$$F_r = \frac{V}{\sqrt{gH}} = \sqrt{\frac{2(\int - \int')}{\int} (1-n)\, t/H \quad (1-t/H)} \qquad \text{....(1)}$$

or

$$F_r = 0.208 \sqrt{t/H}\, (1-t/H) \qquad \text{....(2)}$$

assuming

$\int' = 0.92\int$
$n = 0.73$

where

n = porosity (ratio of volume of voids to total volume of ice)
t = ice thickness (m)
H = mean hydraulic depth (m)
V = velocity (m/s)
I = water density (kg/m^3)
I' = density of ice pan (kg/m^3)
g = acceleration due to gravity (m/s^2)

EQUATIONS 1 AND 2

The equations shown above are based on the Bernoulli equation, considering nonsubmersion of the frontal edge of the ice, and the continuity equation.

2.3 ICE DEPOSITION AND TRANSPORT

A simple limiting velocity criterion was proposed by Robert Newbury (1968). It was observed that frazil ice will be deposited at under-ice velocities between 0.8 to 1.5 m/s. Unconsolidated slush is estimated to erode at velocities greater than 1.5 m/s.

In the VARY-ICE program, when ice is available to be deposited under the ice cover, the volume of ice is 'transported' downstream from cross-section to cross-section until a location is found where the velocity is less than the specified maximum which will permit deposition. If deposition of the entire volume of ice at a cross-section would result in a velocity in excess of the maximum at this location, then an appropriate portion is again transported further downstream 'in search of' low velocity areas. If at the furthermost downstream cross-section, a volume of ice remains to be deposited, the elevation of the ice cover at that cross-section can be increased by a prescribed amount if this is appropriate to the situation being studied (e.g. if deposition downstream could, in fact, contribute to an increase in water level at the starting point of the VARY-ICE calculations).

2.4 ICE EROSION

A check for ice erosion is incorporated in the water surface profile subroutine. It uses a single limiting velocity criterion. At any section, 'j', if the section velocity 'V_j' is less than or equal to a maximum non-eroding velocity, then the ice cover will not erode. Otherwise, the volume of eroded ice is calculated and deposited downstream as described in Section 2.3.

2.5 BORDER ICE GROWTH

Three options are incorporated in VARY-ICE for calculating the rate of border ice growth.

2.5.1 Newbury Method

One approach uses an empirical border ice growth equation developed by Newbury (1968).

$$B = (M/V^{1.5})\ DD \qquad \text{....(3)}$$

where

B = width of border ice (m)
M = coefficient varying between 0.04 and 0.06 (usually 0.054)
V = mean velocity (m/s)
DD = degree-days of freezing (°C days).

EQUATION 3

The empirical equation is based on data from the Nelson River incorporating several years of varying severity. Care must be taken in applying this equation to other rivers.

2.5.2 Matousek Method (Description in Development – Not Relevant for Yukon River)

2.5.3 Direct Empirical Method

An empirical "border ice factor" can be sued to calculate border ice growth. This factor is a fraction of the total water area which remains open, and is input to the program as a function of degree-days of freezing. It is based on field observations or judgement. Use of this factor may be advantageous where the reach under study is short and the amount of border ice growth is relatively constant along the river.

2.6 ICE RETREAT BY SHOVING

As the ice cover progresses upstream, stresses in the ice cover increase. The forces which increase ice stress include the hydrodynamic shearing force of the flow under the cover, the periodic shearing stress of wind on the cover, the weight of ice along the slope of the ice/water interface and the hydrodynamic thrust on the leading edge of the cover. These forces must be opposed by the internal resistance of the ice cover and the resistance of the banks, otherwise the ice cover will be unstable and a shove will occur.

From Michel (1971) the hydrodynamic force is defined as:

$$F_T = \frac{\gamma}{2g} D \left(1 - d/_D\right)^2 V_u^2 W$$

$$= 5000 \left(1 - d/_D\right)^2 V_u^2 W \qquad \ldots.(4)$$

where

F_T = hydrodynamic thrust of the flow (N)
D = depth of water upstream of leading edge (m)
d = depth of flow under the leading edge (m)
V_u = velocity under the leading edge (m/s)
W = width of ice cover (m)
γ = weight density of water (9800 N/m^3)

EQUATION 4

The force on the ice cover from frictional drag on the cover was shown by Michel (1971) to be computed using the following equation.

$$F_D = \frac{\gamma}{2} \frac{d\, S\, n_i^{1.5}}{n_e^{1.5}} A$$

$$= 4905 \frac{d\, S\, n_i^{1.5}}{n_e^{1.5}} A \qquad \text{....(5)}$$

where

F_D = friction drag force (N)
S = slope of hydraulic grade line
n_i = Manning's roughness coefficient of the ice under surface (computed from Torok-Sabaneev equation)
n_e = Manning's roughness coefficient of the composite cross section
d = depth of flow under the ice cover (m)
A = under-surface area of ice exposed to flow (m^2).

EQUATION 5

The force from the weight of the ice cover was derived from Pariset, Hausser and Gagnon (1966) and is based on a simple buoyancy criterion, which is independent of porosity n. It is calculated as:

$$F_W = 9025\ V\ S \qquad \text{....(6)}$$

where

F_W = gravitational force acting along the channel (N)
V = volume of ice cover (m^3)
S = slope of hydralic grade line.

EQUATION 6

The force exerted on the ice cover due to the wind can be calculated as follows:

$$F_{WD} = P_W A \quad ....(7)$$

where

F_{WD} = wind drag force (N)
P_W = wind force per unit area of ice cover (Pa)
(+ve if from upstream to downstream)
A = ice surface area (m^2).

EQUATION 7

Resisting forces include the cohesion of the ice cover to the riverbanks and friction of the ice cover against the riverbank.

The cohesion expression (Pariset, Hausser and Gagnon, 1966) is given as follows:

$$F_C = 2\ C\ t\ L \quad ....(8)$$

where

F_C = force of cohesion of ice to 2 riverbanks (N)
C = cohesion per unit area of ice/bank interface (Pa)
t = average thickness of ice cover between cross sections (m)
L = distance between cross sections (m).

EQUATION 8

The value of cohesion is best derived by prototype measurements. Experience indicates a reasonable value for cohesion is zero at the time of initial formation, with an increase later as frost penetration occurs.

The hydraulic forces exerted on the ice cover in the stream-wise direction create stresses in the ice, which are spread laterally towards the riverbanks. The lateral stress results in a reaction of static friction at the riverbank, which acts as a stabilizing influence on the cover.

From Pariset, Hausser and Gagnon (1966)

$$F_F = 2\ f\ t\ L\ k_1\ \tan \phi \qquad \text{....(9)}$$

where

F_F = friction force on the ice along the riverbank (N)
f = accumulative stress in the ice cover in the direction of flow (Pa)
k_1 = a coefficient equal to the ratio of lateral stress to longitudinal stress in the ice cover (a ratio less than or equal to 1.0)
= angle of friction of ice.

EQUATION 9

The internal resistance of the ice cover (after Pariset et al., 1961, 1966) is given as:

$$F_{IR} = \rho' \left(1 - \frac{\rho'}{\rho}\right) \frac{g t^2}{2} K_2 W \qquad \text{....(10)}$$

EQUATION 10

which is reduced approximately to

$$F_{IR} = 361\ K_2\ t^2\ W \qquad \ldots.(11)$$

where

F_{IR} = internal resistance of the fragmented ice cover (N)

t = ice thickness (m)

K_2 = a coefficient analogous to Rankine's passive coefficience in soils

W = river width (m).

EQUATION 11

It should be noted that the combined values of K_1, K_2 and tan Ø have been based on actual observations (after Pariset et al., 1966). Although the individual values of K_1, K_2 and tan Ø have not been measured precisely, comparative simulations with the mathematical model have indicated that the predictions of shoves and hence ice thicknesses are relatively insensitive to the choice of their individual values, provided that K_1, K_2 tan Ø is between 1.1 to 1.6.

The total force in the ice cover at a cross section is

$$F = F_P + F_D + F_W + F_{WD} - F_C - F_F \qquad \ldots.(12)$$

where

F = total force

F_P = total force at previous cross section (at the leading edge of the ice cover, this would be made up solely of the hydrodynamic thrust, F_T)

F_D, F_W, F_{WD}, F_C, F_F = forces defined above.

EQUATION 12

If the force, F, exceeds the internal resistance of the ice cover, then a shove is assumed to occur to permit the ice cover to thicken to the appropriate value necessary for stability.

When a shove occurs, the required stable thickness of the ice cover is computed

$$t_{REQD} = \sqrt{(F/(361\ k_2\ W))} \quad \ldots\ldots(13)$$

EQUATION 13

This process continues from upstream to downstream until the furthermost downstream cross-section is reached. Next, the volume of ice required to thicken all of the unstable cross-sections is calculated. Finally, the time to produce this volume of ice is calculated and updated.

VARY-ICE can also make allowance, if deemed appropriate, for a reduction in downstream forces due to grounding of an ice cover and additional cohesion of ice to banks at islands.

2.7 WATER SURFACE PROFILES / FLOWS

VARY-ICE provides a full solution of the St. Venant equations of motion using the same methodology used by common programs such as the U.S. Army Corps of Engineers' “HEC-RAS-3” and the U.S. National Weather Services' “Dambrk”. It is a fully dynamic solution.

APPENDIX G

FINDINGS FROM LA SALLE CONSULTING GROUP

Comprised of 3 Separate Appendices:
Annex 1: LaSalle Consulting Group – Memorandum on Dauphin River
Annex 2: LaSalle Consulting Group – Memorandum on Fairford River
Annex 3: LaSalle Consulting Group Model Files (Not Printed – Included on DVD)

APPENDIX G - ANNEX 1

LASALLE CONSULTING GROUP
MEMORANDUMS ON DAUPHIN RIVER

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DAUPHIN RIVER ICE CONDITIONS DURING THE 2011-2012 WINTER SEASON

Memorandum prepared by Jean-Philippe Saucet, P. Eng. October 4, 2011

I attended meetings of the Frazil Ice Team (FIT) on September 28 and 29 at the Aecom's office in Winnipeg, and I was introduced to the water system, the apprehended ice situation during the coming winter and the analysis undertaken to assess possible solutions.

The work done by KGS and AECOM has to be commended in view of the complexity of the water system and the lack of data available at the beginning of the work. It took just over two months to bring together existing information, organize and conduct detailed bathymetric surveys (sonar, LIDAR) and to implement and validate various numerical models (HEC-RAS, MIKE11, RIVICE) representing the state of the art in the analysis of free surface flows and in the presence of ice.

I was asked to comment or provide advice or guidance on the modeling techniques of the ice conditions, particularly in the downstream reach of the Dauphin river. I drew attention to four specific questions:

<u>Water temperature.</u> It was considered that water at the outlet of Lake Manitoba (Fairfort CS) will be at the freezing temperature at the onset of freezing in November. It is known that in a deep lake or reservoir, the surface ice cover is formed while the water mass at depth is still a few degrees above 0 ° C. The water at the outlet is then withdrawn from the relatively warm and stratified layers, and is at a temperature a few tenths of a degree above 0°C throughout the winter. This reduces the volume of ice generated in river, since it is necessary that water reaches 0° C to begin to form ice, and this 0°C point may be few kilometers downstream of the outlet, depending of the discharge, river width and air temperature.

As there is no data to water temperatures for Lake Manitoba it was suggested to carry out some measurement this fall and winter. I provided information on the methodology and

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instruments required. I also proposed to conduct a sensitivity analysis of maximum water levels assuming 0.5 ° C at the outlet instead of 0.0 ° C

However, the Lake Manitoba seems shallow and its hot water content at freeze-up is probably very low. Pictures taken at the freeze-up of November 2007, submitted after our meetings, suggest that water is almost at 0 ° C at the outlet since some frazil ice is observed to drift from the first hundred meters. The assumption of 0.0°C at the outlet is therefore probably realistic, and safe in terms of maximum water levels.

Volumes of ice. The RIVICE model is used to accumulate ice in the downstream reach (km 40 to 52.2) by injecting a constant flow of ice drifting from upstream. The volume of ice generated and accumulated is not computed explicitly by the model, but has been correctly evaluated by a separate computation. It is argued that the amount of ice generated by the river still at free surface, when it is -20 ° C, may exceed 10 m^3, and I agree with this figure: some 50 kms of river 100 m wide correspond to a 5 km^2 of generating surface, and the rate of heat loss is 400 W/m^2 for an air temperature of -20°C. This can generate in a single second a volume of ice that occupies 10.8 m^3, when accumulated with a 40% void ratio.

On the other hand, the jam calculated by RIVICE between km 40 and 52 is about 2.5 to 3 m thick and contains 4 to 5 millions m^3. It is therefore true that if the jam initiates at the outlet, it will takes a week or so to advance up to km 40.

Ice jam initiation at km 52.2 I believe that one should not rule out that a substantial amount of ice can accumulate in the lake without raising the water level to the point that the velocity and Froude numbers at the mouth are reduced, to such an extent that the jam can be initiated and move upward. This upward progression will be unusually difficult this winter because of the increased flow. For example, in the La Grande Complex in Quebec, the Boyd River, now regulated, flows into Lake Sakami with a high discharge. The frazil generated on the last 15 kms is transported and deposited under the thermal ice cover present on the lake. The photo below shows the frazil dune stretching over some 1500 m long in the lake. The photo was taken on May 16 when the snow has melted from the thermal ice cover surface, allowing us to see the hanging dam through the ice cover which is somewhat transparent. The lake is deep, the hanging dam did not raise the water level and the river remained with a free surface throughout the winter.

If the Dauphin river remained open along the 52 km during a winter of 2300 ° C-days, the total volume of frazil ice generated would be about 100 million m^3 (again with a void ratio of 40%) and it may seem impossible to accumulate this large volume into Lake Winnipeg. However, this is comparable to the volume of an accumulation 8 km long, 5 km wide and 2.5 m thick in lake Winnipeg at the mouth of the river. Inspection of bathymetric or navigation charts of the Lake would help to evaluate if such an accumulation is likely to be seen.

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The principles governing the ice jam calculation.

The RIVICE model calculates the packing and accumulation of ice in the river by solving the so called equations of mechanical stability of Pariset-Hausser, reflecting a balance of forces between the hydrodynamic downward thrust, the friction against the banks and the internal resistance of the jam. The final jam results from a combination of advance of the leading edge and downstream shoves.

We are used to reserve for this analysis for spring breakup jam formed by large ice blocks, while our model MIKE-ICE considers that the frazil ice, when it is swept under the leading edge of the arrested jam, is transported by the flow and deposited in the slower areas to form a suspended or hanging dam. However, the hydraulic conditions for the leading edge to progress upward are the same in both models, and they both compute in the same way the thickness of the packed ice required to allow progression. The final jam results from a combination of advance of the leading edge and deposition under the hanging dam.

The chaotic, hummocked aspect of the surface of the ice jam does not always distinguish what is the prevailing mode of formation, because it may result from the mechanism of packing at the leading edge of various ice type, ice pans and/or broken plates of skim ice. We have begun October 3 to implement our model MIKE-Ice to study these questions and compare results.

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NUMERICAL MODELLING OF THE DAUPHIN RIVER ICE CONDITIONS DURING THE 2011-2012 WINTER SEASON

Memorandum No 2 prepared by Jean-Philippe Saucet, P. Eng. October 26, 2011

At the request of the Frazil Ice Team (FIT), the LaSalle Consulting Group carried out a short study of the ice conditions to be expected during the coming winter. Two numerical models developed jointly by LaSalle and the Danish Hydraulic Institute (DHI) were used to provide advice and guidance on the likely maximum water levels to be expected in the lower Dauphin river, particularly along its downstream steeper reach. These models are part of the MIKE 11 software: the Frazil Ice Generation and Accumulation module models the thermal regime, ice generation, transport and accumulation of frazil ice into hanging dams, whereas the Ice Jam module was originally aimed at reproducing jamming of larger blocks of ice resulting from break-up.

Open water calibration

The MIKE 11 model was run for the flow of the Dauphin river measured in July 2011, 412 m^3/s, and the resulting water levels were compared to the ones measured at this time at various location along the lower reach. The bed roughness coefficients were adjusted in order to match the calculated and measured levels. The resulting calculated and measured water levels are presented on Figure 1 below.

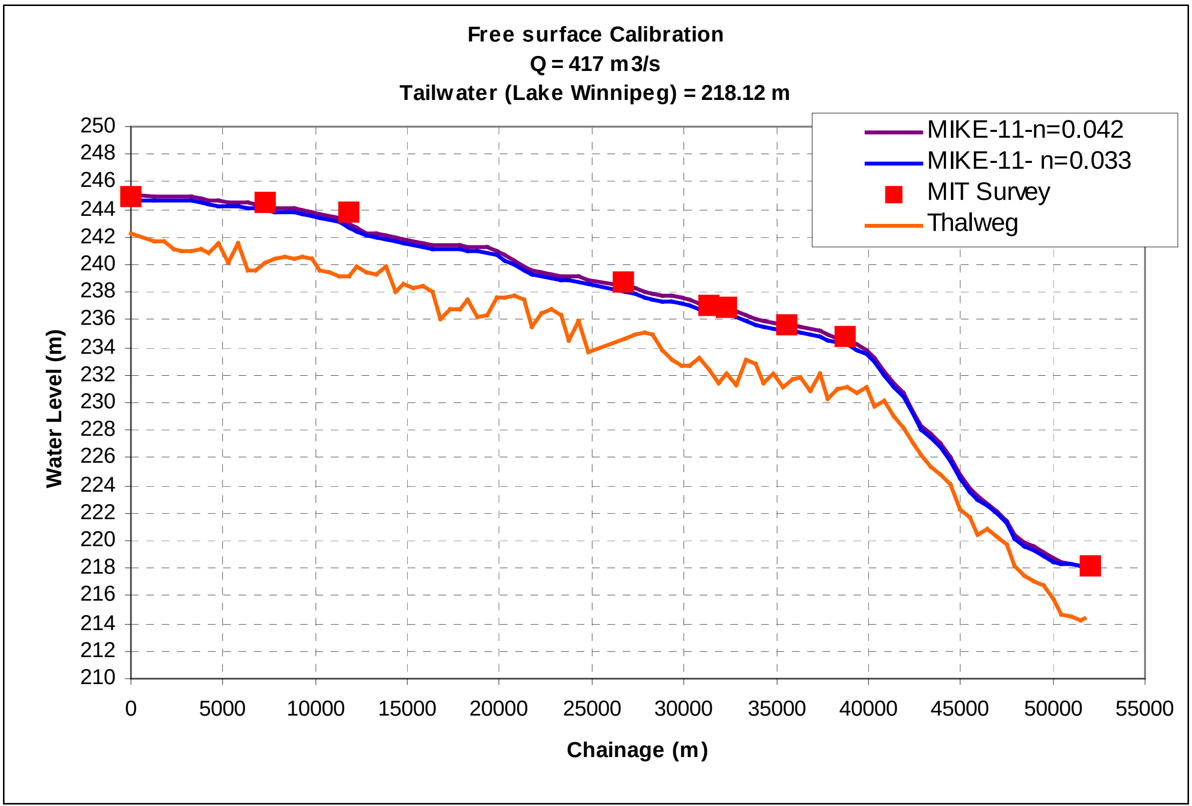

Figure 1: Free surface calibration

Calibration for the 2010-11 winter

A set of simulations using the Frazil Ice Generation and Accumulation module was carried out in order to match the maximum water levels observed during the previous, 2010-11 winter. The calibration data were provided by R. Carson from KGS as follows:

1. The ice cover advanced up from Lake Winnipeg (Km 52.4) through the community of Dauphin River First Nation on about Nov 20. It advanced rapidly, reaching the upper end of the steep river reach (Km 38 +/-) by about November 24.

2. The flow in the Dauphin River during that time was estimated to be about 190 to 200 m^3/s.

3. The water level on Lake Winnipeg is estimated to have been El 218.0 m during the ice accumulation period

4. We have a photograph taken on Nov 22 at Km 49.7 that shows that the river water level was nominally above the road surface. We estimate the peak water level to have been El 221.8 m at that location.

5. The low point of that same road at Km 49.3 was inundated at the peak of the ice formation and we estimate a maximum water level of 222.0 m.

6. The road at Km 48.2 m (immediately across from the mouth of Buffalo Creek) was inundated, and a peak water level of 224.8 m is estimated to have occurred at that location.

7. Aside from the flooding of the road at these three points, we understand that there were no residences or other infrastructure affected by the ice in 2010/2011.

8. The road (Highway 513) near Cranberry Creek (Km 35.7 km) was inundated at the peak of the ice formation period, and raised the water level to an estimated El 236 m at that location.

9. The ice cover advanced by juxtaposition and reached Lake St. Martin by about December 7.

A significant effort was made to analyze our model results and adjust various parameters to calibrate it against these observations. The resulting water profile along the lower reach are presented on figure 2 below:

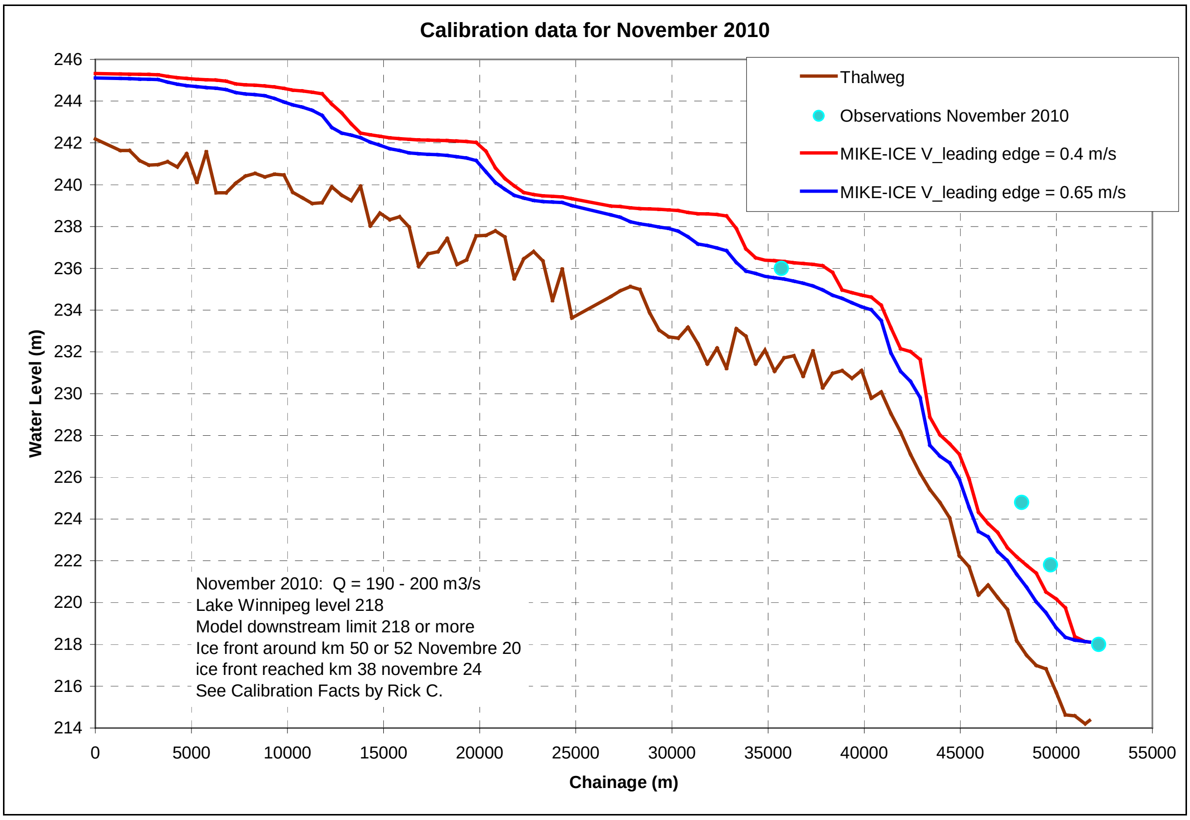

Figure 2. Water levels simulated with the Frazil Ice module.

