Alex Salki

Ecosystem Evidence for the Need to Remove Phosphorus from the City of Winnipeg's Wastewater Effluents

by

Michael Stainton[1], Alex Salki[1], Len Hendzel[1], and Hedy Kling[2]

[1]Freshwater Institute, DFO

[2]Algal Taxonomy and Ecology

A submission to the Manitoba Clean Environment Commission Public Hearing on the City of Winnipeg Wastewater Collection and Treatment Systems, April 2003

Preface: This submission responds to the Manitoba Clean Environment Commission request for public and agency input into their review of "appropriate ammonia, nutrient, combined sewer overflow and microbiological limits on effluents from the City's systems necessary to protect the aquatic environment and recreational activities, including Lake Winnipeg" authorized by the Manitoba Minister of Conservation, October 2002. It focuses specifically on the nutrients Nitrogen (N) and Phosphorus (P) introduced into the Red River from point and non-point sources[1] and their impacts on the Lake Winnipeg ecosystem.

Introduction:

The International Year of Freshwater 2003 was declared by the United Nations to raise awareness of the worsening state of the world's water resources. The two biggest components of the looming global water crisis are the contamination of drinking supplies with human faeces, and the massive wastage of water that is inherent in prevailing agricultural practices. At the recent 3rd World Water Forum in Japan, the World Wildlife Fund urged international commitment for investments in the environmental health of watersheds, such as reforestation programs and pollution reduction of rivers and wetlands.

The government of Manitoba, recognizing the need to preserve provincial freshwater supplies, has:

- Appointed a Livestock Stewardship Panel, June 2000 to seek the views of Manitobans on the expansion of the livestock industry. In their report[2], the Panel recommended that the province should move toward regulating manure application according to phosphorus content of soil and manure, and future intensive livestock operations should be located in order to provide sufficient acres for manure application according to phosphorus content.
- Undertaken revisions of surface water quality objectives. The provincial regulations of 1988 and 1990 will be superceded by "Manitoba Water Quality Standards, Objectives, and Guideline". Manitoba Conservation is proposing guidelines which limit nitrogen, phosphorus and carbon to the extent necessary to prevent the nuisance growth and reproduction of rooted, attached and floating plants, fungi, or bacteria, or to otherwise render the water unsuitable for other beneficial uses. For general guidance, total phosphorus should not exceed 0.025 mg/L in any reservoir,

lake, or pond, or in a tributary at the point where it enters such bodies of water[3].

- As recommended by the Livestock Stewardship Panel, initiated the Manitoba Phosphorus Expert Committee to address issues regarding the environmental impacts from agricultural phosphorus associated with livestock production.
- Announced an Action Plan for Lake Winnipeg which included establishment of a Lake Winnipeg and Basin Stewardship Board to help Manitobans identify further actions necessary to reduce nitrogen and phosphorus levels in the lake to pre-1970 levels and reverse the observed trend of eutrophication[4,5].

The City of Winnipeg, has presented plans for future development of its wastewater collection and treatment system[6]. "While the City is not proposing a specific development of nutrient control facilities at it WPCC's at this time, the cost and timing for BNR (Biological Nutrient Removal) was allowed for in the City's plan to improve wastewater collection and treatment". The proposed timeframe for nutrient removal implementation, 2019 – 2026, reflected indications that "much work is still to be done before the Province will have a strategy and significant public consultation is expected in defining the strategy".

The purpose of this submission is to present the considerable body of scientific evidence that argues for more complete, immediate removal of phosphorus from wastewater treatment facilities of the City of Winnipeg, an action within the spirit of commitment expressed by the Government of Manitoba for the remediation of Lake Winnipeg. This submission:

(1) outlines how we have acquired an understanding of the link between phosphorus, nitrogen and the eutrophication process,
(2) presents evidence of deteriorating environmental conditions in Lake Winnipeg and the linkage to phosphorus loading,
(3) discusses estimates of nutrient loading to the Red River (and Lake Winnipeg) submitted to the Clean Environment Commission by the City of Winnipeg Water and Waste Department[6] and the Province of Manitoba (www.cecmanitoba.ca),
(4) assesses the City's proposal for wastewater pollution control and its implication for the health of Lake Winnipeg.

1. Eutrophication of aquatic ecosystems

Eutrophication, as defined by Vallentyne[7], refers to "the complex sequence of changes initiated by the enrichment of natural waters with plant nutrients. The first event in the sequence is an increased production and abundance of photosynthetic plants. This is followed by other changes that increase biological production at all levels of the food chain, including fish. Successional changes in species populations occur in the process". The original meaning of eutrophication was simply nutrient enrichment. In recent years, it has become more common to use the term in connection with the results rather than the cause i.e an increase in trophic status caused by nutrient enrichment". As will be demonstrated, the trophic status of Lake Winnipeg has increased significantly during the past several decades.

1.1 Lessons from the Laurentian Great Lakes

Our understanding of the key role played by phosphorus (P) in the eutrophication of surface waters began in 1964 when the Governments of the United States and Canada requested the International Joint Commission (IJC) to inquire into the pollution of the lower St. Lawrence Great Lakes. Following thorough investigations, IJC Advisory Boards of Lake Erie and Lake Ontario published a report[8] in 1969 with findings and recommendations including a program of P control to halt the growing trends of cultural (man-induced) eutrophication. The Boards recommended that:

(a) phosphates in detergents be immediately reduced to minimum practical levels, with total replacement by environmentally less harmful compounds in 1972;
(b) the remaining phosphate in municipal sewage effluents be reduced by not less than 80% prior to specific dates from 1972 to 1978 for different parts of the basins, with continued reductions thereafter to the maximum extent economically feasible;
(c) programs to be developed for the reduction of P inputs into water from agricultural sources;
(d) any new and significant changes in the addition of phosphate to waters in the basins be regulated.

The rationale of the Advisory Boards for recommending P rather than N removal from wastes to combat eutrophication of the Great Lakes included:

1. in most natural waters the growth of algae is controlled more by the supply of P than by the supply of N;
2. the loading of P to lakes can be controlled more effectively than that of N;
3. efficient and relatively inexpensive methods are available for 80-95% removal of P during sewage treatment, whereas comparable elimination of N is not yet feasible;
4. N is contributed more from uncontrollable sources such as soils, sediments, precipitation, and the atmosphere.

The requirement for phosphorus removal from detergents was strongly refuted by the detergent industry which claimed that the process of eutrophication was far too complex to regulate without extensive study. This assertion was criticized by Vallentyne[7], a scientific advisor to the IJC in the 1970 hearings, when he pointed out the "necessity to make a clear distinction between the knowledge needed to understand eutrophication and the knowledge needed to control it. Representatives of the detergent industry repeatedly confused this issue by stressing the complexity of the process of eutrophication, without referring to the comparative simplicity of control". Opponents of phosphorus control also proposed that phosphates released from sediments of shallow lakes (such as the western basin of Lake Erie and Lake Winnipeg) would stimulate algal growth even after phosphorus removal from detergents and sewage treatment plants. In reality, this argument added more weight to the immediate necessity of a program for phosphorus control. " The logic is simple - the more phosphorus that goes into a lake, the more stored in the sediments available for release at a later time, and the longer it will take to control man-made eutrophication once it has started". The critics also claimed that nitrogen limited algal growth more than phosphorus in the western basin of Lake Erie. Vallentyne pointed out that the cause of eutrophication (nutrient enrichment) was being confused with the suggested cure (phosphate depletion). "Sewage effluents contain high concentrations of phosphorus relative to other elements required for the growth of aquatic plants. As a result, one of the typical responses of unpolluted lakes to the addition of sewage effluents is the change from a state of phosphorus deficiency to a state of nitrogen deficiency. This is because of the high ratio of inorganic phosphorus to inorganic nitrogen in sewage (1P:4N by weight) relative to the needs of plants (1P:7N by weight) and the supply from natural sources (1P:14N by weight). The fact that in 1969, algal growth in the western end of Lake Erie was more limited by nitrogen than phosphorus only showed that the area was heavily polluted with phosphorus, probably from detergents" and sewage.

1.2 Experimental Lakes Area (ELA) studies

The most direct and convincing evidence of the role of P in the control of algal growth in lakes came from laboratory culture experiments and whole lake fertilization studies at the Experimental Lakes Area conducted in 1969 and later. Lab[7,9] and field [10,11,12,13,14,15,16,17,18,19,20,21,22,23] experiments clearly demonstrated that additions of P in raw sewage, secondary effluent or phosphate (PO_4) to lake water stimulated algal growth. Nutrient additions to the upper water layer of thermally stratified ELA Lakes 226 and 227 provided convincing scientific and visual evidence of the pre-eminent role of P in eutrophication (Fig. 1; Fig. 2).

Lake 226 was a double basin experiment designed to demonstrate that P is the key element that ultimately limits algal growth. One basin, 226N, received a combination of C, N, and P while the other basin 226S (separated by a curtain) received only C and N (Table 1). The results were both visually dramatic and quantitatively convincing (Fig. 3)

Table 1. Nutrient additions to Lake 226, 1973 - 1974

Fertilizer Added tonnes/km²/year					
Lake Basin	P	N	C	N/P (mole:mole)	Response
226N	0.59	3.16	6.05	13:1	Blue-greens
226S	None	3.16	6.05		None

Lake 227 was initially fertilized in 1969 with N and P at loading rates similar to that experienced by Lake Erie in the mid 1960s. Designed originally as an experiment to demonstrate that lakes are not normally carbon (C) limited (which it did), Lake 227 was then continuously fertilized for 33 years with variable amounts of N and P to develop an understanding of the effect of N:P ratios on development of blooms of N_2 fixing blue-green algae. Since 1990, the lake has received only P loading and continues to be highly eutrophic (Fig. 4).

1.3 Nutrient ratio studies at ELA

In addition to the absolute amount of P and N available for aquatic plant growth, the ratio of N to P was found to strongly influence the response and composition of the algal community. Experimental evidence indicated that N/P ratios below 15:1 induced nitrogen fixing blue-green algal dominance while those above 20:1 promoted a more diverse algal community structure of non-blue green species. From ELA studies, it was concluded that:

(1) In Lake 226, the N/P ratio of 13:1 (mole:mole) resulted in an immediate dominance by nitrogen-fixing blue-green algal species[13]. Following termination of P additions in 1974, the phytoplankton community reverted quickly to its former state.

(2) Similarly, ELA L227 was experimentally enriched for more than 30 years, first by adding N and P in amounts roughly equivalent to Great Lakes loadings (1969-1974, N:P 29:1) that resulted in the domination by green algae, and then for the next 15 years (1975-1989) at an N:P ratio of 11:1 when blue-green algae became abundant and variably maintained dominance throughout this latter period. The effective N:P ratio in water gradually increased (due to N_2-fixation and increased internal re-cycling of N) and the vigor of the blue-green blooms began to decline. However, in 1990, when all experimental additions of N ceased but P additions continued, dense blue-green blooms developed immediately[24,25].

These fundamental observations at the ELA on the relevance of P additions to freshwaters eventually guided the implementation of the International Great Lakes Water Quality Agreements of 1972 and 1978 aimed at reducing the levels of algal biomass in lakes Erie and Ontario to below those of nuisance conditions (www.IJC.org).

Newer investigations into the internal physiology and nutrient levels in algal cells have presented further evidence of the control exerted by phosphorus on phytoplankton community dynamics[24,26,27,28,29,30,31,32]. The physiological indicators of algae in Lake Winnipeg consistently demonstrate that excess amounts of phosphorus are present which favor the persistence of blue-green species in the lake.

1.4 Recent insights

Among the many recent examples of the cultural eutrophication of global freshwaters, Lake Kinneret in Israel and Lake Okeechobee in Florida, USA, illustrate the serious consequences of excessive P loading from agricultural and urban activities. Lake Okeechobee, a large, shallow lake with persistent sediment re-suspension and a water residence time of 3 years regulated by dams and dikes (similar to conditions in Lake Winnipeg), was originally P-limited (N:P >25:1)[33]. About 1980, with inputs of 500 tonnes P

yr^{-1} from agriculture, the lake changed to a high phosphorus, low N:P (□ 15), high chlorophyll-a (mean 25 μg L^{-1}) state accompanied by massive blooms of nitrogen fixing algae.

Lake Kinneret, Israel's only natural freshwater source for drinking water, irrigation, fisheries and recreation was originally dominated by desirable species of algae. Reservoir creation and demand for irrigation water reduced river inflows to the lake but increased soluble phosphorus loading. The resulting nitrogen limitation promoted the development of blue-green species that fixed about 700 tonnes of N in 1994[34,35]. In order to prevent blooms and further water quality deterioration, restrictions on external phosphorus loading to elevate water column N:P ratios were recommended.

In 2001, an extensive review of nutrients and their impact on the Canadian environment[36] and drinking water sources[37] concluded that:

- Nutrients released to the environment from human activity are impairing the health of certain ecosystems:
    - Amount of available N has more than doubled since the 1940s with 210 M tonnes per year contributed to the global supply from human activites compared to only 140 M tonnes from natural processes[38].
    - Natural weathering of phosphate-bearing rocks is now overshadowed by mining activities as a source of P, with approximately 140 M tonnes of rock mined each year[39].
- Natural nutrient cycles have been disrupted and replaced with "once-through" systems whereby manufactured fertilizers are applied to agricultural processes to produce foodstuffs for citizens, who deposit wastes in landfills or surface and ground waters
- Most inland waters in Canada are intrinsically P-limited and thus addition of P has accelerated eutrophication.
- The predominant and most demonstrable impacts to date have occurred in aquatic ecosystems and caused water-use impairments (e,g, excessive algal growth), and aesthetic (taste and odour) concerns related to water supplies

The review includes a comparison of the N and P loading to Canadian surface and ground waters from various sources in 1996 (Table 2). The notably high loading of N from the atmosphere to water does not include the gaseous N_2 available to blue-green algae in unlimited quantities (implications for Lake Winnipeg). As suggested by the International Joint Commission, attempts to control N would be difficult and costly.

Table 2. A comparison of the N and P loading to Canadian surface and ground waters from various sources, 1996[37].

Nutrient Source	N (10^3 tonnes/yr)	P (10^3 tonnes/yr)
Municipality		
- municipal WWTP	80.3	5.6
- sewers (untreated)	11.8	2.3
Septic systems	15.4	1.9
Industry[1]	11.8	2.0
Agriculture (post-harvest field residual)[2]	293	55
Aquaculture	2.3	0.5
Atmospheric deposition to water[3]	182	N/A

[1] Industrial N loads are DIN (based on $NO_3 + NH_3$) not TN and do not include NB, PEI or NS. Quebec data only for industries discharging to the St. Lawrence River.
[2] Agricultural residual is the difference between the amount of N or P available to the growing crop and the amount removed in the harvested crop: data are not available as to the portion of this residual that moves to surface or ground waters: [3] NO_3- & NH_4+ only

Eutrophication of surface waters is a global problem whose persistence is linked to the expansion of human populations. Eutrophication is still one of the most pressing environmental issues confronting the scientific community today (Table 3). As the population of Manitoba continues to concentrate in urban centers, the necessity for nutrient control by municipal point-sources will become even more imperative. Of the major urban centers in the Lake Winnipeg watershed, Winnipeg is the only one that lacks tertiary wastewater treatment.

Table 3. Electronic searches (02/03) of aquatic science research topics in Cambridge Scientific Abstracts

Topic	ASFA	EES
Eutrophication	11862 (2322)	15633
Mercury	9590	20346
Toxins	5661	22750 (3011)
Climate Change	5090	8805
Overfishing	3791	1136
Exotic species	1824	2256
Xenobiotics	1478	6420
Zoogeography	1415	730
Endocrine Disrupters	64	253

ASFA - Aquatic Sciences & Fisheries Abstracts (1978 - 2003). Bracketed values 1998 -2003.
ESS - Earth & Environmental Sciences (1981 - 2003). Bracketed values 1998 - 2003.

