

# **Water Level Regulation in the Lake Winnipeg Basin and its Effect on Nutrient Status of the Lake**

A report prepared for the  
**Manitoba Clean Environment Commission**

In preparation for a review of the licensing of regulation of Lake Winnipeg under  
*The Water Power Act.*

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## Introduction

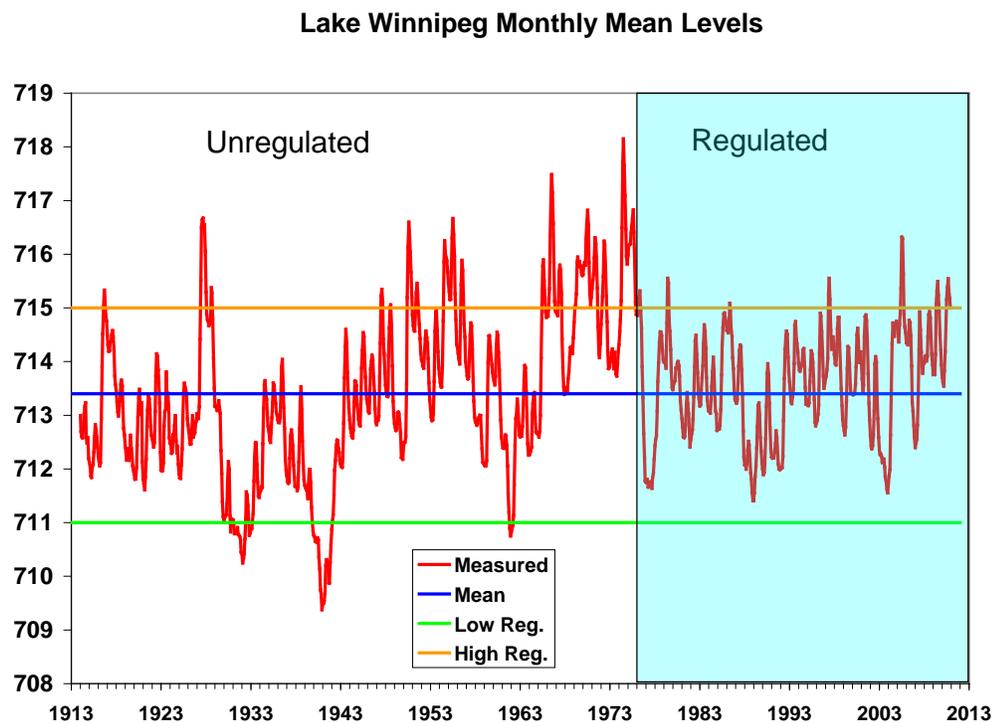
The purpose of this report is to assess the impact that regulation of outflows from Lake Winnipeg (Nelson River) may have had or may have in the future on the nutrient regime and the algal productivity in the lake. The report will be divided in five sections. 1. A brief review of flow regulation. 2. A review of the nutrient and algal status of Lake Winnipeg. 3. An assessment of the influence that regulation may have exerted on the nutrient status. 4. An assessment of the possible future influence that regulation may have on the nutrient status of the lake and 5. Concluding remarks about flow regulation and nutrients in Lake Winnipeg.

## A Brief Review of Flow Regulation of Inflows and Outflows of Lake Winnipeg.

The issue covered by this report is typically referred to as “Lake Winnipeg Level Regulation” but that really is a misnomer in view of the terms of the existing interim license (and proposed final license) for the operation of the control structures at the outflow of Lake Winnipeg (the beginning of the Nelson River). The license allows Manitoba Hydro to manage the control structures for its purposes (generation of electricity) when the level is between 711 and 715 feet above sea level (fasl). The license requires that the structures be operated to allow maximum outflow if the level rises above 715 fasl and states that decisions on the operation of the structures revert to the Minister in charge if the level falls below 711 fasl. In the range of 711-715 fasl Manitoba Hydro has two basic objectives in managing the control structures. The first objective is to provide appropriate flows to produce electric power, as required by its customers, from turbines at dam sites along the Nelson River. This objective is coordinated with the operation of its turbines at dam sites other than on the Nelson River in a manner beyond the scope of this report. The level of the lake is not normally a significant concern for these operational decisions. The second objective in management of the outflows has the longer term objective of leaving enough water in the lake for power production in following years (not allowing the lake to go below their optimal operating range of 711-715 fasl) and leaving enough capacity in the lake below 715 fasl to accept the next year’s inflows. The level of the lake is the marker for this component of outflow management. The license also states that Manitoba Hydro is to regulate the outflows so as to avoid having the level of the lake fall below 711 fasl. Although not explicitly stated in the license, it is likely that Manitoba Hydro would, if possible, operate the outflow structures in such a way as to avoid having the level rise above 715 fasl. In order to properly represent the activity addressed in the license, I will refer to it as outflow

regulation, not level regulation because in the level range of 711-715 the objectives of regulation by Manitoba Hydro are focused primarily on flow.

The level of Lake Winnipeg has been regularly measured at least since 1913 (Figure 1). Over the last century the level has ranged from a minimum of about 709.5 fasl to a maximum of just above 718 fasl. Both of these extremes occurred prior to the onset of regulation of the outflow (begun in 1975). Since the onset of regulation the level has never been below 711 fasl and has only rarely and briefly exceeded 715 fasl in spite of the relatively high precipitation in the last two decades.



**Figure 1.** Mean levels of Lake Winnipeg from all stations with correction for wind effects (from Hesslein, 2011)

Although the impetus for this report is the review of licensing conditions for the operation of the Lake Winnipeg outflow control structures constructed in the early 1970's, effective human regulation of flows from Lake Winnipeg actually has a longer history. The Lake of the Woods Control Board (LWCB) was formed in 1919 to regulate the outflows of Lake of the Woods. Lake of the Woods is the source of the Winnipeg River in northwestern Ontario. The LWCB also regulates the outflow of Lac Seul (also northwestern Ontario), the source of the English River, which joins

the Winnipeg River near the Manitoba-Ontario border. A detailed description of the operations and history of the LWCB can be found on the website: [www.lwcb.ca](http://www.lwcb.ca).

Regulation of the Winnipeg River affects the levels of Lake Winnipeg and therefore affects the outflows of the lake and the outflow regulation regime. Historically, since comprehensive flow records have been kept on the major inflows to Lake Winnipeg, the Winnipeg River has supplied about 40% of the total water inflow to the lake. In fact, the fraction of the total inflow supplied by the Winnipeg River has risen slightly over the last century due to regional precipitation patterns and increasing water withdrawals from the Saskatchewan River.

