Manitoba

INFRASTRUCTURE AND TRANSPORTATION

Assiniboine River Overflow Study
Peer Review of Computed "Un-regulated" Water Levels on Lakes Manitoba and St. Martin

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EXECUTIVE SUMMARY

KGS Group has reviewed the engineering calculations and numerical models deployed by Manitoba Infrastructure and Transportation (MIT) to estimate the water levels that would have occurred on Lakes Manitoba and St. Martin if man-made infrastructure did not exist, and runoff was equivalent to that experienced in 2011.

The review focussed mainly on the assumptions and procedures adopted for two numerical models:

- A hydrodynamic two-dimensional model of the zone at the Assiniboine River where overflows from that river to Lake Manitoba have been known to occur in at least one occasion in the major flood of 1882.
- A water balance model of the inflows/outflows to/from Lakes Manitoba and Lake St. Martin

KGS Group agrees with the methodologies applied by MIT, and believes that the estimated water levels are as accurate as can be determined from state-of-the-art numerical models. Twelve issues that could be perceived to affect the accuracy of MIT's calculations were addressed and all were reconciled to clearly have only insignificant effects, either individually, or in combination. Descriptions of the reconciliations are provided in the report.

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1.0 INTRODUCTION

The unprecedented flood of 2011 required the release of large volumes of water through the Portage Diversion into Lake Manitoba. This contributed to high water levels on Lake Manitoba. The Province of Manitoba asserts that under "unregulated" conditions, the water levels on Lake Manitoba in 2011 could have been almost as high as what actually occurred. "Unregulated" conditions were defined by the Province as those that would have prevailed before the start of development of man-made infrastructure. This assertion was based on an analysis of the flood runoff in 2011 combined with extraction of the effects of man-made infrastructure. Numerical models of the systems that govern the water levels of Lakes Manitoba and St. Martin have been developed by Manitoba Infrastructure and Transportation (MIT). The primary models used in that analysis were:

- a hydrodynamic two-dimensional model of the zone near Portage La Prairie where overflow from the Assiniboine River to Lake Manitoba would have occurred under the conditions that prevailed prior to development of roads, railways, and flood protection systems (the so-called "unregulated" case or scenario).
- a flood routing (water balance) model of Lakes Manitoba and St. Martin

KGS Group was requested by the Province of Manitoba to provide a technical peer review of the engineering methods and numerical models deployed by MIT. This report summarizes the findings by KGS Group.

This report is presented in five sections. Section 2 summarizes the primary data and information that was provided by MIT. Section 3 summarizes the various analyses by MIT that led to the estimate of the "unregulated" water levels on Lakes Manitoba and St. Martin. Section 4 addresses possible influences that may affect the accuracy of the calculations done by MIT, and puts those in perspective as well as possible within the context of this review. Section 5 summarizes KGS Group's opinion.

2.0 DATA AND INFORMATION

The data supplied to KGS Group by MIT was extensive. In addition to a variety of individual emails responding to specific questions from KGS Group, and a presentation to KGS Group on February 25, the following key pieces of information were made available electronically:

Information Pertaining to the Hydrodynamic Model of the Overflow Zone at the Assiniboine River

1. A pdf of the presentation made to KGS Group by MIT on February 25, 2013.
2. Topographic mapping of the study area bounded by the Mike 21 upstream model limits.
3. Colour-coded mapping show the depth-averaged velocities in the overflow zone at the peak of the hypothetical "unregulated" flood event.
4. Cross sections of the overflow area cut from the LiDAR mapping of the area and also from the DEM used for the Mike 21 model.
5. Miscellaneous historical reports and information on the events in the past when water was known to overflow from the Assiniboine River to Lake Manitoba.
6. A brief email description of the process used to estimate "holdouts" from the reservoirs in the Assiniboine/Souris watersheds upstream of the overflow zone to Lake Manitoba.
7. Hydrographs showing for selected locations the water level history of the Mike 21 simulation of the "unregulated" condition with the 2011 flood event.
8. Hydrograph of total overflows from the Assiniboine River to Lake Manitoba as estimated by the Mike 21 model to have occurred in the simulation of the "unregulated" conditions with 2011 flood runoff.

