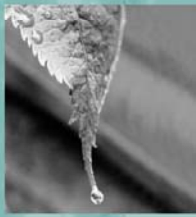
water for life



knowledge and research

Lac St. Cyr Water Quality Assessment

North Saskatchewan Watershed Alliance, Alberta Environment and Sustainable Resource Development
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March 2013

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North Saskatchewan Watershed Alliance

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The North Saskatchewan Watershed Alliance (NSWA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. The organization is guided by a Board of Directors composed of member organizations from within the watershed. It is the designated Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River under the Government of Alberta's *Water for Life Strategy*.

This report was prepared by Melissa Logan, P. Biol., David Trew, P. Biol., and Dr. L. Gammie of the North Saskatchewan Watershed Alliance. Hydrologic analysis were provided by Sal Figliuzzi and Associates Ltd.

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Executive Summary

This report has been prepared by NSWA under contract for Alberta Environment and Sustainable Resource Development. The document contains a review of historic water quality monitoring and related studies at Lac St. Cyr, plus an update on the current hydrology and water quality of the lake.

Lac St. Cyr is located 16 km southeast of the Town of St. Paul and is part of the Frog sub-watershed, a hydrological component of the larger North Saskatchewan River (NSR) watershed. The lake has a relatively deep northern basin (>20 m), shallower east and west basins, and does not have an active surface outlet. The lake has a surface area of 2.2 km^2, a gross drainage area of 26.74 km^2 and an effective drainage area of 15.6 km^2. Land cover in the watershed is a mixture of forest, cropland and pastureland, with limited recreational development.

The Town of St. Paul has withdrawn its raw drinking water supply from Lac St. Cyr since 1951. Lake levels declined by approximately two metres between 1959 and 1971 due to mid-century population growth and increased water demand from the municipality. After reviewing the issue, Alberta Environment and Sustainable Resource Development committed to providing the Town with a reliable source of drinking water, and to enhance the recreational and aesthetic characteristics of the lake. It was decided to divert raw water from the North Saskatchewan River into the lake over the winter months; this diversion began in 1978 and continues to present.

This report presents a new, long-term water balance analysis for Lac St. Cyr for the period 1979-2009. During that period, Lac St. Cyr received an overwinter average diversion of 1,221,512 m^3 from the North Saskatchewan River, and an average of 936,835 m^3 of lake water was removed annually for the Town's drinking water supply. The new water balance was developed on the basis of the "effective" drainage area, as opposed to the "gross" drainage area that was reported in all previous studies. The diversion has effectively doubled the natural water supply to the lake since 1978, and the municipal withdrawal effectively provides a hydraulic flushing of the lake that did not occur prior to 1951.

River water quality was initially a concern with respect to the diversion because the river had much higher nutrient levels than the lake during the 1970s and early 1980s. The high nutrient levels in the NSR were due to ongoing discharges from Edmonton-area wastewater treatment plants. Significant upgrades to both the Gold Bar Plant and the newer Capital Region Wastewater Commission Plant were implemented in 1998 and 2005 respectively (biological nutrient removal and UV disinfection) and these changes led to dramatic improvements in effluent quality, and consequently to river water quality. An upstream industrial lagoon leakage during the winter of 1983-84 resulted in measurable effects on the lake in 1984 and 1985.

The water quality data records available for both the lake and the diversion were discontinuous. Detailed sampling was conducted between 1978 and 2000, and then terminated. Sampling was re-instated in 2012. Statistical interpretation of effects was constrained by these data gaps. Nevertheless, the descriptive data analysis did reveal several interesting water quality trends for the diversion and the lake.

In general, the NSR diversion has had a long-term effect on the water quality of the lake. Significant changes can be seen in the major ion concentrations (increases in sodium, chloride and sulphate; decreases in potassium and bicarbonate). Initially, nutrient levels in the lake increased to a eutrophic level due to the river diversion, but over time the levels have declined due to improvements in river water quality. The lake has returned to a mesotrophic level of productivity.

Trace organics and metal concentrations did not appear to be a concern within the lake; however the data record ended in 2000. New research on the NSR between 2004 and 2009 has revealed that pharmaceuticals and personal care product residues are now detectable in the river, and are presumably also present in the lake. The long-term effects of these compounds is unknown at this point, but their presence is worthy of further investigation.

A lake water quality model (BATHTUB) was calibrated for Lac St. Cyr by students at King's College University as a research project during winter semester 2013. The model is now available to support future management discussions regarding increased diversions from the NSR and any land management changes for the watershed. The updated hydrological analysis and nutrient modeling work indicate that the diversion provides the majority of nutrient supply to the lake in average years.

Lac St. Cyr has taken on the chemical and hydrological characteristics of an off-stream reservoir, as the water quality is nearly equivalent to that of the river and the system has a higher hydrological flushing rate than most central Alberta lakes. Long-term management of river water quality and prudent land use management of the watershed are strongly recommended to ensure the safety of the drinking water supply for the Town of St. Paul and other municipalities. Enhanced monitoring of lake levels, biological communities, river and lake water quality are necessary to assess drinking source water protection and the ecological integrity of the lake.

Acknowledgements

The NSWA gratefully acknowledges the contribution of the following persons towards the completion of this report: Sal Figliuzzi, P.Eng., for completion of an updated water balance for the lake; Candace Vanin of the Science & Technology Branch, Agriculture and Agri-Food Canada for source data, analysis and map outputs; Jacinda Johnston, Alyssa Wesselson and Chelsea Dyck, along with their supervisor Dr. John Wood of King's University College, for the development of a lake water quality model (BATHTUB) for Lac St. Cyr; Darcy MacDonald and Joe Prusak of Alberta Environment and Sustainable Resource Development for background information on the lake and water diversion; Ed Hoyes for hydrology review; Gordon Thompson for report review and provision of wastewater treatment information. Long-term lake and river data were provided by AESRD. ALMS LakeWatch provided the 2012 lake data.

1.0 Introduction

Purpose of Report

The North Saskatchewan Watershed Alliance was contracted by Alberta Environment and Sustainable Resource Development in 2012 to summarize and evaluate all available water quality information for Lac St. Cyr, and to determine what impact, if any, the annual water diversions from the North Saskatchewan River (NSR) have had on the lake. Diversions from the river began in 1978, and occur annually between November and March. This report presents water quality data for both the pre- and post-diversion periods, but primarily the latter.

Long Term River Network (LTRN) data for the North Saskatchewan River at Pakan, as analyzed and summarized by Anderson (2012), are also presented. A brief comparison is made between the river water sampled at the site of the diversion (the NSR pumphouse), and the river water at the Pakan LTRN station, which is approximately 100 km upstream of the pumphouse. In addition, summaries of land use, land cover, and other readily available environmental information about the watershed and lake have been provided.

The water quality assessment of Lac St. Cyr is important from the viewpoint of addressing both drinking source water protection and the health of the lake ecosystem. Both of these considerations represent localized goals of the North Saskatchewan Watershed Alliance's larger basin planning initiative, the *Integrated Watershed Management Plan for the North Saskatchewan River Watershed in Alberta*.

Background and History of Diversion

The Town of St. Paul has withdrawn its raw drinking water from Lac St. Cyr since 1951. The lake is located approximately 16 km southeast of the Town. Lake levels declined by approximately two metres between 1959 and 1971 due to mid-century population growth in the town and increased water demand. Alberta Environment completed a hydrologic assessment of the lake in 1972, which projected that the annual water demand would increase to 1728 acre-feet (approximately 2,131,457 m^3) by the year 2000. Water use at that time was licensed at 300 acre-feet (370,045 m^3), but actual withdrawals were in excess of 600 acre-feet (740,089 m^3). As a result of this lake level problem, Alberta Environment committed to providing the Town with a reliable source of drinking water, and to enhance the recreational and aesthetic characteristics of the lake (Alberta Environment, 1972).

In a follow-up report in 1974, Alberta Environment examined alternate sources of water for the Town, including Atimoswe Creek and other lakes in the area. The surrounding lakes were assessed as being too high in phenols and nutrients, and were prone to algal blooms; Atimoswe Creek was found to be insufficient as a long-term water source. The report therefore recommended a diversion from the North Saskatchewan River, avoiding pumping during the spring runoff and summer periods. The river was deemed to have an "unlimited supply" of water and therefore future increases in demand would not be a problem. Concern was expressed over the quality of the river water, which was at that time poorer than the water quality in Lac St. Cyr, and further studies were recommended (Alberta Environment, 1974).

A subsequent study, completed in 1974 by Associated Engineering Services Ltd., explored alternative water sources but recommended that supplementation of the lake from the North Saskatchewan River would be the best course of action. As a result, a pumphouse was built on the NSR in 1977-78 mid-way between the Myrnam Bridge (Highway 881) and the Elk Point Bridge (Highway 41), with a pipeline extending from that point into the east bay of Lac St. Cyr.

A number of water quality studies were conducted on Lac St. Cyr as a result of the proposal and final decision to build the pipeline from the NSR. The first study provided a preliminary examination of how a diversion could potentially impact the water quality in the lake (Reynoldson, 1976). A single trip was made to the lake, and the three bays of the lake were sampled at 1 metre, 5 metre, and 10 metre depths for water chemistry; drag samples were taken for plankton; grab samples were taken for benthos; littoral sampling was completed and shoreline vegetation was coarsely mapped. At that time, the North Saskatchewan River had higher values for hardness, conductivity and chloride, as well as phosphate and nitrate. The author(s) tentatively concluded that the addition of river water after fall overturn would likely have little impact, but that addition of river water during the summer months “could have a disastrous effect”, possibly pushing the lake into blue green algae bloom conditions.

Prior to the initial diversion in 1978, Alberta Environment staff completed a more detailed water quality study of Lac St. Cyr to assess potential effects (Reynoldson, 1977). The study evaluated parameters in the river that were of concern with respect to drinking water supplies, and those which could negatively impact Lac St. Cyr. The study also attempted to document the trophic status of the lake, establish nutrient loadings from the surrounding landscape and predict nutrient loadings via the diversion. Plankton species were identified and a nutrient budget was calculated. The study concluded that the lake was at a mesotrophic level, and received the majority of its nutrient loading in runoff from the surrounding watershed. It was estimated that the lake received high loadings of 13.3 $gm/m^2/yr$ of nitrogen, and 1.67 $gm/m^2/yr$ of phosphorus from the watershed (based on the gross drainage area). It was speculated that diversion from the river would increase the annual phosphorus loading to the lake, but that the extra contribution would not be significant when compared to the existing abundant supply. It was recommended that diversion take place in late summer through early winter, and that continual monitoring take place in order to detect any changes that might occur in the river water quality. The study warned that its conclusions were based on a single year of data only, which might not be representative of average lake conditions, and that the diversion should be approached with caution.

The “Lac St. Cyr Lake Stabilization Study” was also completed by Alberta Environment in 1978. For the first year of the diversion, pumping was to be restricted to the months of October to December. It was hoped that restricting the pumping period would allow the Department to assess the impact of the diversion on the hydrology and ecology of the lake. A long-term coordinated monitoring program was deemed to be necessary, and was to be established by Alberta Environment.

A taste and odour study was conducted on Lac St. Cyr by Alberta Environment in 1985 (AENV unpublished). The report was spurred by concerns from the residents of the Town of St. Paul regarding the taste of their drinking water, which they felt had declined in quality and become “muddy”. Samples of water were taken from the lake, the reservoir and the town’s drinking water and sent to a lab in Ontario to be analyzed for microbial byproduct compounds that are commonly implicated in affecting drinking water flavour (geosmin and 2-methylisoborneol (MIB)). The study also collected submergent and emergent macrophytes in order to identify the epiphytic and filamentous algal communities. Benthic algae samples were collected using a bottom mud sampler. The study found evidence of *Oscillatoria tenuis* and *Oscillatoria agardhii*, which are types of blue green algae that are often associated with geosmin and MIB. The dominant macrophyte species in the lake was *Chara spp.*, which often has a skunky odour to it. The lab results from the water samples indicated the presence of geosmin and MIB in both lake and drinking water reservoir samples. Only geosmin was found in the town's drinking water samples. It was concluded that the taste and odour problems were as a result of nuisance algal growth within the lake and reservoir (Richey and Klemka, 1985).

Another study to assess the effects of the NSR diversion on lake water quality up to 1986 was completed by Mitchell (1987). The study found that the yearly loads of phosphorus and nitrogen had increased by 25% since the diversion began; however post-diversion chlorophyll levels in 1986 were not significantly different from pre-diversion levels. A high nutrient loading episode occurred in winter 1983-84, resulting from leaking lagoons at an upstream fertilizer plant in Fort Saskatchewan. The event probably stimulated the algal growth patterns seen in 1984 and 1985 and may have triggered the taste and odour complaints and investigation described above.

The report also noted that phosphorus in the hypolimnion of the north basin of the lake had increased five-fold, suggesting that the bottom sediments and waters had become a sink for phosphorus. The study also noted a shift in the major ions of the lake, particularly sulphate. This was noted as a concern, because sulphate can bind with iron in lakes, potentially releasing phosphorus from the bottom sediments; this process may have contributed to the increased phosphorus concentrations observed in the hypolimnion (Mitchell, 1987). Water transparency had improved, and winter oxygen depletion had not increased in 1986. It was speculated that the bottom sediments had become the "sinks" for the excess phosphorus from the diversion. The report speculated that the lake might shift to a higher trophic level if the diversion continued.

2.0 Watershed and Lake Ecosystem Characteristics

General Description

Lac St. Cyr is located in the Boreal Forest – Dry Mixedwood natural subregion of Alberta (Figure 1) and is part of the Frog subwatershed, a hydrological component of the larger North Saskatchewan River watershed (Figure 2). The Frog subwatershed encompasses 562,622 hectares, including 41,229 hectares of natural and artificial water bodies (NSWA, 2005). There are two Provincial Grazing Reserves in the Frog subwatershed: the St. Paul Grazing Reserve and the Rannach Grazing Reserve, both located along the banks of the North Saskatchewan River (Figure 3) upstream of the diversion point. Lac St. Cyr is located in the County of St. Paul, about 16 km southeast of the Town of St. Paul (Figure 4).

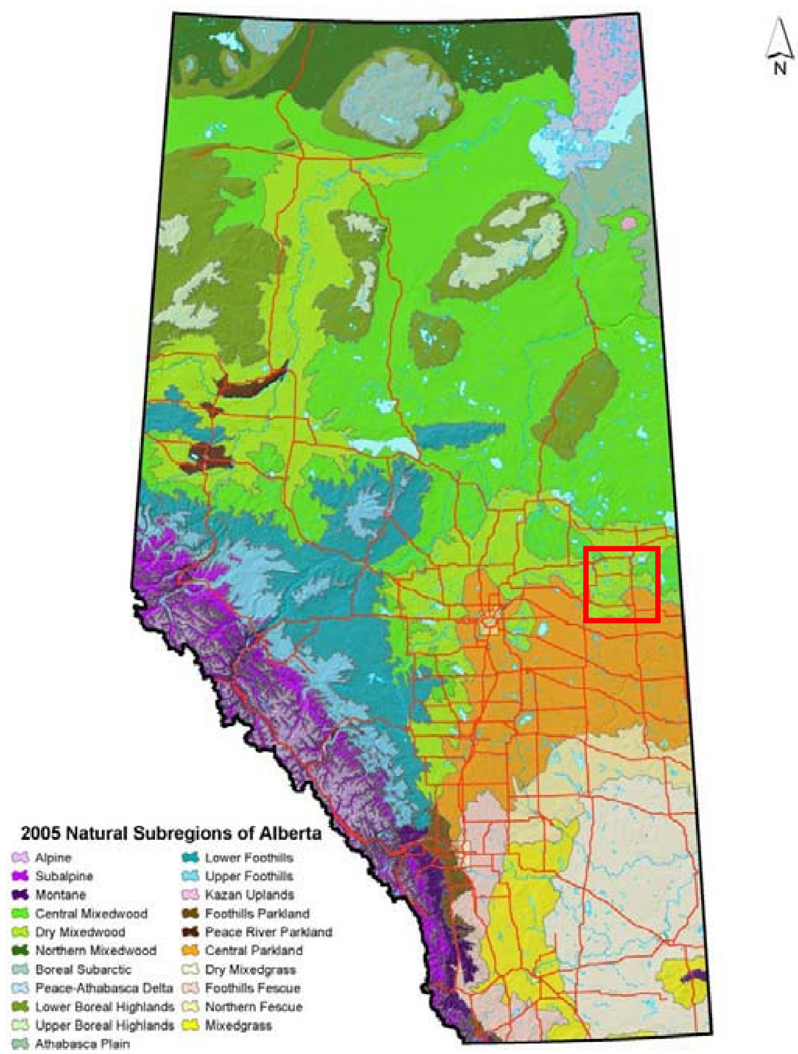


Figure 1. Natural Subregions of Alberta. The red box indicates approximate location of Lac St. Cyr, in the Dry Mixedwood subregion (Natural Subregions Committee, 2006).

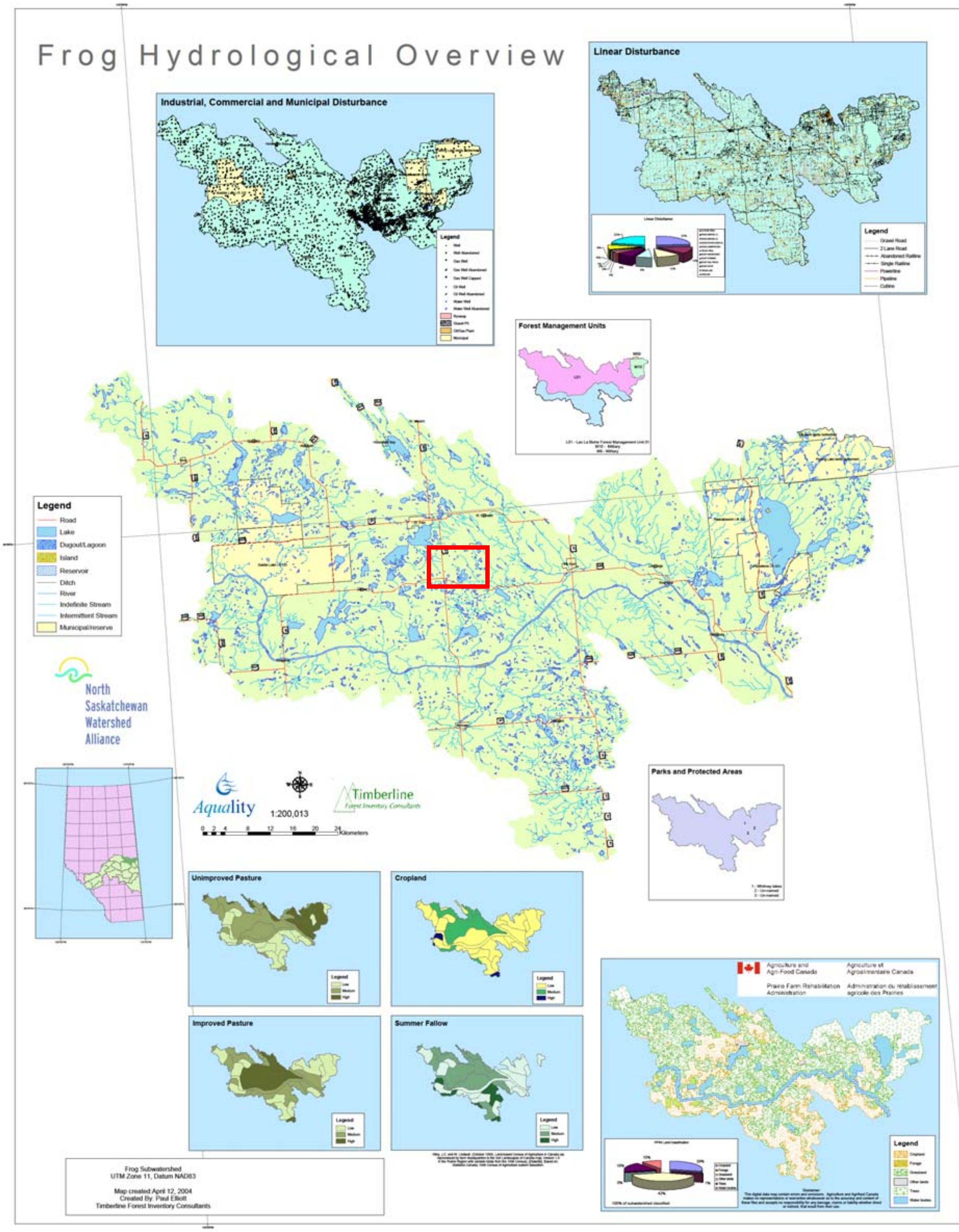


Figure 2. Overview of the Frog subwatershed (NSWA, 2005). The location of Lac St. Cyr is indicated by the red square.

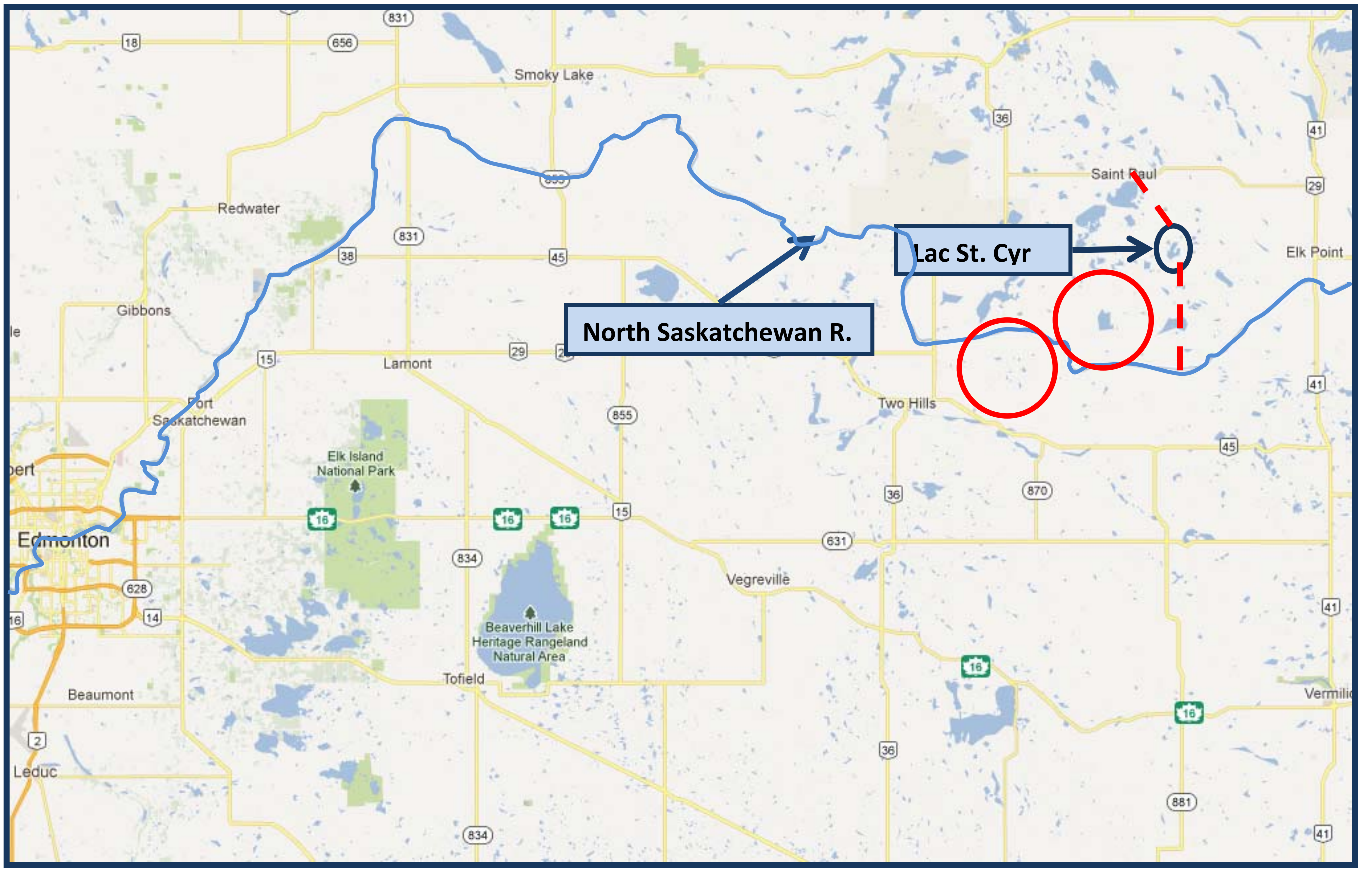


Figure 3. Map of Lac St. Cyr (Figliuzzi, 2013). The dashed red line in the south approximates the pipeline running from the river (between Highway 881 and Highway 41) to the lake, while the dashed red line in the north approximates the pipeline from the lake to the town. The red circles indicate the locations of the St. Paul Grazing Reserve (right) and the Rannach Grazing Reserve (left).

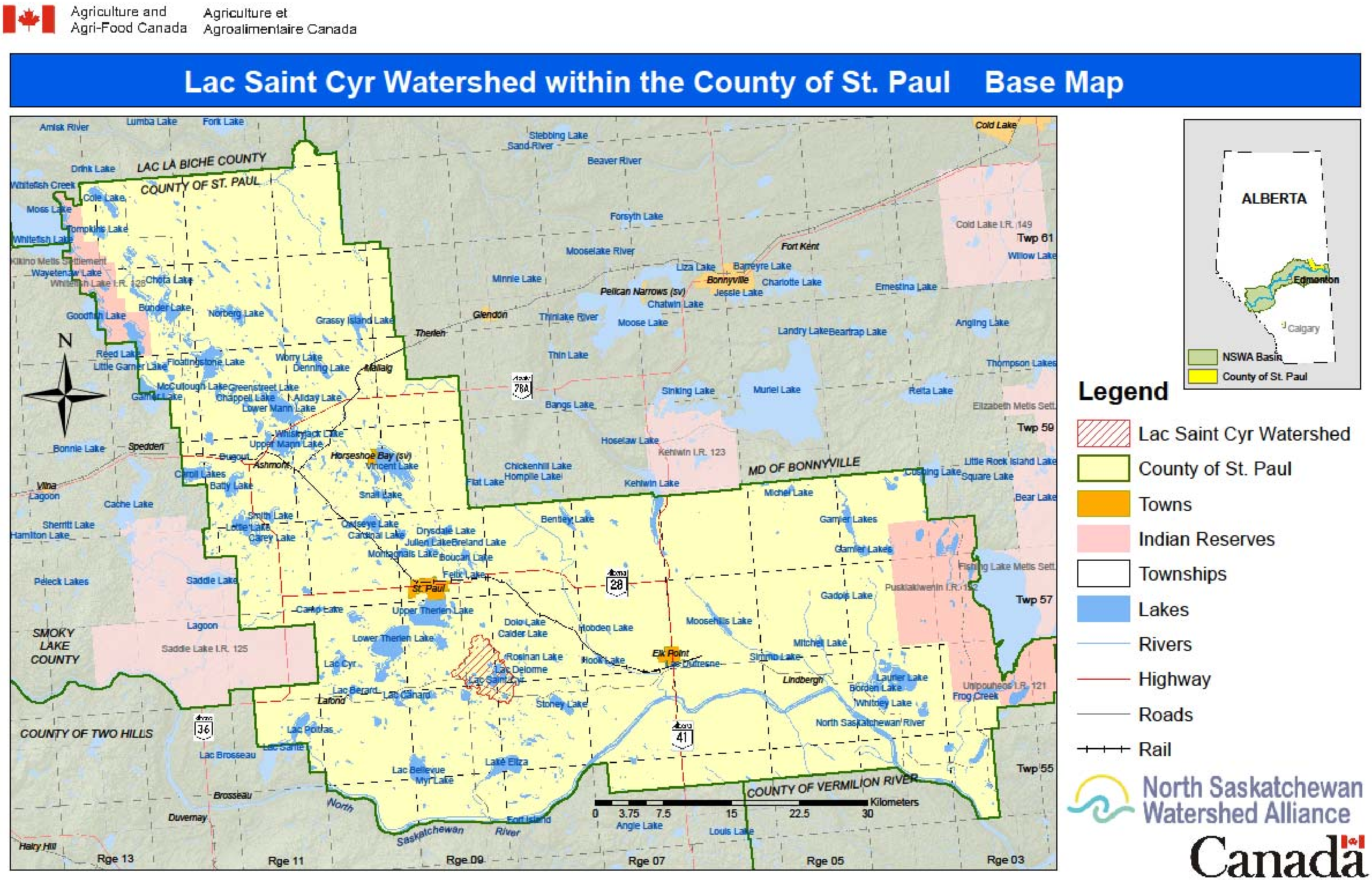


Figure 4. Map of the County of St. Paul (AAFC, 2013). The Lac St. Cyr watershed is located within the red hash marked area.

Figure 5. Land ownership around Lac St. Cyr (County of St. Paul, 2011)

Much of the land on the northern shoreline of the lake is owned by the Crown or the Town of St. Paul, while the remainder is owned privately (Figure 5).

There are no major natural surface inflows to the lake, and the historic outlet, at an elevation of 647.7 metres above sea level, has not flowed for "many years" (Atlas of Alberta Lakes, 1991). At one time, the outlet drained toward Stony Lake (also known as Siler Lake) and then to the North Saskatchewan River.

The terrain around the lake is gently to strongly rolling (6 to 30% slope) (Atlas of Alberta Lakes, 1991). The dominant soils in the watershed are loams, sandy clay loams, silty loams and silty clay loams (Figure 6). The lake has three small basins, with the southern (east and west) basins being far shallower than the deeper north basin (Figure 7).

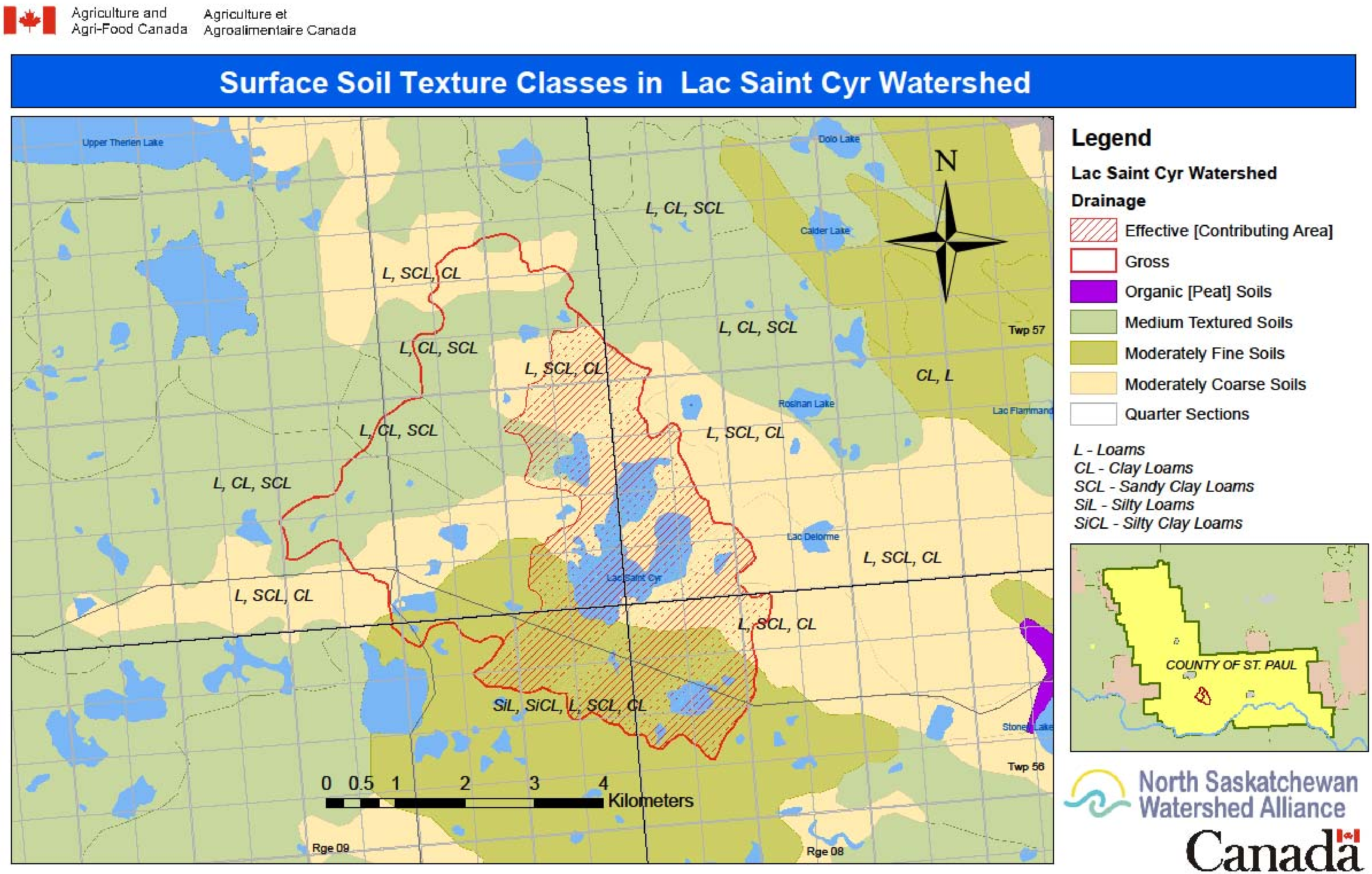


Figure 6. Surface soil texture classes in the Lac St. Cyr watershed (AAFC, 2013).

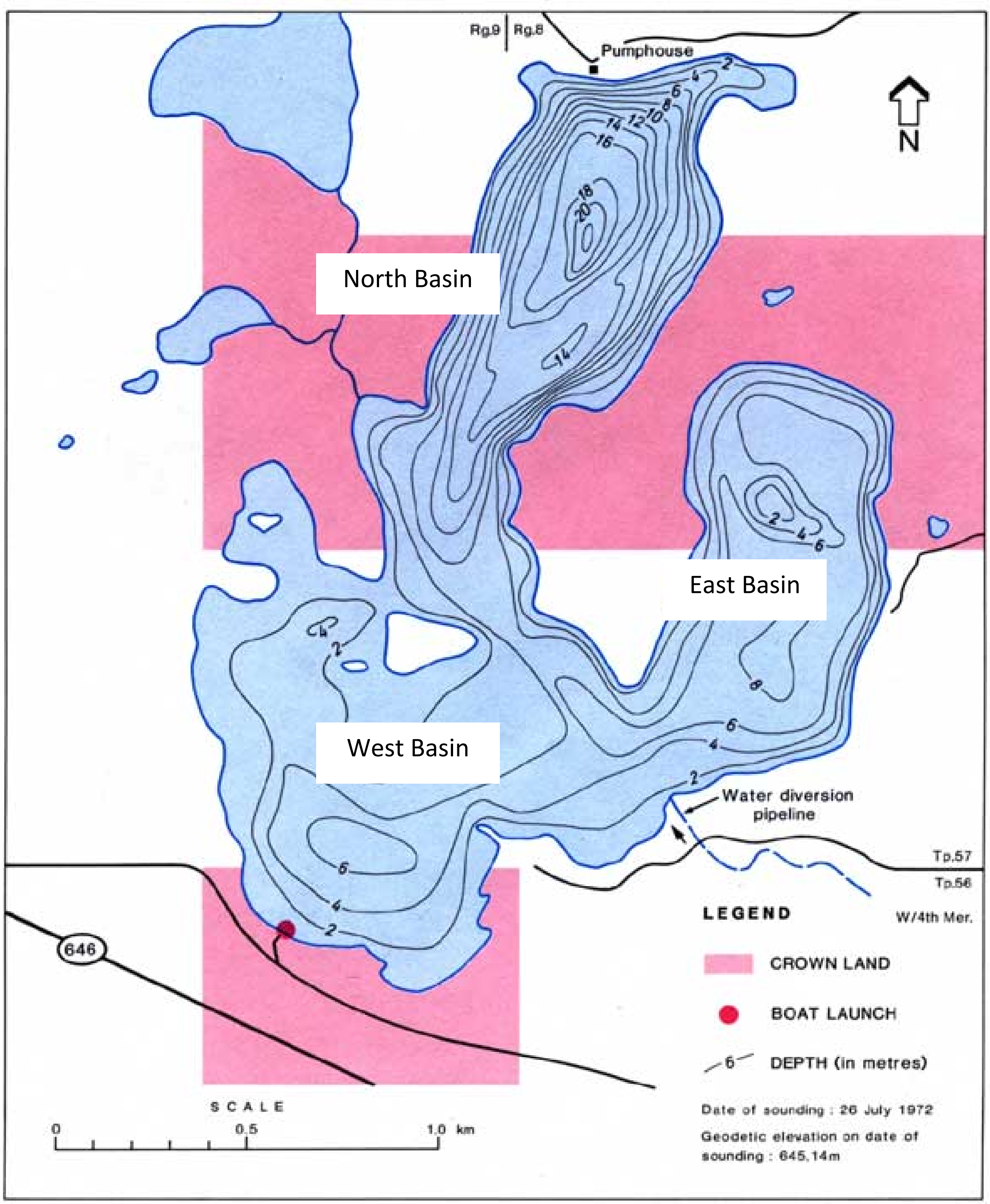


Figure 7. Depth contours of Lac St. Cyr (Atlas of Alberta Lakes, 1991). The north basin, with a maximum depth of 20 metres, is much deeper than the southern (east and west) basins of the lake.

Land Cover

The Dry Mixedwood subregion is characterized by aspen (*Populus tremuloides*) stands with scattered white spruce (*Picea glauca*) interspersed with fens; there are also cultivated areas on suitable soils throughout. Approximately 15% of this subregion is covered by wetlands (NSC, 2006). Wetlands are important features on the landscape, providing water and carbon storage, groundwater recharge, wildlife and waterfowl habitat, and removal of excess nutrients and contaminants from surface runoff (Mitsch and Gosselink, 2000). Wetlands and wetland complexes have been greatly impacted by agricultural activities within Alberta; many wetlands in the central regions of Alberta have been drained for agricultural production (Wray and Bayley, 2006).

The Lac St. Cyr watershed was further sub-divided into “gross” and “effective” drainage areas in the detailed hydrological analysis following in Section 4.0. Land cover in these gross and effective drainage areas includes shrub land, wetlands, grassland, crops and pasture and deciduous and coniferous forests. Land cover is illustrated below in Figures 8 and 9 (AAFC, 2013). The amount of developed recreational land in the watershed (2%) is still quite small compared to other recreational lakes in Alberta.

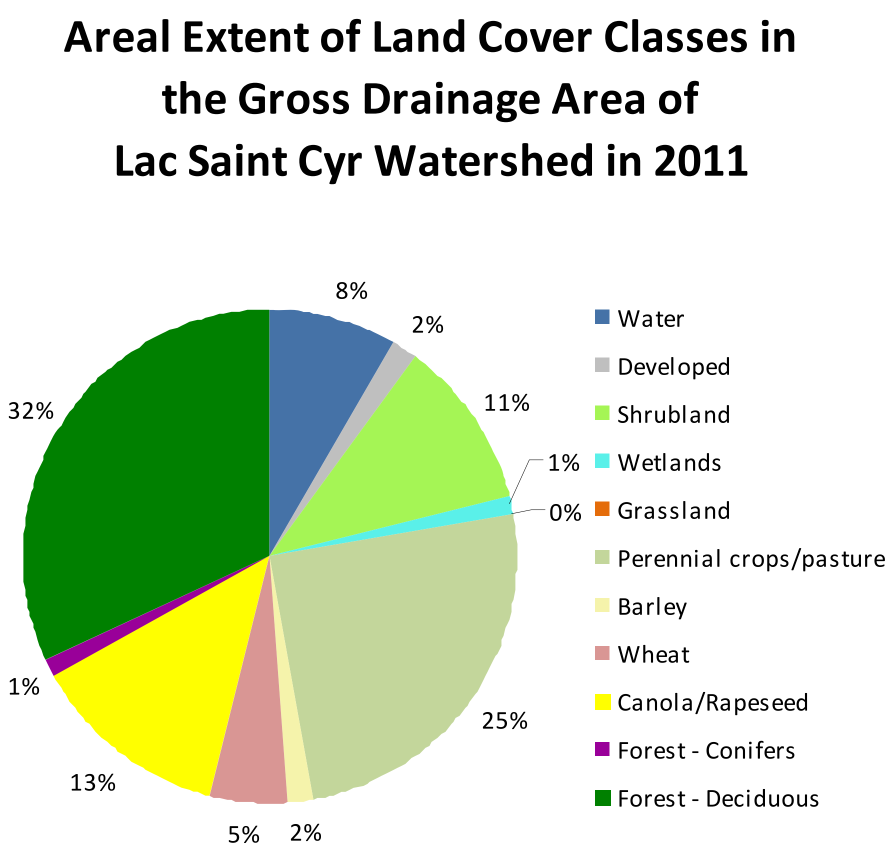


Figure 8. Land cover classes within the gross drainage area of the Lac St. Cyr watershed (AAFC, 2013). A total of 46.4% of the gross drainage area is used for crops, pasture or limited recreational development.

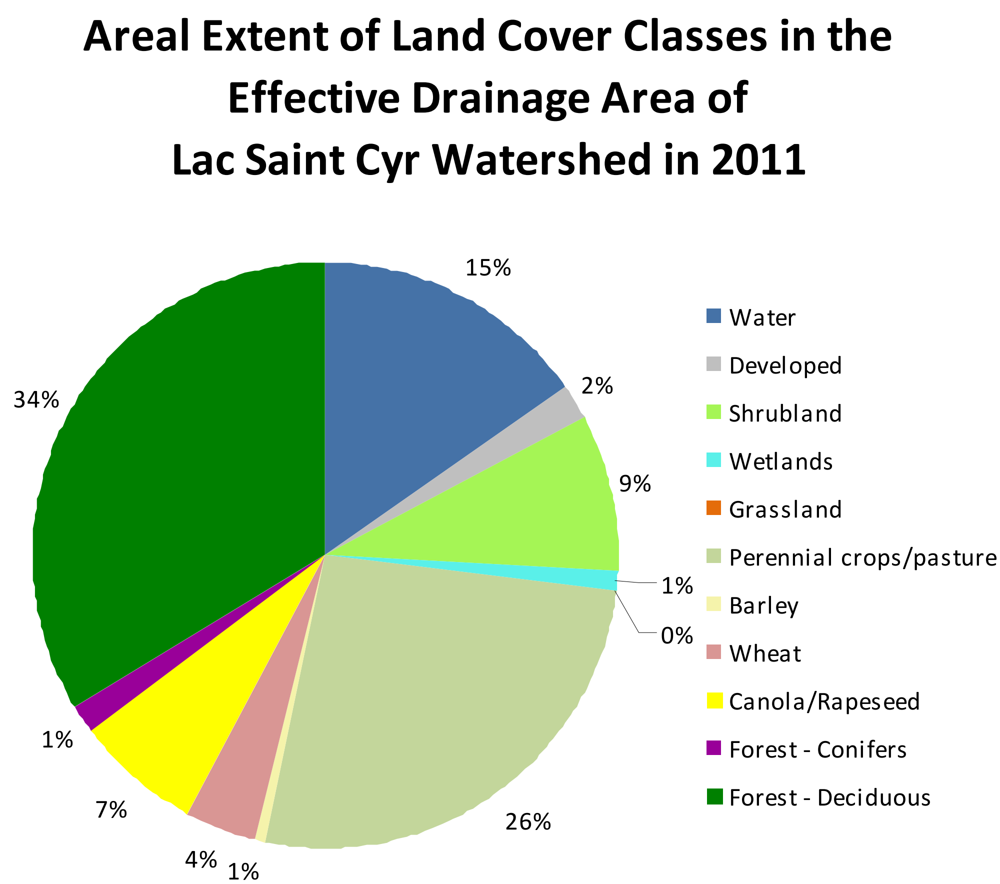


Figure 9. Land cover classes within the effective drainage area of the Lac St. Cyr watershed (AAFC, 2013). A total of 39.6% of the effective drainage area is crops, pasture or limited recreational development.

The distribution of land cover changes over the years 2000 to 2011, within both the gross and effective drainage areas of the watershed, is illustrated in Figure 10. The largest changes can be seen as increases in the shrub land, annual crops and deciduous forest, with decreases in perennial crops.

Land cover classes in the watershed as of 2011 are illustrated in Figure 11. The majority of the deciduous forest is located around the shoreline of the lake, which indicates the lake still has a good quality riparian buffer. Maintenance of this buffer will be important for preserving the water quality and littoral zone habitat in the lake over the long term.

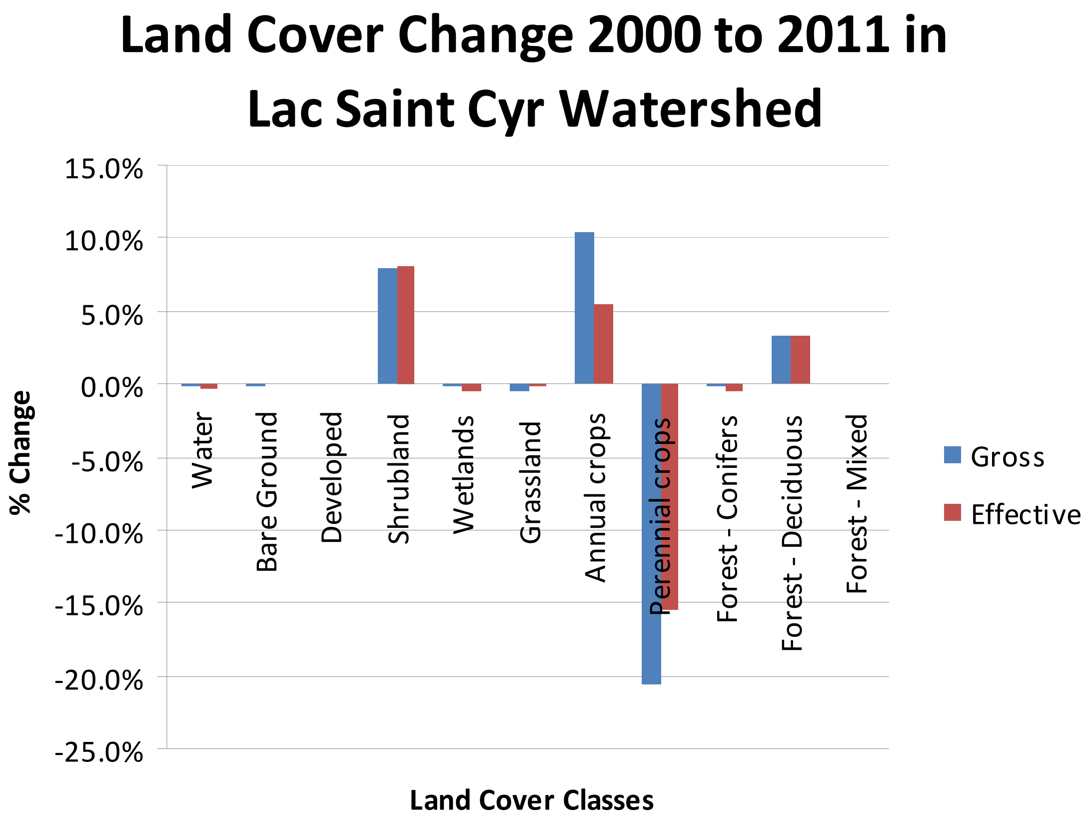


Figure 10. Land cover changes in the gross and effective drainage areas of the Lac St. Cyr watershed 2000-2011 (AAFC, 2013).