Water regulation of the English River is carried out at the Ear Falls outflow of Lac Seul and of the Winnipeg River at the Norman Dam near Kenora. The LWCB consists of four members, one from Canada, one from Manitoba and two from Ontario. A number of factors influence the regulation decisions as are detailed on the website. Because one of the objectives of the LWCB is to maintain relatively constant lake levels in Lake of the Woods, significant purposeful drawdowns or overfills are rare and the regulation regime does little to alter the total annual flow of the river. However, in an effort to meet its combined objectives, the seasonal flows are often significantly altered in magnitude and timing.

Since the construction of the dam at Grand Rapids and the formation of Cedar Lake in 1962, and the creation of Lake Diefenbaker with the completion of the Gardiner Dam in 1967, the flow of the Saskatchewan River has also undergone significant regulation. The Saskatchewan River delivers about 30% of the inflow to Lake Winnipeg (closer to 40% earlier in the 20<sup>th</sup> century). Again, as with the regulation of the Winnipeg River, annual flows are not greatly affected but the seasonal distribution of those flows can be significantly modified due to requirements for efficient hydroelectric power production.

The flows of the Red River (about 10-20% of the total water input to Lake Winnipeg as measured at Lockport, MB) south of the City of Winnipeg are essentially unregulated because there is no significant storage capacity in that system. Seasonal regulation is effected only under severe flood conditions when significant short-term storage is created in the valley by bank overflow. The Assiniboine River joins the Red River in the City of Winnipeg and its flows are regulated by outflows from the Shellmouth Dam (completed in 1972) near the origin of the river in western Manitoba. In flood years, the flows of the Assiniboine River are managed by diverting flow to Lake Manitoba through the Portage Diversion Channel (built in 1970). This floodwater is then released much more gradually (and directly to Lake

Winnipeg) through the outflow of Lake Manitoba (presently undergoing reconstruction). Again, as with the other regulation of the other rivers, total annual inputs from the Red and Assiniboine Rivers are little affected but seasonal patterns have been changed.

In summary, it can be shown that the seasonal pattern of the level of Lake Winnipeg has been increasingly altered due to increased regulation of nearly all of the major inflows to the lake. Prior to the construction of the Lake Winnipeg outflow structures in the early 1970's the natural outflow "structure" simply responded to those altered inflow regimes with altered outflows. Since the construction of the outflow structures, the management of the outflow can take into consideration the existing and predicted managed flows of the major inflows. The coordination of the inflow and outflow management of Lake Winnipeg is beyond the scope of this report but needs to be considered in assessing the total impact of outflow regulation and in devising the rules for that regulation.

The construction of the outflow control structures for Lake Winnipeg not only provided for the ability to adjust the outflow but significantly increased the capacity for outflow at a given lake level. This increased capacity provides the possibility of effectively responding to the water level changes resulting from the regulation of inflows.

I have not discussed in detail the effect that regulation of the outflow of Lake Winnipeg has had on either the level of the lake or the flow and levels of the Nelson River. Manitoba Hydro has more extensively assessed this topic in their 2014 submission in support of their request for a final license and Hesslein, 2011. Aspects of these changes as they affect the nutrient regime of Lake Winnipeg will be described in later sections of this report.

## **The Nutrient History and Status of Lake Winnipeg**

Lake Winnipeg has always been a nutrient rich lake (Bajkow, 1930, Brunskill et al 1973., McCullough et al., 2012,). This has been the case because large quantities of nutrients are delivered to the lake by inflowing rivers, especially the Red River (including the Assiniboine river flow). Even though the Red River has annually delivered only 10-20% of the water flowing into Lake Winnipeg (according to the records since 1913, Water Survey of Canada website) it has delivered 60-80 % of the phosphorous, the principal nutrient in promoting algal blooms in the lake (McCullough et al., 2012). Because the Red (and Assiniboine) River drains a semi-

arid area, and is subject to varying climate and precipitation patterns, its flow is subject to large variations. These large variations in flow result in large variations in nutrient delivery to Lake Winnipeg. The effect of flow variation on nutrient delivery is further exacerbated because the concentrations of nutrients in the river increase with increased flow (McCullough et al., 2012).

Although this large variation in nutrient delivery is strongly affected by climate patterns, the delivery of nutrients likely has also been enhanced by human activity in the basin. Some major changes to the prairie landscape for enhancing nutrient export to the rivers have been the increased use of fertilizers for agricultural crop management, the increased drainage of farmlands, increased animal husbandry, and increased human population. As well, the drainage of wetlands and the enormous increase in the extent of drainage canals have increased the efficiency and rate of delivery of water and nutrients to the rivers. The combination of these basin manipulations and increased precipitation over the last two decades has resulted in very high nutrient deliveries to Lake Winnipeg (McCullough et al., 2012).

Increased nutrient loading generally leads to increased concentrations in lakes, but because so much of the loading to Lake Winnipeg comes with relatively little flow (the Red River), outflows of nutrient from the lake are only slightly enhanced by increased water flows of the Red River.

Although there has been discussion over the last decade about the relative importance of the nutrients phosphorous or nitrogen in controlling the growth of algae in Lake Winnipeg, the preponderance of scientific evidence supports the role of phosphorous (P) as the primary limiting nutrient. (Schindler, 2006, Schindler et al. 2008, McCullough et al. 2012). It has been known for decades from worldwide research on lakes that algal growth and algal biomass is generally proportional to the loading of phosphorous to the lakes. Evidence from Lake Winnipeg also supports this relationship (McCullough, 2012). Consequently, further discussion of the nutrient dynamics of Lake Winnipeg in this report will focus on phosphorous.

The concentration of any chemical in a lake at a given point in time can be described by the following equation:

$$\text{Eq 1. } P_{(t+1)} / V_{\text{lake}} = (P_{(t)} + P_{\text{inflow}} - P_{\text{outflow}} - P_{\text{sed}}) / V_{\text{lake}}$$

In words, the equation says the concentration of chemical (in this case P for phosphorous) at some future time (t+1) is equal to the mass of P at the present time

(t) **plus** the mass of P from inputs **minus** the mass of the P lost to the outflow **minus** the net loss of P mass to the sediments all **divided** by the volume of the lake.

Both loss terms,  $P_{\text{outflow}}$  and  $P_{\text{sed}}$  are typically modeled as first order fluxes. This means that the flux of P is proportional to the concentration of P. The total loss of P due to outflow is equal to the concentration of P multiplied by the amount of outflowing water. Likewise, the loss of P to the sediments is equal to the concentration of P multiplied by some net sedimentation velocity. So if we increase the amount of outflowing water, we increase the outflow of P and decrease the predicted concentration of P ( $P_{(t+1)}/V_{\text{lake}}$ ). If the loading ( $P_{\text{inflow}}$ ) increases but the outflow ( $P_{\text{outflow}}$ ) changes only a little, the concentration of P must rise to balance the equation. This would be the situation if the Red River flow increases, delivering a lot more P but not much water to cause increased outflow.