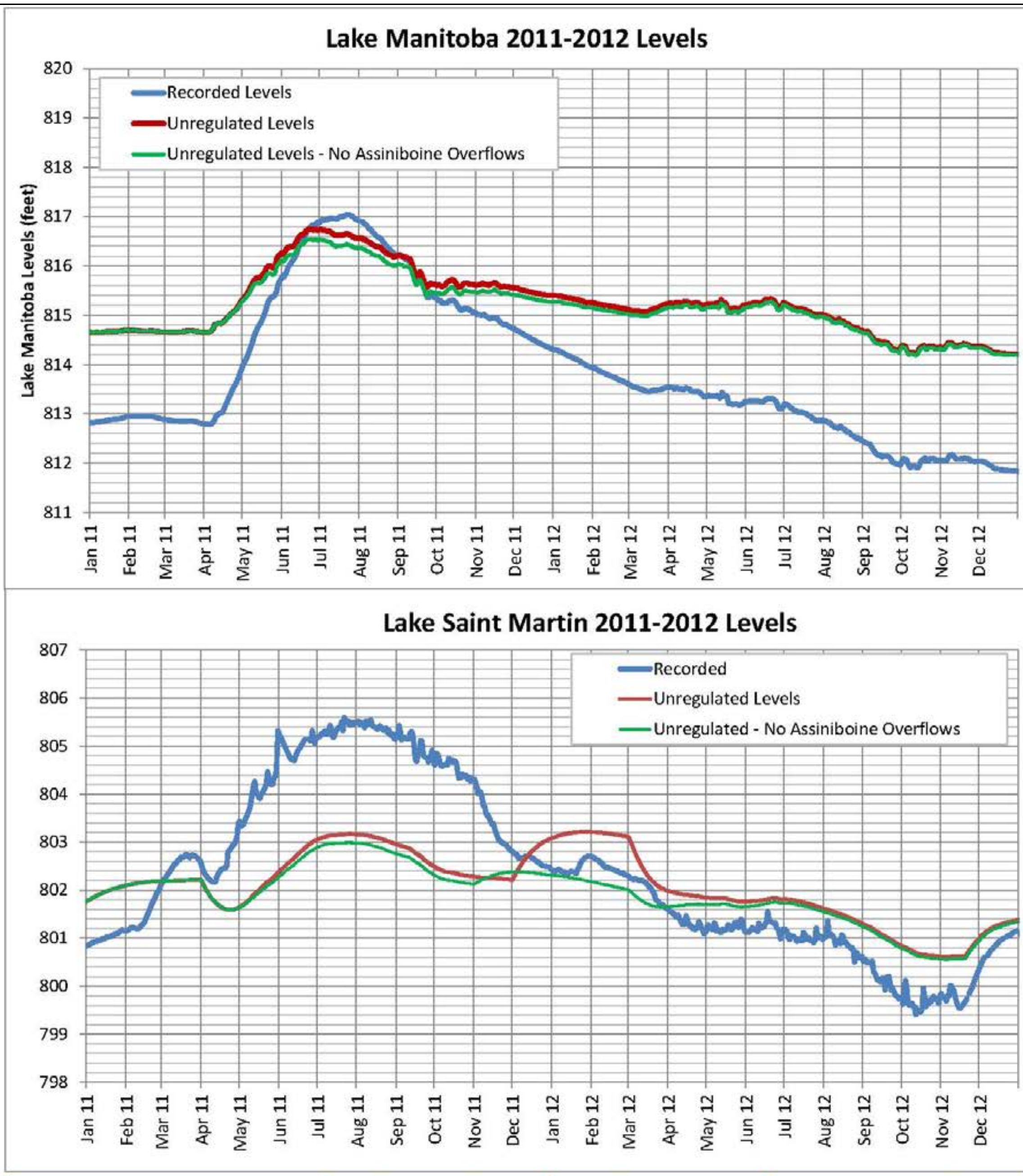
Information Pertaining to the Water Balance Model of Lakes Manitoba, Pineimuta and St. Martin

1. Precipitation and evaporation data used as part of the process to define inflow available for outflow (IAO) from Lake Manitoba.
2. Excel spreadsheet used for flood routing studies of the "unregulated" scenario.
3. A general description of the Excel-based model of the Lake Manitoba water balance, including assumptions and rationale for the procedures used.

4. Hydrograph of total overflows from the Assiniboine River to Lake Manitoba as estimated by the Mike 21 model to have occurred in the simulation of the "unregulated" conditions with runoff equivalent to that in 2011.

5. Mapping and explanations of the estimation of the surface area of Lake Manitoba as a function of water level on the lake.

6. Graphical results of the estimations of lake levels for the hypothetical "unregulated" case. Figure 2.1 below shows the results. These represent static lake levels with the effects of wind eliminated.



	Lk. Manitoba May 31	Lk. Manitoba Peak	Lk. St. Martin Peak
Recorded (average 2 stations)	815.72	817.05	805.60
With Modelled Overflows	816.24	816.75	803.17
With No Overflows	816.08	816.55	802.99

FIGURE 2.1:
COMPUTED “UNREGULATED” COMPARED TO ACTUAL LAKE LEVELS FOR THE 2011 EVENT

3.0 OVERVIEW OF ESTIMATIONS OF “UNREGULATED” WATER LEVELS ON LAKES MANITOBA AND ST. MARTIN BY MIT

The physical phenomena that directly affect the rise and fall of water levels on Lakes Manitoba and Lake St. Martin are as follow:

1. Inflows from rivers and streams and local surface runoff immediately adjacent to the lakes.
2. Inflows from the Assiniboine River through the Portage Diversion.
3. Precipitation falling directly on the lake surfaces.
4. Evaporation from the lake surfaces, and sublimation of snowfall during the winter while it lies on the surface of the ice cover.
5. Groundwater inflow to the lakes.
6. Outflows from Lake Manitoba through the Fairford River.
7. Outflows from Lake St. Martin via the Dauphin River and the Emergency Flood Relief Channel at the north end of Lake St. Martin.
8. Storage of water in the lakes as the water level rises, and releases from storage as the lake levels fall.
9. Wind setup on the lakes, caused by wind pushing water from one side of the lake to the other, depending on the direction of the wind.