2. Deterioration of Lake Winnipeg water quality – the linkage to phosphorus loading

Lake Winnipeg receives its water from four provinces and three US states via three major rivers, the Red, Saskatchewan and Winnipeg and empties via the Nelson to Hudson Bay (Fig. 5). 65% of the lake's inflow is regulated either for electric power production or flood control. The delivery of water and nutrients to the lake is complex. While the Winnipeg River is the largest single source of water (40%), the Red river (which contributes less water to the lake than direct precipitation) delivers most of the phosphorous (58%) and suspended sediments to the lake. (Fig. 6; Fig. 7).

Basin activities have been largely dominated by agricultural development over the past 100 years. Increasingly, human and livestock populations have become concentrated in areas of intensive habitation creating a growing number of point sources of nutrient discharge that have the potential to enter prairie waterways and eventually Lake Winnipeg.

The productive capacity and ecosystem health of Lake Winnipeg is determined by a complex interplay between external and internal sources of nutrients that stimulate, and turbidity which retards, algal growth. Both of these factors that control productivity have been or are being modified by human activity in Lake Winnipeg's basin and watershed.

There is considerable evidence (sediment cores, surface water chemistry, direct physiological measurements, satellite imagery and observations by fishers) indicating that Lake Winnipeg is experiencing significant increases in algal productivity, the bulk of which is from nitrogen fixing blue greens. This accelerated productivity, (eutrophication) is being driven by one or all of several factors: increased P loading from municipal and agricultural sources, increased P loading by a decade of relatively high runoff, increased transparency brought about by retention of turbidity behind a hydro dam at Grand Rapids or increased P retention in a flow managed hydro reservoir. Presently, P loadings to Lake Winnipeg are comparable to those delivered to Lake Erie prior to phosphorus removal (Fig. 24).

2.1 Evidence from the sediments

Sediments at the bottom of lakes reflect what was in the water column at a previous date either because it was delivered there by rivers or precipitation or it formed or grew in the water column. Surface sediments contain indicators of relatively recent conditions or events. Cores taken down into the sediments contain historical conditions or events in a time sequence where deeper equals older. Surface sediments have been collected and analyzed from most areas of the lake on four occasions over the past three decades[40,41,42,43] Analysis of these surface sediments for phosphorous has shown a steady and significant increase in the P content of lake sediments over the past 30 years (Fig. 8). Mayer et al (2002)[44] have analysed various forms of P found in sediments of the south basin and conclude that "..much of the sedimentary P increase is attributable to changes in the nutrient status of the water column related to anthropogenic activities".

A sediment core, taken in 1994 in the middle of the north basin of lake Winnipeg has been dated (using lead 210, a naturally occurring radio tracer) and analysed by us for various nutrient elements, algal remains and algal pigments (indicators of algal productivity). This core reveals several interesting and disturbing trends:

- Sedimentation rate which was in decline from 1920 has increased dramatically since 1960 (Fig. 9),
- Deposition rates of Carbon, Nitrogen and Chlorophyll remains have increased dramatically since 1960 and are still increasing (Fig. 10),
- Phosphorous deposition shows an increase only near the surface (Fig. 11),
- There is a marked increase in the remains of N2 fixing blue green algae in the last 30 years. (Fig. 12).

This data indicates a major change in the algal productivity of the north basin of Lake Winnipeg beginning in the 1960s. While this has led to the burial of large amounts of carbon and nitrogen, phosphorous has remained at or near the surface, available for re-suspension and re-introduction into the nutrient pool.

2.2 Evidence from the plankton community of Lake Winnipeg

Over the past three decades there has been a significant increase in algal biomass (Fig. 13) along with a change in the algal community structure of the North and South basins of Lake Winnipeg towards nitrogen fixing blue-green algae (Fig. 14; Fig. 15). This change is evidenced in the increasing occurrence of basin wide algal blooms in the north basin and localised blooms in the south basin. This increase in biomass and shift to N2 fixing blue greens infers an increase in nitrogen fixation.

In Lake Winnipeg, we have made direct measurements of nitrogen fixation rates associated with the now dominant blue-green algal community in 1999, 2000 and 2001[45]. Fixation rates vary from 10 to 1000 kg of nitrogen per km^2 per hour with the higher level observed at chlorophyll levels and heterocyst (the blue-green algae organelle responsible for nitrogen fixation) counts typical of the large blooms observed in 1999 and 2000. We have estimated the surface area of the 1999 bloom to be $6000km^2$ (Fig. 16). Allowing for 6 hours of peak N-fixing activity, we estimate the 1999 bloom to have captured 6600 tonnes of nitrogen per day. Bourne et al have estimated the total N load to Lake Winnipeg (major rivers and atmospheric deposition to be 63,207 tonnes per year for the period 1994 to 2001. At these measured rates of fixation a large algal bloom can capture from the atmosphere in 10 days, an amount of nitrogen equivalent to the entire annual nitrogen load from rivers. This is clear and specific evidence of the impact of the blue green algal community on the nutrient budget of Lake Winnipeg. This is also clear and specific evidence of the futility of controlling N inputs as a means of limiting algal growth in the lake.

2.3 Evidence from changes in the nutrient dynamics of Lake Winnipeg

A recent Manitoba Conservation publication[46] contains a detailed analysis of trends in N and P concentration in major rivers in Manitoba. The analysis indicates that the Red river at Selkirk has seen a 29% increase in flow adjusted P concentration over the past 25 years while the Nelson river at Norway house has shown a 21% decrease in P concentration for the same period. Simply stated, more P is going into the lake, less is leaving, more P is being retained and more P is available for recyling into the food web. (Fig. 17; Fig. 18)

This is consistent with the observed P build-up in surface sediments mentioned above and is not unexpected for a lake whose water discharge is managed for hydro production. Since 1976 the level and discharge of Lake Winnipeg has been regulated, with a control structure at the outlet to the Nelson river, to store water in summer for winter power production.. This has produced an inversion of the natural discharge pattern (Fig. 19) with less water than normal discharged during the summer. Natural peak discharge times (June-July-August) are also peak times for plankton production (plankton = particles rich in N and P). Prior to regulation, normal water discharge flushed significant amounts of N and P, as plankton, down the Nelson river to Hudson Bay. This export of particles and nutrients is now diminished leading to increased retention in Lake Winnipeg and decreased discharge down the Nelson to Hudson Bay (Fig. 20). This retention of over 200 tonnes of P per year is an unavoidable consequence of managing Lake Winnipeg discharge to supply winter, peak demand, electrical power production.

All of the above observations are consistent with increased delivery, retention and build-up of P in Lake Winnipeg and the not unexpected response of increased algal production dominated by nitrogen fixing blue greens. In the short term, changes to the algal community have consequences to:

- Water quality (cyanophytes produce algal toxins and taste-odour problems in drinking water to downstream Nelson River communities.
- Fouling of commercial fishing nets.
- Deterioration of recreational property values in the cottage communities that line the south basin of the lake.

In the long term, increases in algal biomass can lead to under ice anoxia and loss or changes to the benthic community and their contribution to the food web.

3. Phosphorous sources - the Red River basin and the City of Winnipeg

We are focusing our concern and analysis on phosphorous because research and case studies clearly indicate that this element is the trigger for eutrophication. Also the direct estimates of nitrogen fixation in Lake Winnipeg indicate that nitrogen control will have little impact on the production of nuisance algal blooms.

In particular, we focus on that part of P loading to Lake Winnipeg which is derived from the Manitoba portion of the Red River and the City of Winnipeg effluent. We have used data from two recent reports that contain estimates of nutrient budgets for the Red River and Lake Winnipeg written by Bourne (2002)[1] and McCullough (2001)[47].

Data in Table 4 show N and P contributions from different points in the red River basin. While there is some diversity in reported areas for the Red River basin and the US vs Canadian portions we have used data from Bourne. Other sources attribute a smaller percent of the basin to Manitoba.

Table 4. Nitrogen and Phosphorus contributions from locations of the Red River Basin (from Bourne et al.[1])

Red River Basin Part	Area	P Load	N Load	P Yield per Unit Area	N Yield per Unit Area	N/P Ratio
	km^2	tonnes	tonnes	kg/km^2	kg/km^2	mole/mole
Total	127,000	4268	29083	33.6	6814	15.1
US (80%)	101,600	2537	18983	25	7482	16.6
Man. (20%)	25400	1731	10100	68.1	5834	12.9
Assiniboine		637	3682			12.8
Total at Selkirk		4905	32765			14.8
Total to Lake Winnipeg		5838	63207			24

Noteworthy items are: the significantly higher yield of P per km^2 in Manitoba compared to the US portion of the basin, the significantly lower yield of N per km^2 in Manitoba, and the extent to which Manitoba sources drive the N:P ratio from 17 down to 15 before waters enter Lake Winnipeg. Again, this demonstrates the need to focus on phosphorous management as this is the nutrient element whose source is disproportionately attributable to Manitoba.

There is a very strong relationship between water yield (mm) of the Red River and the yield of P from the watershed (Fig. 21). At the high end of this curve (high mm yield = high flow), P loading is dominated by watershed processes (runoff, erosion). At the low end, P loading is dominated by point sources of which Winnipeg is the largest in the Red River basin.

We have calculated the proportion of the City of Winnipeg total P load to the Red River and to Lake Winnipeg using the figure of 390 tonnes per year estimated by Bourne (2002)[1] and assumed this as a constant annual load in all following calculations.

The proportionate contribution of City of Winnipeg effluent P to the Red River depends largely on the flow of the Red River. However, the proportionate contribution of the City's P to Lake Winnipeg is a function of the relative flows of other rivers (and their P loads) to the lake.

Using data from McCullough (2001)[47], we have calculated the percent that the 390 tonnes of P from the City of Winnipeg represents as a contribution to both the Red River and Lake Winnipeg for the period 1969 to 1998 and have compared this with similar calculations from Bourne[1] (Fig. 22). For the period 1994 to 1998, where our calculations overlap those of Bourne, there is excellent agreement. It is this period that has been used to estimate the city of Winnipeg's contribution to the Red at 7% and we do not dispute this figure for this time period. However, as can be seen from Figure 23, the 1994 - 1998 is a period of unusually high flow and is not typical of the last 30 years. For the period 1969 to 2001, the annual average P contribution to the Red River from City of Winnipeg effluent is 24% and ranges from 5% to 65%. Using annual P loading from the Red, Saskatchewan and Winnipeg rivers as calculated by McCullough (2001)[47], we have calculated the proportionate contribution of Winnipeg's effluent P to Lake Winnipeg (major rivers only). As can be seen, Winnipeg's effluent P contribution varies from 5% to 35% of the total load from major rivers to Lake Winnipeg and hence is a significant part of the total.

The proportion of contribution is of caurse greater if one compares the City's contribution to P sourced in Manitoba which is the P load to Lake Winnipeg that this commission is in a position to advise on.

In terms of total P contribution, we suggest that the City of Winnipeg's P contribution to Lake Winnipeg is significant and is the single largest manageable source of P in the Manitoba portion of the Lake Winnipeg basin. This significant source of P loading to lake Winnipeg is further exacerbated by the following additional considerations:

- The forms of P in City of Winnipeg effluent are more available for algal growth than Red river waters which contain significant amounts (25%) of relatively unavailable mineral P (apatite)[48],
- None of the above calculations take into account the large amount of PO4-P now being added as phosphoric acid to City of Winnipeg drinking water to control lead

levels. At the current addition rate of 2.0 mg L^{-1}, this amounts to >200 tonnes of P per year. While some of this PO4-P is lost as a coating on water distribution pipes (to prevent dissolution of lead), we consistently measure P levels in the Fort Richmond area at 0.6 mg L^{-1}. This contributes another 50 to 60 tonnes of P, not included in our calculations, that is unlikely to be retained by secondary treatment and is highly available for algal growth when it reaches Lake Winnipeg.

- Lower flows, due to either cyclical drought or climate change, increase the impact of Winnipeg effluent P on Lake Winnipeg.
- Lake Winnipeg is now a managed reservoir and as such no longer has its normal capacity to flush nutrients down the Nelson river to Hudson Bay. P levels have built up over decades and it will now take decades to recover. Every decade of delay in controlling P inputs to the lake adds another 2000 tonnes of P retention to the north basin of the lake and will make recovery an even longer process.

In summary:

Manitoba's P contribution to the Red River is disproportionately high on a Km^2 basis compared to the US portion of the watershed but is significantly lower for N.

The city of Winnipeg is currently a major contributor of P to the Red River and Lake Winnipeg when assessed under the a normal range of flows witnessed over the past 30 years.

Climate change and or drought will increase the impact of City of Winnipeg effluent P on the Red River and Lake Winnipeg

4. City of Winnipeg plans for waste water pollution control

The analysis presented in our submission indicates that the average proportion of phosphorus contributed annually to the Red River and Lake Winnipeg by the City of Winnipeg was considerably underestimated by Manitoba Conservation (24% versus 7%). This large proportion requires attention sooner than the timeframe (2019 - 2026) proposed in the City's wastewater pollution prevention plan (EIS Table 8-1, p 8-2). The disproportionately high areal yield of P from the Manitoba portion of the Red River basin places an extraordinary responsibility on Manitoba and Winnipeg to aggressively manage their P contributions and set an example for upstream and downstream resource users. The City of Winnipeg has acknowledged responsibility for fulfilling its mandate to protect human health and the integrity of the Red River (EIS p 4-35). The City shares responsibility for phosphorus induced changes in Lake Winnipeg and therefore must act to control phosphorus at its water pollution control centers (WPCC) to reduce impacts on this important ecosystem.

The City of Winnipeg Waste and Water Department is proposing an expenditure of $270M between 2003 and 2050 to design, implement and operate a system that will reduce combined sewer overflow (CSO) spills from 18 to 4 events annually. Total spillage to the Red River from CSOs represents about 1% of the total annual volume of wastewater generated in Winnipeg in a typical year during the recreation season[6]. While CSO events, temporary in nature, may slightly increase nutrient loadings to the Red River, the main concern is their impact on fecal coliform abundance and river aesthetics. Lowering CSO spills to 4 per year will only result, however, in a relatively modest (~7%) increase in compliance to the Manitoba Surface Water Quality Objectives for fecal coliform (200 CFU/100ml). A compliance level of 75% will be achieved by planned effluent disinfection at the north end WPCC by 2004 and at the west end WPCC by 2051. The proposed program of CSO controls will only elevate compliance to 82% (EIS Fig. 5.2). The benefit of this minor improvement was questioned in a report on illness risk management prepared for the City ("CSO control will be costly and the benefits subjective"[49]).

A further concern of the proposed CSO strategy will be its ineffectiveness to handle intense storm events predicted to increase with global warming. In-line storage plus distributed storage and transfers will be inadequate to handle heavy rainfall events. On the other hand, additional storage will be unnecessary during periods of drought.

We suggest that it would be more prudent for the City to carry out effluent disinfection ($18M) and centrate ammonia treatment ($10M) as outlined in the EIS, in concert with development of tertiary treatment for phosphorous removal ($181M).

We wish to draw to the attention of the Clean Environment Commission that phosphate recovery/recycling is now desirable and technically feasible as demonstrated by urban sewage treatment plants throughout the world[50]. The P-recovery strategy appears to be particularly well suited to Winnipeg's needs because local conditions fulfill all of the pre-requisites for successful implementation which are:

1. Improvement of sludge management - Winnipeg Water and Waste is now studying methods to reduce sludge production, facilitate disposal and optimize agricultural re-use.
2. Sustainable development and recycling policy - The City and Province are committed to and promote sustainability.
3. Improvement of biological nutrient removal process performance - Phosphorus loads from the City are seriously impacting the Lake Winnipeg ecosystem. Because Winnipeg WPCCs operate on the principle of biological nutrient removal, they offer the most convenient means of recovery. The liquid supernatant streams are suitable for the precipitation of recyclable calcium phosphates, struvite or aluminum phosphates.
4. Resale of recovered phosphates - Winnipeg is located in a region with a high demand for inorganic fertilizers. Sales revenues would help to defray treatment plant capital and operating costs.