On moist, rich sites, balsam poplar (*Populus balsamifera*), aspen and white spruce occur as pure or mixed stands. Understories contain red-osier dogwood (*Cornus stolonifera*), prickly rose (*Rosa acicularis*), and a diverse array of herbaceous species in deciduous and mixedwood stands, or a carpet of feathermosses (*Hypnaceae* spp.) and horsetails (*Equisetum* spp.) in coniferous stands (NSC, 2006).

Emergent macrophytes seen in Lac St. Cyr include greater bulrush (*Schoenoplectus tabernaemontani*), common cattail (*Typha latifolia*), and various grass species (*Carex spp.*). Among the submergent vegetation species in Lac St. Cyr, the most abundant were stonewort (*Chara globularis*), northern watermilfoil (*Myriophyllum exalbescens*) and large-sheath pondweed (*Potamogeton vaginatus*). In addition, various species of *Potamogeton* and *Ranunculus aquatilis* were found (Mitchell, 1987). Aquatic plant surveys in 1978 and 1984 suggested a change in submergent plant populations and an increase in filamentous algal growth. *Potamogeton vaginatus* and *Chara spp*. were found to be more abundant in 1984, while the abundance of *Myriophyllum exalbescens* had decreased. Exact measurements of biomass were not taken.

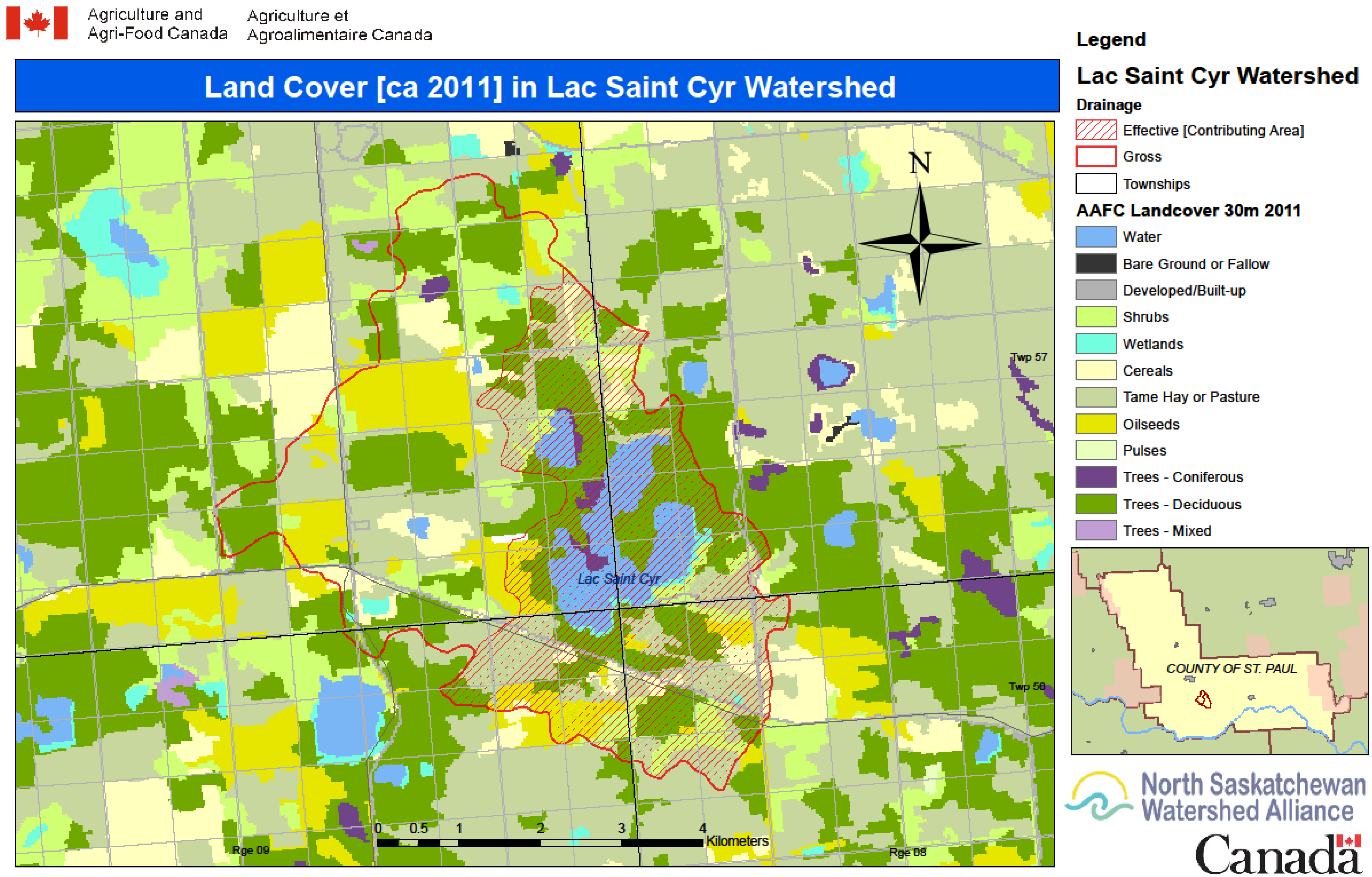


Figure 11. Land cover in the Lac St. Cyr watershed in 2011 (AAFC, 2013).

Land Use

In the County of St. Paul, there are a total of 795,000 agricultural acres of which 445,000 acres are cropped annually (AESRD, 2011b). The remainder is improved and unimproved pasture, and woodlots. There is also a very diverse livestock industry in the area, which ranges from beef and dairy cattle, and hogs, to domesticated elk and bison.

The 1977 Alberta Environment report noted that much of the Lac St. Cyr shoreline was owned by the Town of St. Paul, but was undeveloped, with the remainder being mostly farmland. A smaller part of the shoreline had been subdivided and contained camping sites, a motel resort and a number of cottages. It was recommended that a development plan or use regulations be established for the lake in order to preserve the water quality and assure the value of the lake as a water supply and a recreational destination. Power boat use was to be limited in the west basin of the lake, where potential waterfowl staging areas existed.

Richard (pers. comm., 2013) reports that random RV camping is common on the south shore of the lake, near the public access point, and there are three permanent residences in the developed area. There are approximately 20 other seasonal use lots developed. There is often heavy powerboat use on the lake in the summer months.

Figure 12 indicates that Lac St. Cyr is located in an area of moderate manure production in the province. This can be a concern with respect to water quality, as nutrients and bacteria in manure can wash into surface waters via overland flow during storm events. Unfortunately, there is a lack of coliform and *E. coli* data for the lake, precluding further discussion and assessment on microbial conditions. Manure could also enter the river water from farming and grazing activities immediately upstream of the diversion point, and microbes could consequently be transferred to the lake via the diversion.

There were no data available regarding domestic wastewater management or riparian health studies available for this assessment.

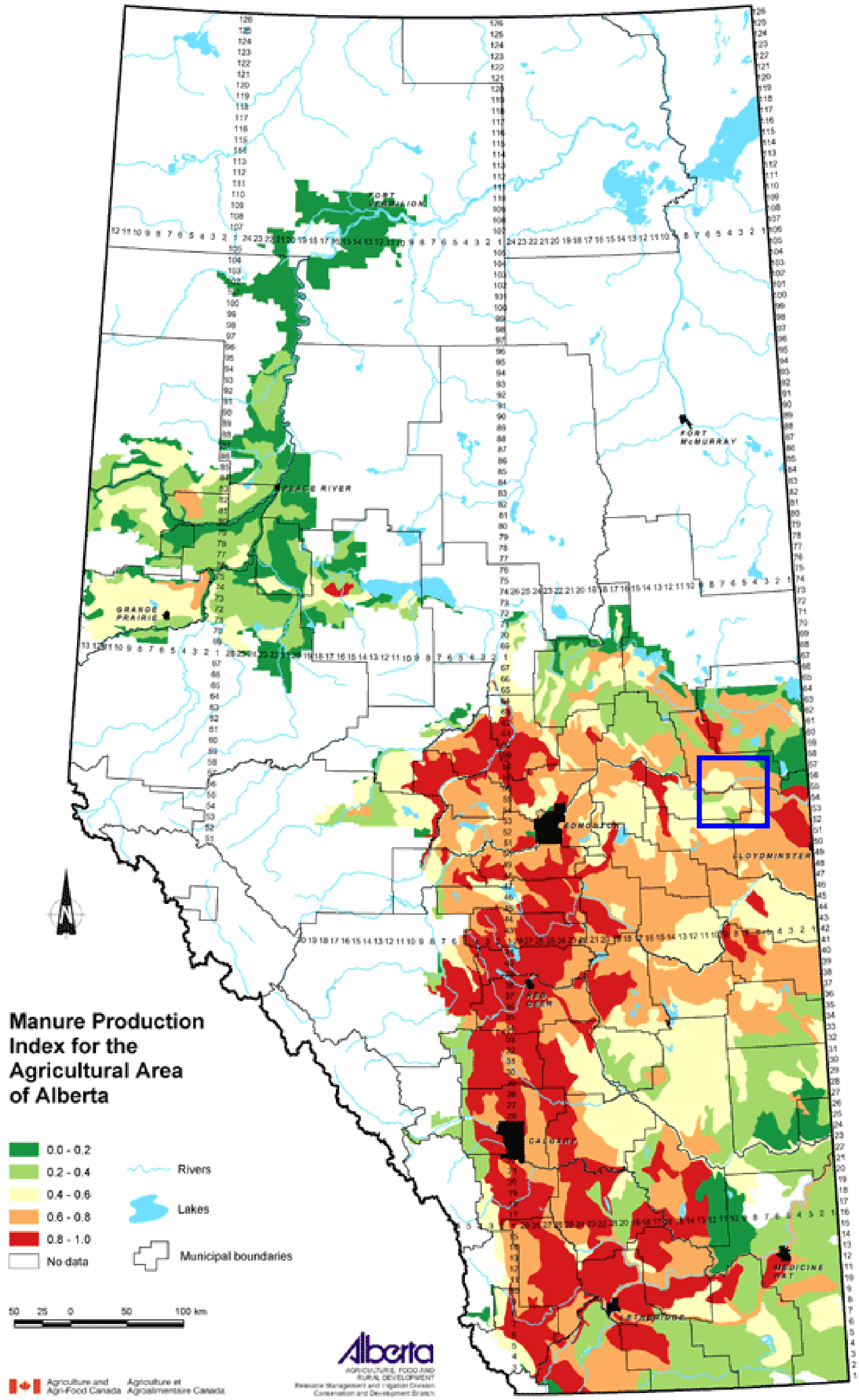


Figure 12. Manure production Index for Alberta. The blue square indicates the approximate location of the Lac St. Cyr watershed (Alberta Agriculture Food and Rural Development, 2006).

Groundwater Resources

There were 5,116 groundwater wells on record in the County of St. Paul at the time of the regional groundwater assessment in 1999 (HCL, 1999). At the end of 1996, there were 84 licenced groundwater diversions, with 81% of the licences being used for agricultural purposes. A map of the water wells in the County is presented below (Figure 13). There are two AESRD monitoring wells in the County, one in the west-central portion, and one in the southern portion. A 0.4 metre drop in groundwater level was noted between 1990 and 1992.

A recent search of the Alberta Environment and Sustainable Resource Development Alberta Water Well Information Database indicates there are approximately 66 water wells in the immediate Lac St. Cyr watershed. The majority of these wells have been drilled for domestic purposes, and some for stock watering (AESRD, 2011a).

Groundwater quality in the area is typically hard, and high in dissolved iron (>1 mg/L) (Hydrogeological Consultants Ltd., 1999). Chloride concentrations are generally low, and the dominant ions are typically sodium and bicarbonate. Lac St. Cyr is underlain by shale deposits with some sandstone present. Coal zones occur, as well as minor amounts of ironstone.

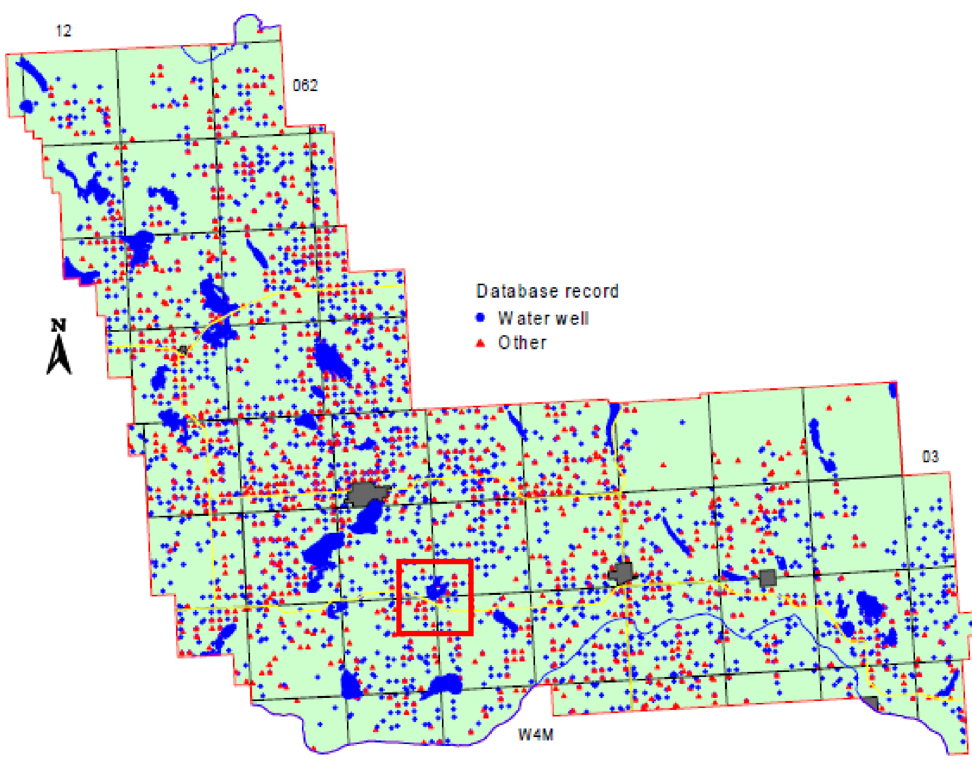


Figure 13. Location of groundwater wells in the County of St. Paul (Hydrogeological Consultants Ltd, 1999). Lac St. Cyr is indicated by the red square.

The groundwaters from the surficial deposits are mainly calcium-magnesium-bicarbonate type waters with total dissolved solids from less than 500 to more than 1,000 mg/L (Hydrogeological Consultants Ltd, 1999). The majority of the groundwaters from the southern part of the County have total dissolved solids of less than 1,000 mg/L (Hydrogeological Consultants Ltd, 1999). All of the groundwater from the surficial deposits is expected to have concentrations of dissolved iron greater than 1 mg/L.

Even though the majority of the groundwaters are of the calcium-magnesium-bicarbonate type, there are groundwaters with sodium as the main cation and there are also groundwaters with significant concentrations of the sulfate ion. The groundwaters with elevated levels of sulfate occur in areas of elevated levels of total dissolved solids (mainly the northern portion of the County). There are very few groundwaters with appreciable concentrations of the chloride ion and in most of the County the chloride ion concentration is less than 100 mg/L (Hydrogeological Consultants Ltd, 1999).

Lac St. Cyr is at moderate to high risk of groundwater contamination (below, Figure 14) and is located in transition and recharge areas, as shown in Figure 15. This indicates that development in the area should be planned with care, so as not to contaminate groundwater supplies.

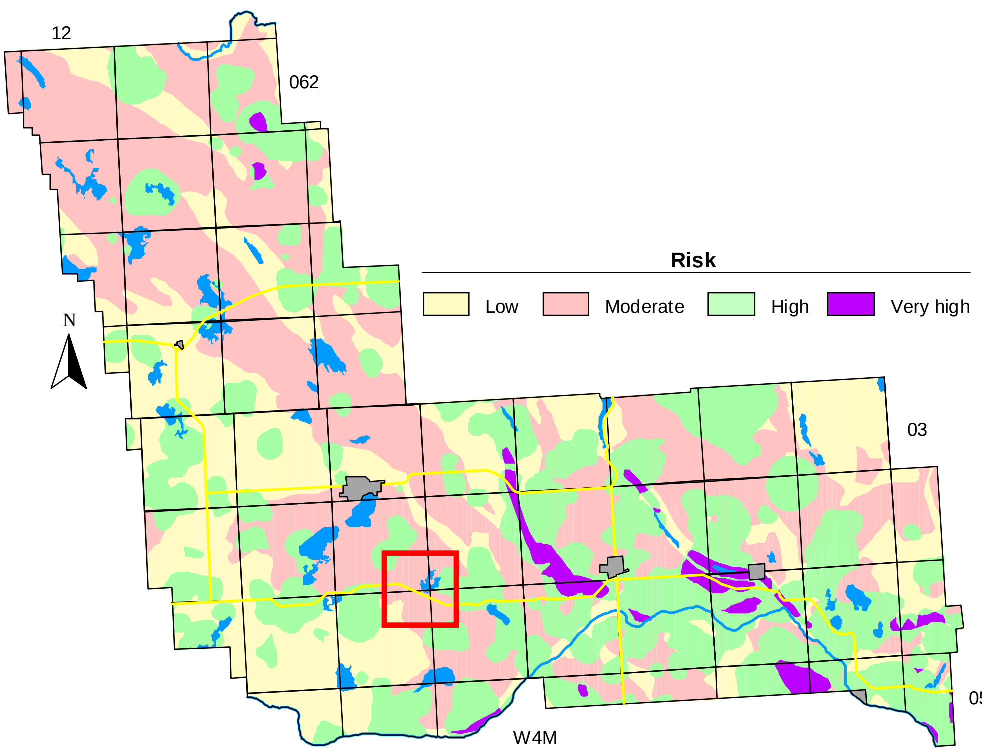


Figure 14. Groundwater contamination risk in the County of St. Paul (Hydrogeological Consultants Ltd, 1999). Lac St. Cyr is indicated by the red square.

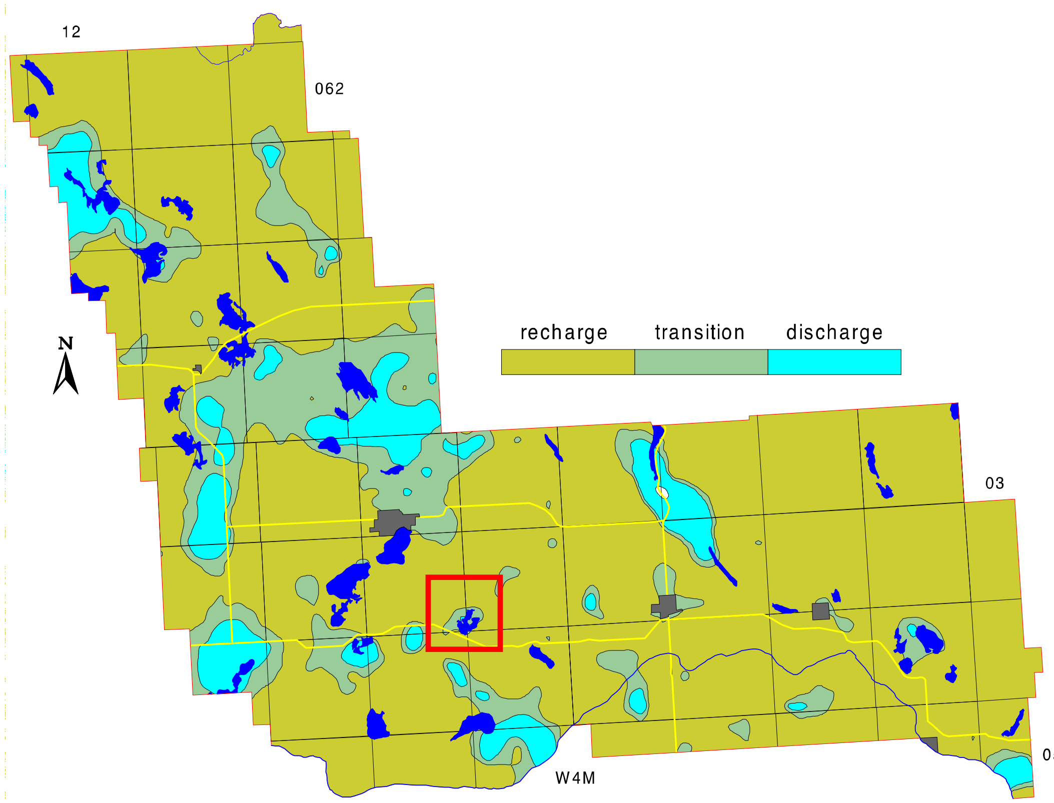


Figure 15. Groundwater recharge, discharge and transition areas in the County of St. Paul. Lac St. Cyr is indicated by the red square (Hydrogeological Consultants Ltd, 1999).

Phytoplankton

Reynoldson (1977) noted that peaks in algal standing crops occurred during late May and middle October, typical of moderately productive and deeper Alberta lakes. Maximum water transparency was seen in May, June and July, and it was speculated that these May and October blooms were actually diatom blooms, associated with spring and fall overturn. The dominant species in a 1974 plankton haul were *Asterionella* spp. and *Fragilaria* spp., which are both diatoms. Other species that were present or rarely present in the lake included: *Uroglenopsis; Anabaena; Oscillatoria; Ceratium; Tribonema; Sirigonium; Chrysocapsa; Pediastrum; Diatomella; Gomphoneis, Surirella* and *Spirulina* (Reynoldson, 1977).

Large peaks in phytoplankton were seen in July 1983, 1984, 1985 and September 1984; these summer peaks were new and dominated by the blue-green algae *Aphanizomenon flos-aquae* and *Anabaena flos-aquae* (Alberta Environment, 1987). The dominance of these species was not noted in 1979 or 1980.

Invertebrates

Benthic invertebrates were collected with an Ekman dredge in 1974 and October 1976 from each basin of the lake (Reynoldson, 1977). Flatworms *(Dugesia tigrina*) were dominant in the shallowest areas near shore; leeches (*Nephelopsis obscura*, *Glossiphonia complanata* and *Helobdella stagnalis*) and caddis fly larvae (*Trichoptera: Leptocella* spp.) were also abundant. In the deepest area of the north basin, the phantom midge larva (*Chaoborinae*: *Chaoborus* spp.) was dominant, but midge larvae (*Chironominae* and *Tanypodinae*) and aquatic earthworms (*Oligochaeta*) were common as well. *Chaoborus* spp. was also very abundant in the deeper water of the other basins. Common zooplankton species include *Rotifera* spp. and *Copepoda* spp. (Reynoldson, 1977).

Fish

Limited fisheries information was available for this assessment. Yellow perch (*Perca flavescens*) and northern pike (*Esox lucius*) are present in the lake, and walleye were stocked as eggs in May 1959. No significant walleye population developed from this stocking (Atlas of Alberta Lakes, 1991). The lake was reported to be used fairly heavily by pleasure boaters and casual anglers (Atlas of Alberta Lakes, 1991; Alberta Environment, 1977). Large yellow perch are the main target for the local sport fishery. The lake is not fished commercially.

Wildlife

In the older AESRD reports, Lac St. Cyr was reported as being “not particularly valuable for wildlife”; waterfowl production is low compared to that on surrounding pothole lakes (Atlas of Alberta Lakes, 1991; Alberta Environment, 1977). No documentation of species nesting on the lake exists. Beaver and muskrat activity had declined due to low water levels and human activity (Alberta Environment, 1977). Alberta Agriculture has identified approximately four to six species at risk in the Lac St. Cyr area (Figure 16).

A. Richard (pers. comm., 2013) provided new anecdotal information, and describes the lake as a “bird sanctuary”. He noted that the lake is host to a number of mammals, songbird and waterfowl species, as well as raptors. Common species seen include common loons, various hawk species, eagles, ospreys, turkey vultures, lesser scaups, terns, red neck grebes, bitterns (rarely), saw whet and great horned owls and Canada geese. Mammalian species include moose, elk, mule and white tail deer, lynx, cougars, black bears, wolves, beavers, mink and muskrat.

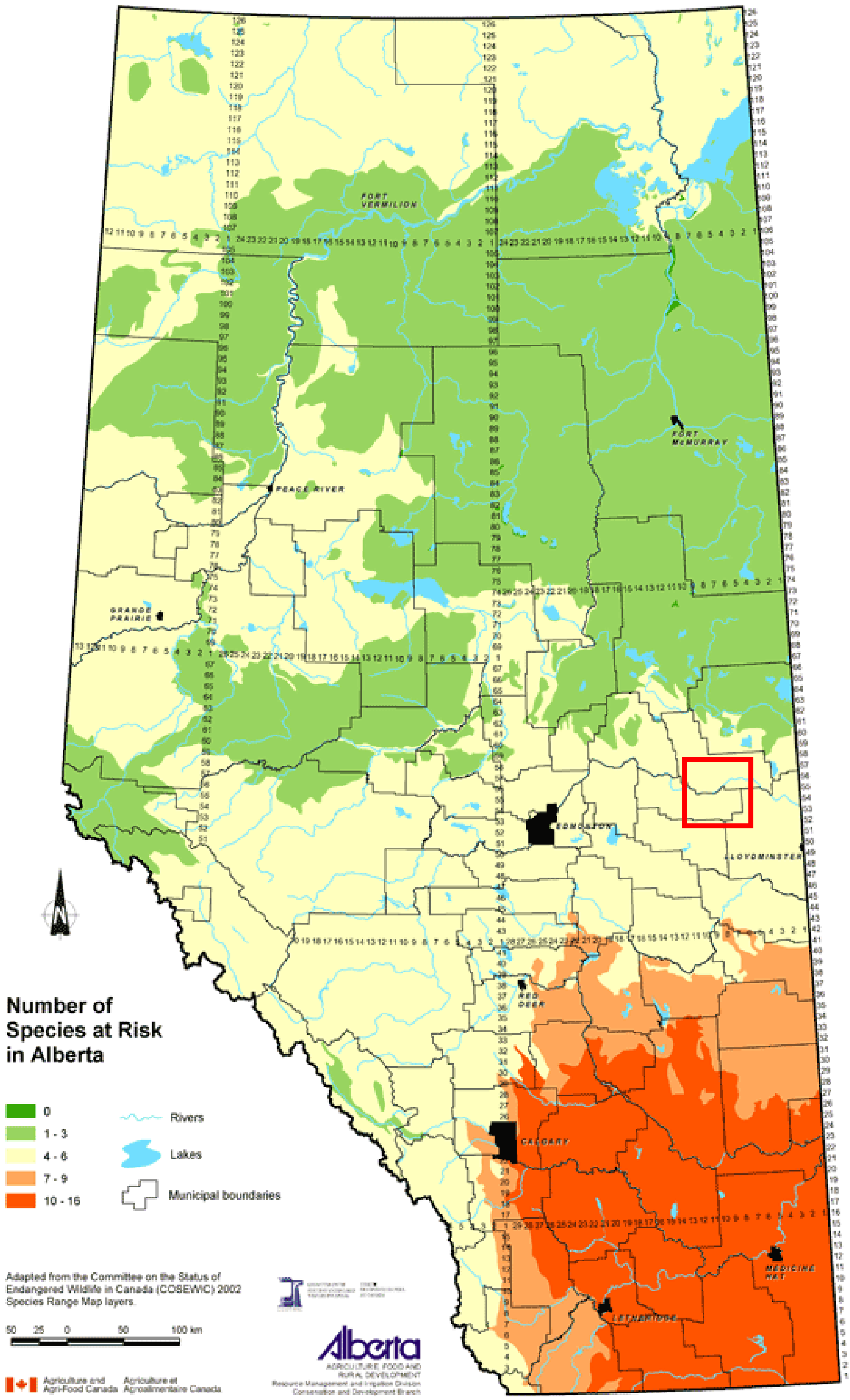


Figure 16. Species at risk in Alberta. The red square indicates the approximate location of the Lac St. Cyr watershed (Alberta Agriculture Food and Rural Development, 2006).

3.0 Hydrology

Water Balance

An updated water balance for Lac St. Cyr was completed by Sal Figliuzzi and Associates (2013). The water balance considered evaporative losses, surface runoff, diversion inputs and withdrawals, groundwater inputs, precipitation, water licences and drainage area. The following is a summary of the findings of the report; the full report is available in Appendix 1.

Computation of Drainage Area

Lac St. Cyr is a small landlocked lake with no active outlet channel. The lake is comprised of two main components; a north and a south basin (combined east and west basins). The north basin has a maximum depth of 22 metres and a capacity of over 7,000,000 m^3 while the south basin has a maximum depth of 10 metres and a capacity of 6,000,000 m^3.

The land area surrounding the lake from which surface runoff drains into the lake is called the drainage area, catchment area or watershed area. Because of the glacial landscape and climate of the Canadian Prairies, the watershed area which contributes to the runoff actually reaching a waterbody can vary significantly from event to event and from year to year, due to local depressions or storage areas. Ideally, a water balance would be carried out for each of these storage and depression areas towards identifying the actual quantity of runoff reaching the water body under consideration for each time step. However, as this level of analysis is not practical or possible in most instances, the concepts of “gross” and “effective” areas have come into common use to account for this variability in the “contributing drainage area”. These terms are defined as follows:

- “Gross” drainage area is the land surface area which can be expected to contribute runoff to a given body of water under extremely wet conditions. It is defined by the topographic divide (height of land) between the water body under consideration and adjoining watersheds.
- “Effective” drainage area is that portion of the gross drainage area that can be expected to contribute runoff to a given body of water under average conditions. The effective drainage area excludes portions of the gross drainage area that drain to peripheral wetlands and other natural depressions or storage areas that would prevent runoff from reaching the water body under consideration in a year of average runoff (also referred to as a “non-contributing area”).

The gross drainage area for Lac St. Cyr (including the lake surface area of 2.2 km^2) was computed as 27.64 km^2 using Canadian Digital Elevation Data and ortho-photography (Figures 17 and 18). However, as much of this area drains to other ponds, wetlands and storage, which likely would not contribute to the runoff reaching Lac St. Cyr other than in wet years, it was necessary to compute the effective area or area which would contribute to Lac St. Cyr in average years. The effective drainage area, including the surface area of the lake, was estimated at 15.6 km^2, thus resulting in a contributing effective watershed drainage area of 13.15 km^2.

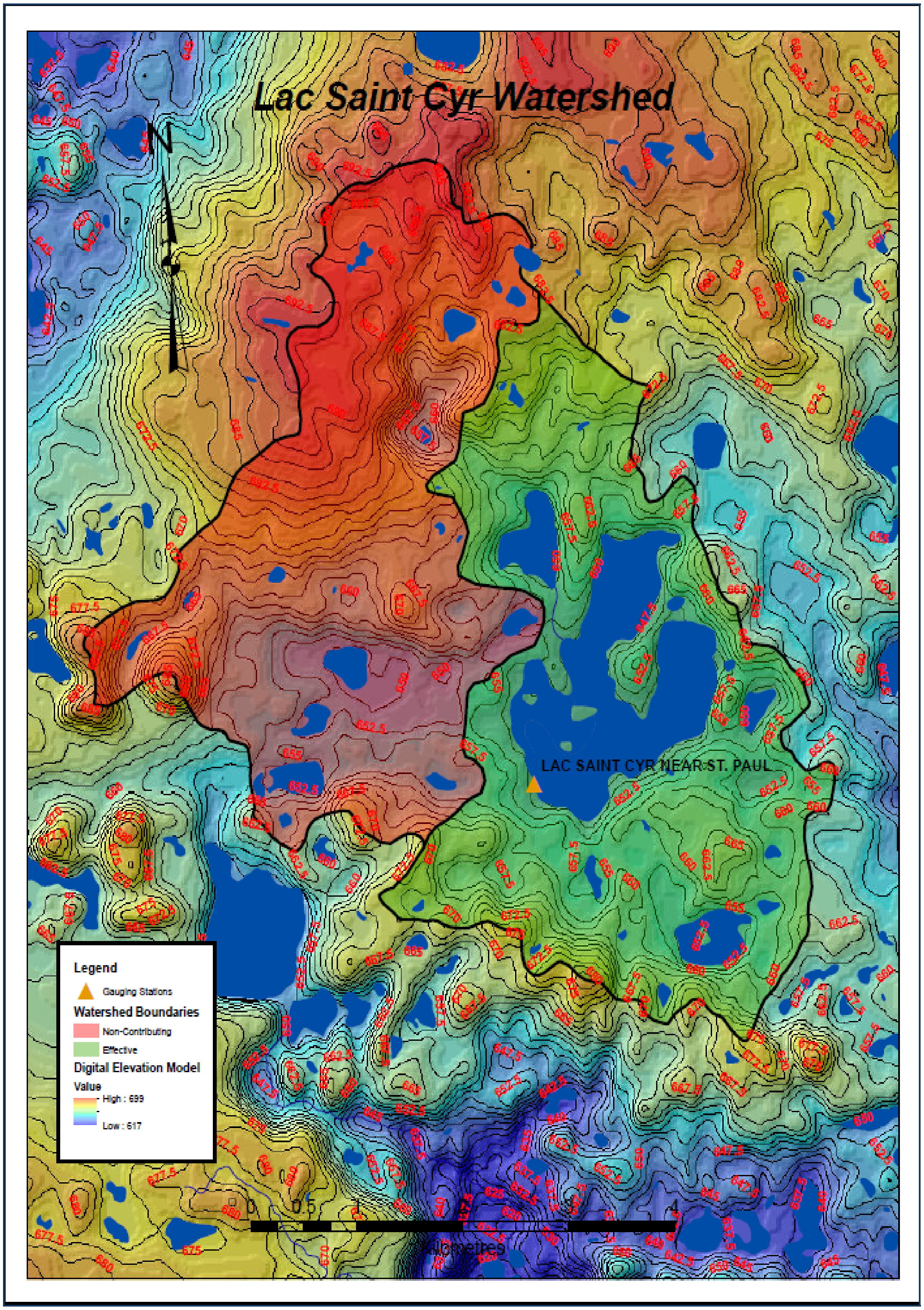


Figure 17. Digital elevation model of non-contributing and effective drainage areas within the Lac St. Cyr watershed (Agriculture and Agri-Food Canada, 2013).

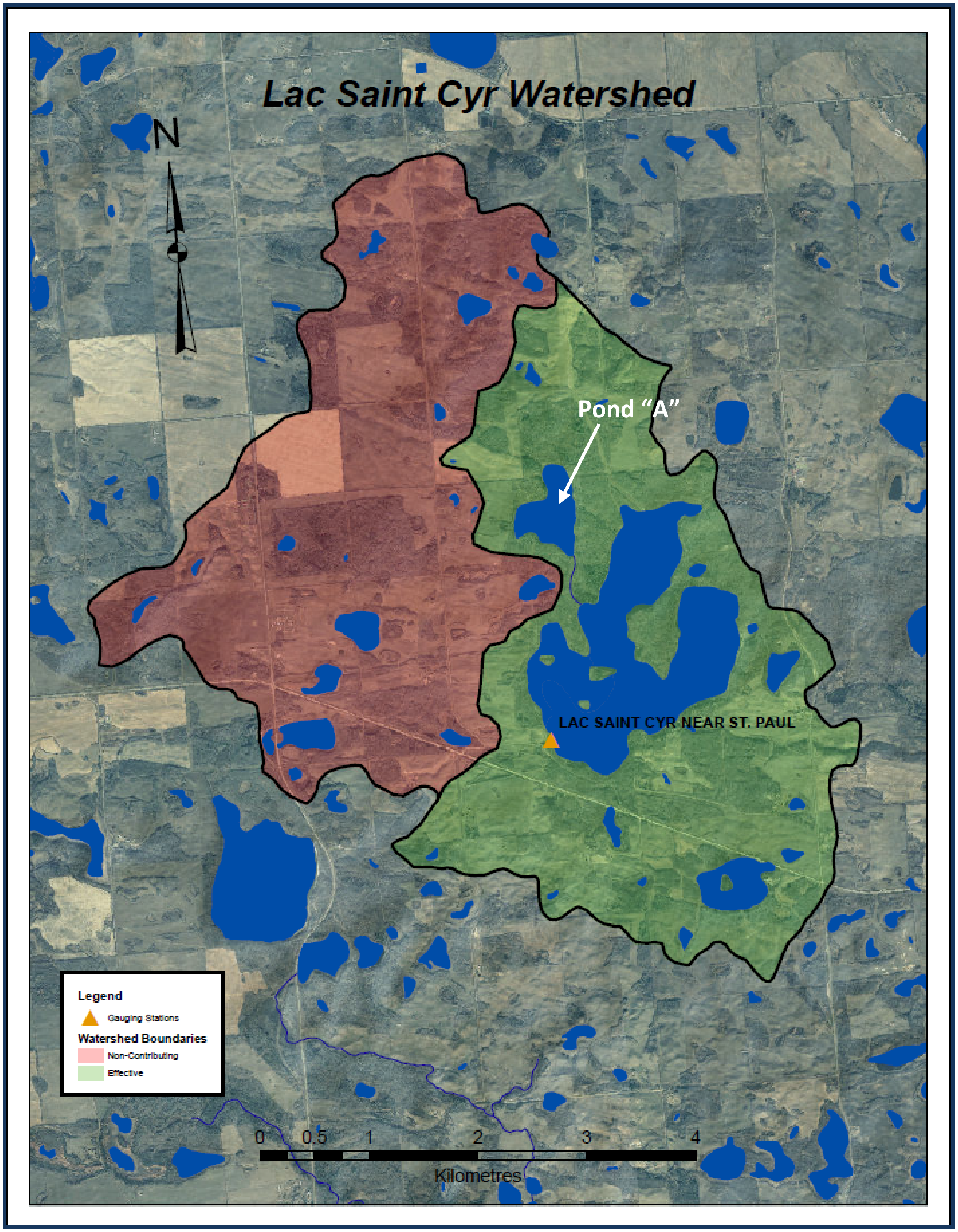


Figure 18. Non-contributing and effective drainage areas for Lac St. Cyr (Agriculture and Agri-Food Canada, 2013). Pond "A" is indicated by the white arrow.

Computation of Precipitation Inputs

The 1979-2009 monthly precipitation for Lac St. Cyr was estimated using the recorded data from the nearest station having the longest complete set of records (Water Survey of Canada Station 05ED003, Moosehill Creek near Elk Point). The mean annual precipitation input directly to the lake is estimated at 405.8 mm, or 994,139 m^3.

Computation of Evaporation Losses

Lake evaporation was calculated using the annual Morton gross lake evaporation estimates for Cold Lake, which is the nearest site to Lac St. Cyr for which data are available. This figure was then adjusted by the ratio of AESRD's estimated long-term mean annual lake evaporation contours for the Lac St. Cyr region to the mean annual lake evaporation contours for the Cold Lake region. Mean annual evaporative loss from Lac St. Cyr is estimated at approximately 644.9 mm, or 1,579,887 m^3.

Assessment of Diversions

A search of AESRD's Environmental Management System indicates two licenced allocations associated with Lac St. Cyr. File 17261 permits Alberta Environment to divert up to a maximum of 2,220,300 m^3/yr from the North Saskatchewan River and transfer the diversion into Lac St. Cyr. The NSR diversion takes place between October and March every year. File 08862 permits the Town of St. Paul to divert up to a maximum of 937,460 m^3/yr from Lac St. Cyr, under two different interim licences.

A third temporary licence, File 25119, permits the diversion of 574,802 m^3/yr to Elk Point through the Town of St. Paul water works. Construction of a water transmission line between St. Paul and Elk Point was initiated in 2011.

While the licences permit a maximum diversion up to a specific amount, the actual diversions vary from year to year and depend on a number of factors, including weather conditions and municipal water demand. However, in most instances the actual diversion is substantially lower than the water allocation. The actual mean diversion from the North Saskatchewan River into Lac St. Cyr from 1979-2009 was 1,221,512 m^3/yr. The actual mean annual diversion from Lac St. Cyr to the Town of St. Paul Water Treatment Plant during the same time period was 936,835 m^3/yr.

Groundwater Inflows and Outflows

Lac St. Cyr is in a groundwater transition/recharge area although little information is available on the movement of groundwater through the lake. Isotopic studies could be used to explore the question in more detail.

Annual Water Balance

The findings of the water balance are summarized Table 1.

Table 1. Summary of physical and hydrologic parameters for Lac St. Cyr (taken from Figliuzzi, 2013).

Table 13 - Summary of Physical and Hydrologic Parameters for Lac St Cyr			
Physical Parameters	**North Basin**	**South Basin**	**Lac St Cyr**
Gross Drainage Area (km^2)			27.64
Directly Contributing Drainage Area (including Lake surface areas) (km^2)	2.30	9.71	12.01
Contributing Drainage Area draining through Pond A (including Lake surface areas) (km^2)	3.59	0.00	3.59
Total Contributing Drainage Area (including Lake surface areas) (km^2)	5.89	9.71	15.60
Effective Drainage Area (excluding Lake surface areas) (km^2)	1.58	8.23	9.81
Effective Drainage Area draining to Pond A (excluding Lake surface area) (km^2)	3.34	0.00	3.34
Lake surface area (at elevation 644.75 m) (km^2)	0.72	1.48	2.20
Lake surface area of Pond A (km^2)	0.25	0.00	0.25
Hydrologic Parameters			
mean annual surface runoff (mm)			22.7
mean annual precipitation (mm)			405.8
mean annual lake evaporation (mm)			645

Table 14 - Summary of (1979-2009)Water Balance Parameters for Lac St Cyr			
Parameter	**North Basin**	**South Basin**	**Lac St Cyr**
Inflow from area drained by Pond A (m^3)	17,353	0	17,353
Direct Surface Inflow (m^3)	36,024	187,644	223,668
Precipitation Input (m^3)	292,155	600,541	892,696
Gross lake Evaporation (m^3)	-464,293	-954,381	-1,418,674
Diversion into Lac St Cyr (m^3)	0	1,221,512	1,221,512
Diversion from Lac St Cyr (m^3)	-936,835	0	-936,835
Net Groundwater Inflow (m^3)	5,392	5,392	10,783
Transfer from South Basin to North Basin (m^3)	1,053,642	-1,053,642	0
Change in Storage (m^3)	3,437	7,066	10,503

The small positive residual in storage indicates that Lac St. Cyr is located in a transition/recharge area, which is supported by the results of the Hydrogeological Consultants Ltd. (1999) report discussed in the Groundwater Resources section above (Section 3.0). There may be significant error associated with this estimate.

Lake Level Fluctuations

Lake level fluctuations are of concern to area residents (Richards, pers. comm., 2013). Lake levels drop naturally due to summer evaporative losses, but these declines in Lac St. Cyr will be exacerbated to some degree by the ongoing water withdrawals for the town. The seasonal and long-term changes in water levels in the lake from 2003-2011 are illustrated in Figure 19; an overall increasing trend is evident.

In general, the highest water levels are seen in April and early May, which corresponds with the end of pumping season and the spring freshet. Water levels then continue to decline over the summer months, and lowest water levels are seen in the early winter months, usually November and December. The change in water levels over the summer is approximately 0.5 metres, which may have an impact upon the shallow littoral environment of the lake. Water temperatures in these areas will increase as water levels decrease through the mid-summer period, potentially impacting fish populations and other biological communities that utilizing the littoral zone of the lake. The lake retains an ice-free open area during winter near the site of the diversion inflow to the southern basin. There appears to be an overall increasing trend in water levels during the past decade.

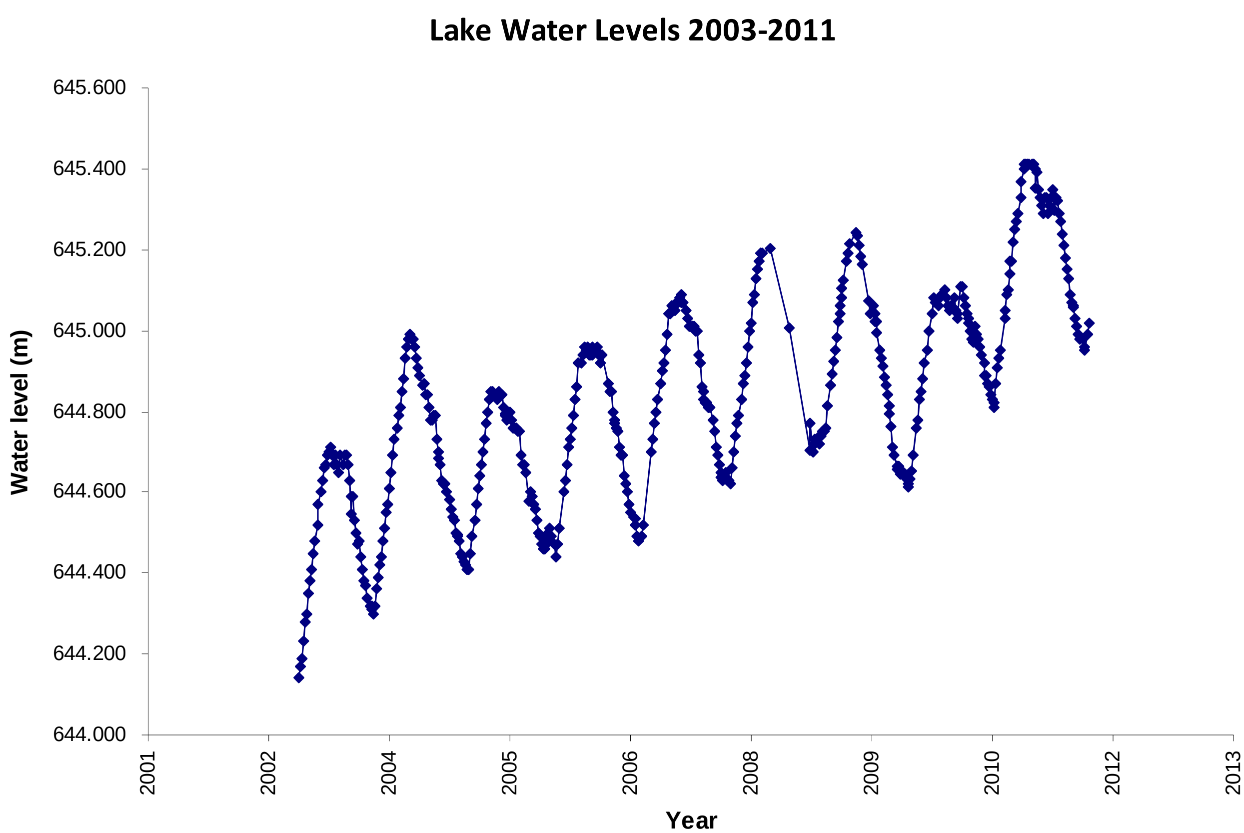


Figure 19. Lake water levels between 2003 and 2011.

Residence Time and Flushing Rate

A lake's residence time is defined as the filling time, or the number of years required to completely replace the water volume of the lake by incoming water, assuming complete mixing. Using the lake volume, as well as inflows to the lake, the current residence time of Lac St. Cyr is as follows:

Residence time = Lake volume/ (surface inputs + diversion + (precipitation – evaporation))

= 13,385,650 m^3/ (17,353 m^3 + 223,668 m^3 + 1,221,512 m^3 + (892,696m^3-1,418,674 m^3))

= 14 years

The flushing rate of a lake is defined as the annual outflow divided by lake volume. This gives a flushing rate of 0.07/yr, which means 7% of the lake volume is removed every year. Prior to diversion, the lake would not have flushed unless water levels were extremely high.