The recorded lake water levels that were experienced in 2011 are considered undisputable. They were measured by federal and provincial authorities using well established methods and equipment and can be assumed to be as accurate as possible. There is no significant uncertainty in this data.

The water levels that would have occurred if the flood control works in Manitoba, Saskatchewan and North Dakota, and the transportation/drainage infrastructure in the Portage la Prairie area did not exist. This is herein called the “unregulated” case or conditions, a name used routinely in the documents supplied to KGS Group. The “unregulated” conditions must be estimated by numerical analyses, and are more open to controversy.

The methodologies and assumptions adopted by the Province of Manitoba to quantify these phenomena and extract the effects of the flood protection works such as the Portage Diversion are summarized below. They are separated into two groups for the two major models deployed in the study process.

Hydrodynamic Model of Overflow Zone at Assiniboine River

1. The overflows from the Assiniboine River that would have occurred in the "unregulated" conditions were estimated by deployment of a two-dimensional numerical hydraulic model. MIT deployed Mike 21, well-known modern software developed and commercially distributed by the Danish Hydraulic Institute of Denmark.

2. The zone modeled with Mike 21 extended from the river control structure at the Portage Diversion to Baie St. Paul, with lateral extents about 27 km north of the Assiniboine River at Portage La Prairie and 23 km south towards the southern limits of the LaSalle River watershed. All roads, dikes and other infrastructure that would affect the flow of water were removed in the representation of this area for hydraulic calculation purposes.

3. Inflows to the Mike 21 model from the Assiniboine River were adjusted to represent what would have occurred if the various flood control works in Manitoba, Saskatchewan and North Dakota did not exist. The Portage Diversion Channel and structures were removed entirely.

4. The Assiniboine River channel in the vicinity of the Portage Diversion was restored to a configuration that it would have had if the Portage Diversion had not been built.

5. The potential for backflow from Lake Manitoba to the Assiniboine River through Long Lake Drain was considered but concluded to be insignificant due to the high topography in that area.

6. The storage effects at the Shellmouth Dam were computed, and channel routing effects along the Assiniboine River to Portage la Prairie were estimated with a Muskingum flood routing procedure.

7. The storage effects from the reservoirs on the Souris River were based on reported "natural flows" at Minot by the US Army Corps of Engineers. The reported effects on flows at Minot were lagged by 13 days to represent the timing of arrival at the Assiniboine River.

Flood Routing Model of Lakes Manitoba and St. Martin

1. To avoid the difficulties with estimating all the inflows from the various rivers and streams, the Province has computed the "inflow available for outflow" (IAO). This is a relatively simple technique that computes what the net inflow to the lake must have been, based on the known outflow, the known change in lake level and correspondingly the amount of water retained or released from the lakes. Smoothing of the water level

data is done by averaging the daily recorded lake levels over several days so as to eliminate the swings that would be suggested by short term wind effects.

2. The fact that the surface area of the lake varies as a function of lake level compelled the Province to extract the components of precipitation and evaporation from the IAO. These components would vary to some extent due to the differences in lake level between the actual and the "unregulated" case, and therefore should ideally be segregated and adjusted.

3. Precipitation was based on numerical averages of rain and snow gauge information around the lake. However, for most of the period surrounding 2011, only the precipitation data for the meteorological stations at Narcisse and Marsh Station were used.

4. Snowfall was also based on measurements and records at nearby meteorological stations. The water equivalent was assumed to be 10% of the measured snow depths. The snow water contribution was assumed to be available to the lake immediately upon falling on the lake surface.

5. Evaporation was based on data generated by the Prairie Farm Rehabilitation Association (PFRA) for water bodies in Manitoba.

6. The inflows to Lake Manitoba from the Portage Diversion were based on records from Environment Canada, in turn a result of frequent measurements of flows in the Portage Diversion during the 2011 event.

7. The water stored in, or released from, Lake Manitoba was estimated from the record of water levels, or from the computed "unregulated" levels. A simple volumetric estimate for each day was based on the change in water level in the lake and the variation of the surface area of Lake Manitoba during that day.

8. The surface area of Lake Manitoba as a function of lake level was estimated from topographic maps with 2 ft contour intervals. Unfortunately a small portion of the north basin does not have full coverage of the flooded areas.

9. Inflows to, or outflows from, the lakes as groundwater seepage were considered for the actual event and for the "unregulated" estimate to be equal.