The calculated water levels were significantly lower than the observed ones, and we had to acknowledge that it was apparently not feasible to adjust them with a realistic set of parameters. The physical processes which are included into the Mike-Frazil Ice software differ from the main dynamics which govern the ice accumulation and packing into the lower reach of the Dauphin river. As suggested by Rick Carson, the governing process seems to be more of the jamming type, and the equations which control the final jam thickness and water level are not included in the Mike-Frazil Ice model.

Calibration with the Ice Jam module.

The Ice Jam module compute the jam thickness and resulting water elevations using the Pariset-Hausser equations, based upon a balance of the forces exerted on the ice accumulation: component of the weight of the ice along the water line, shear stress under the ice, friction against the banks, etc. The river discharge, the total volume of ice and the downstream location of the foot of the jam are defined by the user. We adjusted the total volume of ice accumulated in order to match the observed upstream location of the head of the jam, at km 40. The water level of Lake Winnipeg was set at its observed value, 218 m.

It was then possible to match the observed water level in a more satisfactory manner, as depicted on Figure 3 below.

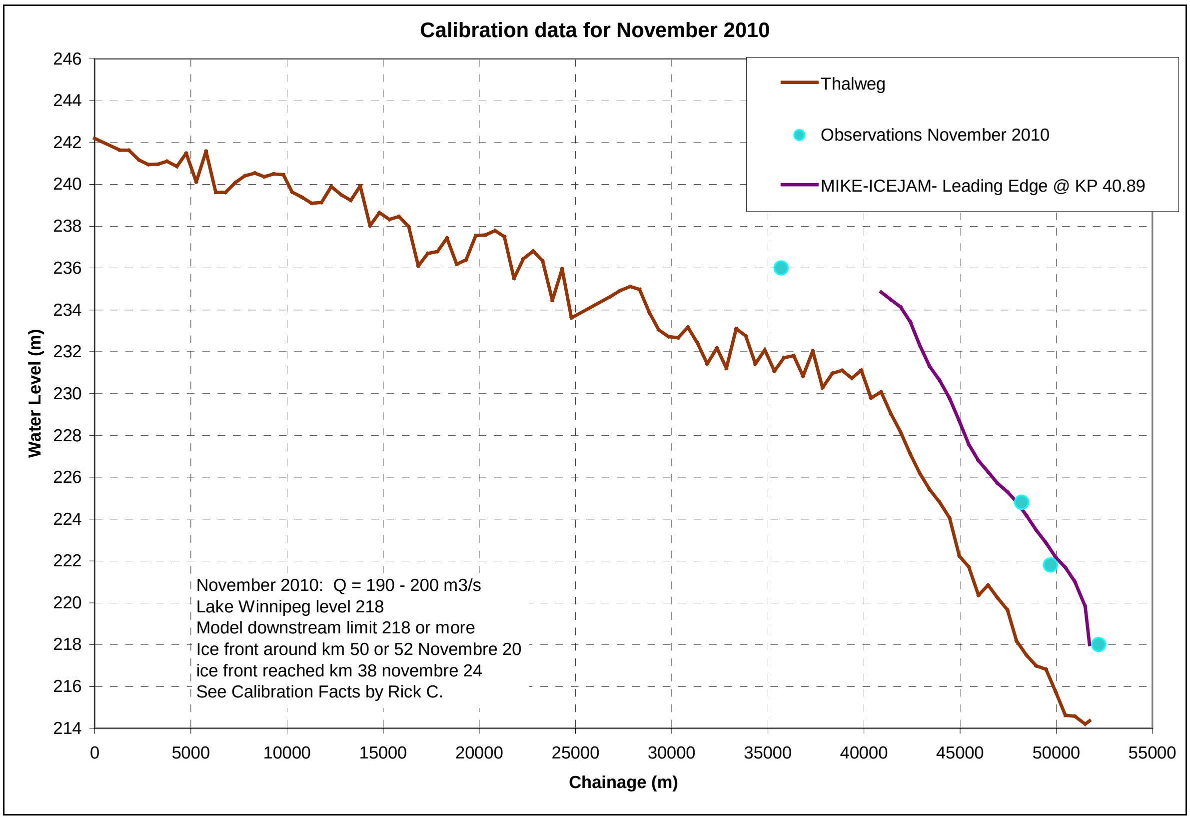

Figure 3: Water levels simulated with the Ice Jam module.

Future conditions

The Ice Jam module was used to analyze the maximum water levels in the lower Dauphin River for Scenario 1, corresponding to a river flow of 420 m^3/s, increasing to 500 m^3/s downstream of km 48, the extra 80 m^3/s arriving from Buffalo Creek once the second outlet of Lake St-Martin, presently under construction, is commissioned. The Lake Winnipeg water level, away from the mouth of the river, is 218 m. The effective width of the lower reach of the river is limited to 150 m, to take into account the fact that the jam will not likely extend into the flood plains on the left and right banks.

At the onset of freeze-up, the river is still ice free and is capable of generating a very large volume of drifting ice. The river is 52 km long from the outlet of Lake St-Martin, and its average width is about 150 m. Considering a freezing-index of 2 100°C-day ([1]), the total volume of ice generated throughout the winter would be some 100 millions m^3, should the river remain open surface all winter long ([2]).

Some ice will flow past the mouth of the river, km 52,3, and accumulate into Lake Winnipeg, raising the water level at the mouth. The staging at km 52,3 will finally allow upward progression and jamming into the river. The model evaluates the accumulation downstream of the river mouth, checks for stability of the jam pushing against the thermal ice field formed on the Lake early in winter, and the water levels at the mouth and further upstream result from the final location and thickness of the jam.

It is recognized that very little bathymetric data is available to model the lake downstream of the mouth. The nautical chart No 6240 suggest a relatively shallow area, which was first schematized as a rectangular channel 2 km long, 650 m wide, with a bed elevation of 215 m.

The Figure 4 below present the resulting ice thickness and water level elevation once the total volume of ice is adjusted in such a manner that the upstream limit of the jam is at km 40.

---

[1] This freezing-index is estimated from nearby meteorological stations, such as Birch River, Mafeking, Ashern.

[2] This volume is estimated using a typical heat exchange coefficient of 20 $W/m^2/°C$ and a void ratio of 40% for the ice accumulation.

The resulting water level at the mouth of the river, km 52,3, is 221.87 m

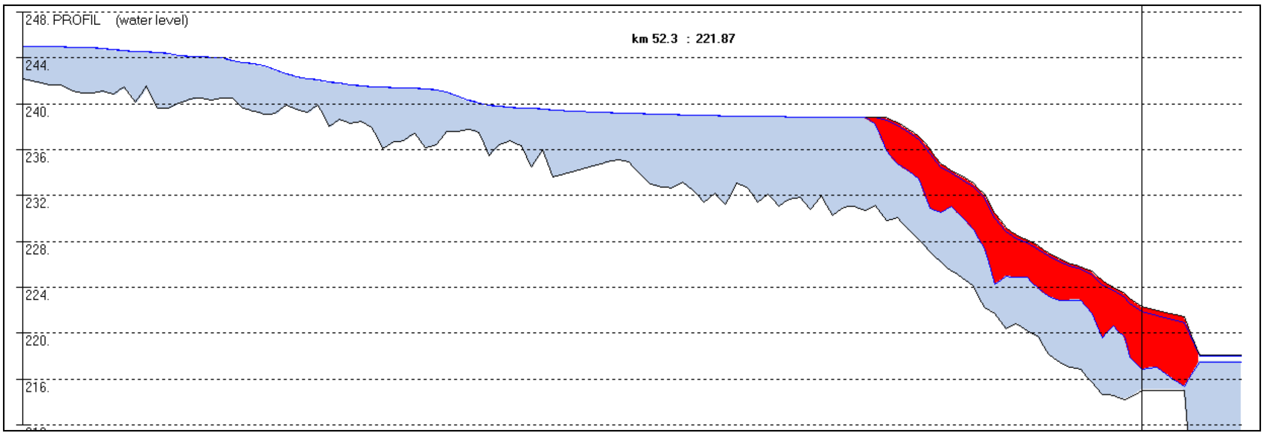

Figure 4: Ice jam in future conditions, scenario 1, case 1

This result depends in part on the schematization of the lake, and on the thickness and stability of the thermal ice cover that forms on the lake in early winter. Figure 5, 6 and 7 present results obtained by varying these parameters. Case 2, Figure 5, was computed for the same conditions except that the thermal cover on the lake is weaker and fails more easily under the thrust exerted by the ice accumulation. The foot of the resulting jam is moved downstream, but the water level at the mouth of the river is unchanged, 221.87 m

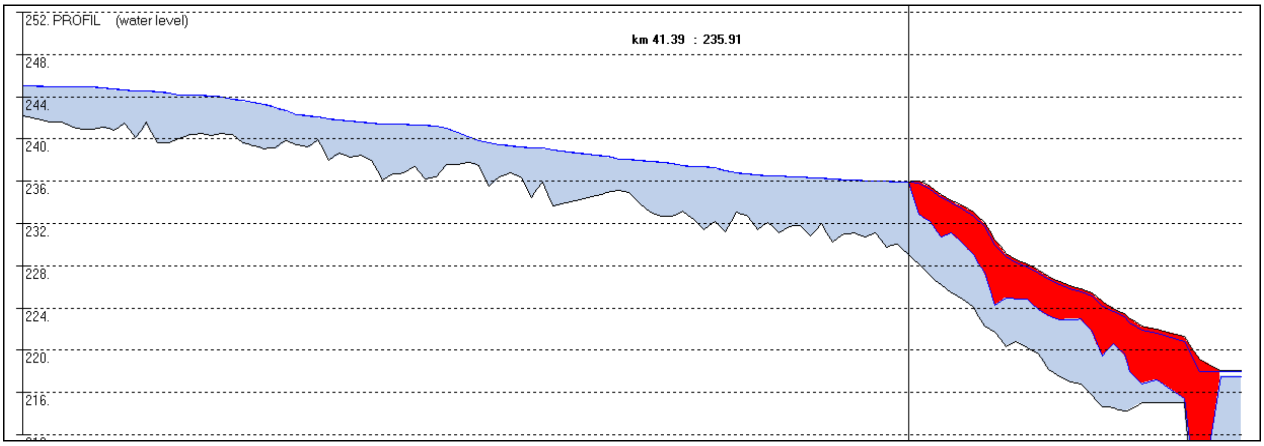

Figure 5: Ice jam in future conditions, case 2

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Case 3, Figure 6, corresponds to a different schematization of the lake, with a much deeper (elevation 210 m) and wider channel (1 500 m). The volume of ice accumulated downstream of the mouth is larger, and the resulting water level at the mouth is lower than for case 1.

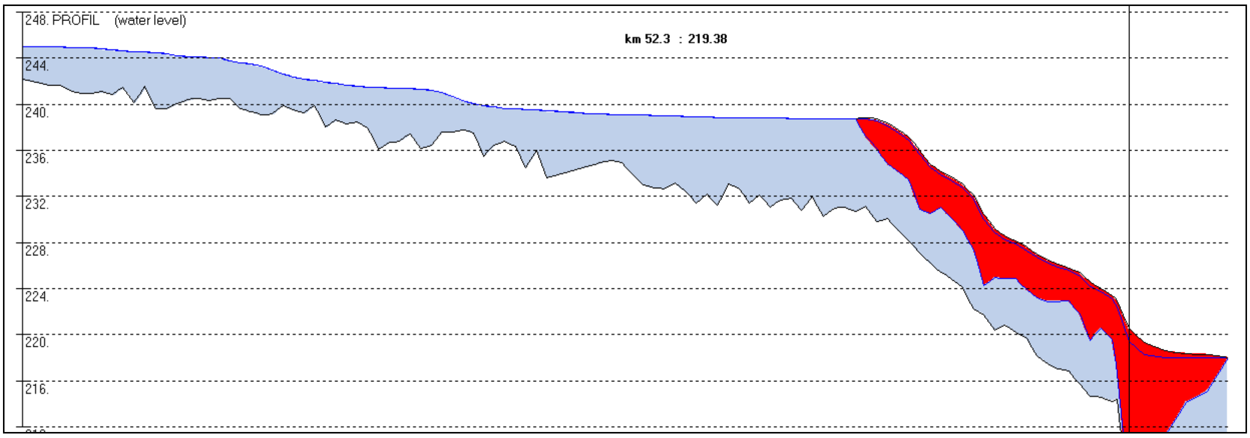

Figure 6: Ice jam in future conditions, case 3

Case 4, Figure 7, is an intermediate case, with a wide channel at elevation 212 m, and a weak ice cover on the lake, failing rapidly against the horizontal thrust exerted by the packed ice.

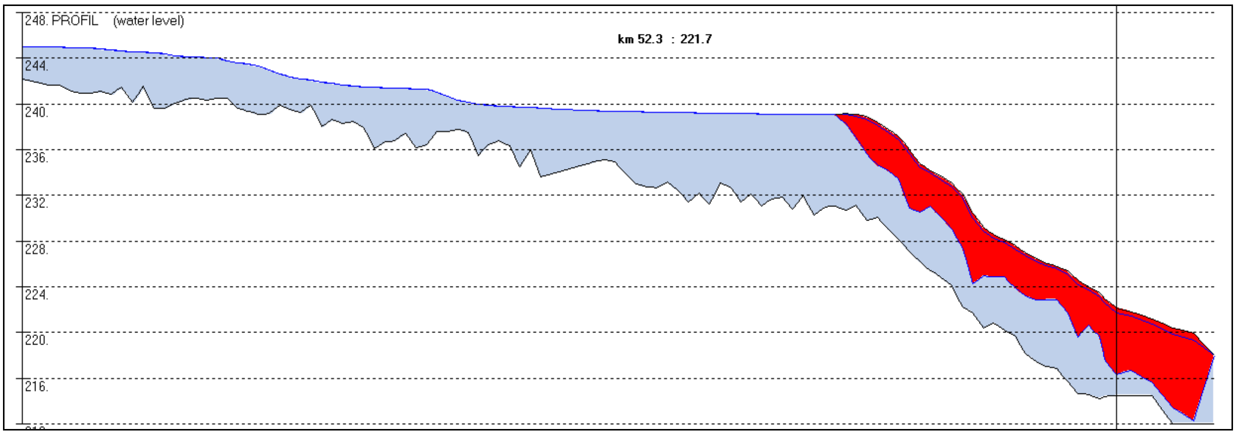

Figure 7: Ice jam in future conditions, case 4

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The resulting maximum water levels corresponding to the various cases are presented on Figure 8, along with the water levels previously computed by KGS with the RIVICE model.

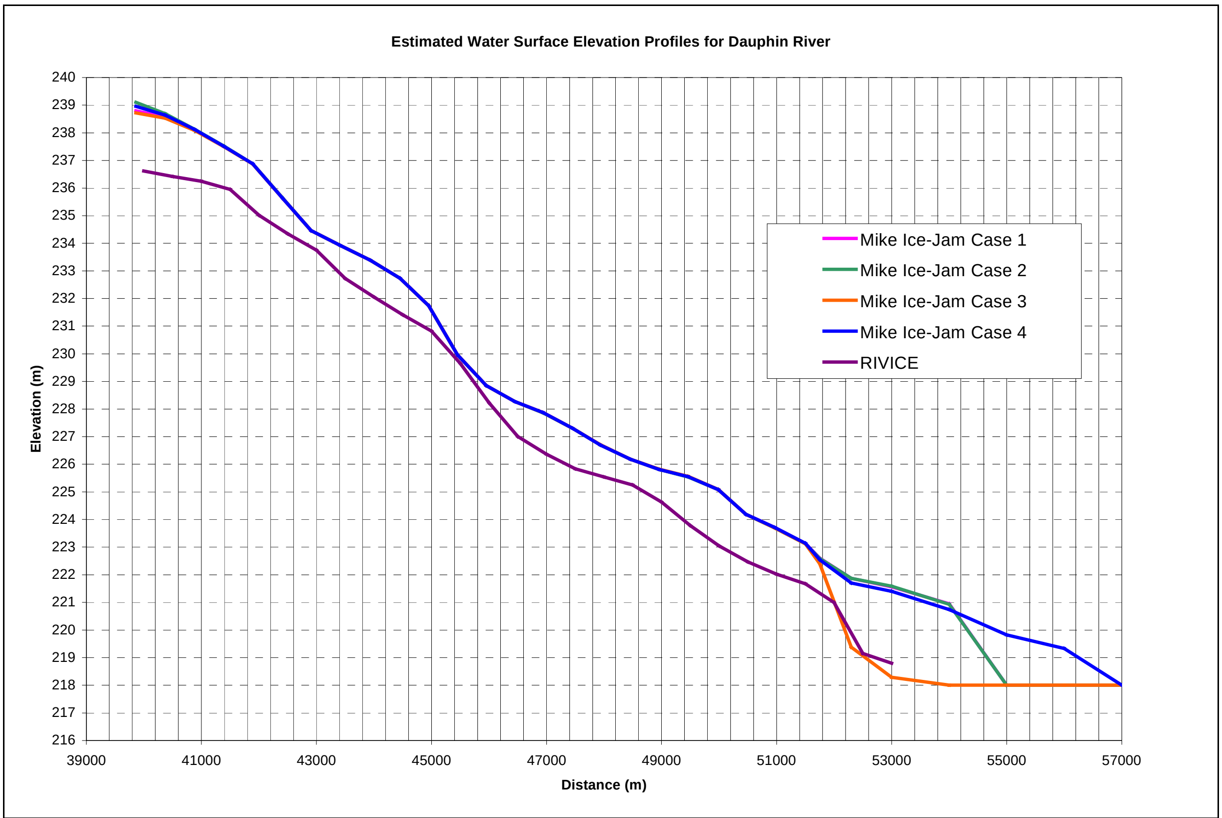

Figure 8: Estimated water surface elevation profiles

Three conclusions emerge from this comparison:

- Except for the somewhat unrealistic case 4 (very deep lake), the maximum water levels upstream of km 54 are not affected by our schematization of the lake and its ice dynamics.

- The volume of ice accumulating into the lake, downstream of km 52.3, is relatively small, 10 to 25 millions cubic meter, smaller than the 100 millions cubic meter potentially generated into the river: the water levels will increase sufficiently enough at the mouth to allow upstream progression of the jam into the river.

- The water level at the mouth required to do so is significantly higher than the one estimated by KGS. The resulting water levels along the river are higher than the RIVICE results, by an average of 1,5 m.

This discrepancy may result from an underestimation by KGS of the staging at km 52.3 resulting form the ice accumulation into the lake, but also from.

:

- the limitations of the Mike Ice-Jam module, which does not represent properly the upstream progression of the jam by juxtaposition. The resulting jam is solely governed by the Pariset-Hausser equations.

- our limited present knowledge of the packing process into the lake, crudely represented in our model. It is to be noted than this does not result only from the limited bathymetric data available, the process is inherently bi-dimensional and its dynamics is not well modeled with the tools presently available.

In any case, the high flow of the Dauphin River during the 2011 freeze-up will result in a serious ice jam event and the RIVICE maximum water levels values cannot be considered as over-conservative.

APPENDIX G - ANNEX 2

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ICE EFFECTS ON THE FAIRFORT RIVER DURING THE COMING WINTER

Memorandum prepared by Jean-Philippe Saucet, P. Eng. November 2nd, 2011

As requested, we reviewed the methodology and results presented recently by KGS regarding the future ice regime on the Fairfort river, and its impact on discharge and water levels of Lake Manitoba and St. Martin in the coming months.

The problem is complex because of the interconnection between the various processes: mode of accumulation of ice in the river, upstream and downstream lake levels in response to varying flow rates and to the ice regime, etc.. A first simplified approach was to calculate the ice regime between Lake Manitoba and Lake St. Martin by considering a constant flow throughout the winter, set successively to values representative of possible scenarios. A comprehensive approach, that integrates the calculation of ice effects and flow routing across the water system, is being completed and will confirm the results of the simplified approach.

In all cases the dominant mechanism is the following: ice forms in the river at the onset of freeze-up and drifts toward Lake St. Martin. The flow velocity downstream of Lake Pinemuta and further upstream are quite low, and the drifting ice stops at the leading edge of the ice cover, which moves rapidly upward by juxtaposition of ice. It is estimated that this process continues until a point is reached few kilometres downstream of Lake Manitoba, where the local hydrodynamic conditions no longer allow this progression by juxtaposition: the drifting ice goes under the leading edge, is transported by the flow and will eventually accumulate under the fixed ice cover to form a hanging dam. The hanging dam creates a head loss which reduces the river flow and velocity, and ultimately allows the progression of the ice up to the Lake. Once this is completed, the river is completely covered with ice and the hanging dam is no longer supplied: the obstruction remains the same, and the river flow is almost constant for the remainder of the winter (it varies a little due to the fluctuation of levels in lakes Manitoba and St. Martin.)

This mechanism is well known from previous experience and observations, and its analysis respects the state of the art regarding the winter regime of northen rivers. The dynamics at the leading edge plays a key role: if the incoming ice can resist velocities at the leading edge higher than estimated, without being swept under the ice cover, the river will be covered by ice quickly before a large hanging dam is formed and the final obstruction will be less important. Under this assumption, the ice effect and flow reduction will be lower than expected, whereas they will be stronger if the drifting ice reaching the leading edge is more easily washed away under the arrested ice cover.

The criterion adopted by VARYICE to model the leading edge dynamics is a Froude number criterion: the front edge is stable (juxtaposition) if the local Froude number is below a limit defined by the model user, set at 0.08 and 0.12 by KGS.

In studies and numerical models developed in LaSalle, mainly to Hydro-Québec, we use a slightly more sophisticated stability criterion: the front edge is stable if the Froude number is below a certain limit (in the range of 0.06 to 0.08) OR if the local speed below a speed limit, typically set at 0.65 m/s. One can easily show that the speed criteriom is the most compelling, except in very deep river, 10 meters or more, while the typical depth of the Fairfort in the first few kilometers downstream from Lake Manitoba are more in the order of 3 m.

The reach that generates the drifting ice is short, a few kilometers between Lake Manitoba and the leading edge, the ice fragments are small and the speed limit is probably low. We would consider a value of about 0.5 m / s, which corresponds to a Froude number of 0.09 in 3 meter of water. This suggests that we should give more confidence in the results calculated by KGS with the lowest value of the Froude number limit, which predict a stronger ice effect. The critical velocity of deposition of frazil ice beneath the dunes, 0.5 m / s, seems correct in view of the short length of the ice generating reach. The fact that we neglect the presence of border ice along the open water reach may have some effect on the ice generation rate and the rate of upstream progression of the leading edge, but not on the final result in term of reduced discharge.

More generally, the ice builds up in one way or another in the river as long as the leading edge has not reached Lake Manitoba, and the process is stopped when the flow has decreased enough to allow a stable leading edge at the outlet of the lake ([1]). The flow then remains almost constant for the remainder of the winter.

This reasoning indicates qualitatively the influence of the date of the first cold spell on the winter flow. The water level of the Lake and along the upstream reach of the river would be higher during an early freeze-up, and the leading edge would hence be capable to progress against a higher flow, resulting in a higher flow for the remainder of the winter . On the contrary, a late freeze-up, when the Lake level is less by 0.3 or 0.5 m, would result in a lesser winter flow. If the sequence of the air temperatures in early winter has some effect, the total freezing index accumulated over the winter has little effect on the final flow regime.

Later in winter, the first calculations by KGS considered that ice dams remain in place with their original thickness, and the ice effects remained unchanged until the spring break-up, which was not simulated but was apparently supposed to occur almost instantly. This is too pessimistic, and obstruction by the ice will gradually decrease during the second half of winter, from smoothing of the underside of the hanging dam, a fairly well documented process, and from the gradual melting of the ice by the water coming from Lake Manitoba, which will warm gradually, especially from the solar radiation penetrating below the Lake ice field. We therefore expect a gradual increase of the flow starting late March or early April, which has to be taken into account in the overall analysis.

