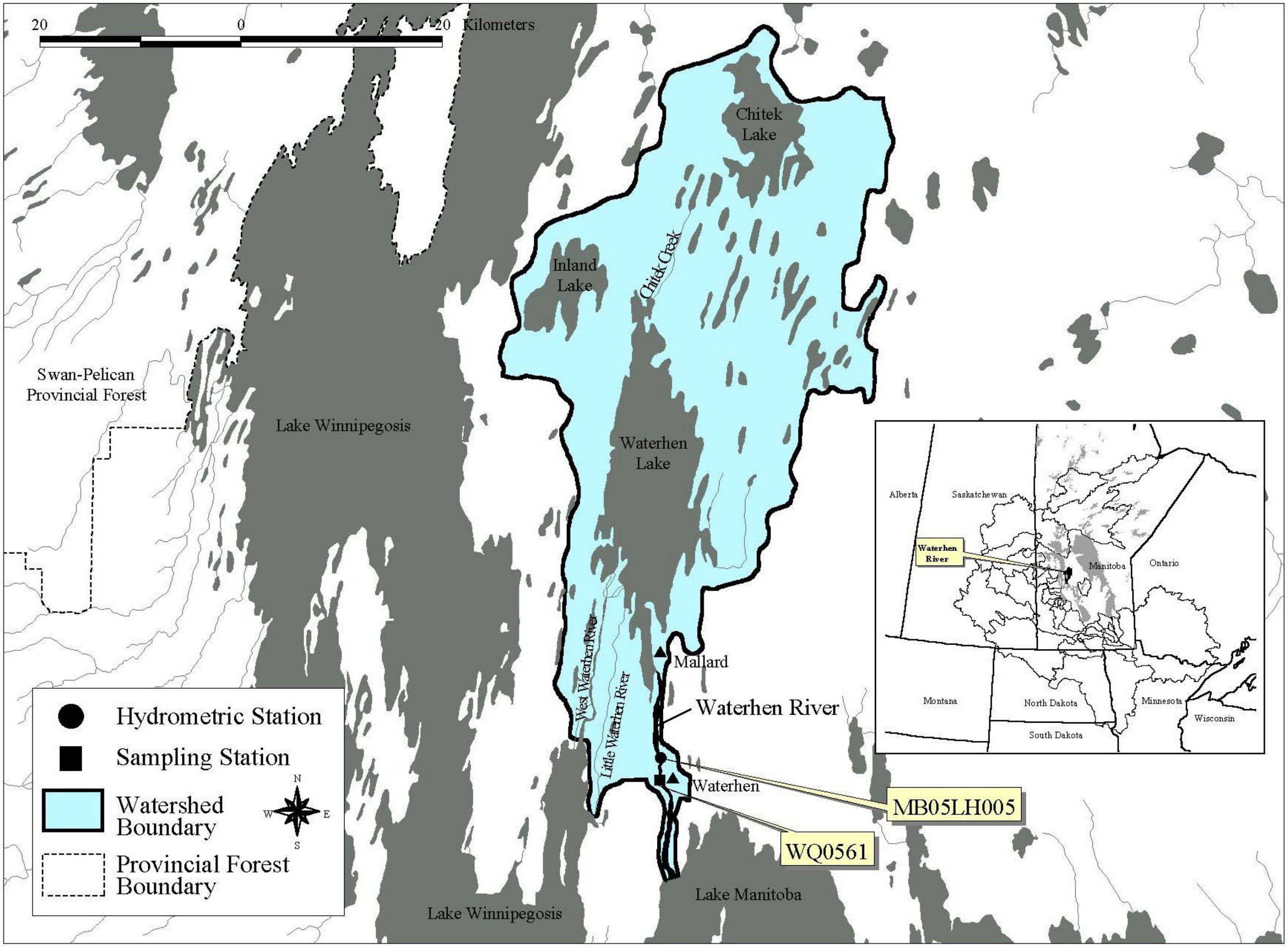


Figure 97. Waterhen River watershed showing the location of water quality sampling site WQ0561 and hydrometric station MB05LH005 on the Waterhen River.

Wastewater effluent discharges to the Waterhen River system include a facility at the community of Mallard and a second facility at the community of Waterhen. The former discharges to Waterhen Lake north of the outflow to the Waterhen River, while the latter discharges to the Waterhen River downstream of the bridge on PR #328. Both facilities are small and, given the volume of water flowing in the river, the impacts of the effluent on water quality are likely only negligible and very localized.

Trends in TP and TN in the Waterhen River were analyzed using data collected from 1981 to 1999 at station WQ0561, which is located at the bridge on PR #328. Total nitrogen and TP data from 60 water samples were used in the analysis. Flow data for the Waterhen River were provided by hydrometric station MB05LH005, which is located approximately 1 km upstream of the water quality station. Note that the water quality station is also located upstream of the Frontier School wastewater effluent discharge.

The analysis revealed a significant trend ($p=0.0279$) of increasing flow-adjusted TN concentration in the Waterhen River from 1981 to 1999 (Figure 98). This has, however, been a very gradual trend with the median of the trend line increasing less than 20% over the entire period of record. The slope of the trend line for the TP data is negative, which suggests that flow-adjusted concentrations of TP at the site are declining (Figure 99). However, the p-value for the trend was 0.054, and although this is only slightly above 0.05, the trend cannot be considered statistically significant at $\alpha=0.05$. The water quality station continues to be monitored on a regular basis, and analysis in the future, with additional years of data, may provide a statistically stronger result.

The trend analysis results for the Waterhen River at WQ0561 indirectly implies that the loading rate of nutrients from anthropogenic sources to Lake Manitoba from the Lake Winnipegosis drainage basin (via the Waterhen system) is relatively low. There appears to have been a very gradual increase in nitrogen compounds, but no corresponding increase in phosphorus compounds over the last 20 years. These results, although not as strong statistically, are similar to the results for the Mossy River, which drains Dauphin Lake into the south end of Lake Winnipegosis. Both sets of results suggest that phosphorus is likely being retained in upstream waterbodies, while nitrogen appears to be more mobile and moves more readily through the system.

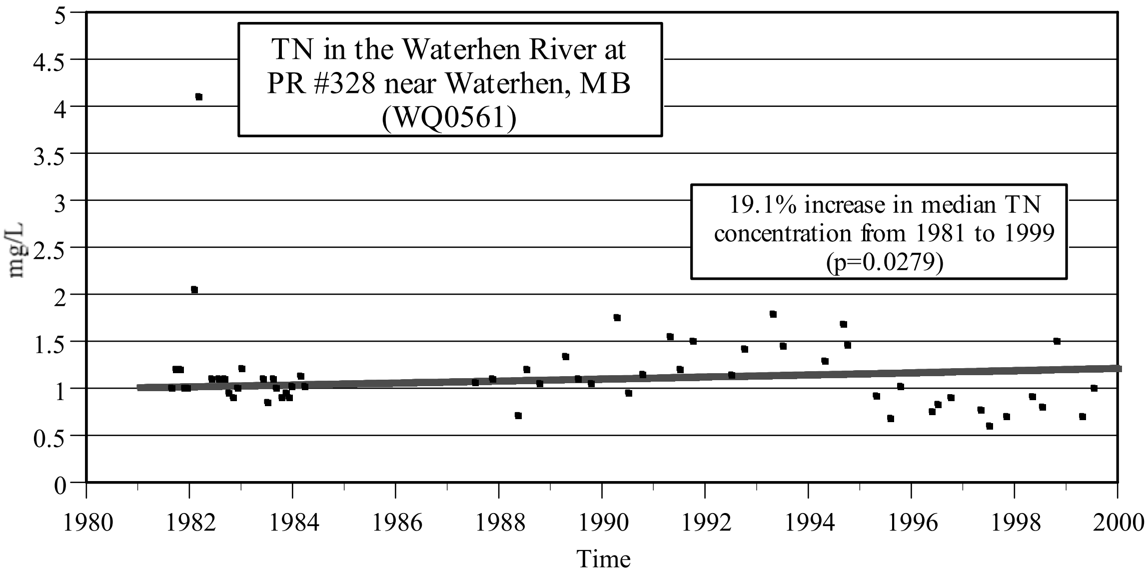


Figure 98. Trend in TN concentration in the Waterhen River at PR #328 near Waterhen, MB, 1981 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

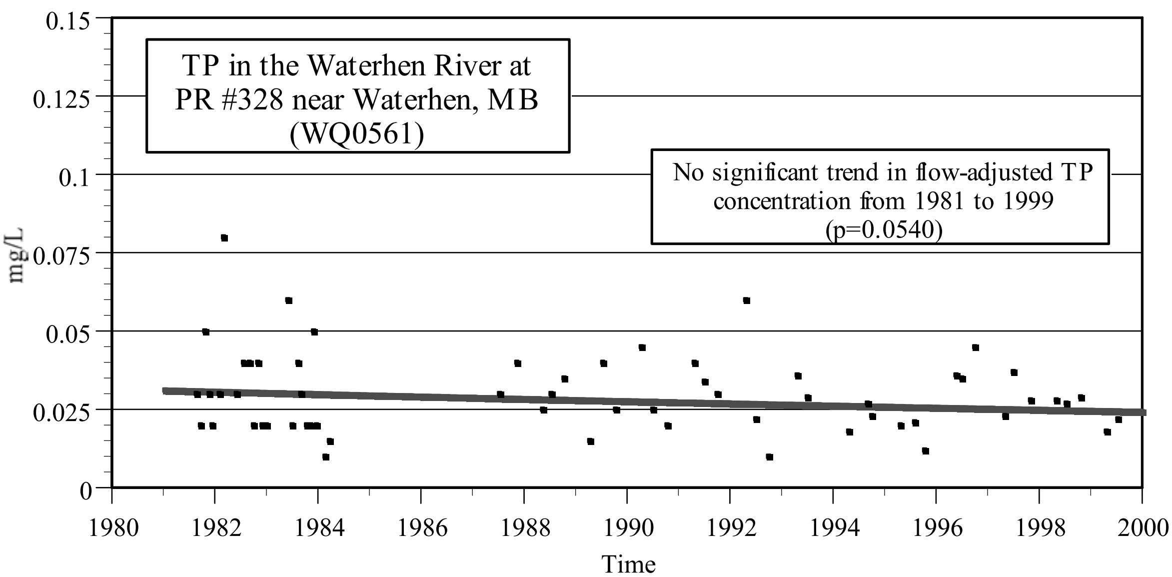


Figure 99. Trend in TP concentration in the Waterhen River at PR #328 near Waterhen, MB, 1981 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

DAUPHIN RIVER

The Dauphin River originates as the outflow from Lake St. Martin, in the interlake region of central Manitoba (Figure 100). In conjunction with the Fairford River and Lake St. Martin, the Dauphin River is the sole conduit for water flow from Lake Manitoba into Lake Winnipeg. Water flow through the system from Lake Manitoba to Lake Winnipeg is regulated by a control structure (Fairford Dam) on the Fairford River at PTH #6. The Dauphin River itself is relatively short; flowing northward for about half of its 47 km length before turning eastward to empty into Sturgeon Bay in Lake Winnipeg, near the community of Dauphin River. No major tributaries empty into the river so that almost all of the flow in the river comes from Lake St. Martin.

Since the Dauphin River is the only inflow to Lake Winnipeg from Lake Manitoba its drainage area could arguably be said to encompass the combined drainage areas of Lake Winnipegosis, Dauphin Lake, and Lake Manitoba, a total area of approximately 79800 km^2. On the other extreme, the immediate catchment area of the Dauphin River downstream of Lake St. Martin is approximately 780 km^2. However, for the purposes of this discussion we will consider the Dauphin River watershed to be the drainage area between Lake Manitoba and Lake Winnipeg (as shown in Figure 100), which has a total area of 3100 km^2.

The watershed of the Dauphin River (as illustrated in Figure 100) corresponds closely to the Gypsumville Ecodistrict of the Interlake Plain Ecoregion of the Boreal Plains Ecozone (Smith *et al.* 1998). Natural vegetation in the area consists mainly of mixed stands of aspen, balsam poplar, and white spruce. Soils tend to be imperfectly or poorly drained and can be quite stony and highly calcareous, which limits agricultural land-use to only a very small portion of the watershed (generally the area west of Lake St. Martin. Other activities in the immediate watershed include logging, traditional hunting and trapping, sport and commercial fishing, and recreational pursuits such as canoeing and camping. Waterways within the immediate watershed provide habitat fish spawning and are important migratory waterfowl breeding and staging areas (Smith *et al.*1998).