10. The outflow from Lake Manitoba through the Fairford River was estimated with a stage-discharge relationship that had been based on hydrometric records prior to the construction of the Fairford Control Structure in 1961.

11. Outflows from Lake St. Martin were estimated using a long established stage discharge relationship for the lake. Effects of ice accumulation in late 2011 and early 2012 were based on actual observations.

12. The combination of the inflows, outflows and storage of water in the lakes was done using an Excel spreadsheet that conducted daily calculations to generate the estimated "unregulated" conditions.

13. The water levels computed with the techniques and assumptions described above exclude wind setup.

4.0 DISCUSSION OF METHODOLOGIES AND ASSUMPTIONS ADOPTED BY MIT

The various methods and assumptions described in Section 3 are consistent with standard procedures used by modern hydraulic engineers and hydrologists. KGS Group believes that adoption of these methods and assumptions would lead to accurate estimates of the "unregulated" conditions.

KGS Group has addressed all components of the analyses, and particularly those that could lead to, or be perceived to lead to, inaccuracies in estimating the hypothetical "unregulated" conditions. The components that are potential sources of error are discussed below.

1. MIT has adopted the position that all flood protection works, as well as all roads, dikes etc. should be excluded for this hypothetical scenario, and would represent the country-side as it existed in approximately 1882. It is a well established fact that in 1882 the Assiniboine River overflowed its banks which resulted in diversion of some of the floodwaters to Lake Manitoba. The development of the Mike 21 model of the overflow zone from the Assiniboine River was devised to simulate this condition.

   An obvious question is to what extent the estimated overflows from the Assiniboine River affect the calculation of the peak water level on Lake Manitoba for the "unregulated" case. This can be interpreted from the analyses done by MIT. MIT included a case where the overflows from the Assiniboine River were assumed to be zero, and all other "unregulated" conditions were assumed to be the same. The results are included graphically in Figure 2.1 above. They showed peak water levels on Lake Manitoba that are about 0.2 ft lower than with the Assiniboine overflows predicted by the Mike 21 model. Similarly, the static water level (excluding wind effects) on May 31 would have been approximately 0.16 ft lower without the overflows. May 31 was the date when much damage was inflicted along the southern shores of Lake Manitoba due to wind effects. ***These differences of 0.2 ft and 0.16 put in perspective the effects on Lake Manitoba from the hypothetical estimates of overflow from the Assiniboine River.***

2. The model of the overflow described in Item 1 above does not include the potential effects of erosion as the flow continues over time. MIT has shown "snapshot" outputs from the Mike 21 model that indicate peak velocities of flow in excess of 1.5 m/s in some areas of the overflow zone. It is conceivable that some erosion of the ground and enlargement of the overflow zone could occur. This is speculative, however, because the ground could be held together by vegetation and its root system, or be erosion resistant due to the nature of the soil, or because of frost penetration prior to the overflow event, or a combination of these factors.

   KGS Group experimented with enlargement of the overflow capacity due to potential erosion, by adjusting the overflows in the Excel model used by MIT to compute the "unregulated" water levels. It suggested that in order for the "unregulated" lake level to rise an additional 0.2 ft above the current estimate by MIT, the erosion would have to cause the overflow to be triple that which the Mike 21 model computed. It seems quite unlikely that that extent of erosion would occur.

KGS Group agrees with the position that MIT has taken in ignoring the additional overflows that could occur due to erosion along the path of the overflows from the Assiniboine River. This approach provides a conservatively low estimate (from this perspective) of the “unregulated” water levels on Lake Manitoba. Furthermore, KGS Group believes that any erosion that could occur would only raise the “unregulated” water levels by less than 0.1 ft.

3. The software used by MIT for simulation of the overflow zone is a leading commercially available product that is at the leading edge of the capability to do hydraulic simulations of the type needed in MIT’s analyses. KGS Group is very familiar with the software and has used it and other comparable software to do similar analyses. KGS Group agrees that the choice was appropriate and there is no other software that would be superior.

In spite of the capability of the software, the configuration selected for the Mike 21 to represent the hydraulic phenomenon of the overflow is not ideal. The western boundary is close to the zone of overflow and the assumption of the inflow distribution at the upstream boundary may have some influence on the computation of the overflow to the north. The overflow also meanders sharply towards the west after leaving the Assiniboine River and flows immediately adjacent to the western boundary of the model. This does not theoretically allow an unbiased estimate of the flow in this area.

Having pointed out these imperfections, however, KGS Group is of the opinion that their influence on the computation of the overflow magnitude is relatively minor.