<u>In conclusion</u>, the VARYICE model used by KGS incorporate the main ice processes which will control the winter flow of the Fairfort river. The flow for the remainder of the winter reflects the leading edge dynamics during a two week or so period of time, when the leading edge is moving up to Lake Manitoba. Hence, the criterion used to decide if the leading edge is stable or not is of paramount importance. We are accustomed to use a two fold criterion: stable leading edge if the velocity is less than a limiting velocity OR the Froude number less than

[1] The required capacity could almost be calculated without simulating the accumulation of ice, by a simple calculation of velocities and Froude numbers near the lake outlet various flow and water levels in the lake.

a limiting Froude number. With usual limiting values, the velocity criterion is the more compelling, except for deep rivers (more than 10 m or so, which is not the case of the Fairfort). We would use a low limiting velocity, 0,5 m/s, considering the short generating length. This would translate in a low Froude number, 0.09 as a crude estimate. So we would be inclined to trust the 0.08 results presented by KGS.

In a qualitatively way, the winter flow will be higher in the case of an early freeze-up, occuring when the lake is an higher level, whereas a late freeze-up will induce a lower discharge for the remanider of the winter. In the other hand, the severity of the winter, measured by its accumulated freezing degree-days, will have little or now influence on the flow regime.

There will be some relaxation of the ice effect during the second part of the winter. It is doubtful that the hanging dam(s) reorganize, but they will be smoother and partially melted in late winter. Lake Manitoba will act as a large solar panel, collecting the March and April solar radiation which penetrates its thermal cover, and this heat will flow down the Fairfort.

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NUMERICAL MODELLING OF THE FAIRFORD RIVER ICE CONDITIONS DURING THE 2011-2012 WINTER SEASON

Memorandum prepared by C. Denault, P. Eng & J.-P. Saucet, P. Eng. November 17, 2011

In 2011, widespread record flooding resulted in unprecedented high inflows into Lake Manitoba, which drains into the Fairford River, Lake Pinemuta, Lake St. Martin and ultimately Lake Winnipeg. Due to Lake Manitoba high water levels, water is currently being released via the Fairford Control Structure into the Fairford River. Possible ice effects on the Fairford River in the upcoming winter months are now of concern, as they might decrease the outflows from Lake Manitoba.

At the request of KGS, the LaSalle Consulting Group (LCG) carried out a short study of the ice conditions to be expected during the 2011-2012 winter. The *Frazil Ice Generation and Accumulation module*, part of the MIKE 11 software, was used to provide advice and guidance on the reduced flows to be expected in the Fairford River.

1. Ice Model Description

The *River Ice Generation and Accumulation* module has been developed by The LaSalle Consulting Group, DHI Water & Environment and Hydro-Quebec. It is aimed at simulating the formation and general characteristics of river ice components during a full winter period and to simulate spring pre-breakup conditions.

The *River Ice Generation and Accumulation* module calculates the generation and transport of different types of ice such as suspended frazil ice, surface ice, ice pans, border ice, anchor ice, static ice covers, suspended dam under ice cover, and the feedback and dynamic impact of these parameters on the hydrodynamic conditions. In addition, as generation and general properties of river ice are highly dependent on water temperatures in the modelled region, a detailed calculation of the total heat exchange budget is included to obtain an accurate calculation of water temperatures.

2. Fairford River HD Model

The MIKE11 hydrodynamic model of the Fairford River was provided by AECOM[1]. This model has a relatively complex network, with a total of eight branches reproducing the series of natural channels from Lake Manitoba to Lake Pinemuta.

The MIKE11-Ice module does not allow for multiple-branch networks. AECOM's model was therefore modified to simulate only one channel. Flow in the river was then varied along the river length to account for actual flow division between branches. Flow distribution along the main channel was fixed based on AECOM's multiple-branch model results. Figure 1 illustrates the resulting river network with the flow spatial variation obtained for a 300 m³/s outflow from Lake Manitoba.

River cross-sections were kept identical as the ones defined in the AECOM's model. For most branches, cross-sections were cut from a Digital Elevation Model (DEM) that combined LiDAR survey data for the out of river ground elevations and a sonar survey for the river bathymetry. According to AECOM, the MIKE11 cross-sections were the most up-to-date survey information for the Fairford River.

The Fairford Control Structure, modeled as a weir by AECOM, was kept the same in the LaSalle Consulting Group (LCG) model.

The LCG single-branch model was run for flows of 100, 200, 300, 400 and 500 m³/s and the resulting water levels were compared to the ones obtained with AECOM's multiple-branch model. Results were found to be very close and no further adjustments were made to the model. It was assumed that AECOM's multiple-branch model had been calibrated with observations and measurements for free surface conditions.

[1] FairfordRiver_LkManToLSM_111031.sim11 and its associated files:

- FairfordRiver_LkManToLSM_111031.nwk11;
- FairfordRiver_LkManToLSM_111031.xns11;
- FairfordRiver_LkManToLSM_111031.bnd11;
- FairfordRiver_LkManToLSM_111031.hd11.

Figure 1: MIKE11-Ice Fairford River Representation

3. Fairford River Ice Model

The Fairford River Ice Model was run with a time series of hourly air temperature registered at Grand Rapids station (5031A10) during the 2010-2011 winter. Measured temperatures were adjusted to obtain a total freezing index of 2 600°C-days, which is approximately equivalent to the freezing index of a 1 in 20 years winter in the studied region. The resulting air temperature time series is shown on Figure 2.

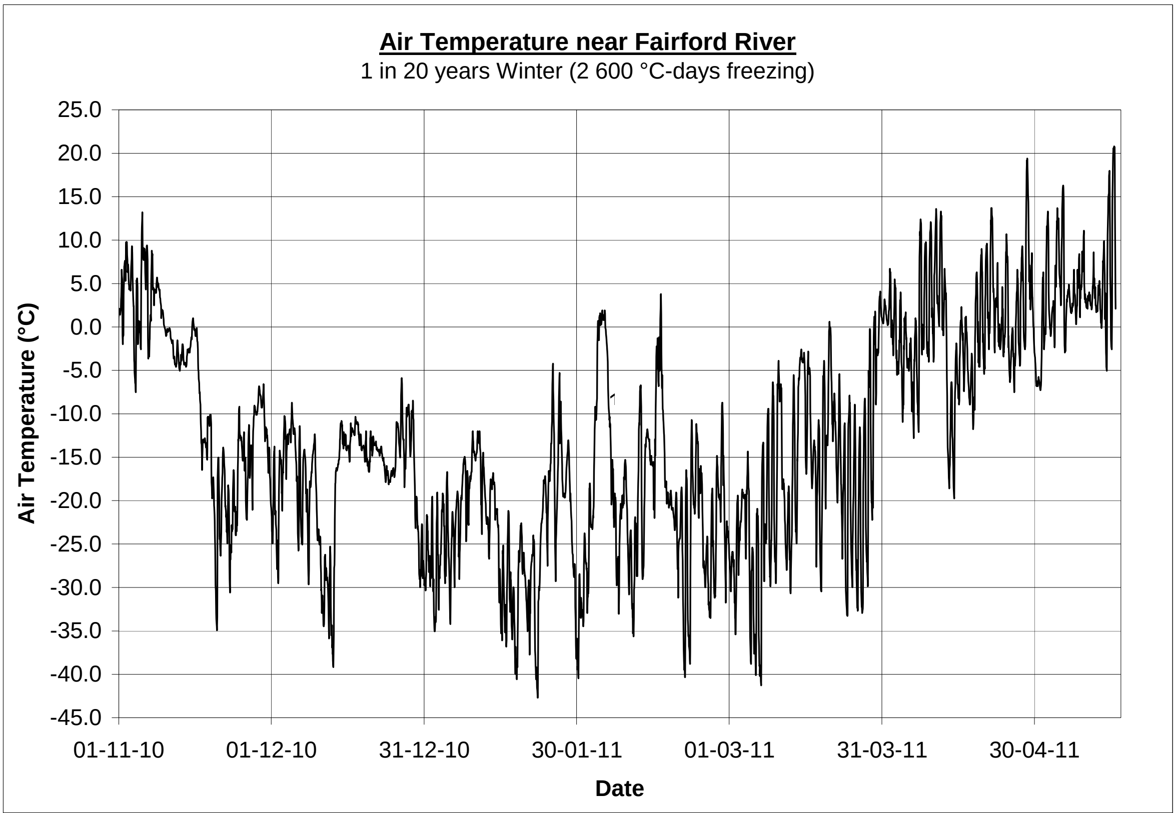


Figure 2: 1 in 20 years Winter Air Temperatures

Water outflow from Lake Manitoba was considered to be at 0°C from the beginning of winter until the month of March. Water temperatures were then increased from 0°C to 1°C in May, to represent the response of Lake Manitoba to increased solar radiation at springtime.

Downstream water level in Lake St. Martin was first set constant at an elevation of 245.12 m (804'). Sensitivity analysis with a higher water level of 245.43 m (805') showed that Lake St.

Martin water level had little effect on the water levels upstream of Lake Pinemuta. Final simulations were therefore run with a constant level of 245.12 m.

The main ice parameters were defined as follows:

- Maximum velocity for frazil ice deposition = 0.5 m/s ;
- Maximum velocity for ice pan deposition = 0.6 m/s
- Critical Froude number at the leading edge = 0.08
- Critical velocity at the leading edge = 0.5 m/s
- Roughness of ice covers = Manning *n* value of 0.018
- Roughness of juxtaposed ice covers = Manning *n* value of 0.04
- Roughness of the underside of hanging dams = Manning *n* value of 0.04

The model simulates an ice smoothing effect with time, and reduces hanging dams and juxtaposed covers roughness from 0.04 toward 0.018 exponentially with a time constant of 30 days.

4. Results

4.1 Constant flow simulations

In order to gain an initial insight of the ice generation and accumulation into the Fairford River, a first set of simulations was carried out with a constant flow throughout the river: 100, 200, 300, 400 and 500 m^3/s, for a sequence of air temperatures corresponding to a severe, 1 in 20 years winter.

Results show that the border ice progresses rapidly in the low velocity reaches, upstream of Lake St. Martin and into Lake Pinemuta. The higher velocities upstream of km 8.262 hinder ice progression, and the river remains ice free in December and January. The frazil ice generated into this upstream reach accumulates around km 8, and the hanging dam formed at this location eventually rises water levels, reduces velocities and allows for upstream progression of the ice cover by juxtaposition and closure of the generating surfaces. The resulting water and ice profiles are presented on Figures 3, 4 and 5, capturing the instant when the hanging dams are at their maximum extent.

For the lowest flows, 100 and 200 m^3/s, the ice effects are mostly driven by the thickening of the thermal covers, since they form rapidly and do not allow for a significant frazil ice generation and accumulation. For the highest flows, some ice accumulation occurs on the lower reach, downstream of Lake Pinemuta, but the main hanging dam is still observed in the upper reach.

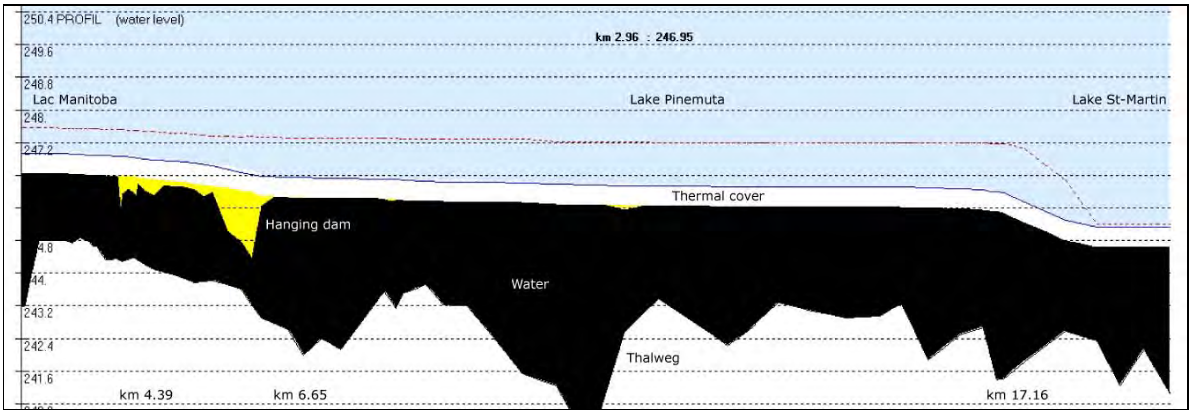


Figure 3: Constant Flow Simulation: 100 m^3/s

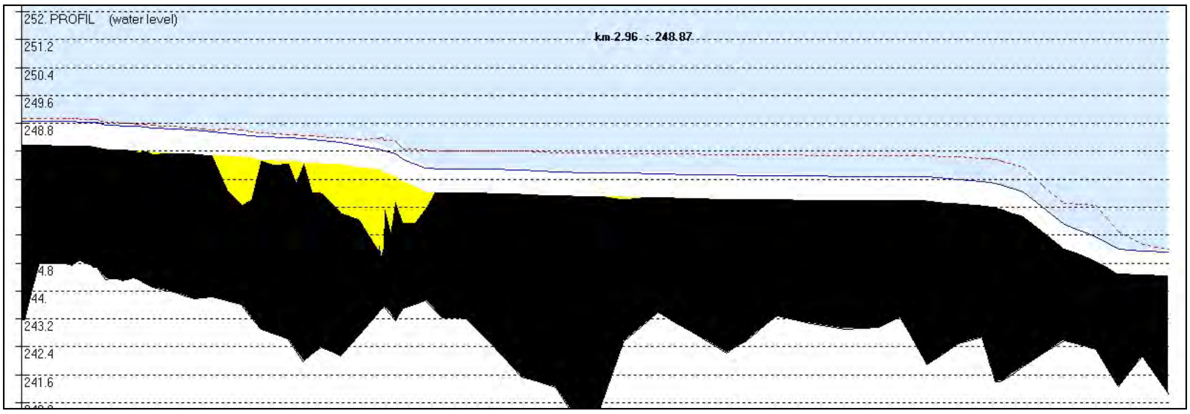


Figure 4: Constant flow simulation: 300 m^3/s

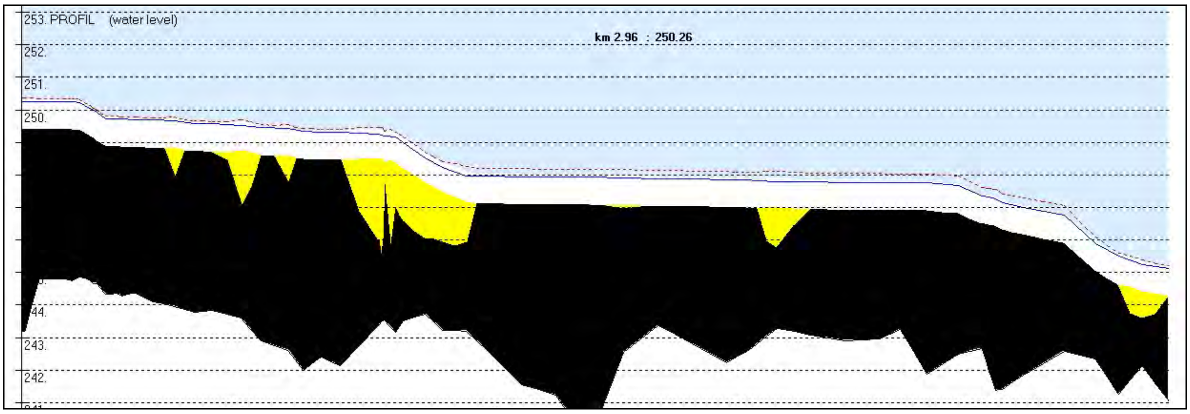


Figure 5: Constant Flow Simulation: 500 m^3/s

The resulting maximum level reached at the upstream end of the model, which corresponds to the outlet of Lake Manitoba, is higher that the level computed for the ice free conditions. The ice effects, varying with the flow, are presented at the outlet of Lake Manitoba on Figure 6, and at the tailrace of the Fairford Control Structure on Figure 7.

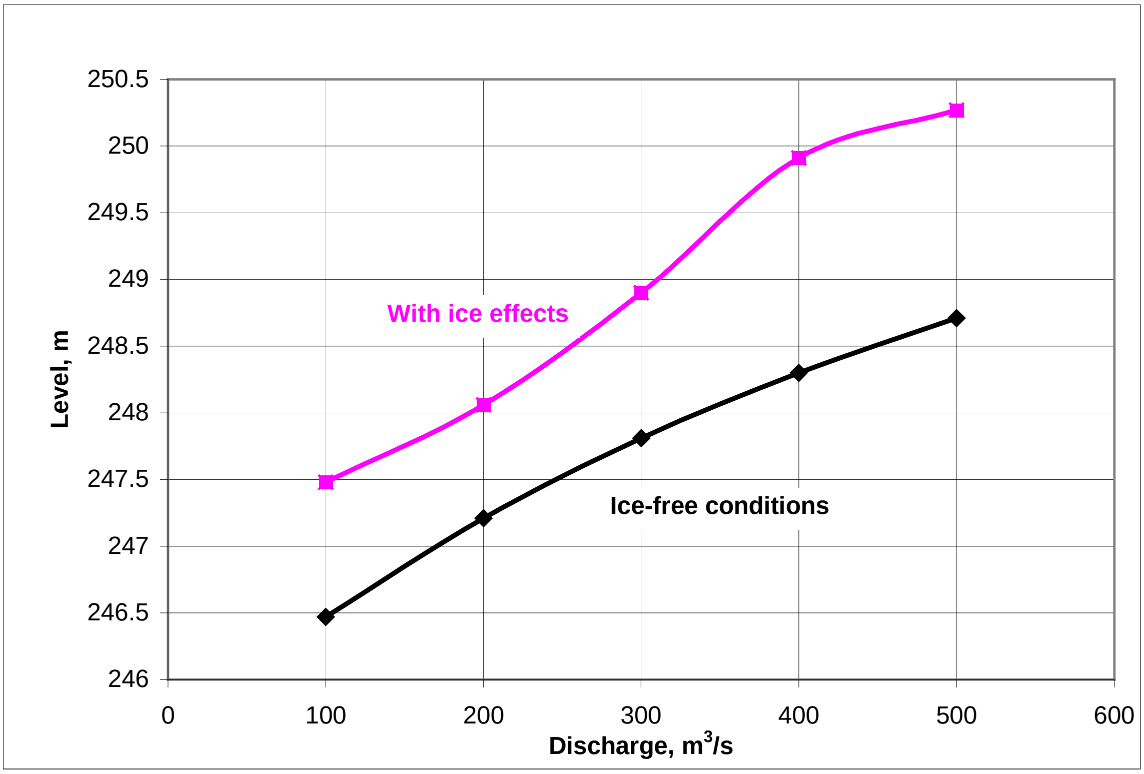


Figure 6: Water Levels at the Outlet of Lake Manitoba, km 2.96

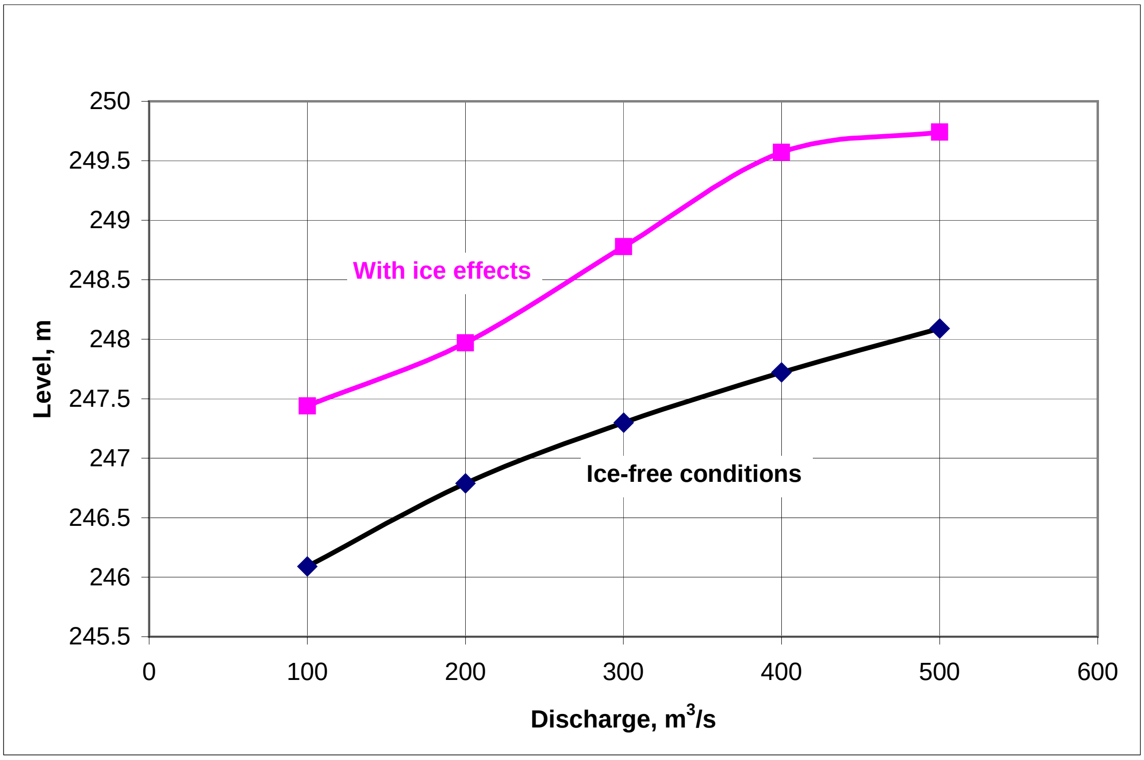


Figure 7: Water Levels at the Tailrace of the Fairford Control Structure, km 4.18

It is acknowledged that the presence of ice does not actually rise the level of Lake Manitoba, but rather reduces the outflow from the lake and into the Fairford River because of the obstruction it creates. Inspection of Figure 6 shows that for a given constant level of Lake Manitoba, the flow in the presence of ice is reduced by some 150 to 250 m^3/s. It is expected under these conditions that the winter flow in the river would be about 200 m^3/s lower than it would be in the absence of ice effects.

Flow reduction caused by ice is evaluated with a better accuracy through a variable flow calculation, presented in the next section.

4.2 Variable flow simulations

In a second type of simulations, the MIKE-Ice model was run by defining the upstream and downstream water levels as boundary conditions.,The downstream condition (Lake St. Martin) was held constant at 245.12 m. As it was previously mentioned, the actual Lake St. Martin level throughout the winter has little effect on the ice dynamics in the upstream reach of the Fairford River (upstream of lake Pinemuta). The imposed Lake Manitoba levels were obtained iteratively: during a first run of the model, the water level was varied from 248.50 m (815') to 248.17 m (814') in early winter and kept constant at 248.17 m (814') for the rest of the winter. These values were obtained from results previously presented by KGS. This first run of the model resulted in a time series of the lake outflow affected by ice, Q_{out}, . This time series was then used to compute a better estimate of the variation of the lake level, *y*. A simple flow routing through the lake was used to this purpose:

$$A \frac{dy}{dt} = Q_{in} - Q_{out}$$

The surface *A* of Lake Manitoba is 4 624 km^2, and the natural inflow Q_{in} , varying in time, was estimated from results previously presented by KGS. A single iteration was sufficient to obtain a stable solution, for which the assumed lake level matched the one resulting from the computed winter outflow.

The ice cover progresses thermally and by juxtaposition from Lake St. Martin in early winter. Frazil ice is generated in December and early January in the upper reach, and accumulates near the inlet of Lake Pinemuta, while the river flow is progressively reduced. The river is fully closed by January 18th, and the hanging dams are at their maximum extent at this time. The resulting ice conditions are depicted on Figure 8 below. The river discharge is then reduced to 208 m^3/s, and its variation until mid-April is solely driven by the water level of Lake Manitoba and the gradual thickening of the thermal ice covers.