List of Figures

Literature References

1. A. Bourne, N. Armstrong, and G. Jones. 2002. A Preliminary Estimate of Total Nitrogen and Total Phosphorus Loading to Streams in Manitoba, Canada. Manitoba Conservation Report 2002- 04, 49 p.
2. E. Tyrchniewicz, , N. Carter, and J. Whitaker. 2002. Sustainable livestock development in Manitoba: Finding Common Ground. Report for the Government of Manitoba. p
3. D. Williamson 2002. Manitoba Water Quality Standards, Objectives, and Guidelines. Final Draft. Manitoba Conservation Report 2002-11. 76p.
4. Winnipeg Free Press, February 19, 2003
5. Interlake Spectator, February 24, 2003
6. City of Winnipeg Waste and Water Department. 2003. Environmental Impact Statement: Continued Operation and Future Development of the City of Winnipeg Wastewater Collection and Treatment System. Submitted to the Manitoba Clean Environment Commission, February, 27, 2003.
7. Vallentyne, J.R. 1974. The algal bowl: lakes and man. Misc. Spec. Publication 22. Fish. and Marine Service, Dept. of the Environment. Ottawa. 186 p.
8. International Lake Erie Water Pollution Board and International Lake Ontario-St. Lawrence River Water Pollution Board. Report to the International Joint Commission on the Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River. Volume 1, Summary (1969); Volume 2, Lake Erie (1970); Volume 3, Lake Ontario and the International section of the St. Lawrence River (1970).
9. Vallentyne, J.R. 1969. Sewage treatment and algal growth in Lakes Erie and Ontario (in manuscript).
10. Schindler, D.W. 1971. Carbon, nitrogen, phosphorus and the eutrophication of freshwater lakes. *J. Phycol.* 7: 321-329.
11. Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. *Science* 184: 897899
12. Schindler, D.W. 1975. Whole-lake eutrophication experiments with phosphorus, nitrogen and carbon. *Int. Ver. theor. angew. Limnol. Verh.* 19: 3221-3231
13. Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes: natural mechanisms compensate for deficiencies of nitrogen and carbon in eutrophied lakes. *Science* 195: 260-262
14. Schindler, D.W. 1978. Predictive eutrophication models. *Limnol. Oceanogr.* 23: 1080-1081.
15. Schindler, D.W. 1980. The effect of fertilization with phosphorus and nitrogen versus phosphorus alone on eutrophication of experimental lakes. *Limnol. Oceanogr.* 25: 1149-1152.
16. Schindler, D.W., F.A.J. Armstrong, S.K. Holmgren, and G.J. Brunskill. 1971. Eutrophication of Lake 227, Experimental Lakes Area, northwestern Ontario, by addition of phosphate and nitrate. *J. Fish. Res. Board Can.* 28: 1763-1782.
17. Schindler, D.W., and E.J. Fee. 1974a. The Experimental Lakes Area: whole-lake experiments in eutrophication. *J. Fish. Res. Board Can.* 31: 937-953.

18. Schindler, D.W., E.J. Fee, and T. Ruszczynski. 1978. Phosphorus input and its consequences for phytoplankton standing crop and production in the Experimental Lakes Area and in similar lakes. *J. Fish. Res. Board Can.* 35: 190-196.

19. Schindler, D.W., R.H. Hesslein, and M.A. Turner. 1987. Exchange of nutrients between sediments and water after 15 years of experimental eutrophication. *Can. J. Fish. Aquat. Sci.* 44: (Suppl. 1): 26-33.

20. Schindler, D.W., J. Kalff, H.E. Welch, G.J. Brunskill, H. Kling, and N. Kritsch. 1974b. Eutrophication in the high Arctic - Meretta Lake, Cornwallis Island (75^0 N lat.). *J. Fish. Res. Board Can.* 31: 647-662.

21. Schindler, D.W., H. Kling, R.V. Schmidt, J. Prokopowich, V.E. Frost, R.A. Reid, and M. Capel. 1973. Eutrophication of Lake 227 by addition of phosphate and nitrate. Part 2. The second, third and fourth years of enrichment, 1970, 1971, 1972. *J. Fish. Res. Board Can.* 30: 1415-1440.

22. Schindler, D.W., and D.R.S. Lean. 1974c. Biological and chemical mechanisms in eutrophication of freshwater lakes. *Ann. N.Y. Acad. Sci.* 250: 129-135.

23. Schindler, D.W., T. Ruszczynski, and E.J. Fee. 1980. Hypolimnion injection of nutrient effluents as a method for reducing eutrophication. *Can. J. Fish. Aquat. Sci.* 37: 320-327.

24. Hendzel, L.L., R.E. Hecky, and D.L. Findlay. 1994. Recent changes of nitrogen fixation in Lake 227 in response to reduction of the N:P loading ratio. *Can. J. Fish. Aquat. Sci.* 51: 2247-2253.

25. Findlay, D.L., R.E. Hecky, L.L. Hendzel, M.P. Stainton, and G.W. Regehr. 1994. Relationship between N_2-fixation and heterocyst abundance and its relevance to the nitrogen budget of Lake 227. *Can. J. Fish. Aquat. Sci.* 51: 2254-2266

26. Healey, F.P. 1975. Physiological indicators of nutrient deficiency in algae. Fish. Mar. Serv. Res. Dev. Tech. Rep. 585: 30 p.

27. Healey, F.P., and L.L. Hendzel. 1979. Fluorometric measurement of alkaline phosphatase activity in algae. *Freshwater Biol.* 9: 429-439.

28. Healey, F.P., and L.L. Hendzel. 1980. Physiological indicators of nutrient deficiency in lake phytoplankton. *Can. J. Fish. Aquat. Sci.* 37: 442-453.

29. Hecky, R.E., P. Campbell, and L.L. Hendzel. 1993. The stoichiometry of carbon, nitrogen, and phosphorus in particulate matter of lakes and oceans. *Limnol. Oceanogr.* 38: 709-724.

30. Guildford, S.J., L.L. Hendzel, H.J. Kling, E.J. Fee, G.G.C. Robinson, R.E. Hecky, and S. Kasian. 1994. Effects of lake size on phytoplankton nutrient status. *Can. J. Fish. Aquat. Sci.* 51: 2769-2783.

31. Klemer, A.R., L.L. Hendzel, D.L. Findlay, R.A. Hendin, M.T. Mageau, and A.E. Konopka. 1995. Carbon availability an the pattern of cyanobacterial dominance in enriched low-carbon lakes. *J. Phycol.* 31: 735-744.

32. Paterson, M.J., D. Findlay, A.G. Salki, L.L. Hendzel, and R.H. Hesslein. 2002. The effects of Daphnia on nutrient stoichiometry and filamentous cyanobacteria: a mesocosm experiment in a eutrophied lake. *Freshwater Biology* 47: 1217-1233.

33. Havens, K.E., N.G. Aumen, R.T. James, and V.H. Smith. 1996. Rapid ecological changes in a large subtropical lake undergoing cultural eutrophication. Ambio 25:150-155.

34. Gophen, M., S. Serruya, and S. Threlkeld. 1990. Long-term patterns in nutrients, phytoplankton, and zooplankton in Lake Kinneret and future predictions for ecosystem structure. Arch. Hydrobiol. 118: 449-460.

35. Berman, T. 1995. Cyanobacteria in the Sea of Galilee (Lake Kinneret). ASLO Bulletin 4:13-14.

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

37. Environment Canada. 2001. Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No. 1. 72 p.

38. Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger and D.G. Tilman. 1997. Human alteration of the global nitrogen cycle: sources and consequences. Ecol Appl. 7: 737-750.

39. Steen, I. 1998. Phosphorus availability in the 21st century: management of a non-renewable resource. Phosphorus Potassium 217: 25-31.

40. Brunskill, G.J., and B.W. Graham. 1979. The offshore sediments of Lake Winnipeg. Can. Fish. Mar. Serv. MS Rept. 1540.

41. L. Lockhart (personal communication)

42. L. Lockhart (personal communication)

43. P. Ramlal (unpublished data)

44. Mayer, T., W. L. Lockhart, S.L. Simpson and P. Wilkinson 2002. Phosphorous geochemistry of recent sediments in Lake Winnipeg (In press).

45. L. Hendzel (unpublished data)

46. Jones, G., and N. Armstrong 2001. Long-term trends in total nitrogen and total phosphorous concentrations in Manitoba streams. Manitoba Conservation Report No. 2001 - 07.

47. McCullough, G. 2001. Organic carbon, nitrogen and phosphorous fluxes in rivers flowing into and out of Lake Winnipeg Final report of a study prepared for the Department of Fisheries and Oceans, Winnipeg Manitoba

48. Brigham, M.E., T. Mayer, G.K McCullough, and L.H. Tornes 1996. Transportation and speciation of nutrients in tributaries to southern Lake Winnipeg, Canada. Abstracts of presentations from the 16th annual International Symposium on lake Reservoir and Watershed Management, Nov 13 - 16 1996, Minneapolis/St. Paul, MN, North American Lake Management Society, p. 64.

49. Wardrop/TetES Consultants Inc. 2002a. Appendix #1. "Illness Risk Report". Unpublished report to the City of Winnipeg, Waste and Water Department. Winnipeg.

50. Second International Conference on the recovery of phosphorus from sewage and animal wastes. Noordwijkerhout, Holland. 2001.

51. Schelske, C.L., and D.A. Hodell. 1995. Using carbon isotopes of bulk sedimentary organic matter to reconstruct the history of nutrient loading and eutrophication in Lake Erie. Limnol. Oceanogr. 40: 918-929.

52. Brunskill, G.J., S.E.M. Elliot, and P. Campbell. 1980. Morphometry, hydrology, and watershed data pertinent to the limnology of Lake Winnipeg. Can. MS Rep. Fish. Aquat. Sci. 1556: v+23p

53. Patalas, K., and A. Salki. 1992. Crustacean plankton in Lake Winnipeg:L variationin space and time as a function of lake morphology, geology, and climate. Can. J. Fish. Aquat. Sci. 49: 1035-1059.

54. Stewart, A.R., G.A. Stern, A. Salki, M.P. Stainton, W.L. Lockhart, B.N. Billeck, R. Dannell, J. Delaronde, N.P. Grift, T. Halldorson, K. Koczanski, A. MacHutcheon, B. Rosenberg, D. Savoie, D. Tenkula, G. Tomy, and A. Yarchewski. 2000. Influence of the 1997 Red River Flood on contaminant transport and fate in southern Lake Winnipeg. Report prepared for the International Red River Basin Task Force.