4.0 Surface Water Quality

Water Quality in the North Saskatchewan River

Industries, the City of Edmonton and surrounding municipalities had a significant impact on the water quality of the North Saskatchewan River during the mid to late 20th century as a result of direct stormwater and wastewater discharges. However, the quality of treated wastewater discharges has improved significantly in recent decades, and river water quality downstream of Edmonton has also undergone significant improvement. The City of Edmonton's Gold Bar Wastewater Treatment Plant became operational in 1956, and only provided secondary treatment at that time. From 1995-2001, Biological Nutrient Removal (BNR) was added, and UV disinfection was added in 1998. Enhanced primary treatment was implemented in 2010 to improve treatment capacity during wet weather for combined sewer overflows. The Alberta Capital Region Wastewater Treatment Plant opened in November 1984, and treats sewage from growing the municipalities in the Capital Region (including Stony Plain, Spruce Grove, St. Albert, northeast Edmonton and Sherwood Park). BNR and UV disinfection were implemented in this plant in mid 2005 (Thompson, pers. comm., 2013).

Trends in downstream NSR water quality were examined by Hebben (2005). This report noted that variables such as hardness, sodium, magnesium and sulphate had increased significantly, while others, such as total phosphorus, total dissolved phosphorus, total nitrogen, total coliform and fecal coliform bacteria had shown significant decreases at Pakan, as would be expected from the improvements in upstream municipal wastewater treatment.

Anderson (2012) updated the Hebben (2005) report using LTRN data from Pakan for 1987-2011. The report utilizes monotonic and step trend analyses to look for trends in certain water quality variables of concern (VOCs) as identified by AESRD (McDonald, 2012), as well as some additional variables chosen to provide further insight into the river water quality over time. Monotonic trend analyses were performed using the Kruskal-Wallis test, and were used to test for seasonal effects in the data. Autocorrelation in the data was also tested. The report looked at the data record as a whole, and also assessed trends for ice cover (November to March) and open water seasons (April to October) separately.

The overall trends noted in the report are summarized in Tables 2 and 3. Similar to the results presented by Hebben (2005), significant declines in nutrient and bacterial concentrations were detected.

Table 2. Monotonic trends in common water quality parameters throughout all seasons (1987-2011), as well as under ice cover, and open water conditions. The arrows indicate either a significant increasing or decreasing trend. ns = no significant trend. From Anderson (2012).

Parameter	All Seasons	Ice Cover	Open Water
Ammonia (NH3)	↓	↓	↓
NO2-NO3-N	↓	ns	↓
Total Nitrogen	↓	↓	↓
Total Phosphorus	↓	↓	↓
Total Dissolved Phosphorus	↓	↓	↓
Chlorophyll-a	↓	ns	↓
Fecal Coliforms	↓	↓	↓
E. coli	↓	↓	↓
Dissolved Oxygen	↑	↑	↑
Total Dissolved Solids	↑	↑	↑
Chloride	↑	ns	↑
Sulphate (SO4)	↑	↑	↑

No trend analyses for pesticides or metals were possible at Pakan, as data continuity was interrupted for these parameters after analytical detection levels were lowered in 2005. However, high selenium levels, resulting from industrial discharges, were detected in the 2007 and 2008 monitoring seasons, and corrective measures to improve this situation were taken in 2009 (Anderson, 2012).

An observation of similar monotonic trends between under ice and open water data suggest that trends in nutrients and bacteria are related to point source loadings, while increasing trends in TDS and SO_4 in the open water season may be related to non-point source loadings (Anderson, 2012).

Step Trends at the Pakan LTRN Station

Step trend analyses were completed using the Wilcoxon-Mann-Whitney test, and were used to evaluate water quality trends on all data. Data were segregated into pre- and post-treatment plant upgrade years, and as open water and ice cover data. A summary of the findings of these analyses is presented Table 3.

Comparisons were made in the step trends between ice cover and open water post-1998 and post-2005. Post-1998, the under ice periods saw greater changes in DO, ammonia, TP, TDP, TDS, SO_4 and fecal coliform bacteria. Concentration changes for NO_2-NO_3-N, TN and Chl-a were larger during the open water period. Post-2005, changes were larger under ice for ammonia, TN, TDP and Chl-a. Changes in TP, TDS and SO_4 were larger during the open water period.

Anderson (2012) concluded that declining trends in both nutrients and bacteria occurred at this site, coinciding with upgrades in the municipal treatment plants in 1998 and 2005. Trends for these parameters are stronger during ice cover conditions. Increasing trends in dissolved solids and sulphates were noted, particularly in the open water season.

Table 3. Step trends in common water quality parameters throughout all seasons, as well as under ice cover, and open water conditions. The arrows indicate either a significant increasing or a decreasing trend. ns = no significant change. From Anderson (2012).

Parameter	All Data Post 1998	All Data Post 2005	Ice Cover Post 1998	Ice Cover Post 2005	Open Water Post 1998	Open Water Post 2005
Ammonia (NH3)	↓	↓	↓	↓	↓	ns
NO2-NO3-N	↓	↓	ns	ns	↓	↓
Total Nitrogen	↓	↓	↓	↓	↓	↓
Total Phosphorus	↓	↓	↓	↓	↓	↓
Total Dissolved Phosphorus	↓	↓	↓	↓	↓	↓
Chlorophyll-a	↓	↓	ns	↓	↓	↓
Fecal Coliforms	↓	ns	↓	ns	↓	ns
E. coli	↓	↓	↓	↓	↓	ns
Dissolved Oxygen	↑	↑	↑	ns	↑	↑
Total Dissolved Solids	↑	ns	↑	ns	↑	↑
Chloride	↑	ns	↑	ns	↑	ns
Sulphate (SO4)	↑	↑	↑	↑	↑	↑

Diversion Water Quality

Water quality data were collected at the NSR pumphouse monthly over the winter diversion period, from November to March 1978-2000, and then again in summer 2012. Since the intake location is approximately 100 km downstream from Pakan, it was important to compare water quality at these two points on the river to support an interpretation of diversion effects after 2000.

A comparison of paired monthly total phosphorus concentration data from the NSR diversion and from the LTRN station at Pakan is presented in Figure 20. Data were selected from the winter pumping months from 1987 to 2000 only, as Pakan data were unavailable prior to 1987.

The results indicate a strong correlation over the years for winter TP data from these two sites, with Pakan [TP] somewhat higher than diversion [TP]. The data suggest that the longer term record at Pakan could be used to infer diversion water quality, post-2000.

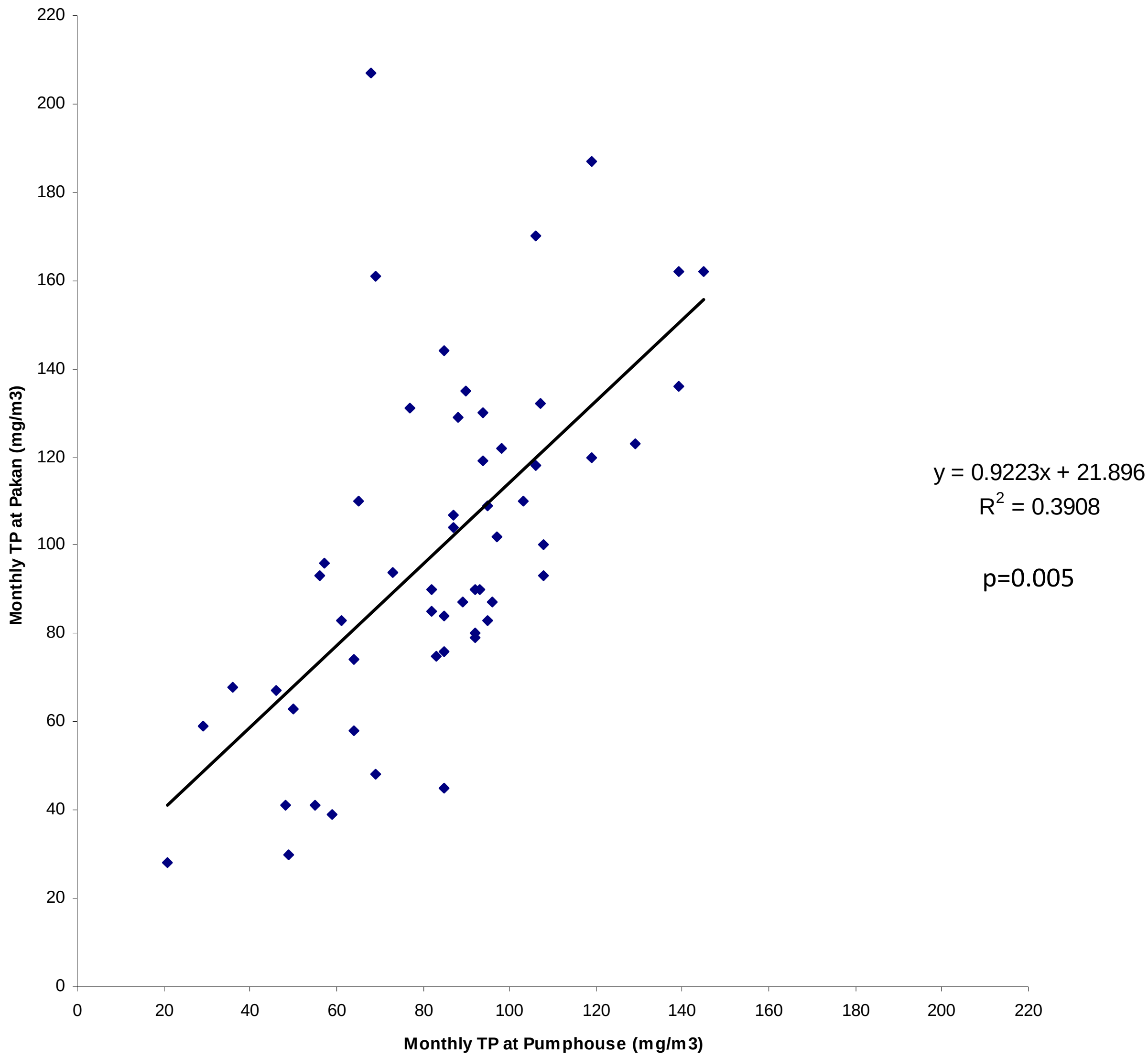


Figure 20. Comparison of paired monthly [TP] in diversion water and at Pakan [TP] (1987-2000).

A very rough comparison was also made among recent summer water quality data for the Pakan station and the Lac St. Cyr pumphouse (Table 4). Unfortunately, paired sample data were not available for these two sites during recent winter pumping periods. Data were utilized from all summers of 2005-2011 for Pakan, and for the summer 2012 for the diversion (pumphouse). Data for Pakan during summer 2012 were not available. Median values were used for all comparisons.

Many of the median values are similar at both sites, however differences can be seen in ammonia, total phosphorus, total nitrogen and *E. coli* values (Table 4). This may indicate non-point source runoff influences taking place along the 100 km stretch of river between Pakan and the pumphouse during the summer months, but further investigation would be required to confirm this preliminary observation.

Table 4. Comparison between selected water quality variables for the North Saskatchewan River at Pakan and for the NSR diversion (at pumphouse). The most recent median values from summer samples are presented. Variations in the data between sites are highlighted in yellow.

Parameter (mg/L unless noted)	River (Summer 2005-2011) (n=56)	Pumphouse (Summer 2012) (n=5)
pH	8.4	8.2
Dissolved Oxygen	9.8	7.2
Ammonia	0.03	0.095
NO_2-NO_3-N	0.17	0.17
Total Nitrogen	0.51	0.74
Total Phosphorus	0.022	0.15
Total Dissolved Phosphorus	0.008	0.011
Chlorophyll a (µg/L)	3.92	3.27
Total Dissolved Solids	200	190
Sodium	7.5	6.7
Chloride	3.5	2.6
Sulphate (SO_4)	36	42
Fecal coliforms (no/100 mL)	30	30
E. coli (no/100 mL)	10	50

Long-term winter data for [TP] and [TN] are plotted for the period 1978–2000 in Figures 21 and 22*. The concentrations of these two parameters often exceeded the Alberta Surface Water Quality (ASWQ) Protection of Aquatic Life (PAL) guidelines. There are large peaks in nitrogen and phosphorus in 1983-84 and smaller peaks in 1984-1985, probably due to the leaking industrial lagoons at Fort Saskatchewan described previously. When examining the raw diversion data, other parameters show a peak in these years, including ammonia, NO_2-NO_3, and to a lesser extent, Na and Cl.

**NOTE: The winter pumping start time varies from year to year, depending upon river freeze-up conditions.*

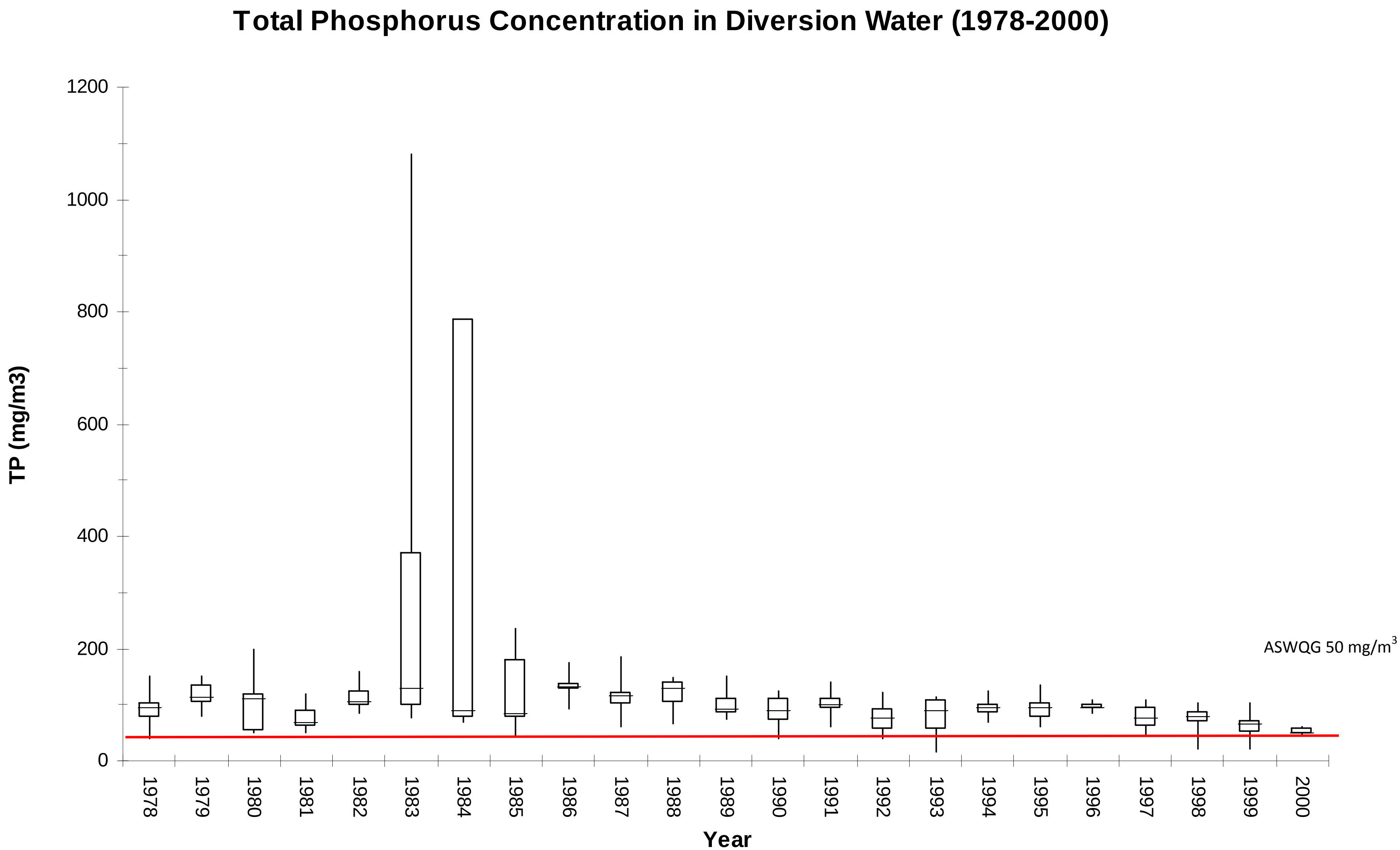


Figure 21. Total phosphorus concentrations in diversion water sampled at the pumphouse. The red line indicates the ASWQG PAL value. There was a general decreasing trend in TP concentrations up to 2000. (Note: year date indicates the starting year for each over-winter diversion).

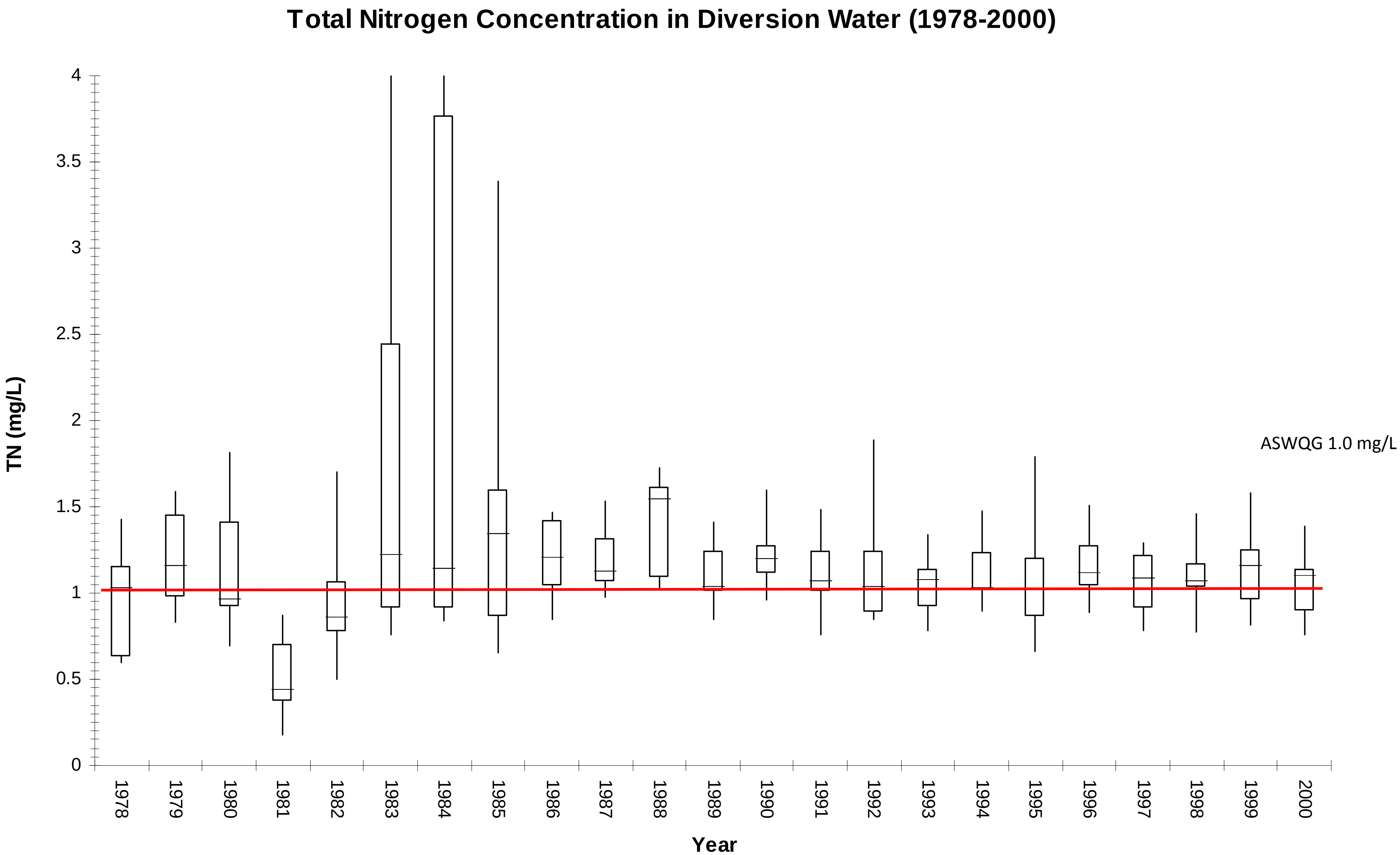


Figure 22. Total nitrogen concentrations in diversion water sampled at the pumphouse. The red line indicates the ASWQG PAL value. There appears to be general decreasing trend in concentrations. (Note: year date indicates starting year for over-winter diversion)

Lac St. Cyr Water Quality

Sampling Methods

Water quality data for Lac St. Cyr have been collected at various times and locations, using various sampling methods during the 1976-2012 period. The lake sampling methods used by AESRD evolved from single site, discrete grab samples in the 1970s to vertically integrated, euphotic zone composite samples after 1980. Analytical methods also evolved. Detection limits for total phosphorus declined from 50 mg/m^3 in the late 1970s to 2 mg/m^3 in 1981. These sampling and analytical changes minimize the value of comparisons between 1970s data and data collected after 1980.

The water quality data records available for the lake are discontinuous. Detailed sampling was conducted between 1978 and 2000, and then terminated. Sampling was re-instated in 2012.

"Whole lake" data are defined as integrated euphotic zone samples collected at numerous locations around the lake, and mixed together to form one composite sample. Discrete grab samples from the upper (epilimnion), middle (thermocline) and lower (hypolimnion) portions of the water column provide a vertical snapshot of key chemical variables. Vertical profiles of temperature, dissolved oxygen and specific conductance were made *in situ*. In 2012, composite samples of the southern basin were collected, as well as profile and composite samples from the north basin. The individual basin composite data were averaged in this assessment to provide a "whole lake"estimate for 2012.

Physical Characteristics

In situ temperature profiles for the east, west and north basins of the lake were created using Excel (Figures 23-26). The summer dissolved oxygen profiles for all three basins are presented in Figures 27-30. Specific conductance profiles are presented in Figures 31-34.

Chemical Characteristics

A summary of the available lake water quality data is presented in Tables 5-8. Parameters collected include nutrients, major ions, metals and organic contaminants. Given the paucity of the data, and the inconsistency in sampling times and methods, direct statistical comparisons/trends were not warranted. Only descriptive observations on the data were made in this assessment.

The concentrations of major ions and routine variables from each basin are presented in tabular format (Tables 9-12) and comparisons of whole lake composite data are made to the *Surface Water Quality Guidelines for Use in Alberta* and the *Canadian Environmental Quality Guidelines* in Table 13.

Nutrient and chlorophyll a data for each basin are presented using "box and whisker" plots (Figures 36 and 37 and 40 to 53). This format clearly illustrates the maximum and minimum concentrations within the sampling year, as well as the median values.

Table 5. Summary of available water quality data for "whole lake" composite samples. Note the large data gaps. (Inorganics = major ions, nutrients, TDS).

Whole Lake Composite

Year	Mo.												Parameters		
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Freq.	Inorganics	Metals	Comments
1983					x	x	x	x	x	x			1x/mo.	x	x	
1984				x	x	x	x	x	x	x			1x/mo.	x	x	
1985	x		x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)	
1986					x	x	x	x	x	x			1x/mo.	x	x (Fe only)	
1991					x	x	x	x	x				1x/mo.	x	x (Fe only)	
1995					x	x	x	x	x	x			1x/mo.	x	x (Fe only)	
2012						x	x	x	x				1x/mo.	x	x	East/West and North basin composite data combined for 2012

Table 6. Summary of water quality data for discrete grab samples from the epilimnion, thermocline and hypolimnion of the north basin. Note the large data gaps.

North Basin Profile

Year	**Mo.**													**Parameters**			
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Freq.**	**Inorganics**	**Metals**	**Organics**	**Comments**
1976				x	x	x	x	x	x	x	x	x	1x/mo.	x	x (Fe only)		
1977	x	x				x	x	x	x	x		x	1x/mo.	x	x (Fe only)		
1978	x	x	x		x	x	x	x	x	x		x	1x/mo.	x	x		
1979	x	x	x		x	x	x	x	x	x		x	1x/mo.	x	x (Fe only)		
1980	x	x	x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)		
1983	x				x	x	x	x	x	x			1x/mo.	x	x (Fe only)		
1984				x	x	x	x	x	x	x			1x/mo.	x	x		
1985	x		x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)		
1986	x		x		x	x	x	x	x	x			1x/mo.	x	x (Fe and Hg only)		
1987		x											1x/mo.	x	x (Fe only)		
1991		x			x	x	x	x	x				1x/mo.	x	x	x (Feb only)	
1995		x			x	x	x	x	x	x			1x/mo.	x	x	x	
2012						x	x	x	x				1x/mo.	x	x		Composite and discrete sample done of North basin

Table 7. Summary of water quality data for discrete grab samples from the epilimnion, thermocline and hypolimnion of the east basin. Note the large data gaps.

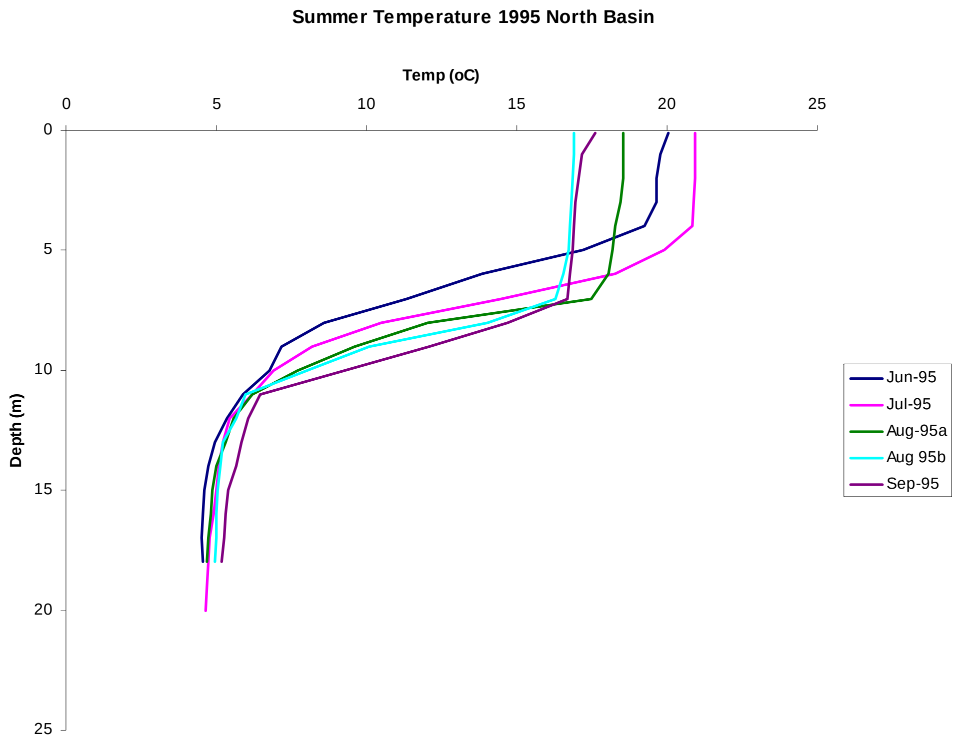
East Basin Profile

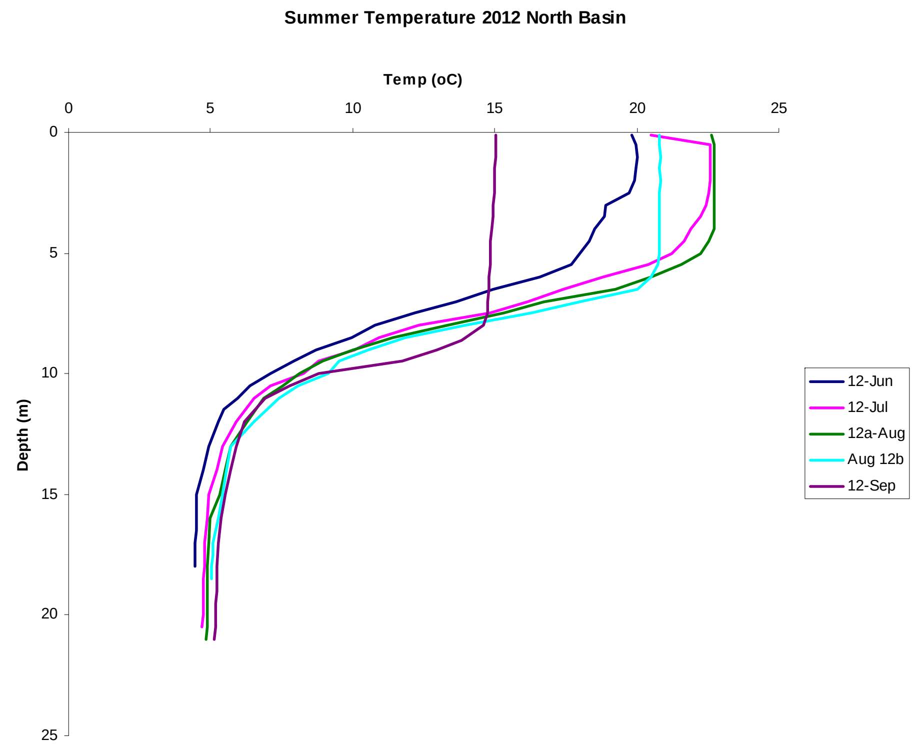
Year	Mo.												Parameters		
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Freq.	Inorganics	Metals	Organics
1976		x		x	x	x	x	x	x	x	x	x	1x/mo.	x	x (Fe only)	
1977	x	x				x	x	x	x	x		x	1x/mo.	x	x (Fe only)	
1978	x		x		x	x	x	x	x	x		x	1x/mo.	x	x	
1979	x	x	x		x	x	x	x	x	x		x	1x/mo.	x	x (Fe only)	
1980	x	x	x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)	
1983	x				x	x	x	x	x	x			1x/mo.	x	x	
1984				x	x	x	x	x	x	x			1x/mo.	x	x	
1985	x		x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)	
1986	x		x		x	x	x	x	x	x			1x/mo.	x	x (Fe and Hg only)	
1987		x											1x/mo.	x	x (Fe only)	
1991		x			x	x	x	x	x				1x/mo.	x	x	x
1995			x		x	x	x	x	x	x			1x/mo.	x	x	x

Table 8. Summary of water quality data for discrete grab samples from the epilimnion, thermocline and hypolimnion of the west basin. Note the large data gaps.

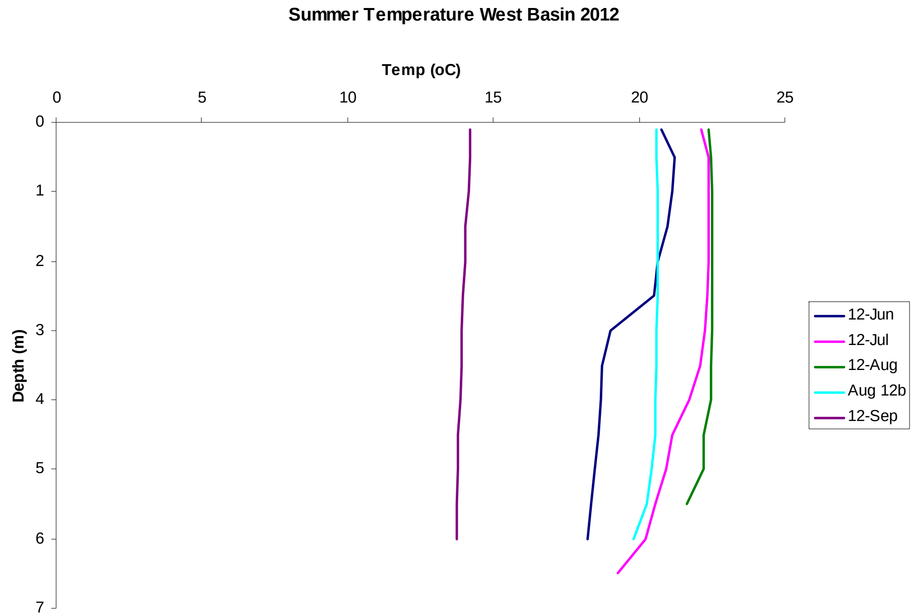
West Basin Profile

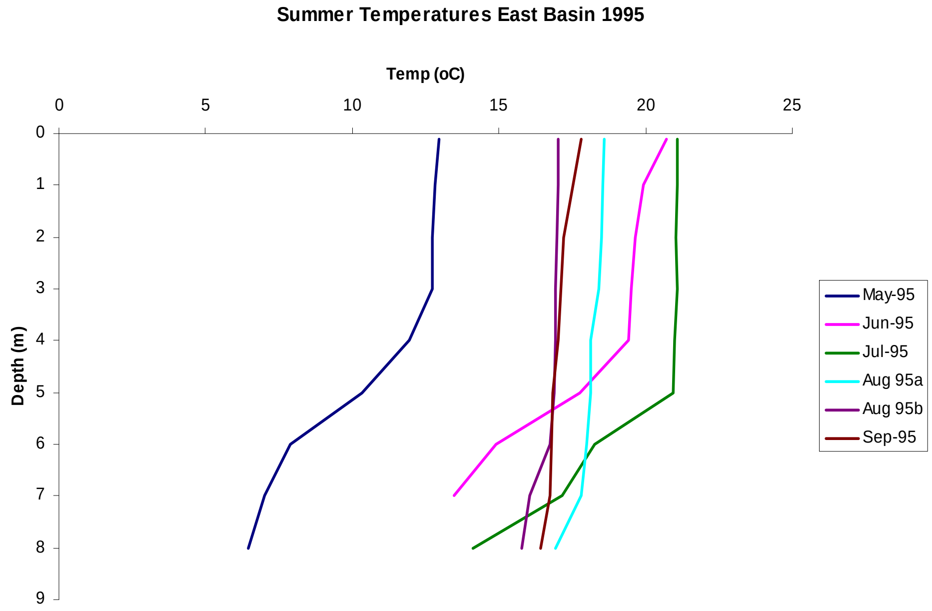
Year	Mo.												Parameters	
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Freq.	Inorganics	Metals
1976		x		x	x	x	x	x	x	x	x	x	1x/mo.	x	x (Fe only)
1977	x	x				x	x	x	x	x	x	x	1x/mo.	x	x (Fe only)
1978	x	x	x		x	x	x	x	x	x			1x/mo.	x	x
1979	x	x	x		x	x	x	x	x	x		x	1x/mo.	x	x (Fe only)
1980	x	x	x		x	x	x	x	x	x			1x/mo.	x	x (Fe only)
1995		x											once	x	x (Fe only)



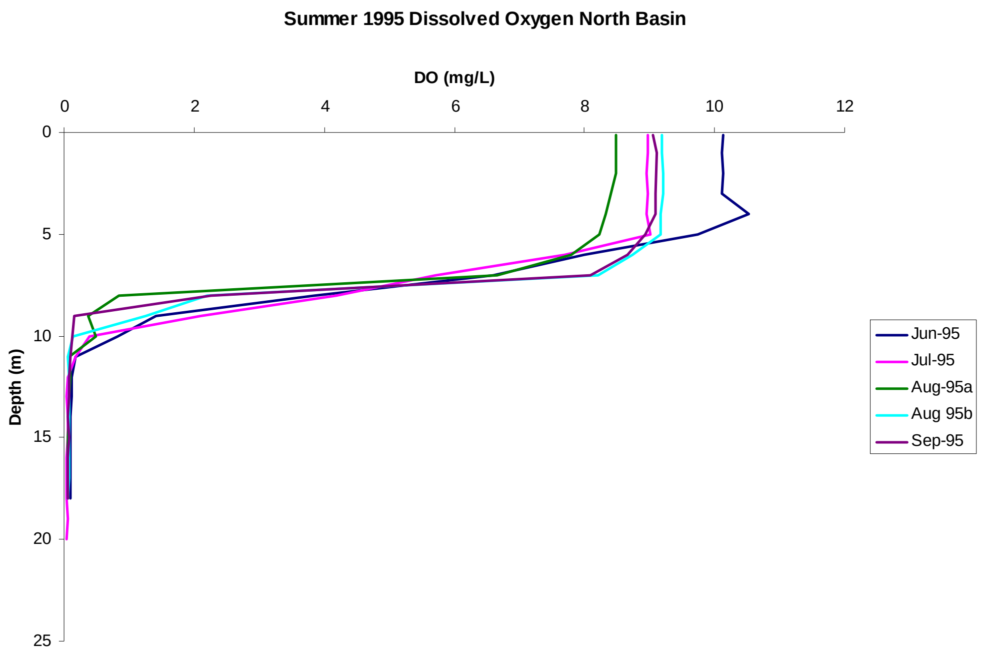


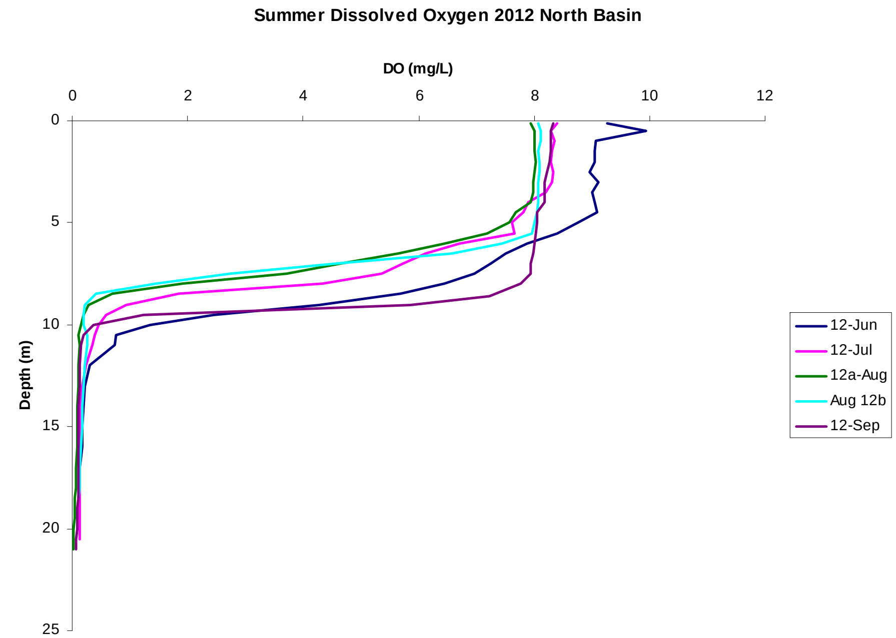
Figures 23 and 24. In situ summer temperature profiles (June-September) in 1995 and 2012 for the north basin of Lac St. Cyr. Similar thermal density stratification patterns are seen in the water column during both years, with a thermocline occurring between 5 to 8 metres depth. Summer thermal stratification appears to commence early in this basin.



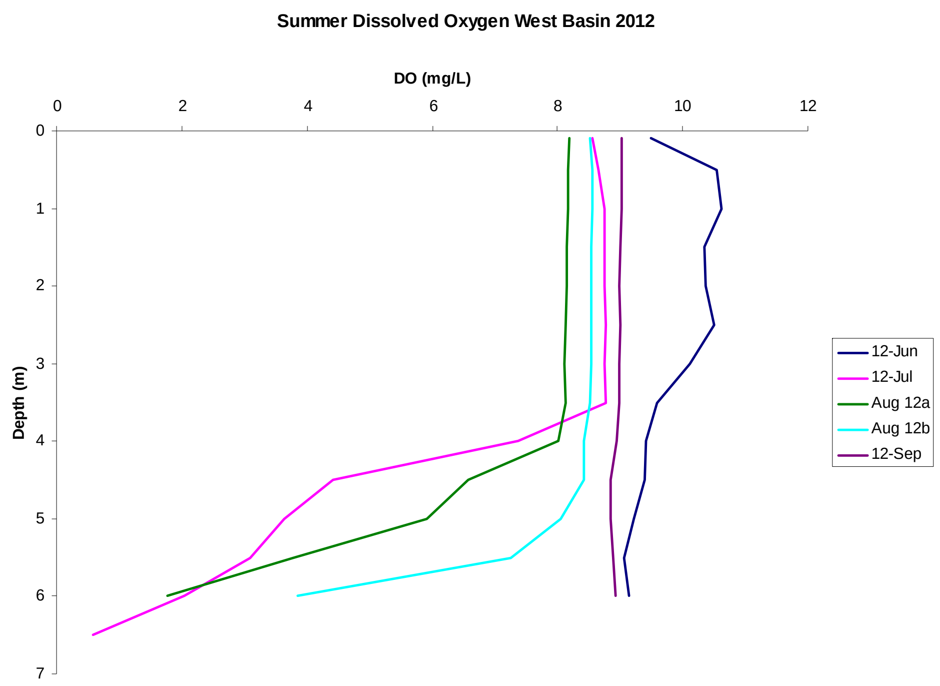


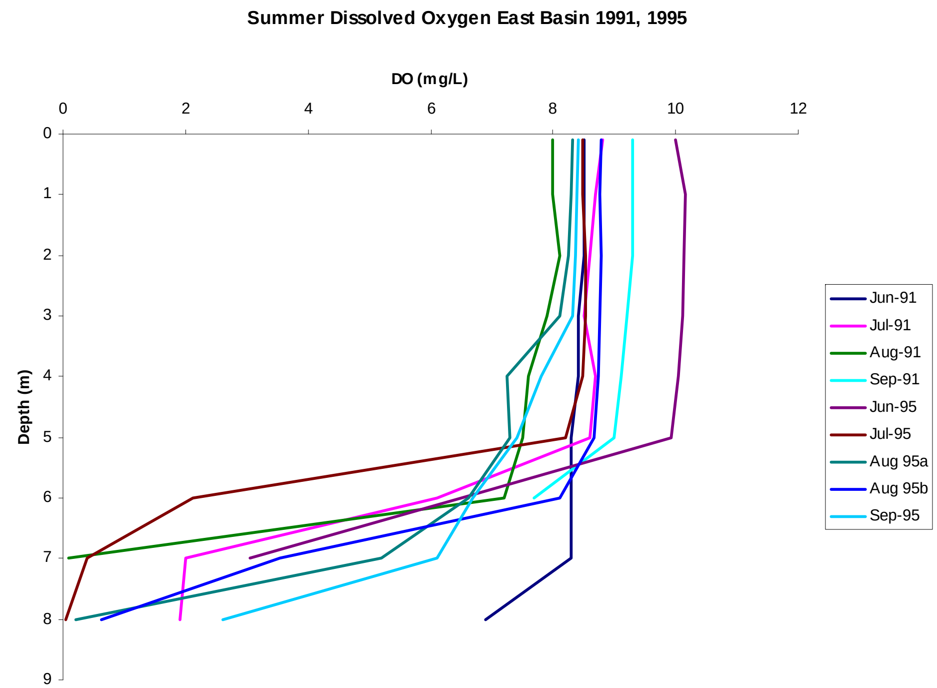
Figures 25 and 26. In situ summer temperature profiles (June-September) in 2012 (west basin) and 1995 (east basin) in Lac St. Cyr. The west basin appears to stay relatively uniform in temperature throughout the water column in the summer, indicating complete mixing. The east basin shows some temporary summer stratification, with a weak thermocline from approximately 4 to 6 metres depth, and more complete mixing in spring and fall.



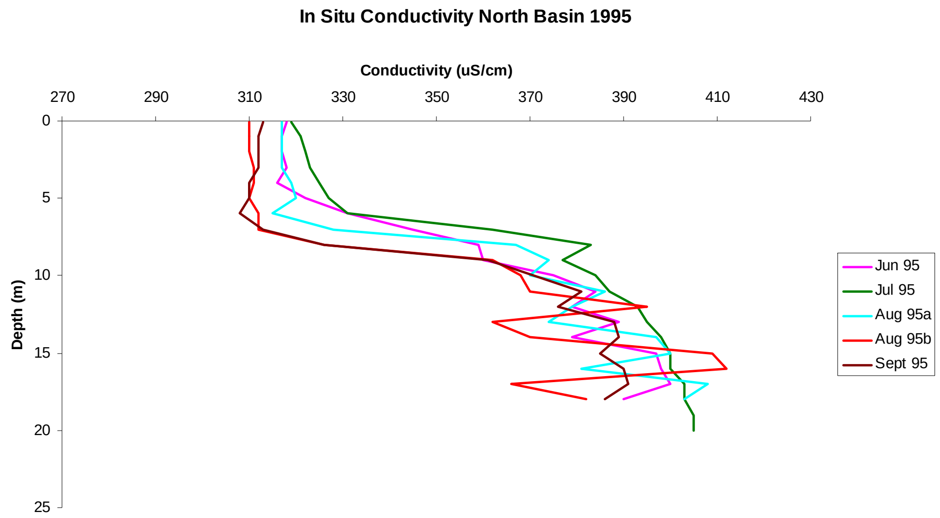


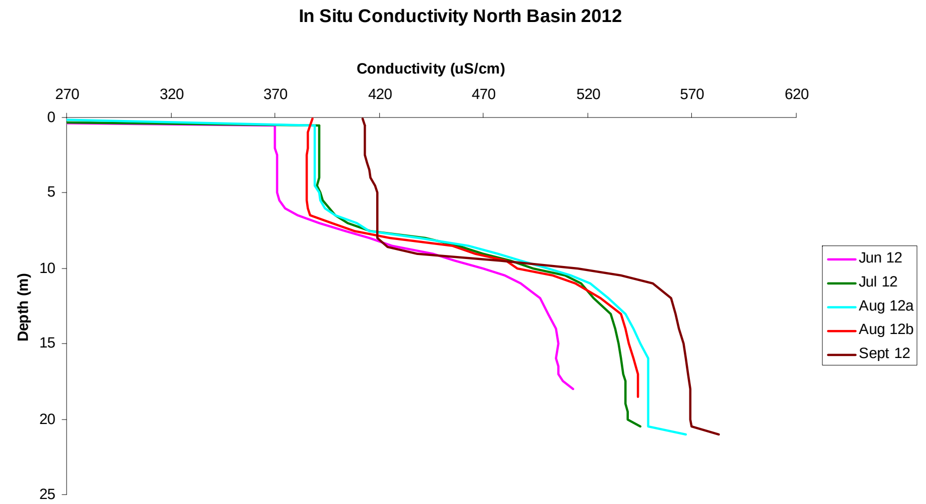
Figures 27 and 28. Summer (June-September) dissolved oxygen levels in 1995 and 2012 in the north basin of Lac St. Cyr. The north basin, being the deeper basin, shows clear signs of thermal stratification in the summer months, with depths below 10 metres becoming almost completely anoxic. The thermocline in this basin of the lake begins at approximately 5 metres depth. Summer hypolimnetic anoxia is evident very early in this basin for both years; Mitchell (1987) speculated that this (north) basin may not undergo regular spring mixing.