The term “residence time” refers to the average period of time that water spends in a lake. The residence time ( $y$ ) is calculated as the volume of the lake (in  $\text{m}^3$ ) divided by the outflow ( $\text{m}^3 \text{y}^{-1}$ ). The annual value for Lake Winnipeg over the last century has ranged between 3 and 10 years. Over the last two decades the value has generally been closer 3-4 years due to the higher flows. The residence time can be translated into an annual average change in level. The average depth of Lake Winnipeg is about 11 meters. If it takes 3-10 years for the outflow to move all of the water then the equivalent of about 1-4 meters of water flows out the outflow each year. The recent average water residence time of 4 years means that the average outflow is about  $2.75 \text{ m y}^{-1}$  or about 0.25 m per month.

Because Manitoba Hydro tries to have enough capacity in the lake to manage each year’s inflows, it tries to achieve a similar lake level by about May of each year (with minor variations due to predictions of inflows for each year). This means Manitoba Hydro cannot change the natural annual residence time of the lake by very much, or the lake would be higher or lower than the previous May. Of course, in the longer term (many years) outflow regulation cannot be allowed to change the residence time from the natural value resulting from inflows without emptying or overfilling the lake.

## The Effect of Outflow Regulation on Nutrient Concentrations in Lake Winnipeg

Because the long-term residence time cannot be altered, concern over the change in residence time (due to outflow regulation) and its potential effect on nutrient

concentrations is really about the short-term change that could occur during any year. The amount of P leaving the lake, and therefore the concentration of P in the lake, is controlled by the concentration of P and the outflow of water. A change in the concentration due to change in outflow can only happen if the concentration changes over the year. Because the annual flow (and residence time) cannot be significantly changed, any additional flow at one time of the year must be made up by lowered flow at some other time. If the concentration of P is the same at both times then the export of P will be the same and the concentration will not change. If the concentration of P varies over the year (due to the effects of inflow and sedimentation, and possibly, internal recycling of P) then more or less P could be exported annually and the P concentration could be further affected.

The following example will give some estimate of the possible change in P concentration that could occur due to short-term alteration of the outflow. Natural flows into the Lake Winnipeg generally are highest in spring and early summer due to water from melting snow. Outflow regulation for the purpose of meeting power demands in Manitoba requires increased winter flow. This change in the flow regime is used in the in the example. Without regulation of the outflow, typical winter flows from Lake Winnipeg are lower than average annual flows (Hesslein, 2011). For the example, average flows in January are near 0.2 m per month and in July they are near 0.3 m per month (this is consistent with the recent annual average of 0.25 m per month). The concentrations of P vary seasonally in the lake but the pattern is not well established. Typically concentrations in the Nelson River at Jenpeg are lower in the winter and higher in the late summer due to the spring inflows (McCullough, 2011, pers. comm.). The modern annual average concentration of P is near 40 ug L<sup>-1</sup>. If we postulate that it is 50 ug/L in July and 30 ug/L in January (this is a fairly extreme range) these conditions would result in the export of about 504 tons of P from the lake in those 2 months. If the outflow were regulated to increase the January flows by 50% to 0.3 m/mo. (and to reduce the July flows to 0.2 m/mo. to balance the flow) then about 456 tons of P would leave the lake. If the extra 48 tons were left in the water of the lake it would increase the concentration of P by about 0.2 ug/L or 0.5% of the annual average concentration of 40 ug/L.

The difference in summer and winter P concentration postulated above can be used to make more detailed calculations of P export for the whole year based on measured flows from the lake and compare those to outflows calculated if the lake was unregulated and the new outflow structures had not been built. (The method for these outflow calculations is described by Hesslein, 2011 and a comparable but slightly different method by Manitoba Hydro, 2014.) Figure 2. shows the average

measured flows and the calculated unregulated flows for each month during the dry period of 1979-1991 and the wetter period of 1995-2008. The pattern of calculated unregulated flow for both periods is similar but of course the magnitude is greater during the wetter years. Although the actual outflows with regulation show the flow reversal toward the winter months, the change in pattern is more dramatic during the dry period. This is because during the wetter years the demands of lowering the lake level to allow for the following year's inflow and protect against exceeding a level of 715 fasl to some extent overwhelm the requirements of power production.

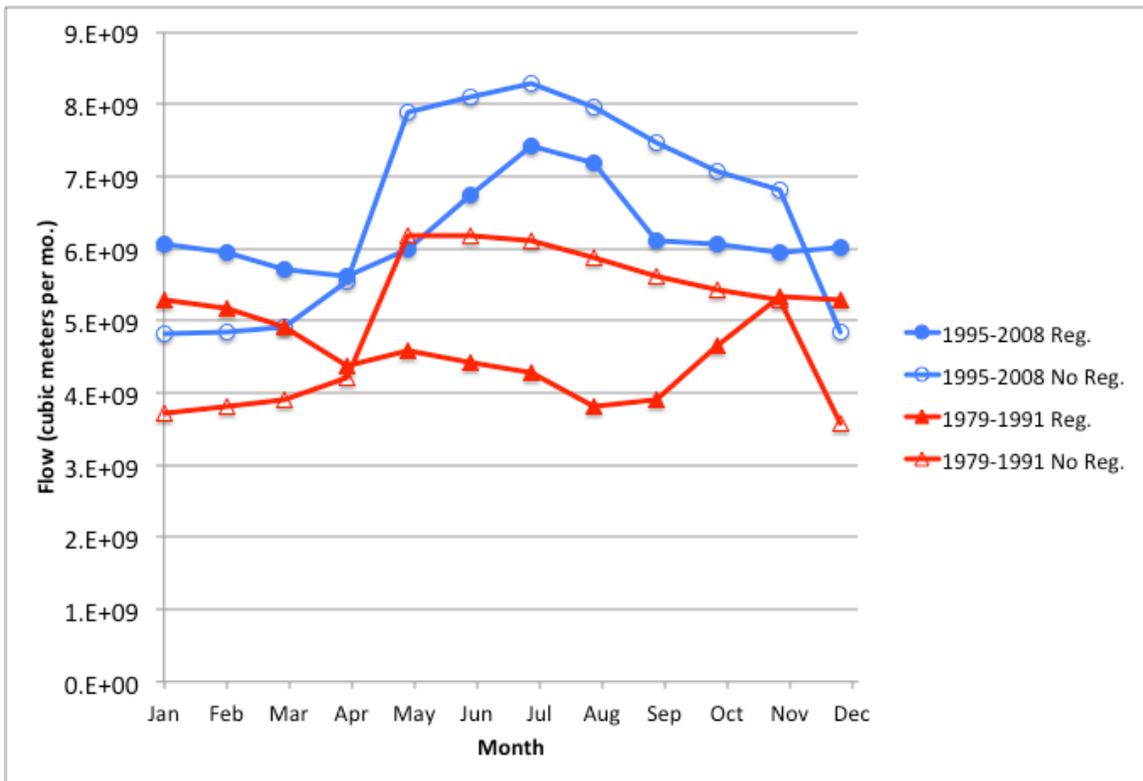


Figure 2. Average monthly outflows from Lake Winnipeg grouped in a drier period, 1979-1991, and a wetter period, 1995-2008. Actual flows estimated by Water Survey of Canada and flows calculated based on modeling of the natural unregulated outflow are shown.