A single long-term monitoring station is located on the Dauphin River at a point approximately halfway between Lake St. Martin and Lake Winnipeg. The station (WQ0404) was originally monitored by the Province of Manitoba from 1978 to 1988. Environment Canada assumed responsibility for monitoring the river in 1989 and moved the site to a new location further downstream near the community of Dauphin River (MA05LM0004). After sampling the river at

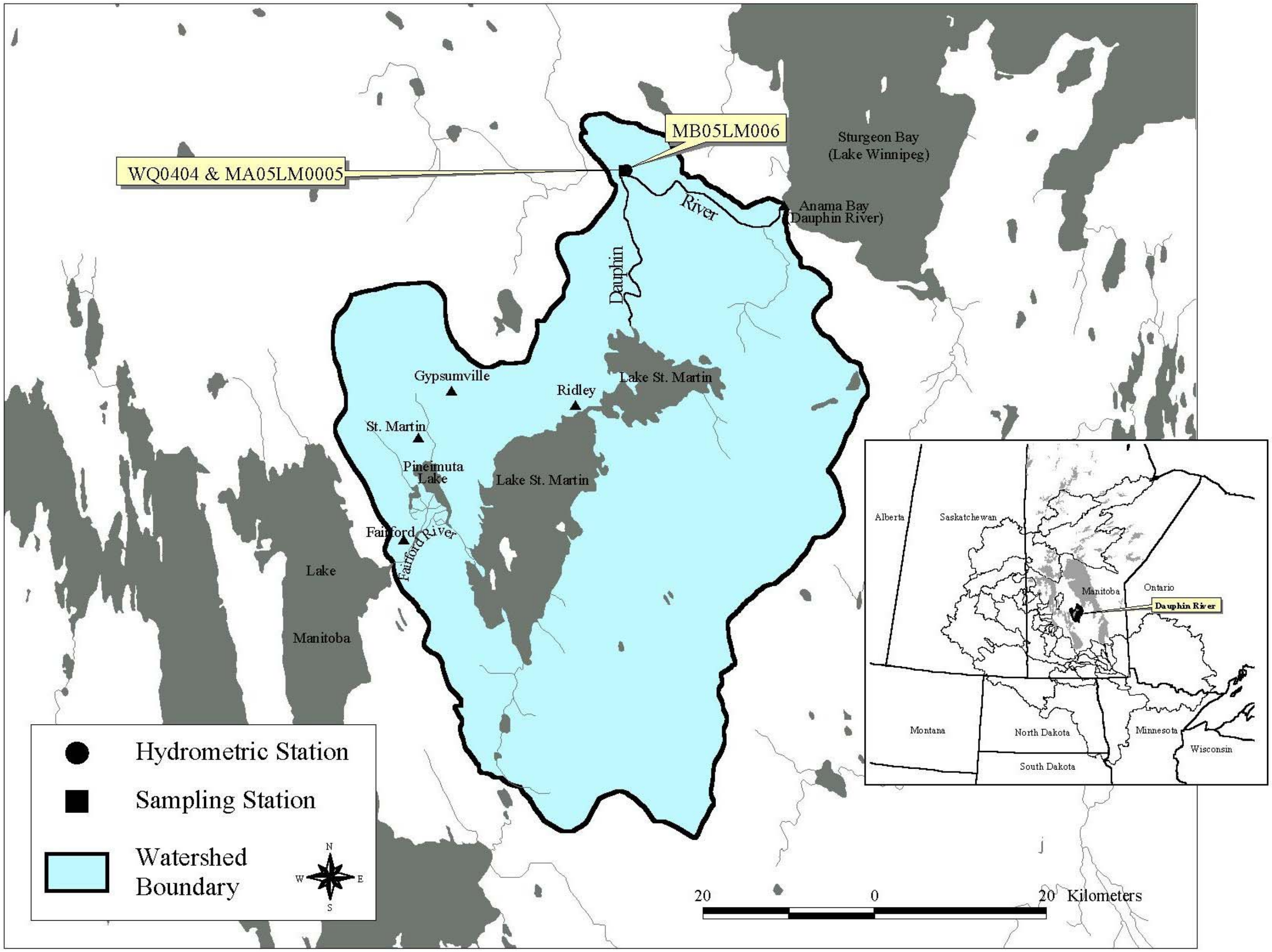


Figure 100. Dauphin River watershed showing the location of water quality sampling sites WQ0404 and MA05LM0005 and hydrometric station MB05LM006 on the Dauphin River.

this location for approximately one year, monitoring activities were resumed at the original site (MA05LM0005), where data were collected until the end of 1997.

Only TP data were considered in the trend analysis of the Dauphin River. Prior to conducting the trend analysis, the 1989 data collected at MA05LM0004 were deleted from the data set and a step trend was inserted to account for the change in monitoring agencies. This yielded a total of 178 data points for the trend analysis. The step trend proved not significant (p=0.2007), indicating that the change in monitoring agency did not affect the measured TP concentration at the site.

The results of the analysis showed a significant trend (p<0.0001) of decreasing flow-adjusted TP concentration in the Dauphin River from 1978 through 1997 (Figure 101). This trend appeared to be quite strong as evidenced by the low p-value and the almost 50% reduction in the median of the trend line over the period of record. However, although statistically significant, the trend may not be ecologically significant given that the concentration of TP in the river is quite low overall (median of 0.022 mg/L and 10% quartile and 90% quartiles of 0.014 and 0.04 mg/L respectively).

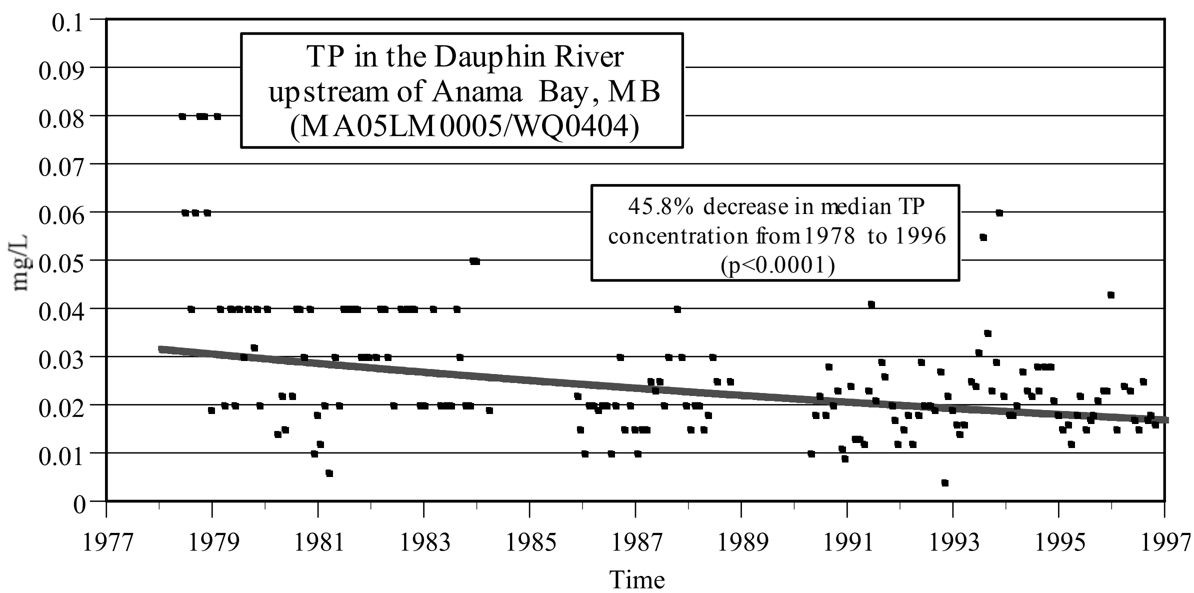


Figure 101. Trend in TP concentration in the Dauphin River near the community of Dauphin River, MB, 1978 to 1996 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

SASKATCHEWAN RIVER

The Saskatchewan River system drains a vast area of western Canada from the Rocky Mountains in Alberta eastward to Lake Winnipeg in Manitoba (Figure 102). The two major branches of the system are the North and South Saskatchewan Rivers. The North Saskatchewan River originates in the Rocky Mountains of west-central Alberta and flows eastward across Alberta to join the South Saskatchewan River east of the city of Prince Albert in central Saskatchewan. The South Saskatchewan River rises at the confluence of the Oldman and Bow Rivers in the foothills region of southwestern Alberta. Both the Bow and Oldman Rivers originate high in the Rocky Mountains near the Alberta - British Columbia border. The South Saskatchewan flows in a northeast direction towards its confluence with the North Saskatchewan. This confluence is often referred to as the Forks and forms the headwaters of the Saskatchewan River. The flow distance from their headwaters to the Forks is about 1230 km for the North Saskatchewan River and just under 1100 km for the South Saskatchewan River. The Saskatchewan River continues eastward from the Forks across eastern Saskatchewan and into west-central Manitoba, and eventually empties into the north basin of Lake Winnipeg at the community of Grand Rapids. Flow distance from the Forks to Lake Winnipeg is roughly 560 km (includes distance across Cedar Lake). Major tributaries of the Saskatchewan River system include the Battle River (North Saskatchewan River), the Red Deer River (South Saskatchewan River), and the Carrot River (Saskatchewan River).

The Saskatchewan River system drains a total area of approximately 416000 km^2. Most of the drainage area is located in Alberta (220000 km^2) and Saskatchewan (174000 km^2), with only a relatively small portion in Manitoba (22000 km^2). The basin covers much of the Boreal Plains Ecozone and the western portion of the Prairies Ecozone of western Canada (Smith *et al.* 1998). Soils are generally rich and natural vegetation is diverse and includes marsh/wetland, grassland, aspen parkland, and boreal forest communities. Land use within the drainage basin is mainly related to agriculture, although forestry is also significant in the Boreal Plains Ecozone portion. Agricultural land-use can be very intensive and varies from cultivation of specialty, cereal, and forage crops, to range and pasture lands, to livestock feedlots. There is a high potential for nutrient loading to the river system from agricultural related point and non-point sources within the watershed. Numerous wastewater treatment lagoons and sewage treatment plants discharge effluent either directly to the Saskatchewan and its two branches, or indirectly via its tributaries. Examples of major urban point sources include the cities of Edmonton and Prince Albert (on the North Saskatchewan River), and

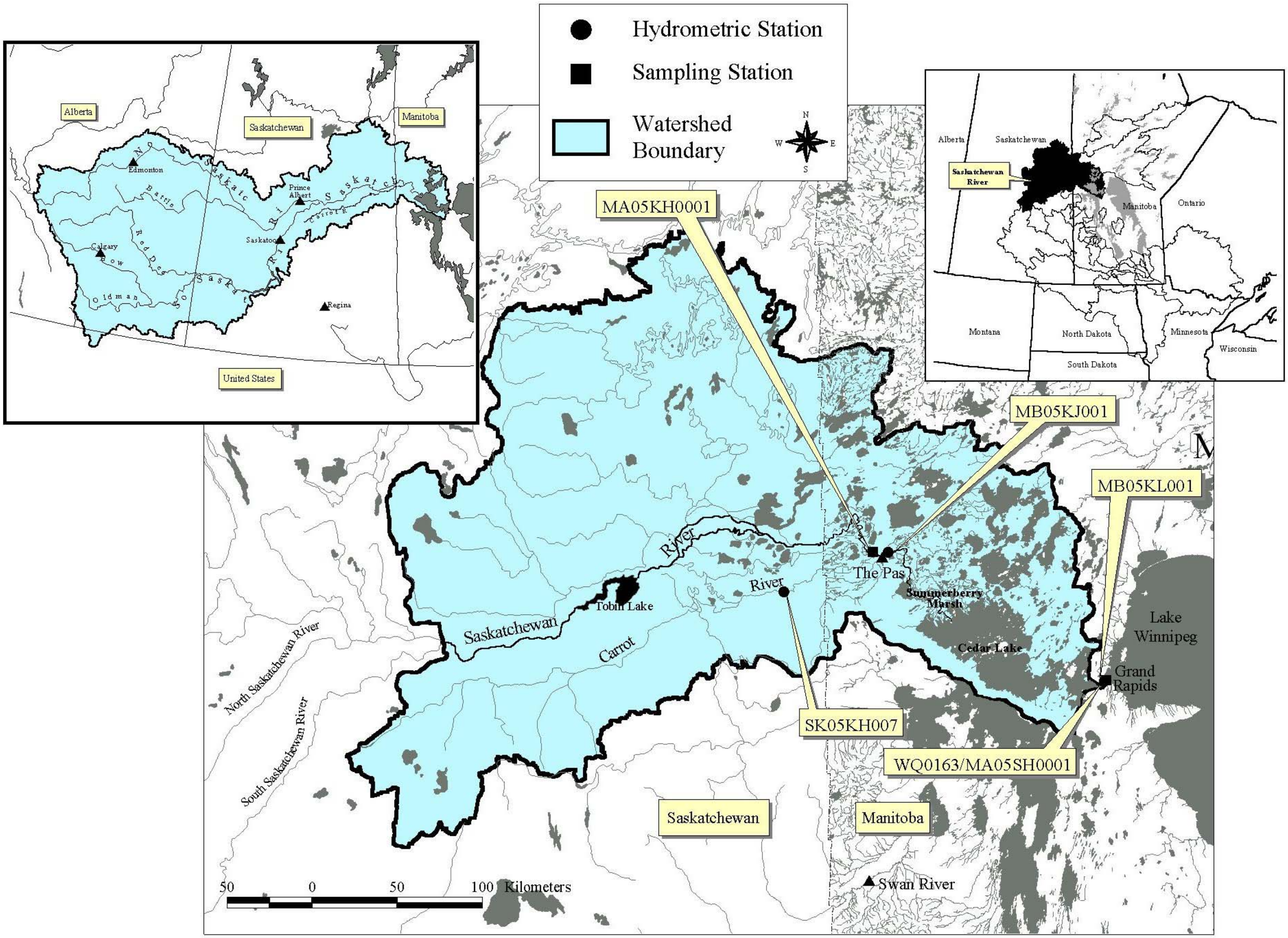


Figure 102. Saskatchewan River watershed showing the location of water quality sampling sites MA05KH0001 and WQ0163/MA05SH0001, and hydrometric stations SK05KH007 on the Carrot River and MB05KJ001 and MB05KL001 on the Saskatchewan River.

Saskatoon (on the South Saskatchewan River). As well, pulp and paper mills at Prince Albert and The Pas also discharge to the system.

The Saskatchewan River system is a very important, multi-use waterway. Besides providing habitat for a diverse assemblage of fish and other aquatic and semi-aquatic organisms, it is used extensively for agricultural irrigation and livestock watering, recreational purposes, domestic and industrial consumption, and hydro-electric power generation (*i.e.* Gardener Dam in Saskatchewan and Grand Rapids Dam in Manitoba). Numerous reservoirs constructed for water storage, flood control, and hydro-electric power are located along the course of the river system. The largest of these include Lake Abraham near the headwaters of the North Saskatchewan River, Lake Diefenbaker on the South Saskatchewan River in central Saskatchewan, Tobin Lake on the Saskatchewan River downstream of the Forks, and Cedar Lake immediately upstream of the Grand Rapids dam.

Data from two water quality sampling stations were used to assess trends in the Saskatchewan River in Manitoba. Station MA05KH0001 is operated by Environment Canada and is located on the river immediately upstream of its confluence with the Carrot River. The closest hydrometric station to the water quality station is MB05KJ001, which is located further downstream at The Pas. Since the water quality station and the hydrometric station are located upstream and downstream (respectively) of the confluence with the Carrot River, the flow data used in the trend analysis at MA05KH0001 were calculated by subtracting the flow in the Carrot River (hydrometric station SK05KH007) from the flow in the Saskatchewan River at The Pas (MB05KJ001).

The second water quality station used in the trend analysis is located downstream of the Grand Rapids dam, just upstream of the river's entrance into Lake Winnipeg. The Province of Manitoba monitored this location (as station WQ0163) from March 1973 through to April 1989. Environment Canada then assumed monitoring responsibilities for the location (as station MA05SH0001) from April 1989 through to the beginning of 1997. Flow data for the trend analysis at the site were obtained from hydrometric station MB050KL001, which is located in the immediate vicinity of the water quality station.