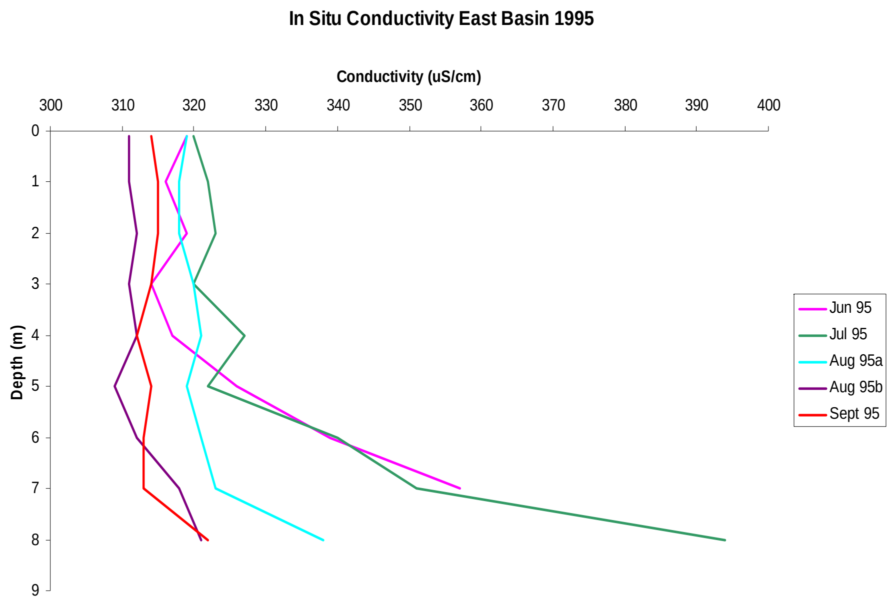


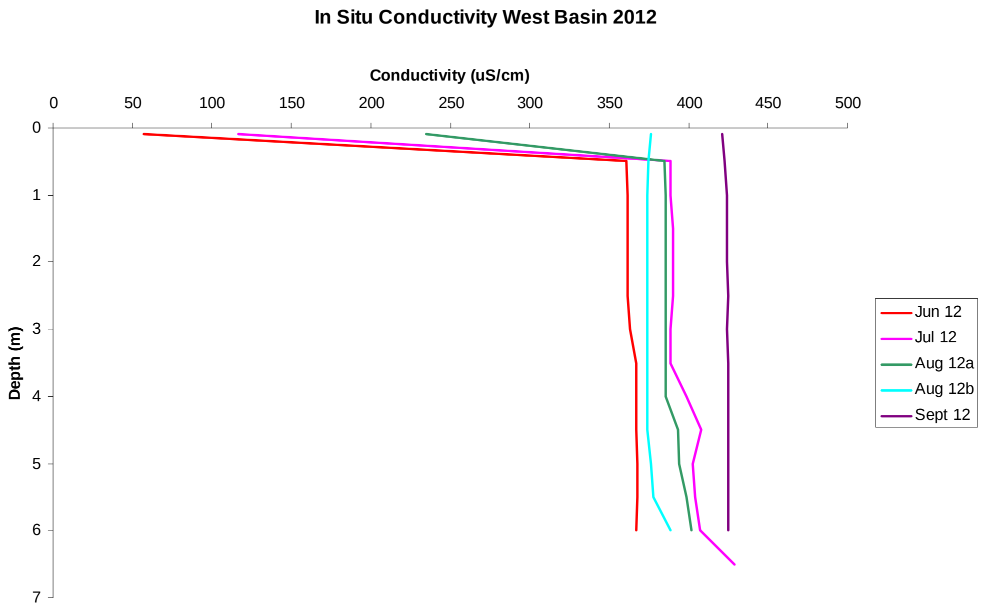
Figures 29 and 30. Summer (June-September) dissolved oxygen levels in 2012 (west basin) and 1991 and 1995 (east basin) in Lac St. Cyr. The west basin appears to be well mixed during June and September (likely during turnover events), with slight stratification occurring in the warmer months of July and August. During these warmer months, dissolved oxygen levels can drop to low levels below 5.0 to 6.5 metres depth. The east basin appears to be well mixed in June and September 1991, but shows signs of stratification in June and September 1995. Oxygen depletion is evident throughout summer, starting to decline at approximately 5.5 metres depth.





Figures 31 and 32. *In situ* conductivity profiles for the north basin in 1995 and 2012. Conductivity increased significantly in and below the thermocline, and has increased overall from 1995 to 2012.





Figures 33 and 34. *In situ* conductivity profiles for the east (1995) and west (2012) basins of Lac St. Cyr. The east basin data display increases with depth during mid summer. The very low surface values in the west basin during June and July are unusual.

Chemical Characteristics

Major Ions

Overall, the lake major ion concentrations appear to be approaching concentrations seen in the river. Lake water has progressively been "replaced" by river water, with some ions decreasing due to dilution, and others increasing because of higher concentrations present in the river water. Chemically, the lake is now functioning more like an "off stream" reservoir, and is being flushed frequently because of the diversion.

Median values for the major ions and related variables from whole lake composite samples are presented in Table 9. The variables highlighted in yellow have shown a change in concentrations since the beginning of the diversion in 1978. As noted in Anderson (2012), chloride and sulphate have both shown significant increases at the Pakan sampling station on the North Saskatchewan River, and this increase is also evident in the Lac St. Cyr data. Bicarbonate appears to be declining slightly within the lake, and potassium is showing a marked decline in concentrations.

Table 9. Median values for major ions in whole lake composite samples. Units are in mg/L unless otherwise indicated. Cells in yellow indicate parameters that have changed considerably since the diversion began in 1978.

Major Ions Whole Lake	1983-86	1991	1995	2012
Calcium	26	26	28	no data
(n)	27	2	7	no data
Magnesium	18	22	19	no data
(n)	27	2	7	no data
Potassium	10	8	6	4
(n)	27	2	7	12
Chloride	3	3	4	6
(n)	27	2	7	12
Bicarbonate	183	171	171	150
(n)	26	2	7	12
Sulphate	13	21	26	40
(n)	27	2	7	12
Sodium	7	8	9	9
(n)	27	2	7	12
Conductance (µS/cm)	331	326	324	325
(n)	27	2	7	12
TDS	175	176	177	178
(n)	26	2	7	12

The east basin directly receives the diversion from the river. Median values for the major ions and related variables from the east basin are presented in Table 10. Increases in the concentrations of certain ions in the east basin of the lake are evident since the diversion began, particularly calcium, sodium, chloride and sulphate. Total dissolved solids (TDS) have increased slightly, while a downward trend can be seen in potassium concentrations, likely due to dilution.

Table 10. Median values for major ions in east basin of Lac St. Cyr. Units are in mg/L unless otherwise indicated. Cells in yellow indicate parameters that have changed considerably since the diversion began in 1978.

Major Ions East Basin Site 1

	1976-80	1983-85	1986-87	1991	1995
Calcium	25	27	34	26	31
Magnesium	22	18	20	22	19
Sodium	6	7	8	8	9
Potassium	14	10	9	8	6
Chloride	2	3	3	3	4
Bicarbonate	174	188	206	189	174
Sulphate	8	12	18	21	26
Conductance (µS/cm)	318	331	355	334	328
TDS	178	173	189	176	206
(n)	43	36	23	7	19

Median values for the major ions and related variables from the north basin are presented in Table 11. There have been slight increases in average calcium concentrations, and increasing trends in sodium, sulphate and chloride concentrations. Potassium and bicarbonate concentrations have declined, while the remaining variables have remained at relatively constant levels.

Table 11. Median values for major ions in north basin of Lac St. Cyr. Units are in mg/L unless otherwise indicated. Cells in yellow indicate parameters that have changed considerably since the diversion began in 1978.

Major Ions North Basin Site 3	1976-80	1983-87	1991	1995	2012
Calcium	31 (1980 only)	30	33	34	no data
(n)	18	95	9	27	no data
Magnesium	23	19	22	21	no data
(n)	218	95	9	27	no data
Sodium	6	8	8	9	8
(n)	219	95	9	27	7
Potassium	15	11	8	7	4
(n)	218	95	9	27	7
Chloride	2	3	3	4	6
(n)	171	94	9	27	7
Bicarbonate	no data	204	203	198	151
(n)	no data	93	9	27	7
Sulphate	8	14	22	27	39
(n)	78	94	9	27	7
Conductance (µS/cm)	336	344	373	376	326
(n)	218	95	9	27	7
TDS	183	182	197	202	178
(n)	200	92	9	27	7

Due to the lack of recent ion data for the west basin, no trends can be established for these parameters. The ion concentrations in 1977-1980 are very similar to those seen in the north and east basins, during the same time period.

Table 12. Median values for major ions in west basin of Lac St. Cyr. Units are in mg/L unless otherwise indicated.

Major Ions West Basin Site 2	
	1977-80
Calcium	24
(n)	8
Magnesium	22
(n)	149
Potassium	14
(n)	149
Chloride	2
(n)	148
Bicarbonate	no data
(n)	no data
Sulphate	8
(n)	148
Conductance (µS/cm)	320
(n)	149
TDS	174
(n)	137

Medians of routine variables, major ions and nutrients from whole lake composite samples in 2012 are generally below the ASWQO/CCME/USEPA PAL guideline values (Table 13), suggesting that the general quality of the lake is good, insofar as the assessment of such data allows. Assessments of other detailed indicators of water quality (organics, pesticides, pharmaceutical and personal care products) are constrained in this report because fewer recent data are available (see below).

Table 13. Median concentration values for whole lake, composite samples for Lac St. Cyr in 2012 and associated water quality guideline values.

Parameter	Concentration	ASWQ/CCME/USEPA Guidelines (PAL/Recreation/Agriculture)
Na	9.0 mg/L	N/A
K	4 mg/L	N/A
Fe	0.03 mg/L	5.0 mg/L ASWQG (irrigation water), 0.3 mg/L CCME PAL (interim), 1.0 mg/L USEPA PAL (continuous)
Cl^-	6 mg/L	640 mg/L acute exposure; 120 mg/L chronic exposure (ASWQG)
SO_4	40 mg/L	1000 mg/L CCME (livestock watering)
Alkalinity ($CaCO_3$)	124 mg/L	20 mg/L USEPA (continuous concentration)
CO_3	<1 mg/L	N/A
Hardness ($CaCO_3$)	142 mg/L	N/A
TN	0.63 mg/L	1.0 mg/L ASWQG PAL
$NO_3 + NO_2$	0.007 mg/L	100 mg/L CCME (livestock watering)
TP	0.020 mg/L	0.050 mg/L ASWQG (PAL–chronic)
Chl a	3.0 mg/m^3	N/A

Metals

Median concentration values for selected metals in diversion water and lake locations for 2012 are presented in Table 14. Generally, all metals in all three sample locations fell well below the Alberta and CCME Water Quality Guidelines for the Protection of Aquatic Life, except for mercury at the pumphouse. Comparisons were not made to the North Saskatchewan River data as limited metals data were available in the Anderson (2012) report. In general, there were no trends noted in the metals concentrations in the river itself, except for a significant decline in selenium levels in post-2009 data.

Table 14. Median total/recoverable metal concentrations in the diversion water, and in Lac St. Cyr composite samples in 2012. The metals presented are those selected by Anderson (2012) report. Parameters in red exceeded the CCME or ASWQG Protection of Aquatic Life guidelines. Lines in yellow indicate concentrations that vary widely between the pumphouse and the lake. (BDL = below detection limits).

Total or Recoverable Metal	Diversion at Pumphouse 2012 ug/L (n=5)	North Basin 2012 ug/L (n=7)	East/West Basin 2012 ug/L (n=4)	CCME or ASWQ PAL Guideline (ug/L)
Arsenic	1.38	0.743	0.725	5
Cadmium	0.06	0.003	0.0035	0.047
Cobalt	1.22	0.0161	0.00905	-
Copper	3.66	0.3615	0.4035	24
Lead	1.73	0.01035	0.0145	4
Mercury	0.0079	0.000671	0.000558	0.005
Selenium	0.212	0.18	0.154	1
Nickel	3.02	0.07545	BDL	110
Zinc	10.6	0.417	0.4255	30

Summer hypolimnetic iron concentrations in the north and east bays in 1995 were at a median concentration of 43 µg/L, while epilimnetic concentrations had a median value of 11 µg/L. Median pumphouse concentrations for the same year were significantly higher than the lake, at 165 µg/L (ASWQ PAL Guideline value for iron is 300 µg/L).

Trace Organic Contaminants

Water from the diversion and in Lac St. Cyr was tested for various trace organic contaminants up to 2000. The analytical suite of compounds included hydrocarbons and phthalates.

Many organic compounds were detected in the diversion water. Table 15 presents the compounds that were found, as well as the year, the common use of the compound, the applicable surface water quality guideline (if applicable) and the analytical detection limit. None of the detected compounds exceeded surface water quality guidelines, and many were present at the analytical detection limit. The presence of these compounds is likely due to upstream municipal and industrial wastewater inputs into the river.

In the east basin of the lake, there were two detections of di-N-butyl phthalate in 1991 and one in 1995. In the north basin of the lake, there were two detections of methylene chloride (dichloromethane) in 1991. Both detections were at the analytical detection limit of 1 µg/L.

Pesticides

Pesticide data were only available for the diversion up to 2000. Out of the 45 compounds in the analytical suite, only four compounds were detected; 2,4-D (dichlorophenoxyacetic acid) (detected in 1996-1998); gamma-benzenehexachloride (Lindane) (detected in 1998); MCPP (Mecoprop) (detected in 1998) and P,P'-DDT (detected in 1980). Surface water quality guidelines exist for gamma-benzenehexachloride (Lindane) only; the two detections of this compound exceeded this ASWQ Protection of Aquatic Life Guidelines of 0.01 µg/L. Lindane is commonly used as an agricultural insecticide.

Pharmaceuticals

According to recent work done by AESRD (D. McDonald, pers. comm., 2013), there are a number of pharmaceutical and personal care product residues that can be found in the North Saskatchewan River. There are no data on these products for the diversion or Lac St. Cyr proper, but presumably some of these compounds are entering the lake.

Commonly found compounds include caffeine, codeine, naproxen (a muscle relaxant) and diclofenac (anti-inflammatory) (Figure 35). The effects of these compounds in the NSR are not well understood, either from an environmental or drinking water perspective. These compounds may not be effectively removed during conventional wastewater treatment, or by conventional drinking water treatment.

Table 15. Trace organic compound detections in diversion water up to 2000.

Compound	Year(s)	No. of Detections	Concentration (µg/L)	ASWQG PAL	Detection Limit (ug/L)	Use
Methylene chloride (dichloromethane)	1989-1991	13	1-15	98.1		Solvent
P-isopropyltoluene	2000	1	0.1	N/A	0.1	Solvent; used as a chemical intermediate in the flavor and fragrance industry; found as a byproduct of paper manufacturing
1,2,4-trimethylbenzene	2000	1	0.2	N/A	0.1	Used as a gasoline additive and a sterilizing agent in dyes, perfumes and resins. Naturally occurring in petroleum
Butylbenzyl phthalate	1999 2000	2	0.148 0.302	N/A	0.1	Used as a plasticizer for PVC
Di-N-butyl phthalate	1989 1990 1993 1999 2000	10	0.22 to 4	19	0.1	Used in plastics, paints, glue, insect repellents, carpet backing, nail polish and hair spray
Diethyl phthalate	2000	1	0.155	N/A	0.1	Used to bind cosmetics and fragrances; as a detergent base; a plasticizer and in aerosol sprays.
Polychlorinated biphenyls	1979 1980	6	0.1	N/A	0.1	Were at one time used in coolants; their use has been banned

Toluene	1999 2000	2	0.1 0.2	2.0	0.1	Solvent; occurs naturally in crude oil; octane booster in gasoline
Bromomethane	1989	1	17	N/A	1	Used as a pesticide and for fumigation
Bis (2-ethylhexyl) phthalate	1986 1988-1991	9	1 4.1	N/A	1	Plasticizer in medical devices
Hexadecanoic acid	1990	2	3	N/A	3	Used to produce soaps, cosmetics, processed foods and release agents. Found in palm oil, meats, cheese, butter and milk
O-Xylene	2000	1	0.1	N/A	0.1	Used in the production of plasticizers
Chloroethane	1989	1	6	N/A	1	Used as a gasoline additive; propellant; anaesthetic; refrigerant. Now used to make binders and thickening agents for cosmetics and paints
M- + P-Xylene	2000	1	0.1	N/A	0.1	Found in gasoline and airplane fuels; used as a solvent and as a chemical precursor

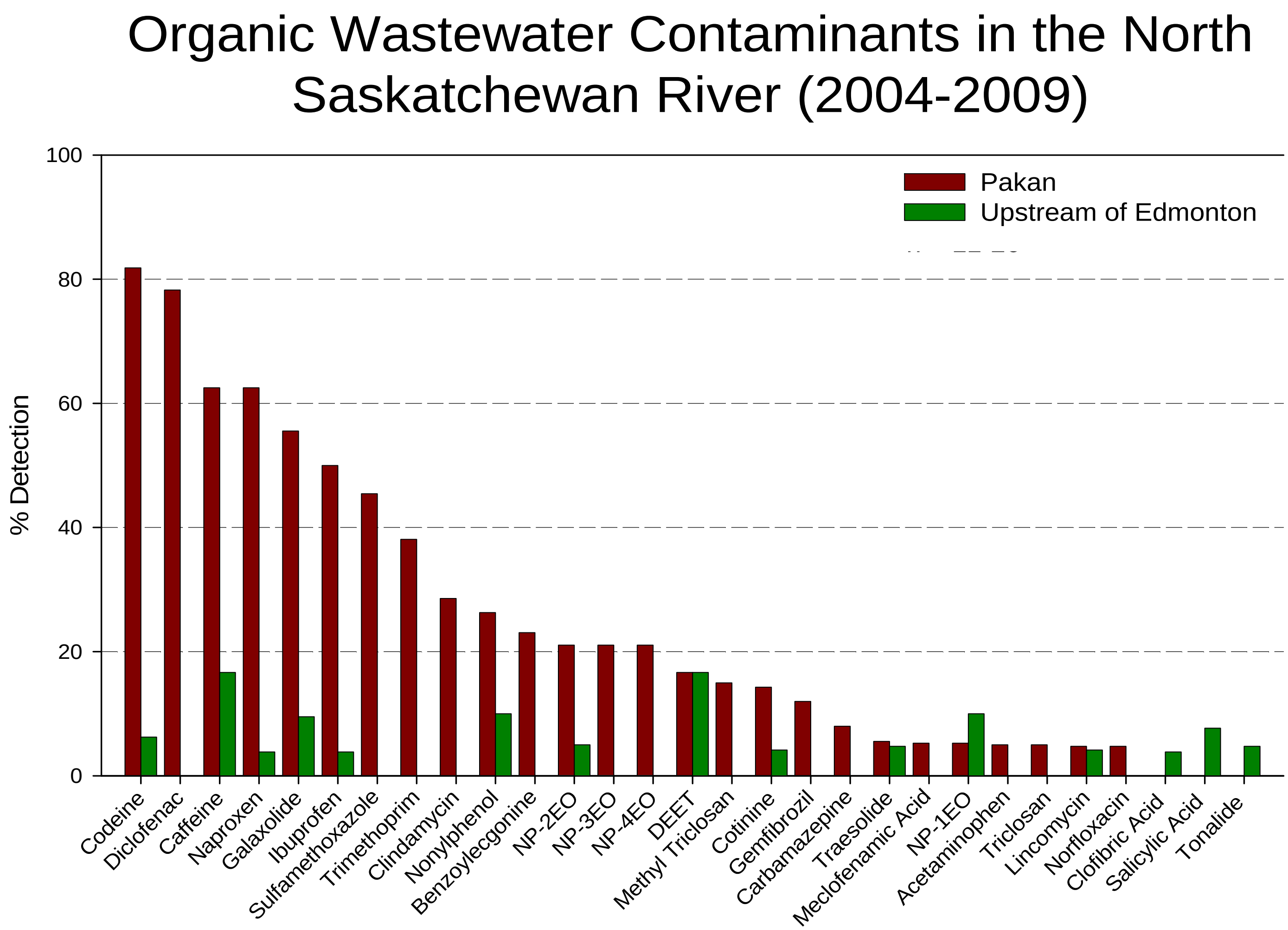


Figure 35. Pharmaceutical and personal care product detections in the North Saskatchewan River, upstream and downstream of Edmonton (D. McDonald, pers. comm., 2013).

Nutrients

The following graphs show changes in concentrations of common trophic indicators (Chlorophyll a, total phosphorus*, total nitrogen, ammonia-N, $NO_{2+}NO_3$-N) for whole lake composite samples, and each of the basins separately. Overall, these parameters show a similar trend, with increases in concentrations occurring in the early to mid-1980s, and declines in concentrations seen through the mid 1990s and into 2012. Composite data for the whole lake are presented, and epilimnetic and hypolimnetic concentrations are presented for certain variables for the east and north basins. Data for the west basin are very limited, and discrete grab sample data were not taken after 1980 in that basin. North basin and east/west composite sample data for 2012 have been combined to represent a 2012 "whole lake" composite sample. Recent discrete grab sample data are not available for the east and west basins.

East, west and north basin samples were also examined using discrete grab sample data from the epilimnion (0-1 metre depth). Total phosphorus was graphed using hypolimnetic data as well.

Recent water quality trends in the east and west basins of the lake cannot be assessed due to the paucity of data.

**Note: Detection limits for total phosphorus in 1976-1977 were high (50 mg/m^3). This limit was lowered to 20 mg/m^3 in 1978, and then to 2 mg/m^3 in 1981. Data for this parameter were available as early as 1976, but all measurements before 1978 were below the 50 mg/m^3 detection limit. Therefore, the TP data from the late 1970s were of limited diagnostic use.*

Whole Lake Composite Samples

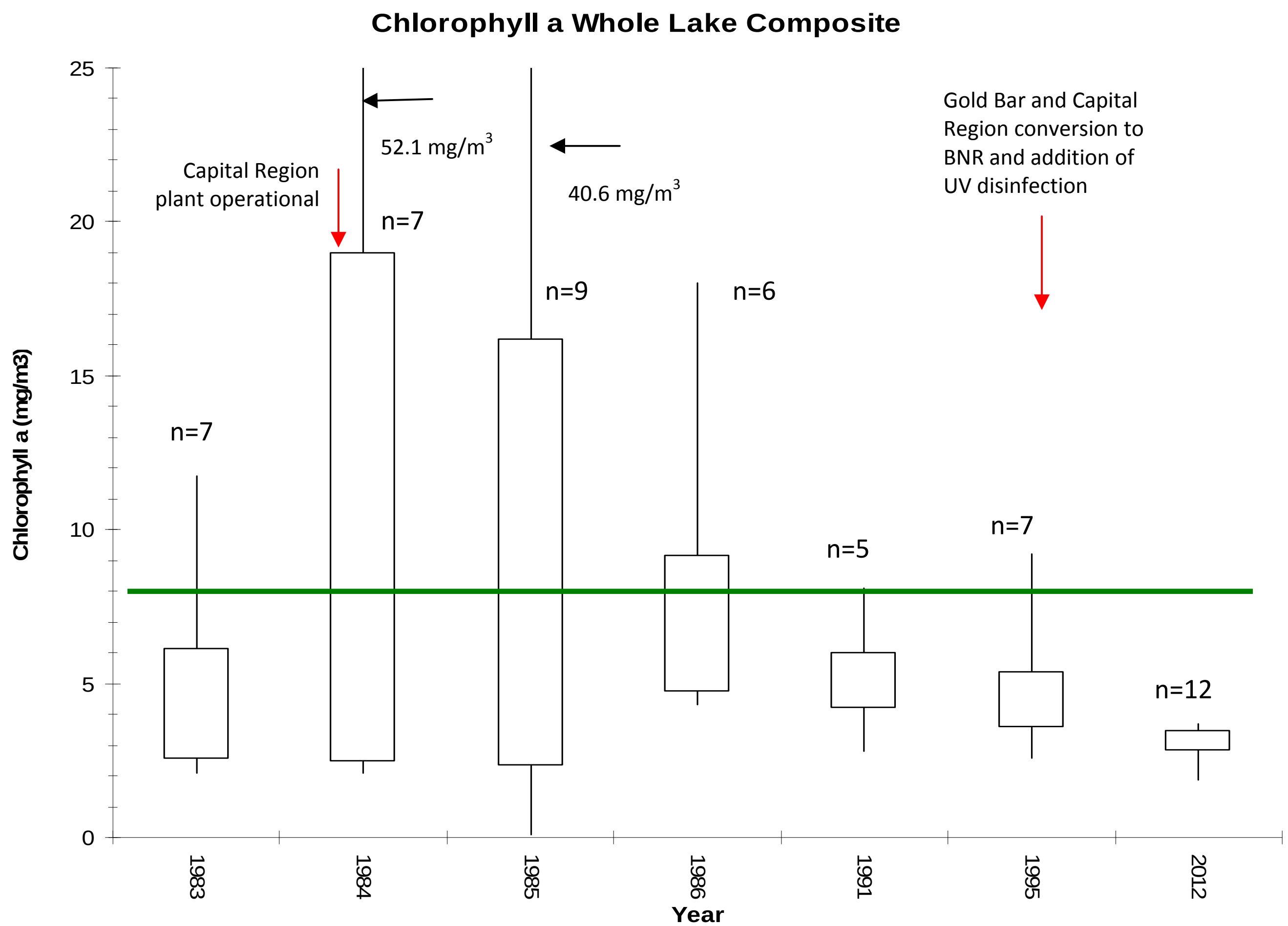


Figure 36. Chlorophyll-a levels in whole lake composite samples. Values greater than the scale are shown next to the arrows. Peak concentrations are seen in 1984 and 1985, and levels declined into 2012. The green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). Based on chlorophyll-a concentration criteria the lake is now in a mesotrophic state.

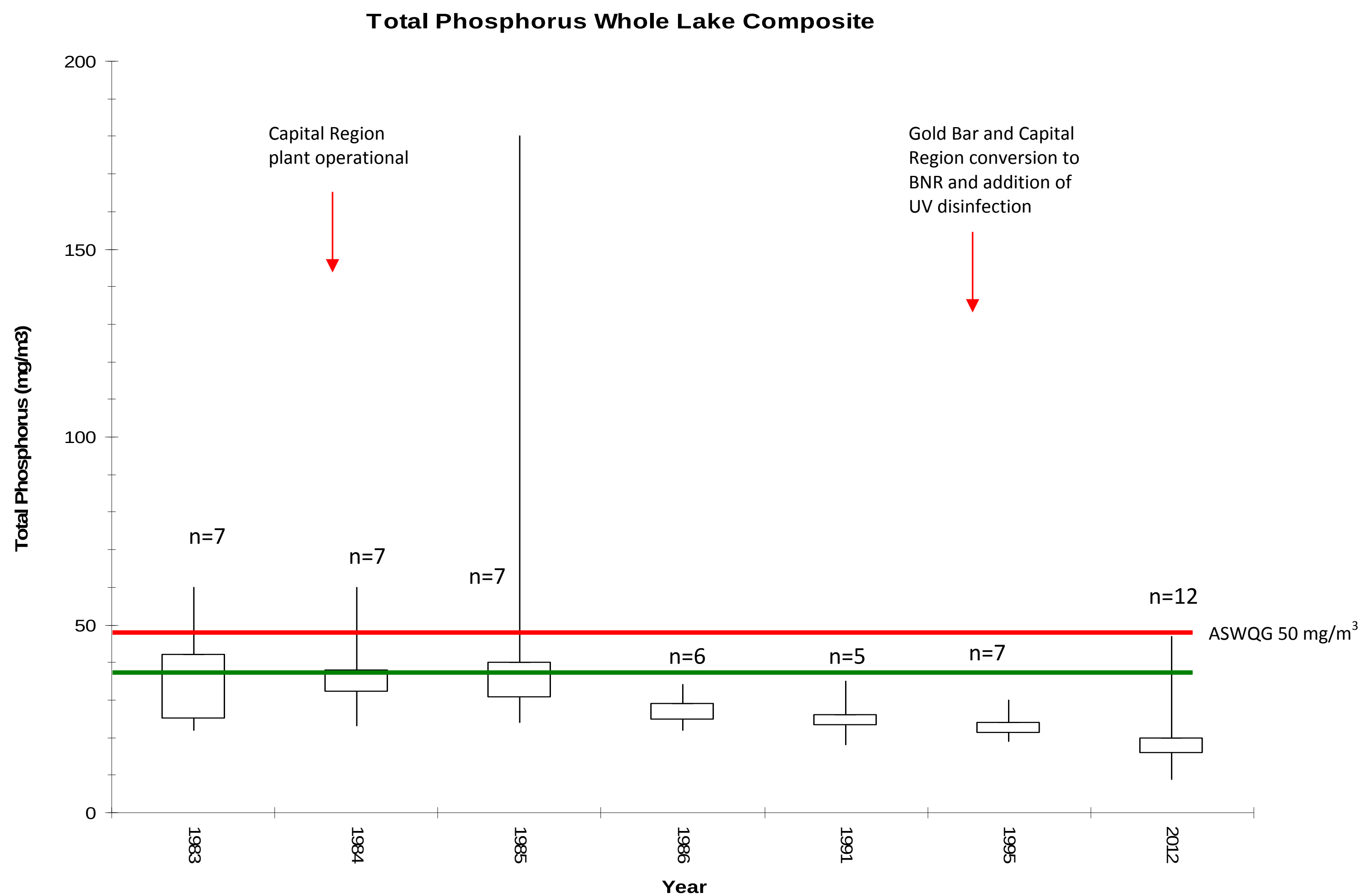


Figure 37. Total phosphorus levels in whole lake composite samples. A decreasing trend in concentrations can be seen. The Alberta Surface Water Quality Guideline for the Protection of Aquatic Life is indicated by the red line, while the green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). Based on TP concentration criteria the lake is now in a mesotrophic state.

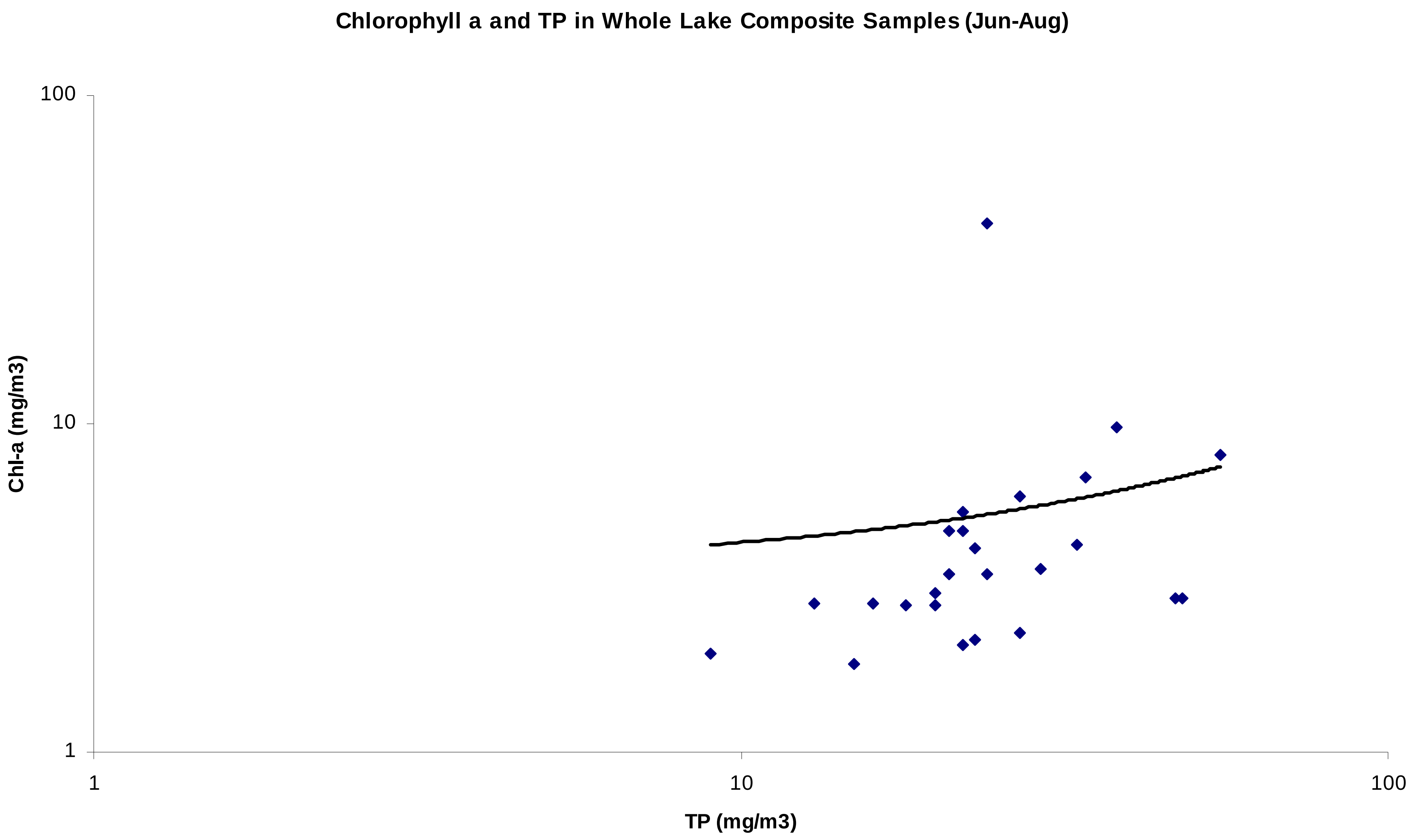


Figure 38. The chlorophyll-a total phosphorus relationship for "whole lake" sample data (June-August). Chlorophyll-a concentrations rise slightly as total phosphorus levels increase.

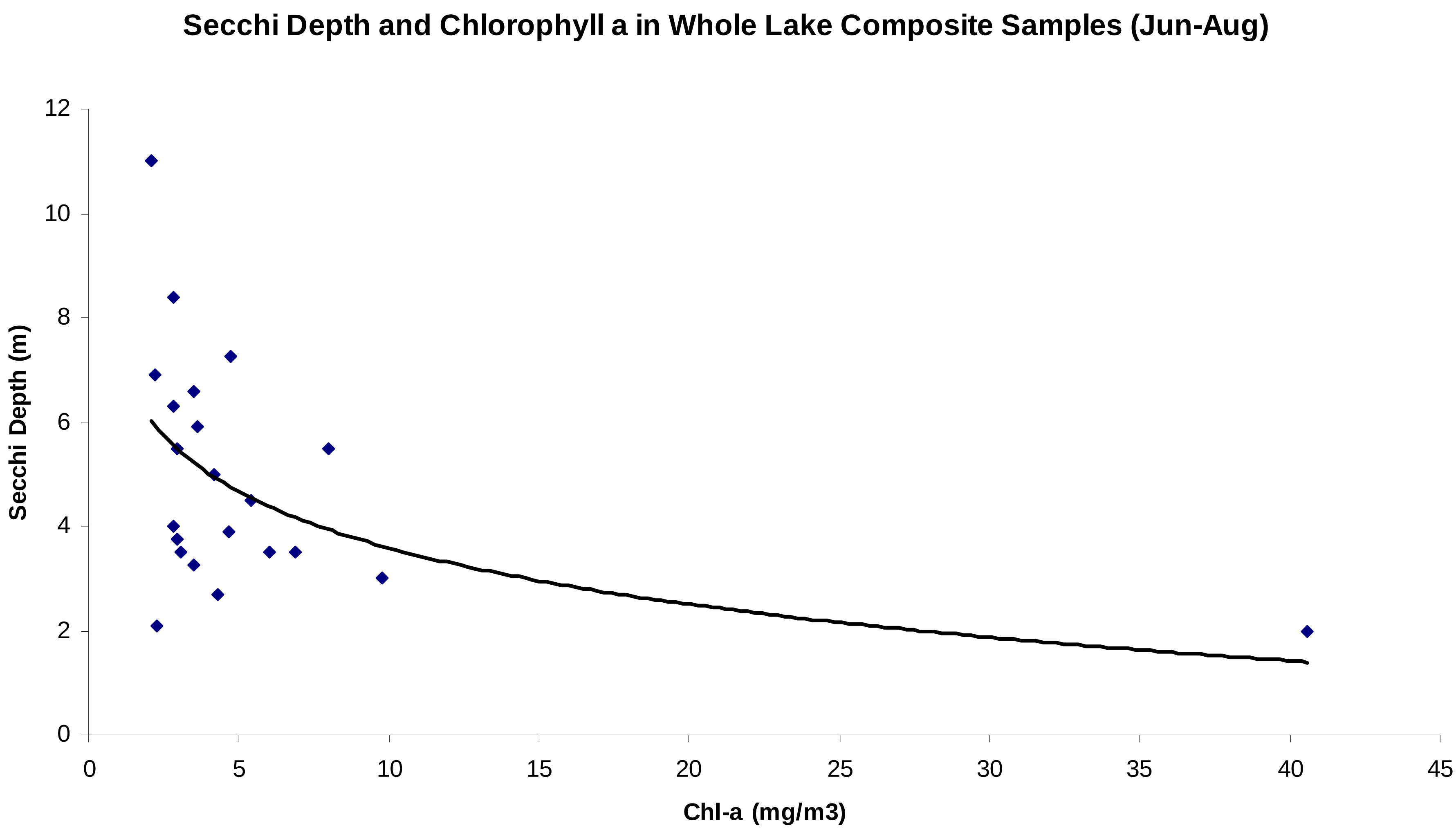


Figure 39. Secchi depth and chlorophyll-a relationship in "whole lake" sample data from June to August. This plot weakly demonstrates that as chlorophyll-a concentrations increase, Secchi depths (and therefore water clarity) decrease.

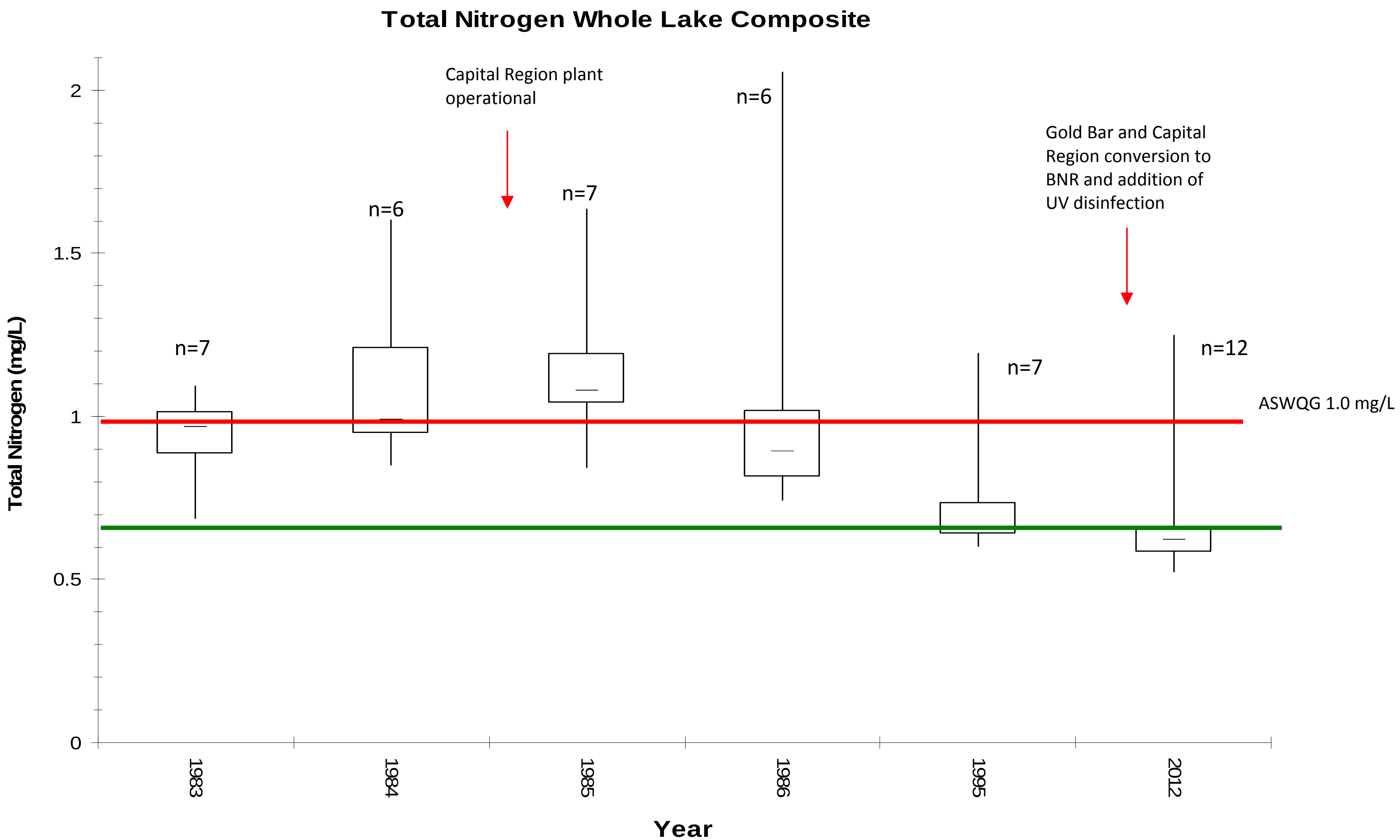


Figure 40. Total nitrogen levels in whole lake composite samples. High concentrations in 1984 and 1985 are followed by a decreasing trend. The Alberta Surface Water Quality Guideline for the Protection of Aquatic Life is indicated by the red line, while the green line indicates the transition concentration from mesotrophic status (Vollenweider, 1982; Nurnberg, 1996). Based on TN concentration criteria the lake is now in a mesotrophic state.

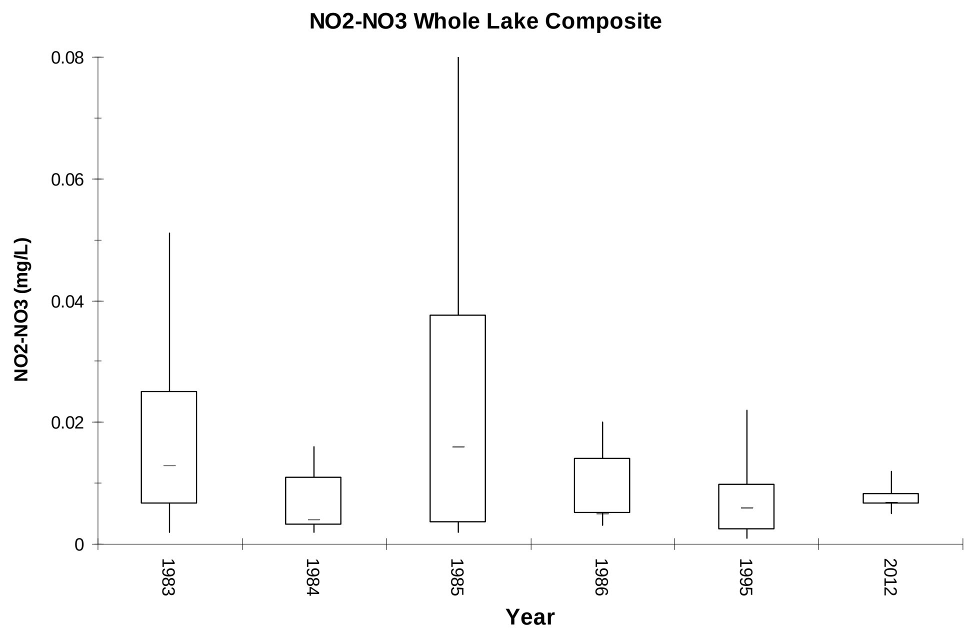


Figure 41. Nitrite-nitrate levels in whole lake composite samples. A decreasing trend after 1985 is evident.

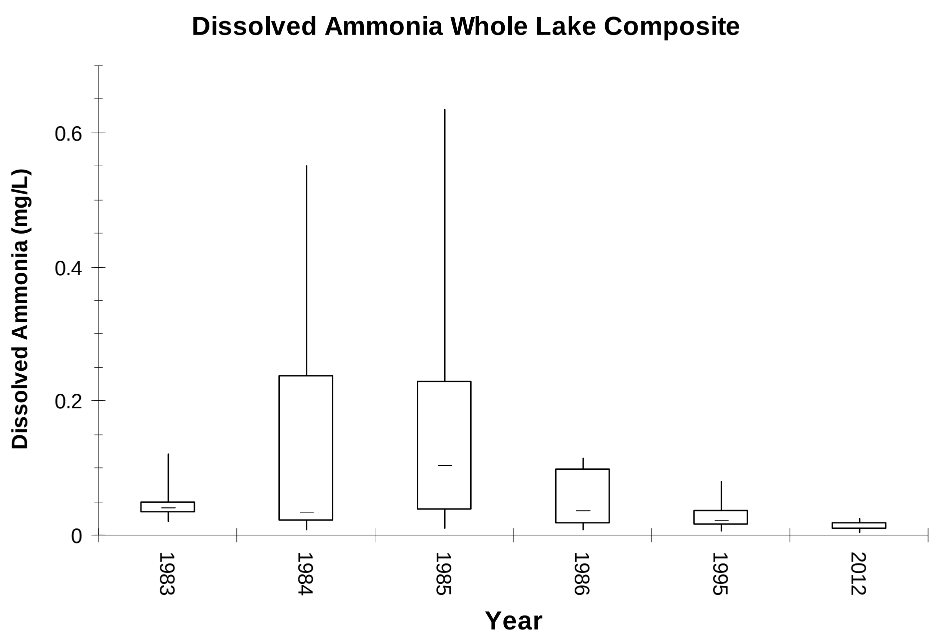


Figure 42. Dissolved ammonia concentrations in whole lake composite samples. A decreasing trend after 1984 and 1985 is evident. Concentrations are well below ASWQ PAL guideline values of 1.37 to 2.20 mg/L.

East Basin Samples

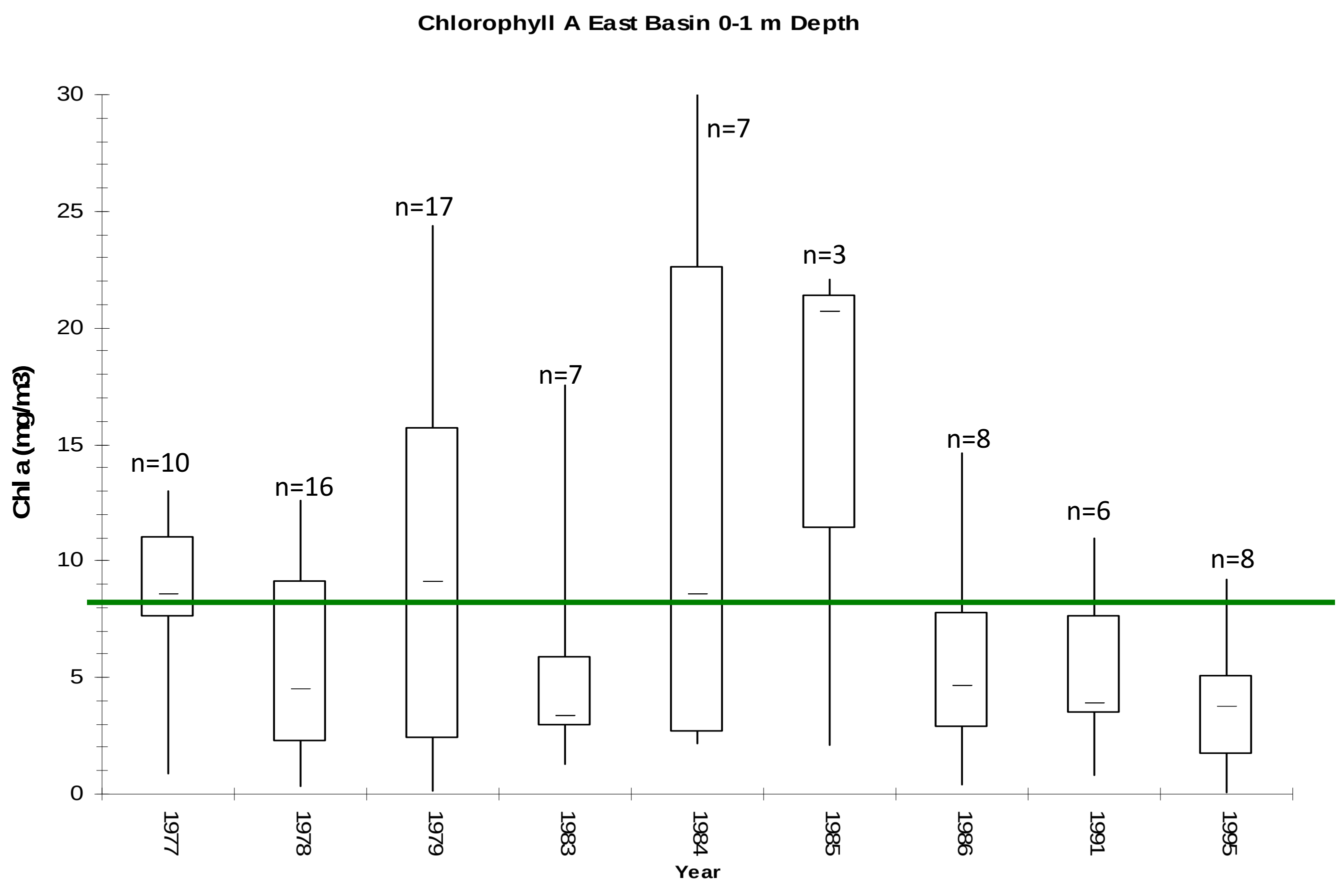


Figure 43. Chlorophyll-a concentrations in east basin epilimnion (0 to 1 metre depth) samples. The green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). Similar to the whole lake composite data, a decreasing trend after 1984 and 1985 is evident and the lake had returned to a mesotrophic state by 1986.