The average monthly flow data presented in Fig. 2 was used to make the estimates of the change in P concentration that might be expected from seasonal flow alteration. The values for both the wet and dry period are less than 1 ug/l P. That is less than 2.5 % of the average concentration in the lake. This small effect is in spite of using fairly extreme estimates for the difference between winter and summer concentrations of P.

The concentrations of P in Lake Winnipeg vary annually and seasonally, and in different locations in the lake by much by much more than 2.5% (McCullough et al., 2012, Greg McCullough, U of Manitoba, pers. comm.) so there would be no way to verify this kind of projection. Furthermore, P sedimentation and internal loading are not well enough understood to state these processes might not compensate for part of the calculated change in P. Algal dependence on P concentrations is not constant seasonally or annually. It would be very uncertain to try to estimate just how algae might respond to these very small projected changes. However, the general response of algae to P would suggest a small increase in algal abundance with a small increase in P concentrations..

The conclusion that must be drawn from the above arguments is that changes in seasonal outflows of Lake Winnipeg for the purpose of power production cause no significant changes in the annual residence time of the water in the lake. These seasonal changes in outflows (and short term residence times) may result in small, probably unverifiable changes in the P concentrations. These changes are also very unlikely to cause any significant changes in algal growth and in any case, changes in algal growth could not be verified with present scientific methods.

The magnitude of the calculated changes in P that could be attributed to outflow management (<2.5%) must also be seen in context of the variations in P caused by inflow variation. The dramatic increase in river flows, especially in the Red-Assiniboine River basins, over the last 2 decades (McCullough et al., 2012) has been accompanied with a dramatic rise in the concentration of P in lake Winnipeg (as much as 100%). This has resulted in an increase in growth and biomass of algae in the lake (McCullough et al., 2012). The < 2.5% change calculated for the effect of historic regulation of the outflow is very small compared to the changes in P concentration caused by inflow variations and insignificant in the overall nutrient management of the lake.

Recent assessment of P concentrations data in the north basin of Lake Winnipeg and the Nelson River at Jenpeg have raised some questions about the seasonal pattern of those values (Greg McCullough, University of Manitoba, pers. comm.). This assessment shows that, opposite to the river data from Jenpeg, the lake data suggest that the concentrations are actually higher in the fall and winter (by a mean value of about 15 ug/L). If this is a more meaningful assessment of the concentrations it would mean that the winter/summer flow changes described above would cause a small decrease in P in the lake rather than an increase. However the change would be less than 2% and would not change the general conclusion that regulation will

not significantly effect the nutrient concentrations, nutrient status, or algal conditions in Lake Winnipeg.

## **The Effects of Future Outflow Regulation on the Nutrient Status of Lake Winnipeg.**

Based on the discussion of the potential effects historic outflow regulation could have had on the concentrations of nutrients (P) in the lake and the likelihood of changes in algal growth, there is no reasonable expectation for an effect in the future. The nutrient status of Lake Winnipeg has been shown to depend strongly on the loading from inflowing rivers (McCullough et al., 2012). The variability of these inflows is high and the effect variability of concentrations in the lake even higher because concentrations in the rivers are very different and vary with flow. Historically, changes in inflow driven by precipitation as well as other manipulations in the Lake Winnipeg watershed have resulted in a range of annual average concentrations of P in the lake of 20-60  $\mu\text{g L}^{-1}$  (McCullough et al., 2012). Although the future cannot be predicted because it depends on weather, changes of similar magnitude are not unlikely in the future. In addition to changes due to weather, the governments in the lake Winnipeg basin have committed to significantly reducing the nutrient loads to the lake. Hypothetical alterations in P concentrations of less than 2.5% due to management of the outflow will not result in significant or verifiable changes in nutrient status or algal growth in the future.

## Summary and Conclusions on the Effect of Outflow Regulation on the Nutrient Status of Lake Winnipeg

1. The magnitude and variation of the nutrient status of Lake Winnipeg depends primarily on loading from its inflowing rivers. Both the flows of the rivers and the concentrations of P (the critical nutrient) in the rivers have changed considerably over the last century.
2. All (with the exception of the Red River south of Winnipeg) of the inflowing rivers to Lake Winnipeg have inflow regulation. This does little to change the annual amounts of water from each river but does significantly alter the seasonality of the flows and therefore the seasonality of the nutrient inputs. Therefore, outflow regulation must be considered as only one of several tools in the management of flows to the Nelson River and management of the levels of Lake Winnipeg.
3. Because the range of regulations allowed, 4 ft., is only equivalent to about one third of the inflow (and outflow) in any given year, outflow regulation has very little capacity to significantly change the residence time of the lake when calculated over periods of one year or longer.
4. Because the concentrations of phosphorous vary seasonally but may be lower or higher in the winter, flow regulation for the production of electrical power (more in the winter) has the potential to alter the P budget (and P concentrations and algal response). Calculations comparing the P budget based on actual (regulated) flows and flows calculated without regulation show that the change in P concentration would be less than 2.5%.
5. The calculated potential change in P concentration is very small compared to the seasonal, annual, and regional variations of P in Lake Winnipeg and no projection of any effect on algal growth can be made or verified.
6. Future changes in P concentrations as a result of outflow regulations under the existing terms of the license are not expected to be different than in the past. The changes will continue to be insignificant and unverifiable in the future.
7. Continued management of inflows to Lake Winnipeg and changed land use practices in the watershed will exert very considerable influences on both the magnitude and timing of the P inputs to the lake and therefore

concentrations of P in the lake. The regulation of these inflows will also have as great an effect the water levels of the lake and seasonality of those levels as regulation of the outflows. Regulation of the outflows and levels of Lake Winnipeg for the multiple objectives of hydroelectric power, shoreline stability, flood control, the fishery, recreational uses and ecosystem health will require integrated management of flows and land use in the whole basin of about 1 million km<sup>2</sup>.