Data from 268 water samples collected from 1974 through 1999 were used in the trend analysis of TP at station MA05KH0001, while data from 176 samples were used in the analysis of TP at the Grand Rapids site. A step trend was also inserted into the trend analysis model to account for the change in monitoring agencies at the Grand Rapids site.

Analysis of data from the Saskatchewan River site upstream of The Pas (MA05KH0001) did not detect a significant trend ($p=0.1012$) in flow-adjusted TP concentration for the period of record (Figure 103). The analysis of the data from the Grand Rapids site did identify a significant difference between reporting agencies (step trend $p<0.0001$), but did not detect a significant trend across the entire data set ($p=0.3654$) (Figure 104). Thus, according to the trend analysis results, artificial loading of TP from point sources and non-point sources within the watershed has not resulted in increased concentrations of TP at these two downstream stations over the period of record.

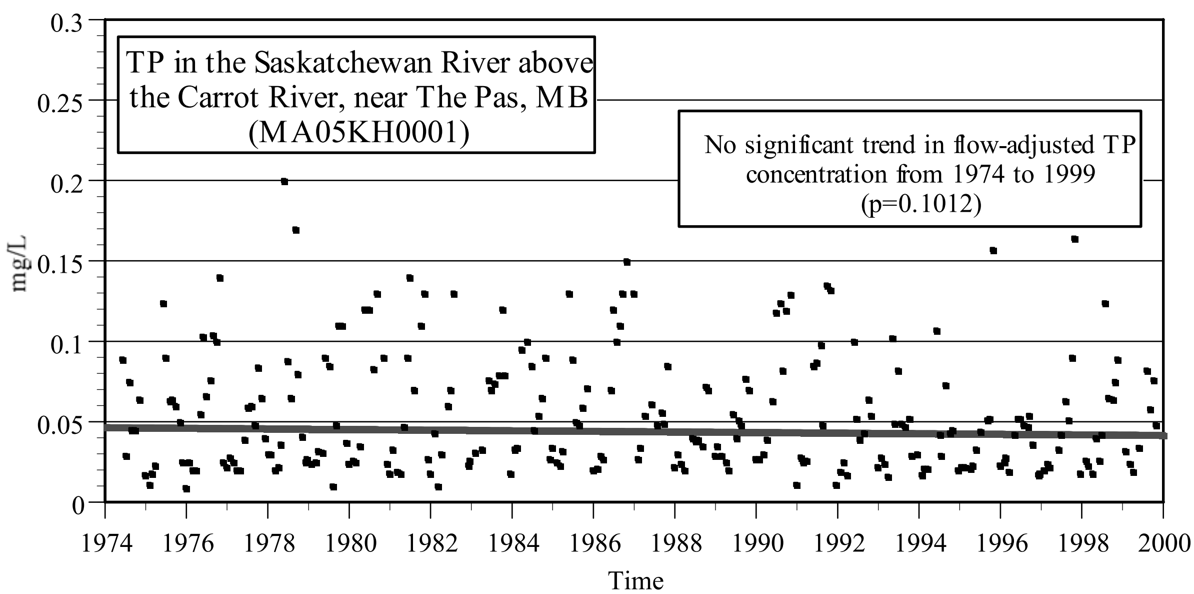


Figure 103. Trend in TP concentration in the Saskatchewan River above the Carrot River, near The Pas, MB, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

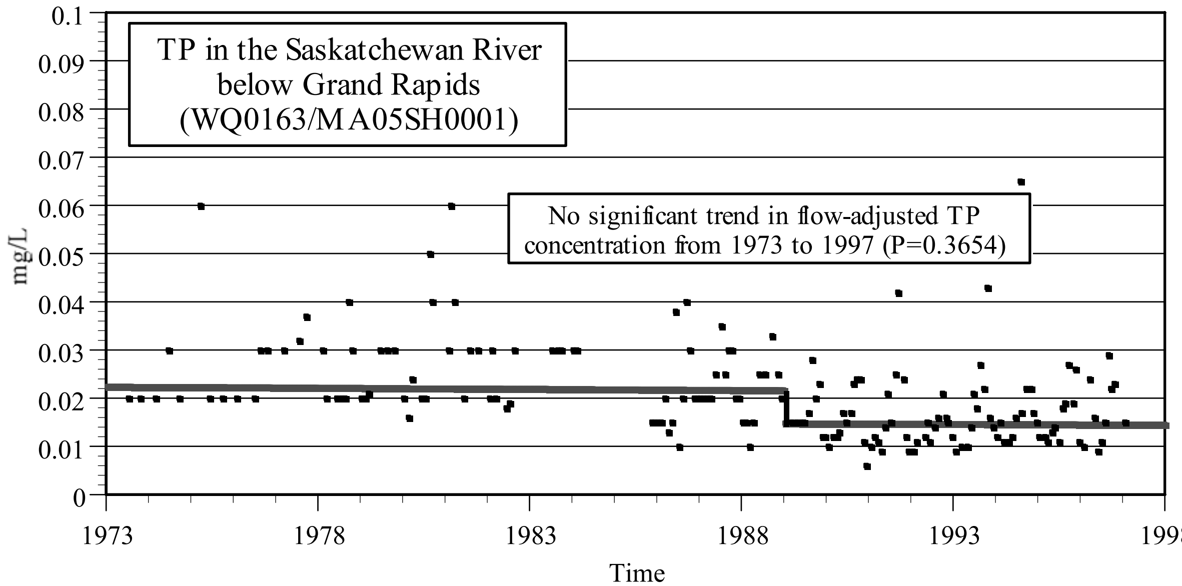


Figure 104. Trend in TP concentration in the Saskatchewan River below Grand Rapids, MB, 1973 to 1997 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

Since much of the watershed upstream of Manitoba is highly susceptible to nutrient loading from point and non-point sources (Wood 1999), we expected a positive trend in flow adjusted TP concentration that would be reflective of increased TP input to the system. However, less extensive agricultural land-use, a lower population density, and significantly more run-off to the river (per unit area) in the lower portion of the river basin (Boan and Duncan 1961) likely contributed to an overall reduction in TP concentration in the lower reaches of the river. This, in conjunction with the modifying effects of the Tobin Lake and Cedar Lake reservoirs (Allison 1978, Frick *et al.* 1996), may be responsible for the lack of a significant trend in the TP data.

It should be noted that the concentration and variability in TP concentration were generally lower at the Grand Rapids site than at the site upstream of The Pas. This reduction in concentration is likely due to a combination of phosphorus assimilation by vegetation in the Summerberry Marsh area immediately upstream of the Cedar Lake reservoir, as well as phosphorus retention in the reservoir itself. However, because the Saskatchewan River is second only to the Winnipeg River in terms of inflow contributions to Lake Winnipeg (Brunskill *et al.* 1980), the low concentration of TP in the river water still results in a significant amount of nutrient loading to the lake.

CARROT RIVER

The Carrot River is a major tributary of the Saskatchewan River system. The Carrot River originates in the Wakaw Lake area of east-central Saskatchewan and flows in a northeast direction for approximately 400 km before emptying into the Saskatchewan River west of the town of The Pas in Manitoba (Figure 105). Along its route the river receives contributions from a number of tributaries that drain northward from the southern rim of the watershed. The largest tributaries in terms of flow volume include the Leather River and Melfort, Goosehunting, and Burntout Creeks. Most of the smaller tributaries originate further east in the Pasquia Hills region, which is an extension of the Manitoba Escarpment that runs into Saskatchewan and forms the southeast rim of the drainage basin.

The Carrot River and its tributaries drain an area of approximately 19700 km^2. The watershed is about 320 km in length from west to east, but never more than 80 km wide from north to south. Most of the watershed is in Saskatchewan, with only about 800 km^2 in Manitoba. Topography in the watershed is variable. The highest elevations and steepest slopes are found in the headwaters region in the southwest and the Pasquia Hills region in the southeast, while the rest of the watershed varies from gently rolling terrain to flat lowlands and depressions. Natural vegetation cover within the watershed includes stands of deciduous and conifer tree species in the upland areas, and bush, grassland, marsh, and peatland species in the lowlands and depressions. Although there is a long history of agricultural activity within the watershed (Collier 1965, Johnson 1977), because of poor drainage in the lowlands and the variable topography of the uplands, much of the natural vegetation cover within the catchment remains undisturbed. However, past improvements in overland drainage, such as dredging and straightening natural channels and construction of new channels, have allowed a gradual increase in the amount of land put into agricultural production (Johnson 1977).

Trend analysis of TP in the Carrot River was conducted using data recorded at the Environment Canada water quality sampling station near Turnberry, SK (SA05KH0002). Total phosphorus data from 278 water samples collected from 1974 to 1999 (inclusive) were used in the analysis. Flow data for the analysis were obtained from hydrometric station SK05KH007, which is also located near Turnberry.

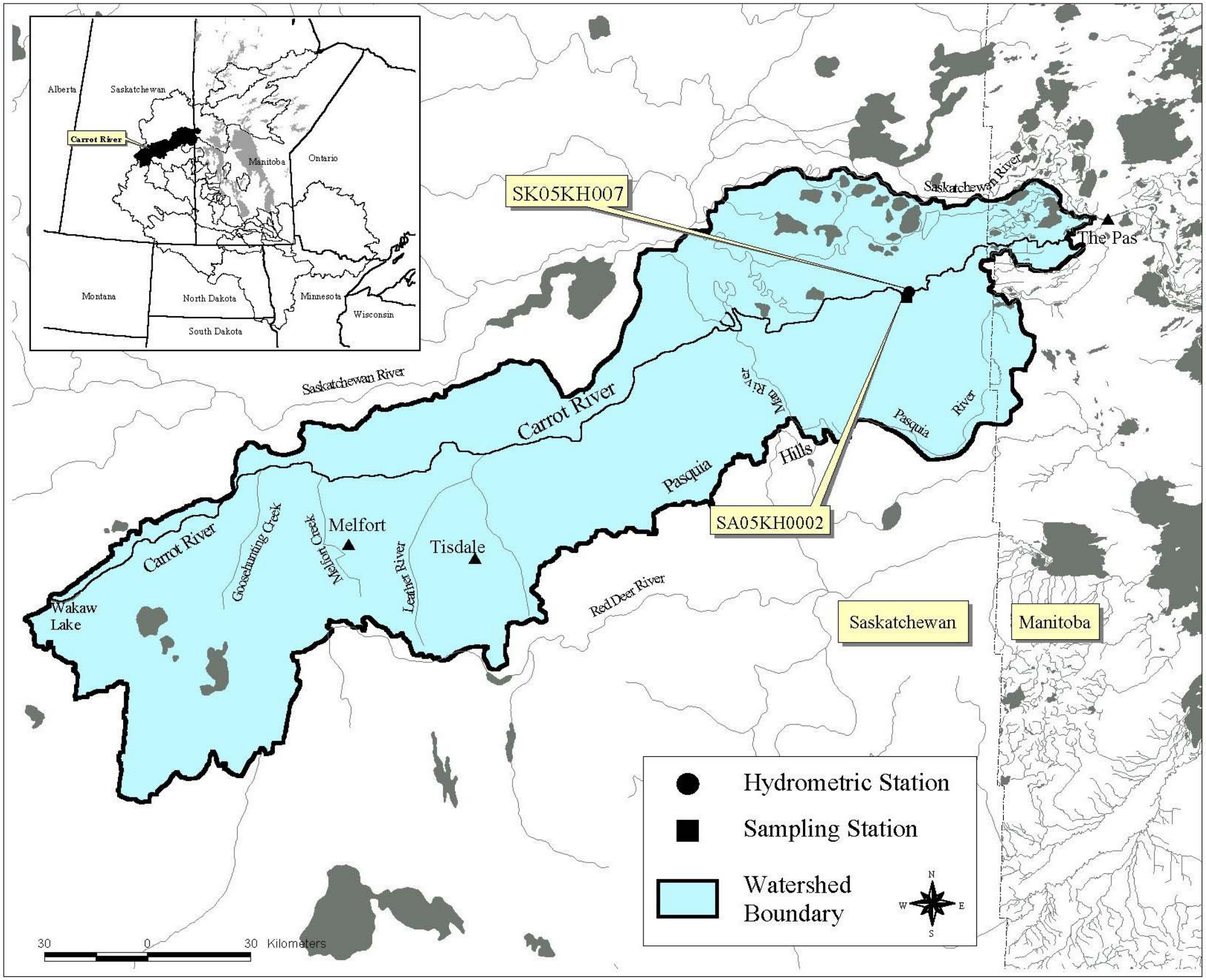


Figure 105. Carrot River watershed showing the location of water quality sampling site SA05KH0002 and hydrometric station SK05KH007 on the Carrot River.

Results of the analysis indicated that there was a significant trend of increasing flow-adjusted TP concentration at the sample station from 1974 through 1999 (Figure 106). This trend of increase may have been due in part to agricultural development and increased erosion associated with land clearing and improved drainage within the watershed (Johnson 1977). However, because of the variability in the flow and concentration data, the level of significance for the trend line was not very high (p=0.0466) and thus the relationship between time and flow-adjusted concentration was relatively weak.