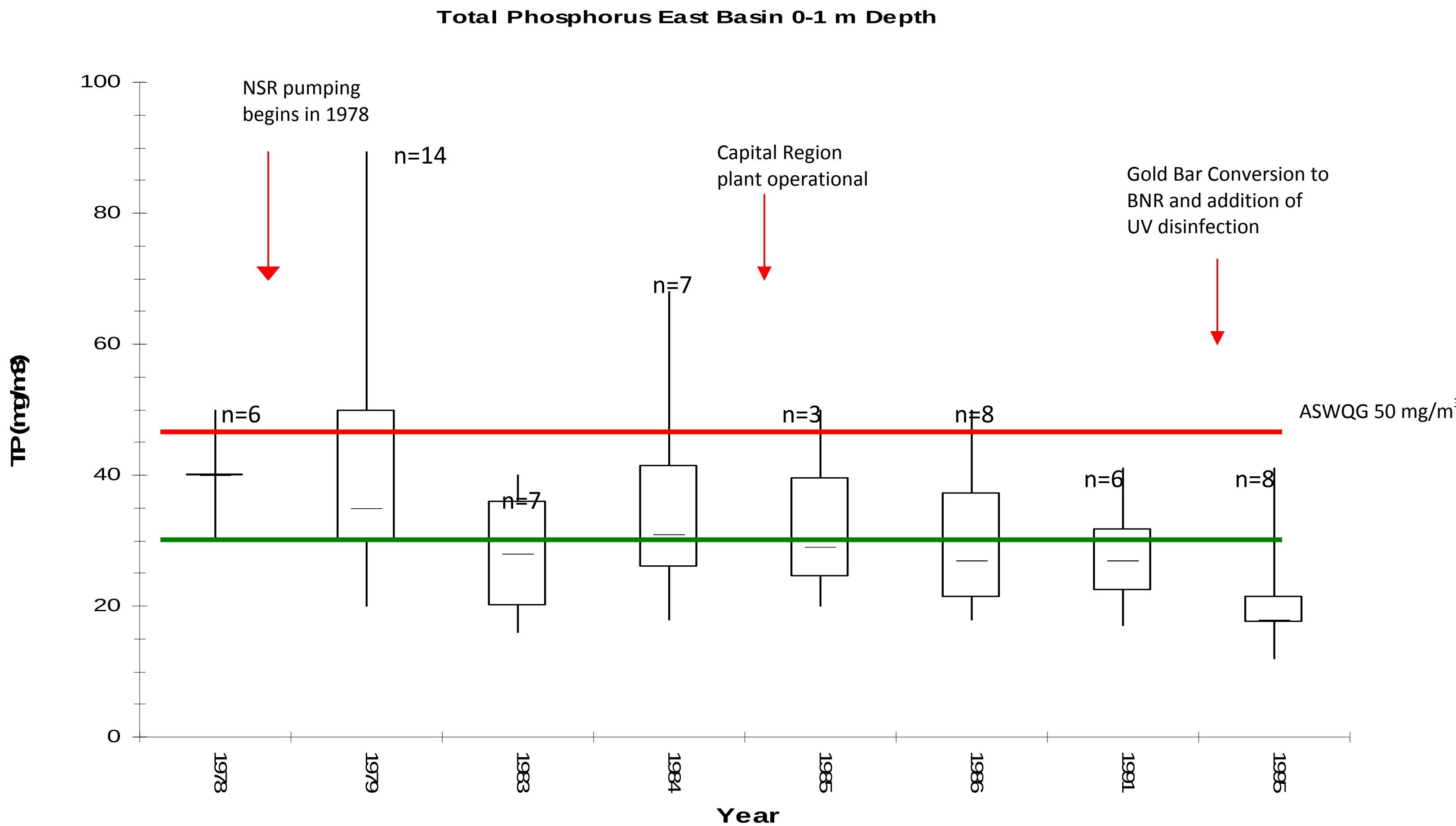


Figure 44. Total phosphorus concentrations in east basin epilimnion (0 to 1 metre depth) samples. A slight decreasing trend in concentrations to 1995 can be seen. The green line indicates the transition concentration from mesotrophic to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). The results are similar to the whole lake composite data, and the lake was mesotrophic by 1995. The red line indicates the ASWQ PAL guideline value.

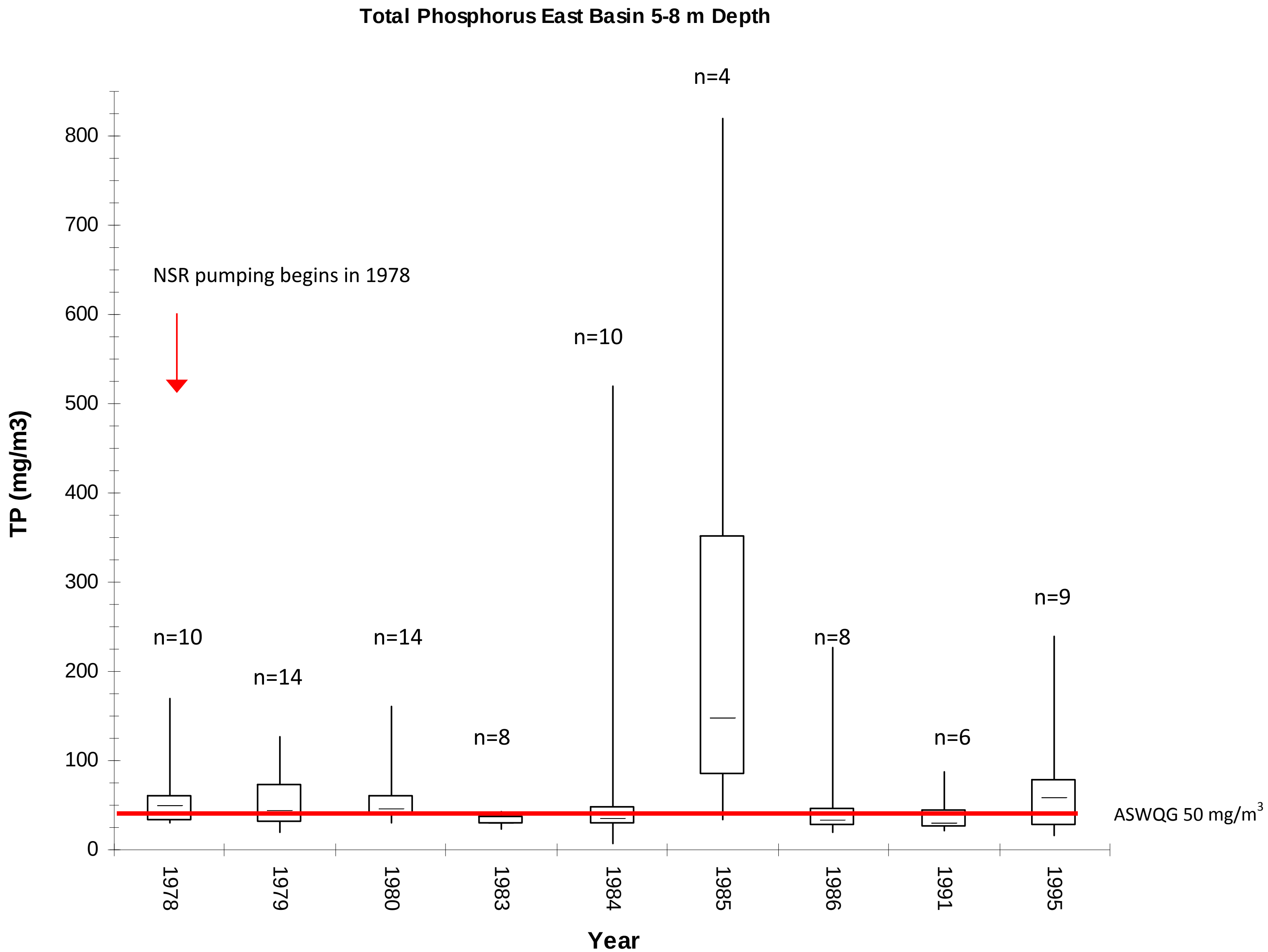


Figure 45. Total phosphorus concentrations in east basin hypolimnion (5 to 8 metre depth) samples. Phosphorus concentrations were very high in 1984 and 1985 at these depths, indicating a significant change in conditions at or near the sediment-water interface. The red line indicates the ASWQ PAL guideline value.

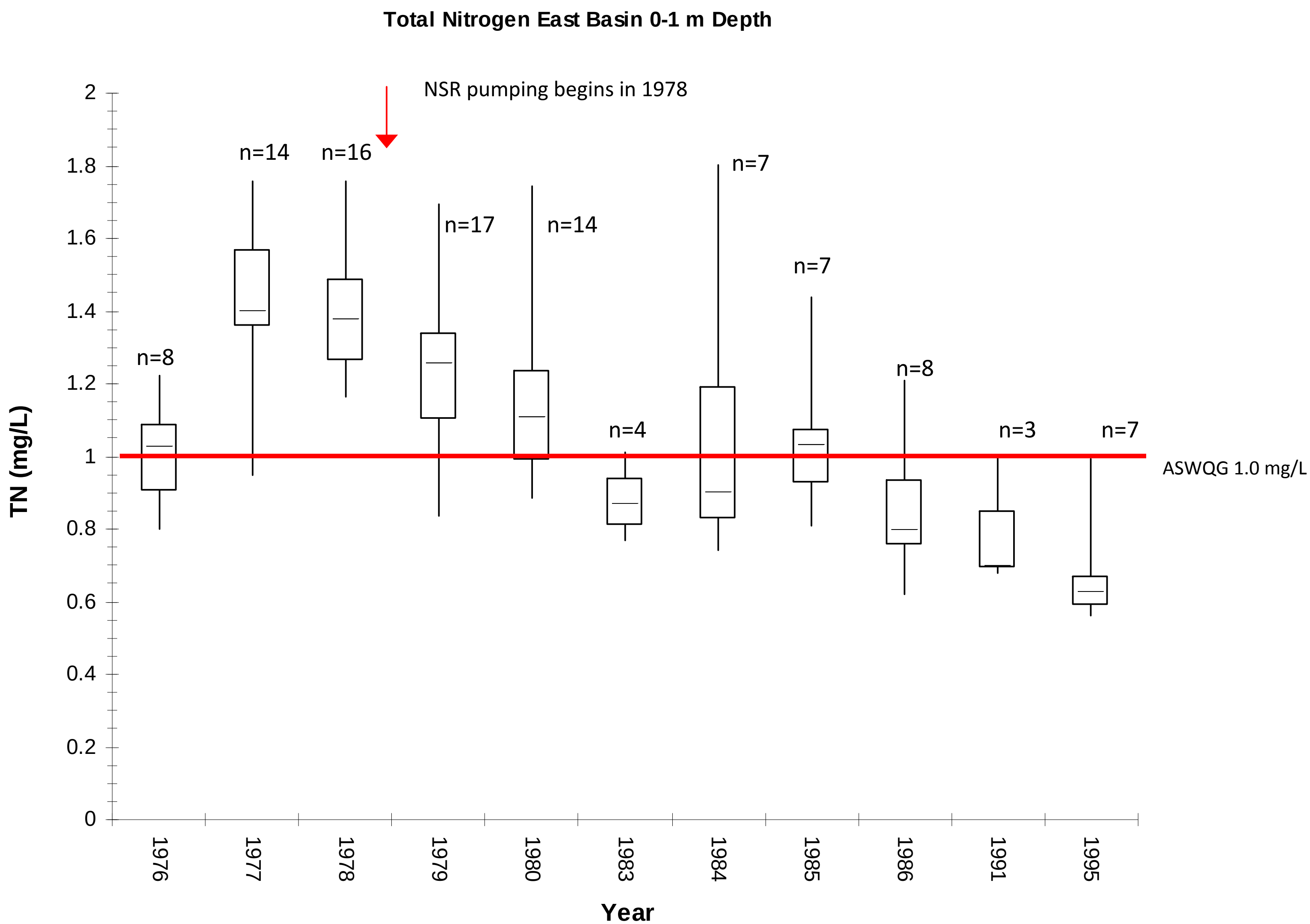


Figure 46. Total nitrogen concentrations in east basin epilimnion (0 to 1 metre depth) samples. Total nitrogen declined to 1995, reflecting changes in river water quality. The red line indicates the ASWQ PAL guideline value.

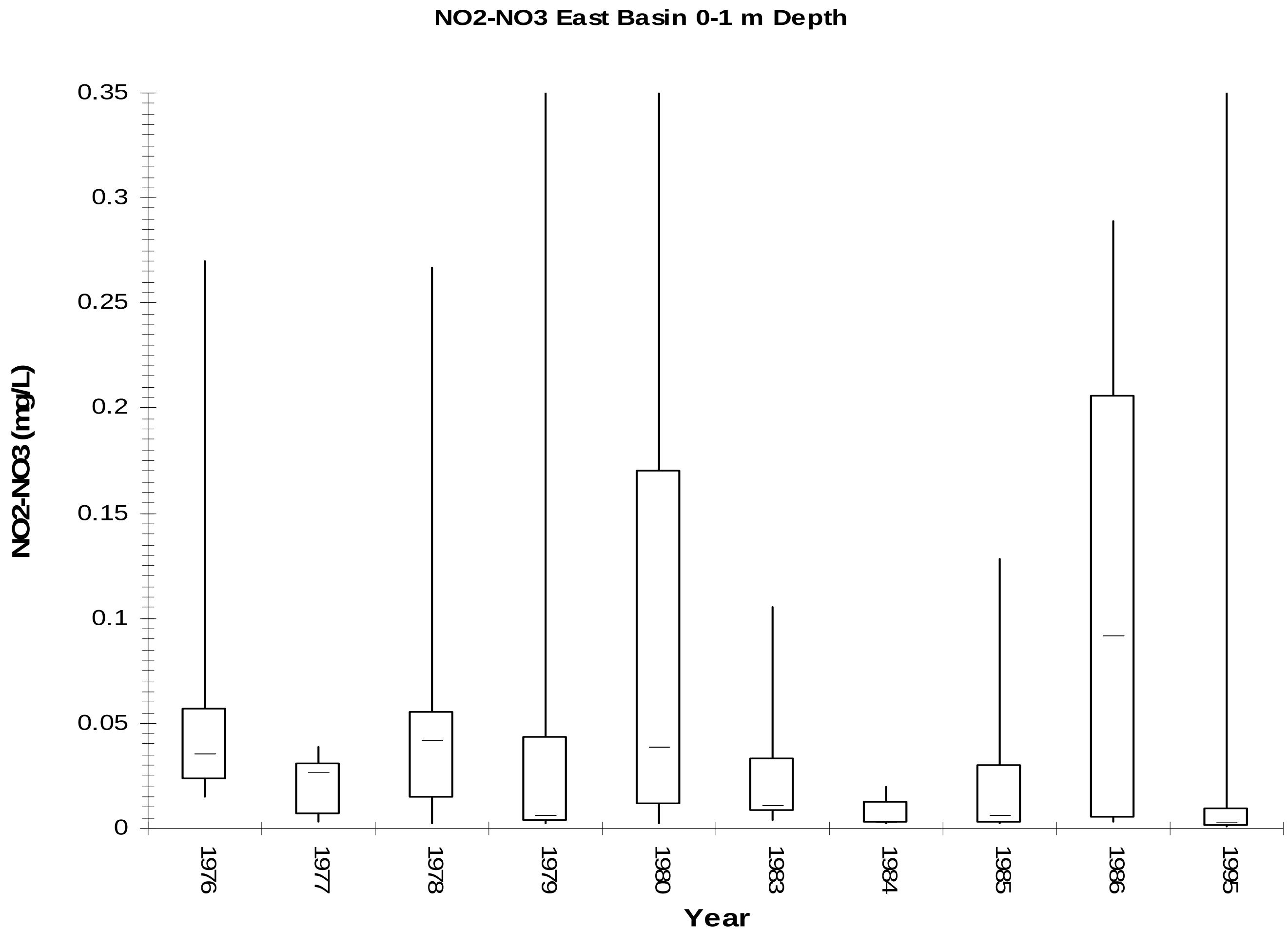


Figure 47. Nitrite-nitrate concentrations in east basin epilimnetic (0 to 1 metre) samples. Peak concentrations in each year were usually evident in early spring shortly after ice-out and declined rapidly thereafter.

West Basin Samples

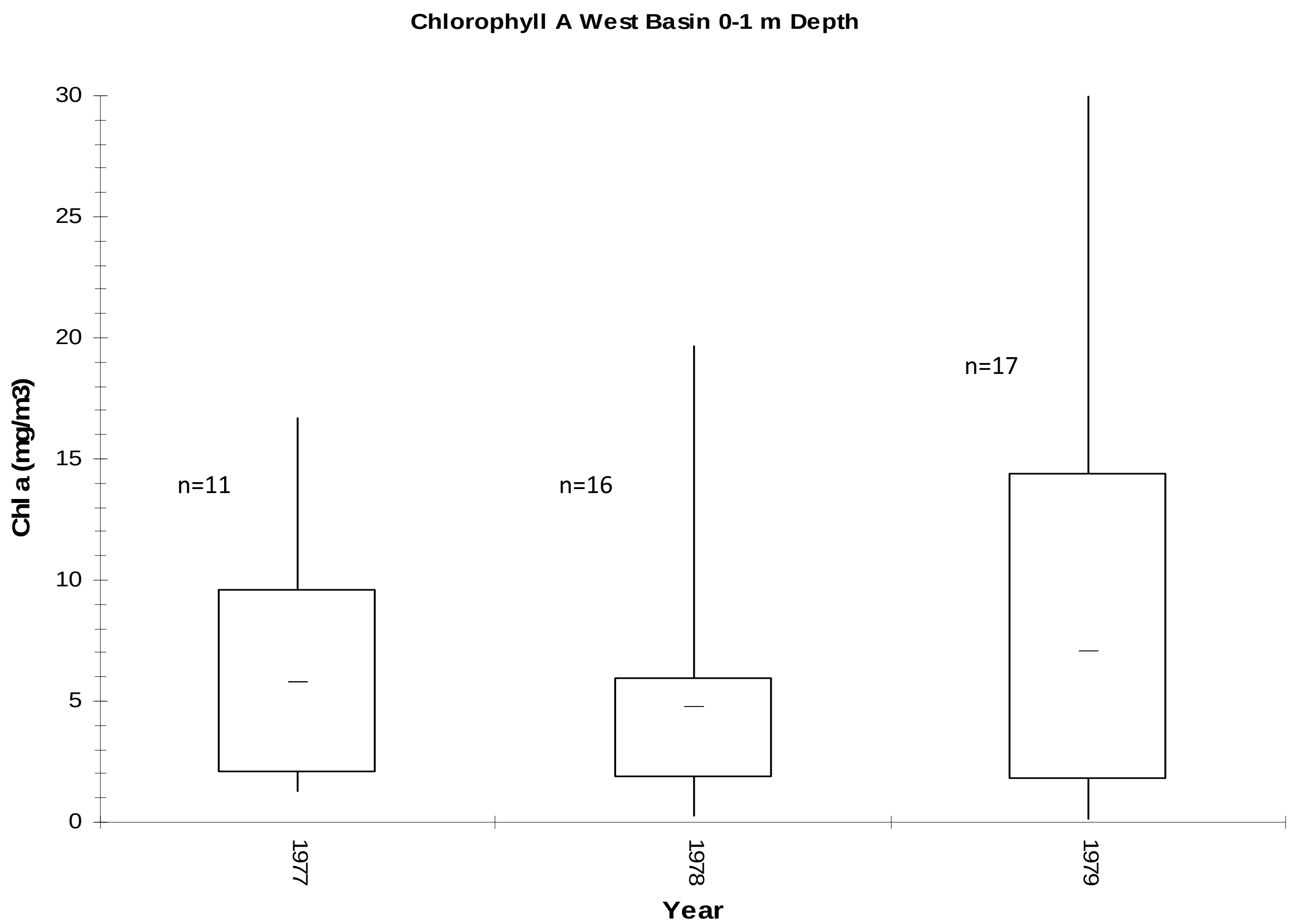


Figure 48. Chlorophyll-a (1977 to 1979) in the west basin epilimnion (0 to 1 metre depth) samples. Limited data were available for this basin. An early fertilization response to the diversion is suggested in the 1979 data.

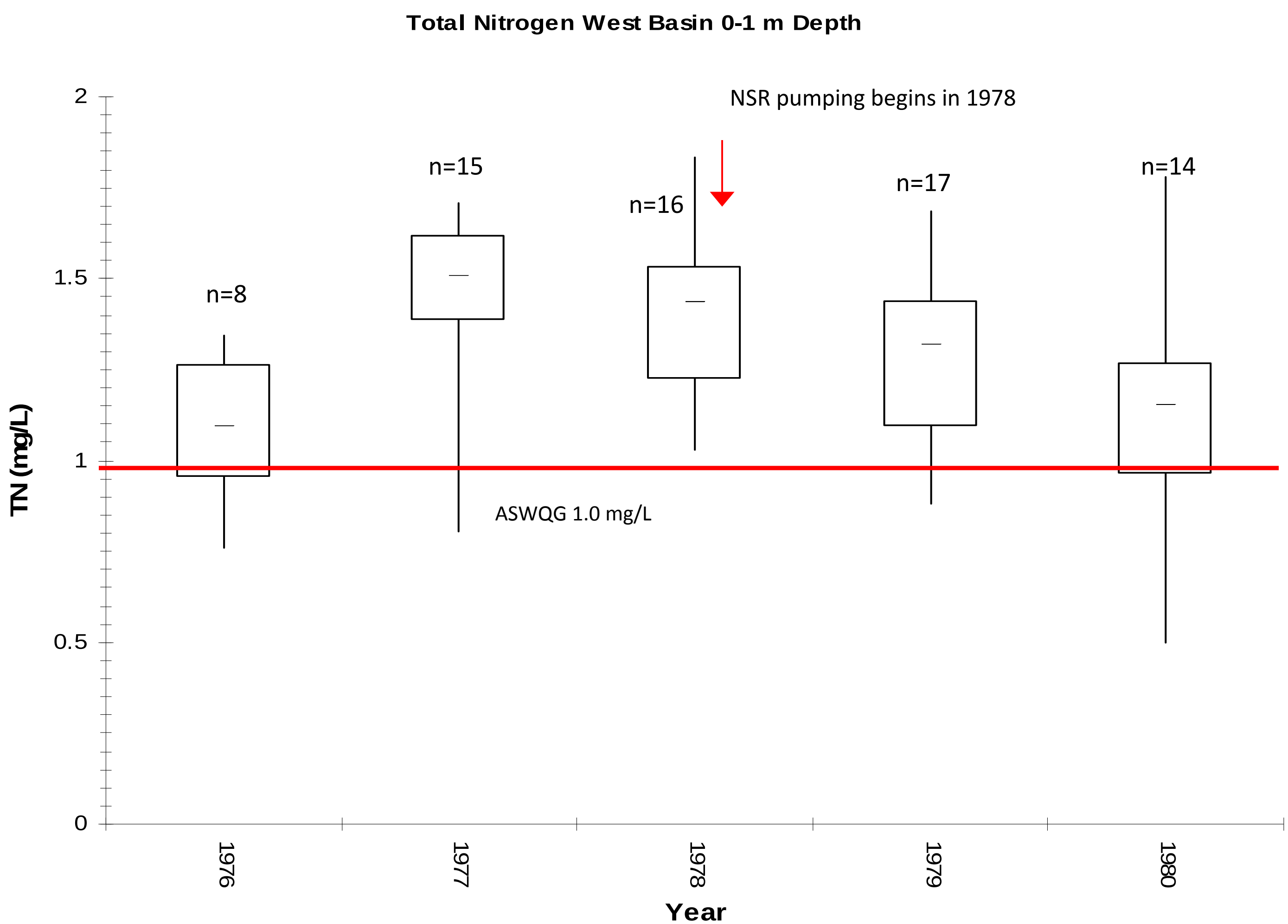


Figure 49. Total nitrogen in the west basin epilimnion (0 to 1 metre depth) samples. The red line indicates the ASWQ PAL guideline value. Limited data were available for this basin; no assessment is made.

North Basin Profile Samples

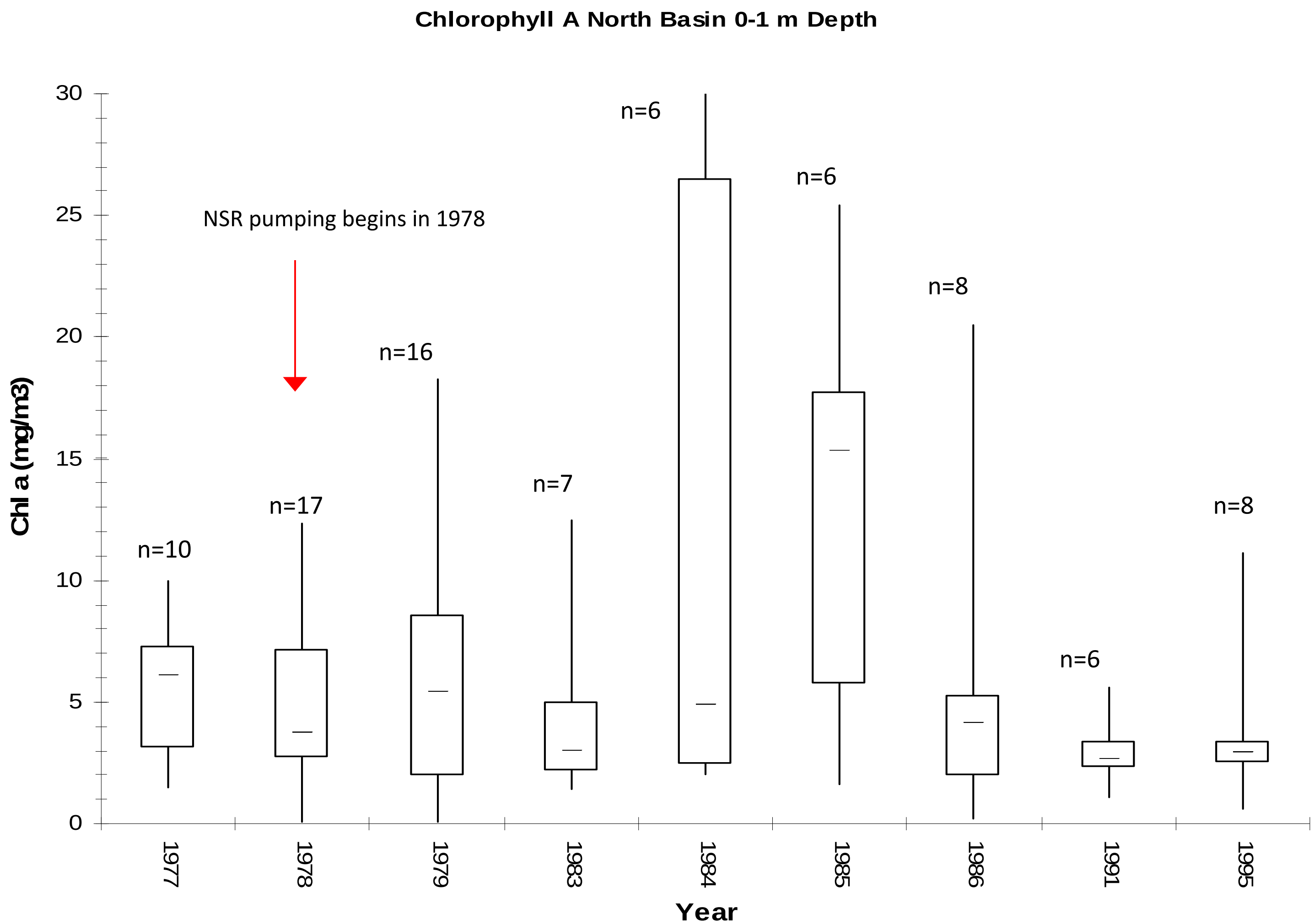


Figure 50. Chlorophyll-a in the north basin epilimnion (0 to 1 metre depth) samples. Concentrations declined after peaks in 1984 and 1985.

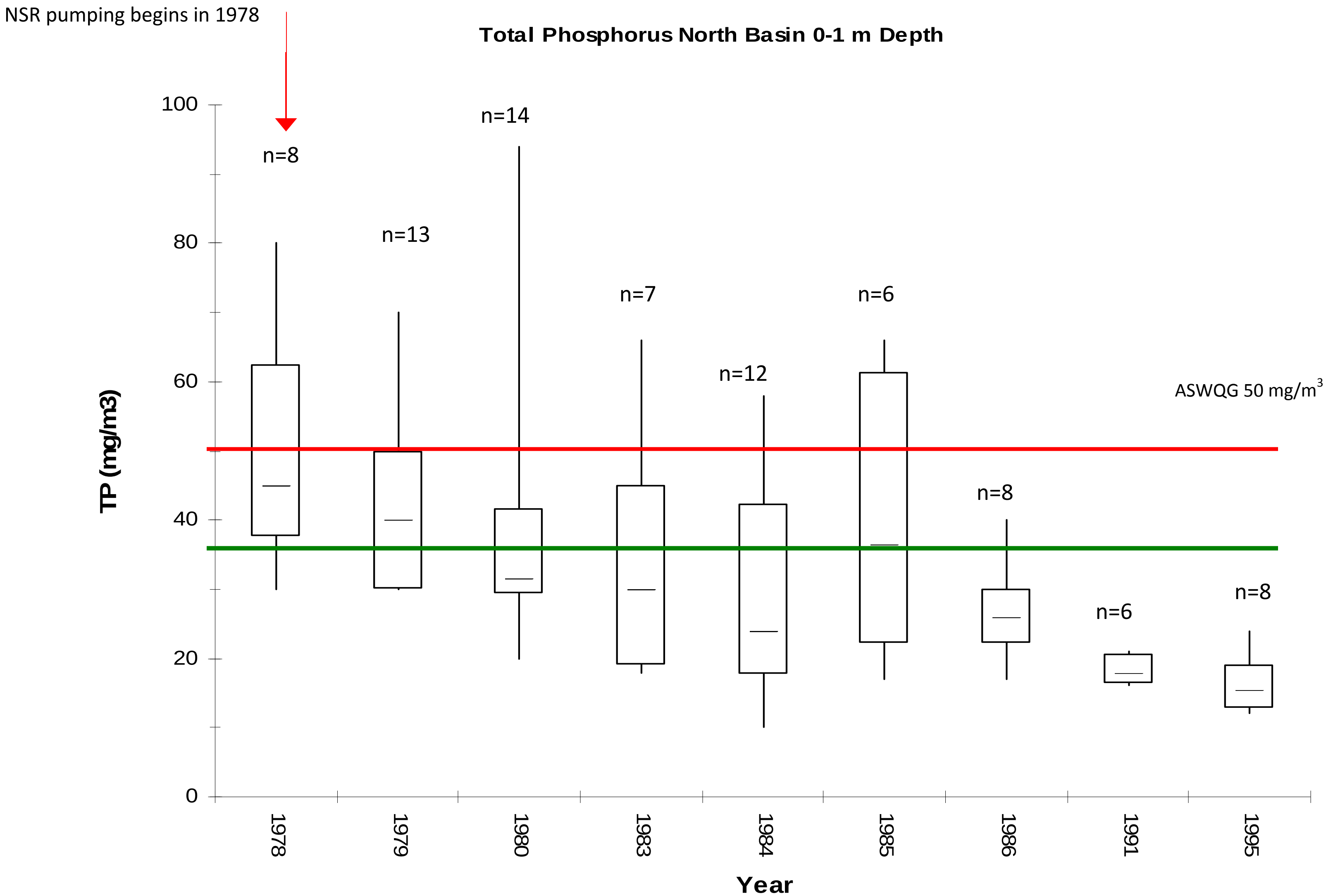


Figure 51. Total phosphorus in the north basin epilimnion (0 to 1 metre depth) samples. The green line indicates the transition concentration from mesotrophic status to eutrophic status (Vollenweider, 1982; Nurnberg, 1996). The lake had evolved to a mesotrophic state by 1986. The red line indicates the ASWQ PAL guideline value.

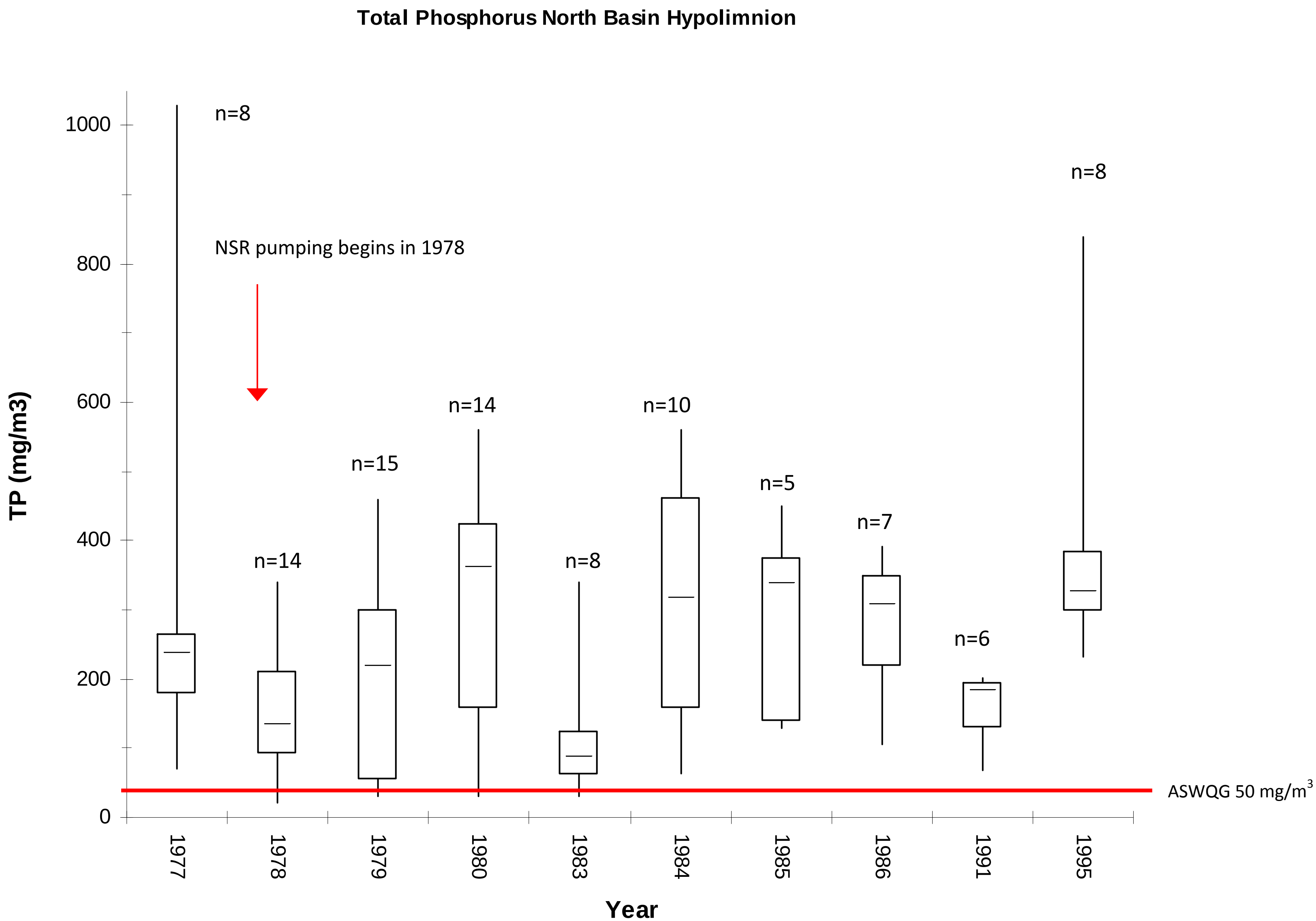


Figure 52. Total phosphorus in the north basin hypolimnion (12 to 21 metre depth) samples. The red line indicates the ASWQ PAL guideline value. Total phosphorus is very high at these depths, suggesting phosphorus release from the bottom sediments and limited vertical mixing.

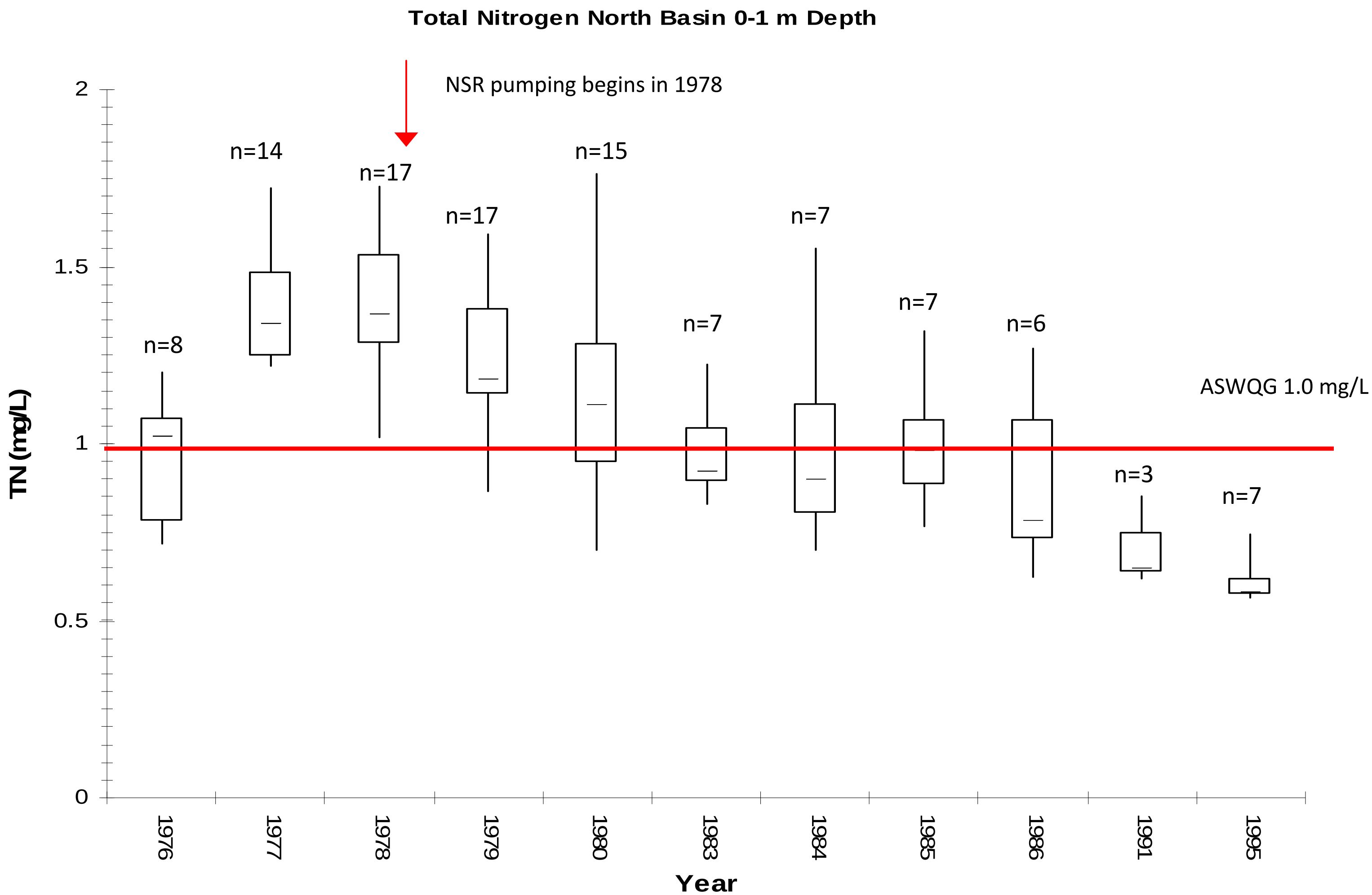


Figure 53. Total nitrogen in the north basin epilimnion (0 to 1 metre depth) samples. The red line indicates the ASWQ PAL guideline value. TN declined steadily into 1995.

Discussion

Due to the greater depth of the north basin (maximum depth = 20 metres), strong thermal stratification occurs, creating anoxic conditions in the hypolimnion. This particular basin is sheltered around the shoreline, which results in less wind fetch and shallower mixing depths. This basin may only experience a turnover within the water column in spring and fall and, as noted, spring mixing may be incomplete in certain years.

The east and west basins exhibit slightly different patterns in dissolved oxygen concentrations because of their shallower depths. The west basin shows mixing periods in June and September, and with slight oxygen depletion in mid-summer. The east basin is slightly deeper, and more oxygen depletion is evident throughout summer.

The diversion from the NSR commenced in 1978. The lake was immediately enriched by the high nutrient content of the river water; this was further enhanced by an upstream industrial lagoon leakage incident in 1984. This enrichment appears to have peaked in 1984-1985, and then steadily declined through the years to 2012.

The water quality of the river has improved significantly in recent years due to improvements in water treatment processes at both the Capital Region and Gold Bar Wastewater Treatment plants, and this improvement is directly reflected in lake water quality. Average river total phosphorus concentrations are now near 15 mg/m^3, an order of magnitude less than the concentrations observed in the NSR in the early 1980s.

Lac St. Cyr was classified as a mesotrophic lake in the Atlas of Alberta Lakes (1991). Mesotrophic means "having a moderate level of plant and algal productivity", typically with chlorophyll a levels in the range of 2.5 to 8 mg/m^3 (Vollenweider 1982). Recent data from whole lake composite samples confirm that the lake remains in a mesotrophic state, with average chlorophyll a levels of approximately 3.0 mg/m^3.

Chlorophyll-a, TP, and Secchi depth all appear to have the relationships common to freshwater lakes in Alberta. Chlorophyll-a increases are related to TP increases; Secchi depth transparency decreases are related to chlorophyll-a increases. Lac St. Cyr appears to be phosphorus limited, as demonstrated by the TN/TP ratios in the data which are all greater than 16:1.

From a trophic indicator viewpoint Lac St. Cyr seems to be in a favorable condition, however the very large pools of phosphorus observed in bottom waters near the sediment-water interface are of interest (Figures 45 and 52). The deeper northern basin of the lake appears to mix poorly in spring, allowing the winter accumulation of phosphorus to carry through into the summer season trapped in bottom waters. As long as this phosphorus-rich bottom water remains trapped in the hypolimnion few issues are apparent.

Nitrite-nitrate nitrogen and dissolved ammonia show similar trends in concentrations, with peaks occurring in the mid 1980s and decreases to 2012. All levels have been well below ASWQG PAL values.

Other chemical indicators of water quality reveal that the lake is becoming closer in character to that of the NSR, due to the large annual winter diversions of river water. Potassium in the lake water declined from 10 mg/L in 1985 to 4 mg/L in 2012, reflecting the lower river water potassium concentration of about 1 mg/L. Similarly, lake concentrations of sulphate and chloride have increased; both were initially lower than river water. The concentration of sulphate was 13 mg/L in 1983-1986 and has increased to 40 mg/L in 2012; river water concentrations were 50 mg/L. Chloride concentrations have increased from 3 to 6 mg/L; river water chloride concentrations are approximately 4.5 mg/L.

Anderson (2012) suggests that the increase in sulphate concentrations in the North Saskatchewan River may be due to non-point source loadings from the surrounding watershed. It is important to note that sulphate can compete with phosphorus for binding sites with iron in bottom sediments; sulphate increases in the lake water may result in more phosphorus being released into the water column from sediments (Hupfer and Lewandowski, 2008; Holmer and Storkholm, 2001).

The data record for trace organics and pesticides in the lake is incomplete, and allows no interpretation past 2000. The lake has not been sampled for pharmaceutical and personal care product residues.

5.0 Preliminary Phosphorus Budget

Phosphorus is considered to be the most common limiting chemical factor for algal growth in freshwater lakes in central Alberta (Prepas and Trew, 1983). The nitrogen content of our freshwater lakes can also be an important factor, and may influence the types of algal species succession that occur during the open-water growing season (Prepas and Trimbee, 1988). Other factors such as salinity, turbidity and physical mixing patterns are also important determinants of the quantity and types of algae that develop (Bierhuizen and Prepas, 1985). Algal blooms are a major feature of summer water quality in Alberta lakes, affecting water transparency and aesthetics directly, and other internal lake processes such as deoxygenation and cyanotoxicity. Therefore, the control of excessive algal growth and blooms is an important goal of lake management.

The use of phosphorus budgets has become commonplace in the lake research and management literature, and they are used as diagnostic tools to identify pollution problems and point the way to long-term management options for both the watershed and the lake (Rast et al., 1989; Volleweider, 1982). The development of phosphorus budgets and models has been an ongoing field of limnological research since the first watershed/lake nutrient relationships were hypothesized in the 1960s. Today, computerized phosphorus models are available to provide rapid assessments of current lake conditions and the effects of future management scenarios.

A preliminary phosphorus budget for Lac St. Cyr was presented in the Atlas of Alberta Lakes (1991). The budget estimated the amount of phosphorus being supplied by external sources in the post-diversion period, based on the gross drainage area. The budget is presented in Table 16.

Table 16. Theoretical total phosphorus supply to Lac St. Cyr, taken from the Atlas of Alberta Lakes (1991).

Source		Phosphorus (kg/yr)	Percentage of Total
watershed	forested/bush	151	24
	agricultural/cleared	260	41
	residential/cottage	50	8
sewage[a]		—	—
precipitation/dustfall		54	8
diversion input		119	19
	TOTAL	634	100
annual areal loading (g/m^2 of lake surface) 0.26			

NOTE: [a]negligible
SOURCE: Mitchell 1987

From this budget, it was suggested that the majority of TP loadings come via surface runoff from the agricultural and cleared land (41%). Diversion TP loads were estimated at 119 kg/yr. Internal loads via sediment release were not estimated.

The diversion loading was also examined for the full period of the available data record (1978-2000), to provide a comparison with the single year budget estimate in Table 16. Using the winter monthly diversion volumes, along with mean monthly total phosphorus and nitrogen averages for each winter diversion period, it is estimated that on average 126 kg of total phosphorus and 1,235 kg of total nitrogen were loaded into the lake each winter between the years of 1978 and 2000 (Figures 54 and 55). Note that peak loadings occurred in 1983-1984.

Winter diversion TP loading figures are unavailable post-2000. Diversion loads were inferred for this period by extending the comparisons of concentration data from Pakan and the diversion (1988 to 2000) as presented in Figure 20. The monthly total phosphorus concentrations measured at the two locations over the pumping season were multiplied by the corresponding monthly diversion amount from the river. This provided an estimated monthly diversion load based on TP from each site. When the monthly totals are summed for each site, the resulting totals (Figure 56) provide parallel estimates of phosphorus loading into Lac St. Cyr throughout that winter pumping season.