As part of an independent check on the magnitude of the overflow, KGS Group requested cross sections to be cut from the topographic mapping along the route of the estimated overflows. This enabled a simple one-dimensional steady-state model using standard software that might confirm the magnitudes predicted by the Mike 21 model. This check could only be considered approximate since it was not possible to clearly define the downstream boundary condition for the calculations, and the cross sections are only rough indications of the channel geometry that is defined more intensively and accurately by the Mike 21 model. Nevertheless, the approximate check showed a peak discharge of about 230 m^3/s (8,400 cfs), compared to the peak computed by the Mike 21 model of 153 m^3/s (5,400 cfs). Even if this result with a simple one-dimensional model were considered precise (which it clearly is not), the difference between the simple model and the Mike 21 Model would only affect the “unregulated” peak water level on Lake Manitoba by less than 0.05 ft (i.e. 0.05 ft higher than reported by MIT). This relatively small disparity demonstrates the relative insensitivity of the estimation of the “unregulated” water levels to the precision of the computation of the overflows from the Assiniboine River. ***It appears to KGS Group that the inaccuracies introduced by the less than perfect configuration of the Mike 21 model would not affect the estimated water levels on Lake Manitoba by more than 0.05 ft. KGS Group considers that any further refinement of the Mike 21 model is unnecessary and unjustified.***

4. The topographic information upstream of the upstream boundary of the Mike 21 model was not available to KGS Group for this review. However, MIT reported that they examined topographic information and selected the model boundary on the basis that all zones to the west were high and could not permit overflows. This appears to be a reasonable strategy, but is an aspect of the modeling that could not be independently verified by KGS Group within the time and budgetary constraints of the contract with MIT. ***However, it is clear that the elimination of any potential overflow in this upstream zone was an assumption that would understate any possible natural overflow. It would lead to a conservatively low estimate of the "unregulated" water level on Lake Manitoba.***

5. The boundary conditions adopted by MIT for the downstream end of the Mike 21 model are not ideal and almost certainly distort the representation of flow patterns in the downstream portion of that numerical model. However, KGS Group believes that the backwater effects from this inaccuracy would not extend upstream more than about half the length of the model. They clearly do not unduly influence the calculations of the flow magnitudes and patterns in the critical area of the potential overflow to the north. It is ***KGS Group's opinion that the assumptions for the downstream boundary are quite acceptable for the purposes of this study, and introduce no significant error in the hydraulic simulation of the overflow zone to Lake Manitoba.*** However, it should be cautioned that the model results that show flow conditions in approximately the downstream half of the Mike 21 model are unreliable and should not be used to predict realistic conditions in that zone.

6. IAO includes many components, one being groundwater inflow. It has been assumed by MIT in the calculation of IAO that inflow to Lake Manitoba through the seepage of groundwater would remain the same for both the actual conditions in 2011 and for the hypothetical "unregulated" case. In the opinion of KGS Group, however, it is likely that there is indeed a difference between the actual and the "unregulated" groundwater inflows. This difference would be caused by the deviations in lake level between the actual and "unregulated" conditions that would affect the gradient of the groundwater flow from the areas surrounding the lakes. Unfortunately there are no extensive measurements of the groundwater flow or its gradient towards the lake. Approximations have been made by KGS Group based on experience and knowledge of the groundwater regime in this part of the province. KGS Group estimates that the total groundwater inflow to Lake Manitoba in 2011 could have been in the order of 10 m3/s. For increased lake levels, initially there would be a flattening of the groundwater gradient near shore, which would reduce groundwater inflow rates. This would be short term, as the groundwater levels inland would adjust and groundwater inflow to the lake would approach the previous rates as the system equilibrates. It would be highly unlikely for the differences in lake level between the actual and the estimated "unregulated" case to cause more than a 10% change in the groundwater inflow, and even then only for the short term. That would result in only a negligible difference, at least two orders of magnitude less than the surface inflows/outflows. Based on this rationale, KGS Group concluded that it is acceptable that the groundwater inflow for the "unregulated" case could be assumed equal to the actual conditions in 2011 for practical purposes. ***There would be no significant error introduced by this assumption.***

7. MIT has appropriately acknowledged that both precipitation and evaporation vary as a function of the surface area of the lake, and as such there would be a difference between the "unregulated" case and the actual conditions. However, the action taken by MIT to correct for this difference is susceptible to a variety of uncertainties. Key ones include:

   i. The precipitation records used in the analysis include only two stations near the southern end of Lake Manitoba. This is unavoidable since records are not available for other locations. But even if there were more gauge locations surrounding the lake, there is the question of whether they could accurately depict the precipitation that occurred over the entire body of Lake Manitoba which has an area of 4700 km^2. There are obviously no gauges on the lake itself.

   ii. The evaporation from the surface of the lake is very difficult to predict and can vary widely depending on water temperature, and wind conditions. KGS Group accepts that what has been assumed is the best that can be adopted. However, it is clear that the magnitude of the estimated evaporation must be considered only a rough approximation.

   iii. The surface area of the lake increases significantly as the water level increases. Submergence of shorelines creates theoretically more surface area for which to include precipitation and evaporation. However, the procedure used by MIT does not recognize that even without inundation of the shoreline areas, there would be precipitation that reaches the lake quickly through sheet runoff without entering streams and rivers. Similarly, evaporation occurs even without submergence through evapo-transportation from the vegetation and ground surface. As a result the direct application of precipitation and evaporation to the incrementally inundated area "double accounts" to some unknown extent.