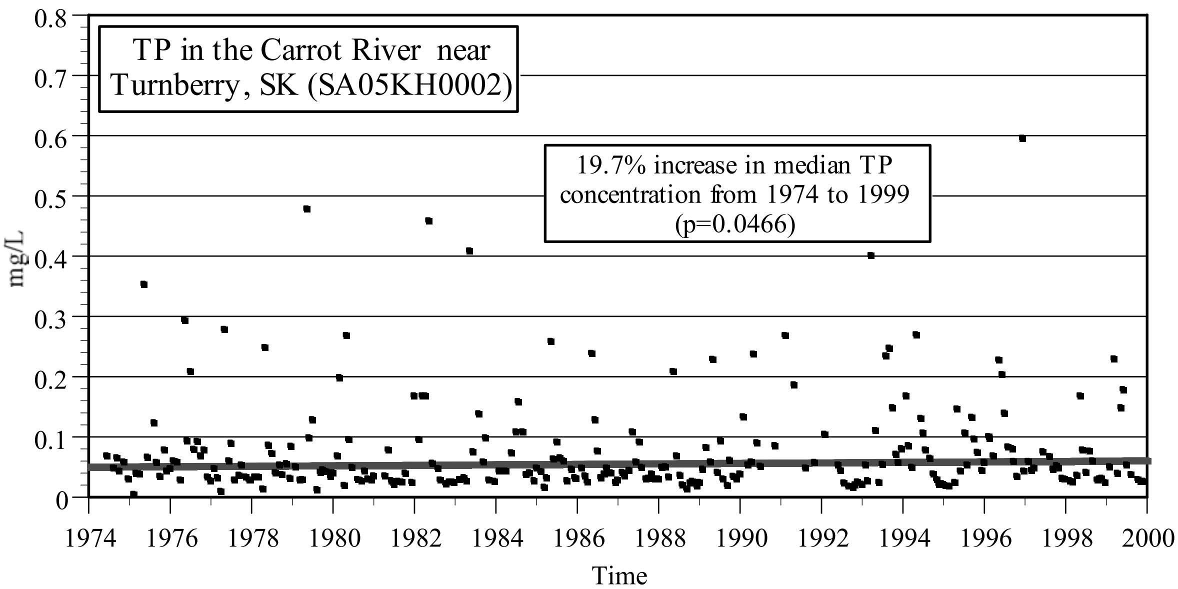


Figure 106. Trend in TP concentration in the Carrot River near Turnberry, SK, 1974 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

NELSON RIVER

The Nelson River is one of the primary waterways in northern Manitoba. It originates as the outflow from the north end of Lake Winnipeg and travels over 600 km in a north by northeast direction to eventually empty into Hudson Bay (Figure 107). A short distance after exiting the lake the river divides into two separate channels. The east channel carries water past the community of Norway House and into Cross Lake, while the west channel directs water through a series of smaller lakes, past Jenpeg, and then into Cross Lake. The river exits Cross Lake as a single channel.

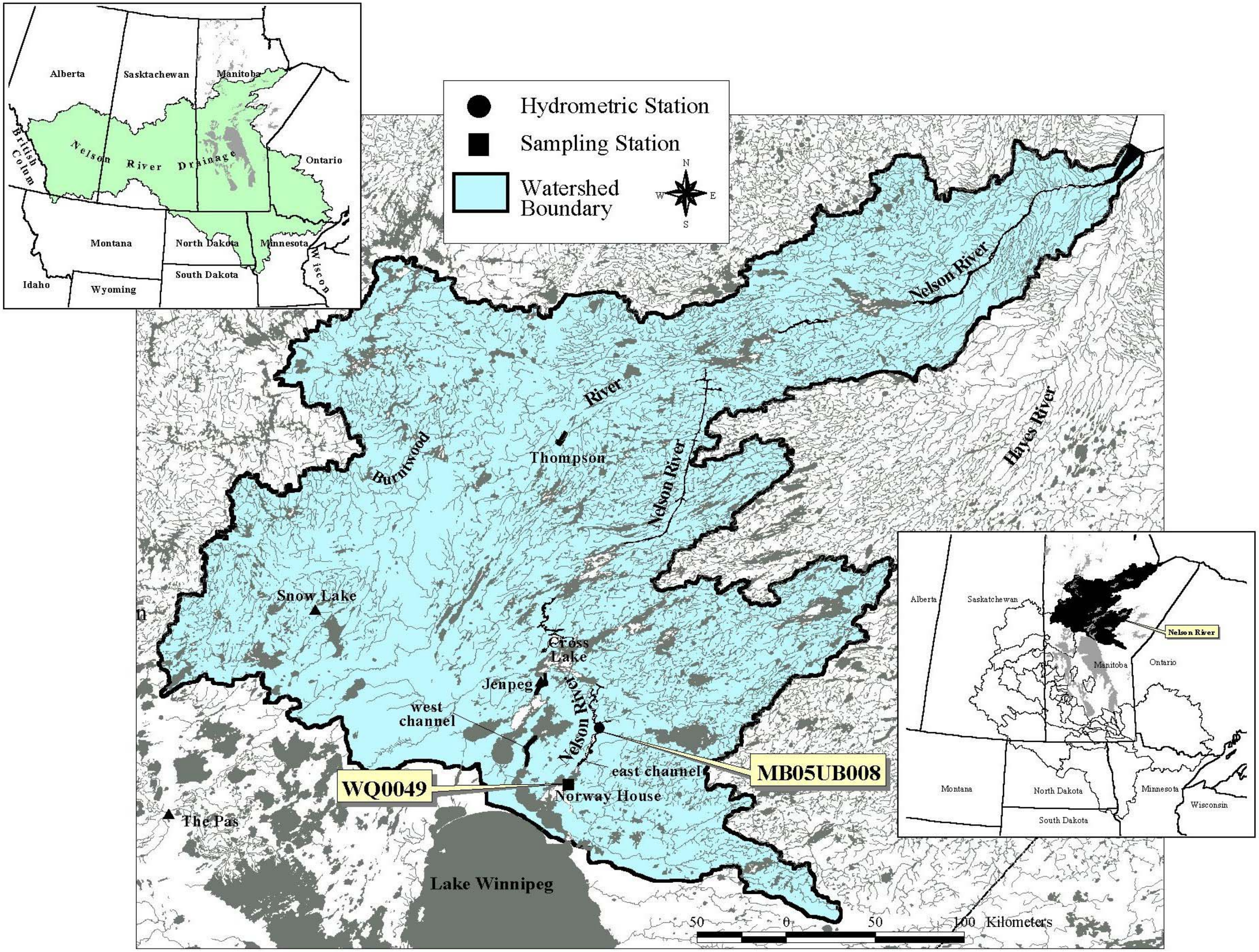


Figure 107. Nelson River watershed showing the location of water quality sampling site WQ0049 and hydrometric station MB05UB008 on the Nelson River.

The Nelson River watershed encompasses an area of approximately 100000 km^2; all in northern Manitoba. However, since it is the only outlet from Lake Winnipeg, the Nelson is actually the principle drain for a much larger basin of over 1100000 km^2 that extends eastward from the Rocky Mountains and northward from the headwaters of the Red and Winnipeg Rivers (see inset map Figure 107). Most of the watershed of the Nelson River is situated on the Canadian Shield in the Boreal Shield Ecozone (Smith *et al.* 1998). However, the river carries an uncharacteristically high amount of dissolved solids (Duncan and Williamson 1988) and a high sediment load (Williamson and Ralley 1993) compared to many other Canadian Shield rivers because lacustrine clay materials underlie much of the extended drainage basin upstream of Lake Winnipeg.

Flow volumes in the Nelson River are highly regulated for the purpose of hydro-electricity generation. Five generating stations have been established on the river since the mid-1970s. The furthest upstream of these is the generating station and control structure at Jenpeg. Prior to the construction of the station at Jenpeg, Lake Winnipeg water levels fluctuated naturally and flow volumes in the river varied in accordance with changes in lake water levels. By 1976 a series of channels and dikes was constructed at the north end of Lake Winnipeg to increase the volume of flow from the lake and to divert a greater proportion of the outflow northwestward via the west channel toward the site of the Jenpeg generating station. Once the diversion and regulation structures were in place, the majority of the water outflow from the lake was directed to the west channel of the Nelson, and, according to Duncan and Williamson (1988), the flow volume in the east channel at Norway House declined approximately 25%. Figure 108 illustrates the difference in flow volumes in the east and west channels of the river. Note that the pattern of fluctuation in the east channel has remained fairly stable throughout the period of lake level regulation (since mid-1976), while that of the west channel has varied considerably more over the same period.

The diversion and regulation of flows out of Lake Winnipeg have been linked to changes in water quality variables in the east channel of the river. Playle and Williamson (1986) compared pre- and post-regulation data (before and after mid-1976, respectively) from water quality sampling station WQ0049, which is located in the east channel at Norway House. They found that turbidity, total organic carbon (TOC), total inorganic carbon (TIC), and TP increased significantly in post-regulation water samples collected from mid-1976 to 1984. These were presumably due to increased shoreline soil erosion in the area following water level changes and channel construction at the north end of the lake. A further assessment of the data up to 1992 by Williamson and Ralley (1993) found that TIC and TOC had returned to near pre-regulation levels, but TP levels remained significantly higher than the pre-regulation period.

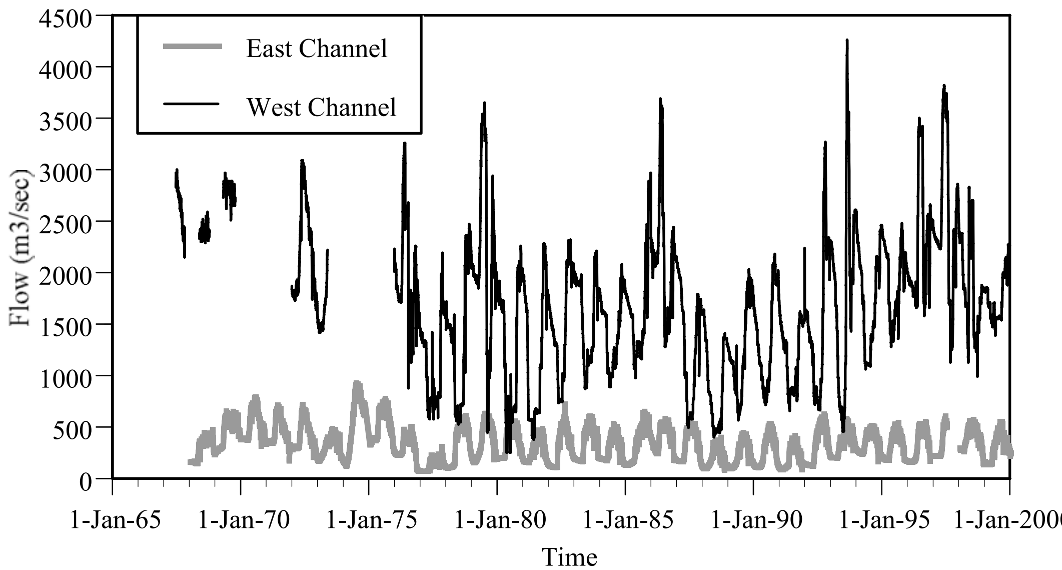


Figure 108. Water flow volume in the east and west channels of the Nelson River. Flow data for the east channel were obtained from hydrometric station MB05UB008, located at Sea River Falls, north of Norway House, MB, while flow data for the west channel were provided by hydrometric station MB05UB009, located at Jenpeg.

Long-term trends in the TN and TP concentrations in the Nelson River were assessed using data collected from water quality sampling station WQ0049, in the east channel at Norway House. The TN data were gathered from 102 water samples collected from 1978 through 1999, while the TP data were obtained from 121 samples collected from 1975 through 1999. All of the TN samples and most of the TP samples were collected following the establishment of Lake Winnipeg water level regulation, and as such can only be used to infer post-development trends in the data. As well, any trends identified in the data from site WQ0049 do not provide any information regarding trends further downstream, or in the west channel, but rather provide an indication of trends in TN and TP in a portion of the outflow from Lake Winnipeg. Flow data for the analysis were provided by hydrometric station MB05UB008, which is located about 30 km downstream of WQ0049 at Sea River Falls.

Although the analysis did not detect a significant trend ($p=0.1935$) in flow-adjusted TN concentrations at the site (Figure 109), it did show that there was a significant trend ($p=0.0013$) of decreasing flow-adjusted TP concentration in the east channel site from 1975 to 1999 (Figure 110). The lack of a trend in the TN data indicated that much of the variation in TN concentration can be accounted for by variation in flow. This may mean that increased nutrient inputs to Lake Winnipeg, particularly from the Red River in the south, have not resulted in an increase in TN in the outflow from the lake via the east channel of the Nelson. The significant trend in the TP data indicated that fluctuations in TP concentration cannot be totally accounted for by changes in the flow regime. The fact that the trend is negative suggests that the concentration of TP, which rose significantly following the implementation of water level regulation, has gradually declined. This is somewhat contrary to findings by Williamson and Ralley (1993). However, their work was aimed at assessing differences between pre- and post-development periods and not long-term continuous trends in the data. As well, they did not account for the correlation between flow and concentration in their analysis. Our results indicated that nutrient loading to the lake from anthropogenic sources did not cause an increase in TP in the lake discharge that flows out of the lake via the east channel of the river. Furthermore, since the trend in TP was negative, it implies that most of the phosphorus that enters the lake from streams such as the Red River either settles-out in the sediment or is assimilated by algae and aquatic macrophytes.

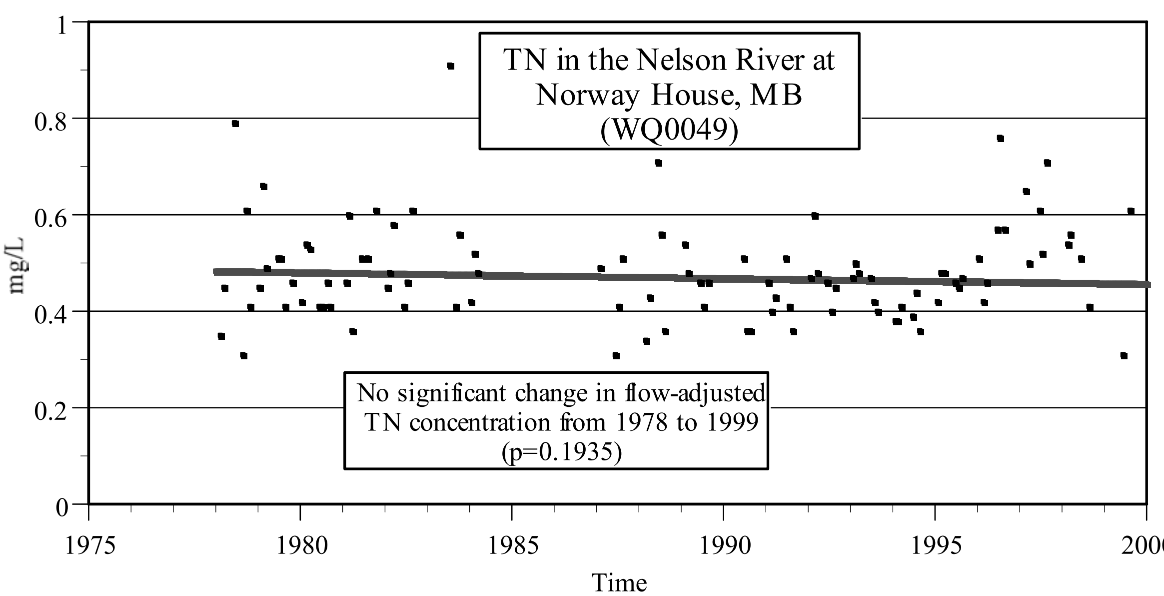


Figure 109. Trend in TN concentration in the Nelson River Norway House, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations.