The model reproduces the thermal conditions at spring time, and the ice is progressivly melted by the increase of air temperature, solar radiation, and water temperature from Lake

Manitoba. It was assumed that the incoming water temperature increased quadraticaly from 0 to 1°C from April 1st to May 1st. The flow velocity along the river in April remains low, 0.2 to 0.6 m/s, and it is estimated that the ice will melt in place, without break-up and ice-run.

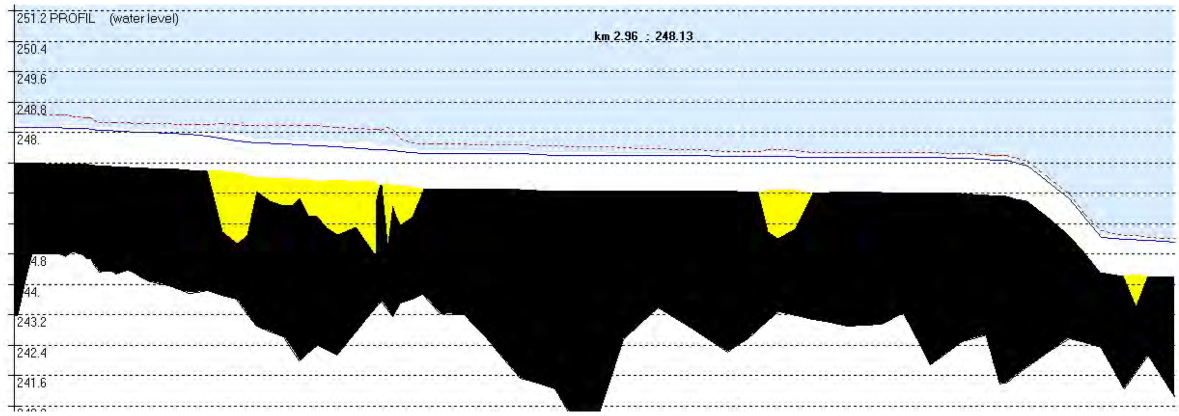


Figure 8: Variable Flow Simulation. Ice Conditions, January 18th.

The flow variation resulting from these processes is presented on Figure 9 below for a severe, 1 in 20 years winter (2 600 freezing °C-days). The resulting water level of Lake Manitoba is depicted on Figure 10. The minimum water level is 248.10 m (813.98'), reached on April 15th.

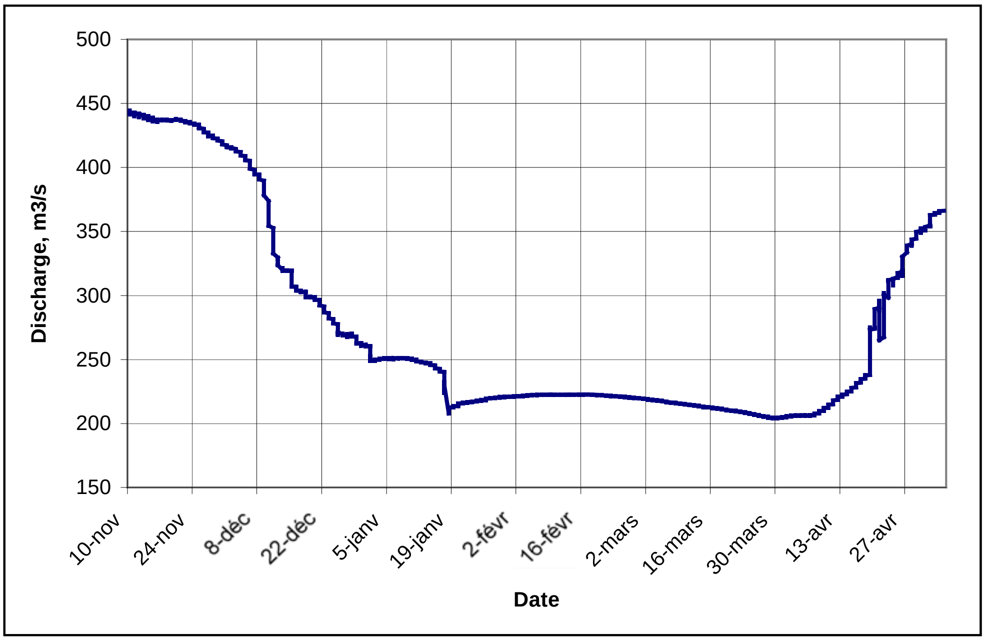


Figure 9: Winter Flow Variation in the Fairford River.

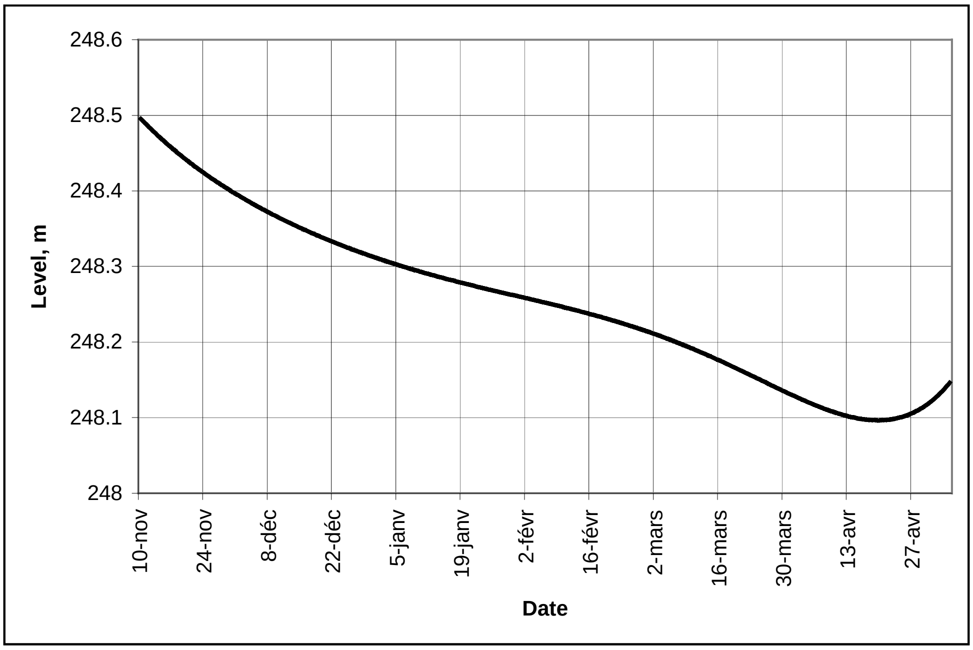


Figure 10: Lake Manitoba Winter Level.

Finally, the sensitivity of these results to the coldness of winter was assessed by considering an average winter, instead of the harsh, 1 in 20 years winter previously considered. To this purpose, the air temperature recorded at the Grand Rapid station was used, with its 2 200 °C-days freezing index, close to the long term average. The resulting flow reduction is presented on Figure 11.

As shown in Figure 11, the minimum flow is less than during the more severe winter. This is due to the fact that the border ice does not progress as rapidly, allowing a larger volume of frazil ice to be generated and accumulated. The effect on the Lake Manitoba water level is less than 5 cm, at the limit of the accuracy of our analysis.

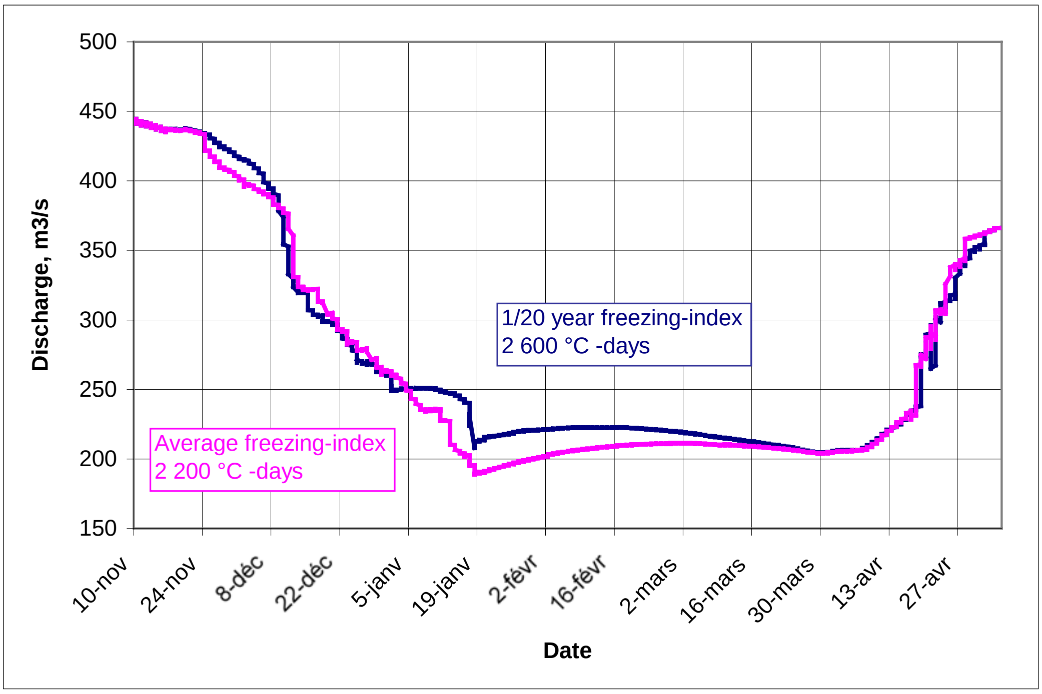


Figure 11. Flow Variations during Average and Cold Winters

5. Conclusions

The numerical model MIKE-Ice was used to clarify the ice regime in the Fairford River during the incoming winter.

A first set of simulations at constant flow was run to establish rating curves in the presence of ice for the lake outlet, and showed that the formation and accumulation of ice in the river, upstream of Lake Pinumeta, would reduce the winter flow by some 200 m^3/s.

A gradual reduction of the winter flow was then simulated, controlled by the level of Lake Manitoba and the ice conditions in the river. Results show that the river discharge gradually decreases from 450 m^3/s in early winter to a minimum of 200 m^3/s, reached in the second half of January. It remains at that value until mid-April, when the melting in place of the ice creates an increase of flow, up to 350 m^3/s reached on May 1st. The resulting water level for Lake Manitoba passes through a minimum of 248.10 m (814 '), reached on April 15th.

These results differ somewhat from those presented by KGS. The change of flow is more gradual in early winter and spring, and the minimum flow in the middle of winter is larger. The total volume of water leaving the lake is however comparable, and the minimum level reached during winter is the same.

APPENDIX G – ANNEX 3

LASALLE CONSULTING GROUP MODEL FILES

(Not Printed – Included on DVD)

APPENDIX H

PHOTOS AND SATELLITE IMAGERY

Comprised of 2 Separate Appendices:
Annex 1: Time Lapse Camera and Air Photos (Not Printed – Included on DVD)
Annex 2: Satellite Imagery

APPENDIX H – ANNEX 1

TIME LAPSE CAMERA AND AIR PHOTOS

(Not Printed –Included on DVD)

APPENDIX H - ANNEX 2

SATELLITE IMAGERY

Garrett Wellwood

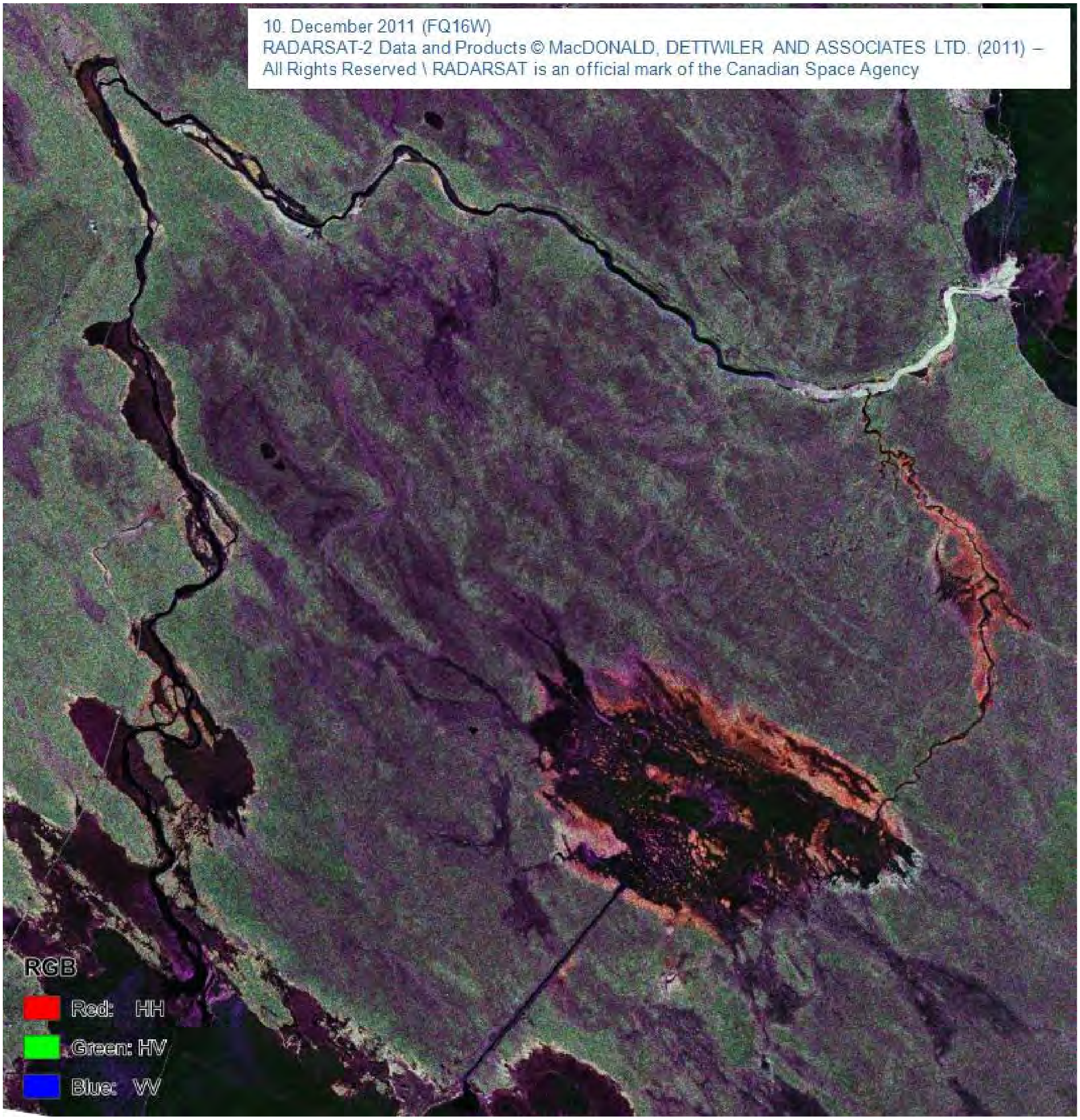
From: Patrice Leclercq [PLeclercq@kgsgroup.com]
Sent: Tuesday, January 22, 2013 10:46 AM
To: 'Patrice Leclercq'
Subject: FW: high resolution satellite imagery of Dauphin River - Buffalo Creek system

----- Original Message -----
From: Lindenschmidt, Karl-Erich (MWS)
To: 'Rick Carson'
Cc: Kaatz, Ron G (MIT) ; Harrison, Bob (MWS)
Sent: Tuesday, December 13, 2011 8:57 AM
Subject: high resolution satellite imagery of Dauphin River - Buffalo Creek system

Hi,

Below is a high resolution satellite image of the Dauphin River – Buffalo Creek system revealing many details and features. E.g.:

- Extent of hanging dam at mouth of Dauphin River (red shading)
- Extent of frozen flooded area around Buffalo Lake and mid-reach of Buffalo Creek (orange shading)
- Extent of ice cover along the Lower Dauphin River into Lake Winnipeg (white colouring)
- etc. (more on the phone if required)



Karl-Erich Lindenschmidt (Ph.D., P.Eng.)
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E: Karl-Erich.Lindenschmidt@gov.mb.ca

Garrett Wellwood

From: Rick Carson [RCarson@kgsgroup.com]
Sent: Wednesday, January 04, 2012 10:51 AM
To: 'Brian Bodnaruk'; 'Patrice Leclercq'
Cc: 'Colin Siepman'
Subject: FW: Satellite image - 4 Janaury 2012

FYI

R.W. Carson, P.Eng., P.E., M.Sc.C.E.
Senior Consultant
KGS Group
865 Waverley Street, KGS Place
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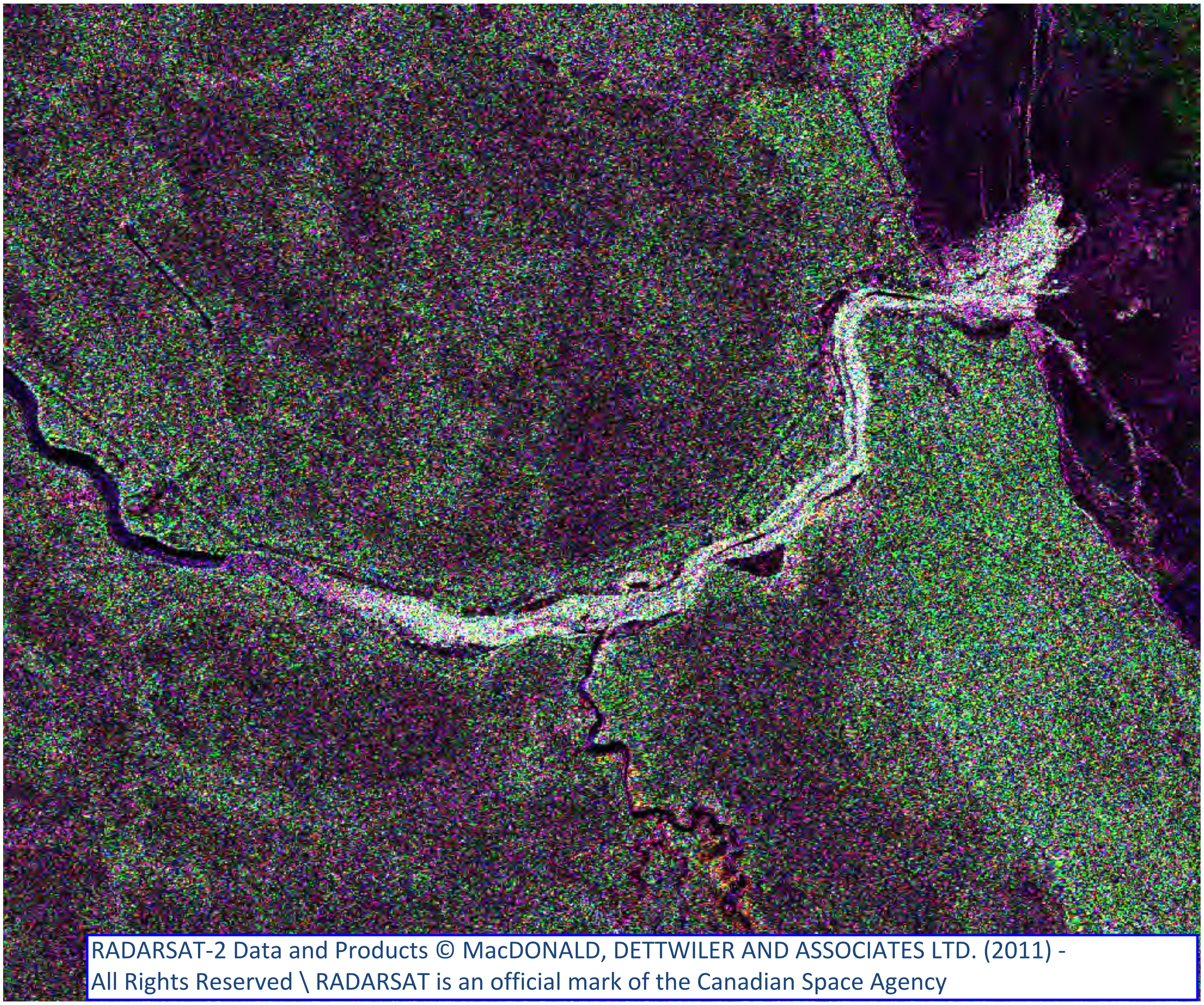
From: Lindenschmidt, Karl-Erich (MWS) [mailto:Karl-Erich.Lindenschmidt@gov.mb.ca]
Sent: Wednesday, January 04, 2012 10:43 AM
To: 'RCarson@kgsgroup.com'
Cc: 'Colin Siepman'; Kaatz, Ron G (MIT)
Subject: Satellite image - 4 Janaury 2012

Hi Rick,

Below is a satellite image of the Lower Dauphin River acquired this morning. There is a substantial amount of ice in the Lower Dauphin River, but still open leads along the ice cover between Buffalo Creek and Lake Winnipeg. It looks like that the ice cover upstream of the Buffalo Creek confluence may be intact. Perhaps we can discuss on the phone.

Karl



Karl-Erich Lindenschmidt (Ph.D., P.Eng.)
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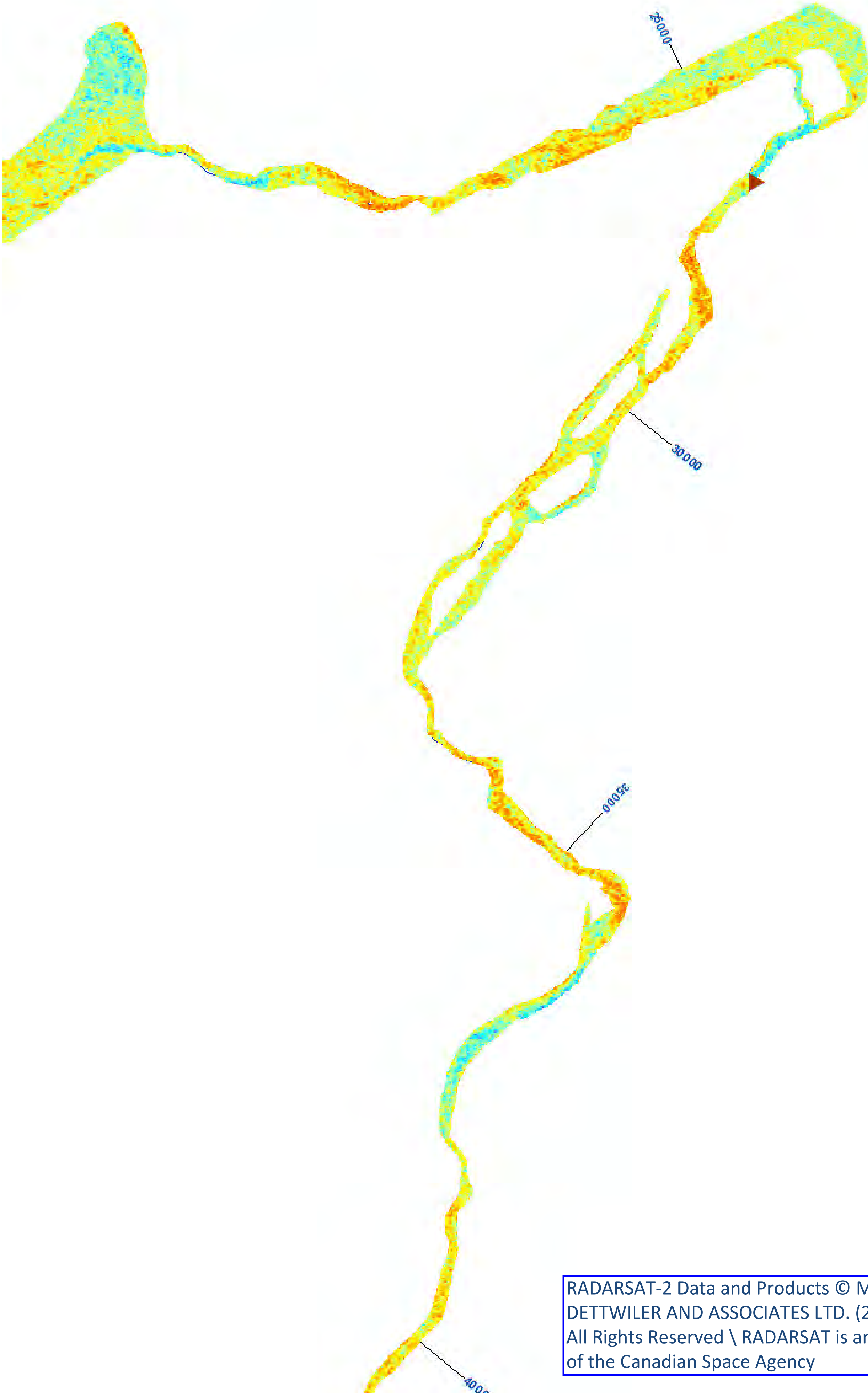
E: Karl-Erich.Lindenschmidt@gov.mb.ca
W: http://www.gov.mb.ca/waterstewardship

Frenchman’s Rapids
20 January 2012

SPOT-5
2.5 m resolution

20 January 2012
SPOT5


25000
30000
35000

From: Colin Siepman [CSiepman@kgsgroup.com]
Sent: Wednesday, March 14, 2012 12:36 PM
To: Patrice Leclercq
Subject: FW: 14 March 2012 satellite iamge

Follow Up Flag: Follow up
Flag Status: Red
Please file this image

From: Lindenschmidt, Karl-Erich [mailto:karl-erich.lindenschmidt@usask.ca]
Sent: March 14, 2012 12:21 PM
To: Colin Siepman (CSiepman@kgsgroup.com)
Cc: Kaatz, Ron G (MIT) (Ron.Kaatz@gov.mb.ca); Rick Carson; Brian Bodnaruk
Subject: 14 March 2012 satellite iamge

Hi,

The satellite imagery from today shows lots of areas with water (dark and light blue areas) long the Dauphin River, especially in the upper reach between Lake St. Martin and Big Bend. The imagery cannot differentiate between open-water column and water-on-ice, though. The lower reach still has an ice cover of about 10 km in length (yellow areas).