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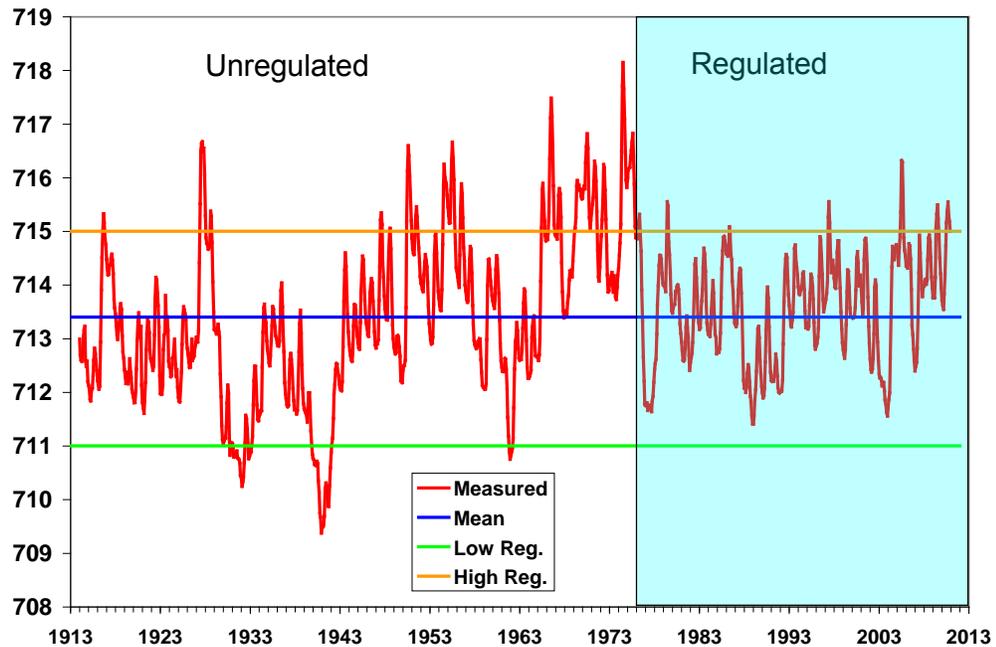
# **An Assessment of the Effect of Regulation of the Outflow of Lake Winnipeg on the Levels of the Lake**

**Raymond H. Hesslein**

In 1976 Manitoba Hydro began regulating the outflow of Lake Winnipeg, using a structure built during 1972-1976, which allowed them to exert some control on the flow of the Nelson River. The Nelson River is the only outflow of Lake Winnipeg. This new outflow structure replaced the natural outflow channel of the Nelson River. By regulating the flow of the Nelson River through the outflow, Manitoba Hydro can influence to some degree the level of Lake Winnipeg. In the last few years, the effect of regulation on the level of the lake has received a lot of attention in the public arena. As well, some people have raised the concerns that the flow regulation has influenced the nutrient budgets of the lake. In addition, Manitoba Hydro and the Province of Manitoba have initiated a process for converting the interim license by which the control structure presently operates to a final license. This process has involved public information sessions for which Manitoba Hydro has designed a presentation on the history of the lake levels (Figure 1.). This graph shows that the average level in the lake during the period 1976-present is very close to that from 1913-1975, the prior period of record. The other feature shown in the record is that the variations in level have been lower, that is the lake level has been more stable, since 1976. Exerting control beyond that which was provided by the old natural outflow channel has been possible because the structure that started operation in 1976 is larger and provides the possibility to release more at the same lake level than was possible prior to 1976. Because the new outflow is adjustable it also allows for reduced outflow at a given level.

A quick review of the terms of the operating permit for the outflow structure can help to understand the effect its operation has had on the levels as I will describe below. At levels between 711 and 715 feet Manitoba Hydro can operate the outflow to benefit its electricity production. This might mean reducing flow when demand is low and increasing flow when demand is high. However, when the level is at 715 feet or higher the permit requires that the new, larger outflow must be operated at its maximum capacity to reduce the level to below 715 feet. This explains why the peak levels which would have been reached with the natural outflow have been avoided. When the level drops to 711 feet the outflow is operated at the direction of the Minister of Water Stewardship to maintain the level of the lake. Manitoba Hydro does not control the operation of the outflow structure outside the range of 711-715 feet.

### Lake Winnipeg Monthly Mean Levels

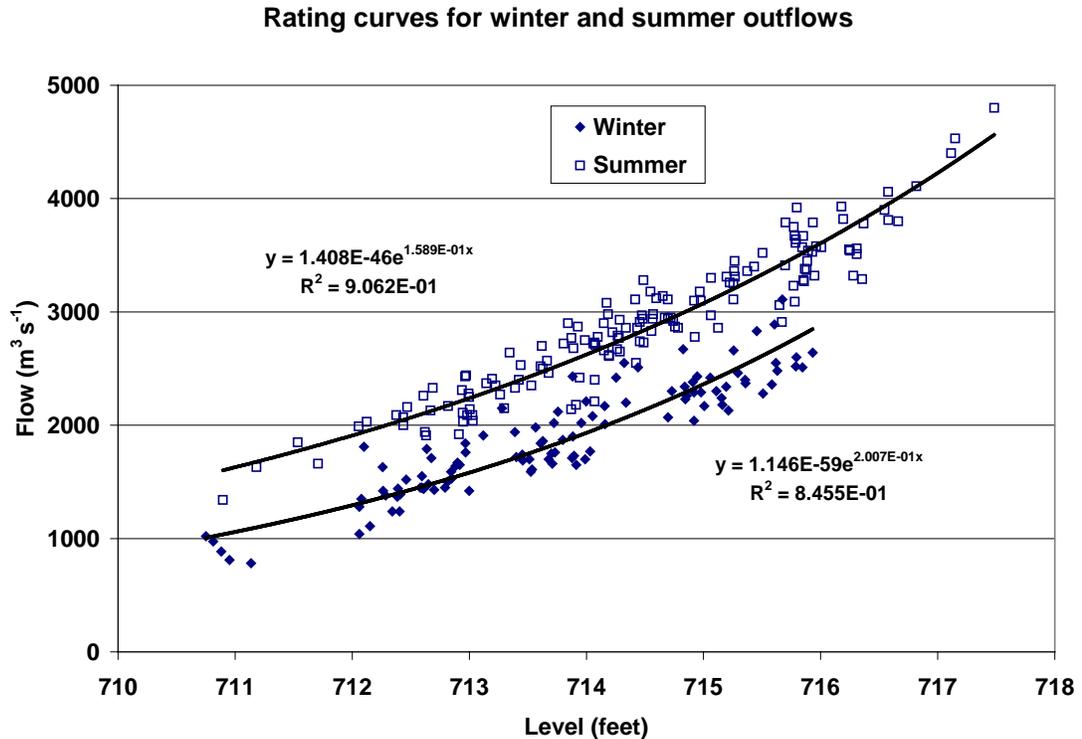


**Figure 1.** Mean levels of Lake Winnipeg from all stations with correction for wind effects (data from Manitoba Hydro, Dale Hutchinson).