   iv. The surface area of the lake is not accurate at Lake Manitoba water levels exceeding the normal range. MIT has explained that there is a zone around the north end of Lake Manitoba that is not covered by suitable topographic information to include in the inundated area at high lake elevations. It has been excluded and the calculation of precipitation and evaporation is correspondingly affected.

   v. The snowfall used in the analysis does not recognize the losses due to sublimation or due to drifting of snow off the lake surface due to wind effects. The water equivalent of the snowfall has been added directly to the lake at the time that it occurred. At first glance that may suggest a significant error, as the snow only melts in the spring and appears as a liquid at that time. However, it can shown that the flotation effects of the ice and the snow result in a rise in lake level as the snow accumulates, and only a negligible error occurs in adopting the snow as direct inflow to the lake in the course of the winter.

The effects described above clearly complicate the extraction of the precipitation and evaporation ("P-E") in the comparison of the "unregulated" case to the actual case in 2011. To test this, KGS tried simple sensitivity checks by multiplying MIT's computed daily "P-E" values by factors varying from 50 to 150% for each test and quantified the resulting influences on the estimated "unregulated" peak of Lake Manitoba water levels. The range of +/-50% of the "P-E" values caused only an error of less than +/- 0.01 ft in the peak water level computed for Lake Manitoba. It is uncertain exactly how much the "P-E" can be in error, but even in the unlikely event that it would be several times the sensitivity range described above, it would still have only an insignificant effect on the estimates of the "unregulated" lake levels.

KGS Group has concluded that although the accuracy of "P-E" is questionable, it is entirely adequate for the purposes of estimating the "unregulated" water levels. KGS Group estimates that any errors introduced by the vagaries of the approximation of "P-E" would be less than 0.02 ft in water level on Lake Manitoba.

8. Item 7 identified the issue of exclusion of a portion of the surface area at the north end of Lake Manitoba at high lake levels. That was shown to be of negligible influence in the correction for "P-E", but it also affects the calculation of IAO to Lake Manitoba. ***MIT explained that sensitivity studies of the effect of the uncertainty in surface area of the lake at high elevations showed that errors would be less than 0.01 ft. KGS Group concurs that this uncertainty would have no significant effect on the estimation of the "unregulated" conditions.***

9. The effects of wind on lake levels at any one point can be significant. In reality, there are wind effects that are constantly occurring, causing seiches in the lake and variations in water level. The wind generally causes water levels to rise on one side of the lake, where water is "piled" due to the frictional effect of the wind on the water surface. But it causes a nearly equal decline in the water level on the opposite side of the lake. All calculations by MIT for the "unregulated" case assume an estimate of the static water level (i.e. effects of wind are removed) on Lake Manitoba based on an average of the measured water levels at Steep Rock and at Westbourne. It would be ideal to use an average water level from several more water level gauges at diverse locations on the lake to derive an appropriate average water level for the lake as a whole. However, in addition to averaging two water level records from different geographic locations on the lake, MIT has also smoothed out the wind effects by applying a moving average of five days of water levels. This is a standard technique and results in a good representation of the lake level that would exist without wind.

   Irrespective of the estimation of the appropriate wind-eliminated average water level across the lake for water balancing purposes, the change in surface area of the lake would be expected to be relatively small during a wind storm. The increase in area on the windward side of the lake would be compensated by the reduction in surface area on the leeward side. KGS Group believes that the variation in total surface area would be insignificant in the context of the calculations of IAO, and "P-E".

   The outflows into the Fairford River would also be affected by upswings with winds from the south (rises in water level at the north end of Lake Manitoba), and downswings with winds from the north (recession in water level at the north end of Lake Manitoba). MIT has not corrected for that directly in the calculations, but it could be considered to be part of the computation of the IAO. As such, the effects would be included to some extent in the estimation of the "unregulated" water levels. In any case, there would be a self-cancelling influence, with increases in outflow due to winds from the south cancelling decreases in outflow due to winds from the north. In addition, the effects are short-lived, and infrequent.

It is the opinion of KGS Group that the effects of wind have been appropriately addressed and no further refinement is necessary. The error introduced by ignoring the temporary effects of wind is insignificant.

10. The effects of key reservoirs such as the Shellmouth Dam and reservoirs on the Souris River were quantified by MIT in their studies. Flows in the Assiniboine River in 2011 were augmented by MIT to represent what would have occurred without those reservoirs. However, there are other reservoirs in the watersheds upstream of the Portage Diversion and in the watershed of Lake Manitoba that were not addressed. Examples are the Minnedosa Dam, the Rivers Dam, small reservoirs in the Qu'Appelle River, and the dam at the outlet of Dauphin Lake. KGS Group has examined data for these structures and is confident that they either have relatively small and negligible storage capacities, or were operated in such a way that there were no significant "holdouts" that should be introduced into the simulation of "unregulated" conditions. ***KGS Group agrees that the effects of these reservoirs would be negligible and exclusion of their influence on the computed lake levels is justifiable.***