I hope to get another image in two days that will have finer resolution and show more detail.

Karl

Radarsat-1 image from 14 March 2012 (preliminary results – for review only):

______ ______________________

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Global Institute for Water Security

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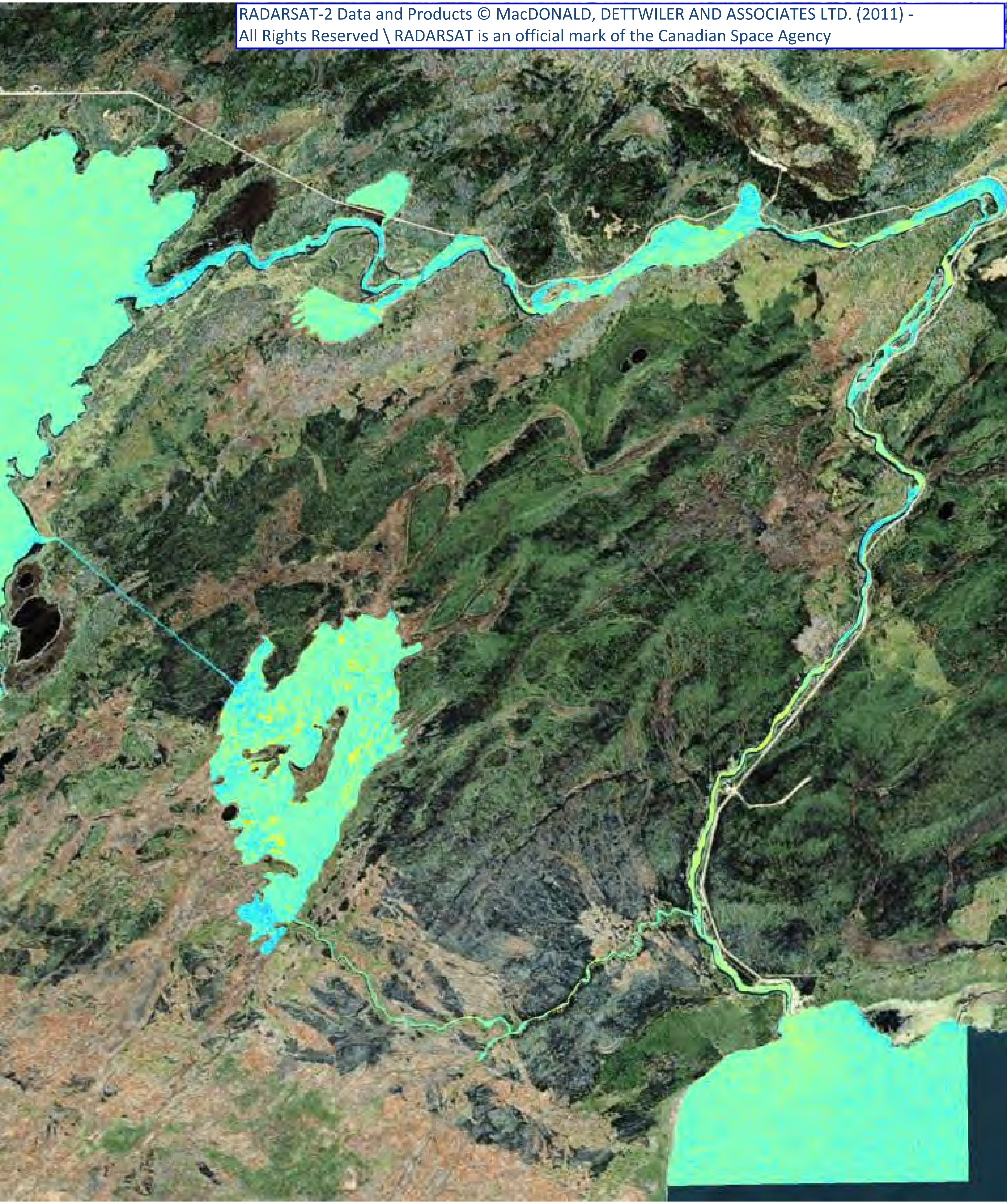
Tel: (306) 966-6174
Fax: (306) 966-1193
email: karl-erich.lindenschmidt@usask.ca



From: Colin Siepman [CSiepman@kgsgroup.com]
Sent: Friday, March 16, 2012 11:46 AM
To: Patrice Leclercq
Subject: FW: Dauphin River ice cover report - 16 March 2012

Attachments: DauphinRiver_RS2-FQ5W_16march2012.pdf
Please file

From: Lindenschmidt, Karl-Erich [mailto:karl-erich.lindenschmidt@usask.ca]
Sent: March 16, 2012 10:03 AM
To: Colin Siepman (CSiepman@kgsgroup.com)
Cc: Rick Carson; Kaatz, Ron G (MIT) (Ron.Kaatz@gov.mb.ca); Brian Bodnaruk
Subject: Dauphin River ice cover report - 16 March 2012

Hi Colin,

Attached is a RADSAT-2 image from today (16 March 2012). Please note that the image for the upper Dauphin River is rotated so that "North" points to the left.

It appears (observations in the flow direction):

- Dauphin River inlet has open water
- still some ice immediately upstream of Frenchman's Rapids
- Sarvis Flats still has ice
- there is still ice upstream and downstream of Big Bend (imagery does not encompass Big Bend area, though)
- substantial ice cover upstream of Cranberry Creek
- open water for 2 km (possibly 4 km) downstream from Cranberry Creek
- remaining stretch of lower Dauphin River has an intact ice cover – open water lead between Buffalo Creek inlet and Lake Winnipeg.
- Lake Winnipeg's ice cover at the Dauphin River confluence is intact.

The ice cover is tenaciously staying intact in some places. Let's see what happens after all the warm weather this weekend. Perhaps you can send the KGS survey crew out again beginning of next week.

Unfortunately, the next image will be acquired 23 March 2012. After that, the acquisition frequency is daily or every second day. Ron Kaatz will fly over Dauphin River on Monday (19 March 2012) to capture video and still imagery). Hence, we'll only be in "the dark" for 3 days. Perhaps I will pick up some imagery from the visible-spectrum satellites (SPOT5 and Rapideye) during that time but cannot guarantee that a suitable image will be captured. Unlike RADARSAT, the visible-spectrum satellites can only acquire images during daylight hours and are obviously affected by cloud cover.

Karl

P.S.: As always, an important caveat with RADARSAT imagery is that it is difficult to distinguish between open water and water-on-ice stretches. This is because much of the microwaves transmitted from the satellite (transmitted obliquely to the earth's surface) bounces off water surfaces away from the satellite and the image appears dark (black) in those areas. Microwaves scatter from ice surfaces and the backscattered signal can be received by the satellite, hence images are brighter (red-green-blue hue) from ice surfaces.

_____ ___________________

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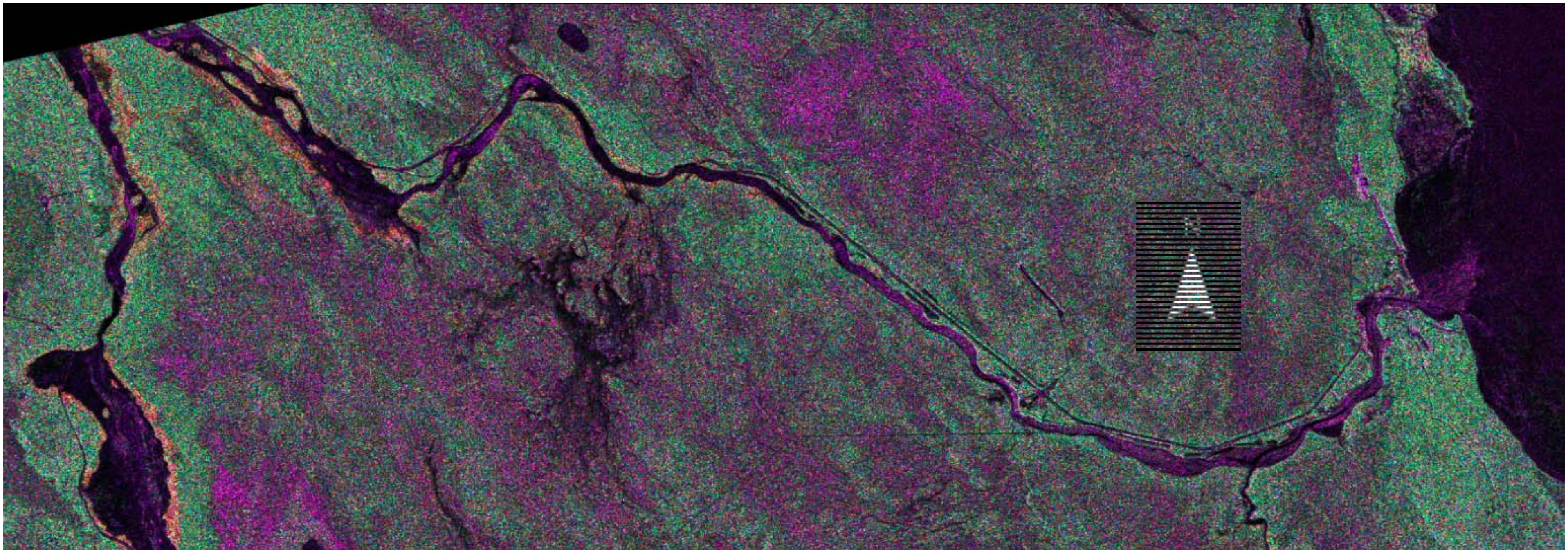
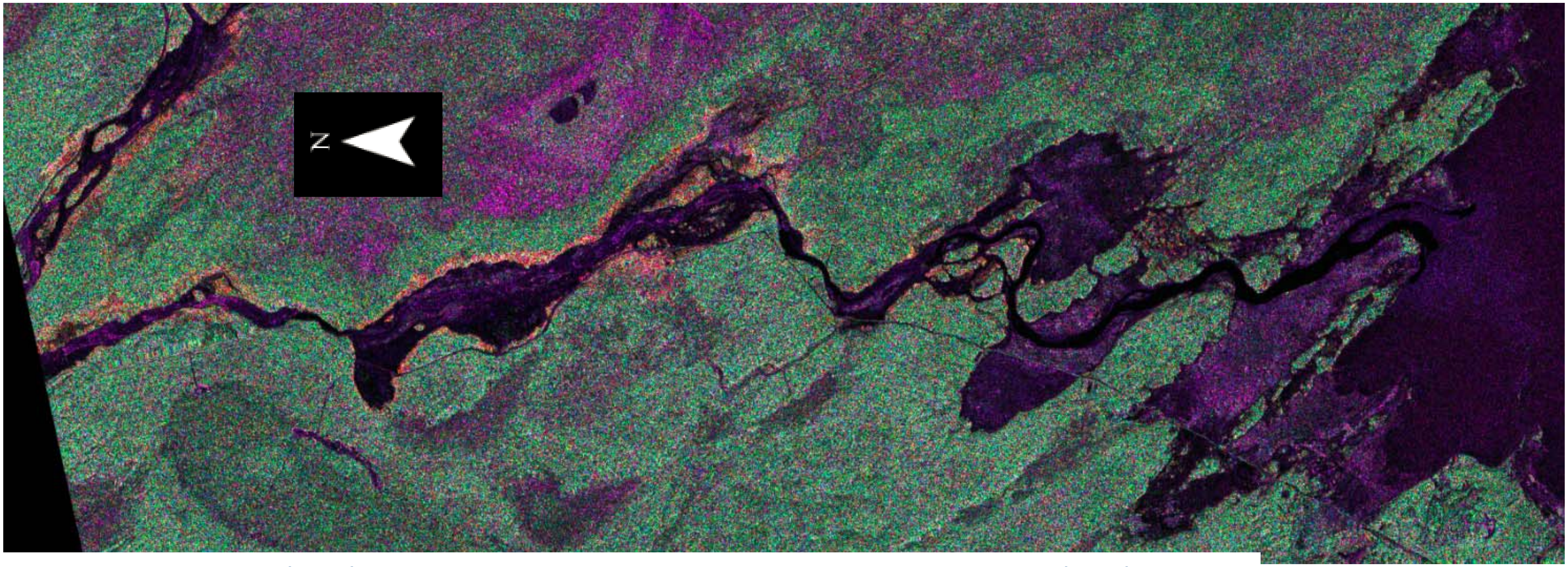
Fax: (306) 966-1193
email: karl-erich.lindenschmidt@usask.ca

RADARSAT-2 image (16 March 2012) of Lower Dauphin River →



RADARSAT-2 image (16 March 2012) of Upper Dauphin River →



prepared by Karl-Erich.Lindenschmidt@usask.ca

Garrett Wellwood

From:	Colin Siepman [CSiepman@kgsgroup.com]
Sent:	Sunday, April 01, 2012 9:31 PM
To:	Patrice Leclercq
Cc:	Brian Bodnaruk; Steve Offman; Warren Bernhardt
Subject:	FW: status of lake ice covers
Follow Up Flag:	Follow up
Flag Status:	Completed
Attachments:	MODIS_01April2012.pdf

FYI,

Patrice please file this info.

From: Lindenschmidt, Karl-Erich [mailto:karl-erich.lindenschmidt@usask.ca]
Sent: April 1, 2012 8:05 PM
To: Colin Siepman (CSiepman@kgsgroup.com)
Cc: Kaatz, Ron G (MIT) (Ron.Kaatz@gov.mb.ca); Rick Carson
Subject: status of lake ice covers

Hi,

Referring to today's (1 April 2012) MODIS satellite image (see attached), there is still on ice cover on the south basin of Lake St. Martin. The ice covers on the north basin of Lake St. Martin and on Buffalo Lake have almost completely (≈80% - 90%) thawed. The Lake Winnipeg ice cover is still intact.

Karl

______ ______________________

Karl-Erich Lindenschmidt, Ph.D., P.Eng.
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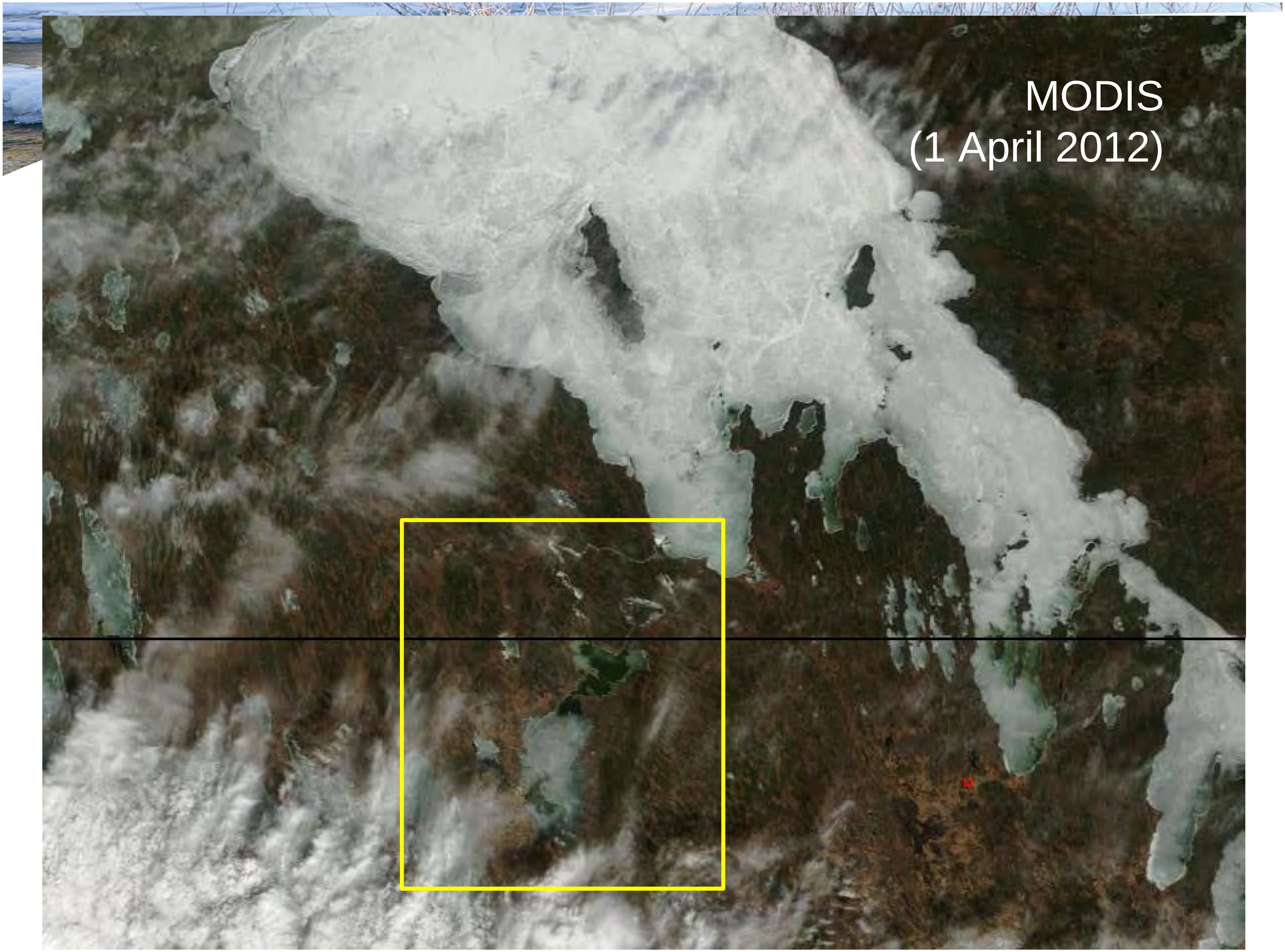

MODIS
(1 April 2012)

APPENDIX I

SURVEYED WATER LEVELS

Comprised of 2 Separate Appendices:

Annex 1: MIT Data
Annex 2: KGS Group Data

APPENDIX I - ANNEX 1

MIT DATA

TABLE I1-1: Measured Water Levels on Fairford and Dauphin River

	LMB @ Decker RD	Lake MB Shore - Gauge 1	Gauge 1A - 100m u/s dam	Gauge 2 - @ Dam (u/s)	Gauge 3 - @ Dam (u/s)	Gauge 3A/B - 100 m d/s	Gauge 4 - Old RR bed	Gauge 6 - Partridge Creek	Gauge 5 - Lower Fairford Br.	Gauge 5A - Lower Fairford Br. (u/s)	Gauge 5B/C - Lower Fairford Br. (d/s)	Gauge 8 - Big Rock Camp	Gauge 9 – DR Internal Site	Gauge 10 - Frenchmens Rapids	Gauge 11	Gauge 12	Guage 13	Guage 14	Gauge 15	Dauphin River Reserve
Coordinates	5714771 N	5714771 N	5715265 N	5715193 N	5715268 N	5715377 N	5716880 N	5728977 N	5718399 N	5718369 N	5718283 N	5741284 N	5747336 N	5749424 N	5761434 N	5759395N	5759101 N	5760338 N	5759021 N	5756807 N
	518221 E	518221 E	518701 E	518842 E	518916 E	519022 E	520705 E	523737 E	526505 E	526422 E	526606 E	544134 E	545549 E	546077 E	546041 E	549163 E	549565 E	551850 E	554423 E	563905 E
DATE	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
27-Oct-11	248.46	248.30	248.24	248.20	247.80	247.72	246.52	245.57	245.35			245.09	245.09	243.93						
1-Nov-11	248.69	248.26	248.25	248.21	247.81	247.74	246.51	246.01	245.35			245.06	245.06	243.09						
8-Nov-11	248.38	248.24	248.16	248.14	247.74	247.65	246.47	245.92	245.24	245.49	245.21	244.88	244.45	243.69						
10-Nov-11	248.35	248.21	248.14	248.11	247.71	247.63	246.44	245.89	245.21	245.46	245.18	244.82	244.40	243.61			236.74	235.48		
12-Nov-11	248.36	248.20	248.14	248.10	247.71	247.63	246.44	245.89	245.19	245.46	245.16	244.79	244.37	243.58		236.81	236.72	235.46		
14-Nov-11	248.71	247.31	247.30	247.34	246.93	246.61	245.49	245.45	245.18	245.43	245.14	244.76	244.34	243.54		236.49	236.22	234.90		
15-Nov-11	248.38	248.24	248.17	248.13	247.74	247.66	246.46	245.89	245.16	245.45	245.13	244.76	244.33	243.52	239.52	236.73	236.64	235.38		
17-Nov-11	248.714	247.306	247.298	247.344	246.932	246.605	245.492	245.447	245.155	245.393	245.133	244.712	244.282	243.425			236.744	235.477		
19-Nov-11	248.384	247.306	247.298	247.954	247.682	246.605	246.522	245.887	245.185	245.423	244.263	244.666	244.206	243.345	239.522		236.644	235.377		
21-Nov-11	248.384	247.306	247.298	247.934	246.932	246.605	246.562	245.887	245.195	244.543	244.263	244.636	244.251	243.545	239.522		236.644	235.377		
23-Nov-11	248.714	248.210	248.120	247.944	247.732	247.663	246.562	245.967	245.125	245.423	245.355	244.620	244.175	243.385	238.162		236.224	235.152		218.168
25-Nov-11	248.714	248.190	248.130	248.044	247.702	247.623	246.482	245.887	245.095	245.273	245.135	244.620	244.175	243.375	238.162		236.431	235.162		217.968
27-Nov-11	248.714	248.200	248.104	248.024	247.692	247.623	246.452	245.847	245.055	245.193	245.105	244.605	244.175	243.375	237.896		236.431	235.182	234.416	217.898
29-Nov-11	248.714	248.280	248.104	248.054	247.702	247.643	246.472	245.837	245.025	245.223	245.085	244.605	244.160	243.355	238.031		236.421	235.212	234.426	218.088
1-Dec-11	248.714	248.220	248.074	247.994	247.662	247.603	246.432	245.837	245.065	245.243	245.125	244.590	244.160	243.355	237.991		236.501	235.382	234.506	218.308
3-Dec-11	248.714	248.240	248.064	247.964	247.672	247.593	246.432	245.827	245.045	245.243	245.065	244.559	244.130	243.295	238.001		236.611	235.422	234.686	218.238
5-Dec-11	248.714	248.240	248.064	247.994	247.672	247.603	246.442	245.847	245.115	245.263	245.145	244.559	244.160	243.335	237.991		236.561	235.382	234.566	
7-Dec-11	248.714	248.240	248.060	248.034	247.662	247.603	246.472	245.937	245.275	245.293	245.165	244.559	244.206	243.465	237.941		236.121	235.302	234.446	
9-Dec-11	248.714	248.240	248.050	247.904	247.682	247.603	246.542	246.047	245.325	245.353	245.235	244.575	244.175	243.365	237.801		236.121	235.072	234.286	
11-Dec-11	248.714	248.240	248.045	247.904	247.672	247.603	246.512	245.997	245.235	245.273	245.175	244.544	244.145	243.285	238.281		236.801	235.562	234.656	
13-Dec-11		248.220	248.030	247.914	247.662	247.583	246.452	245.897	245.155	245.263	245.085	244.559	244.206	243.365	238.211		236.731	235.512	234.646	
15-Dec-11		248.109	248.010	247.874	247.662	247.573	246.432	245.857	245.165	245.273	245.045	244.562	244.114	243.205	238.251		236.811	235.632	234.716	
17-Dec-11		248.068	248.03	247.894	247.662	247.583	246.422	245.847	245.125	245.263	245.015	244.5593	244.1753	243.385	238.211		236.641	235.502	234.606	
19-Dec-11		248.098	247.995	247.904	247.642	247.563	246.402	245.807	245.253			244.544	244.145	243.262	238.281		236.841	235.602	234.666	
21-Dec-11		248.088	247.990		247.632	247.543	246.382	245.787	245.095	245.253	244.835	244.544	244.114	243.212	237.891		236.861	235.512	234.586	
3-Jan-12		247.388	247.940		247.572	247.513	246.362	245.807	245.145	245.293		244.514	244.145		237.831				234.276	220.350
12-Jan-12		247.965	247.860		247.472	247.453	246.312	245.767	245.125	245.313		244.498	244.236		237.596				234.101	
16-Jan-12		247.967	247.864		247.522	247.468	246.322		245.095	245.283										
19-Jan-12		247.965	247.889	247.799	247.472	247.473	246.372		245.205	245.453	245.295	244.483	244.236							
24-Jan-12		247.958	247.835	247.802	247.492		246.342		245.095	245.353		244.568								
2-Feb-12		247.911	247.786	247.777	247.452		246.282		245.095	245.283		244.575								
9-Feb-12		247.866	247.767	247.738	247.384	247.361	246.202		244.989	245.184	244.986	244.544								
16-Feb-12		247.859	247.739	247.713	247.384	247.346	246.232		244.968	245.168	244.958	244.428								
23-Feb-12		247.830	247.709	247.695	247.396	247.314	246.202		244.916	245.127	244.921	244.417								
1-Mar-12		247.787	247.663	247.643	247.316	247.276	246.172		244.890	245.090	244.890	244.378								
8-Mar-12			247.625	247.623	247.290	247.249	246.162		244.881	245.081	244.876	244.366								
15-Mar-12		247.760	247.637	247.625	247.298	247.245	246.142	245.557	244.843	245.063	244.848	244.345	243.930	243.248	238.244		236.682	235.408	234.676	
19-Mar-12												244.292	243.779	243.089	237.817		237.028	235.718	234.934	
21-Mar-12												244.302	243.793	243.117	237.373		236.118	234.835	234.151	
22-Mar-12		247.768	247.650	247.627	247.298	247.250	246.142	245.552	244.818	244.938	244.808	244.264								
23-Mar-12												244.240	243.720	243.046	237.330		236.029	234.666	234.055	

FIGURE I1-1
Fairford River Water Surface Elevation
MIT Gauge Stations

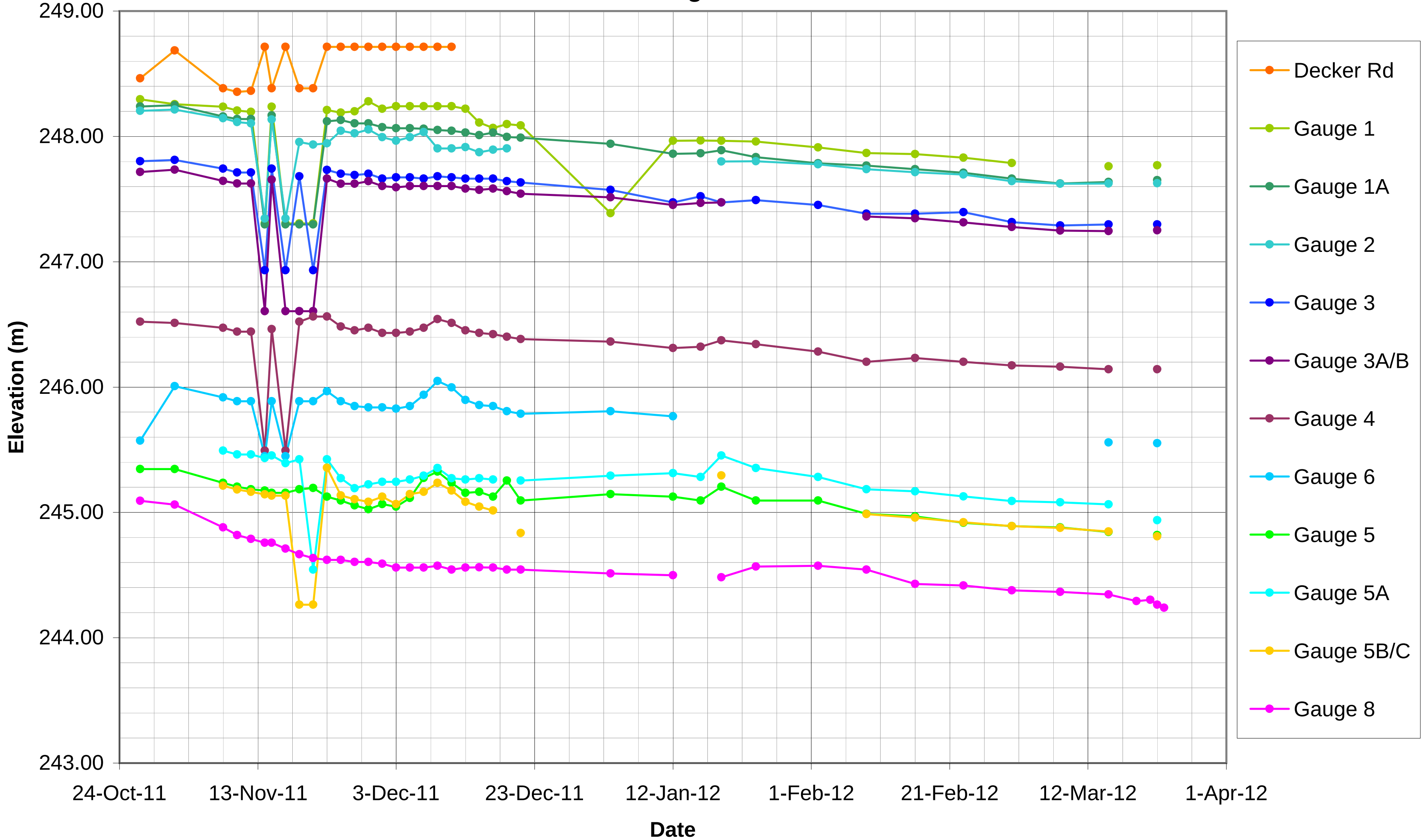
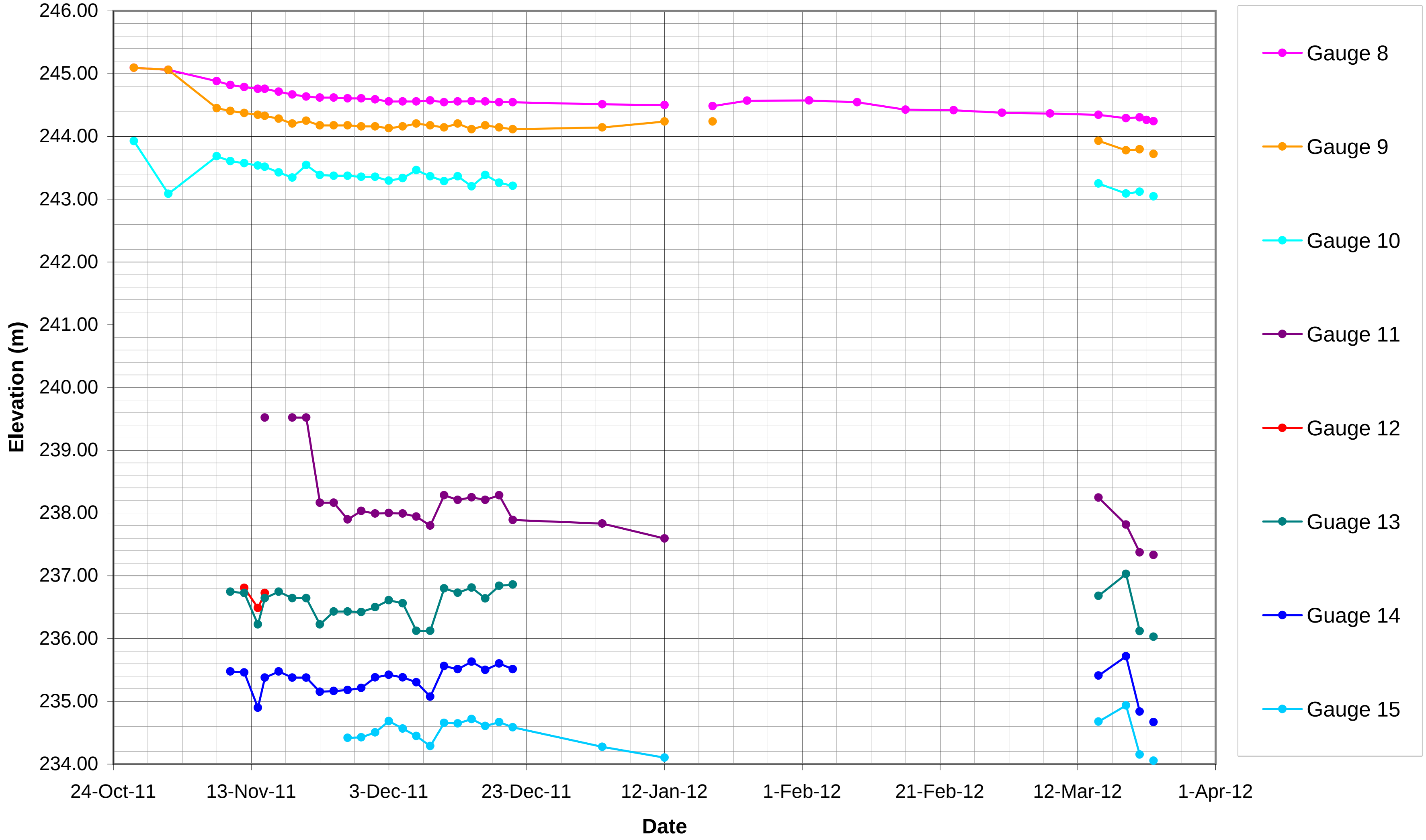


Figure I1-2
Dauphin River Water Surface Elevation
MIT Gauge Stations



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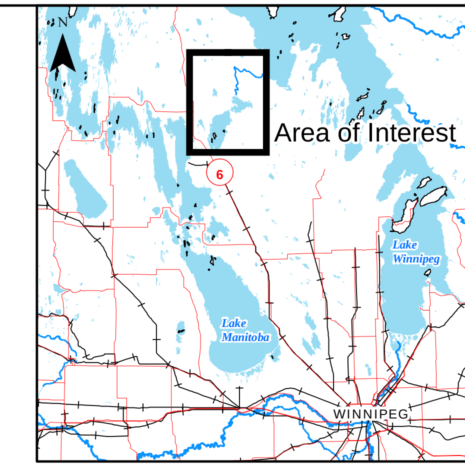
11"x17" PLOT SCALE 1:1



LEGEND:

- MIT Water Level Gauges
- Reach 3 Emergency Channel
- Buffalo Creek Channel
- Reach 1 Emergency Channel
- Trail
- Municipal Road
- Highway
- Transmission Line
- Limited Use Road
- Water Line
- Wetlands
- Water Feature
- First Nation
- Campsite

0 2 4 6 8 10
Kms

SCALE: 1:200,000 METRIC 11"x17"

All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

NO.	YY/MM/DD	DESCRIPTION	BY
0	14/03/05	ISSUED WITH FINAL REPORT	PAL

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS

Manitoba INFRASTRUCTURE AND TRANSPORTATION

EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

MIT WATER LEVEL GAUGE LOCATIONS

MARCH 2014 | FIGURE I1-3 | REV: 0

APPENDIX I - ANNEX 2

KGS GROUP DATA

KGS GROUP WATER LEVEL MONITORING

January 6, 2012

TABLE 1. DAUPHIN RIVER WATER LEVELS

Date	Time	Water Level (m)								
		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
20-Nov-11	10:30	218.410	218.550	219.210	-	-	-	-	-	-
20-Nov-11	10:30	218.640	218.750	219.320	-	-	-	-	-	-
21-Nov-11	09:00	218.650	218.850	219.400	-	-	-	-	-	-
21-Nov-11	17:00	218.670	218.860	219.410	-	-	-	-	-	-
22-Nov-11	10:00	218.610	218.850	219.410	-	-	-	-	-	-
22-Nov-11	17:30	218.410	218.580	219.410	-	-	-	-	-	-
23-Nov-11	08:30	218.320	218.510	219.460	-	-	-	-	-	-
24-Nov-11	18:00	217.860	218.000	219.120	-	-	-	-	-	-
25-Nov-11	08:30	217.700	218.100	219.270	-	-	-	-	-	-
25-Nov-11	17:00	217.670	218.050	219.280	-	-	-	-	-	-
26-Nov-11	08:30	217.690	218.060	219.260	-	-	-	-	-	-
26-Nov-11	16:30	217.850	218.170	219.290	-	-	-	-	-	-
27-Nov-11	08:00	217.630	218.000	219.260	-	-	-	-	-	-
27-Nov-11	16:00	217.470	217.900	219.280	-	-	-	-	-	-
28-Nov-11	16:30	217.710	218.090	219.300	-	-	-	-	-	-
29-Nov-11	17:00	217.860	218.180	219.250	-	-	-	-	-	-
30-Nov-11	17:00	217.990	218.330	219.330	-	-	-	-	-	-
1-Dec-11	08:00	218.550	218.740	219.350	-	-	-	-	-	-
1-Dec-11	17:00	218.770	218.950	219.450	-	-	-	-	-	-
2-Dec-11	08:30	218.280	218.600	219.370	-	-	-	-	-	-
2-Dec-11	17:30	218.300	218.570	219.840	-	-	-	-	-	-
3-Dec-11	08:00	218.320	218.650	219.400	-	-	-	-	-	-
3-Dec-11	16:30	218.450	218.650	219.400	-	-	-	-	-	-
4-Dec-11	08:30	218.670	218.880	219.410	-	-	-	-	-	-
4-Dec-11	16:00	219.060	219.190	219.560	-	-	-	-	-	-
5-Dec-11	09:00	219.470	220.350	220.620	-	-	-	-	-	-
5-Dec-11	16:30	219.510	220.680	220.891	-	-	-	-	-	-
6-Dec-11	08:00	219.630	220.865	221.360	-	-	-	-	-	-

KGS GROUP WATER LEVEL MONITORING

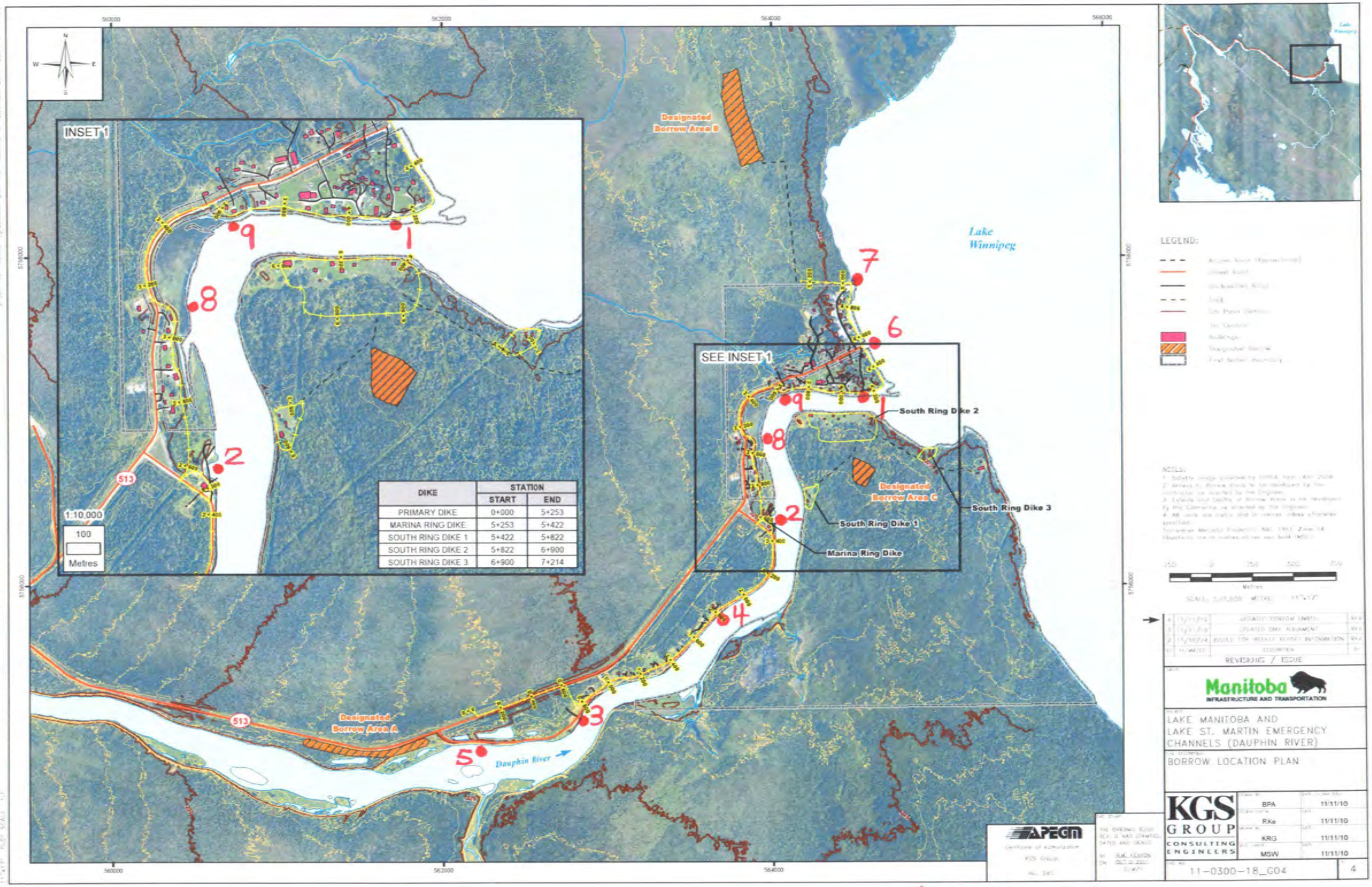
January 6, 2012

Date	Time	Water Level (m)								
		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
6-Dec-11	18:30	219.104	220.692	221.432	221.302	221.434	-	-	-	-
7-Dec-11	09:00	219.420	220.640	221.570	221.270	221.650	218.570	217.952	-	-
7-Dec-11	16:30	219.530	221.000	221.570	221.490	221.650	218.650	217.957	-	-
8-Dec-11	08:45	219.270	220.660	222.140	221.860	222.150	218.500	217.840	-	-
8-Dec-11	11:30	219.170	221.320	222.280	222.050	222.290	218.430	217.790	-	-
8-Dec-11	16:30	219.190	220.700	222.300	221.700	222.600	218.440	217.800	-	-
9-Dec-11	09:00	N/A[1]	N/A[1]	222.628	N/A[1]	222.929	218.410	217.870	N/A[1]	N/A[1]
9-Dec-11	16:30	N/A[1]	N/A[1]	222.744	N/A[1]	223.358	218.564	217.961	N/A[1]	N/A[1]
10-Dec-11	08:45	219.360	220.810	223.190	222.320	223.270	218.740	218.100	220.487	220.026
10-Dec-11	16:00	219.390	220.480	222.960	221.950	223.220	218.640	217.980	220.120	219.950
11-Dec-11	09:00	219.440	N/A[1]	222.600	N/A[1]	223.090	218.550	217.900	219.950	219.840
11-Dec-11	16:30	219.280	220.080	222.320	N/A[1]	222.960	218.540	217.920	219.850	219.730
12-Dec-11	09:00	219.540	220.160	222.390	220.950	222.700	218.670	218.050	219.980	219.890
12-Dec-11	16:00	219.400	219.920	221.860	220.820	222.300	218.670	218.130	219.850	219.750
13-Dec-11	09:00	219.350	219.980	221.670	N/A[1]	222.170	218.750	218.370	219.770	219.720
13-Dec-11	12:00	N/A[1]	219.920	221.640	220.730	222.150	218.730	218.360	219.740	219.600
13-Dec-11	15:30	219.260	219.840	221.580	220.690	222.110	218.730	218.360	219.690	219.570
14-Dec-11	09:00	218.980	219.670	221.410	220.600	221.990	218.540	218.210	218.210	219.480
14-Dec-11	15:30	218.970	219.670	221.420	220.640	222.080	218.530	218.210	218.510	219.520
15-Dec-11	09:00	219.220	219.830	221.540	220.730	222.140	218.640	218.330	219.740	219.610
15-Dec-11	16:30	219.580	220.100	221.420	220.700	222.020	218.710	218.420	219.950	219.870
16-Dec-11	09:00	219.750	N/A[1]	221.320	220.760	221.930	219.000	218.510	220.260	220.230
16-Dec-11	16:00	219.790	220.330	221.380	220.810	221.970	219.070	218.630	220.310	220.260
17-Dec-11	09:00	219.630	N/A[1]	221.230	220.660	221.990	219.050	218.600	220.090	220.000
17-Dec-11	16:30	219.570	N/A[1]	221.320	220.690	N/A[1]	219.010	218.580	220.050	221.980
06-Jan-12	14:00	219.719	N/A[1]	N/A[1]	220.858	N/A[1]	219.165	218.447	N/A[1]	N/A[1]

Notes:
1. Reading not available due to impeding ice formations.