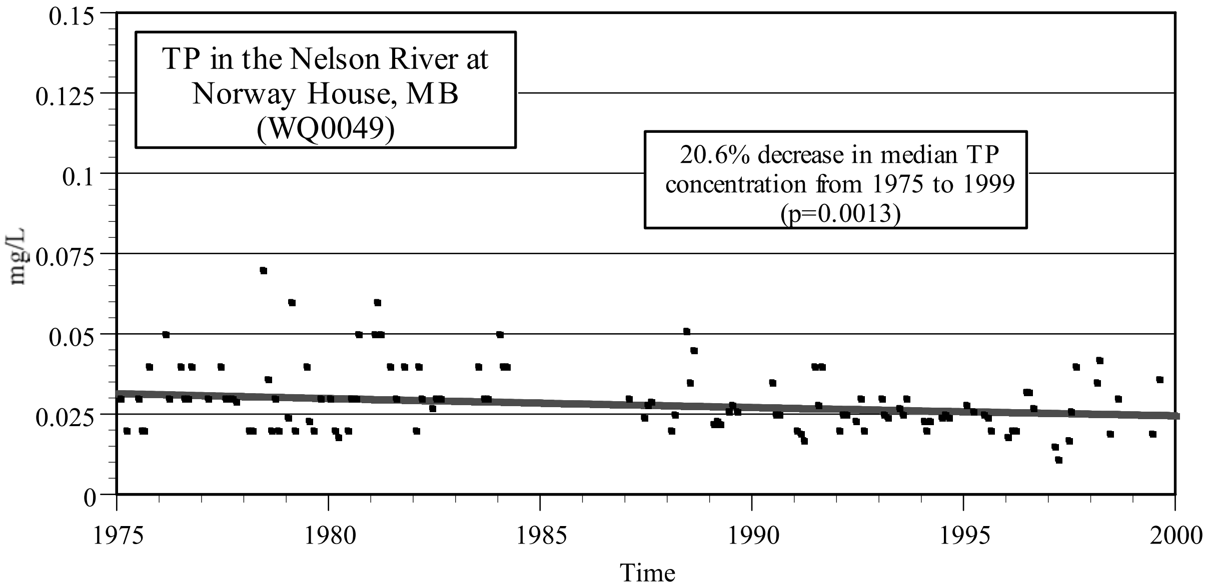


Figure 110. Trend in TP concentration in the Nelson River Norway House, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

BURNTWOOD RIVER

The Burntwood River originates as the outflow from Burntwood Lake in northern Manitoba (Figure 111). The Burntwood River flows in a east by northeast direction for a river distance of approximately 350 km from its headwaters and empties into the Nelson River (Split Lake) near the City of Thompson. Major tributaries of the Burntwood River include the Driftwood, Apeganau, Wimapedi, Rat, and Odei Rivers.

The Burntwood River system drains an area of approximately 26000 km^2. Much of the area the Burntwood system drains belongs to the Churchill River Uplands Ecoregion of the Boreal Shield Ecozone (Smith *et al.* 1998). Outcroppings of granitic Precambrian bedrock are very common throughout the ecoregion. When not exposed at the surface, the bedrock is overlain by a variety of soil types including brunisols (derived from sand deposits), luvisols (derived from lacutrine clay deposits), and deep organic soils (derived from peat deposits). Some streams and lakes in the watershed are underlain by lacustrine clay deposits and are naturally turbid – a feature which could be considered uncharacteristic of most water bodies in the Boreal Shield Ecozone. Coniferous

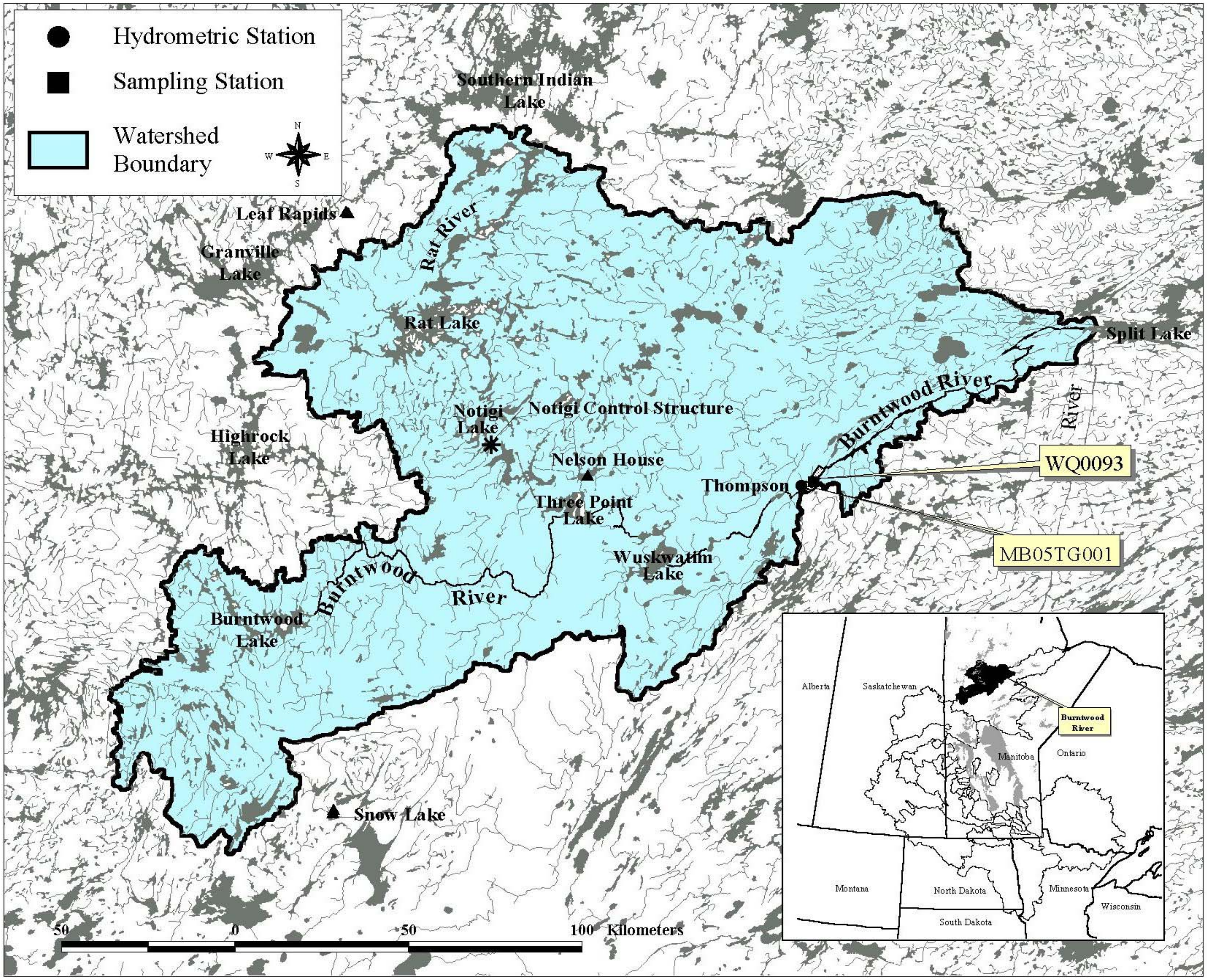


Figure 111. Burntwood River watershed showing the location of water quality sampling site WQ0093 and hydrometric station MB05TG001 on the Burntwood River.

forest, bog, and fen plant species characterize the vegetation of the watershed. Black spruce and jack pine dominate the forest cover, while sphagnum moss, black spruce, and ericaceous shrubs, and sedges and brown mosses dominate the bogs and fens, respectively.

Land-use within the Burntwood River drainage basin includes forestry, mining, recreation, and hunting and trapping. The climate and soil are not suitable for agriculture. Many of the lakes and rivers in the watershed support fish populations that are important for commercial fisheries and the tourism industry (CEC 1982). The watershed is sparsely populated, with the only major urban centre being the city of Thompson. The city uses the Burntwood River as its raw water supply. The INCO mining and smelting complex, located immediately east of the city, also draws a significant volume of water from the river to be used for domestic and industrial purposes. Both the city and the mining and smelting operation discharge treated domestic and industrial effluent to the river.

The Burntwood River has been part of the Churchill River Diversion system since it first began operation in 1976 (Guilbault *et al.* 1979). The Churchill River Diversion involves redirecting water from the Churchill River via the Rat River to the Burntwood River and eventually into the Nelson River. The diversion was designed to increase flows in the Burntwood and Nelson Rivers for the purpose of hydro-electric generation. A control structure at Missi Falls on the lower Churchill River was constructed to raise water levels in Southern Indian Lake and force water to flow through a diversion channel from the south end of the lake, across the drainage divide between the Churchill River and Burntwood River basins, and into the Rat River. Flows into the Burntwood River from the Rat River are regulated by the Notigi control structure.

The establishment and operation of the diversion has caused the flow in the Burntwood system to rise dramatically (CEC 1982). This rapid rise in flow volume (illustrated in Figure 112) resulted in flooding and extensive shoreline erosion in many of the streams and lakes upstream and downstream of the structure (CEC 1982). Although somewhat naturally turbid, the river experienced a significant increase in sediment loading as a result of the shoreline and stream bank erosion (CEC 1982). As well, a significant increase in the phosphorus concentration, which appears to be linked to the shoreline erosion and increased sediment load, was also observed in the river at Thompson following the opening of the diversion (Guibault *et al.* 1982, Playle and Williamson 1986, Duncan and Williamson 1988).

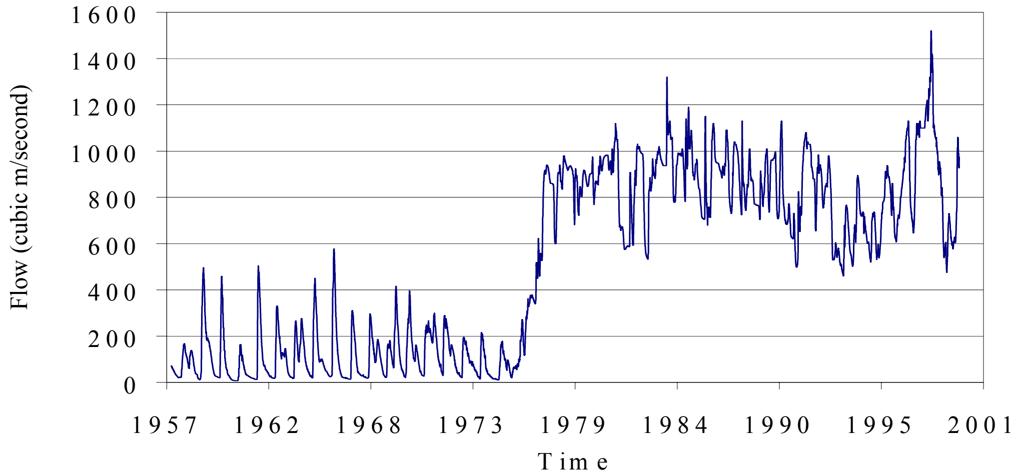


Figure 112. Water flow volume in the Burntwood River at hydrometric station MB05TG001, located in Thompson, MB, from 1957 to 1999 (inclusive).

Data for the trend analysis of TN and TP in the Burntwood River were obtained from water samples collected at water quality sampling station WQ0093, located in Thompson. Flow data for the analysis were provided by hydrometric station MB05TG001, which is located about 4 km upstream of WQ0093. The data set contained 112 data points for TN and 120 data points for TP collected over a 25-year period from 1975 through 1999.

The results of the analysis revealed significant ($p<0.0001$) trends of decreasing flow-adjusted concentrations of TN and TP over the period of record (Figures 113 and 114). The overall decline in TP was more dramatic than that of TN as evidenced by the greater percent decline in the median of the TP trend line (43.8% decrease) compared to that of the TN trend line (24.1% decrease). These trends suggested that loading of nitrogen and phosphorus to the system was greater around the time of the construction and initial operation of the diversion, and that this loading of nutrients has been declining ever since. It is likely that the rapid erosion of shoreline and stream bank soils, caused by the sudden increase in water level, led to the release of a significant amount of nutrients to the river system over a relatively short period. Over time the flooding and erosion within the river system has stabilized somewhat and nutrient inputs to the river have gradually decreased.