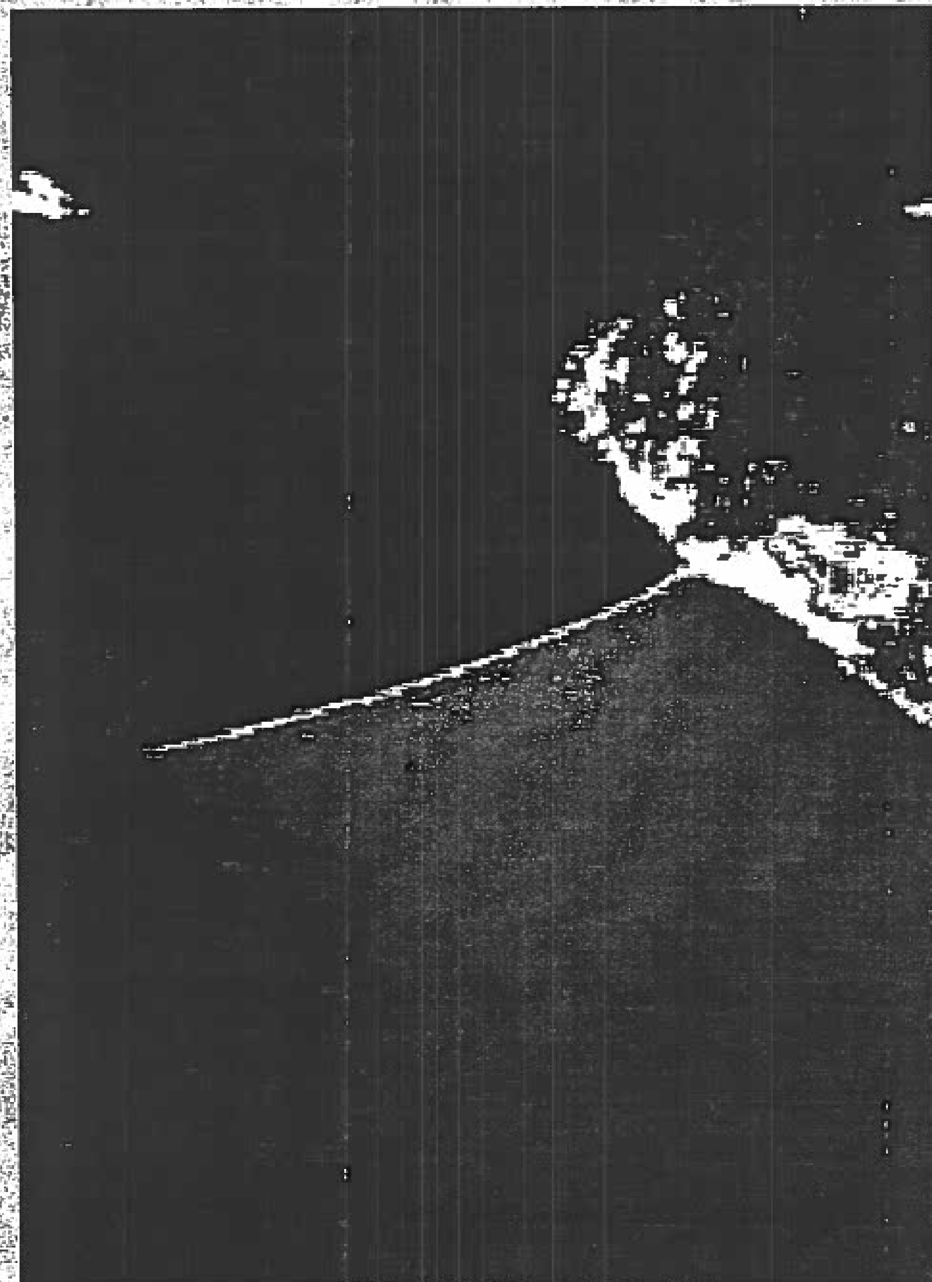


Figure 1

Figure 2

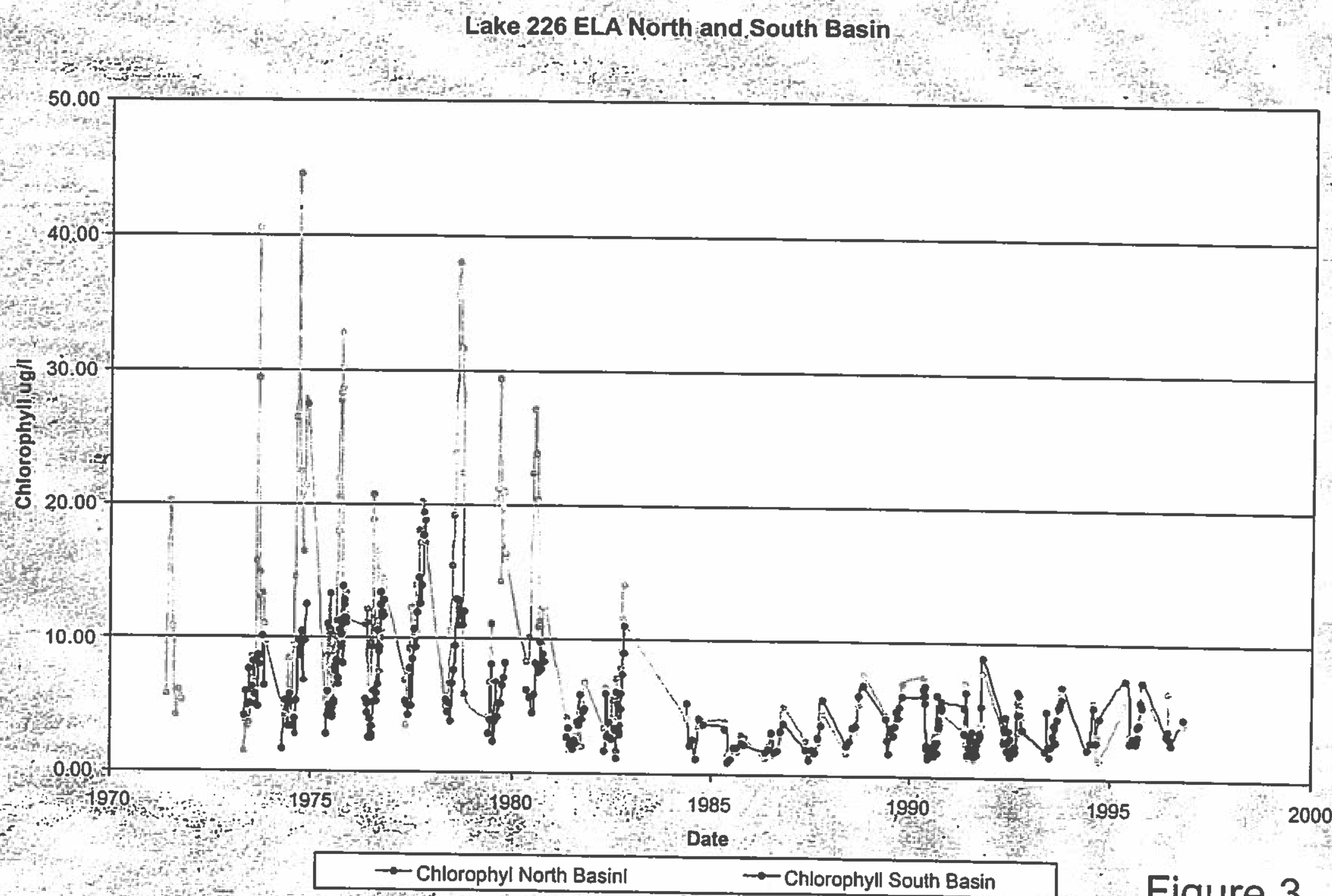

Lake 226 ELA North and South Basin
Chlorophyll ug/l
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
Date
Chlorophyl North Basinl
Chlorophyll South Basin

Figure 3

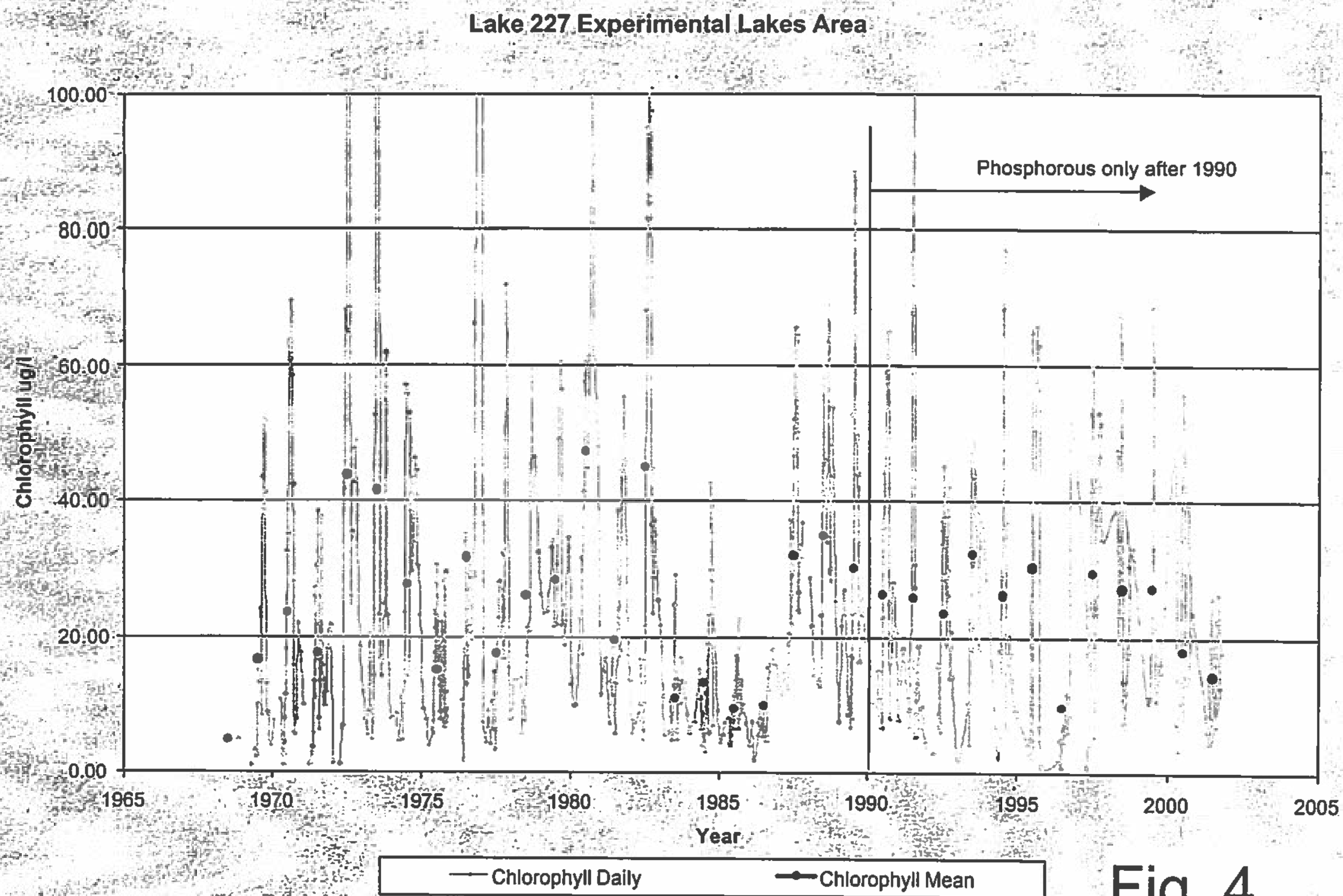

Lake 227 Experimental Lakes Area
Chlorophyll ug/l
100.00
80.00
60.00
40.00
20.00
0.00
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
Phosphorous only after 1990
Chlorophyll Daily
Chlorophyll Mean

Fig. 4

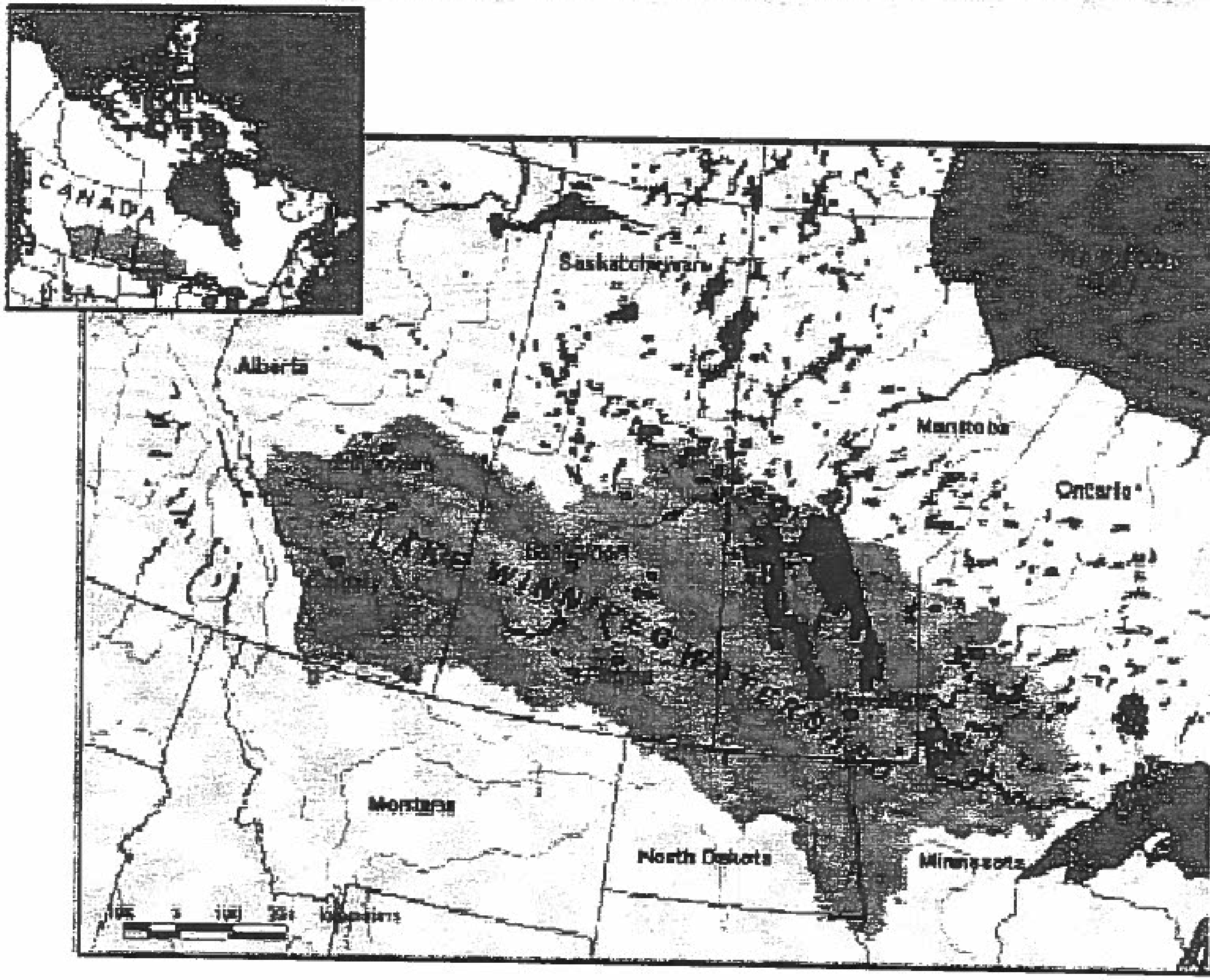

CANADA
Alberta
Saskatchewan
Manitoba
Ontario
Montana
North Dakota
Minnesota

Figure 5

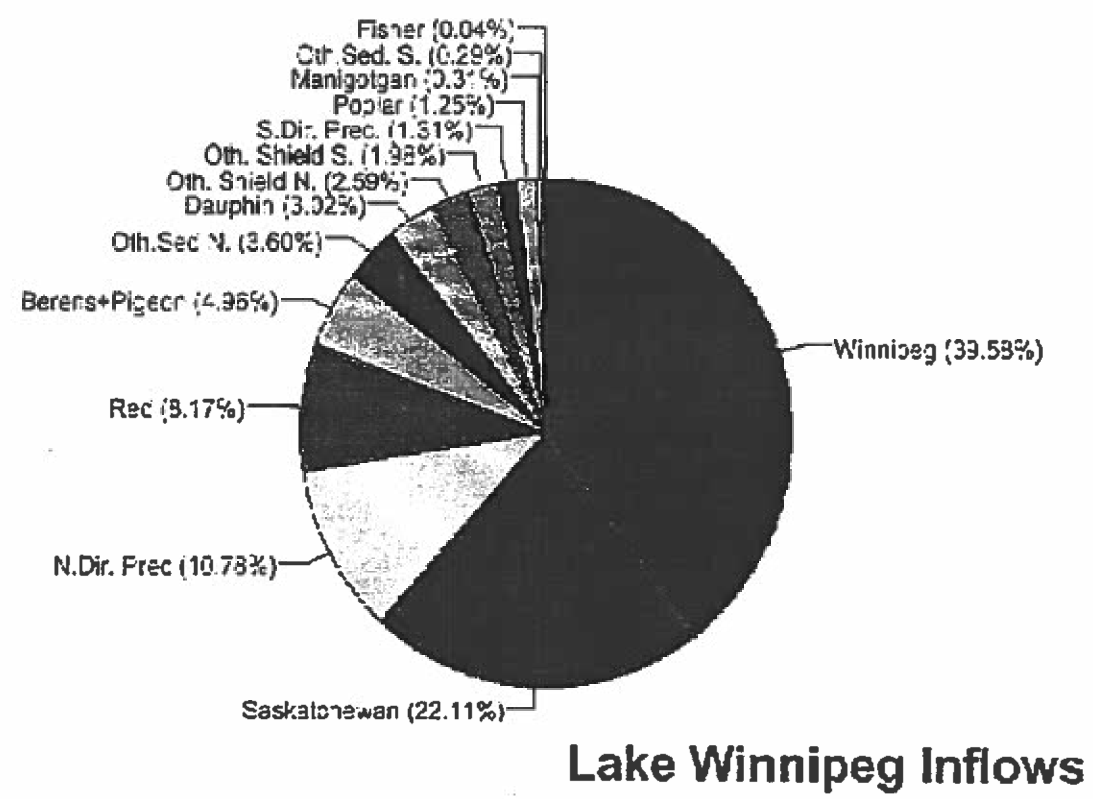

Fisher (0.04%)
Ctr.Sed. S. (0.29%)
Manigotgan
Poplar (1.25%)
S.Dir. Prec. (1.31%)
Oth. Shield S. (1.98%)
Oth. Shield N. (2.59%)
Dauphin (3.02%)
Oth.Sed N. (3.60%)
Berens+Pigeon (4.96%)
Red (8.17%)
N.Dir. Prec (10.78%)
Saskatchewan (22.11%)
Winnipeg (39.58%)
Lake Winnipeg Inflows