The TP loads calculated using Pakan TP data were slightly higher than the loads calculated from the diversion TP data between 1978 and 2000. The loading data based on Pakan TP data for 2001-2011 are used to infer diversion TP loading patterns into Lac St. Cyr. Those Pakan loading estimates suggest that a substantial reduction in diversion TP loads probably occurred between 2001 and 2011 (Figure 56).

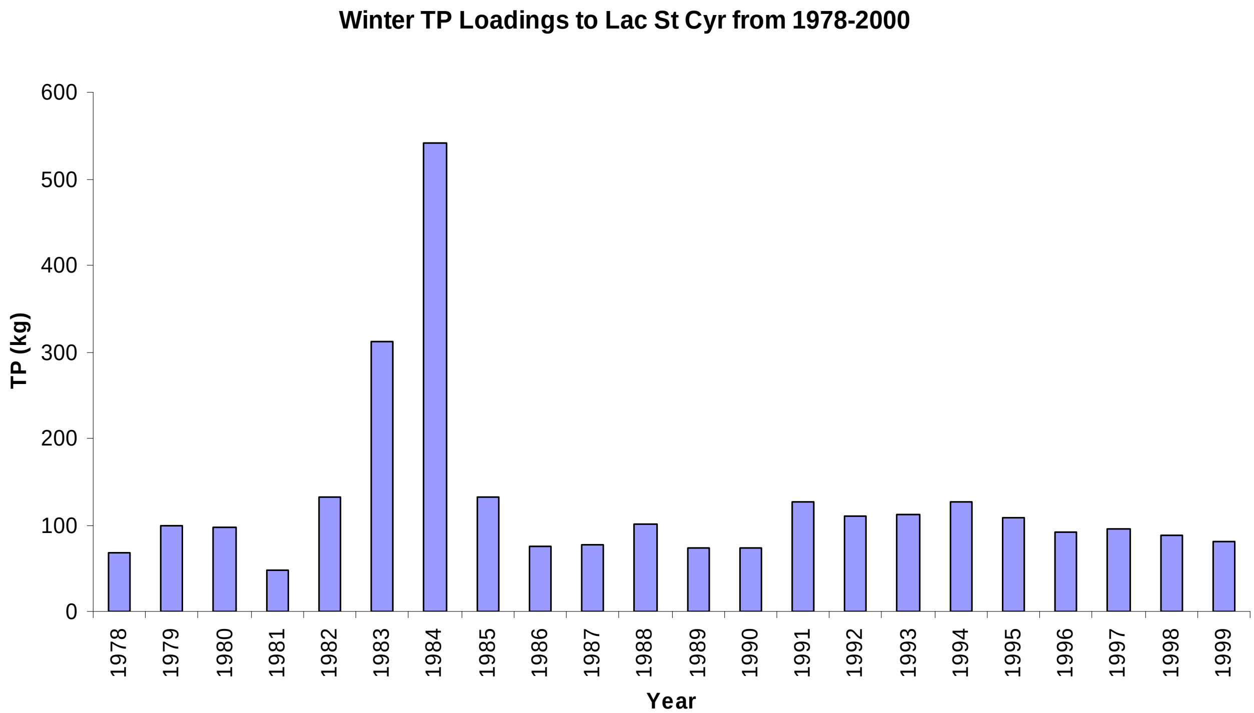


Figure 54. Overwinter TP loadings (via diversion) to the lake 1978 to 2000.

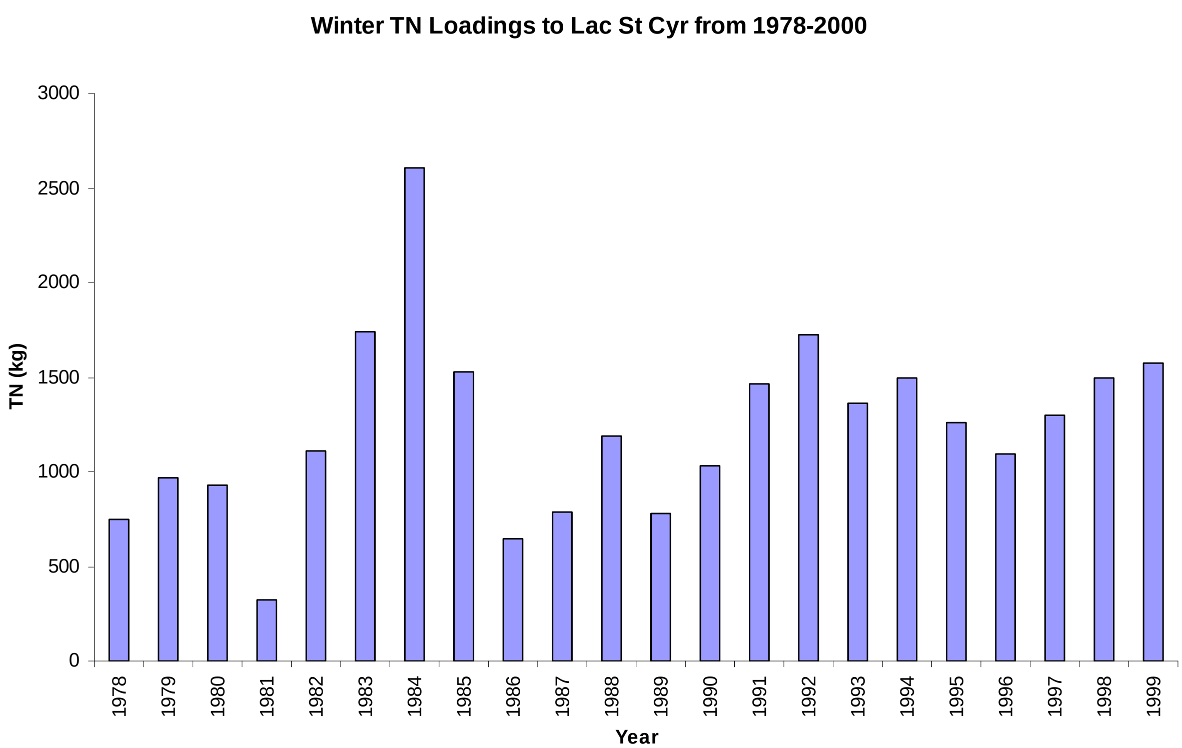


Figure 55. Overwinter TN loadings (via diversion) to the lake 1978 to 2000.

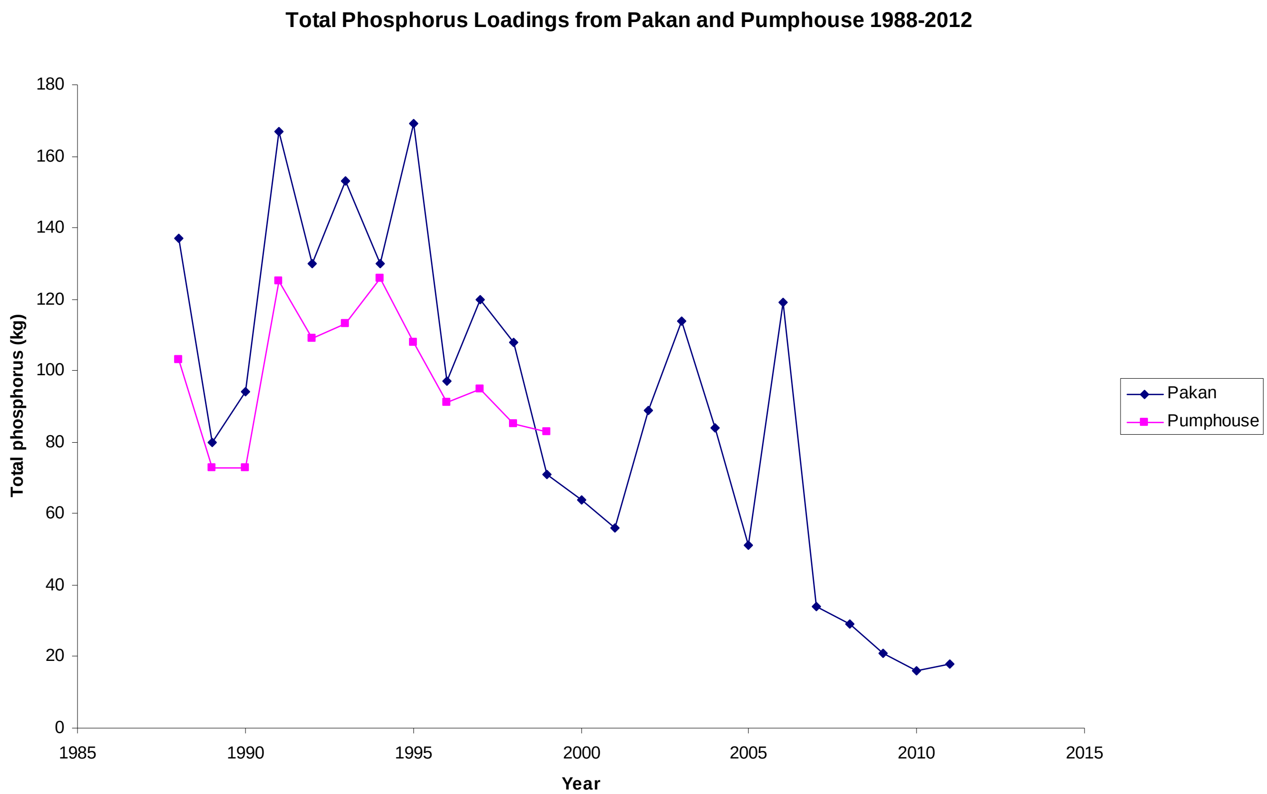


Figure 56. Estimated total phosphorus loadings using concentration data from Pakan and the diversion between 1988 and 2000. The data record for Pakan has been used to infer the diversion loading pattern between 2001 and 2011.

Lake Water Quality Model

A lake water quality model developed by the US Army Corps of Engineers (BATHTUB) was calibrated for Lac St. Cyr by students at King's College University as a research project during winter semester 2013.

The calibration year selected was 1995. The model simulates nutrient concentrations based on the 1995 loading regime and the lake's hydrology. As part of this work an updated phosphorus budget was completed, but it was based on the "effective" drainage area (Table 17) in consideration of the update water balance, which also utilized the effective drainage area.

The surface runoff loads for the 1995 calibration year are estimated to be much smaller than those presented in the Atlas of Alberta Lakes (1991) budget. This new budget suggests the majority of TP loading (~60%) in 1995 came from the diversion from the NSR, with precipitation being the second highest source. Internal loading and sewage estimates were not independently estimated.

Table 17. Theoretical external phosphorus supply to Lac St. Cyr based on 1995 data.

Total Phosphorus Loadings 1995

Source	TP (kg/yr)	Percentage of Total
Surface runoff to North Basin	0.30	0.1%
Surface runoff to South Basin	24.17	11.1%
Pond A flow into North Basin	0.81	0.4%
Diversions from NSR Inflow Pipe	129.58	59.6%
Precipitation	62.59	28.8%
TOTAL	217.45	100.0%

The model was then used in a preliminary test of a simple management scenario for Lac St. Cyr: a 2% annual increase in water diversions from the NSR and a corresponding consumption increase by the town. Using 1995 as the calibration year, with current estimates of diversion loads, the model predicts that lake total phosphorus levels will level off at 14 µg/L by 2033, and total nitrogen concentrations will reach 580 µg/L (Figures 57 and 58). These are very low nutrient levels, and would likely preclude concerns about algal growth. However, this prediction is based on the presumption that upstream loadings from the Capital region will be managed to keep river nutrient loadings at their current low levels (Dyck, Johnson and Wesselson 2013).

The model is available to support future management discussions regarding increased diversions from the NSR and any land management changes for the watershed. A full report outlining the calibration methods and findings is available from NSWA.

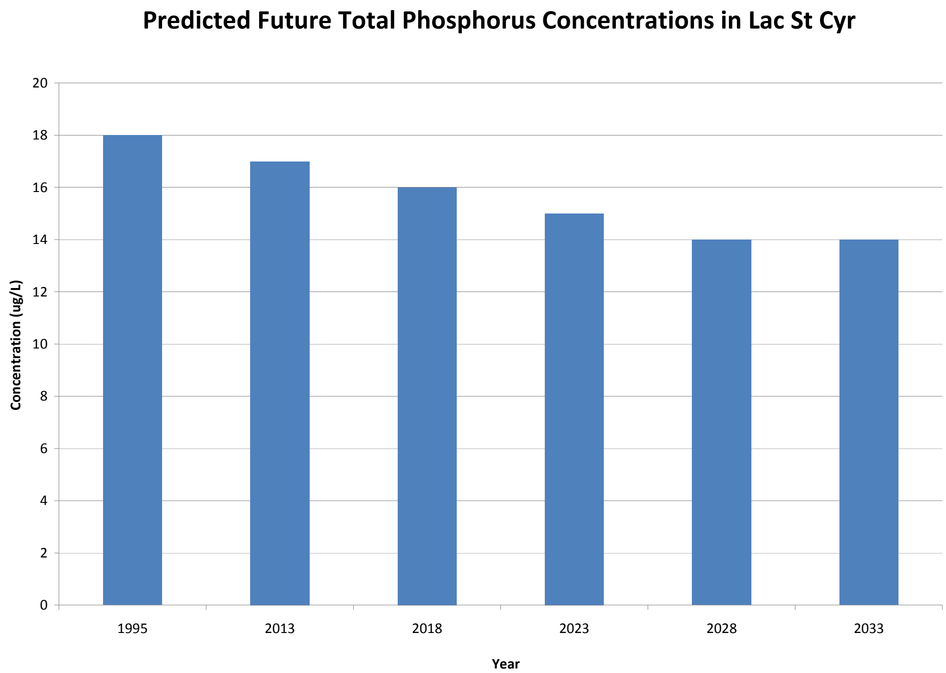


Figure 57. Future total phosphorus concentrations predicted using BATHTUB modeling software.

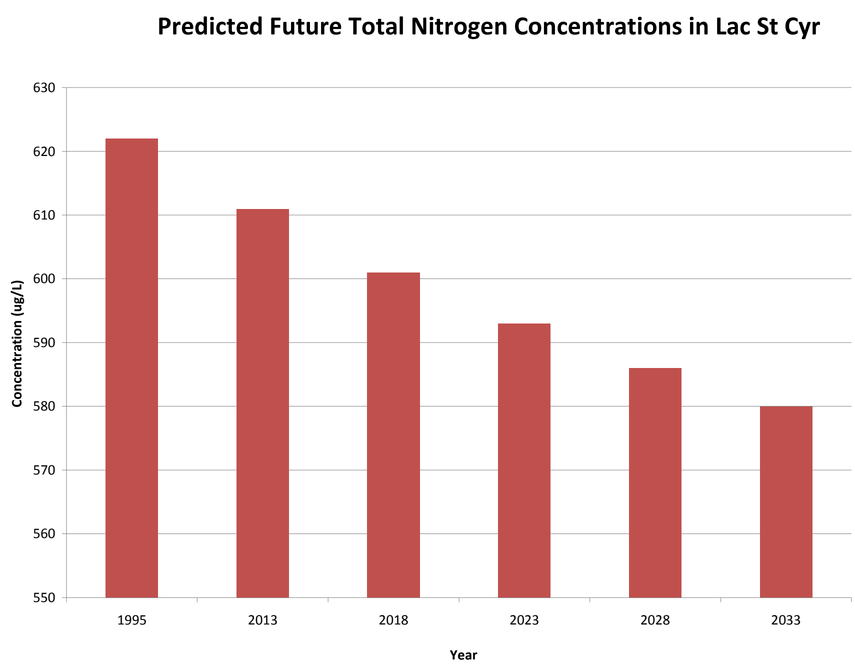


Figure 58. Future total nitrogen concentrations predicted using BATHTUB modeling software.

6.0 Suitability of Lac St. Cyr as a Drinking Water Supply

The suitability of Lac St. Cyr as a drinking water supply for the Town of St. Paul was evaluated against the Canadian Drinking Water Guidelines (CDWG, Health Canada, 2012) and by comparisons to Edmonton's drinking water supply from the upstream NSR; some comments on the treatability of the water are also provided.

As noted above, Lac St. Cyr water quality has been approaching the quality in the NSR, particularly for major ions and trace metals. The lake does not experience the high TSS/colour/turbidity peaks that the river suffers in spring and heavy summer rains because the augmentation is carried out in the fall/winter when river TSS is low.

The withdrawal point for the lake is downstream of the City of Edmonton and the Industrial Heartland, so it does have some additional contaminants in the river water compared to Edmonton's upstream water supply (higher chloride, sodium, phosphate, pharmaceuticals and other compounds).

The water plant on the lake which supplies the Town of St. Paul is located on the north basin, so that basin data has been used to evaluate source quality for drinking water production. As water utility withdrawals increase, lake quality will become even closer to river quality, except for the seasonal in-lake algal growth/TOC increases.

Most of the water quality data are available for 1995 or earlier, with a few limited data sets for 2000 and 2012. There are few recent data on lake chlorophyll-a and none on: algal counts; algal species (green, blue-green, diatoms); algal toxins; pathogens such as *E. coli, Giardia/Cryptosporidium*, and enteric viruses, which are all needed to evaluate treatability. There are also limited data on iron and manganese.

Major ions (TDS, alkalinity, hardness, sulphate, sodium, chloride, fluoride) are very similar to the Edmonton water supply, and are well within any CDWG requirements. Trace metals are all well below CDWG limits. The exceptions may be iron and manganese; data are sparse, but these elements can build up in lake sediments and redissolve in low oxygen conditions, then precipitate out in the water treatment plant in oxidizing conditions.

Most historic (prior to 2000) pesticides/industrial organic sample data were reported as non-detectable or were present in very low concentrations, and are well below any CDWG limits. There are low levels of pharmaceuticals present in NSR water at Pakan (Figure 29), and presumably in the lake as well. The cumulative health impacts of these chemicals are unclear, are currently considered to be low risk (according to USEPA), but are under considerable ongoing international study.

There are limited recent data on bulk "natural" organics in the lake (total organic carbon, organic nitrogen, chlorophyll-a, and algal counts/species). These parameters make treatment more difficult by interfering with coagulation/sedimentation processes; react to form byproducts with disinfection chemicals (chlorine, ozone); increase oxidant demands, and can cause significant objectionable taste and odour.

Lake water quality is very similar in most respects to the Edmonton water supply, and is readily treatable for most parameters. Some issues could arise if algal blooms became more frequent in the lake (high TOC, taste & odour, possibility of algal toxins, etc), requiring extra treatment. Monitoring is required on an ongoing basis for pharmaceuticals and trace organics, and drinking water treatment should be evaluated.

7.0 Conclusions and Recommendations

Lac St. Cyr will continue to receive the diversions from the North Saskatchewan River in order to accommodate the growing drinking water needs of the Town of St. Paul, the County of St. Paul and the Town of Elk Point. Improved monitoring and surveillance on the condition of the lake and the NSR diversion would be prudent.

A routine water quality monitoring program should be re-established for Lac St. Cyr; sampling and analysis should include nutrients, major ion chemistry, metals, trace organics, PPCPs, microbial indicators, phytoplankton and zooplankton. Monitoring should take place throughout the open water season (May-October) at a monthly frequency, and periodically during winter. Composite samples should be taken from the whole lake, and discrete grab samples taken from each basin to optimize comparisons with historic sample and data types.

The biological aspects of the lake and its watershed should be assessed more effectively. From the anecdotal evidence provided, the lake has many species of waterfowl, songbirds and raptors, as well as numerous mammalian species. An up-to-date survey of these communities, identifying key nesting and staging areas, should be completed. The lake fishery should also be surveyed for key species populations and their health. Littoral zone habitats undergo a significant annual cycle; this should be assessed in terms of fish and wildlife habitat. The information about most biological aspects of the lake ecosystem is almost 40 years old; an update would give a more thorough indication of the historic impacts of the diversion upon the lake and insights for future management.

The water quality of the NSR diversion should be monitored in a manner and frequency to support the long-term water quality management needs of the lake, but also to enable the detection of upstream spills and effects from other events that could contaminate the supply.

Watershed scale management of land resources needs to be pursued. This may include developing a watershed management plan for the lake, or specific Land Use Bylaws or Area Structure Plans to protect the lake as a designated water supply. Activities on the land (such as random camping development, oil and gas development, agriculture and grazing) should be assessed to ensure the viability of this lake as a safe drinking water source. The lake still has a largely intact riparian buffer zone and this vegetation should be kept intact in order to help manage overland runoff impacts from the surrounding watershed.

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Appendix 1 – Water Balance

Water Balance

For

Lac Saint Cyr, Alberta

Prepared for:

The North Saskatchewan Watershed Alliance

Prepared by:

Sal Figliuzzi and Associates Ltd.

February, 2013

EXECUTIVE SUMMARY

Lac St. Cyr is a small landlocked lake in east central Alberta, about 160 km east of the City of Edmonton. In 1952 the Town of St Paul, located about 12 km north of Lac St. Cyr, began using the lake as the source of its municipal water supply, diverting approximately 70,000 m^3 per year from the north basin of the lake. In 1978 a pipeline was installed from the North Saskatchewan River to the south basin of Lac St Cyr to provide the Town of St Paul with a reliable municipal water supply and to mitigate lake level declines which were attributed to the Town's municipal diversions. In 2012 the Elk Point/St Paul Regional Water Commission was established to supply municipal water to the Towns of St Paul, the Town of Elk Point and to the south east sector of the County of St Paul No.19 through the existing works of the Town of St Paul. It is expected that, ultimately, the annual water diversion from the North Saskatchewan River could be in the order of 1800 acre-feet (2,220,300 m^3), about 17% of the lake volume.

The quantity of the proposed diversion has raised concerns as to the potential impacts that the diversion may have on the water quality of Lac St Cyr. Within this context, this report conducts a water balance analysis for Lac St Cyr as a whole and for each of two basins (north basin and south basin) which form Lac St Cyr towards providing a better understanding as to the magnitude of the inflow and outflow components to the two basins and for use in a subsequent analysis that will examine the potential implications of the diversion on water quality.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the contribution of the following persons towards the completion of this report. Ernst Kerkhoven and Joe Pruzak of Alberta Environment and Sustainable Resource Development for providing estimates of diversions from the North Saskatchewan River to Lac St Cyr and diversions from Lac St Cyr to the Town of St Paul. Terry Chamuluk of Alberta Environment and Sustainable Resource Development for providing Morton monthly evaporation estimates for Alberta. Ron Woodvine and Rick Rickwood of PFRA for delineating the gross and effective drainage areas of Lac St Cyr.

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Water Balance for Lac Saint Cyr, Alberta

1.0 INTRODUCTION

Lac St. Cyr is a small landlocked lake in east central Alberta, about 160 km east of the City of Edmonton (Figure 1). In 1952 the Town of St Paul, located about 12 km north of Lac St. Cyr, began using the lake as the source of its municipal water supply, diverting approximately 70,000 m^3 per year from the north basin of the lake.

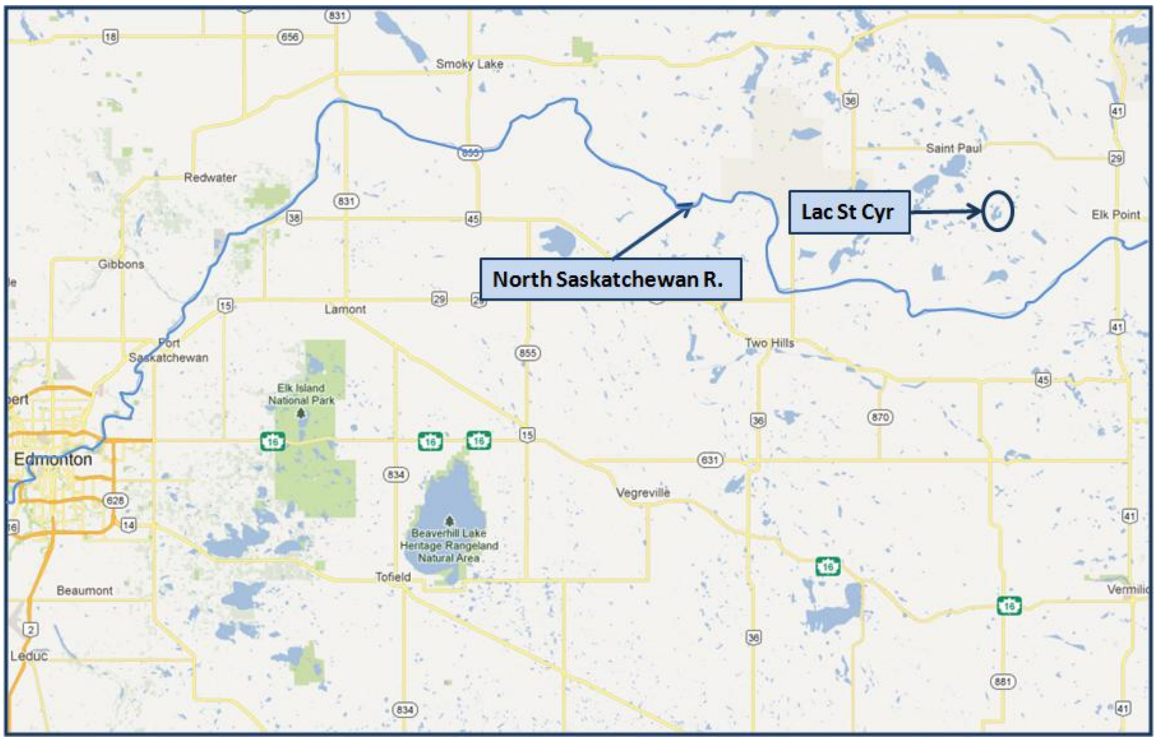

Figure 1 – Location map - Lac St Cyr

In 1959 the water level in the lake was at a high of 647.06 m but by 1978 it had declined to 644.21 m.[1] The decline was mainly attributed to the town withdrawals which by 1978 had increased to approximately 850,000 m^3 per year, about 6.4% of the lake volume.[2]

In 1978 a pipeline was installed from the North Saskatchewan River to the south basin of Lac St Cyr to provide the Town of St Paul with a reliable municipal water supply and to mitigate lake level declines.

In 2010 Alberta Environment and Sustainable Resource Development (formerly Alberta Environment) received an application from the Town of Elk Point for a licence to divert

[1] Patricia Mitchell, 1987
[2] Doell and Tamjeedi 1978

water from the North Saskatchewan River through the works of the Town of St Paul (from the North Saskatchewan River to Lac St. Cyr and on to the Town of St Paul Water Treatment Plant). In 2012 the Elk Point/St Paul Regional Water Commission was established to supply municipal water to the Towns of St Paul, the Town of Elk Point and to the south east sector of the County of St Paul No.19 through the existing works of the Town of St Paul. It is expected that, ultimately, the annual water diversion from the North Saskatchewan River could be in the order of 1,800 acre-feet (2,220,300 m^3), about 17% of the lake volume.

The quantity of the proposed diversion has raised concerns as to the potential impacts that the diversion may have on the water quality of Lac St Cyr. Within this context, the purpose of this report is conduct a water balance analysis for Lac St Cyr as a whole and for each of two basins (north basin and south basin) which form Lac St Cyr (Figures2) to obtain a better understanding as to the magnitude of the inflow and outflow components to the two basins for use in a subsequent analysis that will examine the potential implications of the diversion on water quality. As the semi-permanent water body to the northeast of Lac St Cyr (henceforth referred to as "Pond A") has a significant influence on the surface inflow to the north basin, a water balance is also carried out for this water body so as to accurately estimate the surface water contribution to Lac St Cyr from the drainage area upstream of the this water body.

2.0 PHYSICAL SETTING

Lac St Cyr is a landlocked lake which has no outlet channel. The lake is comprised of two main components, a north basin and a south basin which join on the west side of the lake. A hydrographic survey of Lac St Cyr was conducted in 1972 (Figure 2) by Alberta Environment. The hydrographic survey, supplemented with 1984 aerial photography and more recent data (Shuttle Radar Topography Mission 'SRMT imagery and Indian Remote Sensing 'IRS' imagery) was used (2008) by Alberta Geological Survey (AGS) to construct a bathymetric contour map of the lake. The bathymetric contour map developed by AGS was used to construct the elevation-area-capacity curve for the north basin, south basin and Lac St Cyr (Table 1). Table 1 shows that, at a lake elevation of 644.70 m (the mean elevation during the 1979-2011 period) the north basin has a maximum depth of over 22 metres (72 feet) and a capacity of over 7,000,000 m^3 while the south basin has a maximum depth of about 10 metres (32 feet) and a capacity 6,000,000 m^3. Table 1 further shows that at an elevation of 644.7 m Lac St. Cyr has a lake surface area of 2.2 km^2 and a total storage volume of 13,385,650 m^3; approximately six (6) times the potential future diversion.

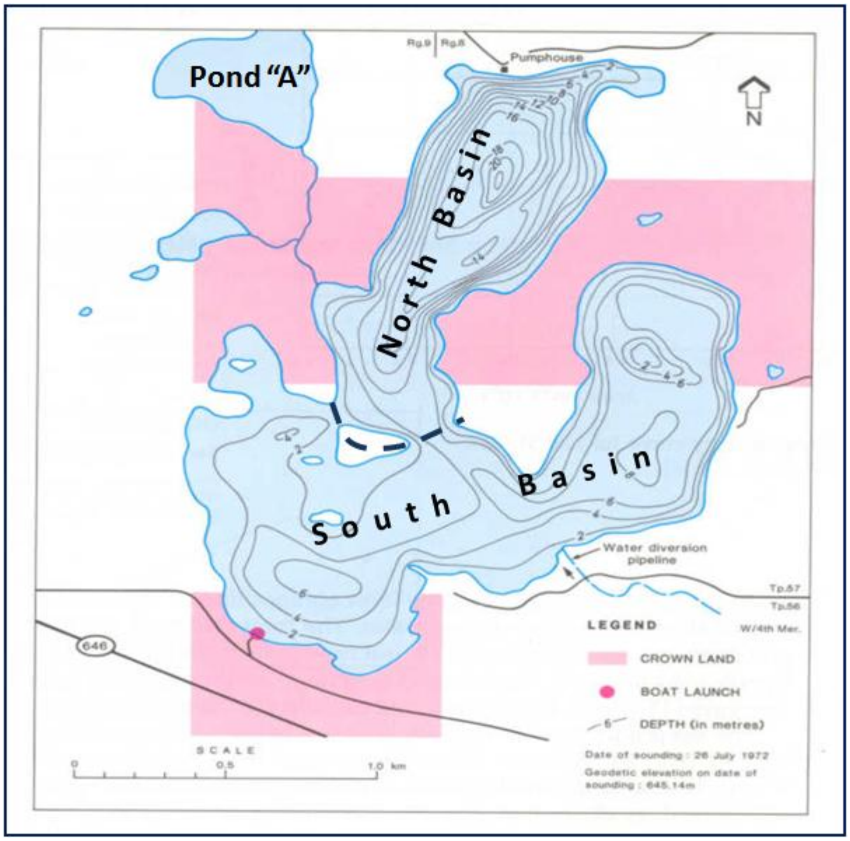

Figure 2 –Lac St. Cyr – hydrographic survey.

Table 1- Lac St Cyr - Elevation-Area-Capacity Relation

	North Basin			South Basin			Lac St Cyr		
Elevation (m)	Depth (m)	Area (m^2)	Volume (m^3)	Depth (m)	Area (m^2)	Volume (m^3)	Depth (m)	Area (m^2)	Volume (m^3)
622.00	0.00	0	0		0	0	0.00	0	0
622.16	0.16	5,409	286		0	0	0.16	5,409	286
623.69	1.69	11,606	11,406		0	0	1.69	11,606	11,406
625.21	3.21	25,295	35,289		0	0	3.21	25,295	35,289
626.74	4.74	63,220	91,398		0	0	4.74	63,220	91,398
628.26	6.26	97,132	202,956		0	0	6.26	97,132	202,956
629.78	7.78	142,035	371,073		0	0	7.78	142,035	371,073
631.31	9.31	217,426	622,991		0	0	9.31	217,426	622,991
632.83	10.83	280,951	982,446	0.00	0	0	10.83	280,951	982,446
634.36	12.36	339,372	1,439,116	1.53	16,340	8,250	12.36	355,712	1,447,366
635.88	13.88	421,025	1,992,195	3.05	69,121	57,155	13.88	490,146	2,049,350
637.40	15.40	486,486	2,662,003	4.57	340,060	285,767	15.40	826,546	2,947,770
638.93	16.93	560,911	3,440,488	6.10	562,436	908,129	16.93	1,123,347	4,348,617
640.45	18.45	634,923	4,326,822	7.62	786,105	1,865,025	18.45	1,421,028	6,191,847
641.98	19.98	671,949	5,315,249	9.15	968,627	3,151,544	19.98	1,640,576	8,466,793
644.70	22.70	725,777	7,186,874	11.87	1,474,223	6,198,775	22.70	2,200,000	13,385,650
645.14	23.14			12.31			23.14	2,500,000	14,393,250
650.00	28.00			17.17			28.00	3,100,000	27,418,050

3.0 ESTIMATION OF WATER BALANCE PARAMETERS

A water balance is an accounting of all water inputs to and outflows from a water body. In its simplest form the water balance can be represented by the following equation:

$$I - O = \Delta S \qquad (1)$$

Where:

I = water inputs to the lake
O = water outflows from the lake, and
ΔS= the change in lake water storage,

For any given time period, Equation 1 can be expanded to its individual components and expressed as follows:

$$(SI\text{-}SO) + LSA^*(P\text{-}E) + (GI\text{-}GO) + (DI\text{-}DO) = \Delta S \qquad (2)$$

Where:

SI = the surface inflow/runoff,
SO= Surface outflow – generally through a channel leaving the lake.
P = Precipitation (rain/snow) falling directly on the Lake Surface Area (LSA),
E = Evaporation from the lake surface area,
GI = Groundwater inflow –water entering the lake via buried channels and connections to aquifers,
GO= Groundwater outflow - water leaving the lake through the groundwater system,
DI = Diversions into the lake due to human activity, and
DO= Diversions from the lake due to human activity.

As Lac St Cyr is a landlocked lake and has no outlet channel, the surface water outflow component within equation (2) can be set to zero and the water balance equation reduced to the following:

$$SI + LSA^*(P\text{-}E) + (GI\text{-}GO) + (DI\text{-} DO) = \Delta S \qquad (3)$$

Where all parameters have been previously defined.

The estimation of each of the parameters within the above equation is carried in the Sections of this report that follow.

3.1 Computation of Effective Drainage Areas

The land area whose surface runoff drains to a particular point in a body of water (lake, stream course, etc,) is called the drainage area, catchment area or watershed area. Because of the relatively flat landscape, the numerous depressional storage areas, and the climate of the Canadian Prairies, the watershed area which can potentially contribute to the surface runoff reaching a water body and the surface area which actually contributes to the runoff reaching a water body can vary significantly from event to event and from year to year. Ideally, a water balance would be carried out for each of these storage and depression areas towards identifying the actual quantity of runoff reaching the water body for each time step. However, as this level of analysis is not practical or possible in most instances, the concept of "gross" and "effective" area have come into common use to account for this variability in the "contributing drainage area". These terms are defined as follows:

- Gross drainage area is the land surface area which can be expected to contribute runoff to a given body of water under extremely wet conditions. It is defined by the topographic divide (height of Land) between the water body under consideration and adjoining watersheds.
- Effective drainage area is that portion of the gross drainage area which can be expected to contribute surface runoff to a given body of water under average conditions. The effective drainage area excludes portions of the gross drainage area which drain to peripheral marshes, sloughs and other natural depressions or storage areas which would prevent runoff from reaching the water body under consideration in a year of average runoff.

The gross drainage area (including the lake surface area) for Lac St Cyr was computed at 27.64 km^2 by Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada (PFRA) using the Canadian Digital Elevation Data and orthophotography. However, much of this area drains into local ponds, sloughs and storage, which likely do not contribute to the runoff reaching Lac St Cyr other than in extremely wet years. The contributing drainage area (effective drainage area plus the lake surface area of Lac St Cyr and the permanent water body to the north of Lac St Cyr) was computed by PFRA at 14.6 km^2 however, based on a review of the Digital Elevation Map the contributing drainage area was adjusted to 15.6 km^2 (Figure 3a). The drainage area contributing surface inflow directly to the north basin and south basin of Lac St Cyr and contributing surface inflow to the north basin through Pond A were determined based on the digital elevation model and are shown in Figures 3a and 3b. The contributing drainage area, effective drainage area and the lake surface area for each of the three water bodies are summarized in Table 2.

Table 2 – Contributing and effective drainage areas and lake surface areas for key water bodies within the Lac St Cyr Basin			
	Contributing Drainage Area (km^2)	Lake Surface Area (km^2)	Effective Drainage Area (km^2)
Pond A – NE of LSC	3.59	0.25	3.34
North Basin LSC (excluding Pond A)	2.30	0.72*	1.58
South Basin LSC	9.71	1.48*	8.23
• *See Section 3.3*			

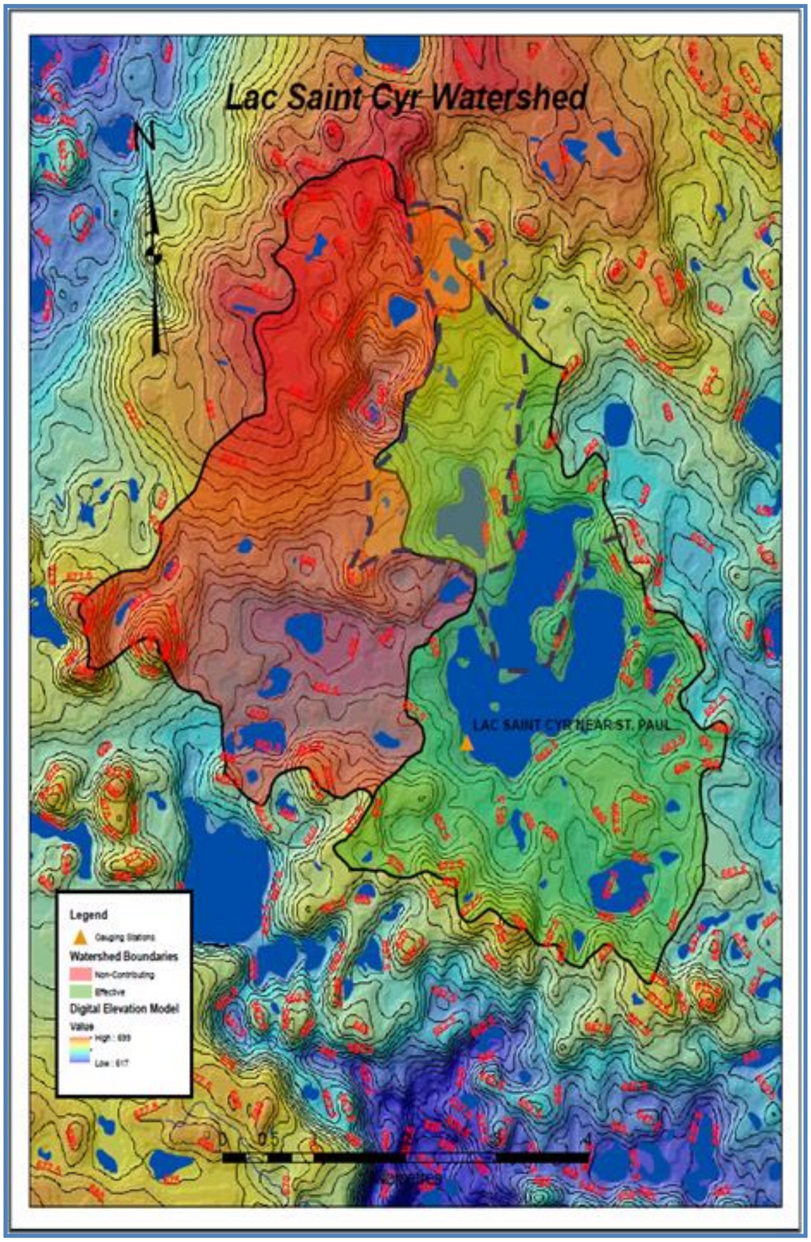

Figure 3a – Digital Elevation model of non-contributing and effective drainage areas for key water bodies within the Lac St Cyr basin

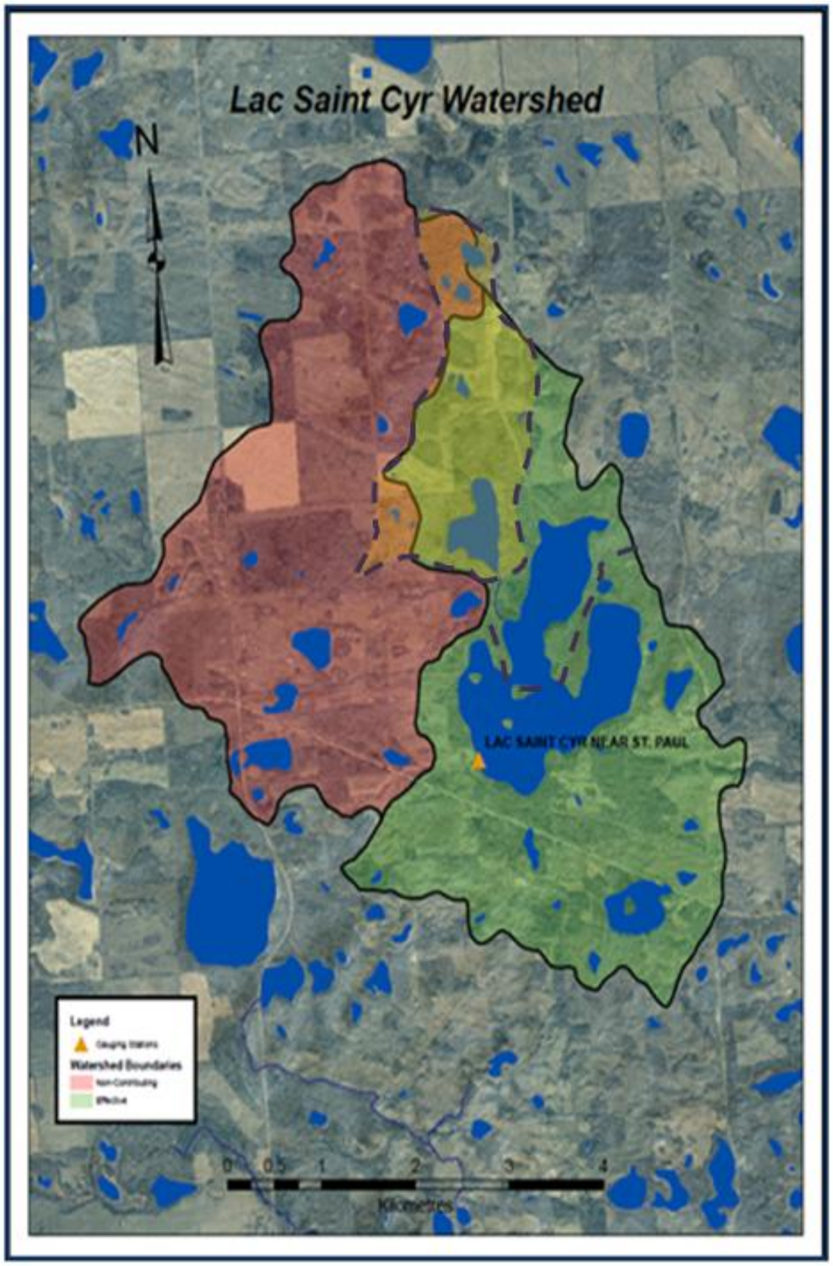

Figure 3b – Non-contributing and effective drainage areas for key Water bodies within the Lac St Cyr basin

3.2 Computation of Surface Inflow

The surface inflow into Lac St Cyr and into each of the three water bodies has not been measured. The procedure generally used to estimate surface inflow for an ungauged basin is to adjust the measured flow from a representative nearby gauged watershed by the ratio of the effective drainage areas of the two basins using the equation:

$$SI_{UB} = (EDA_{UB}/EDA_{GB}) * SI_{GB}$$

Where:

SI = the surface inflow/runoff and

EDA = the effective drainage area for the ungauged basin (UB) and gauged basin (GB) respectively.

The hydrometric station closest to Lac Ste Cyr that is considered representative of local runoff and can be used for the estimation of surface inflow into the each of the water bodies within the Lac St Cyr basin is Water Survey of Canada (WSC) Station #05ED003 (Moosehill Creek near Elk Point). While WSC station #05ED002 is located closer to Lac St Cyr it is not considered as a representative station due to significant lake and depression storage influences. Figure 4 shows the location of the two hydrometric stations relative to Lac St Cyr. The historical runoff for Moosehill Creek near Elk Point along with the gross and effective drainage areas, computed by PFRA, is summarized in Table 3.

The monthly runoff from the sub-basin area to each of the three water bodies was computed by multiplying the recorded monthly flow for Moosehill Creek by the ratio of the effective drainage area of each of the three water bodies to the effective drainage area to Moosehill Creek. The resulting monthly inflow to each of the three water bodies is shown in Appendix A, Tables A1a to A1c. The mean annual inflow to each of the water bodies is summarized in Table 4.