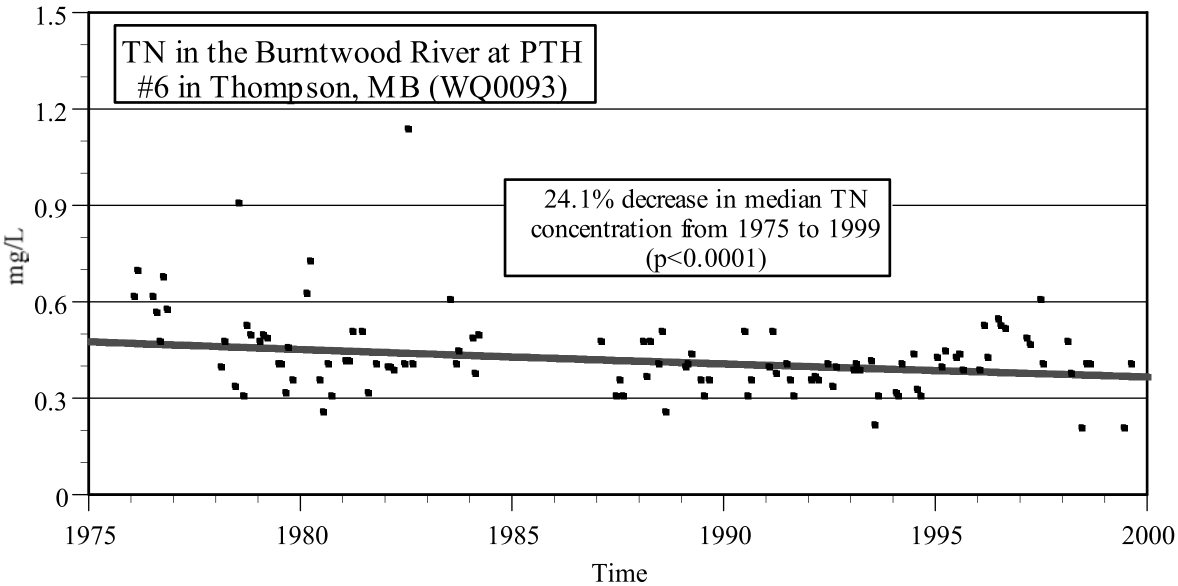


Figure 113. Trend in TN concentration in the Burntwood River at PTH #6 in Thompson, MB, 1975 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

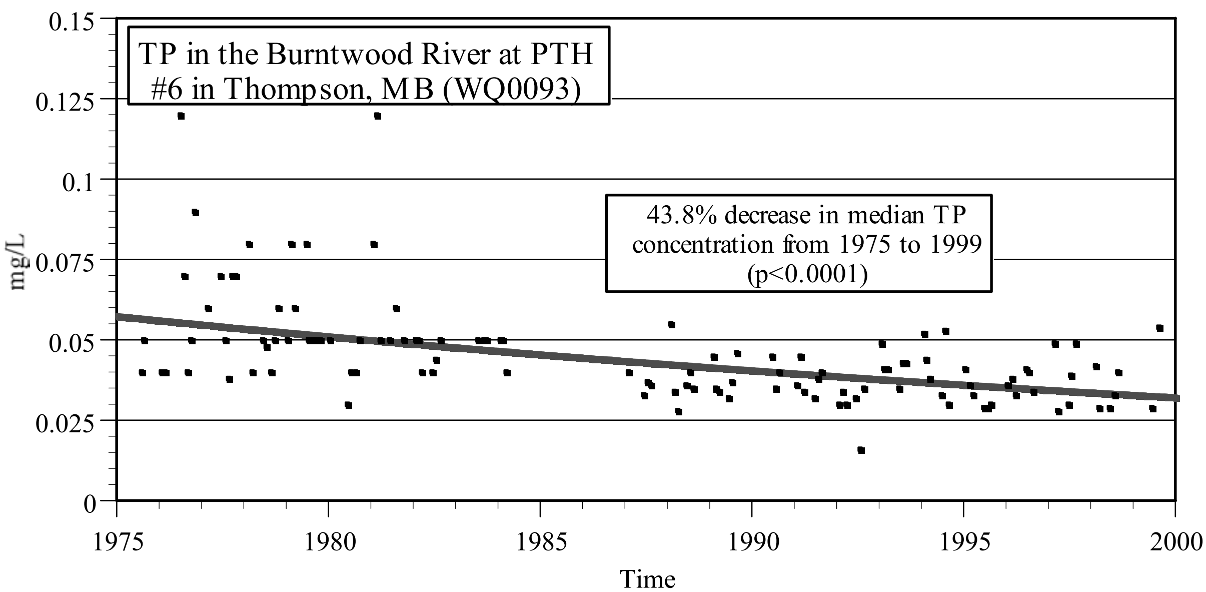


Figure 114. Trend in TP concentration in the Burntwood River at PTH #6 in Thompson, MB, 1975 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted trend line.

SUMMARY

The results of the trend analysis on TN and TP data in Manitoba streams are summarized in Table 2 and in Figures 115 and 116. The results indicate that there was a great deal of variability in long-term trends in TN and TP concentrations between streams and within streams in Manitoba.

Nineteen water quality stations from 13 different streams had trends of increasing flow-adjusted TN concentrations. As well, 18 stations from 15 separate waterways exhibited trends of increasing flow-adjusted TP concentrations. Eleven of these monitoring sites, representing 9 different streams, exhibited trends of increasing concentrations for both variables. Most of the streams with sites that had increases in both variables were in the southern portion of the province in the Assiniboine and Red River watersheds. Some of the most dramatic increases in concentration (in terms of % change in median concentration of the trend) also occurred in rivers from these watersheds (*e.g.* the La Salle, Seine, and Cypress Rivers). The majority of the streams in these watersheds are very susceptible to anthropogenic nutrient loading because human population densities are high and agricultural land-use is very intensive.

Trends of decreasing flow-adjusted TN were observed at four monitoring stations representing four separate streams, while trends in decreasing TP were found in data from seven monitoring stations representing seven different streams. These steams tended to be found in the northern and west-central regions of the province. Only two stations, one on the Swan River and the other on the Burntwood River, had decreasing trends for both TN and TP.

Ten monitoring stations from 10 streams and 20 stations from 15 streams had no significant trends in TN or TP, respectively. Seven of these monitoring stations each from a different stream had no significant trends in both TN and TP concentrations. Streams with stations that showed no trend in either TN or TP or both variables, although found in all areas of the province, tended to be located in the western portion of the Province north of the Assiniboine River and Boggy Creek-

Table 2. Summary of trend analysis results performed on TN and TP data from long-term monitoring sites in Manitoba streams.

Stream	Sample Station	Station Location	Total Nitrogen Trend	Total Nitrogen % Change in Median	Total Phosphorus Trend	Total Phosphorus % Change in Median
Red River	MA05OC0001	At Emerson, MB	Not available		Increase ($p=0.0108$)	22.5
	WQ0367	At south gate of Winnipeg floodway, east of PTH #75	Increase ($p<0.0001$)	28.8	None ($p=0.1487$)	-
	WQ0142	At Selkirk Bridge, Selkirk, MB	Increase ($p<0.0001$)	57.8	Increase ($p=0.0003$)	28.8
La Salle River	WQ0068	Near bridge upstram of PTH #75 in St. Norbert, Winnipeg, MB	Increase ($p<0.0001$)	145.5	Increase ($p=0.0043$)	193.8
Boyne River	WQ0029	At bridge, one block west of PTH #13, Carman, MB	None ($p=0.0940$)	-	Increase ($p=0.0016$)	Not known
Pembina River	MA05OB0001	At Windygates, MB	Not available		Increase ($p<0.0001$)	52.1
Roseau River	WQ0153	At PR #200, Dominion City, MB	Increase ($p<0.0001$)	45.2	Increase ($p<0.0001$)	45.2
Rat River	WQ0131	At PR #303 at Otterburne, MB	None ($p=0.0785$)	-	Increase ($p=0.0026$)	Not known
Marsh River	WQ0365	At PR #303 , west of Otterburne, MB	Increase ($p<0.0001$)	113.8	Increase ($p=0.0100$)	65.9
Seine River	WQ0166	At south perimeter Hwy, Winnipeg, MB	Increase ($p<0.0001$)	74.9	Increase ($p<0.0001$)	187.7
Cooks Creek	WQ0644	At municipal road 1 km south of Millbrook, MB	Decrease ($p=0.0219$)	Not known	None ($p=0.0929$)	-
	WQ0643	At boundary of St. Clements and Springfield	None ($p=0.3659$)	-	None ($p=0.2858$)	-
Assiniboine River	SA05MD0001	At Kamsack, SK	Not available		None ($p=0.0777$)	-
	WQ0009	At 18th Str. Bridge, Brandon, MB	Increase ($p=0.0147$)	12.7	None ($p=0.2290$)	-
	WQ0012/WQ0636	At PR #340 at Treesbank Ferry/At PR #340upstream of Treesbank, MB	None ($p=0.0720$)	-	None ($p=0.0654$)	-
	WQ0014	Downstream of WTP reservoir at Spillway Park, Portage la Prairie, MB	Increase ($p=0.003$)	20.5	Increase ($p<0.0001$)	39.6
	WQ0015	At Trans-Canada Hwy bridge east of Portage la Prairie, MB	Increase ($p=0.0165$)	36.5	Increase ($p<0.0001$)	39.6
	WQ0018	At PR #334, south of Headingley, MB	Increase ($p<0.0001$)	54.5	Increase ($p<0.0001$)	62.2
Little Saskatchewan River	WQ105	At PTH #25 bridge, near Rivers, MB	Decrease ($p<0.0001$)	-28.2	Increase ($p=0.0018$)	39.3
Cypress River	WQ398	On municipal road east of Cypress River, MB	Increase ($p<0.0001$)	66	Increase ($p<0.0001$)	189.7
Souris River	MA05NF0001/US05NFH0001	At Coulter, MB/at Westhope, ND	Not available		None ($p=0.3351$)	-
	WQ0371	At PTH #22 bridge in town of Souris, MB	Increase ($p<0.0024$)	25.9	None ($p=0.1147$)	-
	WQ0350	At PR #530 near Treesbank, MB	Increase ($p<0.0001$)	45.2	Increase ($p<0.0001$)	51.4
Qu' Appelle River	SA05JM0014	Near Welby, SK	Not available		Decrease ($p<0.0001$)	-40.4
Brokenhead River	WQ0038	At PTH #59 bridge, southeast of Scanterbury, MB	None ($p=0.2915$)	-	None ($p=0.0999$)	-
Winnipeg River	MA05PF0022	At Pointe Du Bois, MB	Not available		Increase ($p<0.0001$)	29.4

Table 2. Summary of trend analysis results performed on TN and TP data from long-term monitoring sites in Manitoba streams (cont.).

Stream	Sample Station	Station Location	Total Nitrogen		Total Phosphorus	
			Trend	% Change in Median	Trend	% Change in Median
Boggy Creek - Whitemud River	WQ0201	At PTH #16 at Neepawa, MB	Increase (p<0.0001)	35.8	None (p=0.2549)	-
	WQ0197	At PTH #16 at Westbourne, MB	Increase (p<0.0001)	36.5	Increase (p<0.0001)	64.4
Turtle River	WQ0245	At PTH #5 at Ste. Rose Du Lac, MB	None (p=0.8014)	-	None (p=0.3436)	-
Ochre River	WQ0227	At PTH #5 near town of Ochre River, MB	None (p=0.6226)	-	None (p=0.4483)	-
Vermillion River	WQ0252	At PTH #20 north of Dauphin, MB	None (p=0.1952)	-	None (p=0.0518)	-
Wilson River	WQ0255	At PTH #20 north of Dauphin, MB	Increase (p=0.0345)	21.3	Decrease (p=0.0321)	-13.5
Valley River	WQ0250	At PTH #20 north of Dauphin, MB	Increase (p=0.0027)	16.4	Decrease (p=0.0350)	-9.6
Mossy River	WQ0390	At continuation of PR # 273, approximately 3.2 km east of PTH #20	Increase (p<0.0001)	37.4	None (p=0.1423)	-
North Duck River	WQ0217	At PTH #10 near Cowan, MB	None (p=0.2045)	-	None (p=0.4660)	-
Swan River	WQ0244	At PR #268 near Lenswood, MB	Decrease (p=0.0322)	Not known	Decrease (p=0.0148)	Not known
Woody River	WQ0259	At PR #268	Not available		None (p=0.3065)	-
Red Deer River	SA05LC0001	Near Erwood, SK	Not available		None (p=0.1443)	-
Waterhen River	WQ0561	At PR #328 near Waterhen, MB	Increase (p=0.0279)	19.1	None (p=0.0540)	-
Dauphin River	WQ0404/MA05LM0005	Upstream of Anama Bay, MB	Not available		Decrease (p<0.0001)	-45.8
Saskatchewan River	MA05KH0001	Above the Carrot River in Manitoba	Not available		None (p=0.1012)	-
	WQ0163/MA05SH0001	Below Grand Rapids, MB	Not available		None (p=0.3654)	-
Carrot River	SA05KH0002	Near Turnberry, SK	Not available		Increase (p=0.0466)	19.7
Nelson River (east channel)	WQ0049	At Norway House, MB	None (p=0.1935)	-	Decrease (p=0.0013)	-20.6
Burntwood River	WQ0093	At bridge on PTH #6, Thompson, MB	Decrease (p<0.0001)	-24.1	Decrease (p<0.0001)	-43.8

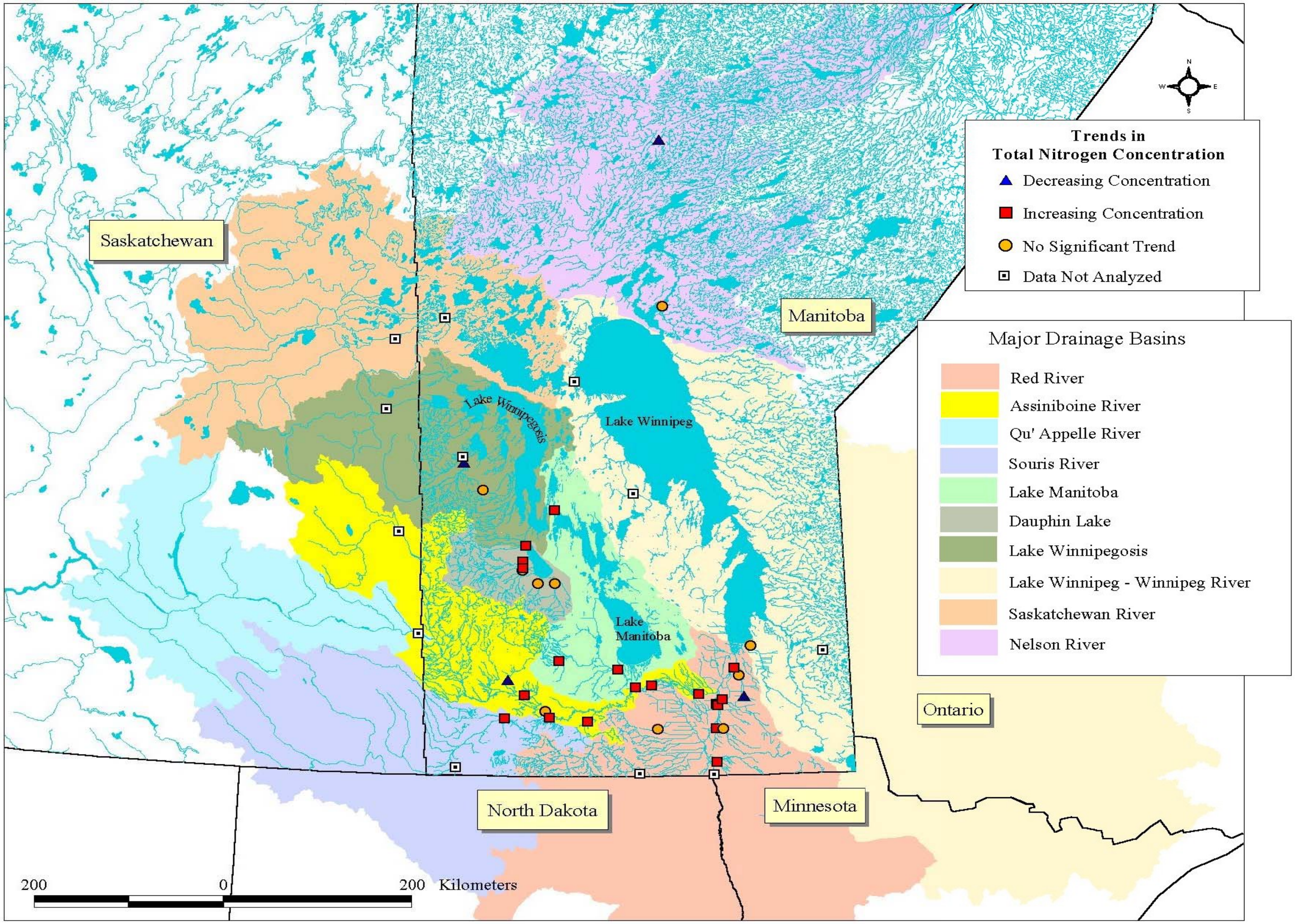


Figure 115. Map showing long-term trends in TN concentration at stream water quality monitoring stations in Manitoba. (Note the period of record often varied between sites. Refer to text for details.)