TABLE 2. STATION LOCATIONS

Station	Northing	Easting
1	5757156.843	564593.969
2	5756367.687	563997.663
3	5755258.105	562854.310
4	5755810.056	563646.284
5	5755044.298	562440.137
6	5757463.120	564563.561
7	5757867.281	564493.202
8	5756837.428	563907.738
9	5757175.851	564027.844



SKETCH No. 1
WATER LEVEL MONITORING LOCATIONS

APPENDIX J

DAUPHIN RIVER DIKES DESIGN, AS-BUILT ELEVATION AND FREEBOARD

Estimated Water Surface Profile for Dauphin River with Ice (m)
(basis for DRFN dike elevations)

River Chainage	Dike Chainage	NEW DIKE CHAINAGE	CURRENT FPL ON TENDER DWGS	Scenario 1 - 17,620 cfs Early Fall Freeze-up (~Nov 10)	Scenario 4 - 24,710 cfs Spring Break-up - 48 km Leading Edge	Max of Scen 1 and 2	CURRENT FREEBOARD ON TENDER DWGS TO MAX WL	Top up Requirment	FINAL EL	FINAL ADJUSTED FREEBOARD		FINAL ASBUILT EL	ASBUILT FREEBOARD	ASBUILT FREEBOARD
48000	N/A	**N/A**		225.36	224.46	225.36								
48100	N/A	**N/A**		225.32	224.45	225.32								
48200	N/A	**N/A**		225.26	224.44	225.26								
48300	WST - 0+000	**00+00**	226.00	225.19	224.42	225.19	0.81	0.00	**226.00**	0.81		**226.27**	1.07	
48400	WST - 0+085	**+85**	225.97	225.12	224.40	225.12	0.85	0.00	**225.97**	0.85		**226.19**	1.07	
48500	WST - 0+175	**1+75**	225.95	225.03	224.37	225.03	0.92	0.00	**225.95**	0.92		**226.13**	1.10	
48600	WST - 0+275	**2+75**	225.92	224.93	224.34	224.93	0.99	0.00	**225.92**	0.99		**226.05**	1.13	
48700	WST - 0+370	**3+70**	225.89	224.82	224.30	224.82	1.07	0.00	**225.89**	1.07		**225.96**	1.14	
48800	WST - 0+450	**4+50**	225.86	224.71	224.26	224.71	1.15	0.00	**225.86**	1.15		**225.97**	1.26	
48900	WST - 0+540	**5+40**	225.83	224.59	224.21	224.59	1.24	0.00	**225.83**	1.24		**225.79**	1.21	
49000	WST - 0+620	**6+10**	225.80	224.45	224.15	224.45	1.36	0.00	**225.80**	1.36		**225.78**	1.34	
49100	125	**7+90**	225.80	224.30	224.08	224.30	1.51	0.00	**225.80**	1.51		**225.67**	1.37	
49200	260	**9+25**	225.40	224.14	224.01	224.14	1.26	0.00	**225.40**	1.26		**225.38**	1.24	
49300	390	**10+55**	225.25	223.99	223.94	223.99	1.26	0.00	**225.25**	1.26		**225.36**	1.37	
49400	500	**11+65**	225.10	223.83	223.86	223.86	1.24	0.00	**225.10**	1.24		**225.28**	1.42	
49500	585	**12+50**	224.95	223.67	223.78	223.78	1.17	0.00	**224.95**	1.17		**225.11**	1.34	
49600	675	**13+40**	224.80	223.50	223.69	223.69	1.11	0.00	**224.80**	1.11		**225.03**	1.35	
49700	740	**14+00**	224.67	223.34	223.60	223.60	1.07	0.00	**224.67**	1.07		**224.76**	1.16	
49800	825	**14+90**	224.50	223.19	223.53	223.53	0.97	0.00	**224.50**	0.97		**224.58**	1.05	
49900	935	**16+00**	224.33	223.06	223.45	223.45	0.88	0.00	**224.33**	0.88		**224.43**	0.98	
50000	1025	**16+90**	224.20	222.94	223.39	223.39	0.81	0.00	**224.20**	0.81		**224.24**	0.85	
50100	1155	**18+20**	224.10	222.83	223.32	223.32	0.78	0.00	**224.10**	0.78		**224.18**	0.86	
50200	1265	**19+20**	224.00	222.72	223.26	223.26	0.74	0.00	**224.00**	0.74		**224.12**	0.86	
50300	1365	**20+30**	223.90	222.60	223.19	223.19	0.71	0.00	**223.90**	0.71		**223.98**	0.79	
50400	1445	**21+10**	223.80	222.49	223.12	223.12	0.68	0.00	**223.80**	0.68		**223.82**	0.70	
50500	1520	**21+85**	223.65	222.36	223.05	223.05	0.61	0.00	**223.65**	0.61		**223.71**	0.66	
50600	1585	**22+50**	223.50	222.24	222.97	222.97	0.53	0.07	**223.57**	0.60		**223.72**	0.75	
50700	1680	**23+40**	223.40	222.13	222.90	222.90	0.50	0.10	**223.50**	0.60		**223.72**	0.82	
50800	1775	**24+40**	223.30	222.03	222.83	222.83	0.47	0.13	**223.43**	0.60		**223.43**	0.60	
50900	2000	**26+00**	223.30	221.94	222.77	222.77	0.53	0.07	**223.37**	0.60		**223.37**	0.60	
51000	2075	**26+85**	223.20	221.86	222.71	222.71	0.49	0.11	**223.31**	0.60		**223.45**	0.74	
51100	2185	**27+40**	223.12	221.80	222.66	222.66	0.46	0.14	**223.26**	0.60		**223.26**	0.60	
51200	2280	**28+40**	223.00	221.73	222.60	222.60	0.40	0.20	**223.20**	0.60		**223.23**	0.63	
51300	2380	**29+40**	222.96	221.67	222.55	222.55	0.41	0.19	**223.15**	0.60	TOP UP REQUIRED	**223.23**	0.69	
51400	2500	**30+70**	222.91	221.60	222.49	222.49	0.42	0.18	**223.09**	0.60		**222.92**	0.42	-0.175 Approx 3+040 to 3+085 (Low .1m to .2m)
51500	2730	**32+90**	222.85	221.54	222.43	222.43	0.42	0.18	**223.03**	0.60		**223.07**	0.64	
51600	2950	**35+15**	222.77	221.47	222.37	222.37	0.40	0.20	**222.97**	0.60		**223.15**	0.78	
51700	3150	**37+15**	222.64	221.38	222.29	222.29	0.35	0.25	**222.89**	0.60		**222.97**	0.69	
51800	3280	**38+50**	222.44	221.28	222.18	222.18	0.26	0.34	**222.78**	0.60		**222.78**	0.60	
51900	3380	**39+50**	222.18	221.12	222.02	222.02	0.16	0.44	**222.62**	0.60		**222.51**	0.50	-0.102 Approx 3+910 to 3+960 (Low .05m to .1m)
52000	3480	**40+50**	221.94	220.80	221.68	221.68	0.26	0.34	**222.28**	0.60		**222.28**	0.60	
52100	3570	**41+40**	221.51	220.41	221.28	221.28	0.23	0.37	**221.88**	0.60		**221.88**	0.60	
52200	3640	**42+10**	221.40	220.13	220.96	220.96	0.44	0.16	**221.56**	0.60		**221.56**	0.60	
52300	3700	**42+70**	221.14	219.76	220.55	220.55	0.59	0.01	**221.15**	0.60		**221.19**	0.65	
52400	3800	**43+70**	220.74	219.12	219.67	219.67	1.07	0.00	**220.74**	1.07		**220.76**	1.09	
52500	3900	**44+70**	220.38	219.02	219.33	219.33	1.06	0.00	**220.38**	1.06		**220.38**	1.06	
52600	4000	**45+70**	220.29	218.92	219.19	219.19	1.10	0.00	**220.29**	1.10		**220.29**	1.10	
52700	4100	**46+70**	220.20	218.82	219.09	219.09	1.11	0.00	**220.20**	1.11		**220.20**	1.11	
52800	4200	**47+70**	220.17	218.72	219.02	219.02	1.15	0.00	**220.17**	1.15		**220.17**	1.15	
52900	4300	**48+70**	220.13	218.62	219.02	219.02	1.11	0.00	**220.13**	1.11		**220.24**	1.22	
53000	4400	**49+45**	220.20	218.52	219.02	219.02	1.18	0.00	**220.20**	1.18		**220.33**	1.31	

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APPENDIX K

INUNDATION MAPS – DAUPHIN RIVER AND BUFFALO CREEK

Comprised of 3 Separate Appendices:

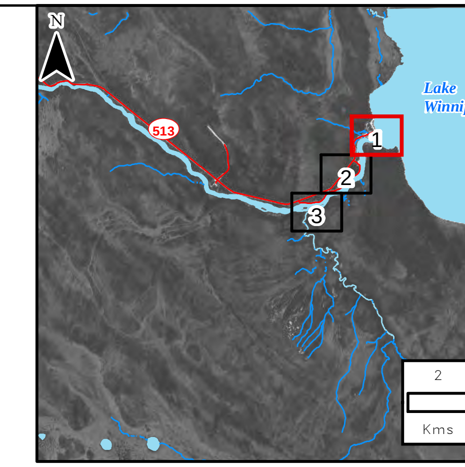
Annex 1: Estimated Inundation Area Without Dikes – Early Freeze Up 2012 (9,500 CFS)

Annex 2: Maximum Inundation Area Without Dikes – November 20 to December 17, 2011

Annex 3: Estimated Inundation Area on Buffalo Creek (4,950 CFS)

APPENDIX K - ANNEX 1

ESTIMATED INUNDATION AREA WITHOUT DIKES
EARLY FREEZE UP 2012 (9,500 cfs)



Legend

- 2011 As-Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
- 0.25m Contour
- Buildings
- Inundated Area
- 218.4 Forecast Water Surface (Early Freeze-up – Nov 10, 2012)

INUNDATION NOTES:

1. Water surface profile for inundation forecast is based on a Rivice model for an early (worst case) freeze-up date of Nov 10, 2012, an estimated flow of 9500 CFS and an estimated Lake Winnipeg level of 217.6m.
2. Estimated flow is based on Mar 12, 2012 preliminary inflow forecast from Manitoba Water Stewardship and is subject to change based on actual conditions.
3. Inundated areas shown assume that current dikes are completely removed (conservative as portions of dikes may remain).
4. Freeboard can be estimated by counting contours outside of the inundated areas (appears to be greater than 0.5m for all buildings).

NOTES:

1. Satelite image provided by Atlis Geomatics, July 2011.
2. All units are metric and in metres unless otherwise specified.

Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

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0	14/03/05	ISSUED WITH FINAL REPORT	PAL

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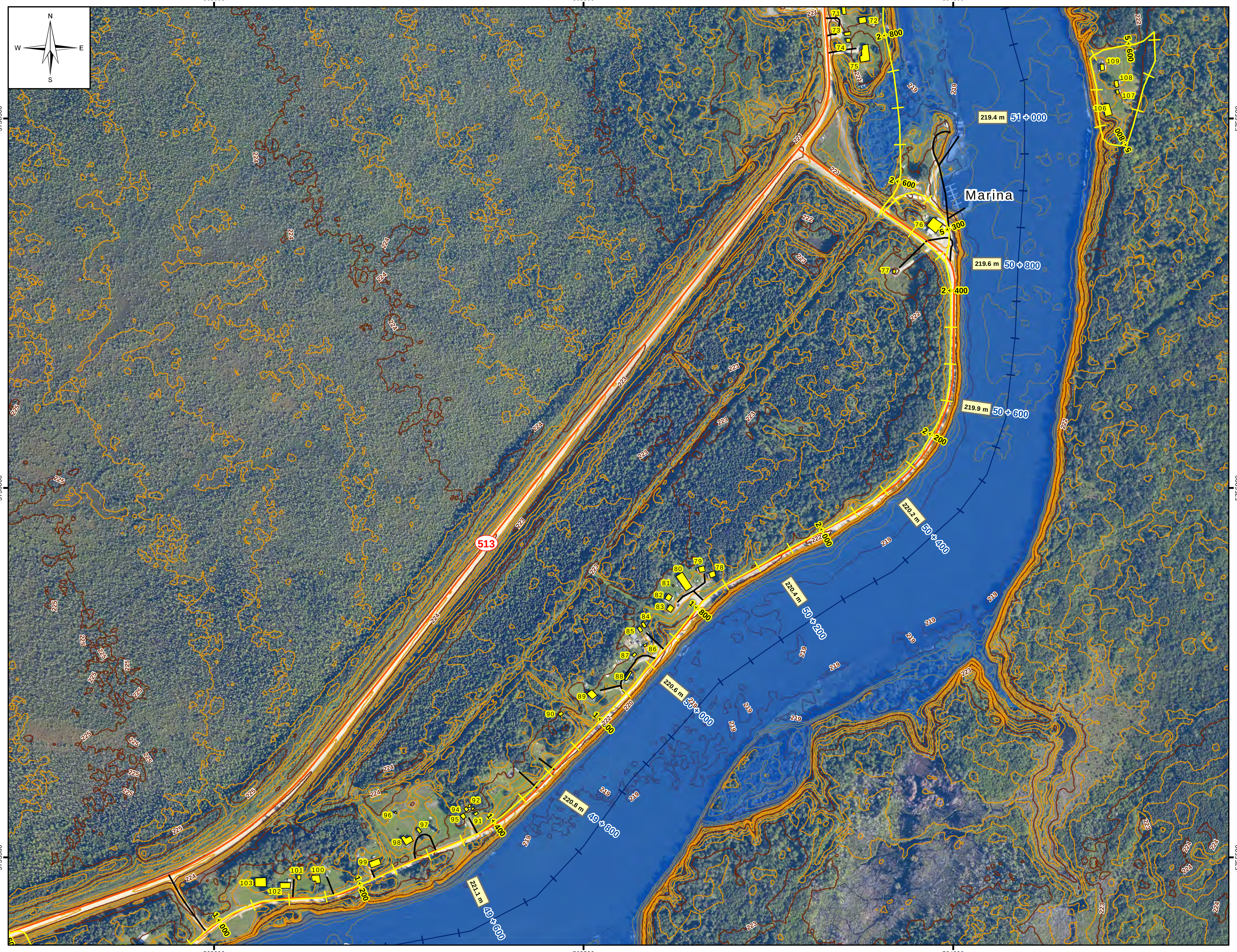
Manitoba INFRASTRUCTURE AND TRANSPORTATION

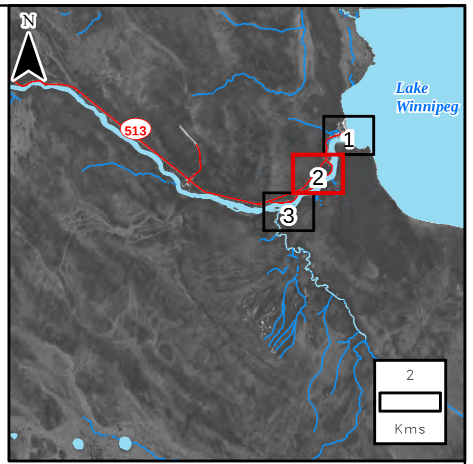
EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

INUNDATION FORECAST NOV 10, 2012 EARLY FREEZE UP – 9500 CFS FLOW (SHEET 1 OF 3)

MARCH 2014 | FIGURE K1-1 | REV: 0

FileName: P:\Projects\2011\11-0300-18\Dwg\GIS\MXD\REV0\ICE_PROCESSES_REPORT\11-0300-18-K1-1-REV0.mxd
11"x17" PLOT SCALE 1:1





Legend

- 2011 As-Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
- 0.25m Contour
- Buildings
- Inundated Area
- 218.4 Forecast Water Surface (Early Freeze-up – Nov 10, 2012)

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Elevations are in metres above sea level (MSL)

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

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Manitoba INFRASTRUCTURE AND TRANSPORTATION

EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

INUNDATION FORECAST NOV 10, 2012 EARLY FREEZE UP – 9500 CFS FLOW (SHEET 2 OF 3)

MARCH 2014 | FIGURE K1-1 | REV: 0

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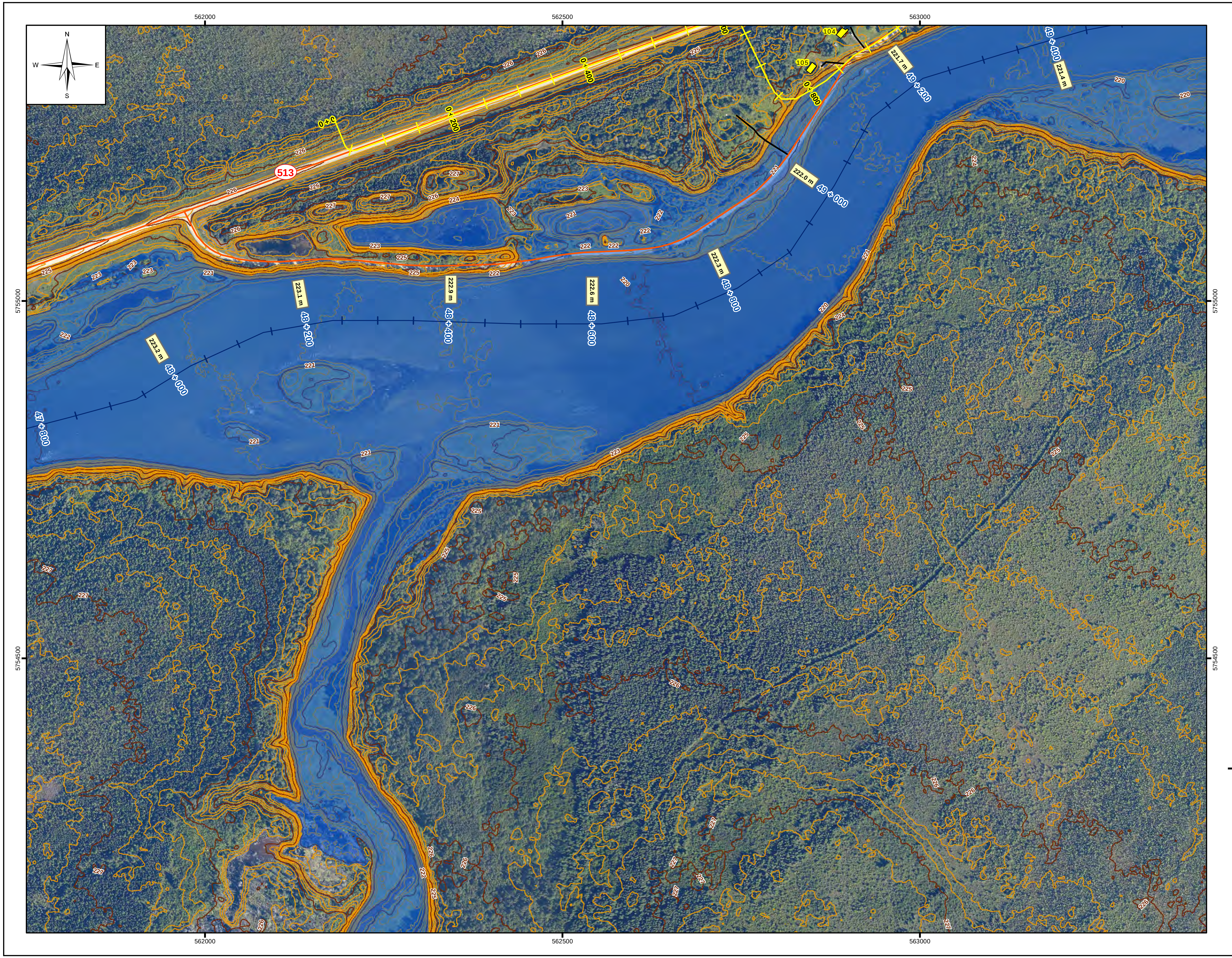
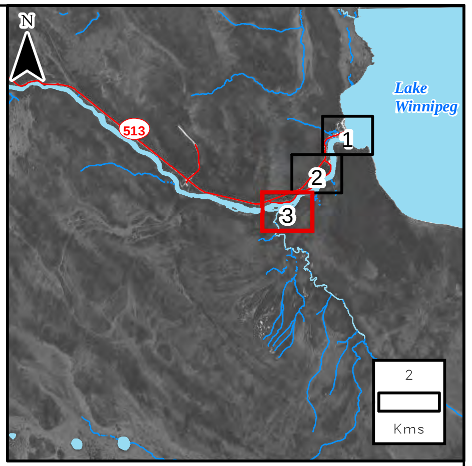
11"x17" PLOT SCALE 1:1





Legend

- 2011 As-Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
- 0.25m Contour
- Buildings
- Inundated Area
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Elevations are in metres above sea level (MSL)

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

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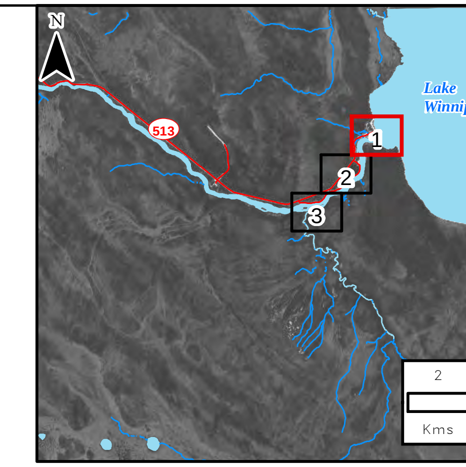
EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

INUNDATION FORECAST NOV 10, 2012 EARLY FREEZE UP – 9500 CFS FLOW (SHEET 3 OF 3)

MARCH 2014 | FIGURE K1–1 | REV: 0

APPENDIX K - ANNEX 2

MAXIMUM INUNDATION AREA WITHOUT DIKES
NOVEMBER 20 TO DECEMBER 17, 2011



Legend

- 2011 As–Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
- 0.25m Contour
- Buildings
- Inundated Area
- Area at Risk of Ice Damage
- Water Level Monitoring Station
- 220.49 m — Maximum Water Level

INUNDATION NOTES:

1. Inundation area generated from best estimate of maximum water surface profile that occured in 2011, based on surveyed water levels between Nov 20 and Dec 17, 2011 and a RIVICE model for a flow of 14,200 CFS. (results from scenario 2).
2. Inundation area shown assumes that dikes were not constructed.
3. Area at risk of ice damage based on 0.6m above maximum water surface profile and indicates to what level ice could be pushed up the river shoreline.

NOTES:

1. Satelite image provided by Atlis Geomatics, July 2011.
2. All units are metric and in metres unless otherwise specified.