Figure 6

The Red River accounts for 60% of the Phosphorus input into Lake Winnipeg

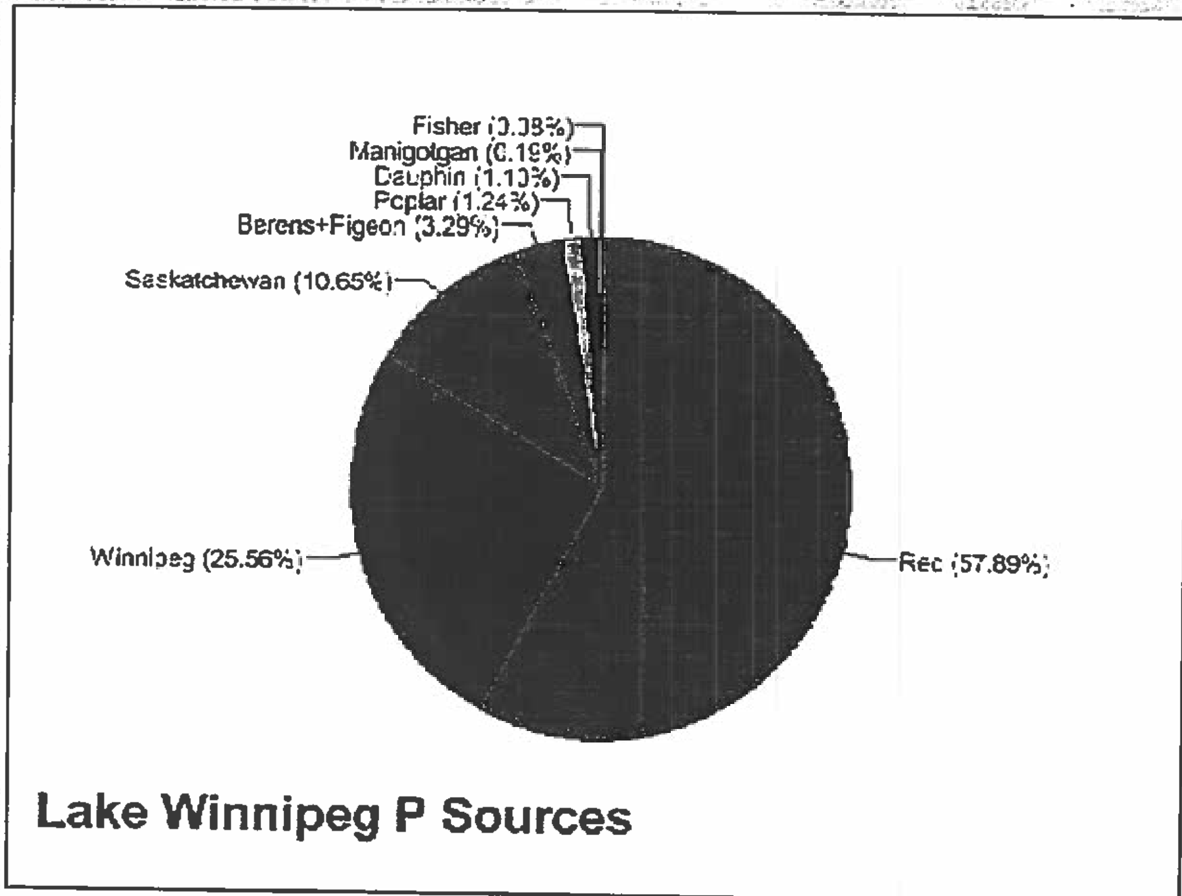
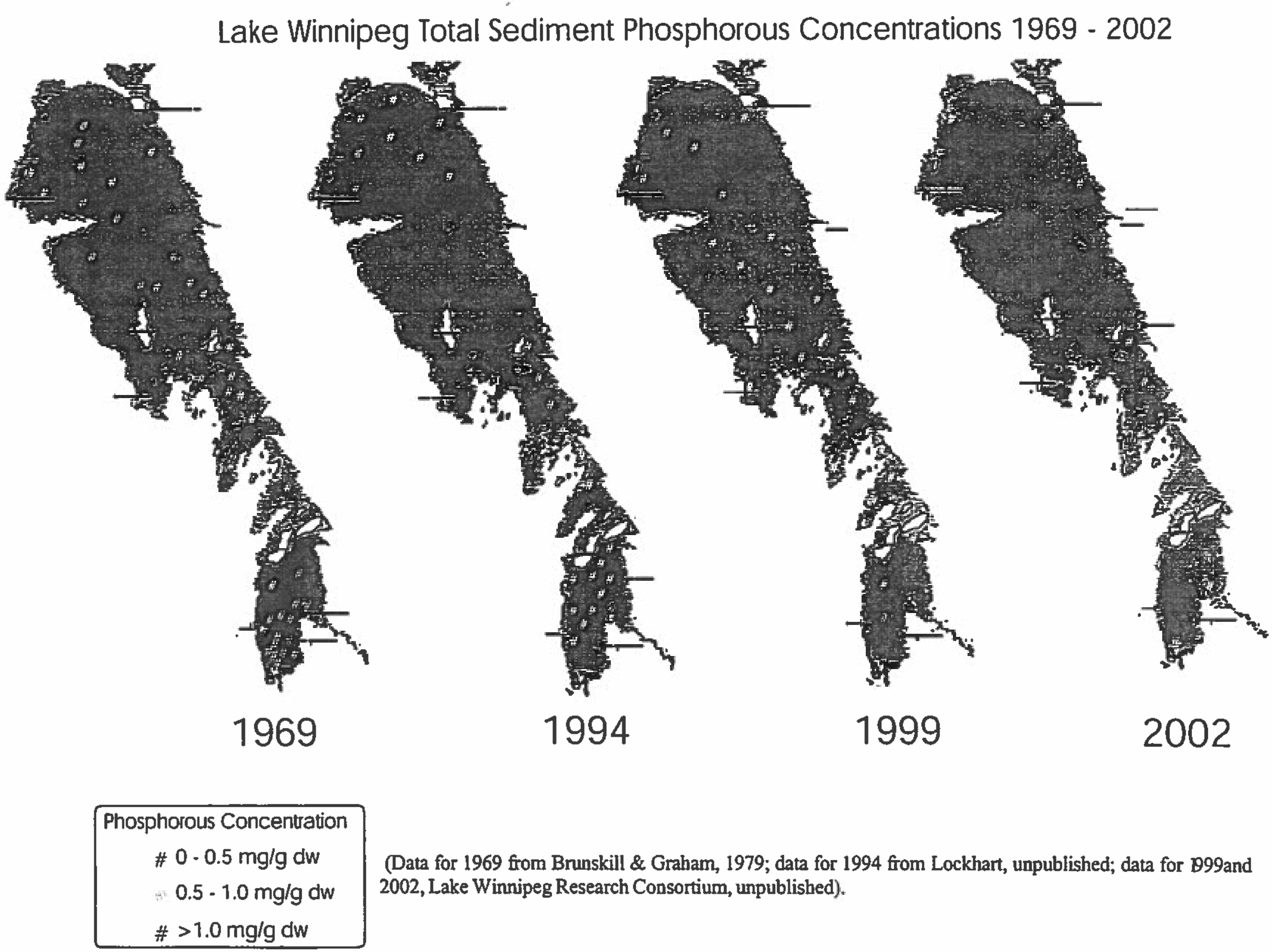


Figure 7



(Data for 1969 from Brunskill & Graham, 1979; data for 1994 from Lockhart, unpublished; data for 1999and 2002, Lake Winnipeg Research Consortium, unpublished).

Figure 8

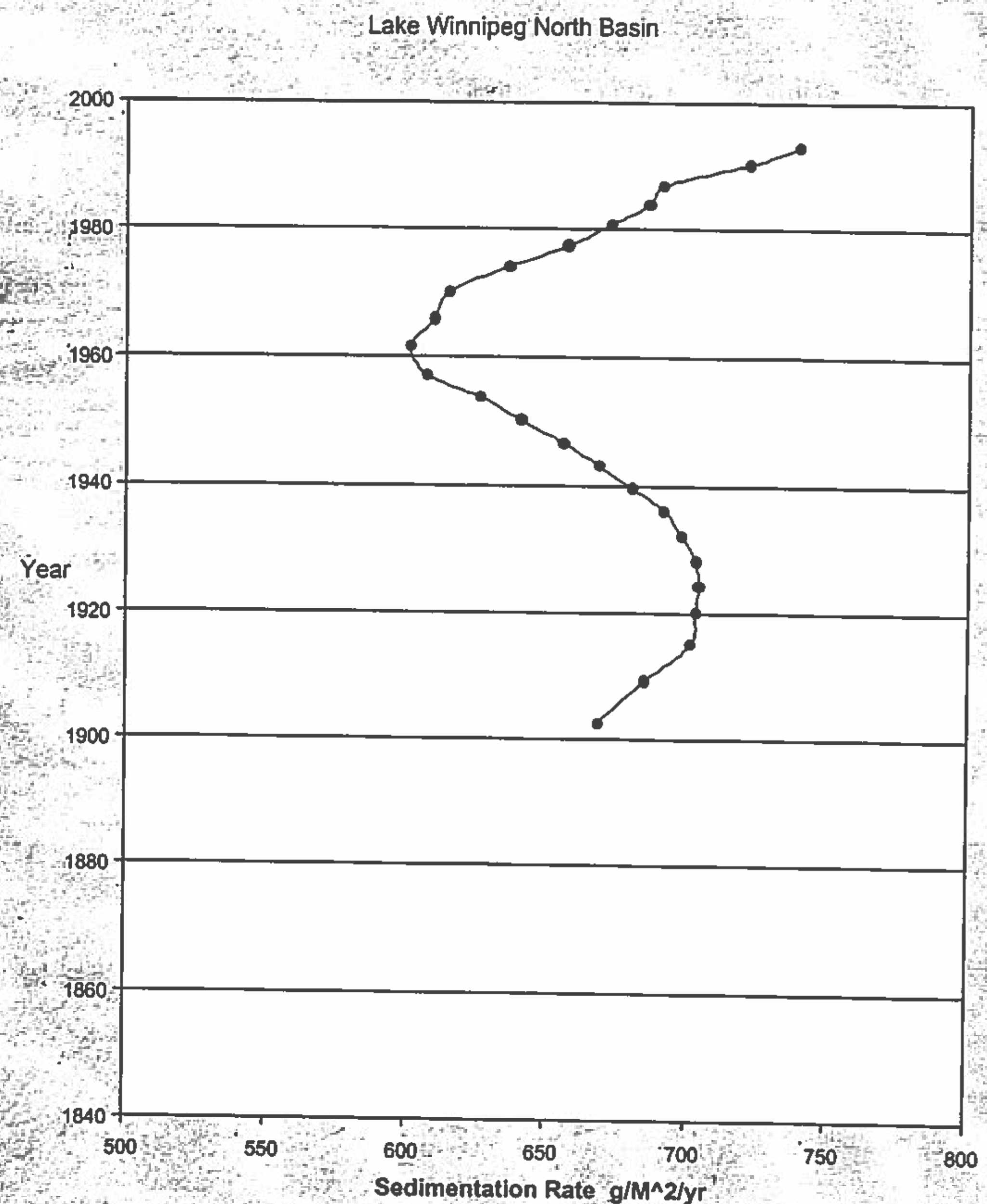
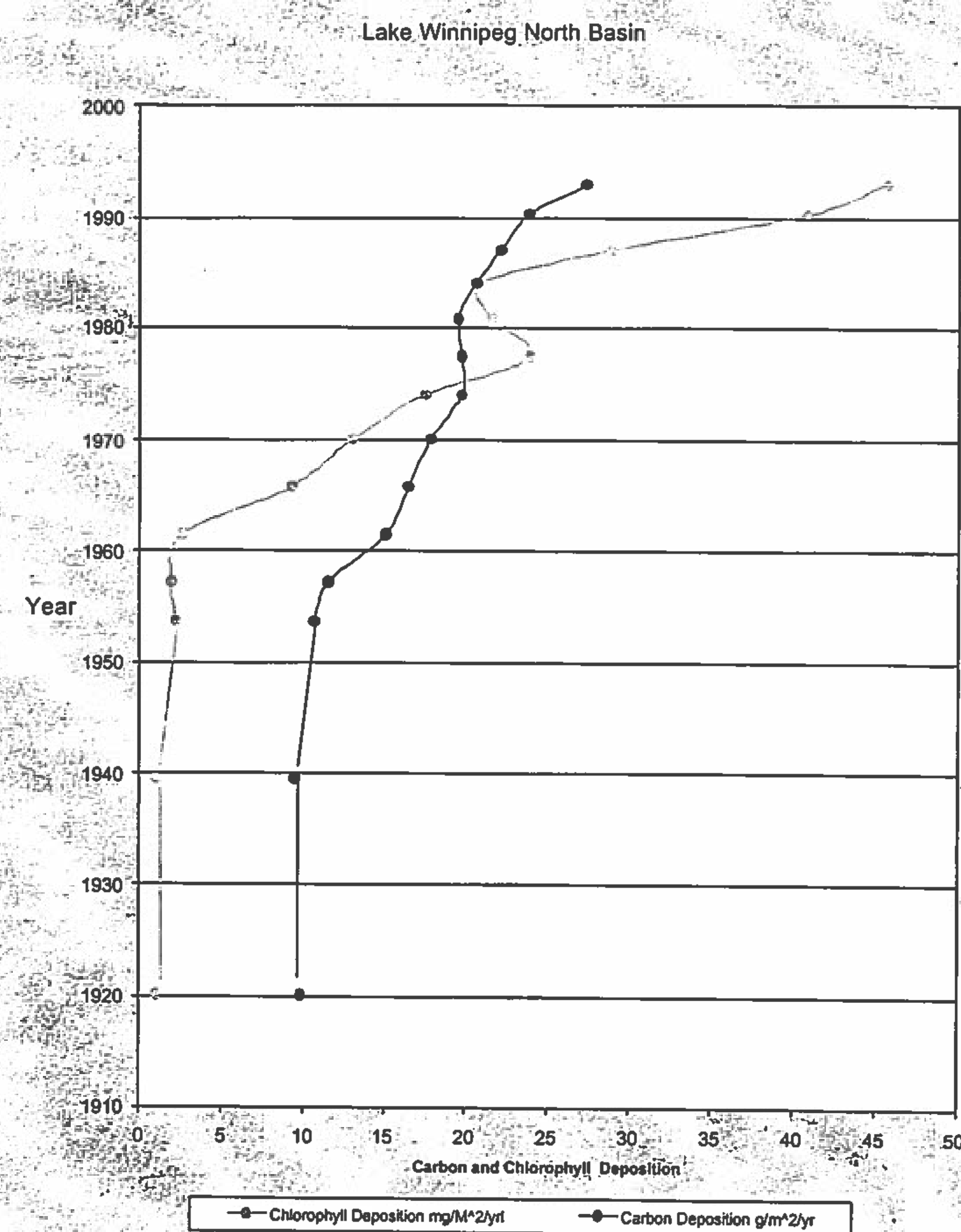
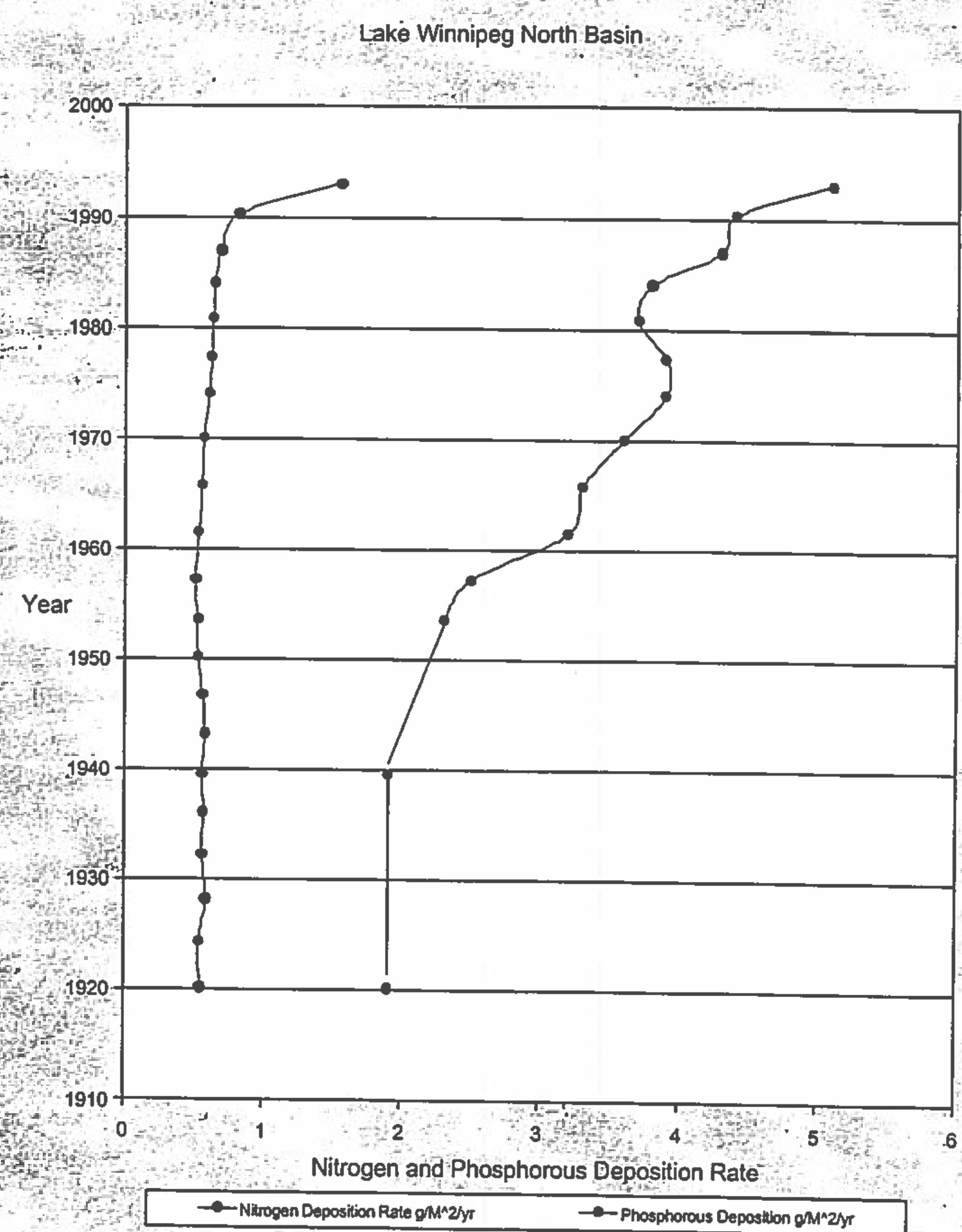