Table 3 - Monthly Runoff for Moosehill Creek near Elk Point - Water Survey of Canada Station #05ED003
Gross Drainage area 41.0 km2 - Effective Drainage Area 37.7 km2

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)
1979	-	-	10,714	717,984	819,590	347,328	174,096	24,106	25,920	16,070	-	-	2,135,808
1980	-	-	2,678	373,248	42,854	12,960	18,749	32,141	28,512	42,854	-	-	553,997
1981	-	-	182,131	406,944	24,106	28,512	133,920	10,714	0	0	-	-	786,326
1982	-	-	0	344,736	176,774	2,592	190,166	72,317	10,368	0	-	-	796,954
1983	-	-	0	80,352	64,282	31,104	211,594	10,714	75,168	16,070	-	-	489,283
1984	-	-	74,995	199,584	219,629	259,200	5,357	2,678	5,184	5,357	-	-	771,984
1985	-	-	0	974,592	425,866	272,160	26,784	37,498	0	5,357	-	-	1,742,256
1986	-	-	166,061	515,808	774,058	64,800	605,318	96,422	7,776	2,678	-	-	2,232,922
1987	-	-	18,749	1,132,704	211,594	36,288	8,035	0	0	0	-	-	1,407,370
1988	-	-	8,035	20,736	26,784	80,352	125,885	26,784	15,552	8,035	-	-	312,163
1989	-	-	0	152,928	2,678	111,456	50,890	5,357	20,736	24,106	-	-	368,150
1990	-	-	37,498	603,936	190,166	20,736	96,422	13,392	0	0	-	-	962,150
1991	-	-	0	101,088	53,568	5,184	0	0	0	0	-	-	159,840
1992	-	-	2,678	0	2,678	7,776	0	0	0	0	-	-	13,133
1993	-	-	2,678	25,920	50,890	0	2,678	0	0	0	-	-	82,166
1994	-	-	0	489,888	198,202	75,168	10,714	0	0	0	-	-	773,971
1995	-	-	8,035	163,296	2,678	0	0	8,035	0	0	-	-	182,045
1996	-	-	0	482,112	305,338	194,400	251,770	10,714	0	0	-	-	1,244,333
1997	-	-	8,035	1,130,112	543,715	982,368	72,317	0	0	0	-	-	2,736,547
1998	-	-	-	-	50,890	0	32,141	0	0	0	-	-	83,030
1999	-	-	40,176	251,424	340,157	12,960	29,462	0	0	0	-	-	674,179
2000	-	-	21,427	90,720	29,462	59,616	96,422	18,749	20,736	5,357	-	-	342,490
2001	-	-	10,714	49,248	50,890	64,800	40,176	37,498	5,184	2,678	-	-	261,187
2002	-	-	2,678	85,536	139,277	0	0	0	0	0	-	-	227,491
2003	-	-	0	28,512	5,357	20,736	16,070	0	0	8,035	-	-	78,710
2004	-	-	8,035	1,277,856	117,850	186,624	123,206	0	12,960	5,357	-	-	1,731,888
2005	-	-	190,166	412,128	270,518	336,960	91,066	56,246	20,736	74,995	-	-	1,452,816
2006	-	-	10,714	876,096	626,746	165,888	66,960	5,357	0	8,035	-	-	1,759,795
2007	-	-	26,784	699,840	155,347	54,432	8,035	0	0	0	-	-	944,438
2008	-	-	0	357,696	214,272	41,472	21,427	0	0	0	-	-	634,867
2009	-	-	0	158,112	48,211	33,696	29,462	0	0	0	-	-	269,482
Max	-	-	**190,166**	**1,277,856**	**819,590**	**982,368**	**605,318**	**96,422**	**75,168**	**74,995**	-	-	**2,736,547**
Min	-	-	**0**	**0**	**2,678**	**0**	**0**	**0**	**0**	**0**	-	-	**13,133**
Mean	-	-	**27,766**	**406,771**	**199,498**	**113,212**	**81,907**	**15,120**	**8,027**	**7,258**	-	-	**845,541**

Table 4 – Mean annual inflow to key water bodies within the Lac St Cyr basin

	Effective Drainage Area Moosehill Cr.(km^2)	Effective Drainage Area to Indicated water body (km^2)	Drainage area Ratio	Mean Annual Flow for Moosehill Creek (m^3)	Mean annual inflow for indicated water body (m^3)
Pond A - NE of LSC	37.70	3.34	0.089	859,558	76,162
North Basin LSC	37.70	1.58	0.042	859,558	36,024
South Basin LSC	37.70	8.23	0.218	859,558	187,644

Note – the inflow to Lac St Cyr is equal to the inflow to the three water bodies minus the net evaporation from the Pond NE of LSC

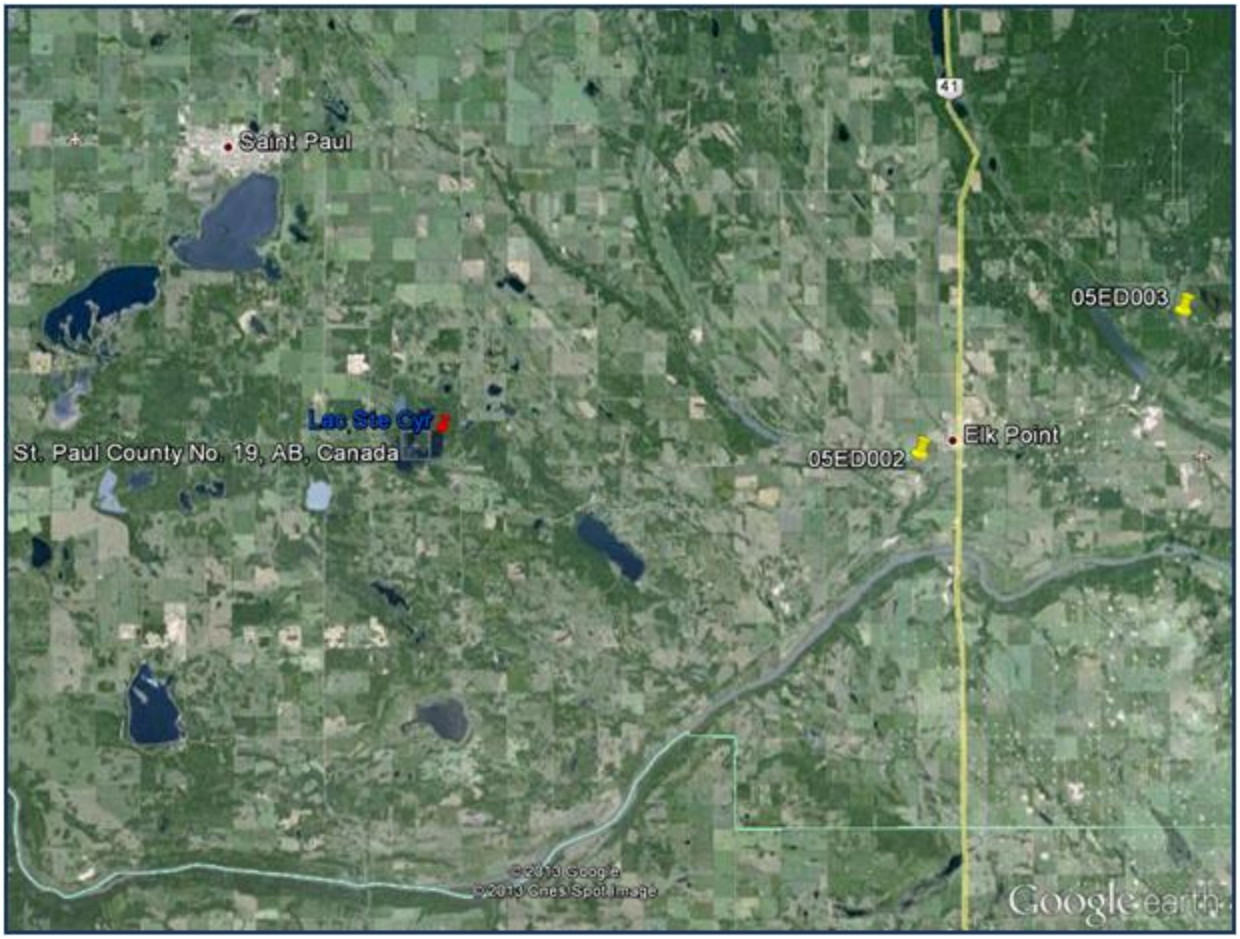

Figure 4 – Location map of hydrometric stations near to Lac St Cyr

3.3 Computation of Lake Surface Areas

Table 5 provides a summary of average monthly water levels for Lac St Cyr during the 1971-2011 period. Table 5 shows that from January 1979 to December 2009, the period for which all parameters required for a water balance analysis are available, Lac St Cyr had an average elevation of 644.753 m. Table 1 shows that at this elevation the north basin of Lac St Cyr has a lake surface area of about 0.72 km^2 while the south basin has a lake surface area of 1.48 km^2.

The lake surface area for Pond A to NE of Lac St Cyr was computed at 0.25 km^2 from aerial photos of the area. The aerial photos also indicate that the other small water body to the south of the Lac St Cyr basin (Figure 3) tends to dry during most periods implying it may have been drained and likely can be ignored as it would have minimal influence on surface inflows to Lac St Cyr.

Table 5 - Lac St Cyr - Average Monthly Water Levels

Year	JAN (m)	FEB (m)	MAR (m)	APR (m)	MAY (m)	JUN (m)	JUL (m)	AUG (m)	SEP (m)	OCT (m)	NOV (m)	DEC (m)
1971					645.259		645.307				645.124	
1972			645.140				645.140			644.917		
1973							644.786	644.774	644.727	644.698	644.667	
1974	644.731		644.576			645.097	645.088			644.957		644.875
1975						645.024		645.030		644.914		
1976		644.838			644.750			644.737	644.631			
1977		644.494			644.548	644.537	644.474	644.442	644.393	644.366		
1978		644.317			644.320		644.332		644.213			
1979	644.495	644.467	644.465	644.499	644.597	644.660	644.647	644.537	644.473	644.444	644.551	
1980	644.873	644.898	644.892	644.874	644.809	644.755	644.634	644.635	644.548	644.597	644.704	644.849
1981	644.975	645.110	645.065	645.076	645.016	644.910	644.803	644.780	644.624	644.653	644.823	644.949
1982	645.058	645.140	645.063	645.107	645.111	645.047	644.948	644.920	644.892	644.886	644.980	645.124
1983	645.257	645.263	645.236	645.199	645.147	645.064	645.053	644.944	644.876	644.834	644.884	645.027
1984	645.182	645.320	645.331	645.322	645.276	645.270	645.153	645.038	644.958	644.942	645.030	645.178
1985	645.317	645.341	645.309	645.277	645.277	645.229	645.149	645.003	644.897	644.852	644.924	645.083
1986	645.228	645.362	645.377	645.373	645.374	645.308	645.251	645.212	645.088	645.009	645.004	644.965
1987	644.938	644.918	644.858	644.893	644.897	644.791	644.709	644.603	644.465	644.397	644.433	644.495
1988	644.689	644.792	644.792	644.762	644.655	644.563	644.621	644.492	644.413	644.349	644.413	644.567
1989	644.711	644.847	644.861	644.801	644.768	644.689	644.630	644.572	644.559	644.405	644.421	644.622
1990	644.724	644.747	644.762	644.753	644.712	644.562	644.537	644.411	644.307	644.199	644.198	644.383
1991	644.528	644.644	644.730	644.660	644.656	644.494	644.520	644.310	644.203	644.096	644.173	644.328
1992	644.476	644.633	644.692	644.654	644.615	644.494	644.384	644.280	644.140	644.064	644.213	644.355
1993	644.500	644.627	644.664	644.674	644.650	644.529	644.464	644.380	644.335	644.246	644.271	644.419
1994	644.553	644.701	644.774	644.759	644.687	644.641	644.609	644.512	644.415	644.334	644.349	644.488
1995	644.665	644.797	644.885	644.874	644.853	644.674	644.570	644.557	644.494	644.394	644.456	644.552
1996	644.669	644.726	644.803	644.825	644.820	644.816	644.814	644.755	644.634	644.555	644.574	644.645
1997	644.791	644.920	645.020	645.018	645.038	645.048	644.960	644.825	644.797	644.699	644.662	644.710
1998	644.850	644.993	645.109	645.079	645.000	644.853	644.827	644.729	644.615	644.538	644.582	644.660
1999	644.807	644.966	645.085	645.099	645.101	645.035	644.961	644.888	644.785	644.658	644.555	644.645
2000	644.765	644.920	645.027	645.103	645.021	644.967	644.978	644.890	644.795	644.669	644.608	644.631
2001	644.738	644.803	644.871	644.878	644.809	644.967	644.795	644.598	644.438	644.316	644.242	644.265
2002	644.395	644.528	644.662	644.800	644.761	644.606	644.432	644.310	644.176	644.100	644.068	644.088
2003	644.202	644.360	644.505	644.640	644.693	644.675	644.680	644.565	644.450	644.344	644.337	644.463
2004	644.614	644.773	644.905	644.978	644.899	644.840	644.774	644.661	644.590	644.506	644.435	644.458
2005	644.623	644.750	644.843	644.834	644.793	644.762	644.695	644.604	644.530	644.468	644.493	644.473
2006	644.653	644.778	644.920	644.948	644.952	644.933	644.843	644.754	644.648	644.543	644.487	644.520
2007	644.750	644.880	645.016	645.063	645.072	645.014	644.965	644.832	644.763	644.655	644.634	644.718
2008	644.860	644.993	645.133	645.190	645.202	-	645.008			644.737	644.718	644.744
2009	644.873	645.013	645.135	645.228	645.198	645.058	645.029	644.921	644.815	644.678	644.643	644.643
2010	644.805	644.917	645.048	645.077	645.073	645.052	645.090	645.014	644.982	644.902	644.832	644.915
2011	645.082	645.216	645.348	645.410	645.381	645.318	645.320	645.302	645.182	645.061	644.990	644.980
All Data												
Max.	**645.317**	**645.362**	**645.377**	**645.410**	**645.381**	**645.318**	**645.320**	**645.302**	**645.182**	**645.061**	**645.124**	**645.178**
Min.	**644.202**	**644.317**	**644.465**	**644.499**	**644.320**	**644.494**	**644.332**	**644.280**	**644.140**	**644.064**	**644.068**	**644.088**
Mean	**644.776**	**644.855**	**644.940**	**644.961**	**644.913**	**644.865**	**644.820**	**644.717**	**644.607**	**644.578**	**644.585**	**644.661**
1979-2009 Data												
Max.	**645.317**	**645.362**	**645.377**	**645.373**	**645.374**	**645.308**	**645.251**	**645.212**	**645.088**	**645.009**	**645.030**	**645.178**
Min.	**644.202**	**644.360**	**644.465**	**644.499**	**644.597**	**644.494**	**644.384**	**644.280**	**644.140**	**644.064**	**644.068**	**644.088**
Mean	**644.766**	**644.871**	**644.929**	**644.943**	**644.918**	**644.842**	**644.788**	**644.684**	**644.591**	**644.522**	**644.544**	**644.635**

3.4 Computation of Precipitation Inputs

The 1979-2009 monthly precipitation for Lac St Cyr was estimated using the recorded data from the nearest precipitation station having the longest complete set of records. The estimated monthly and annual precipitation, along with the station used in the reconstruction is presented in Table 6. Table 6 shows that the 1979-2009 mean annual precipitation for Lac Ste Cyr basin area is in the order of 405.8 mm.

The monthly volume of precipitation input to the north basin and south basin of Lac St Cyr and to Pond A was estimated by multiplying the monthly precipitation by the average water surface area of the water body. The computed monthly precipitation inputs are presented in Appendix A, Tables A2a to A2c. The mean annual volumes of precipitation input to each of the three water bodies and to Lac St Cyr are summarized in Table 7.

Table 6 - Lac St Cyr basin- Monthly and annual precipitation (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1978	36.1	2.3	4.3	30.3	111.9	27.5	64.6	77.5	78.1	12.8	13.8	15.3	474.5
1979	19.2	41.1	6.0	25.4	22.5	111.6	132.8	19.7	72.7	2.8	2.5	25.9	482.2
1980	16.0	11.0	29.4	1.4	28.4	61.8	33.1	106.4	42.6	22.0	23.6	30.1	405.8
1981	20.6	5.0	12.2	6.3	9.0	47.6	113.5	17.1	10.6	13.7	11.2	19.7	286.5
1982	27.3	9.4	31.2	27.8	50.0	26.4	98.0	89.0	34.6	15.2	14.0	9.6	432.5
1983	16.1	12.0	28.8	12.0	23.4	106.6	118.2	4.8	88.0	7.8	25.9	11.4	455.0
1984	17.9	14.6	3.5	16.8	83.8	63.2	43.8	41.2	80.5	35.4	26.0	15.2	441.9
1985	15.8	8.4	0.4	38.8	49.4	82.6	21.2	37.8	46.9	19.9	5.6	28.4	355.2
1986	18.0	5.0	28.2	11.0	90.6	50.4	119.2	21.8	35.4	11.6	19.6	11.0	421.8
1987	12.0	17.0	25.0	50.4	23.4	42.6	61.2	36.6	10.8	1.2	2.4	9.6	292.2
1988	9.5	13.6	37.4	36.4	17.8	142.0	42.4	112.8	33.4	7.6	11.0	22.6	486.5
1989	16.0	7.5	11.6	8.1	58.2	84.4	78.8	96.6	48.4	10.0	18.7	46.6	484.9
1990	20.3	19.6	14.8	19.8	49.6	32.2	95.2	45.2	12.6	13.8	25.2	18.0	366.3
1991	12.8	18.5	10.9	54.0	49.2	86.2	6.8	26.4	6.8	32.0	8.6	26.6	338.8
1992	31.0	23.0	3.2	32.5	46.4	41.0	86.0	36.6	18.4	19.8	9.0	19.0	365.9
1993	12.0	2.6	8.0	119.2	39.4	103.4	54.8	63.8	31.8	20.4	19.6	9.4	484.4
1994	50.4	30.8	5.0	4.6	55.6	99.5	87.6	65.2	28.2	30.6	15.8	33.6	506.9
1995	8.4	6.7	19.4	33.1	3.2	26.3	51.6	133.1	0.0	9.4	35.8	17.5	344.5
1996	7.4	22.0	14.8	27.8	75.2	71.7	106.8	56.6	40.8	19.3	57.4	24.0	523.8
1997	21.0	11.0	15.0	35.5	45.2	131.4	30.6	49.3	50.4	20.9	1.5	6.5	418.3
1998	18.5	0.5	6.0	16.4	11.3	49.8	28.8	17.1	33.5	21.0	11.2	15.5	229.6
1999	35.0	4.5	14.0	6.5	79.0	28.9	112.7	53.2	8.6	18.6	10.5	15.5	387.0
2000	15.5	7.3	24.0	9.0	38.6	79.1	226.0	33.3	59.0	0.5	5.0	20.5	517.8
2001	3.7	3.5	3.0	11.5	46.5	91.9	84.1	10.6	29.2	11.2	18.0	7.5	320.7
2002	3.0	4.0	12.0	45.5	4.2	12.3	34.8	33.3	22.6	6.0	6.0	4.6	188.3
2003	19.0	16.7	21.0	56.7	69.4	60.8	97.7	52.8	58.7	13.9	10.5	6.5	483.7
2004	20.5	0.0	23.0	20.1	39.0	51.2	94.1	28.1	52.6	19.8	1.3	30.0	379.7
2005	12.6	7.5	17.7	33.5	44.1	90.8	78.5	86.7	42.8	24.1	4.6	2.5	445.4
2006	9.5	20.5	67.0	22.7	98.8	55.9	90.1	46.8	94.5	17.9	35.0	12.5	571.2
2007	15.0	14.0	4.0	30.4	43.3	105.8	28.4	108.2	17.1	10.3	14.5	21.5	412.5
2008	21.6	15.0	11.1	35.6	28.4	66.6	87.3	23.8	18.0	15.2	20.2	33.0	375.8
2009	24.6	10.6	42.8	35.2	18.8	75.6	66.0	40.2	8.6	37.6	0.0	13.8	373.8
MIN	**3.0**	**0.0**	**0.4**	**1.4**	**3.2**	**12.3**	**6.8**	**4.8**	**0.0**	**0.5**	**0.0**	**2.5**	**188.3**
MAX	**50.4**	**41.1**	**67.0**	**119.2**	**111.9**	**142.0**	**226.0**	**133.1**	**94.5**	**37.6**	**57.4**	**46.6**	**571.2**
MEAN 1979-2009	**17.7**	**12.4**	**17.8**	**28.5**	**43.3**	**70.3**	**77.7**	**51.4**	**36.7**	**16.4**	**15.2**	**18.3**	**405.8**

Filled using Elk Point
Filled using Chailey
Filled using Cold Lake A

Table 7 – Mean annual precipitation input to key water bodies within the Lac St Cyr basin

	Lake Surface Area (km^2)	Mean Annual Precipitation (mm)	Precipitation Input (m^3)
Pond A - NE of LSC	0.25	405.8	101,433
North Basin LSC	0.72	405.8	292,155
South Basin LSC	1.48	405.8	600,541
Lac St Cyr	2.20	405.8	892,696
To all 3water bodies	2.45	405.8	994,139

Note- minor differences in Table 7 are due to round off of P to one decimal.

3.5 Computation of Lake Evaporation Losses

Evaporation or gross lake evaporation is the water that evaporates from the water body due to the warming effect of solar radiation, mild to hot temperatures and wind. Unlike precipitation, evaporation from a lake cannot be measured directly and must be estimated using energy balance calculations that generally include temperature, wind, solar radiation, sunshine, relative humidity, etc.

Alberta Environment and Sustainable Resource Development uses the “Morton CRLE” model to estimate lake evaporation, as opposed to other models which generally estimate the potential evaporation. Alberta Environment has recently updated its lake evaporation estimates for all major sites across Alberta. Table 8a presents the monthly and annual Morton gross lake evaporation estimates for Cold Lake, the nearest site to Lac St Cyr for which monthly lake evaporation is available.

The computed gross lake evaporation depth at Cold Lake was subsequently transposed to Lac St Cyr by adjusting the Cold Lake evaporation by the ratio of AENV’s long term mean annual lake evaporation at Lac St Cyr (estimated at 649 mm) to the AENV mean annual lake evaporation at Cold Lake (646 mm) (Figure 5).

The resulting monthly and annual gross lake evaporation depths for lakes within the Lac St Cyr basin are shown in Table 8b. The monthly volume of lake evaporation losses from the north basin and south basin of Lac St Cyr and from Pond A was estimated by multiplying the monthly lake evaporation by the average water surface area of the water body. The computed monthly evaporation losses from each of the three water bodies are presented in Appendix A, Tables A3a to A3c. The mean annual volumes of evaporation losses from each of the three water bodies and from Lac St Cyr are summarized in Table 9.

TABLE 8a - MONTHLY AND ANNUAL MORTON GROSS LAKE EVAPORATION (millimeters) - COLD LAKE													
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1979	-3	0	30	46	110	130	155	108	53	18	1	-5	643
1980	-3	-2	12	95	132	119	149	87	39	22	2	-1	651
1981	-5	1	31	64	121	142	131	133	59	17	5	-2	697
1982	-1	0	13	64	103	138	130	95	53	22	-1	-3	613
1983	-5	-2	15	66	96	100	117	128	44	19	-7	-4	567
1984	-1	7	26	73	80	130	141	104	36	17	-1	-2	610
1985	-3	-1	29	64	116	122	147	110	35	18	-1	-1	635
1986	0	1	27	64	101	139	99	125	39	21	-1	-4	611
1987	-3	1	14	66	114	126	137	86	58	19	3	-5	616
1988	-3	0	24	78	110	122	126	103	49	21	-6	-4	620
1989	-2	-2	3	73	100	114	154	103	48	20	-5	-6	600
1990	-5	-3	29	60	118	136	133	107	59	17	-3	-2	646
1991	-3	2	21	70	111	106	154	136	46	14	-4	-5	648
1992	-6	-1	32	59	96	133	119	109	37	18	-5	-3	588
1993	-3	-1	31	52	118	116	117	100	49	20	-1	-5	593
1994	-2	0	32	71	108	121	126	112	65	20	-2	-3	648
1995	-4	0	29	61	129	144	136	91	62	20	-2	-3	663
1996	-2	0	17	62	92	132	135	110	43	18	-1	-3	603
1997	-2	-2	29	62	107	123	146	111	58	17	-2	-4	643
1998	-3	-4	30	78	140	142	144	123	63	18	-3	-4	724
1999	-3	0	28	66	102	136	136	117	59	21	1	-6	657
2000	-3	-1	32	71	109	129	132	101	52	21	-4	-4	635
2001	-7	1	32	72	121	131	142	124	62	19	1	-5	693
2002	-3	5	9	55	116	157	149	109	56	14	-2	-9	656
2003	-2	-1	24	64	118	138	146	113	53	21	-4	-7	663
2004	-3	-4	31	69	103	135	132	97	49	19	5	-4	629
2005	-3	8	30	68	114	128	136	95	53	21	3	-7	646
2006	-6	0	23	85	108	140	148	112	58	19	0	1	688
2007	3	3	30	68	115	127	157	96	54	22	-1	-4	670
2008	-4	0	31	60	120	146	138	106	58	23	5	-3	680
2009	-2	0	20	64	115	134	141	111	68	15	5	-9	662
MIN	-7.0	-4.0	3.0	46.0	80.0	100.0	99.0	86.0	35.0	14.0	-7.0	-9.0	567
MAX	3.0	8.0	32.0	95.0	140.0	157.0	157.0	136.0	68.0	23.0	5.0	1.0	724
MEAN	-3.0	0.2	24.6	66.8	111.1	130.2	137.2	108.5	52.2	19.1	-0.8	-4.1	642

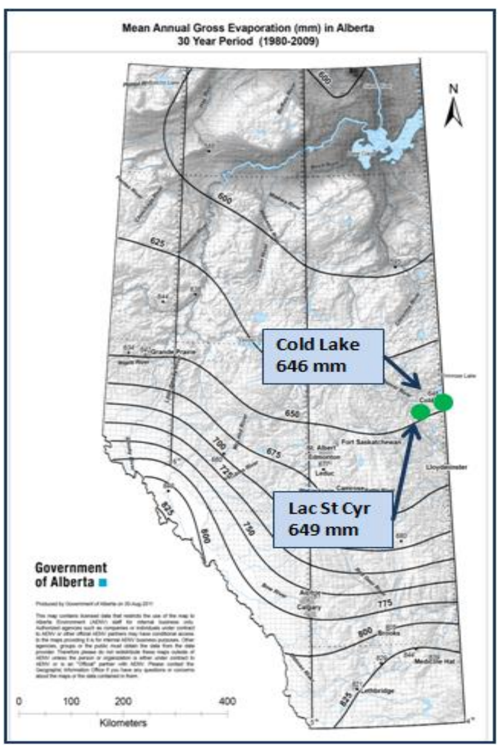

Figure 5 – Morton long-term mean annual lake evaporation

TABLE 8b - MONTHLY AND ANNUAL GROSS LAKE EVAPORATION (millimeters) AT COLD LAKE ADJUSTED TO LAC ST CYR													
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**ANNUAL**
1979	-3.0	0.0	30.1	46.2	110.5	130.6	155.7	108.5	53.2	18.1	1.0	-5.0	**646.0**
1980	-3.0	-2.0	12.1	95.4	132.6	119.6	149.7	87.4	39.2	22.1	2.0	-1.0	**654.0**
1981	-5.0	1.0	31.1	64.3	121.6	142.7	131.6	133.6	59.3	17.1	5.0	-2.0	**700.2**
1982	-1.0	0.0	13.1	64.3	103.5	138.6	130.6	95.4	53.2	22.1	-1.0	-3.0	**615.8**
1983	-5.0	-2.0	15.1	66.3	96.4	100.5	117.5	128.6	44.2	19.1	-7.0	-4.0	**569.6**
1984	-1.0	7.0	26.1	73.3	80.4	130.6	141.7	104.5	36.2	17.1	-1.0	-2.0	**612.8**
1985	-3.0	-1.0	29.1	64.3	116.5	122.6	147.7	110.5	35.2	18.1	-1.0	-1.0	**637.9**
1986	0.0	1.0	27.1	64.3	101.5	139.6	99.5	125.6	39.2	21.1	-1.0	-4.0	**613.8**
1987	-3.0	1.0	14.1	66.3	114.5	126.6	137.6	86.4	58.3	19.1	3.0	-5.0	**618.9**
1988	-3.0	0.0	24.1	78.4	110.5	122.6	126.6	103.5	49.2	21.1	-6.0	-4.0	**622.9**
1989	-2.0	-2.0	3.0	73.3	100.5	114.5	154.7	103.5	48.2	20.1	-5.0	-6.0	**602.8**
1990	-5.0	-3.0	29.1	60.3	118.5	136.6	133.6	107.5	59.3	17.1	-3.0	-2.0	**649.0**
1991	-3.0	2.0	21.1	70.3	111.5	106.5	154.7	136.6	46.2	14.1	-4.0	-5.0	**651.0**
1992	-6.0	-1.0	32.1	59.3	96.4	133.6	119.6	109.5	37.2	18.1	-5.0	-3.0	**590.7**
1993	-3.0	-1.0	31.1	52.2	118.5	116.5	117.5	100.5	49.2	20.1	-1.0	-5.0	**595.8**
1994	-2.0	0.0	32.1	71.3	108.5	121.6	126.6	112.5	65.3	20.1	-2.0	-3.0	**651.0**
1995	-4.0	0.0	29.1	61.3	129.6	144.7	136.6	91.4	62.3	20.1	-2.0	-3.0	**666.1**
1996	-2.0	0.0	17.1	62.3	92.4	132.6	135.6	110.5	43.2	18.1	-1.0	-3.0	**605.8**
1997	-2.0	-2.0	29.1	62.3	107.5	123.6	146.7	111.5	58.3	17.1	-2.0	-4.0	**646.0**
1998	-3.0	-4.0	30.1	78.4	140.7	142.7	144.7	123.6	63.3	18.1	-3.0	-4.0	**727.4**
1999	-3.0	0.0	28.1	66.3	102.5	136.6	136.6	117.5	59.3	21.1	1.0	-6.0	**660.1**
2000	-3.0	-1.0	32.1	71.3	109.5	129.6	132.6	101.5	52.2	21.1	-4.0	-4.0	**637.9**
2001	-7.0	1.0	32.1	72.3	121.6	131.6	142.7	124.6	62.3	19.1	1.0	-5.0	**696.2**
2002	-3.0	5.0	9.0	55.3	116.5	157.7	149.7	109.5	56.3	14.1	-2.0	-9.0	**659.0**
2003	-2.0	-1.0	24.1	64.3	118.5	138.6	146.7	113.5	53.2	21.1	-4.0	-7.0	**666.1**
2004	-3.0	-4.0	31.1	69.3	103.5	135.6	132.6	97.5	49.2	19.1	5.0	-4.0	**631.9**
2005	-3.0	8.0	30.1	68.3	114.5	128.6	136.6	95.4	53.2	21.1	3.0	-7.0	**649.0**
2006	-6.0	0.0	23.1	85.4	108.5	140.7	148.7	112.5	58.3	19.1	0.0	1.0	**691.2**
2007	3.0	3.0	30.1	68.3	115.5	127.6	157.7	96.4	54.3	22.1	-1.0	-4.0	**673.1**
2008	-4.0	0.0	31.1	60.3	120.6	146.7	138.6	106.5	58.3	23.1	5.0	-3.0	**683.2**
2009	-2.0	0.0	20.1	64.3	115.5	134.6	141.7	111.5	68.3	15.1	5.0	-9.0	**665.1**
MIN	**-7.0**	**-4.0**	**3.0**	**46.2**	**80.4**	**100.5**	**99.5**	**86.4**	**35.2**	**14.1**	**-7.0**	**-9.0**	**569.6**
MAX	**3.0**	**8.0**	**32.1**	**95.4**	**140.7**	**157.7**	**157.7**	**136.6**	**68.3**	**23.1**	**5.0**	**1.0**	**727.4**
MEAN	**-3.0**	**0.2**	**24.8**	**67.1**	**111.6**	**130.8**	**137.8**	**109.0**	**52.4**	**19.2**	**-0.8**	**-4.1**	**644.9**

Table 9 – Mean annual gross lake evaporation losses from key water bodies within the Lac St Cyr basin			
	Lake Surface Area (km^2)	Mean Annual Lake Evaporation (mm)	Evaporation Losses (m^3)
Pond A - NE of LSC	0.25	644.9	161,213
North Basin LSC	0.72	644.9	464,293
South Basin LSC	1.48	644.9	954,381
Lac St Cyr	2.20	644.9	1,418,674
To all 3water bodies	2.45	644.9	1,579,887

3.6 Diversions Into and Out of Lac St Cyr

The lake water balance can be significantly affected by human activities which divert water into or away from a lake. In Alberta all water diversions, with the exception of domestic use, must obtain an approval from Alberta Environment and Sustainable Resource Development. Alberta Environment records indicate that there are two licences of relevance with respect to Lac St Cyr water balance, these are:

- File 17261 that permits Alberta Environment to divert up to a maximum of 1,800 acre-feet/yr (2,220,300 m^3/yr) from the North Saskatchewan River and into Lac St Cyr, and
- File 08862 which permits the Town of St Paul to divert up to a maximum of 760 ac-ft/yr (937,460 m^3/yr) from Lac St Cyr under two interim licences.

While the licences permit a maximum diversion up to previously noted quantities, the actual diversions vary from year to year and depend on a number of factors, including weather conditions and municipal water demand. However, in most instances the actual diversion is substantially lower than the water allocation.

The monthly and annual diversions from the North Saskatchewan River to the south basin of Lac St Cyr have been estimated from pump records by Alberta Environment and Sustainable Resource Development and are listed in Table 10. Table 10 shows the actual mean annual diversion from the North Saskatchewan to Lac St Cyr during the 1979-2009 period was about 1,221,512 m^3 per year. It is noted that, due to water quality considerations, under the current operational procedures the diversions from the North Saskatchewan River generally occur during the November 1 to March 31.

The monthly and annual diversions from the north basin of Lac St Cyr to the Town of St Paul Water Treatment Plant have been estimated from raw water diversion reports and from treated water delivery reports by Alberta Environment and Sustainable Resource Development and are summarized in Table 11. Table 11 shows the actual mean annual diversion from Lac St Cyr to the Town of St Paul Water Treatment Plant during the 1979-2009 period was about 936,835 m^3 per year.

Table 10 - Monthly and annual diversion from North Saskatchewan River to Lac St Cyr (m^3)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	Annual
1978	-	-	-	-	-	-	-	-	-	142,240	304,800	314,960	762,000
1979	-	-	-	-	-	-	-	-	-	279,976	270,945	279,976	830,898
1980	279,976	36,126	-	-	-	-	-	-	-	388,546	233,128	261,498	1,199,274
1981	330,573	76,476	-	-	-	-	-	-	-	349,075	307,137	335,507	1,398,766
1982	192,423	105,859	-	-	-	-	-	-	-	336,734	325,872	336,734	1,297,622
1983	184,661	-	-	-	-	-	-	-	-	119,129	297,823	307,750	909,362
1984	307,750	198,548	-	-	-	-	-	-	-	99,912	333,040	344,141	1,283,391
1985	266,432	-	-	-	-	-	-	-	-	103,612	323,172	347,841	1,041,057
1986	320,705	222,026	-	-	-	-	-	-	-	-	-	-	542,731
1987	-	-	-	-	-	-	-	-	-	101,292	276,250	285,458	663,000
1988	333,000	167,000	78,000	-	-	-	-	-	-	-	250,000	344,000	1,172,000
1989	321,000	-	-	-	-	-	-	-	-	-	-	321,000	642,000
1990	114,600	104,900	-	-	-	-	-	-	-	-	233,848	371,758	825,105
1991	371,758	311,797	-	-	-	-	-	-	-	23,984	281,816	371,758	1,361,113
1992	371,758	347,773	23,984	-	-	-	-	-	-	119,922	209,863	371,758	1,445,059
1993	371,758	335,781	-	-	-	-	-	-	-	71,953	197,871	371,758	1,349,121
1994	371,758	335,781	-	-	-	-	-	-	-	83,945	173,887	371,758	1,337,129
1995	371,758	335,781	71,953	-	-	-	-	-	-	167,891	239,844	185,879	1,373,105
1996	173,887	191,875	251,836	-	-	-	-	-	-	23,984	11,992	335,781	989,355
1997	371,758	335,781	143,906	-	-	-	-	-	-	-	23,984	341,777	1,217,207
1998	328,700	240,500	238,600	-	-	-	-	-	-	53,200	246,200	307,600	1,414,800
1999	371,756	335,780	275,820	-	-	-	-	-	-	-	11,992	371,756	1,367,104
2000	371,756	347,772	347,772	-	-	-	-	-	-	-	35,976	185,878	1,289,154
2001	185,878	185,878	263,827	-	-	-	-	-	-	-	-	299,803	935,386
2002	371,756	335,780	371,756	143,905	-	-	-	-	-	-	-	347,772	1,570,970
2003	359,764	335,780	371,756	191,874	-	-	-	-	-	35,976	305,799	359,764	1,960,714
2004	359,764	335,780	359,764	-	-	-	-	-	-	59,961	-	275,820	1,391,089
2005	359,764	335,780	83,944	-	-	-	-	-	-	161,893	95,936	323,787	1,361,106
2006	359,764	305,799	209,862	-	-	-	-	-	-	-	53,964	371,756	1,301,145
2007	371,756	305,799	293,429	23,984	-	-	-	-	-	29,980	135,614	347,772	1,508,334
2008	371,756	323,787	371,756	-	-	-	-	-	-	53,964	149,901	175,956	1,447,120
2009	373,004	338,435	373,497	-	-	-	-	-	-	-	77,624	280,107	1,442,667
2010	376,502	329,902	229,622	-	-	-	-	-	-	-	57,061	369,250	1,362,337
2011	376,583	325,261	342,798	-	-	-	-	-	-	-	-	296,556	1,341,198
2012	330,927	289,838	245,624	-	-	-	-	-	-	-	36,039	334,421	1,236,849
MEAN 1979 2009	**298,096**	**220,399**	**133,273**	**11,605**	**-**	**-**	**-**	**-**	**-**	**85,965**	**164,628**	**307,545**	**1,221,512**
	recorded monthly diversion volumes												
	reported annual diversion distributed based on pump start and end dates												
	based on logs of pump days and pump rate of 1100 U.S gallons per minute												

Source- Alberta Environment and Natural Resources

Table 11 - Monthly and annual diversion (m^3) from Lac St Cyr to Town of St Paul Water Treatment Plant													
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	Annual
1952	6,085	5,665	6,453	6,462	7,549	7,278	6,950	6,824	6,558	6,234	5,907	6,184	78,149
1953	7,256	6,755	7,694	7,706	9,001	8,678	8,288	8,137	7,820	7,434	7,043	7,374	93,187
1954	7,773	7,236	8,243	8,255	9,643	9,297	8,879	8,717	8,378	7,964	7,545	7,900	99,830
1955	8,527	7,938	9,042	9,056	10,578	10,198	9,739	9,562	9,190	8,736	8,277	8,666	109,509
1956	9,381	8,733	9,948	9,963	11,637	11,220	10,715	10,520	10,110	9,611	9,106	9,534	120,476
1957	11,111	10,344	11,782	11,800	13,783	13,289	12,691	12,460	11,975	11,384	10,785	11,292	142,696
1958	15,449	14,383	16,383	16,408	19,165	18,478	17,647	17,325	16,651	15,829	14,997	15,702	198,417
1959	16,756	15,600	17,770	17,796	20,787	20,042	19,140	18,791	18,060	17,168	16,266	17,031	215,206
1960	19,582	18,231	20,766	20,797	24,292	23,421	22,367	21,960	21,106	20,063	19,009	19,903	251,498
1961	23,383	21,769	24,797	24,834	29,008	27,968	26,709	26,223	25,203	23,958	22,699	23,766	300,317
1962	33,852	31,515	35,898	35,952	41,994	40,488	38,666	37,962	36,485	34,683	32,861	34,405	434,761
1963	32,895	30,625	34,884	34,936	40,808	39,345	37,574	36,890	35,455	33,703	31,932	33,433	422,481
1964	41,641	38,766	44,158	44,224	51,657	49,804	47,563	46,697	44,881	42,663	40,422	42,322	534,797
1965	44,015	40,977	46,676	46,746	54,602	52,644	50,275	49,359	47,440	45,096	42,726	44,735	565,292
1966	42,716	39,768	45,299	45,367	52,991	51,091	48,792	47,903	46,040	43,766	41,466	43,415	548,612
1967	46,005	42,829	48,786	48,859	57,071	55,024	52,548	51,591	49,585	47,135	44,658	46,757	590,849
1968	62,517	58,201	66,296	66,396	77,554	74,773	71,408	70,107	67,381	64,052	60,686	63,539	802,911
1969	71,367	66,441	75,682	75,795	88,533	85,359	81,518	80,032	76,920	73,120	69,278	72,534	916,578
1970	65,518	60,995	69,479	69,583	81,278	78,363	74,837	73,473	70,616	67,128	63,600	66,590	841,459
1971	67,754	63,077	71,850	71,958	84,051	81,037	77,391	75,981	73,026	69,418	65,771	68,862	870,177
1972	65,989	61,434	69,979	70,084	81,862	78,926	75,375	74,002	71,124	67,610	64,057	67,068	847,509
1973	70,371	65,514	74,626	74,738	87,298	84,168	80,380	78,916	75,847	72,100	68,311	71,522	903,791
1974	73,138	68,089	77,560	77,676	90,730	87,477	83,540	82,019	78,829	74,935	70,997	74,334	939,323
1975	63,649	59,255	67,497	67,598	78,958	76,127	72,701	71,377	68,601	65,212	61,785	64,690	817,449
1976	69,488	64,692	73,689	73,800	86,203	83,112	79,372	77,926	74,895	71,195	67,454	70,625	892,450
1977	68,132	63,429	72,251	72,360	84,521	81,490	77,823	76,405	73,434	69,806	66,138	69,247	875,036
1978	71,973	67,005	76,325	76,439	89,285	86,084	82,210	80,712	77,573	73,741	69,866	73,150	924,365
1979	77,024	71,708	81,681	81,804	95,552	92,125	87,980	86,377	83,018	78,917	74,770	78,284	989,238
1980	76,025	70,777	80,621	80,742	94,312	90,930	86,838	85,256	81,940	77,892	73,799	77,268	976,400
1981	75,852	70,616	80,437	80,558	94,097	90,722	86,640	85,062	81,754	77,715	73,631	77,092	974,176
1982	83,752	77,971	88,815	88,948	103,897	100,171	95,664	93,921	90,268	85,809	81,300	85,121	1,075,637
1983	79,930	74,412	84,762	84,889	99,156	95,600	91,298	89,635	86,149	81,893	77,590	81,237	1,026,549
1984	69,288	64,505	73,476	73,587	85,954	82,871	79,142	77,701	74,679	70,990	67,259	70,421	889,872
1985	74,824	69,659	79,347	79,466	92,822	89,493	85,466	83,909	80,646	76,662	72,633	76,047	960,973
1986	84,624	78,783	89,740	89,875	104,979	101,215	96,660	94,899	91,209	86,703	82,147	86,008	1,086,843
1987	74,435	69,297	78,935	79,054	92,339	89,028	85,022	83,473	80,227	76,264	72,256	75,652	955,982
1988	71,829	66,871	76,172	76,286	89,107	85,911	82,045	80,551	77,418	73,594	69,726	73,004	922,514
1989	64,599	60,140	68,505	68,607	80,138	77,264	73,787	72,443	69,626	66,186	62,708	65,656	829,659
1990	65,195	60,695	69,137	69,241	80,877	77,977	74,468	73,112	70,268	66,797	63,287	66,262	837,317
1991	74,426	69,289	78,926	79,044	92,328	89,017	85,012	83,463	80,217	76,255	72,247	75,643	955,868
1992	68,545	63,814	72,689	72,798	85,033	81,984	78,295	76,868	73,879	70,229	66,539	69,666	880,340
1993	68,001	63,307	72,112	72,220	84,358	81,333	77,673	76,258	73,292	69,672	66,010	69,113	873,350
1994	63,761	59,360	67,616	67,717	79,098	76,262	72,830	71,503	68,722	65,328	61,895	64,804	818,896
1995	64,100	59,675	67,975	68,077	79,518	76,667	73,217	71,883	69,087	65,675	62,223	65,148	823,246
1996	69,742	64,928	73,958	74,069	86,517	83,415	79,661	78,210	75,168	71,455	67,700	70,882	895,704
1997	66,263	61,689	70,269	70,374	82,202	79,254	75,688	74,309	71,419	67,891	64,323	67,347	851,027
1998	71,458	66,525	75,778	75,892	88,646	85,467	81,622	80,135	77,018	73,213	69,366	72,627	917,748
1999	69,995	65,163	74,227	74,338	86,831	83,717	79,950	78,494	75,441	71,714	67,946	71,140	898,957
2000	67,909	67,277	72,272	74,636	75,545	89,268	75,500	78,481	75,636	72,045	65,727	76,364	890,660
2001	77,636	72,011	87,227	91,045	117,909	81,182	75,582	86,682	94,727	82,773	76,773	79,591	1,023,138
2002	94,527	88,002	100,242	100,392	117,265	113,059	107,972	106,005	101,882	96,849	91,760	96,073	1,214,030
2003	82,874	77,153	87,884	88,016	102,808	99,121	94,661	92,937	89,322	84,910	80,448	84,229	1,064,364
2004	71,818	71,091	75,682	73,864	100,136	85,455	81,272	77,909	69,500	73,227	70,773	71,955	922,682
2005	73,091	65,545	74,091	74,636	83,273	87,000	88,818	86,045	73,182	63,136	67,955	70,136	906,908
2006	66,367	61,000	71,091	74,273	85,545	83,318	92,909	80,237	75,715	73,807	67,918	71,218	903,398
2007	65,249	60,745	69,194	69,298	80,944	78,042	74,530	73,172	70,326	66,852	63,339	66,316	838,008
2008	76,522	69,572	77,225	71,208	80,050	83,226	85,455	81,542	73,724	73,817	71,205	72,397	915,943
2009	72,823	64,530	78,045	79,968	83,388	94,259	78,501	80,286	77,478	74,088	67,674	71,428	922,468
2010	69,214	62,071	68,733	67,238	82,914	81,313	82,310	76,026	76,258	74,592	70,125	72,009	882,803
2011	67,090	65,025	76,946	75,466	88,248	83,406	73,502	73,272	76,240	70,768	65,512	67,880	883,355
MEAN 1979-2009	72,983	67,939	77,359	77,578	90,472	87,237	83,360	81,960	78,482	74,592	70,740	74,133	936,835
	monthly raw water diversions from LSC estimated as 1.145* monthly drinking water delivery												
	monthly raw water diversions from LSC estimated based on annual raw water diversion from LSC.												
	recorded monthly diversions												

3.7 Outflow from Pond A into North Basin of Lac St Cyr

Pond A to the northeast of Lac St Cyr has a catchment area of approximately 3.59 km^2. Outflows from pond A flow into the north basin of Lac St Cyr. As there is no information on the outflow from Pond A and its physical characteristics, the outflow from Pond A into the north basin of Lac St Cyr was estimated by conducting a monthly water balance for the entire January 1979 to December 2009 period using the relation:

$$S_t = S_{(t-1)} + \Delta S_t$$

Where:

S_t, and $S_{(t-1)}$ = the storage volume at time “t” and “t-1” respectively, and
ΔS_t = the change in storage at time “t” which is computed as
$\Delta S_t = SI_t + LSA*(P_t - E_t)$ where all parameters are as previously defined.

In conducting the water balance for pond A the following assumptions were made:

- Groundwater inputs and outflows from Pond A are in balance for all time increments (i.e. GI-GO=0),
- Pond A has a maximum depth of 1.5 m.,
- The pond has a constant 0.25 km^2 surface area throughout its entire depth (i.e. a maximum storage volume of 375,000 m^3),
- Pond A had an initial (January 1, 1979) storage volume of 300,000 m^3, and
- Inputs in excess of the maximum storage volume are spilled in the month in which they occur.

Outflows from pond A into the north basin of Lac St Cyr resulting from the above noted analysis are summarized in Table 12. Table 12 suggest that the outflow from Pond A into the north basin of Lac St Cyr is highly variable and that it has outflow only after a prolonged series of relatively wet years. A sensitivity analysis was carried out to determine the effects on outflow of potential errors in the assumed initial storage conditions, depth and effective drainage area of Pond A. The analysis generally indicated that an underestimation in the depth would have virtually no impact on the computed outflows. While a reduction in pond depth would result in some increase in outflows the increase in outflows was generally not significant unless the depth was reduced to less than 1.0 m, in which case the pond would experience frequent drying out period. While a reduction in the contributing area would reduce the outflow the reduction was generally less than 10,000 m^3. As such the water balance would appear to provide a reasonable estimate of outflows from Pond A.