11. "Holdouts", or corrections for the mitigating effect of the upstream reservoirs in the Souris River, were based by MIT on calculations of what the "natural" flows of the Souris River at Minot would have been in 2011. The calculations for the Souris River at Minot were done by the U.S. Army Corps of Engineers (USACE) but are not available to KGS Group for review. However, given the good reputation of the USACE in matters such as these, it is unlikely that they would contain significant errors. On the other hand, it is evident that the supplements in river flow due to the restoration of the "holdouts" computed by the USACE are transferred by MIT directly to the Assiniboine River. This was done without consideration of the potential attenuating effect of the passage of that incremental increase in flood volume through the floodplain of the Souris River between Minot and the Assiniboine River. This is contrary to the flood routing that was done by MIT along the Assiniboine River between Shellmouth and Portage La Prairie to acknowledge the effects of attenuation in the Assiniboine floodplain. It is difficult to precisely quantify what the reduction in flow at the upstream boundary of the Mike 21 model should be to correctly acknowledge this attenuation effect on the lower Souris River. ***However, given the issues described in Item 1 above, and the sensitivity checks done for that, KGS Group has concluded that ignoring the attenuating effect along the lower Souris River would be acceptable. It would be highly unlikely to affect the computed peak level of Lake Manitoba by more than 0.05 ft. (probably by much less). Further refinement is not deemed to be necessary.***

12. The calculation of what the outflow from Lake Manitoba would have been if the channel improvements associated with the Fairford Control Structure had not been built are critical to the estimation of the "unregulated" case. The description by MIT of the 'natural' stage-discharge relationship for Lake Manitoba prior to 1961 shows that a line of best fit (called a rating curve) was ascribed to the hydrometric data that was collected in the years prior to 1961. See Figure 4.1 below.

    It is not clear whether all the observed points were based on actual measurements of flow in the Fairford River, or from a stage-discharge relationship that itself might have an unintentional bias. However, all of the data was gathered and published by reputable organizations skilled in the measurement of such data, and can safely be assumed to be as accurate as possible. Nevertheless, the scatter in the data does suggest that there could be some minor uncertainty in estimating the true relationship between lake level and outflow.

The scatter shown in Figure 4.1 suggests that the true stage-discharge relationship would almost certainly lie well within 0.15 ft of the line of best fit used in the analysis. If, for example, the true stage-discharge relationship were 0.15 ft above the one used in the calculations, it would be expected that the error introduced in the calculation of the peak "unregulated" water level would be somewhat less than 0.15 ft.

It should be noted that the largest scatter in the data exists at the lower end of the graph provided by MIT, between lake levels of 811.5 ft and 812.5 ft. This scatter resulted from the fact that some of the data was gathered in the period after a stoplog control structure was installed in the Fairford River in the 1930's. The data is influenced by the impeding effect of varying numbers of installed stop logs. The appropriate portion of the data lies on the right-hand side of the scatter, and was used for the derivation of the "unregulated" conditions (no stoplogs). In any case, this wide scatter is irrelevant for the estimation of the "unregulated" water levels for the flow conditions in 2010 and early 2011. The lake in this period and through the 2011 flood event was estimated for the "unregulated" case to be at all times at least 1.5 ft higher than this range of scattered data. The uncertainties in the stage-discharge relationship that appear to exist below the computed water levels in 2011 have no significant effect on the calculations.

Given the fact that it is likely that the uncertainty in the rating curve is considerably less than 0.15 ft in the upper range of Figure 4.1, it has been concluded that its potential effect on the peak water levels on the lakes is very small. KGS Group believes that it is almost certainly less than 0.05 ft. No further work to refine this or quantify it more precisely is considered by KGS Group to be justified.