Lake Winnipeg North Basin
Year
2000
1980
1960
1940
1920
1900
1880
1860
1840
500
550
600
650
700
750
800
Sedimentation Rate g/M^2/yr

Figure 9



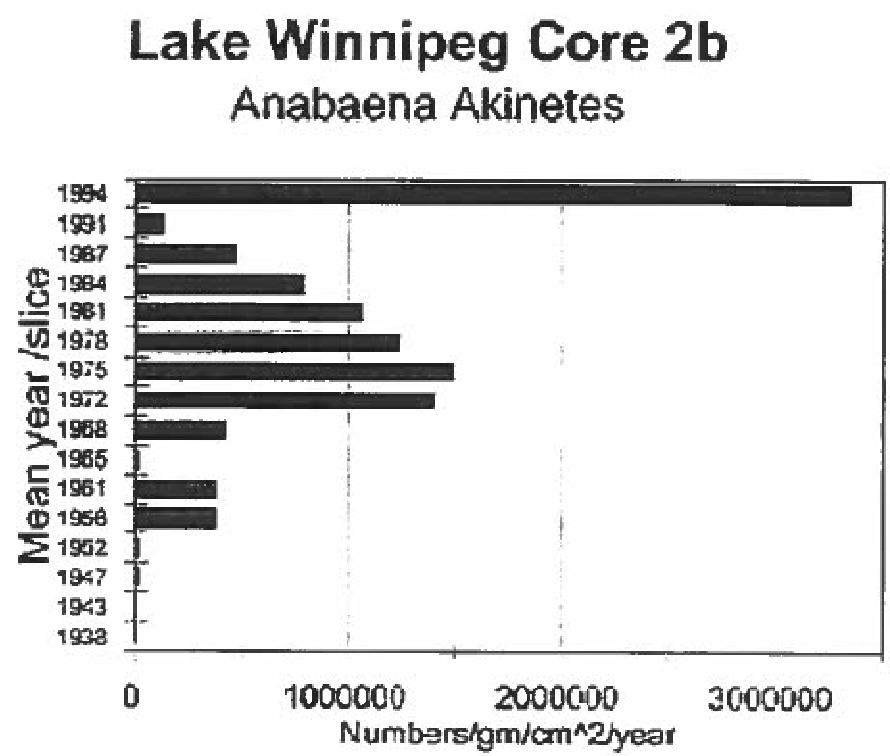
Lake Winnipeg North Basin
Year
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
0
5
10
15
20
25
30
35
40
45
50
Carbon and Chlorophyll Deposition
Chlorophyll Deposition mg/M^2/yrl
Carbon Deposition g/m^2/yr

Figure 10



Lake Winnipeg North Basin
Year
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
0
1
2
3
4
5
6
Nitrogen and Phosphorous Deposition Rate
Nitrogen Deposition Rate g/M^2/yr
Phosphorous Deposition g/M^2/yr

Figure 11



Increase in N Fixing Blue Green Algae Remnants in North Basin Core

Figure 12

Net hauls provide a simple measure of pelagic algal and zooplankton abundance comparable to method used by Bajkov in 1929.

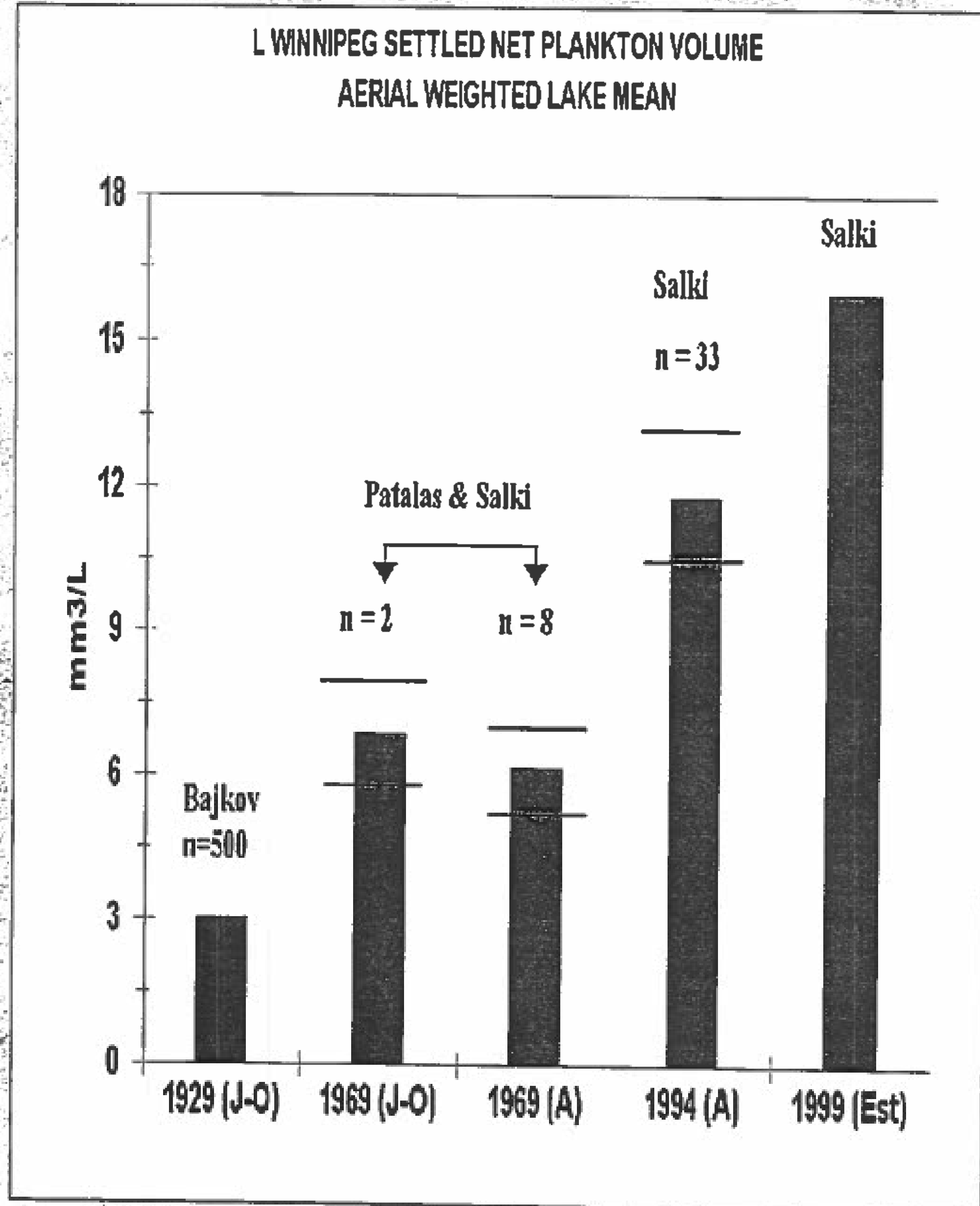
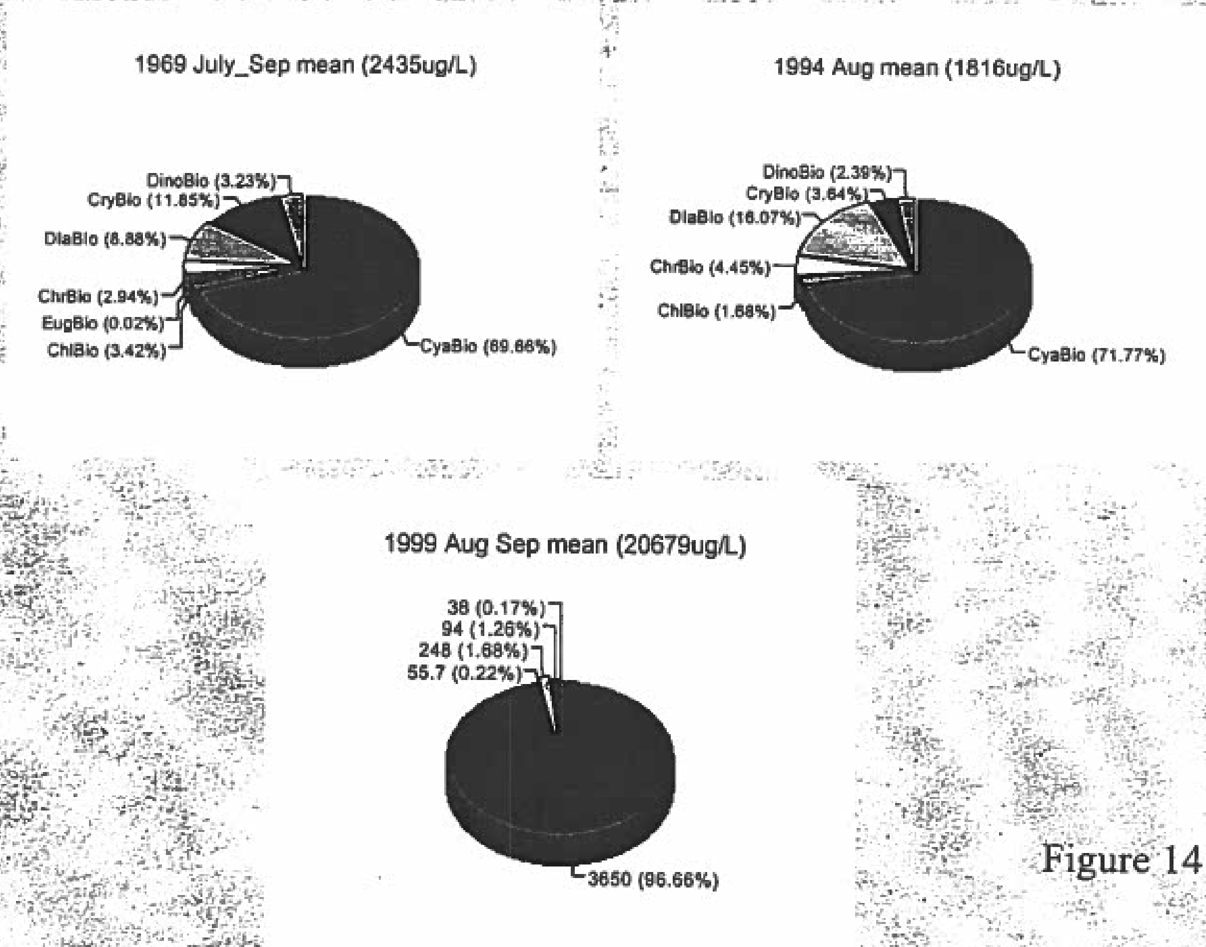


Figure 13

Changes in August September algal composition in the North Basin of Lake Winnipeg 1969, 1994 and 1999



H. Kling

Figure 14

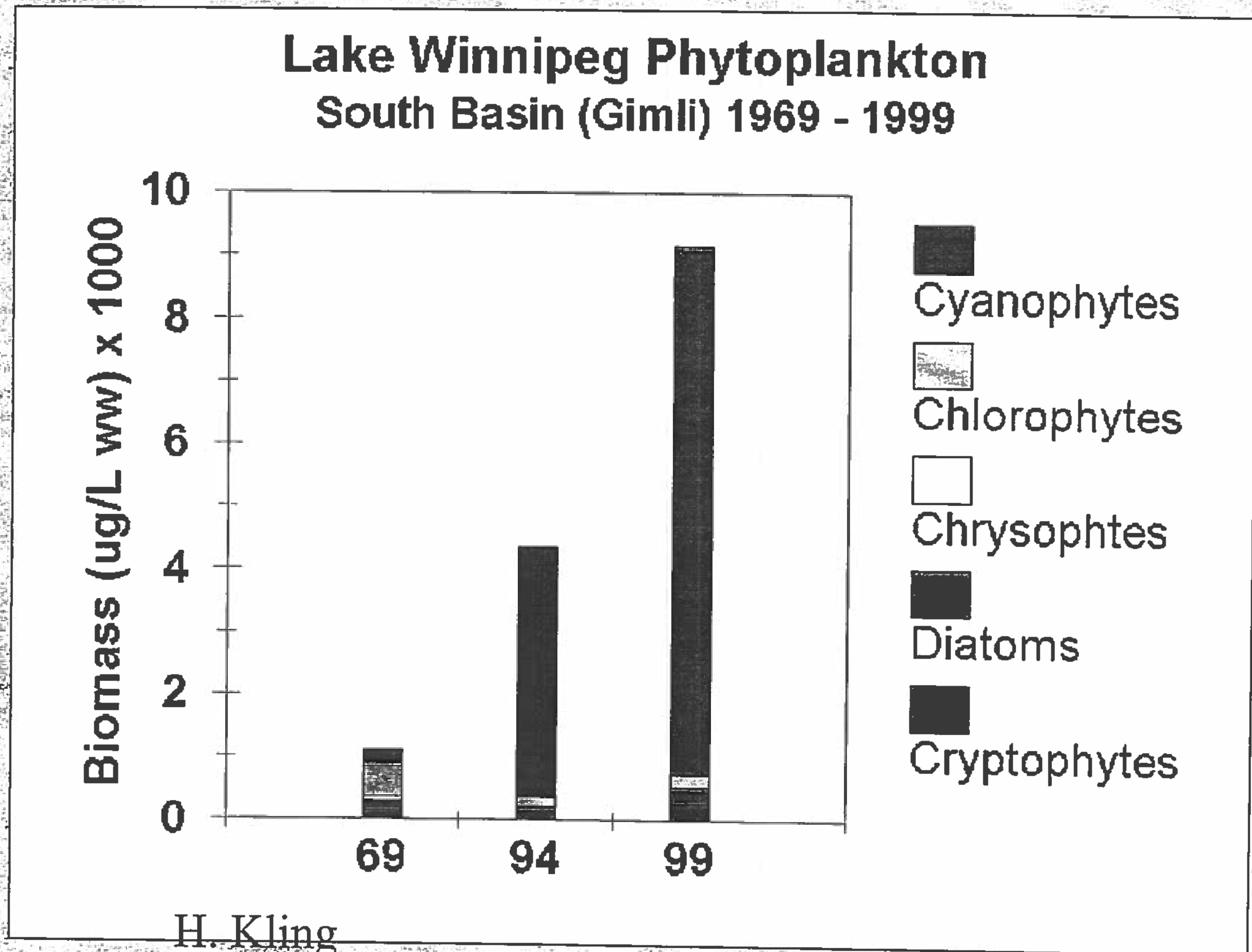

Lake Winnipeg Phytoplankton
South Basin (Gimli) 1969 - 1999
Biomass (ug/L ww) x 1000
10
8
6
4
2
0
69
94
99
Cyanophytes
Chlorophytes
Chrysophtes
Diatoms
Cryptophytes
H. Kling