Transverse Mercator Projection, NAD 1983, Zone 14

Elevations are in metres above sea level (MSL)

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	BY
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EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

MAXIMUM INUNDATION AREA WITHOUT DIKES – NOV 20 TO DEC 17, 2011 (SHEET 1 OF 3)

MARCH 2014 | FIGURE K2–1 | REV: 0

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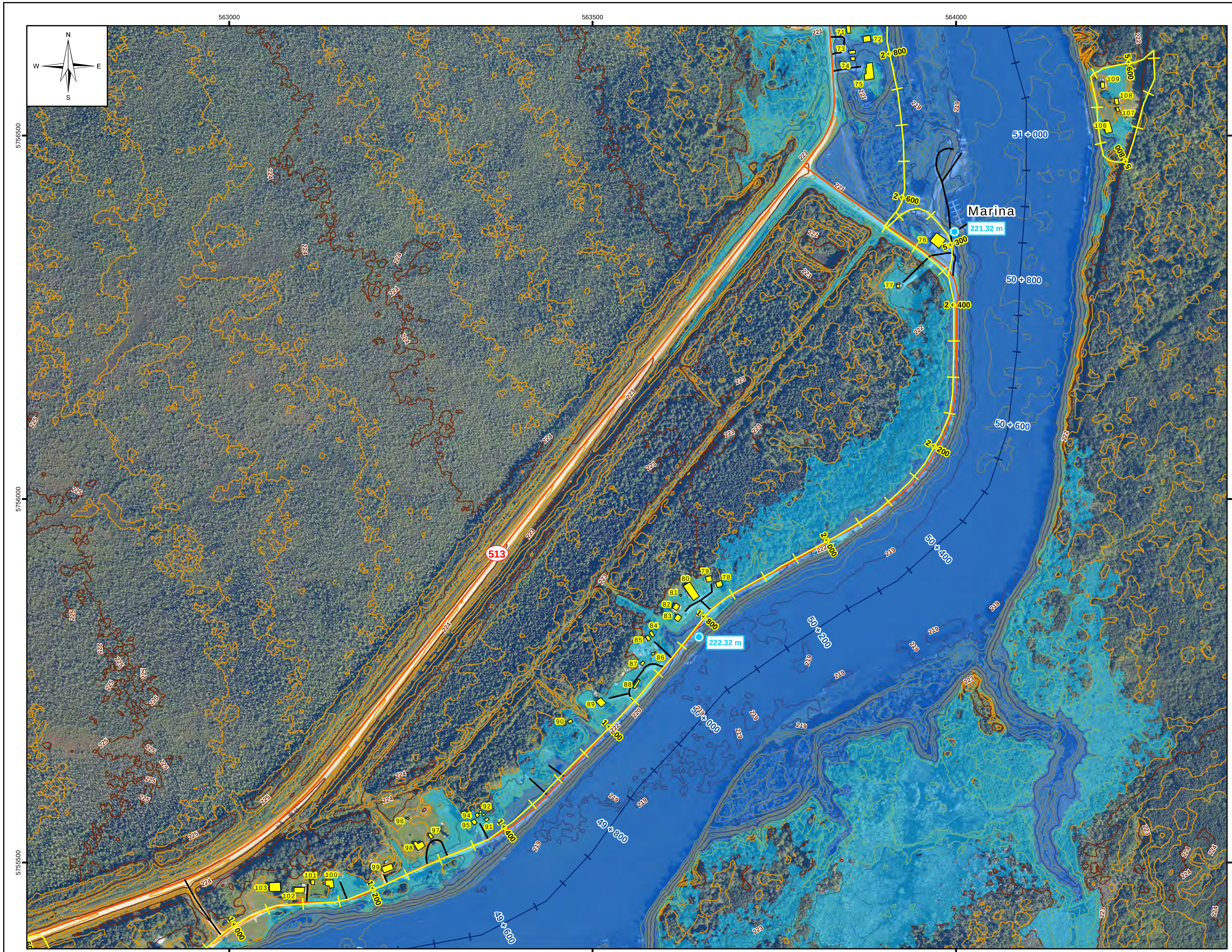
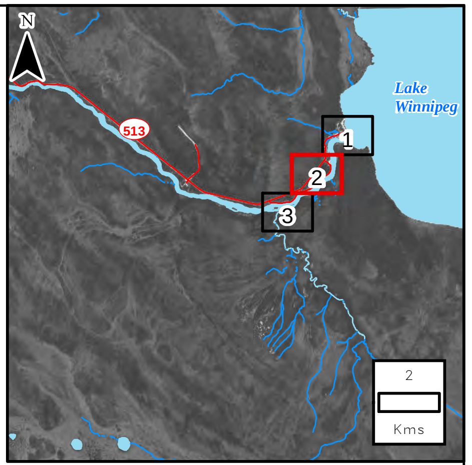
11"x17" PLOT SCALE 1:1





Legend

- 2011 As-Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
- 0.25m Contour
- Buildings
- Inundated Area
- Area at Risk of Ice Damage
- Water Level Monitoring Station
- 220.49 m — Maximum Water Level

INUNDATION NOTES:

1. Inundation area generated from best estimate of maximum water surface profile that occured in 2011, based on surveyed water levels between Nov 20 and Dec 17, 2011 and a RIVICE model for a flow of 14,200 CFS. (results from scenario 2).
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3. Area at risk of ice damage based on 0.6m above maximum water surface profile and indicates to what level ice could be pushed up the river shoreline.

NOTES:

1. Satelite image provided by Atlis Geomatics, July 2011.
2. All units are metric and in metres unless otherwise specified.

Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

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Manitoba INFRASTRUCTURE AND TRANSPORTATION

EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

MAXIMUM INUNDATION AREA WITHOUT DIKES – NOV 20 TO DEC 17, 2011 (SHEET 2 OF 3)

MARCH 2014 | FIGURE K2-1 | REV. 0

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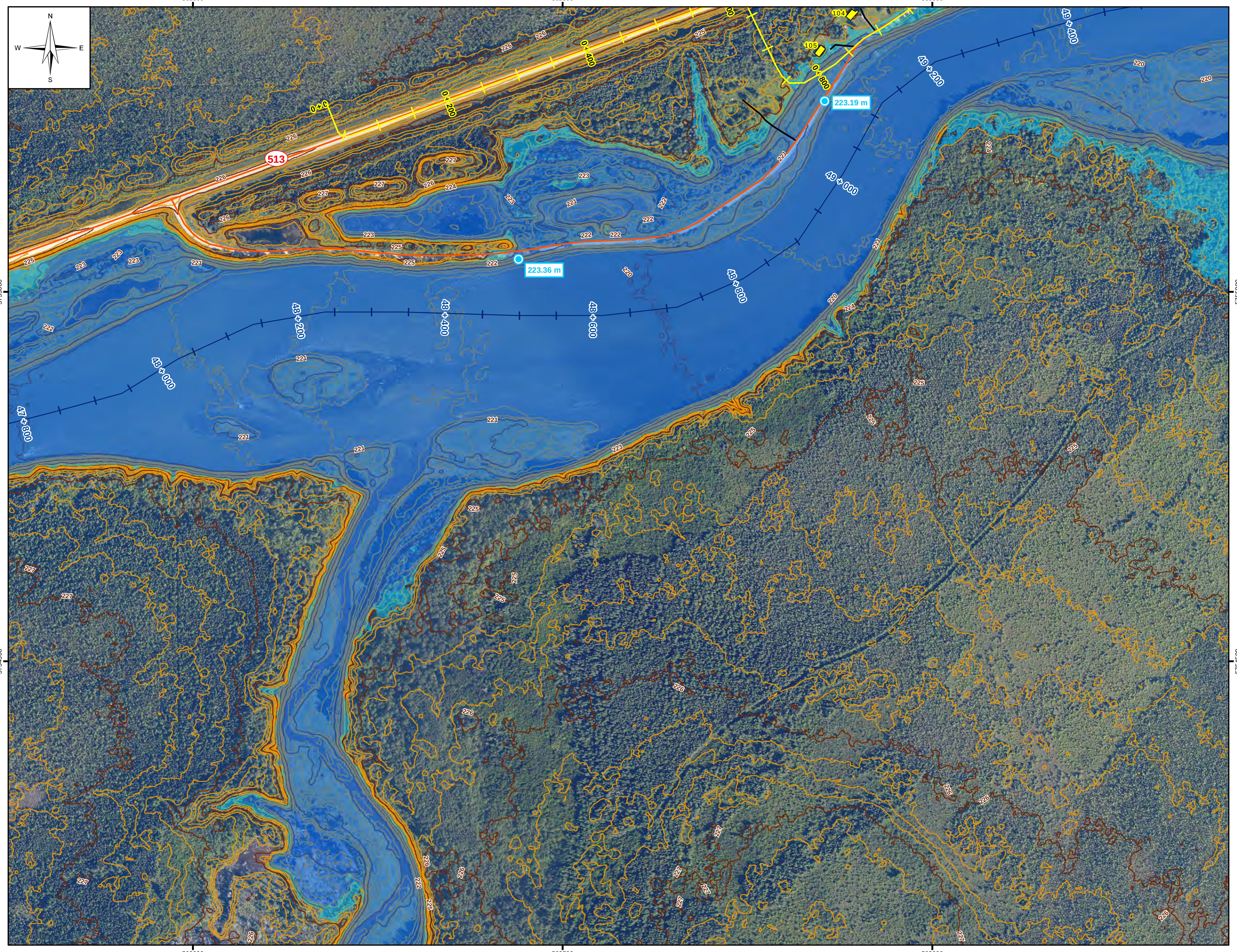

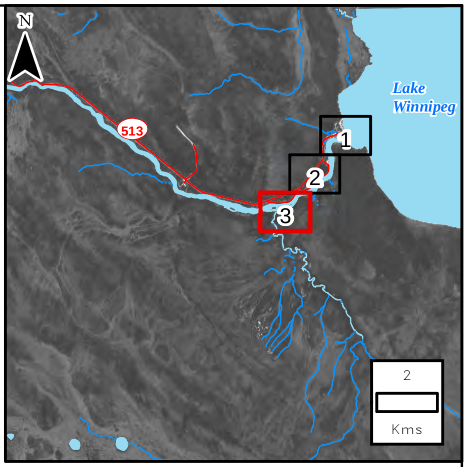

Legend

- 2011 As-Built Dike Alignment
- Dauphin River Centreline
- Coastline 100m Offset
- 1m Index Contour
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- Buildings
- Inundated Area
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2. Inundation area shown assumes that dikes were not constructed.
3. Area at risk of ice damage based on 0.6m above maximum water surface profile and indicates to what level ice could be pushed up the river shoreline.

NOTES:

1. Satelite image provided by Atlis Geomatics, July 2011.
2. All units are metric and in metres unless otherwise specified.

Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

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Manitoba INFRASTRUCTURE AND TRANSPORTATION

EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS – ANALYSIS & MONITORING OF DISCHARGES & ICE PROCESSES

MAXIMUM INUNDATION AREA WITHOUT DIKES – NOV 20 TO DEC 17, 2011 (SHEET 3 OF 3)

MARCH 2014 | FIGURE K2–1 | REV: 0

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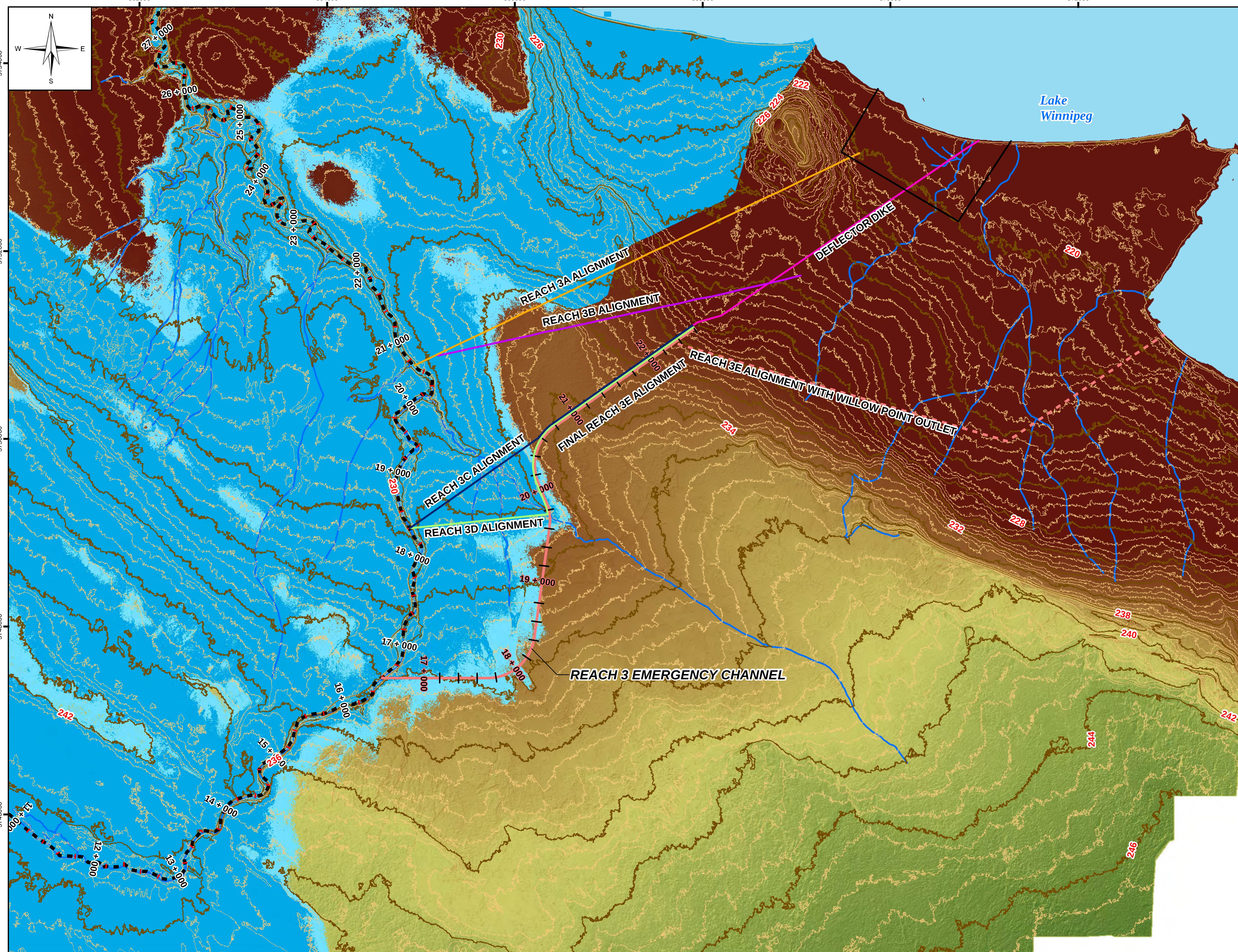
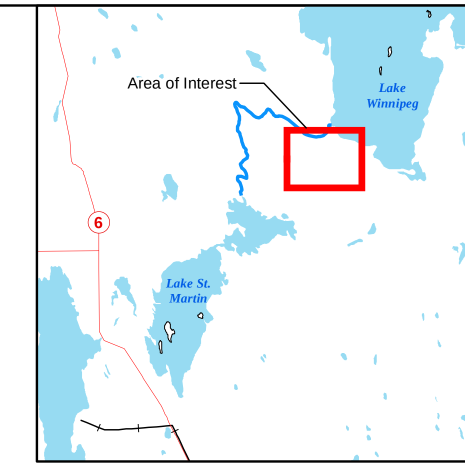
APPENDIX K - ANNEX 3

ESTIMATED INUNDATION AREA ON BUFFALO CREEK (4,950 CFS)





LEGEND:

- Alignment 3A
- Alignment 3B
- Alignment 3C
- Alignment 3D
- Alignment 3E
- Alignment 3E with Willow Point Outlet
- Buffalo Creek Channel
- Deflector Dike
- 2m Index Contour
- 0.5m Contour

Depth of Flooding

- 0 – 0.5m
- >0.5m

NOTE:
Inundation levels are ice staging levels based on a discharge of 4950 cfs (140 m3/s).

300 0 300 600 900 1,200 1,500
Metres

SCALE: 1:40,000 METRIC 11"x17"

All units are metric and in metres unless otherwise specified.
Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

NO.	YY/MM/DD	DESCRIPTION	BY
0	14/03/05	ISSUED WITH FINAL REPORT	PAL

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS

Manitoba INFRASTRUCTURE AND TRANSPORTATION

EMERGENCY REDUCTION OF LMB & LSM WATER LEVELS–ANALYSIS & MONITORING & DISCHARGES & ICE PROCESSES

INUNDATION FORECAST ON BUFFALO CREEK – MAX ICE STAGING – 4950 CFS FLOW

MARCH 2014 | FIGURE K3-1 | REV: 0

FileName: P:\Projects\2011\11-0300-18\Dwg\GIS\MXD\REV0\ICE_PROCESSES_REPORT\11-0300-18-K3-1-REV0.mxd
11"x17" PLOT SCALE 1:1

APPENDIX L

MODEL FILES – (HEC-RAS AND RIVICE)

(Not Printed – Included on DVD)

EMERGENCY REDUCTION OF LAKE MANITOBA AND LAKE ST. MARTIN WATER LEVELS

BINDER 2:
DATA FILES FOR FIGURES AND APPENDICES

All figures created using GIS data are included in a geodatabase found in the “Binder 2/Data/” folder. Other figures created using laboratory data, modelling data, CAD data, Grapher files, and Excel files have been provided in the data folders as indicated below. Any other figures or appendices within the reports that did not require additional data to produce are not included in these files.

B2-1) ANALYSIS AND MONITORING OF DISCHARGES AND ICE PROCESSES

- **Figures**
  - Figure 1 –General Site Plan (Rev. 0)
    - *Provided in geodatabase*
  - Figure 2 – Fairford River Stage Discharge Relationships
    - *Excel file provided*
  - Figure 3 – Computed Water Surface Profile on Fairford River Under Maximum Winter Ice – End of January 2012
    - *Excel file provided*
  - Figure 4 – 2011-2012 Accumulated Degree Days of Freezing in Fisher Branch
    - *Excel file provided*
  - Figure 5 – Dauphin River Open Water Surface Profile – June 29 - July 1, 2011 Survey – 565 cms (19,950 cfs)
    - *Excel file provided*
  - Figure 6 – Lake St. Martin Outlet at Dauphin River Stage Discharge Relationship
    - *Excel file provided*
  - Figure 7 – Dauphin River Open Water Model Calibration – May 19, 2011 – 420cms (14,830 cfs)
    - *Excel file provided*
  - Figure 8 – Dauphin River Ice Cover Model Calibration – Nov 2010 – 190 cms (6,710 cfs)
    - *Excel file provided*
  - Figure 9 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 1: Early Freeze-up (2011) – 500 cms (17,620 cfs)
    - *Excel file provided*
  - Figure 10 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 2: Best Estimate Freeze-up (2011) – 400 cms (14,160 cfs)

    - *Excel file provided*
- Figure 11 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 3: Late Freeze-up (2011) – 365 cms (12,900 cfs)
    - *Excel file provided*
- Figure 12 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 4: Spring Breakup – 700 cms (24,720 cfs)
    - *Excel file provided*
- Figure 13 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 5: Spring Breakup – 1,000 cms (35,310 cfs)
    - *Excel file provided*
- Figure 14 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 6: Spring Breakup – 444 cms (15,680 cfs)
    - *Excel file provided*
- Figure 15 – Estimated Maximum Water Surface Profile for Lower Dauphin River – Scenario 7: Early Freeze-up (2012) – 269cms (9,500 cfs)
    - *Excel file provided*
- Figure 16 – Estimated Maximum Water Surface Profile for Dauphin River – Scenario 1: Early Freeze-up (2011) – 500cms (17,660 cfs)
    - *Excel file provided*
- Figure 17 – Estimated Peak Winter Stage Discharge Relationship on Dauphin River at Lake St. Martin Outlet
    - *Excel file provided*
- Figure 18 – Estimated Maximum Water Surface Profile for Dauphin River – Scenario 7: Early Freeze-up (2012) – 269 cms (9,500 cfs)
    - *Excel file provided*
- Figure 19 – Surveyed Water Levels in Lower Dauphin River during Winter of 2011-2012
    - *Excel file provided*
- Figure 20 – Maximum Water Surface Profile for Lower Dauphin River – November and December 2011
    - *Excel file provided*
- Figure 21 – Estimated Stage Discharge Relationship on Dauphin River during Winter of 2011-2012 22.
    - *Excel file provided*
- Figure 22 – Computed Lake St. Martin Water Level - With and Without Emergency Outlet Channel
    - *Excel file provided*
- Figure 23 – Reach 1 Stage Discharge Relationships
    - *Excel file provided*
- Figure 24 – Estimated Maximum Water Surface Profile with Ice in Buffalo Creek – 80 cms (2,825 cfs)
    - *Excel file provided*

- Figure 25 – Estimated Maximum Water Surface Profile with Ice in Buffalo Creek – 140 cms (4,900 cfs)
    - *Excel file provided*

- **Appendices**
    - Appendix A – Lake Manitoba and Lake St. Martin Forecast Figures and Data
        - Annex 1 – Lake Manitoba Inflow Forecast
            - *No applicable data files*
        - Annex 2 – Lake Manitoba and Lake St. Martin Forecast Figures and Emails
            - *Excel files provided*
    - Appendix B – Flow Metering and Water Level Measurement of the Lake St. Martin Emergency Channel System
        - Figures
            - Figure 1 – Flow Metering and Water Level Monitoring Locations (Rev. 0)
                - *Provided in geodatabase*
            - Figure 2 – Reach 1 Water Surface Profiles
                - *Excel file provided*
            - Figure 3 – Estimated Reach 1 Rating Curve
                - *Excel file provided*
        - Appendices
            - Appendix A – Flow Metering Results
                - *Raw and processed data files provided*
                - *Photos provided in .jpg format*
            - Appendix B – Cableway Installation
                - Drawing S04 – ADCP Cableway and Supports Sections and Details (Rev. 0)
                    - *CAD file provided (saved as E-transmit)*
                    - *Microstation file converted from CAD file*
                    - *PDF of CAD file*
                - *Photos provided in .jpg format*
    - Appendix C – Bathymetric and Cross-Section Data
        - Annex 1 – 1980 Fairford River Cross-Section Data
            - *No applicable data files*
        - Annex 2 – 2011 Fairford River Bathymetric Survey
            - Figure C2-1 – 2011 Fairford River Bathymetric Survey (Rev. 0) – 3 Sheets
                - *Provided in geodatabase*
        - Annex 3 – 2011 Dauphin River Bathymetric Survey
            - Figure C3-1 – 2011 Dauphin River Bathymetric Survey (Rev. 0) – 7 Sheets
                - *Provided in geodatabase*
        - Annex 4 – 2011 Buffalo Creek Cross-Section Locations
            - Figure C4-1 – Buffalo Creek Cross Section Locations (Rev. 0) – 4 Sheets
                - *Provided in geodatabase*

- Appendix D – Historic Photos and Notes
    - Annex 1 – Fairford River January 26, 2004 Photos
        - *Photos provided in .jpg format*
    - Annex 2 – Fairford River November 30, 2007 Photos
        - *Photos provided in .jpg format*
    - Annex 3 – Dauphin River 2005, 2006, and 2010 Photos
        - *Photos provided in .jpg format*
    - Annex 4 – Dauphin River Ice Notes 2007-2011
        - *No applicable data files*
- Appendix E – Water Temperature Data
    - Annex 1 – Fairford River
        - Figure: January 2012 Temperatures
            - *Excel, txt and Grapher files provided*
        - Figure: February 2012 Temperatures
            - *Excel, txt and Grapher files provided*
        - Figure: March 2012 Temperatures
            - *Excel, txt and Grapher files provided*
    - Annex 2 – Dauphin River
        - Figure E2-2
            - *Excel file provided*
- Appendix F – Description of "VARY-ICE" Model
    - *No applicable data files*
- Appendix G – Findings from La Salle Consulting Group
    - Annex 1 – Memorandums on Dauphin River
        - *No applicable data files*
    - Annex 2 – Memorandums on Fairford River
        - *No applicable data files*
    - Annex 3 – Model Files
        - *Model files provided*
- Appendix H – Photos and Satellite Imagery
    - Annex 1 – Time Lapse Camera and Air Photos
        - *Photos provided in .jpg format*
    - Annex 2 – Satellite Imagery
        - *Satellite photos provided in .jpg and .pdf format*
- Appendix I – Surveyed Water Levels
    - Annex 1 – MIT Data
        - Figure I1-1 – Fairford River Water Surface Elevation; MIT Gauge Stations
            - *No applicable data files (tables provided within appendix)*
        - Figure I1-2 – Dauphin River Water Surface Elevation; MIT Gauge Stations
            - *No applicable data files (tables provided within appendix)*

        - Figure I1-3 – MIT Water Level Gauge Locations (Rev. 0)
            - *Provided in geodatabase*
    - Annex 2 – KGS Group Data
        - Figure G04 – Borrow Location Plan (Rev. 4)
            - *No applicable data files (sketch of water level monitor locations; coordinates provided within appendix)*
- Appendix J – Dauphin River Dikes Design, As-Built Elevation and Freeboard
    - *No applicable data files*
- Appendix K – Inundation Maps – Dauphin River and Buffalo Creek
    - Annex 1 – Estimated Inundation Area Without Dikes: Early Freeze-Up 2012 (9,500 cfs)
        - Figure K1-1 – Inundation Forecast Nov 10, 2012: Early Freeze Up – 9500 CFS Flow (Rev. 0) – 3 sheets
            - *Provided in geodatabase*
    - Annex 2 – Maximum Inundation Area Without Dikes – November 20 to December 17, 2011
        - Figure K2-1 – Maximum Inundation Area Without Dikes – Nov. 20 to Dec. 17, 2011 (Rev. 0) – 3 sheets
            - *Provided in geodatabase*
    - Annex 3 – Estimated Inundation Area on Buffalo Creek - (4950 cfs)
        - Figure K3-1 – Inundation Forecast on Buffalo Creek – Max Ice Staging – 4950 CFS Flow (Rev. 0)
            - *Provided in geodatabase*
- Appendix L – Model Files (HEC-RAS and RIVICE)
    - *Model files provided*