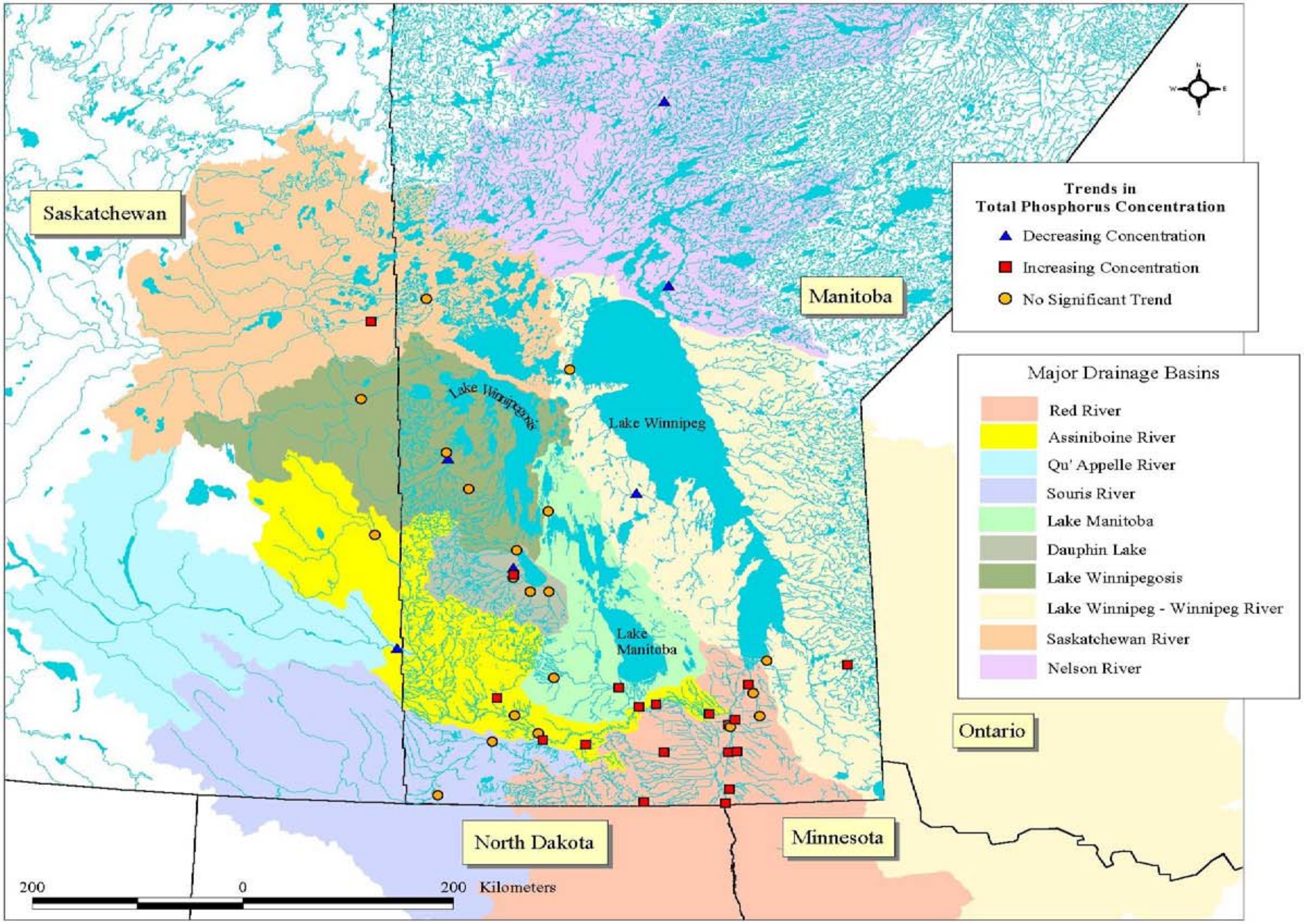


Figure 116. Map showing long-term trends in TP concentration at stream water quality monitoring stations in Manitoba. (Note the period of record often varied between sites. Refer to text for details).

Whitemud River watersheds. Watersheds in this region of the province are generally less dominated by agricultural land-use (on a proportional land basis) than watersheds in the south. Several of the monitoring sites on these streams provided only 12 to 14 years of data and often had fewer than 50 data points. The small sample size and short period of record coupled with the high variability in the data made the detection of statistically significant trends at these sites difficult. Trend detection may increase as more data are collected at these sites.

The main purpose of this report was to identify long-term trends in TN and TP in waterways of southern Manitoba. The results of the analyses were interpreted in terms of there having been an increase, a decrease, or no change in concentration over the period of record. A positive trend at a monitoring station could be interpreted as an increase in nutrient inputs to the waterway. Further study, as identified in the Nutrient Management Strategy (Manitoba Conservation 2000), is required to determine the potential sources of nutrient addition (*i.e.* point or non-point source, natural or anthropogenic). Also, the trend results did not indicate whether such an increase was ecologically significant. Assessment of the potential impact of an increase in nutrients on an aquatic system depends on the magnitude of the increase and the actual recorded concentrations present. As well, monitoring stations where trends were not detected may still be subject to anthropogenic nutrient loading leading to eutrophication. For example, there was no significant trend observed in flow-adjusted TP data collected at site WQ0201 on Boggy Creek. However, the creek may still be susceptible to nutrient loading and eutrophication given that the concentrations of TP at the site fluctuated between 0.05 and 0.15 mg/L over the period of record. Further study is required to determine what magnitude of fluctuation in TP or TN concentration will trigger negative impacts associated with nutrient enrichment.

REFERENCES

Allison, E. W. 1978. Alterations of river water quality downstream of large reservoirs in the Saskatchewan River Basin. Prairie Provinces Water Board. Regina, SK. 7 pp.

Beak Associates Consulting Ltd. 1991. Background report on water quality modeling within the Souris River basin (Draft). A report prepared for the Water Quality Branch, Western and Northern Region, Inland Waters and Lands, Environment Canada. Ottawa, ON.

Beck, A. E. 1981. A report on the 1980 Cladophora bloom on the Souris River. Water Standards and Studies Section, Manitoba Department of Consumer and Corporate Affairs and Environment. Winnipeg, MB. 25 pp..

Beck, A. E., V. T. Chacko, W. Tibbatts, and D. J. Green. 1992. Herbicide contamination of the Stephenfield Reservoir, Manitoba, Canada. Water Quality Management Report #92-2, Manitoba Environment, Winnipeg, MB.

Blachford, B. P. 1987. Data evaluation for objectives development for the Souris River basin. Vol. 1 (Working document). Water Quality Branch, Inland Waters Directorate, Environment Canada. Regina, SK. 132 pp.

Boan, J. and C. Duncan. 1961. Physical features of the Saskatchewan River Basin. Prairie Farm Rehabilitation Agency (PFRA), Agriculture Canada. Ottawa, ON. 56 pp.

Brokenhead River Watershed Management Study. 1995. Information pamphlet of a study sponsored by several Provincial and Federal agencies, Municipal governments, and non-governmental organizations with financial support from the Canada-Manitoba Agreement on Agricultural Sustainability (CMAAS). 8 pp.

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. Western Region, Department of Fisheries and Oceans, Winnipeg, MB. 32 pp.

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

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications. 8:559-568.

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.

CEC (Clean Environment Commission). 1982. Report on a proposal for the classification of Manitoba's surface water:: Grass-Burntwood Rivers principal watershed division. Manitoba Clean Environment Commission. Winnipeg, MB. 122 pp

CEC (Clean Environment Commission). 1990. Pelican Lake enhancement project. Report of hearing by the Manitoba Clean Environment Commission. Winnipeg, MB. 63 pp.

Chacko, V. T. 1986. Nutrient characteristics of the Souris River at Coulter, Manitoba, during low flow years. Water Quality Branch, Inland Waters Directorate, Environment Canada. Regina, SK. 14 pp.

Chacko, V. T. and T. H. Ronmark. 1990. Water quality summary: Red, Assiniboine, and Roseau Rivers. Water Quality Branch, Inland Waters Directorate, Environment Canada. Winnipeg, MB. 111 pp.

Chambers, P. A., M. Guy, E S. Roberts, M. N. Charlton, R. Kent, C. 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. Hull, QC, Canada. www.durable.gc.ca/group/group7/report/index_e.phtml 241 pp..

Cherneski, P. L. and D. L. Ackerman. 1999. The PFRA watershed project. PFRA GIS Unit, Agriculture and Agri-Food Canada. Regina, SK. 8 pp. (available in PDF at www.agr.ca/pfra/gis/download)

Collier, E. P. 1965. Flood of 1957 in the Carrot River basin. Water Resources Branch, Department of Northern Affairs and National Resources. Ottawa, ON. Water Resources Paper No. 121F. 63 pp.

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

Cowan, J and S. Therrien-Richards. 1986. An agricultural chemical use farm survey of the La Salle River Watershed, 1984. Environment Canada, Western and Northern Region. Winnipeg, MB. 19 pp.

Dickson, I. 1964. Artificial aeration of Neepawa Reservoir in winter 1964. Fisheries Branch, Manitoba Department of Mines and Natural Resources. Winnipeg, MB. 8 pp.

Duncan, D. A. and D. A. Williamson. 1988. Water chemistry/water discharge rel;ationships within the Churchill River diversion and Lake Winnipeg regulation region, Manitoba, Canada. Water Standards and Studies, Manitoba Department of Environment and Workplace Safety and Health. Water Standards and Studies report #87-8. 57 pp.

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.

EMD (Environmental Management Division). 1979. Proposed classification of Manitoba's surface water: Souris River principal watershed division. Environmental Management Division, Department of Mines, Natural resources, and Environment. Winnipeg, MB. 47 pp.

EMD (Environmental Management Division). 1980. Proposed classification of Manitoba's surface water: Red River principal watershed division. Environmental Management Division, Department of Consumer and Corporate Affairs and Environment. Winnipeg, MB. 89 pp.

Environment Canada. 1978. Souris River basin study: Canada-Manitoba-Saskatchewan, supplement #4: Water quality. Water Quality Branch, , Inland Waters Directorate, Environment Canada. Regina, SK

Environment Canada. 2001. Environment Canada freshwater management flood control website. www.ec.gc.ca/water/en/manage/floodgen/e_red_fr.htm#portage.

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.

Frick, E. A., G. R. Buell, and E. H. Hopkins. 1996. Nutrient sources and analysis of nutrient water-quality data, Apalachicola-Chattahoochee-Flint River Basin, Georgia, Alabama, and Florida, 1972-90 (abstract). Water Resources Investigations Report 96-4101, United States Geological Survey, Atlanta, GA, USA. wwwga.usgs.gov/publications/abstracts/wrir96-4101.html .

Gaboury, M. N. 1985. A fisheries survey of the Valley River, Manitoba, with particular reference to walleye (*Stizostedion vitreum*) reproductive success. Report#85-02. Fisheries Branch, Manitoba Natural Resources. Winnipeg, MB. 149 pp.

Goodman, L. G. 1997. Phytoplankton activity in the Red and Assiniboine Rivers as the flow through the City of Winnipeg, Manitoba. M.Sc. Thesis. Department of Botany, University of Manitoba, Winnipeg, MB. 275 pp.

Green, D. J. 1997a. Little Saskatchewan River water quality, 1965 - 1996 status report. Water Quality Management Section Status Report. Report No. 97-09. Water Quality Management Section, Manitoba Environment, Winnipeg, MB. 18 pp. (plus appendix).

Green, D. J. 1997b. Water quality of the Bachman Drain and U-Drain, 1996 Status Report: Brokenhead River watershed management study. Water Quality Management Section Status Report. Report No. 97-08. Water Quality Management Section, Manitoba Environment, Winnipeg, MB. 15 pp.

Gregor, D. and V. Chacko. 1987. An overview of phosphorus, nitrogen, and organic carbon of Manitoba interjurisdictional river sites, 1970-1979. Water Quality Branch, Western and Northern Region, Environment Canada. Winnipeg, MB. 51 pp.

Guilbault, R. A., W. D. Gummer, and V. T. Chacko. 1979. The Churchill Diversion: water quality changes in the lower Churchill and Burntwood Rivers. Water Quality Interpretive Report No. 2. Inland Waters Directorate, Water Quality Branch, Western and Northern Region, Fisheries and Environment Canada. Regina, SK. 9 pp.

Hughes, C. 1982. A report on the trophic status of Killarney, Wahtopanah, Rossman, and Sandy Lakes. Water Standards and Studies Section, Manitoba Department of Environment and Workplace Safety and Health. Winnipeg, MB. Report 82-30 13pp.

Hughes, C. E. 1999a. Water quality assessment of eight streams in the West Souris River Conservation District from July 1996 through April 1999, Manitoba, Canada. Water Quality Management Section, Manitoba Conservation. Report No. 99-07. Winnipeg, MB. 67 pp.

Hughes, C. E. 1999b. Water quality assessment of the Whitemud River watershed, 1996 through 1998, Manitoba, Canada. Water Quality Management Section, Manitoba Conservation. Report No. 99-06. Winnipeg, MB. 67 pp.

Hughes, C. E. 2000. A water quality assessment of Cooks Creek, Manitoba, Canada, 1990 to 1999. Water Quality Management Section, Manitoba Conservation. Report No. 2000-02. Winnipeg, MB. 17 pp. (plus appendix).

Hughes, C. E. 2001 (in review). Water and biological quality of twenty seven major streams in south and central Manitoba, Canada, 1995 through 1998. Water Quality Management Section, Manitoba Conservation. Report No. 2001-0?. Winnipeg, MB. 35 pp (plus Appendix).