Figure 15

Lake Winnipeg

26 Sept 2001 13:49 CST

AVHRR NDVI Image

Brown = Low Chlorophyll High Turbidity

Green = High Chlorophyll

Figure 16

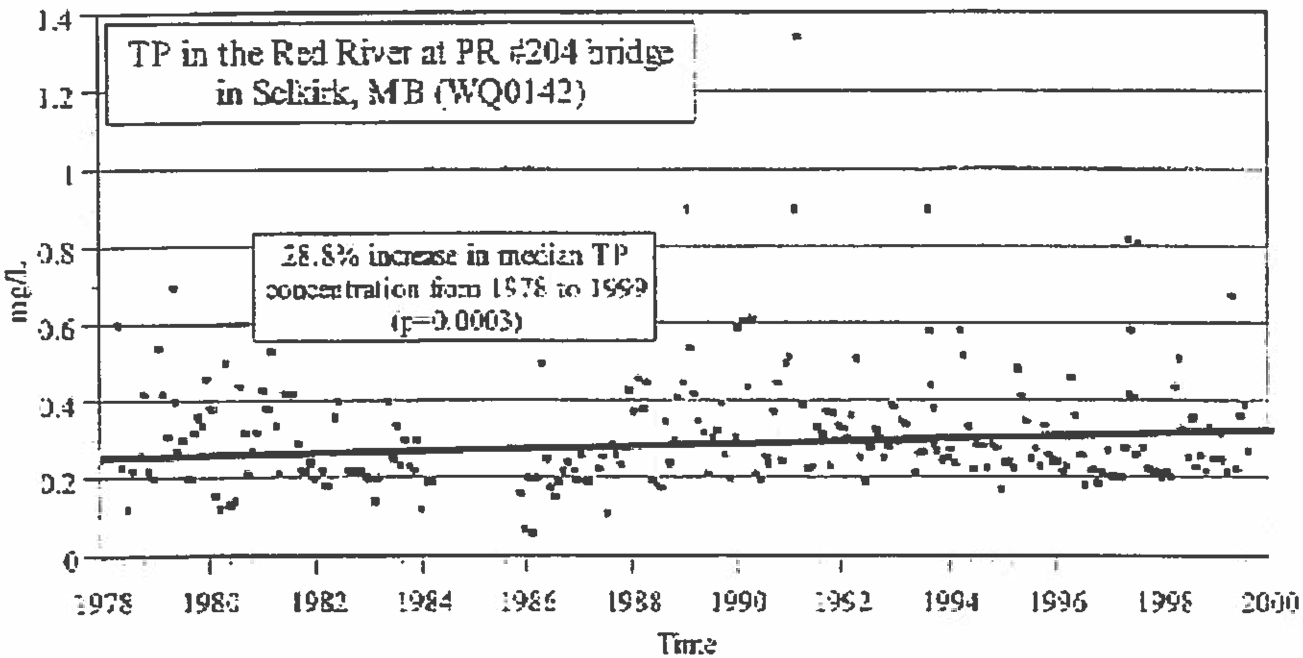


Figure 7. Trend in TP concentration in the Red River at the PR #204 bridge in Selkirk, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration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

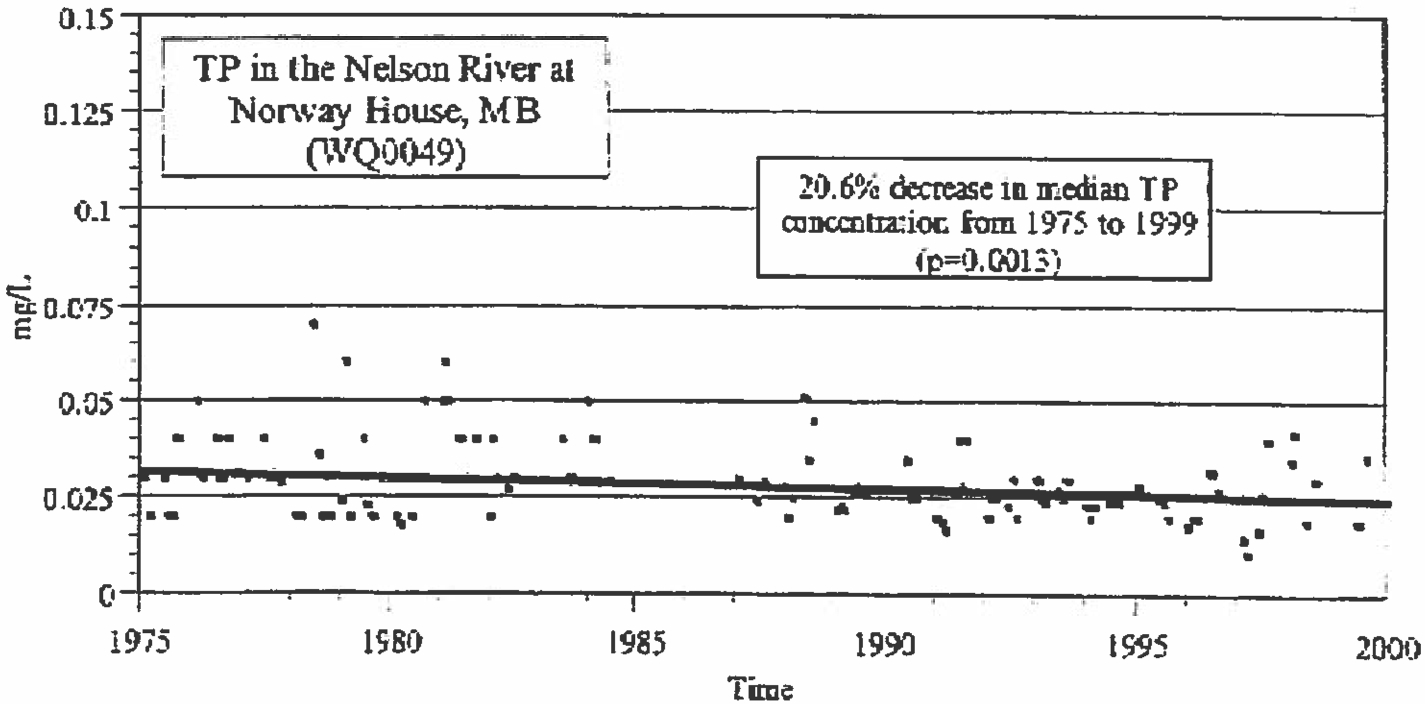


Figure 110. Trend in TP concentration in the Nelson River Norway House, MB, 1978 to 1999 (inclusive). Dots represent measured concentrations, while the solid line represents the trend in flow-adjusted concentrations. The % change in median concentration refers to the median concentration of the flow-adjusted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