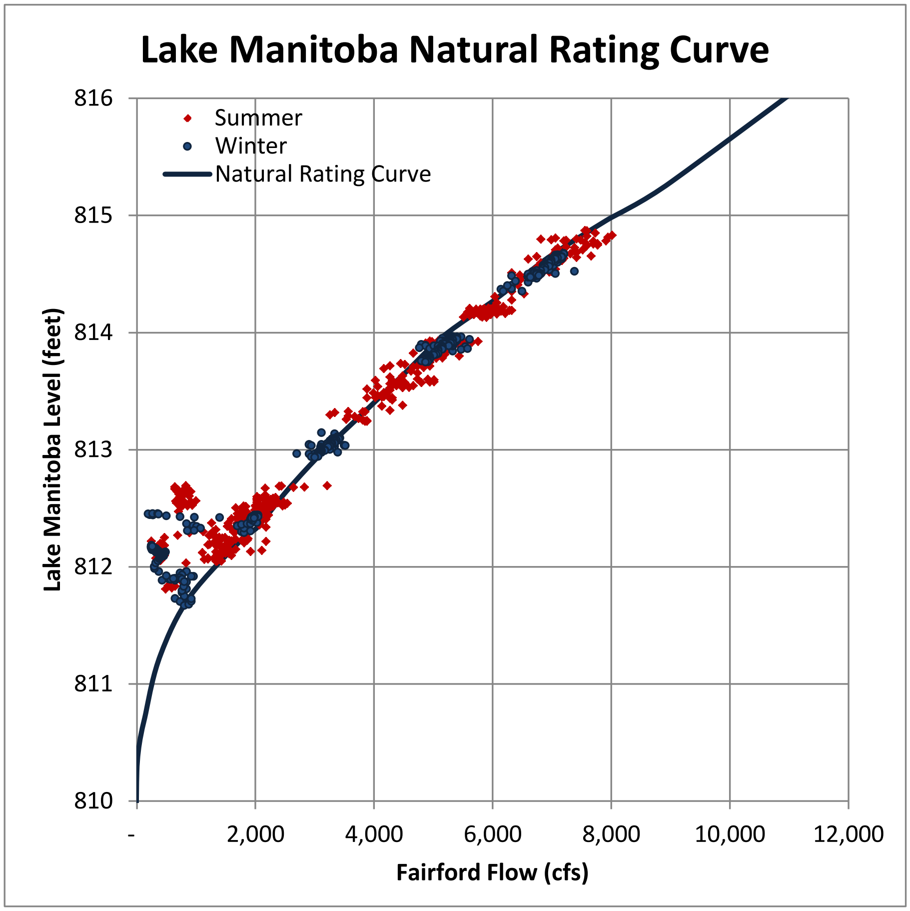


FIGURE 4.1:
STAGE DISCHARGE RELATIONSHIP FOR "UNREGULATED" CONDITIONS ON LAKE MANITOBA

Any single source of error or uncertainty discussed above would have, by itself, only a small (in most cases very small) impact on the overall accuracy of the "unregulated" water levels estimated by MIT. These estimated impacts should be kept in perspective with the total increase in lake level that occurred in 2011, approximately 4 ft. on Lake Manitoba.

KGS Group has also considered how the individual sources could be combined to represent a total impact on the calculations. Table 4.1 summarizes the potential range of impact of each individual source on the estimation of the "unregulated" lake levels. It should be noted the range varies for each source, and differs in magnitude and direction (either on the low side or the high side of MIT's calculated water levels). However, the preponderance of the ranges is skewed in the direction of increasing the estimated lake levels. It could be concluded that the best estimate of the combined impact of all the sources of error or uncertainty would be an increase in the computed water levels by MIT. Furthermore, the maximum amount by which the computed water levels could conceivably be lowered would be only 0.08 ft. Given this small magnitude on the low side, as well as the fact that it would be highly improbable that this combination could occur without any offsetting impacts from the high side, it must be concluded that the errors would not individually, or in combination, have any significant influence to lower MIT's estimate of "unregulated" water levels. It is much more likely that the combination of the sources of uncertainty would result in a best estimate of the "unregulated" water levels that is greater than that reported by MIT.

TABLE 4.1:
SUMMARY OF SOURCES OF ERROR OR UNCERTAINTY IN ESTIMATION OF "UNREGULATED" WATER LEVELS ON LAKE MANITOBA

Source of Error or Uncertainty	Maximum Potential Impact to Lower Computed Water Levels on Lake Manitoba(ft)	Maximum Potential Impact to Raise Computed Water Levels on Lake Manitoba (ft)
1. Overflow from Assiniboine	0	+0.2
2. Potential Erosion in Overflow Area	0	+0.1
3. Configuration of MIKE 21 Model	0	+0.05
4. Topographic uncertainties in overflow zone	0	+?
5. Boundary conditions for MIKE 21 Model	0	0
6. Groundwater inflow	0	0
7. Variations in Precipitation minus Evaporation	-0.02	+0.02
8. Uncertainties in surface area of Lake Manitoba	-0.01	+0.01
9. Wind effects	0	0
10. Attenuating effect of minor reservoirs	0	+?
11. Attenuation of flow in Souris River	0	+0.05
12. Uncertainty in Natural Rating Curve of Outlet of Lake Manitoba	-0.05	+0.05
Summations	-0.08	+0.48 + ?

Note: Sources are numbered to correspond to descriptions located earlier in Section 4.

5.0 SUMMARY

After thorough review, KGS Group believes that the methodologies and assumptions used by MIT to estimate the "unregulated" scenario for Lakes Manitoba and St. Martin are sound, and consistent with modern standards and technology. The estimated water levels on Lakes Manitoba and St. Martin for the "unregulated" conditions are believed to be accurate. Any uncertainties that may arise from the factors discussed in the report are considered by KGS Group to be insignificant. Further refinement is, in the opinion of KGS Group, to be unwarranted.

6.0 STATEMENT OF LIMITATIONS AND CONDITIONS

6.1 THIRD PARTY USE OF REPORT

This report has been prepared for Manitoba Infrastructure and Transportation to whom this report has been addressed and any use a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report.