Table 12 - Estimated monthly and annual outflow (m^3) from Pond A into North Basin of Lac St Cyr

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1979	0	0	0	0	44,757	26,020	9,694	0	0	0	0	0	80,471
1980	0	808	4,573	9,557	0	0	0	0	0	0	0	0	14,939
1981	0	0	0	5,247	0	0	0	0	0	0	0	0	5,247
1982	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	2,912	0	0	0	0	0	0	2,912
1985	0	0	0	67,918	20,945	14,120	0	0	0	0	0	0	102,983
1986	0	0	0	21,615	65,860	0	41,992	0	0	0	0	0	129,467
1987	0	0	1,257	96,374	0	0	0	0	0	0	0	0	97,631
1988	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	85,483	0	0	0	0	0	0	85,483
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	18,822	0	0	0	0	0	0	0	0	18,822
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0
MIN	0	0	0	0	0	0	0	0	0	0	0	0	0
MAX	0	808	4,573	96,374	65,860	85,483	41,992	0	0	0	0	0	129,467
MEAN	0	26	188	7,082	4,244	4,146	1,667	0	0	0	0	0	17,353

3.8 Lac St Cyr Change in Storage

Table 4 shows that in January 1979, the start of the water balance computational period, Lac St Cyr had a mean elevation of 644.495 m. In December 2009, the end of the water balance computational period, the lake had an elevation of 644.643 m; an increase of 0.148 m over the 31 year period. As such, over the 31 year period Lac St Cyr had the following increases:

	Change in Elev.	Lake Surface Area	Δ Storage	Δ Storage/yr
	(m)	(m^3)	(m^3)	(m^3)
North Basin	0.148	0.72	106,560	3,437
South Basin	0.148	1.48	219,040	7,066
Lac St Cyr	0.148	2.20	325,600	10,503

3.9 Lac St Cyr Groundwater Inflow and Outflow (GI-GO)

Groundwater inflow to and outflow from a lake are generally small compared to other parameters. Groundwater inputs and outputs are also difficult to quantify because of the difficulty in obtaining sufficient data to describe the how the geology of an area varies both vertically and horizontally and how the various layers or aquifers interact with each other as well as with the lake under consideration. While sophisticated computer models are at times used to estimate groundwater inflows and outflows, the resulting estimates often have very large associated errors, even under conditions where there is a significant amount of data upon which to calibrate the models. As such, groundwater inflow (GI-GO) is often back calculated as the residual in a lake water balance.

To conduct a back calculation, equation (3) in Section 2 is rearranged as follows:

$$\mathbf{SI + (LSA*P) - (LSA*E) + (GI\text{-}GO) + (DI\text{-} DO) = \Delta S}$$

Where SI includes the direct surface inflow to the north basin and south basin of Lac St Cyr as well as the outflow from Pond A into the north basin of Lac St Cyr.

Applying all previously computed inflows and outflows values to the above water balance equation results in the following estimate of "net groundwater input:

$$\mathbf{(17{,}353 m^3 + 36{,}024\ m^3 + 187{,}644\ m^3) + 892{,}696\ m^3 - 1{,}418{,}674\ m^3 + (GI\text{-}GO) + 1{,}221{,}512\ m^3 - 936{,}835\ m^3 = 10{,}503\ m^3}$$

or

$$\mathbf{(GI\text{-}GO) = 10{,}783\ m^3}$$

The above computation would seem to indicate that Lac St Cyr has a net groundwater inflow of about 10,783 m^3/yr. However, caution is advised in the use of this estimate as it can be out significantly due to inaccuracies in other more significant parameters.

4.0 WATER TRANSFER FROM SOUTH BASIN TO NORTH BASIN

The annual water transfer from the south basin to the north basin of Lac St Cyr is estimated using the following water balance equation for the north basin of Lac St Cyr:

$$\mathbf{SI + (LSA*P) – (LSA*E) + (GI\text{-}GO) + (T_{SB}\text{-} DO) = \Delta S}$$

Where:

SI = the direct inflow to the north basin of Lac St Cyr plus the outflow from Pond A,
T_{SB} = the annual water transfer from the south basin to the north basin,
(GI-GO) is assumed at 50% of the (GI-GO) previously computed for Lac St Cyr,
ΔS = the previously computed change in storage for the north basin =3,437 m^3), and
All other parameters are as previously defined for the north basin of Lac St Cyr.

Applying all previously computed inflow and outflow values for the north basin of Lac St Cyr to the above noted water balance equation results in the following estimate of annual water transfer from the south basin to the north basin of Lac St Cyr.

$$\mathbf{(17,353m^3 + 36,024\ m^3) + 292,155\ m^3 – 464,293\ m^3 + 5,392\ m^3 + T_{SB} - 936,835\ m^3 =3,437\ m^3}$$

or

$$\mathbf{T_{SB} = 1,053,642\ m^3}$$

It is noted that the above computation does not account for additional mixing of waters from the two basins that may occur as a result of wind and or ice action

5.0 SUMMARY AND CONCLUSIONS

Lac St Cyr is a landlocked which is comprised of two main components, a north basin and a south basin which join on the west side of the lake. Since 1952, the north basin of Lac St Cyr has been the source of the municipal water supplies for the Town of St Paul. Since 1978, diversions have been made from the North Saskatchewan River into the south basin to provide a reliable source of water for the Town and to mitigate lake level declines. In 2012 the Elk Point/St Paul Regional Water Commission was established to supply municipal water to the Towns of St Paul, the Town of Elk Point and to the south east sector of the County of St Paul No.19 through the existing works of the Town of St Paul. It is expected that, ultimately, the annual water diversion into Lac St Cyr could be in the order of 1800 acre-feet (2,220,300 m^3), about 17% of the lake volume.

This report has conducted a water balance for the north and south basin of Lac St Cyr, and for all of Lac St Cyr (1979 to 2009), to develop a better understanding of the lake and to provide estimates of the water balance parameters for use in a subsequent water quality analysis. The computed physical and hydrological parameters are summarized in Table 13, the water balance parameters are summarized in Table 14.

Table 13 - Summary of Physical and Hydrologic Parameters for Lac St Cyr

Physical Parameters	North Basin	South Basin	Lac St Cyr
Gross Drainage Area (km^2)			27.64
Directly Contributing Drainage Area (including Lake surface areas) (km^2)	2.30	9.71	12.01
Contributing Drainage Area draining through Pond A (including Lake surface areas) (km^2)	3.59	0.00	3.59
Total Contributing Drainage Area (including Lake surface areas) (km^2)	5.89	9.71	15.60
Effective Drainage Area (excluding Lake surface areas) (km^2)	1.58	8.23	9.81
Effective Drainage Area draining to Pond A (excluding Lake surface area) (km^2)	3.34	0.00	3.34
Lake surface area (at elevation 644.75 m) (km^2)	0.72	1.48	2.20
Lake surface area of Pond A (km^2)	0.25	0.00	0.25
Hydrologic Parameters			
mean annual surface runoff (mm)			22.7
mean annual precipitation (mm)			405.8
mean annual lake evaporation (mm)			645

Table 14 - Summary of (1979-2009)Water Balance Parameters for Lac St Cyr

Parameter	North Basin	South Basin	Lac St Cyr
Inflow from area drained by Pond A (m^3)	17,353	0	17,353
Direct Surface Inflow (m^3)	36,024	187,644	223,668
Precipitation Input (m^3)	292,155	600,541	892,696
Gross lake Evaporation (m^3)	-464,293	-954,381	-1,418,674
Diversion into Lac St Cyr (m^3)	0	1,221,512	1,221,512
Diversion from Lac St Cyr (m^3)	-936,835	0	-936,835
Net Groundwater Inflow (m^3)	5,392	5,392	10,783
Transfer from South Basin to North Basin (m^3)	1,053,642	-1,053,642	0
Change in Storage (m^3)	3,437	7,066	10,503

It is noted that, unlike other parameters, the net groundwater inflow has been computed as the residual in the water balance and, as such, may have significant error associated with it. It is further noted that the hydrometric station Moosehill Creek near Elk Point was discontinued in 2009. As there are no other representative stations in the vicinity of Lac St Cyr the re-activation of this station is recommended.

6.0 REFERENCES

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APPENDIX A

Tables of Monthly Inflows

Table A1a - Monthly Surface Inflow (SR) to Pond A NE of Lac St Cyr

Contributing Drainage area (including Lake Surface area) = 3.59 km^2 - Effective Drainage Area (excluding lake surface area =3.34

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)
1979	-	-	949	63,609	72,611	30,771	15,424	2,136	2,296	1,424	-	-	189,220
1980	-	-	237	33,068	3,797	1,148	1,661	2,847	2,526	3,797	-	-	49,081
1981	-	-	16,136	36,053	2,136	2,526	11,865	949	0	0	-	-	69,664
1982	-	-	0	30,542	15,661	230	16,848	6,407	919	0	-	-	70,605
1983	-	-	0	7,119	5,695	2,756	18,746	949	6,659	1,424	-	-	43,348
1984	-	-	6,644	17,682	19,458	22,964	475	237	459	475	-	-	68,393
1985	-	-	0	86,343	37,729	24,112	2,373	3,322	0	475	-	-	154,354
1986	-	-	14,712	45,698	68,577	5,741	53,628	8,542	689	237	-	-	197,824
1987	-	-	1,661	100,351	18,746	3,215	712	0	0	0	-	-	124,685
1988	-	-	712	1,837	2,373	7,119	11,153	2,373	1,378	712	-	-	27,656
1989	-	-	0	13,549	237	9,874	4,509	475	1,837	2,136	-	-	32,616
1990	-	-	3,322	53,505	16,848	1,837	8,542	1,186	0	0	-	-	85,241
1991	-	-	0	8,956	4,746	459	0	0	0	0	-	-	14,161
1992	-	-	237	0	237	689	0	0	0	0	-	-	1,163
1993	-	-	237	2,296	4,509	0	237	0	0	0	-	-	7,279
1994	-	-	0	43,401	17,560	6,659	949	0	0	0	-	-	68,569
1995	-	-	712	14,467	237	0	0	712	0	0	-	-	16,128
1996	-	-	0	42,712	27,051	17,223	22,305	949	0	0	-	-	110,241
1997	-	-	712	100,121	48,170	87,032	6,407	0	0	0	-	-	242,442
1998	-	-	2,460	36,038	4,509	0	2,847	0	0	0	-	-	45,853
1999	-	-	3,559	22,275	30,136	1,148	2,610	0	0	0	-	-	59,728
2000	-	-	1,898	8,037	2,610	5,282	8,542	1,661	1,837	475	-	-	30,343
2001	-	-	949	4,363	4,509	5,741	3,559	3,322	459	237	-	-	23,140
2002	-	-	237	7,578	12,339	0	0	0	0	0	-	-	20,154
2003	-	-	0	2,526	475	1,837	1,424	0	0	712	-	-	6,973
2004	-	-	712	113,211	10,441	16,534	10,915	0	1,148	475	-	-	153,435
2005	-	-	16,848	36,512	23,966	29,853	8,068	4,983	1,837	6,644	-	-	128,711
2006	-	-	949	77,617	55,526	14,697	5,932	475	0	712	-	-	155,908
2007	-	-	2,373	62,002	13,763	4,822	712	0	0	0	-	-	83,672
2008	-	-	0	31,690	18,983	3,674	1,898	0	0	0	-	-	56,246
2009	-	-	0	14,008	4,271	2,985	2,610	0	0	0	-	-	23,874
Max	-	-	**16,848**	**113,211**	**72,611**	**87,032**	**53,628**	**8,542**	**6,659**	**6,644**	-	-	**242,442**
Min	-	-	**0**	**0**	**237**	**0**	**0**	**0**	**0**	**0**	-	-	**1,163**
Mean	-	-	**2,460**	**36,038**	**17,674**	**10,030**	**7,256**	**1,340**	**711**	**643**	-	-	**76,152**
	Missing values filled with average												

Table A1b - Monthly Surface Inflow (SR) to North Basin of Lac St Cyr

Contributing Drainage area (including Lake Surface area) = 2.30 km^2 - Effective Drainage Area (excluding lake surface area =1.58

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)
1979	-	-	449	30,091	34,349	14,556	7,296	1,010	1,086	674	-	-	89,511
1980	-	-	112	15,643	1,796	543	786	1,347	1,195	1,796	-	-	23,218
1981	-	-	7,633	17,055	1,010	1,195	5,613	449	0	0	-	-	32,955
1982	-	-	0	14,448	7,409	109	7,970	3,031	435	0	-	-	33,400
1983	-	-	0	3,368	2,694	1,304	8,868	449	3,150	674	-	-	20,506
1984	-	-	3,143	8,365	9,205	10,863	225	112	217	225	-	-	32,354
1985	-	-	0	40,845	17,848	11,406	1,123	1,572	0	225	-	-	73,018
1986	-	-	6,960	21,617	32,441	2,716	25,369	4,041	326	112	-	-	93,581
1987	-	-	786	47,471	8,868	1,521	337	0	0	0	-	-	58,983
1988	-	-	337	869	1,123	3,368	5,276	1,123	652	337	-	-	13,083
1989	-	-	0	6,409	112	4,671	2,133	225	869	1,010	-	-	15,429
1990	-	-	1,572	25,311	7,970	869	4,041	561	0	0	-	-	40,324
1991	-	-	0	4,237	2,245	217	0	0	0	0	-	-	6,699
1992	-	-	112	0	112	326	0	0	0	0	-	-	550
1993	-	-	112	1,086	2,133	0	112	0	0	0	-	-	3,444
1994	-	-	0	20,531	8,307	3,150	449	0	0	0	-	-	32,437
1995	-	-	337	6,844	112	0	0	337	0	0	-	-	7,629
1996	-	-	0	20,205	12,797	8,147	10,552	449	0	0	-	-	52,150
1997	-	-	337	47,363	22,787	41,171	3,031	0	0	0	-	-	114,688
1998	-	-	1,164	17,048	2,133	0	1,347	0	0	0	-	-	21,691
1999	-	-	1,684	10,537	14,256	543	1,235	0	0	0	-	-	28,255
2000	-	-	898	3,802	1,235	2,498	4,041	786	869	225	-	-	14,354
2001	-	-	449	2,064	2,133	2,716	1,684	1,572	217	112	-	-	10,946
2002	-	-	112	3,585	5,837	0	0	0	0	0	-	-	9,534
2003	-	-	0	1,195	225	869	674	0	0	337	-	-	3,299
2004	-	-	337	53,555	4,939	7,821	5,164	0	543	225	-	-	72,583
2005	-	-	7,970	17,272	11,337	14,122	3,817	2,357	869	3,143	-	-	60,887
2006	-	-	449	36,717	26,267	6,952	2,806	225	0	337	-	-	73,753
2007	-	-	1,123	29,330	6,511	2,281	337	0	0	0	-	-	39,581
2008	-	-	0	14,991	8,980	1,738	898	0	0	0	-	-	26,607
2009	-	-	0	6,626	2,021	1,412	1,235	0	0	0	-	-	11,294
Max	-	-	**7,970**	**53,555**	**34,349**	**41,171**	**25,369**	**4,041**	**3,150**	**3,143**	-	-	**114,688**
Min	-	-	**0**	**0**	**112**	**0**	**0**	**0**	**0**	**0**	-	-	**550**
Mean	-	-	**1,164**	**17,048**	**8,361**	**4,745**	**3,433**	**634**	**336**	**304**	-	-	**36,024**
	Missing values filled with average												

Table A1c - Monthly Surface Inflow (SR) to South Basin of Lac St Cyr

Contributing Drainage area (including Lake Surface area) = 9.71 km^2 - Effective Drainage Area (excluding lake surface area =8.23

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)
1979	-	-	2,339	156,738	178,919	75,823	38,006	5,262	5,658	3,508	-	-	466,252
1980	-	-	585	81,481	9,355	2,829	4,093	7,016	6,224	9,355	-	-	120,939
1981	-	-	39,760	88,837	5,262	6,224	29,235	2,339	0	0	-	-	171,657
1982	-	-	0	75,257	38,590	566	41,514	15,787	2,263	0	-	-	173,977
1983	-	-	0	17,541	14,033	6,790	46,191	2,339	16,409	3,508	-	-	106,812
1984	-	-	16,372	43,570	47,945	56,584	1,169	585	1,132	1,169	-	-	168,526
1985	-	-	0	212,756	92,967	59,413	5,847	8,186	0	1,169	-	-	380,339
1986	-	-	36,251	112,602	168,979	14,146	132,142	21,049	1,698	585	-	-	487,452
1987	-	-	4,093	247,272	46,191	7,922	1,754	0	0	0	-	-	307,232
1988	-	-	1,754	4,527	5,847	17,541	27,481	5,847	3,395	1,754	-	-	68,146
1989	-	-	0	33,385	585	24,331	11,109	1,169	4,527	5,262	-	-	80,368
1990	-	-	8,186	131,841	41,514	4,527	21,049	2,924	0	0	-	-	210,040
1991	-	-	0	22,068	11,694	1,132	0	0	0	0	-	-	34,893
1992	-	-	585	0	585	1,698	0	0	0	0	-	-	2,867
1993	-	-	585	5,658	11,109	0	585	0	0	0	-	-	17,937
1994	-	-	0	106,944	43,268	16,409	2,339	0	0	0	-	-	168,960
1995	-	-	1,754	35,648	585	0	0	1,754	0	0	-	-	39,741
1996	-	-	0	105,246	66,656	42,438	54,962	2,339	0	0	-	-	271,641
1997	-	-	1,754	246,706	118,694	214,453	15,787	0	0	0	-	-	597,395
1998	-	-	6,061	88,799	11,109	0	7,016	0	0	0	-	-	112,986
1999	-	-	8,771	54,886	74,257	2,829	6,432	0	0	0	-	-	147,175
2000	-	-	4,678	19,804	6,432	13,014	21,049	4,093	4,527	1,169	-	-	74,766
2001	-	-	2,339	10,751	11,109	14,146	8,771	8,186	1,132	585	-	-	57,018
2002	-	-	585	18,673	30,404	0	0	0	0	0	-	-	49,662
2003	-	-	0	6,224	1,169	4,527	3,508	0	0	1,754	-	-	17,183
2004	-	-	1,754	278,959	25,727	40,740	26,896	0	2,829	1,169	-	-	378,075
2005	-	-	41,514	89,969	59,055	73,559	19,880	12,279	4,527	16,372	-	-	317,153
2006	-	-	2,339	191,254	136,820	36,214	14,618	1,169	0	1,754	-	-	384,167
2007	-	-	5,847	152,777	33,913	11,883	1,754	0	0	0	-	-	206,173
2008	-	-	0	78,086	46,776	9,053	4,678	0	0	0	-	-	138,593
2009	-	-	0	34,516	10,525	7,356	6,432	0	0	0	-	-	58,828
Max	-	-	**41,514**	**278,959**	**178,919**	**214,453**	**132,142**	**21,049**	**16,409**	**16,372**	-	-	**597,395**
Min	-	-	**0**	**0**	**585**	**0**	**0**	**0**	**0**	**0**	-	-	**2,867**
Mean	-	-	**6,061**	**88,799**	**43,551**	**24,714**	**17,881**	**3,301**	**1,752**	**1,584**	-	-	**187,644**
	Missing values filled with average												

Table A2a - Monthly and annual precipitation input (m^3) to Pond A NE of Lac St Cyr

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1978	9,025	575	1,075	7,575	27,975	6,875	16,150	19,375	19,525	3,200	3,450	3,825	118,625
1979	4,800	10,275	1,500	6,350	5,625	27,900	33,200	4,925	18,175	700	625	6,475	120,550
1980	4,000	2,750	7,350	350	7,100	15,450	8,275	26,600	10,650	5,500	5,900	7,525	101,450
1981	5,150	1,250	3,050	1,575	2,250	11,900	28,375	4,275	2,650	3,425	2,800	4,925	71,625
1982	6,825	2,350	7,800	6,950	12,500	6,600	24,500	22,250	8,650	3,800	3,500	2,400	108,125
1983	4,025	3,000	7,200	3,000	5,850	26,650	29,550	1,200	22,000	1,950	6,475	2,850	113,750
1984	4,475	3,650	875	4,200	20,950	15,800	10,950	10,300	20,125	8,850	6,500	3,800	110,475
1985	3,950	2,100	100	9,700	12,350	20,650	5,300	9,450	11,725	4,975	1,400	7,100	88,800
1986	4,500	1,250	7,050	2,750	22,650	12,600	29,800	5,450	8,850	2,900	4,900	2,750	105,450
1987	3,000	4,250	6,250	12,600	5,850	10,650	15,300	9,150	2,700	300	600	2,400	73,050
1988	2,375	3,400	9,350	9,100	4,450	35,500	10,600	28,200	8,350	1,900	2,750	5,650	121,625
1989	4,000	1,875	2,900	2,025	14,550	21,100	19,700	24,150	12,100	2,500	4,675	11,650	121,225
1990	5,075	4,900	3,700	4,950	12,400	8,050	23,800	11,300	3,150	3,450	6,300	4,500	91,575
1991	3,200	4,625	2,725	13,500	12,300	21,550	1,700	6,600	1,700	8,000	2,150	6,650	84,700
1992	7,750	5,750	800	8,125	11,600	10,250	21,500	9,150	4,600	4,950	2,250	4,750	91,475
1993	3,000	650	2,000	29,800	9,850	25,850	13,700	15,950	7,950	5,100	4,900	2,350	121,100
1994	12,600	7,700	1,250	1,150	13,900	24,875	21,900	16,300	7,050	7,650	3,950	8,400	126,725
1995	2,100	1,675	4,850	8,275	800	6,575	12,900	33,275	0	2,350	8,950	4,375	86,125
1996	1,850	5,500	3,700	6,950	18,800	17,925	26,700	14,150	10,200	4,825	14,350	6,000	130,950
1997	5,250	2,750	3,750	8,875	11,300	32,850	7,650	12,325	12,600	5,225	375	1,625	104,575
1998	4,625	125	1,500	4,100	2,825	12,450	7,200	4,275	8,375	5,250	2,800	3,875	57,400
1999	8,750	1,125	3,500	1,625	19,750	7,225	28,175	13,300	2,150	4,650	2,625	3,875	96,750
2000	3,875	1,825	6,000	2,250	9,650	19,775	56,500	8,325	14,750	125	1,250	5,125	129,450
2001	925	875	750	2,875	11,625	22,975	21,025	2,650	7,300	2,800	4,500	1,875	80,175
2002	750	1,000	3,000	11,375	1,050	3,075	8,700	8,325	5,650	1,500	1,500	1,150	47,075
2003	4,750	4,175	5,250	14,175	17,350	15,200	24,425	13,200	14,675	3,475	2,625	1,625	120,925
2004	5,125	0	5,750	5,025	9,750	12,800	23,525	7,025	13,150	4,950	325	7,500	94,925
2005	3,150	1,875	4,425	8,375	11,025	22,700	19,625	21,675	10,700	6,025	1,150	625	111,350
2006	2,375	5,125	16,750	5,675	24,700	13,975	22,525	11,700	23,625	4,475	8,750	3,125	142,800
2007	3,750	3,500	1,000	7,600	10,825	26,450	7,100	27,050	4,275	2,575	3,625	5,375	103,125
2008	5,400	3,750	2,775	8,900	7,100	16,650	21,825	5,950	4,500	3,800	5,050	8,250	93,950
2009	6,150	2,650	10,700	8,800	4,700	18,900	16,500	10,050	2,150	9,400	0	3,450	93,450
MIN	**750**	**0**	**100**	**350**	**800**	**3,075**	**1,700**	**1,200**	**0**	**125**	**0**	**625**	**47,075**
MAX	**12,600**	**10,275**	**16,750**	**29,800**	**27,975**	**35,500**	**56,500**	**33,275**	**23,625**	**9,400**	**14,350**	**11,650**	**142,800**
MEAN 1979-2009	**4,437**	**3,088**	**4,439**	**7,129**	**10,820**	**17,577**	**19,436**	**12,856**	**9,178**	**4,109**	**3,792**	**4,581**	**101,443**

Table A2b - Monthly and annual precipitation input (m^3) to North Basin of Lac St Cyr

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1978	25,992	1,656	3,096	21,816	80,568	19,800	46,512	55,800	56,232	9,216	9,936	11,016	341,640
1979	13,824	29,592	4,320	18,288	16,200	80,352	95,616	14,184	52,344	2,016	1,800	18,648	347,184
1980	11,520	7,920	21,168	1,008	20,448	44,496	23,832	76,608	30,672	15,840	16,992	21,672	292,176
1981	14,832	3,600	8,784	4,536	6,480	34,272	81,720	12,312	7,632	9,864	8,064	14,184	206,280
1982	19,656	6,768	22,464	20,016	36,000	19,008	70,560	64,080	24,912	10,944	10,080	6,912	311,400
1983	11,592	8,640	20,736	8,640	16,848	76,752	85,104	3,456	63,360	5,616	18,648	8,208	327,600
1984	12,888	10,512	2,520	12,096	60,336	45,504	31,536	29,664	57,960	25,488	18,720	10,944	318,168
1985	11,376	6,048	288	27,936	35,568	59,472	15,264	27,216	33,768	14,328	4,032	20,448	255,744
1986	12,960	3,600	20,304	7,920	65,232	36,288	85,824	15,696	25,488	8,352	14,112	7,920	303,696
1987	8,640	12,240	18,000	36,288	16,848	30,672	44,064	26,352	7,776	864	1,728	6,912	210,384
1988	6,840	9,792	26,928	26,208	12,816	102,240	30,528	81,216	24,048	5,472	7,920	16,272	350,280
1989	11,520	5,400	8,352	5,832	41,904	60,768	56,736	69,552	34,848	7,200	13,464	33,552	349,128
1990	14,616	14,112	10,656	14,256	35,712	23,184	68,544	32,544	9,072	9,936	18,144	12,960	263,736
1991	9,216	13,320	7,848	38,880	35,424	62,064	4,896	19,008	4,896	23,040	6,192	19,152	243,936
1992	22,320	16,560	2,304	23,400	33,408	29,520	61,920	26,352	13,248	14,256	6,480	13,680	263,448
1993	8,640	1,872	5,760	85,824	28,368	74,448	39,456	45,936	22,896	14,688	14,112	6,768	348,768
1994	36,288	22,176	3,600	3,312	40,032	71,640	63,072	46,944	20,304	22,032	11,376	24,192	364,968
1995	6,048	4,824	13,968	23,832	2,304	18,936	37,152	95,832	0	6,768	25,776	12,600	248,040
1996	5,328	15,840	10,656	20,016	54,144	51,624	76,896	40,752	29,376	13,896	41,328	17,280	377,136
1997	15,120	7,920	10,800	25,560	32,544	94,608	22,032	35,496	36,288	15,048	1,080	4,680	301,176
1998	13,320	360	4,320	11,808	8,136	35,856	20,736	12,312	24,120	15,120	8,064	11,160	165,312
1999	25,200	3,240	10,080	4,680	56,880	20,808	81,144	38,304	6,192	13,392	7,560	11,160	278,640
2000	11,160	5,256	17,280	6,480	27,792	56,952	162,720	23,976	42,480	360	3,600	14,760	372,816
2001	2,664	2,520	2,160	8,280	33,480	66,168	60,552	7,632	21,024	8,064	12,960	5,400	230,904
2002	2,160	2,880	8,640	32,760	3,024	8,856	25,056	23,976	16,272	4,320	4,320	3,312	135,576
2003	13,680	12,024	15,120	40,824	49,968	43,776	70,344	38,016	42,264	10,008	7,560	4,680	348,264
2004	14,760	0	16,560	14,472	28,080	36,864	67,752	20,232	37,872	14,256	936	21,600	273,384
2005	9,072	5,400	12,744	24,120	31,752	65,376	56,520	62,424	30,816	17,352	3,312	1,800	320,688
2006	6,840	14,760	48,240	16,344	71,136	40,248	64,872	33,696	68,040	12,888	25,200	9,000	411,264
2007	10,800	10,080	2,880	21,888	31,176	76,176	20,448	77,904	12,312	7,416	10,440	15,480	297,000
2008	15,552	10,800	7,992	25,632	20,448	47,952	62,856	17,136	12,960	10,944	14,544	23,760	270,576
2009	17,712	7,632	30,816	25,344	13,536	54,432	47,520	28,944	6,192	27,072	0	9,936	269,136
MIN	2,160	0	288	1,008	2,304	8,856	4,896	3,456	0	360	0	1,800	135,576
MAX	36,288	29,592	48,240	85,824	80,568	102,240	162,720	95,832	68,040	27,072	41,328	33,552	411,264
MEAN 1979-2009	12,779	8,893	12,783	20,532	31,162	50,623	55,977	37,024	26,433	11,834	10,921	13,195	292,155

Table A2c - Monthly and annual precipitation input (m^3) to South Basin of Lac St Cyr

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1978	53,428	3,404	6,364	44,844	165,612	40,700	95,608	114,700	115,588	18,944	20,424	22,644	702,260
1979	28,416	60,828	8,880	37,592	33,300	165,168	196,544	29,156	107,596	4,144	3,700	38,332	713,656
1980	23,680	16,280	43,512	2,072	42,032	91,464	48,988	157,472	63,048	32,560	34,928	44,548	600,584
1981	30,488	7,400	18,056	9,324	13,320	70,448	167,980	25,308	15,688	20,276	16,576	29,156	424,020
1982	40,404	13,912	46,176	41,144	74,000	39,072	145,040	131,720	51,208	22,496	20,720	14,208	640,100
1983	23,828	17,760	42,624	17,760	34,632	157,768	174,936	7,104	130,240	11,544	38,332	16,872	673,400
1984	26,492	21,608	5,180	24,864	124,024	93,536	64,824	60,976	119,140	52,392	38,480	22,496	654,012
1985	23,384	12,432	592	57,424	73,112	122,248	31,376	55,944	69,412	29,452	8,288	42,032	525,696
1986	26,640	7,400	41,736	16,280	134,088	74,592	176,416	32,264	52,392	17,168	29,008	16,280	624,264
1987	17,760	25,160	37,000	74,592	34,632	63,048	90,576	54,168	15,984	1,776	3,552	14,208	432,456
1988	14,060	20,128	55,352	53,872	26,344	210,160	62,752	166,944	49,432	11,248	16,280	33,448	720,020
1989	23,680	11,100	17,168	11,988	86,136	124,912	116,624	142,968	71,632	14,800	27,676	68,968	717,652
1990	30,044	29,008	21,904	29,304	73,408	47,656	140,896	66,896	18,648	20,424	37,296	26,640	542,124
1991	18,944	27,380	16,132	79,920	72,816	127,576	10,064	39,072	10,064	47,360	12,728	39,368	501,424
1992	45,880	34,040	4,736	48,100	68,672	60,680	127,280	54,168	27,232	29,304	13,320	28,120	541,532
1993	17,760	3,848	11,840	176,416	58,312	153,032	81,104	94,424	47,064	30,192	29,008	13,912	716,912
1994	74,592	45,584	7,400	6,808	82,288	147,260	129,648	96,496	41,736	45,288	23,384	49,728	750,212
1995	12,432	9,916	28,712	48,988	4,736	38,924	76,368	196,988	0	13,912	52,984	25,900	509,860
1996	10,952	32,560	21,904	41,144	111,296	106,116	158,064	83,768	60,384	28,564	84,952	35,520	775,224
1997	31,080	16,280	22,200	52,540	66,896	194,472	45,288	72,964	74,592	30,932	2,220	9,620	619,084
1998	27,380	740	8,880	24,272	16,724	73,704	42,624	25,308	49,580	31,080	16,576	22,940	339,808
1999	51,800	6,660	20,720	9,620	116,920	42,772	166,796	78,736	12,728	27,528	15,540	22,940	572,760
2000	22,940	10,804	35,520	13,320	57,128	117,068	334,480	49,284	87,320	740	7,400	30,340	766,344
2001	5,476	5,180	4,440	17,020	68,820	136,012	124,468	15,688	43,216	16,576	26,640	11,100	474,636
2002	4,440	5,920	17,760	67,340	6,216	18,204	51,504	49,284	33,448	8,880	8,880	6,808	278,684
2003	28,120	24,716	31,080	83,916	102,712	89,984	144,596	78,144	86,876	20,572	15,540	9,620	715,876
2004	30,340	0	34,040	29,748	57,720	75,776	139,268	41,588	77,848	29,304	1,924	44,400	561,956
2005	18,648	11,100	26,196	49,580	65,268	134,384	116,180	128,316	63,344	35,668	6,808	3,700	659,192
2006	14,060	30,340	99,160	33,596	146,224	82,732	133,348	69,264	139,860	26,492	51,800	18,500	845,376
2007	22,200	20,720	5,920	44,992	64,084	156,584	42,032	160,136	25,308	15,244	21,460	31,820	610,500
2008	31,968	22,200	16,428	52,688	42,032	98,568	129,204	35,224	26,640	22,496	29,896	48,840	556,184
2009	36,408	15,688	63,344	52,096	27,824	111,888	97,680	59,496	12,728	55,648	0	20,424	553,224
MIN	**4,440**	**0**	**592**	**2,072**	**4,736**	**18,204**	**10,064**	**7,104**	**0**	**740**	**0**	**3,700**	**278,684**
MAX	**74,592**	**60,828**	**99,160**	**176,416**	**165,612**	**210,160**	**334,480**	**196,988**	**139,860**	**55,648**	**84,952**	**68,968**	**845,376**
MEAN 1979-2009	**26,268**	**18,280**	**26,277**	**42,204**	**64,055**	**104,058**	**115,063**	**76,105**	**54,335**	**24,325**	**22,448**	**27,122**	**600,541**

Table A3a - Monthly and annual gross lake evaporation losses (m^3) from Pond A													
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**ANNUAL**
1979	-753	0	7,535	11,553	27,628	32,651	38,930	27,125	13,312	4,521	251	-1,256	**161,497**
1980	-753	-502	3,014	23,860	33,153	29,888	37,423	21,851	9,795	5,526	502	-251	**163,506**
1981	-1,256	251	7,786	16,074	30,390	35,665	32,902	33,404	14,818	4,270	1,256	-502	**175,059**
1982	-251	0	3,265	16,074	25,870	34,660	32,651	23,860	13,312	5,526	-251	-753	**153,962**
1983	-1,256	-502	3,767	16,577	24,111	25,116	29,386	32,149	11,051	4,772	-1,758	-1,005	**142,408**
1984	-251	1,758	6,530	18,335	20,093	32,651	35,414	26,121	9,042	4,270	-251	-502	**153,208**
1985	-753	-251	7,284	16,074	29,135	30,642	36,921	27,628	8,791	4,521	-251	-251	**159,487**
1986	0	251	6,781	16,074	25,367	34,911	24,865	31,395	9,795	5,274	-251	-1,005	**153,459**
1987	-753	251	3,516	16,577	28,632	31,646	34,409	21,600	14,567	4,772	753	-1,256	**154,715**
1988	-753	0	6,028	19,591	27,628	30,642	31,646	25,870	12,307	5,274	-1,507	-1,005	**155,720**
1989	-502	-502	753	18,335	25,116	28,632	38,679	25,870	12,056	5,023	-1,256	-1,507	**150,697**
1990	-1,256	-753	7,284	15,070	29,637	34,158	33,404	26,874	14,818	4,270	-753	-502	**162,250**
1991	-753	502	5,274	17,581	27,879	26,623	38,679	34,158	11,553	3,516	-1,005	-1,256	**162,752**
1992	-1,507	-251	8,037	14,818	24,111	33,404	29,888	27,377	9,293	4,521	-1,256	-753	**147,683**
1993	-753	-251	7,786	13,060	29,637	29,135	29,386	25,116	12,307	5,023	-251	-1,256	**148,938**
1994	-502	0	8,037	17,832	27,125	30,390	31,646	28,130	16,325	5,023	-502	-753	**162,752**
1995	-1,005	0	7,284	15,321	32,400	36,167	34,158	22,856	15,572	5,023	-502	-753	**166,520**
1996	-502	0	4,270	15,572	23,107	33,153	33,907	27,628	10,800	4,521	-251	-753	**151,450**
1997	-502	-502	7,284	15,572	26,874	30,893	36,670	27,879	14,567	4,270	-502	-1,005	**161,497**
1998	-753	-1,005	7,535	19,591	35,163	35,665	36,167	30,893	15,823	4,521	-753	-1,005	**181,841**
1999	-753	0	7,033	16,577	25,618	34,158	34,158	29,386	14,818	5,274	251	-1,507	**165,013**
2000	-753	-251	8,037	17,832	27,377	32,400	33,153	25,367	13,060	5,274	-1,005	-1,005	**159,487**
2001	-1,758	251	8,037	18,084	30,390	32,902	35,665	31,144	15,572	4,772	251	-1,256	**174,055**
2002	-753	1,256	2,260	13,814	29,135	39,432	37,423	27,377	14,065	3,516	-502	-2,260	**164,762**
2003	-502	-251	6,028	16,074	29,637	34,660	36,670	28,381	13,312	5,274	-1,005	-1,758	**166,520**
2004	-753	-1,005	7,786	17,330	25,870	33,907	33,153	24,363	12,307	4,772	1,256	-1,005	**157,980**
2005	-753	2,009	7,535	17,079	28,632	32,149	34,158	23,860	13,312	5,274	753	-1,758	**162,250**
2006	-1,507	0	5,777	21,349	27,125	35,163	37,172	28,130	14,567	4,772	0	251	**172,799**
2007	753	753	7,535	17,079	28,884	31,897	39,432	24,111	13,563	5,526	-251	-1,005	**168,278**
2008	-1,005	0	7,786	15,070	30,139	36,670	34,660	26,623	14,567	5,777	1,256	-753	**170,789**
2009	-502	0	5,023	16,074	28,884	33,656	35,414	27,879	17,079	3,767	1,256	-2,260	**166,269**
MIN	**-1,758**	**-1,005**	**753**	**11,553**	**20,093**	**25,116**	**24,865**	**21,600**	**8,791**	**3,516**	**-1,758**	**-2,260**	**142,408**
MAX	**753**	**2,009**	**8,037**	**23,860**	**35,163**	**39,432**	**39,432**	**34,158**	**17,079**	**5,777**	**1,256**	**251**	**181,841**
MEAN	**-745**	**41**	**6,190**	**16,771**	**27,895**	**32,700**	**34,458**	**27,239**	**13,101**	**4,788**	**-203**	**-1,021**	**161,213**

Table A3b - Monthly and annual gross lake evaporation losses (m^3) from North Basin of Lac St Cyr

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1979	-2,170	0	21,700	33,274	79,568	94,035	112,118	78,121	38,337	13,020	723	-3,617	**465,110**
1980	-2,170	-1,447	8,680	68,718	95,481	86,078	107,778	62,931	28,210	15,914	1,447	-723	**470,897**
1981	-3,617	723	22,424	46,294	87,525	102,715	94,758	96,205	42,677	12,297	3,617	-1,447	**504,171**
1982	-723	0	9,403	46,294	74,504	99,821	94,035	68,718	38,337	15,914	-723	-2,170	**443,410**
1983	-3,617	-1,447	10,850	47,741	69,441	72,334	84,631	92,588	31,827	13,744	-5,063	-2,893	**410,136**
1984	-723	5,063	18,807	52,804	57,867	94,035	101,991	75,228	26,040	12,297	-723	-1,447	**441,240**
1985	-2,170	-723	20,977	46,294	83,908	88,248	106,332	79,568	25,317	13,020	-723	-723	**459,323**
1986	0	723	19,530	46,294	73,058	100,545	71,611	90,418	28,210	15,190	-723	-2,893	**441,963**
1987	-2,170	723	10,127	47,741	82,461	91,141	99,098	62,208	41,954	13,744	2,170	-3,617	**445,580**
1988	-2,170	0	17,360	56,421	79,568	88,248	91,141	74,504	35,444	15,190	-4,340	-2,893	**448,473**
1989	-1,447	-1,447	2,170	52,804	72,334	82,461	111,395	74,504	34,720	14,467	-3,617	-4,340	**434,006**
1990	-3,617	-2,170	20,977	43,401	85,355	98,375	96,205	77,398	42,677	12,297	-2,170	-1,447	**467,280**
1991	-2,170	1,447	15,190	50,634	80,291	76,674	111,395	98,375	33,274	10,127	-2,893	-3,617	**468,727**
1992	-4,340	-723	23,147	42,677	69,441	96,205	86,078	78,844	26,764	13,020	-3,617	-2,170	**425,326**
1993	-2,170	-723	22,424	37,614	85,355	83,908	84,631	72,334	35,444	14,467	-723	-3,617	**428,943**
1994	-1,447	0	23,147	51,357	78,121	87,525	91,141	81,014	47,017	14,467	-1,447	-2,170	**468,727**
1995	-2,893	0	20,977	44,124	93,311	104,161	98,375	65,824	44,847	14,467	-1,447	-2,170	**479,577**
1996	-1,447	0	12,297	44,847	66,548	95,481	97,651	79,568	31,104	13,020	-723	-2,170	**436,176**
1997	-1,447	-1,447	20,977	44,847	77,398	88,971	105,608	80,291	41,954	12,297	-1,447	-2,893	**465,110**
1998	-2,170	-2,893	21,700	56,421	101,268	102,715	104,161	88,971	45,571	13,020	-2,170	-2,893	**523,701**
1999	-2,170	0	20,254	47,741	73,781	98,375	98,375	84,631	42,677	15,190	723	-4,340	**475,237**
2000	-2,170	-723	23,147	51,357	78,844	93,311	95,481	73,058	37,614	15,190	-2,893	-2,893	**459,323**
2001	-5,063	723	23,147	52,081	87,525	94,758	102,715	89,695	44,847	13,744	723	-3,617	**501,277**
2002	-2,170	3,617	6,510	39,784	83,908	113,565	107,778	78,844	40,507	10,127	-1,447	-6,510	**474,513**
2003	-1,447	-723	17,360	46,294	85,355	99,821	105,608	81,738	38,337	15,190	-2,893	-5,063	**479,577**
2004	-2,170	-2,893	22,424	49,911	74,504	97,651	95,481	70,164	35,444	13,744	3,617	-2,893	**454,983**
2005	-2,170	5,787	21,700	49,187	82,461	92,588	98,375	68,718	38,337	15,190	2,170	-5,063	**467,280**
2006	-4,340	0	16,637	61,484	78,121	101,268	107,055	81,014	41,954	13,744	0	723	**497,660**
2007	2,170	2,170	21,700	49,187	83,185	91,865	113,565	69,441	39,061	15,914	-723	-2,893	**484,640**
2008	-2,893	0	22,424	43,401	86,801	105,608	99,821	76,674	41,954	16,637	3,617	-2,170	**491,874**
2009	-1,447	0	14,467	46,294	83,185	96,928	101,991	80,291	49,187	10,850	3,617	-6,510	**478,853**
MIN	**-5,063**	**-2,893**	**2,170**	**33,274**	**57,867**	**72,334**	**71,611**	**62,208**	**25,317**	**10,127**	**-5,063**	**-6,510**	**410,136**
MAX	**2,170**	**5,787**	**23,147**	**68,718**	**101,268**	**113,565**	**113,565**	**98,375**	**49,187**	**16,637**	**3,617**	**723**	**523,701**
MEAN	**-2,147**	**117**	**17,827**	**48,301**	**80,338**	**94,175**	**99,238**	**78,448**	**37,731**	**13,790**	**-583**	**-2,940**	**464,293**

Table A3c - Monthly and annual gross lake evaporation losses (m^3) from South Basin of Lac St Cyr													
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1979	-4,461	0	44,606	68,396	163,556	193,293	230,465	160,582	78,804	26,764	1,487	-7,434	956,059
1980	-4,461	-2,974	17,842	141,253	196,267	176,938	221,544	129,358	57,988	32,711	2,974	-1,487	967,954
1981	-7,434	1,487	46,093	95,160	179,912	211,136	194,780	197,754	87,726	25,277	7,434	-2,974	1,036,351
1982	-1,487	0	19,329	95,160	153,148	205,188	193,293	141,253	78,804	32,711	-1,487	-4,461	911,453
1983	-7,434	-2,974	22,303	98,134	142,740	148,687	173,964	190,320	65,422	28,251	-10,408	-5,947	843,057
1984	-1,487	10,408	38,659	108,542	118,950	193,293	209,649	154,635	53,527	25,277	-1,487	-2,974	906,993
1985	-4,461	-1,487	43,119	95,160	172,477	181,399	218,570	163,556	52,041	26,764	-1,487	-1,487	944,164
1986	0	1,487	40,146	95,160	150,174	206,675	147,200	185,859	57,988	31,224	-1,487	-5,947	908,479
1987	-4,461	1,487	20,816	98,134	169,504	187,346	203,702	127,871	86,239	28,251	4,461	-7,434	915,914
1988	-4,461	0	35,685	115,976	163,556	181,399	187,346	153,148	72,857	31,224	-8,921	-5,947	921,861
1989	-2,974	-2,974	4,461	108,542	148,687	169,504	228,978	153,148	71,370	29,737	-7,434	-8,921	892,124
1990	-7,434	-4,461	43,119	89,212	175,451	202,215	197,754	159,095	87,726	25,277	-4,461	-2,974	960,520
1991	-4,461	2,974	31,224	104,081	165,043	157,609	228,978	202,215	68,396	20,816	-5,947	-7,434	963,494
1992	-8,921	-1,487	47,580	87,726	142,740	197,754	176,938	162,069	55,014	26,764	-7,434	-4,461	874,281
1993	-4,461	-1,487	46,093	77,317	175,451	172,477	173,964	148,687	72,857	29,737	-1,487	-7,434	881,716
1994	-2,974	0	47,580	105,568	160,582	179,912	187,346	166,530	96,647	29,737	-2,974	-4,461	963,494
1995	-5,947	0	43,119	90,699	191,807	214,110	202,215	135,305	92,186	29,737	-2,974	-4,461	985,797
1996	-2,974	0	25,277	92,186	136,792	196,267	200,728	163,556	63,936	26,764	-1,487	-4,461	896,584
1997	-2,974	-2,974	43,119	92,186	159,095	182,885	217,083	165,043	86,239	25,277	-2,974	-5,947	956,059
1998	-4,461	-5,947	44,606	115,976	208,162	211,136	214,110	182,885	93,673	26,764	-4,461	-5,947	1,076,496
1999	-4,461	0	41,632	98,134	151,661	202,215	202,215	173,964	87,726	31,224	1,487	-8,921	976,876
2000	-4,461	-1,487	47,580	105,568	162,069	191,807	196,267	150,174	77,317	31,224	-5,947	-5,947	944,164
2001	-10,408	1,487	47,580	107,055	179,912	194,780	211,136	184,372	92,186	28,251	1,487	-7,434	1,030,403
2002	-4,461	7,434	13,382	81,778	172,477	233,439	221,544	162,069	83,265	20,816	-2,974	-13,382	975,389
2003	-2,974	-1,487	35,685	95,160	175,451	205,188	217,083	168,017	78,804	31,224	-5,947	-10,408	985,797
2004	-4,461	-5,947	46,093	102,594	153,148	200,728	196,267	144,227	72,857	28,251	7,434	-5,947	935,243
2005	-4,461	11,895	44,606	101,107	169,504	190,320	202,215	141,253	78,804	31,224	4,461	-10,408	960,520
2006	-8,921	0	34,198	126,384	160,582	208,162	220,057	166,530	86,239	28,251	0	1,487	1,022,969
2007	4,461	4,461	44,606	101,107	170,990	188,833	233,439	142,740	80,291	32,711	-1,487	-5,947	996,205
2008	-5,947	0	46,093	89,212	178,425	217,083	205,188	157,609	86,239	34,198	7,434	-4,461	1,011,074
2009	-2,974	0	29,737	95,160	170,990	199,241	209,649	165,043	101,107	22,303	7,434	-13,382	984,310
MIN	**-10,408**	**-5,947**	**4,461**	**68,396**	**118,950**	**148,687**	**147,200**	**127,871**	**52,041**	**20,816**	**-10,408**	**-13,382**	**843,057**
MAX	**4,461**	**11,895**	**47,580**	**141,253**	**208,162**	**233,439**	**233,439**	**202,215**	**101,107**	**34,198**	**7,434**	**1,487**	**1,076,496**
MEAN	**-4,413**	**240**	**36,644**	**99,285**	**165,139**	**193,581**	**203,989**	**161,254**	**77,557**	**28,347**	**-1,199**	**-6,043**	**954,381**