Lake Winnipeg Discharge Inversion 1990 Data

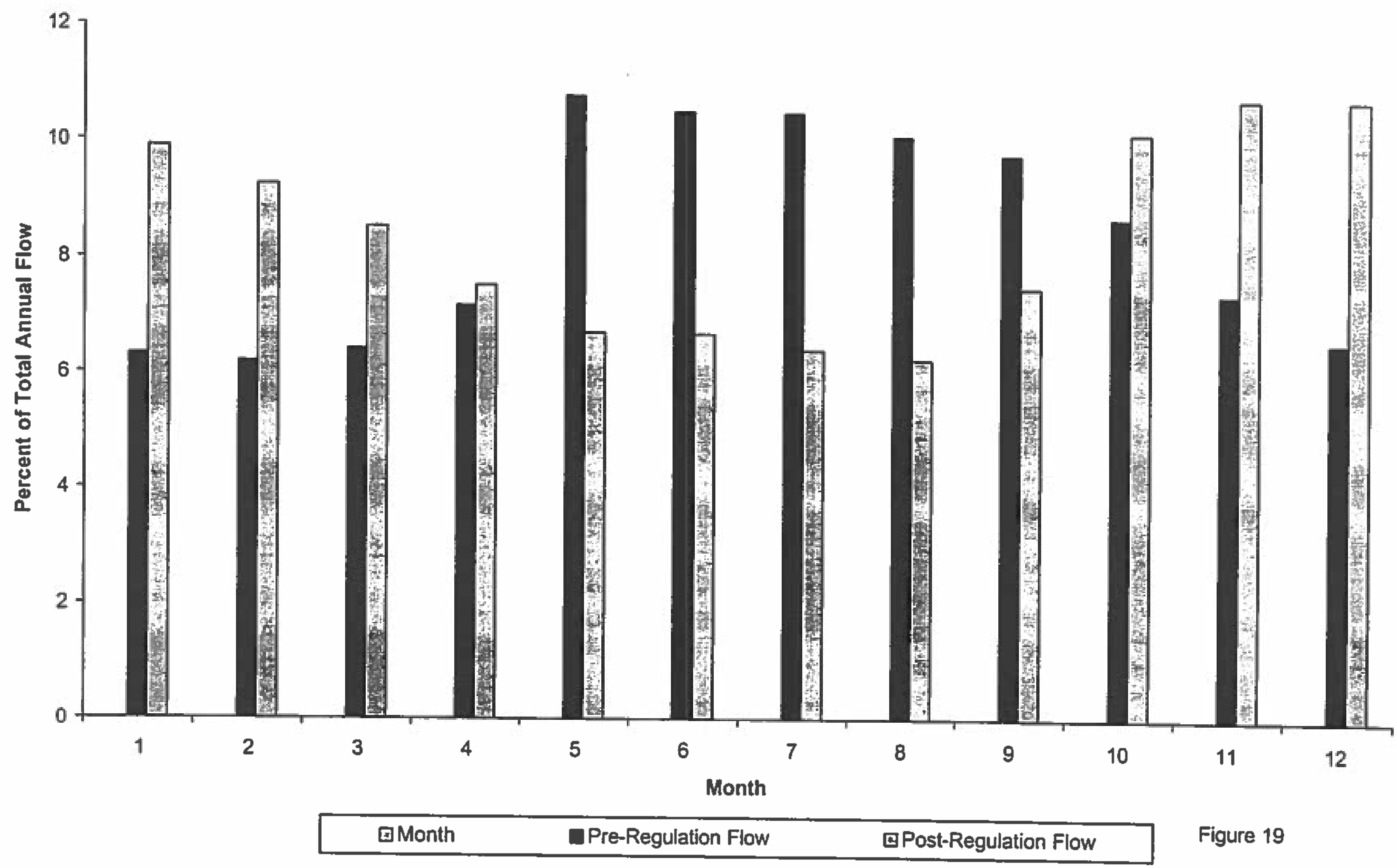


Figure 19

Lake Winnipeg P Retention

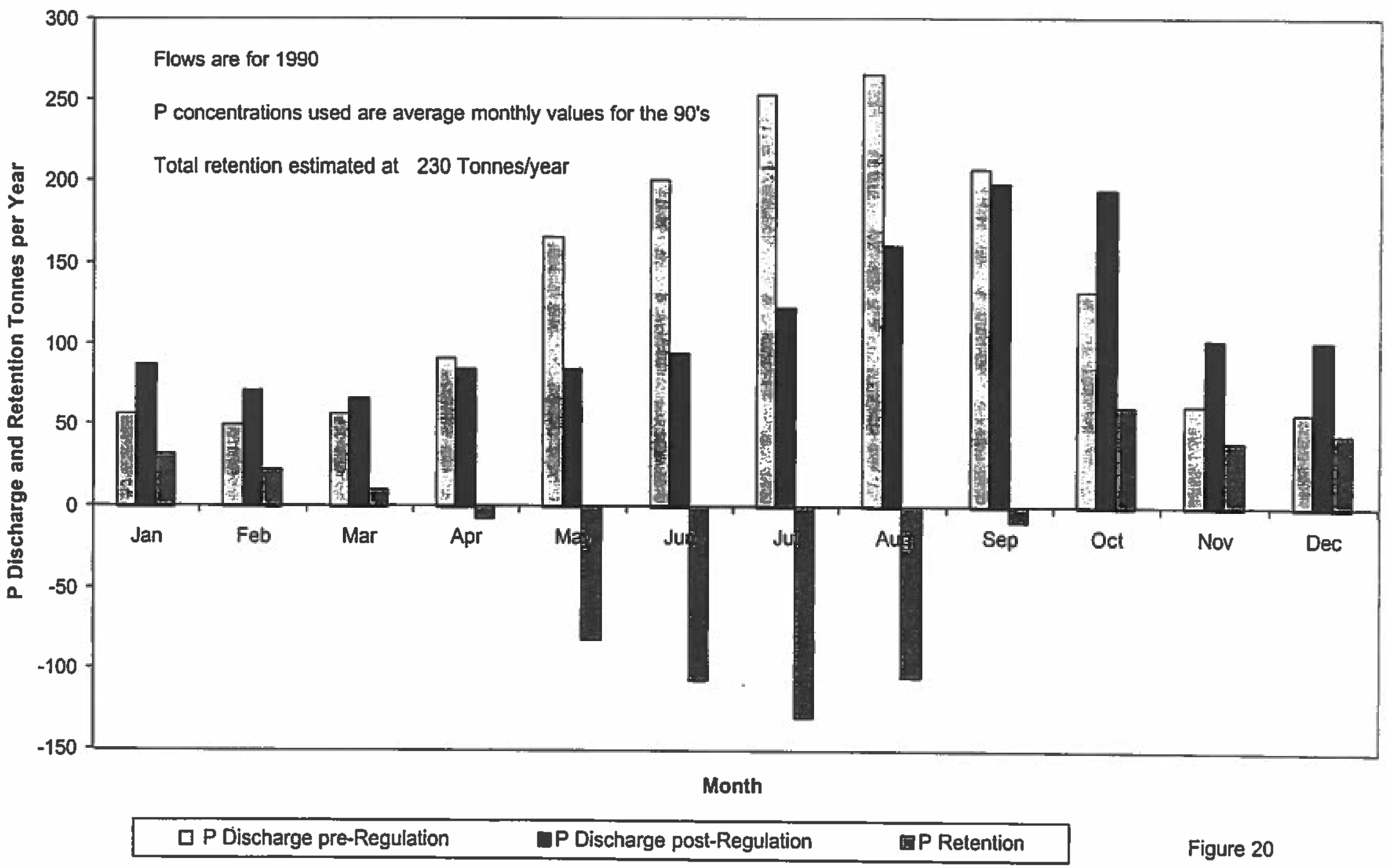


Figure 20

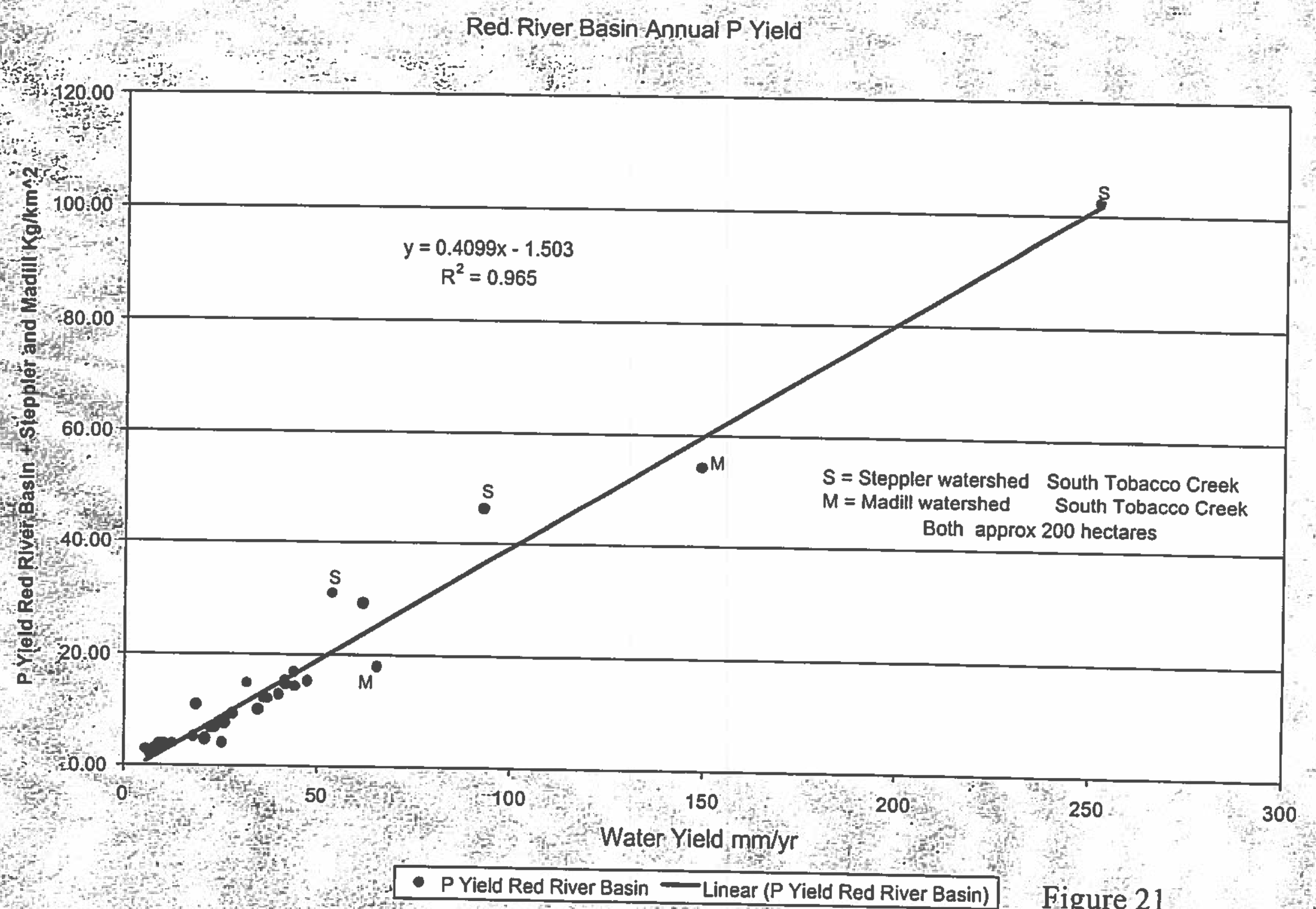

Red River Basin Annual P Yield
P Yield Red River Basin + Steppler and Madill Kg/km^2
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
50
100
150
200
250
300
Water Yield mm/yr
y = 0.4099x - 1.503
R2 = 0.965
S
M
S = Steppler watershed South Tobacco Creek
M = Madill watershed South Tobacco Creek
Both approx 200 hectares
P Yield Red River Basin
Linear (P Yield Red River Basin)

Figure 21

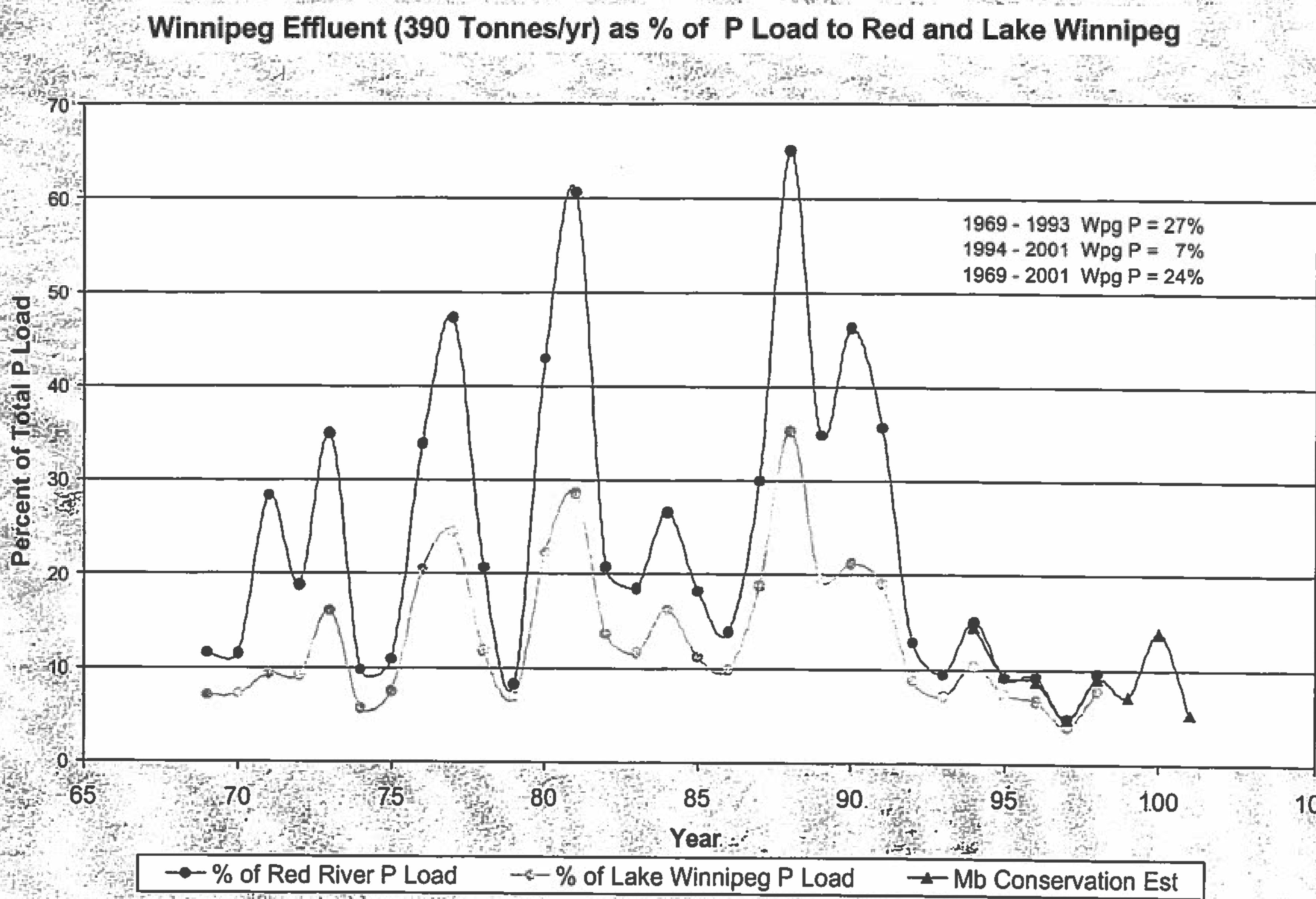

Winnipeg Effluent (390 Tonnes/yr) as % of P Load to Red and Lake Winnipeg
1969 - 1993 Wpg P = 27%
1994 - 2001 Wpg P = 7%
1969 - 2001 Wpg P = 24%
Percent of Total P Load
0
10
20
30
40
50
60
70
65
70
75
80
85
90
95
100
105
Year
% of Red River P Load
% of Lake Winnipeg P Load
Mb Conservation Est

Figure 22

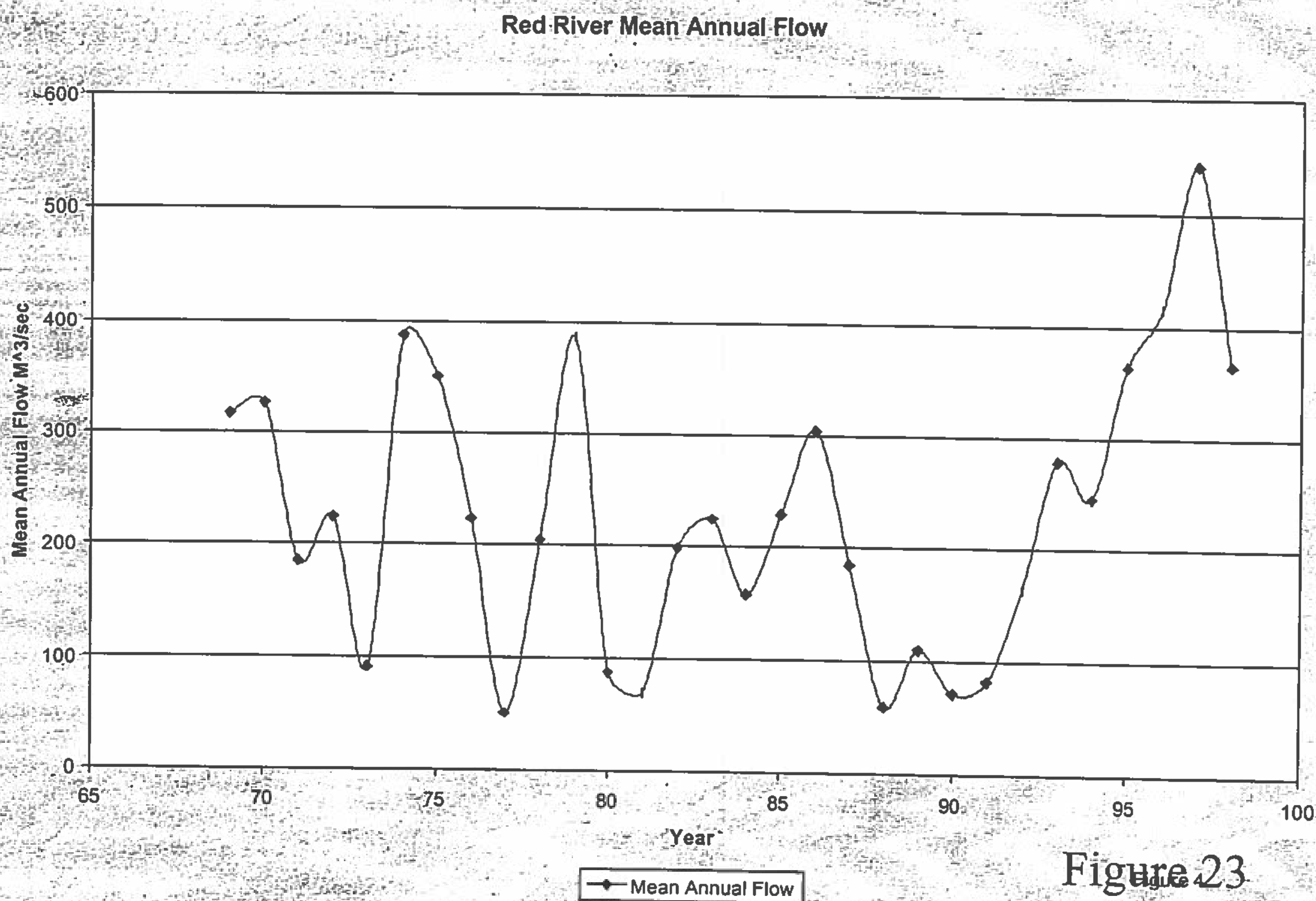

Red River Mean Annual Flow
Mean Annual Flow M^3/sec
0
100
200
300
400
500
600
65
70
75
80
85
90
95
100
Year
Mean Annual Flow

Figure 23

Phosphorous concentrations in inflowing water plotted as a function of water renewal time. Laurentian lakes data from the IJC, 1976. Lake Winnipeg data from Brunskill et al.1980, Patalas and Salki 1992, and Stewart et al. 2000

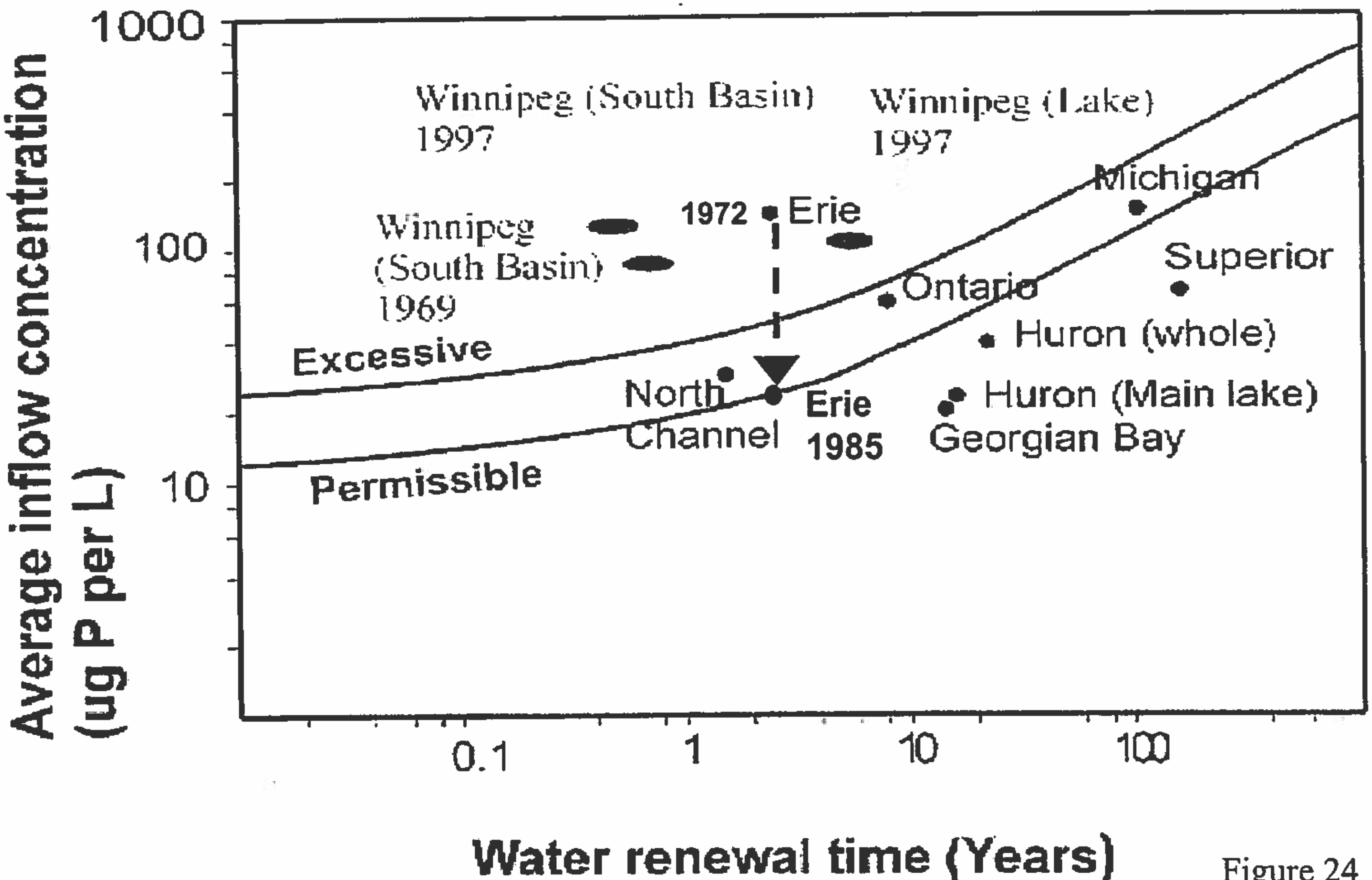


Figure 24