Although the monthly record of level presented by Manitoba Hydro provides some insight into the characteristics of the levels over time, it really doesn't answer the question of how regulation has impacted the lake levels. I believe that question can best be answered by comparing the levels of Lake Winnipeg and the flows of the Nelson River from the period of regulation (1976-present) to those levels and flows that would have occurred had the outflow control structure not been built and utilized. This comparison requires a model for reconstructing the natural levels and flows, which fortunately can be done in a straightforward manner with the available data.

The outflow of any lake with an uncontrolled outflow is characterised by what is called a rating curve. This means that for every level of the lake there is a defined flow. This rating curve applies as long as the features of the outflow channel are unchanged. Because the natural outflow channel of Lake Winnipeg was bedrock, the rating curve did not change for a long time. The data available for reconstructing the old natural rating curve for Lake Winnipeg are the measured flow data for the Nelson River from 1951-1975 (Water Survey of Canada, Kelsey Station) before the outflow structure was in place and the measured lake levels (which go back to 1913). Although only 25 years long, the record does include quite a wide range of monthly flows. I have based the calculation of the rating curve on monthly flows. Practically, in constructing the rating curve, the data

was split into two sets, from December to May and June to November, to account for the presence of ice on the lake at the outflow. Ice at the outflow effectively changes the shape of the outflow channel resulting in a slightly different rating curve. The two rating curves are shown in Figure 2. Although the relationship between the level at the outflow and the flow did not change over the record prior to 1976, the level data I used is the mean for all of the stations on the lake. The number of stations used in the calculation of the mean may have changed over that period. Also, in the last 100 years the level at the outflow may have risen about 10 cm with respect to the mean due to isostatic rebound).

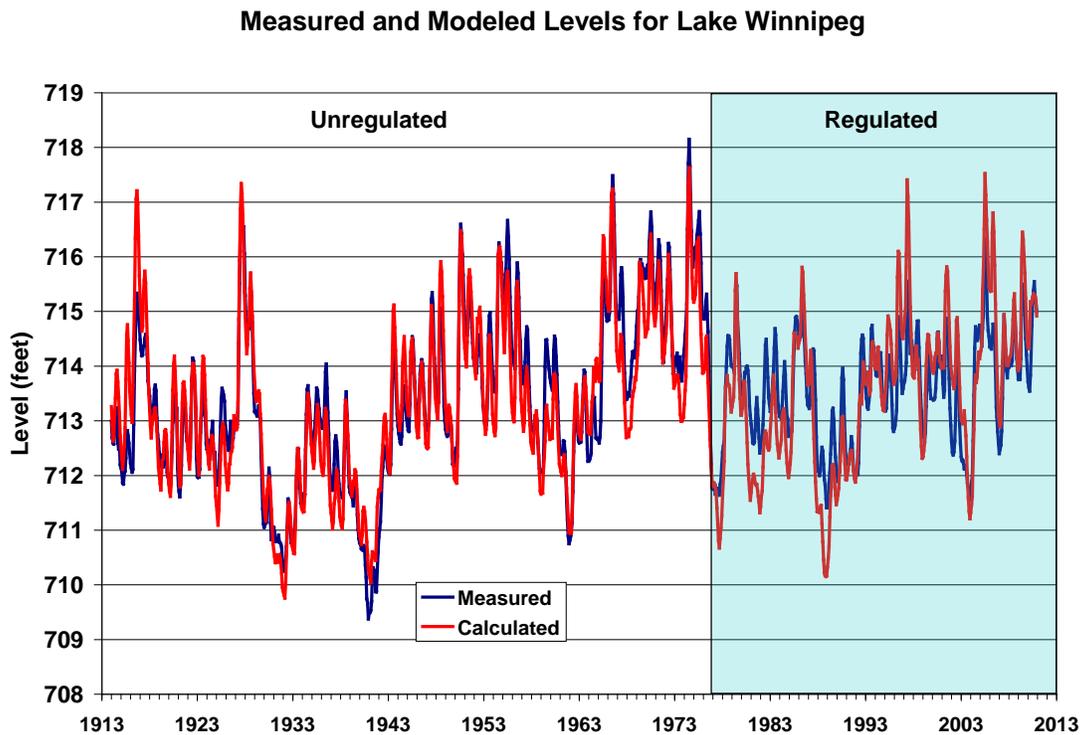


**Figure 2.** Rating curves for the original natural outflow channel of Lake Winnipeg. Winter and summer curves are calculated because ice changes the geometry of the outflow channel. Data is from 1951-1975.

Once I calculated the rating curve(s), it was possible to create a water budget model for the lake. The way this works is that the inflowing water is divided by the 24000 km<sup>2</sup> of area of Lake Winnipeg which converts it to a measurement of level. At the beginning of each month the outflow is defined by the level of the lake and the rating curve. At the end of the month the change in level due to the outflow is subtracted from the previous level and the change in level due to the inflows is added. Thus a new level and outflow is determined to start the next month. If the inflow is higher than the outflow the level rises and then the outflow increases. In order to do these budget calculations I needed the total inflow to the lake. Fortunately, excellent records of all of the major inflows to the lake (Winnipeg River, Saskatchewan River, Red River, Assiniboine River)

are available going back to 1913. Because direct precipitation to Lake Winnipeg is approximately balanced by evaporation from the lake surface, the outflow of the Nelson River is essentially the sum of all of the rivers flowing into the lake. A simple correction factor of 1.32 when multiplied by the sum of the four major measured flows make the inflows balance the outflows in the long term, thus accounting for the unmeasured smaller inflows.

The lake levels predicted by the model are shown in Figure 3 along with the measured levels. The mean difference between the model and the measured values between 1913 and 1975 is less than 0.5 inch. The standard deviation is 6.75 inches. The mean difference between the model and the measured values between 1976 and 2008 is 1.5 inch. The standard deviation is 9.25 inches. It is not surprising that the agreement is worse after 1976 because the model is based on the characteristics of the original outflow, therefore showing what would have occurred if the outflow was not regulated.