International Pembina River Engineering Board. 1964. Joint investigation for development of the water resources of the Pembina River basin Manitoba and North Dakota: volume 1 – main report. International Joint Commission. Washington, DC, USA. 80 pp.

International Roseau River Engineering Board. 1975. Joint studies for the coordinated water use and control in the Roseau River basin Manitoba - Minnesota. Main report. International Joint Commission. Washington, DC, USA. 45 pp.

Johnson, B. N. 1977. Floods of 1972 and 1974 in the Carrot River basin. Water Survey of Canada, Saskatchewan District. Inland Waters Directorate, Environment Canada. Regina, SK. 45 pp. (plus Appendices)

Jones, G., S. E. Gurney, D. Rocan. 1998. Blue-green algae and microcystin-LR in surface water supplies of southwestern Manitoba. Manitoba Environment. Winnipeg, MB. Report No. 98-06. 82 pp.

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

Manitoba Conservation. 2000. Development of a nutrient management strategy for surface waters in southern Manitoba. Water Quality Management Section, Manitoba Conservation. Winnipeg, MB. Information Bulletin 200 – 02E. www.gov.mb.ca/natres/watres/nutrmgt.pdf.

Manitoba Department of Mines, Resources and Environmental Management. various dates from 1960'2 - 1980's. Watershed and drainage map series 1:20000. Water Resources Branch, Manitoba Department of Mines, Resources and Environmental Management. Winnipeg, MB, Canada.

Manitoba Hydro-Electric Board. 1958. The Winnipeg River watershed regulations and controls. Economics and Finance, Manitoba Hydro-Electric Board. Winnipeg, MB. 42 pp plus appendix and map.

Manitoba Natural Resources. 1989. Dauphin Lake: Opportunities for restoration. Manitoba Natural Resources, Government of Manitoba. Winnipeg, MB. 17 pp.

Mills, G. F., L. A. Hopkins, and R. E. Smith. 1977. Organic soils of the Roseau River watershed in Manitoba: Inventory and assessment for agriculture. Monograph No. 17. Agriculture Canada. Ottawa, ON. 69 pp. (plus map).

Muir, D. C. G. and N. Grift. 1987. Herbicide levels in rivers draining two prairie agricultural watersheds (1984). Journal of Environmental Science and Health. B22(3):259-284.

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

Patalas, K. and A. Salki. 1992. Crustacean plankton in Lake Winnipeg: variations in space and time as a function of lake morphology, geology, and climate. Canadian Journal of Fisheries and Aquatic Sciences 49:1035-1059.

PFRA. 1985. Natural flow: Swan River at Sasktchewan – Manitoba border. Technical report to the PPWB Committee on Hydrology. Hydrology Division, PFRA, Agriculture Canada. Regina, SK

PFRA. 1999 (last update July 13, 1999). PFRA gross watershed boundaries, version 2.0. Geographic Information Systems (GIS) Unit, Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, Regina, SK, Canada. www.agr.ca/pfra/gis/download .

PFRA. 2000. Prairie agricultural landscapes: A land resource review. Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, Regina, SK, Canada. 179 pp. (available on-line at www.agr.ca/pfra/pub/pallande.pdf.).

Playle, R. C. and D. A. Williamson. 1986. Water chemistry changes associated with hydroelectric development in northern Manitoba: the Churchill, Rat, Burntwood, and Nelson Rivers. Water Standards and Studies, Manitoba Environment and Workplace Health and Safety. Report #86-8. 50 pp.

Ralley, W. 1990. Rivers Lake (unpublished report). Manitoba Environment. Winnipeg, MB. 12 pp.

Ralley, W. 1998. Water quality of the Roseau River 1996 to 1997: Status report. Water Quality Management Section, Manitoba Environment. Report 98-02. Winnipeg, MB. 30 pp.

Reid Crowther. 1996. Town of Dauphin wastewater treatment facilities preliminary design report. Reid Crowthers & Partners Ltd. Project No. 61700. Winnipeg, MB.

Richards, J. H. and K I. Fung. 1969. Atlas of Saskatchewan. University of Saskatchewan. Saskatoon, SK.

Rounds, R. C. 1990. A user needs survey of Rivers Provincial Recreation Park, Manitoba. The Rural Development Institute, Brandon University, Brandon, MB. 36 pp.

Smith, R. E., H. Veldhuis, G. F. Mills, R. G. Eilers, W. R. Fraser, and G. W. Lelyk. 1998. Terrestrial Ecozones, Ecoregions, and Ecodistricts of Manitoba. An ecological stratification of Manitoba's natural landscapes. Tech Bulletin 98-9E. Land Resource Unit, Brandon Research Centre, Research Branch, Agriculture and Agri-Food Canada. Winnipeg, MB. Report plus map.

Smith, V. H., G. D. Tilman, J. C. Nekola. 1999. Eutrophication impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100:179-196.

Stepaniuk, J. R. 1994. Roseau River stream condition and habitat classification scheme. Prepared for the Manitoba Wildlife Federation Inc. JRS Environmental Consulting. Winnipeg, MB. 57 pp.

Stoner, J.D., D. L. Lorenz, R. M. Goldstein, M. E. Brigham, and T. K. Cowdery. 1998. Water quality in the Red River of the North, Minnesota, North Dakota, South Dakota, 1992-95. U.S. Geological Survey Circular 1169, on line at www.water.usgs.gov/pubs/circ1169., updated April 21, 1998.

Tetres Consultants. 1996. Environmental effects of the wastewater stabilization pond for the town of Dauphin. A report prepared by Tetres Consultants Inc. for Reid Crowther & Partners Ltd. In: Town of Dauphin wastewater treatment facilities preliminary design report. Reid Crowthers & Partners Ltd. Project No. 61700. Winnipeg, MB.

UK Environment Agency. 1998. Aquatic eutrophication in England and Wales: A proposed management strategy. UK Environment Agency, Bristol, U.K. www.environment-agency.gov.uk/ourservices/consultations/aquatic. 36 pp.

Upper Assiniboine River Basin Study Committee. 2000. Upper Assiniboine River basin study: Main Report. Published by Environment Canada, Manitoba Conservation, and Sask Water. Regina, SK and Winnipeg, MB. 125 pp.

USEPA. 1998. National strategy for the development of regional nutrient criteria. EPA 822-R-98-002. Office of Water, United States Environmental Protection Agency. Washington, D.C. www.epa.gov/ostwater/standards/nutrient. 47 pp.

USEPA. 1999. Nutrient criteria technical guidance manual: Rivers and streams. EPA-822-D-99-003. Office of Water, United States Environmental Protection Agency. Washington, DC. www.epa.gov/ostwater/standards/nutrient. 122 pp. plus Appendices.

Vecchia, A. V. 2000. Water-quality trend analysis and sampling design for the Souris River, Saskatchewan, North Dakota, and Manitoba. Water-Resources Investigations Report 00-4019. U.S. Geological Survey. Bismark, ND. 77 pp.

Water Resource Branch. 1979. Turtle River Watershed Conservation District scheme. Prepared for the Turtle River Watershed Conservation Board. Water Resources Branch, Department of Mines, Natural Resources, and Environment. Winnipeg, MB. 57 pp. (plus maps)

Water Survey of Canada. 1975. Streamflow forecasting: Qu' Appelle River to Saskatchewan Manitoba boundary. A technical report prepared by the Water Survey of Canada, Canada Department of Environment, for the Prairie Provinces Water Board Committee on Hydrology. Regina, SK. 57 pp. (plus Appendices).

Weir, T. R. 1983. Atlas of Manitoba. Surveys and Mappings Branch, Manitoba Department of Natural Resources. Winnipeg, MB.

Williamson. D. A. 1984. A preliminary investigation into the presence of agricultural pesticides in the La Salle and Assiniboine Rivers, Manitoba, Canada. Water Standards and Studies Section, Manitoba Department of Environment and Workplace Safety and Health. Report No. 84-5. Winnipeg, MB. 37 pp.

Williamson, D. A. 1988. Rationale document supporting revisions to Manitoba surface water quality objectives. Water Standards and Studies Section, Manitoba Department of Environment and Workplace Safety and Health. Report No. 88-5. Winnipeg, MB. 50 pp. plus appendices.

Williamson, D. A., M. P. Boychuk, and M. T. Ledoux. 1992. Water quality assessment of the Turtle River and two tributaries, Manitoba, Canada. Manitoba Environment and the Turtle River Watershed Conservation District. Water Quality Management Section, Manitoba Environment. Report 92-5. Winnipeg, MB. 52 pp.

Williamson, D. A. and W. E. Ralley. 1993. A summary of water chemistry changes following hydroelectric development in northern Manitoba, Canada. Water Quality Management Section, Manitoba Environment. Report 93-2 68 pp.

Winnipeg Hydro. 1998. Winnipeg Hydro information brochure. Available on the internet at www.city.winnipeg.mb.ca/interhom/govern/hydro/

Wood, J. A. 1999. Water quality in the prairie ecozone. Ecological Research Division, Environmental Conservation Branch, Prairie and Northern Region, Environment Canada. Regina, SK, Canada. www.mb.ec.gc.ca/english/water/wqprairie.

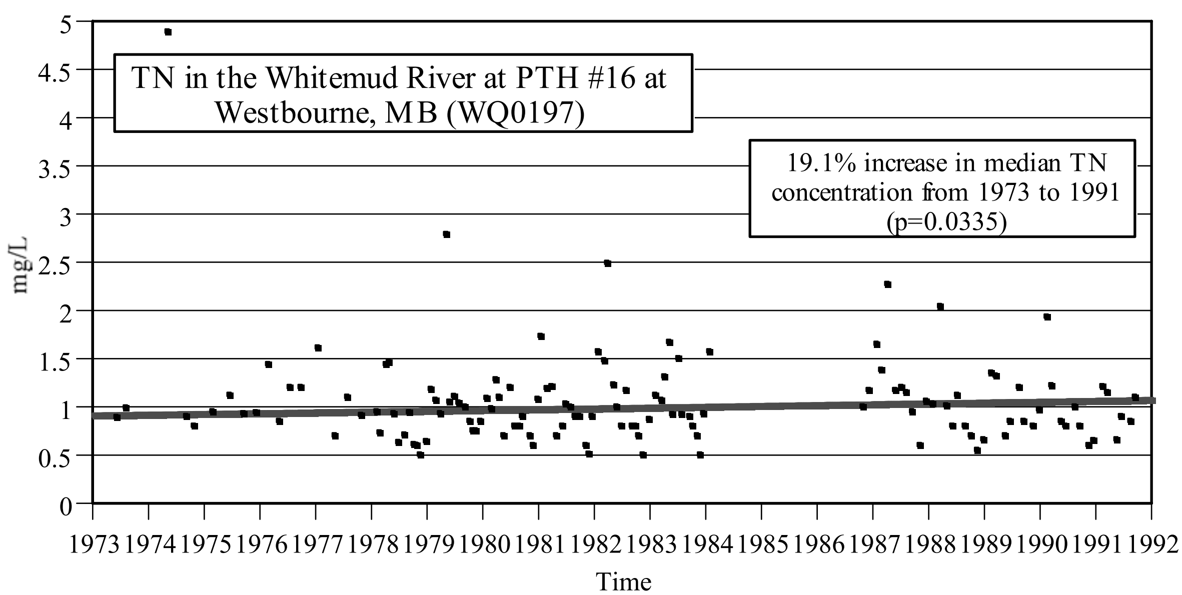
Wristen, K. 1999. The national sewage report card (number two): Rating the treatment methods and discharges of 21 Canadian cities. A Sierra Defence Fund Report prepared for the United Fisherman and Allied Workers' Union, Local 24 and Georgia Strait Alliance. Vancouver, BC. 64 pp. www.sierralegal.org/reports/Sewage.pdf.

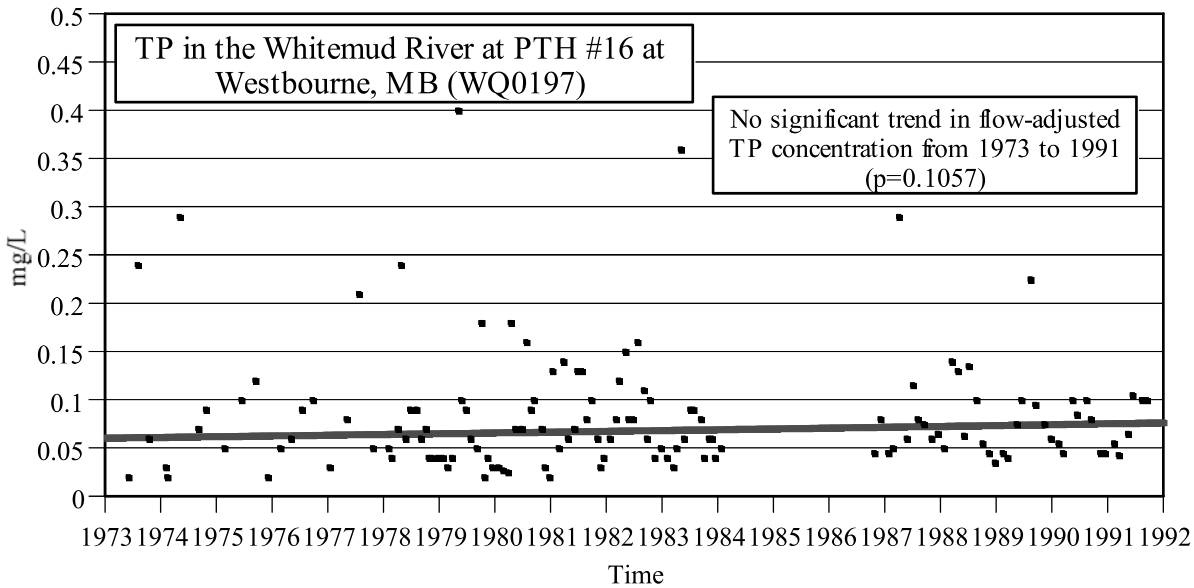
PERSONAL COMMUNICATION

Hughes, C. 2001. Water Quality Management Section, Water Branch, Manitoba Conservation. Winnipeg, MB.

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

APPENDIX 1




TP in the Whitemud River at PTH #16 at Westbourne, MB (WQ0197)
No significant trend in flow-adjusted TP concentration from 1973 to 1991 (p=0.1057)
mg/L
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992
Time