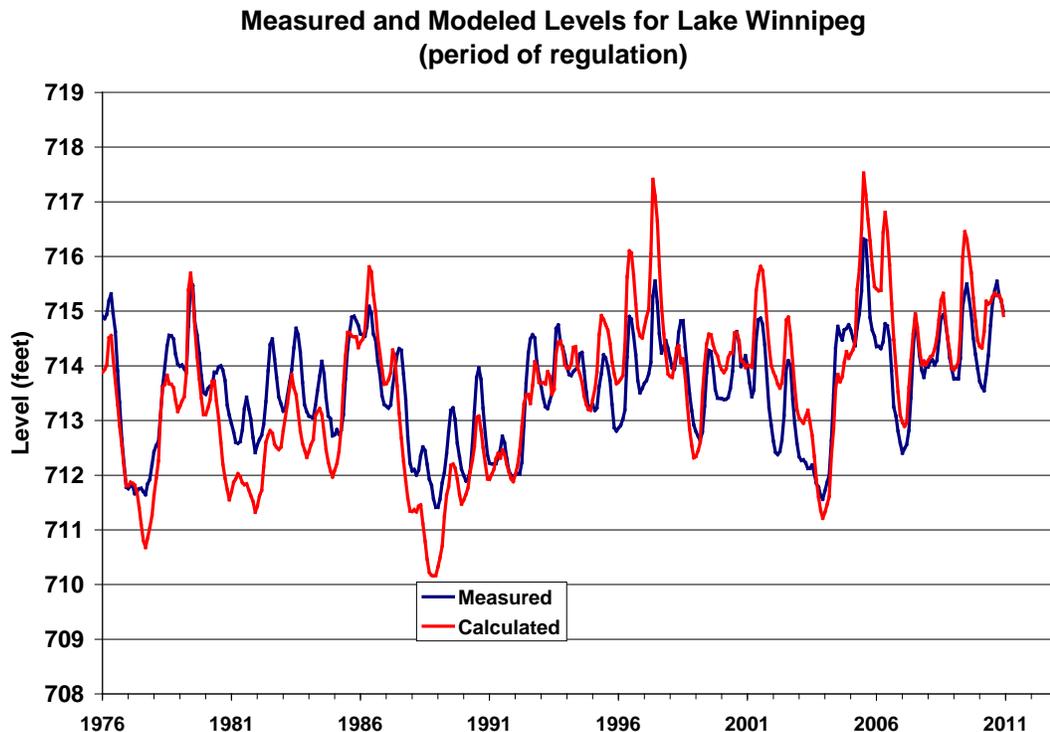


**Figure 3.** Levels in Lake Winnipeg predicted by the water budget model and mean levels calculated from the wind corrected measured levels.

Calculations show that Manitoba Hydro is correct in their assertion that the level has been less variable with regulation. The standard deviation of the level from 1913-1975 was 1.52 feet for the measured values and an almost identical value of 1.49 feet for the model. The model shows that the standard deviation without regulation from 1976-

2009 would have been similar at 1.43 feet. The measured standard deviation with regulation has been only 1.16 feet.

A more detailed look at the measured and modeled levels since 1976 in Figure 4 shows that during the dry period of the 1980's the lake level was maintained above those which would have occurred by the original outflow. In a number of instances since 1992 regulation has prevented the lake level from exceeding 716 feet, as the model predicts it would have with the original outflow.

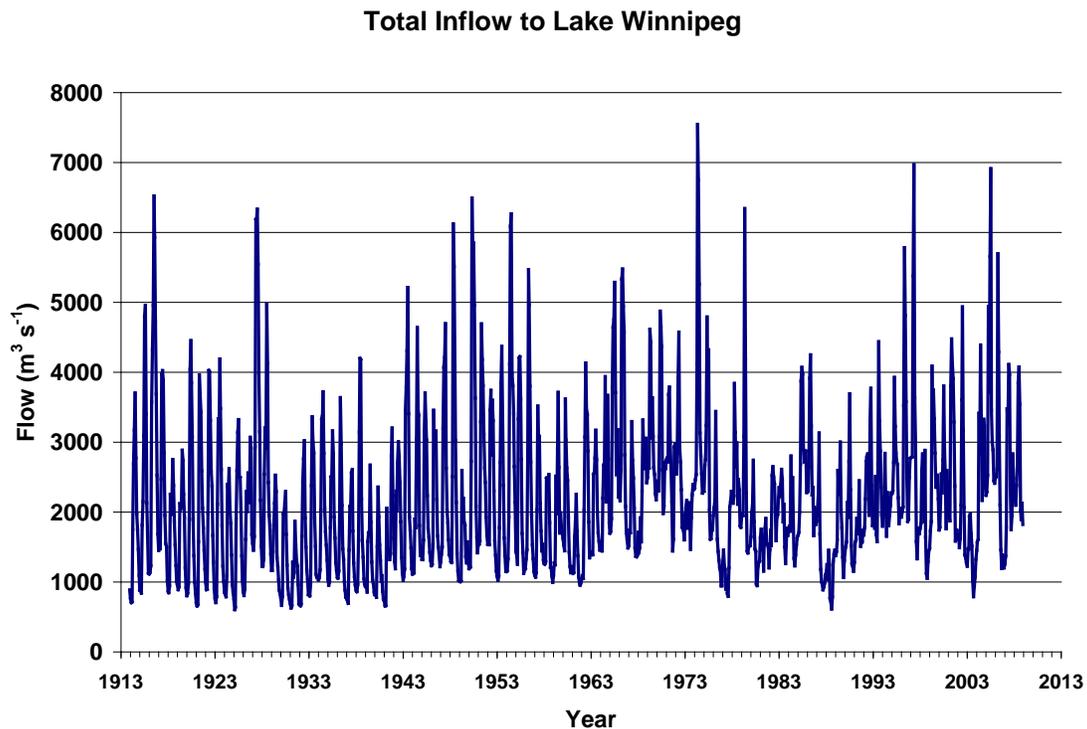


**Figure 4.** Levels in Lake Winnipeg predicted by the water budget model and mean levels calculated from the wind corrected measured levels for the period of regulation.

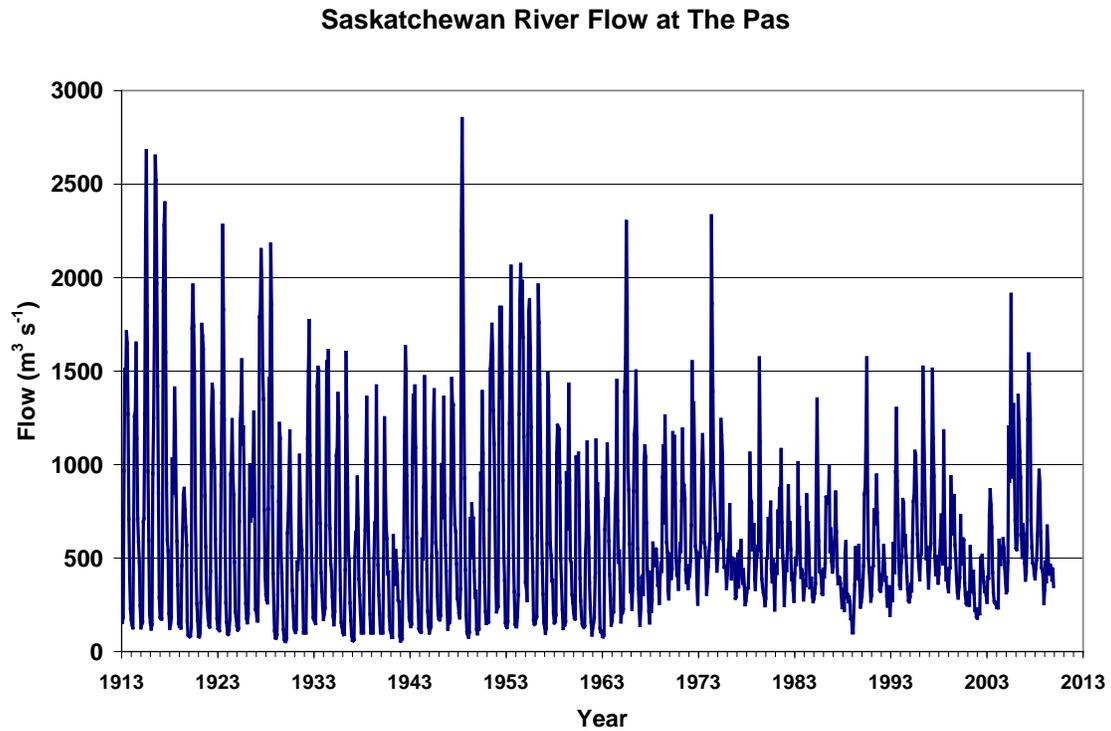
Answering the question about the effect of regulated flow on nutrient levels is far more difficult. Each inflow brings in water with different concentrations of nutrients and those concentrations vary throughout the year and with flow. The lake removes 15-20% of the phosphorous in the lake to the sediments each year and we don't have a good understanding of what controls this rate. Although the data for inflows of water are very good, the data on nutrient concentrations are sparse except in recent years. Nutrient models for Lake Winnipeg are not sophisticated enough or adequately tested to give an answer to the nutrient question.

One interesting observation that I made in carrying out this study was that the total inflows to the lake have changed their summer/winter pattern. The pattern at the beginning of the century was more like a simple Sine curve over each season with high

flows in the spring and early summer and low flows in the fall and winter (Figure 5.) As the record gets more modern this simple pattern becomes much less clear. This is likely due to the regulation and construction of reservoirs on the inflowing rivers and possibly due to changes in the seasonal weather patterns. The control structure on The Winnipeg River, the Norman Dam on Lake of the Woods, was constructed in the late 1800's and rules for regulation for the level of Lake of the Woods came into place in 1925. The actual regulation is done by the Lake of the Woods Control Board and their approach also may have changed with time. The construction of the dam at Grand Rapids and the increased size of Cedar Lake and its regulation started to contribute its effect on the flows of that river (Figure 6) and the total inflow (Figure 5) in 1965. These dramatic changes to the inflows of course have significantly affected the outflow of Lake Winnipeg; however this would have been the case even if the new outflow structure to Lake Winnipeg had not been constructed. One must keep in mind that the model presented here only reconstructed the outflows of Lake Winnipeg based on the measured inputs and the original outflow channel. In order to reconstruct the "natural" outflow that would have occurred in the absence of *any* water regulation of inflows in the whole Lake Winnipeg Basin a much more complex model would be required and a much more comprehensive historic data set, much of which does not exist.



**Figure 5.** Sum of major inflows to Lake Winnipeg (Winnipeg, Saskatchewan, Red, and Assiniboine Rivers) multiplied by 1.32 to correct for flows of all smaller rivers (see text).



**Figure 6.** Record of the inflow of the Saskatchewan River to Lake Winnipeg. Data is from Water Survey of Canada.

I conclude that the regulation of the outflow of Lake Winnipeg has had a minimal effect on the level of the lake. The main changes are decreased peak levels (high and low). The character (seasonal patterns) of the outflow has changed over the period of record (1913-present) but this has been mainly due to the regulation of the major inflows to the lake not the use of the outflow regulation. There may also be some effect due to changes in seasonal weather patterns. The decrease in the variability in the level resulting from inflow and outflow changes may have had some effects on environments such as wetlands in which the successes of some species depend on changing water levels. However, most of the larger longer term variations in levels were caused by annual or multi year trends in weather patterns which influenced the inflows.

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Education: AB 1971 Columbia University, New York, NY; PhD 1976 Columbia University, New York, NY

- 2012-2013 Assessment of Greenhouse Gas Fluxes in Manitoba Hydroelectric reservoirs, contract with North South Consultants
- 2011-2012 Modeling of physical mixing and nutrient cycling in Lake Simcoe, contract with York University
- 2010-2011 Modeling of nutrient additions to Lake 227, contract with York University
- 2009- 2013 Scientist Emeritus Freshwater Institute Department of Fisheries and Oceans

### Professional employment:

- 1998-2009 Senior Scientist Experimental Lakes Area at Freshwater Institute Science Laboratory, Department of Fisheries and Oceans, Winnipeg, MB
- 1995-1998 Research Scientist, Section Leader of Experimental Ecosystems Section and Scientist-in-Charge of Experimental Lakes Area (ELA) for the Department of Fisheries and Oceans Canada.
- 1993-1995 Research Scientist Experimental Ecosystems Section for the Department of Fisheries and Oceans Canada.
- 1990-1993 Research Scientist and Section Leader of the Riverine Ecosystems Section for the Department of Fisheries and Oceans Canada.
- 1988-1990 Research Scientist, Section Leader, Experimental Ecosystems Section for the Department of Fisheries and Oceans Canada
- 1981-1988 Research Scientist Experimental Ecosystems Section for the Department of Fisheries and Oceans Canada
- 1979 –1981 Research Scientist Lamont-Doherty Geological Observatory, Columbia University, Palisades, NY
- 1976-1979 Post-Doctoral Fellow, Freshwater Institute Science Laboratory, Department of Fisheries and Oceans, Winnipeg, MB

### Research Experience:

- Application of stable isotope interpretation to aquatic ecosystem problems
- Carbon and nutrient cycling in freshwater environments
- Air-water gas exchange and GHG fluxes
- Numerical modeling of physical and chemical processes in lakes
- modeling of bioaccumulation of pollutants
- Ecosystem health

### Associations:

- 2010-present Member of Board of Directors, Whiteshell Cottagers Association
- 2010-present Member Lake Winnipeg Foundation Science Advisory
- 2012-present Member of Board of Directors, Friends of ELA
- 2014-present Member of Research Advisory Board, ELA-IISD

### Awards

- 2012 Frank Rigler Award, Canadian Society of Limnologists

### **Recognized Scientific Journals** since 1990

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