Lower Pembina River Flooding Task Team Report to the International Red River Board
November 2012

An exploratory analysis of mitigation measures for the lower Pembina River basin.

Executive Summary

The Lower Pembina River Flooding Task Team (LPRFTT) concludes that the Phase 3 model developed by the Canadian National Research Council (NRC) presents a fairly accurate representation of actual flood events in the Lower Pembina River basin and can be used, given awareness of its parameters, to simulate flood events and to compare the impact of different structural mitigation measures. It is the Task Team's view that this model meets the International Red River Board's (IRRB) key objective of creating a hydrodynamic model that can both act as a basis for developing a scientific understanding of the flooding of the lower Pembina River under existing conditions i.e., determine whether existing structures in the area have an impact on a bi-national level; and, can also act as a tool to analyze the impacts of potential future flood mitigation projects for the entire region. The Task Team endorses the conclusions presented in the report entitled "Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac2D Hydrodynamic Model – Phase 3" in regards to what the model shows for each scenario as presented in both the NRC report and in the appendices.

In regards to understanding the flooding of the lower Pembina River under existing conditions versus those scenarios with various combinations of roads and dykes removed, the model shows clearly that:

-- All roads impact how water flows north-south and east-west during a flood event.

-- The border road/dyke increases flooding in North Dakota, most dramatically in the northeast quadrant east of Gretna at the border.

-- Removal of the border road/dyke would greatly increase flooding in Manitoba along the Aux Marais River and Buffalo Creek.

-- Removal of County Road 55 lowers flood levels only for about a mile (1.6 km.) distance along the border for the 1:10 and 1:50 events and to a lesser distance for a 1:100 event when compared to existing conditions. However, removal of County Road 55 would increase flooding to the south of County Road 55 and increase flooding along the Buffalo Creek drainage system in Manitoba.

In regards to understanding the impact of proposed structural mitigation measures, the model shows what the impact of those measures would be. It also shows that most of the mitigation measures taken would have negative impacts somewhere else in the lower Pembina River basin. This leads the Task Team to conclude that a combination of structural and non-structural measures would be necessary to address the overall goal of reducing the impact of floods throughout the lower Pembina River basin.

The Task Team also notes that the relationships of flooding within the lower Pembina River basin and its sub-basins including the relationship to flooding of the Red River of the North is complex and engineering feasibility studies are required before moving forward with any single or combination of solutions.

The goal should be that that flooding should be no worse than existing conditions north of the border in Manitoba and no worse than natural conditions south of the border in North Dakota.

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1 Introduction

One of the key goals within The International Red River Board's (IRRB) 2008-2012 work plan is to work to resolve the flooding and drainage concerns in the Lower Pembina River floodplains. At the January 2008 meeting, the IRRB established the Lower Pembina River Flooding Task Team (LPRFTT). The mandate of this Task Team is to develop and work with a hydrodynamic model of the basin that was detailed enough to support a science-based solution(s) to mitigate flooding in the lower Pembina River basin.

The four-member Task Team is comprised of Canadian Co-chair Gordon Bell from Agriculture and Agri-Food Canada, United States Co-chair Randy Gjestvang from North Dakota State Water Commission, Bob Harrison from Manitoba Conservation and Water Stewardship and Scott Jutila from the United States Army Corps of Engineers (USACE). The International Joint Commission (IJC) has provided a Canadian adviser, Paul Pilon, and a United States adviser, Robert Reynolds who was later replaced by Anne Chick in the fall of 2011.

The Canadian National Research Council (NRC) was engaged by the Canadian Section of the IJC to undertake the development of a detailed hydrodynamic model to support analysis of various structural features on the distribution of waters within the basin. To date, the LPRFTT has overseen three phases of TELEMAC modelling studies, all undertaken by the NRC. This Task Team report presents results from the third phase and most recent modelling effort, which are more fully described and documented in the report entitled "Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac2D Hydrodynamic Model – Phase 3."

The first report (Phase 1) was completed in July 2009. Model details, including model description, how it was applied to the Lower Pembina River floodplains, calibration, verification etc., were presented at the IRRB at the September 2009 meeting by the NRC modeller, Thierry Faure. (Phase I: Preparation of a two-dimensional Hydrodynamic Model of the Lower Pembina River Flood Plains, Controlled Technical Report CHC-CTR-093, July 2009) The report was later approved by the IRRB at its January 2010 meeting, and was forwarded to the IJC. Reviewers of the first phase agreed that the model fairly accurately replicated what flooding occurred during the spring of 2006. Phase 2 was completed in June 2010, and expanded the model domain geographically to include the northern part of the watershed in Manitoba and further south in North Dakota and included more infrastructure such as more roads and culverts. (Phase II: Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the 2D Hudrodynamic Model, Controlled Technical Report CHC-CTR-106, June 2010)

This was accomplished by provision of additional agency infrastructure data and by additional LiDAR information to the NRC. Based on consultations with a number of stakeholders, simulation scenarios such as removal of both County Road 55 and the border road/dyke, and flattening of all roads, as well as various flood mitigation scenarios, including set-back dykes, various floodway alignments and various diversion alternatives, were simulated using the 2006 flood event. However, due to the lack of specificity of the model and the size of the 2006 flood event, the model was not able to reproduce accurately the flooding along the banks of the smaller rivers and coulees, including: Rosebud Coulee, Louden Coulee, Buffalo Creek and the Aux Marais River.

Phase 3 of the study, "Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac2D Hydrodynamic Model – Phase 3" refined the model along various rivers and coulees to allow more accurate simulation of the flood extent along these watercourses. The model was further enhanced in some key areas in terms of inclusion of additional roads, bridges, and culverts; and the downstream boundary was moved downstream to Morris, Manitoba, to properly assess the confluence of Buffalo Creek with the Red River. Four different flood scenarios were modelled: the 1:10, 1:50 and 1:100 year return period spring (annual) floods and the 1:20 year summer flood allowing a wide range of flood severity levels to be assessed. The model used the USACE developed hydrographs (annual events) and Manitoba Water Stewardship hydrographs (summer rainfall events) at Walhalla along with local hydrographs for specific return periods. Local hydrographs for both annual events and summer rainfall events were estimated by NRC. The model was then used to analyze the increase and decrease of flooding when compared to existing conditions and “natural” (all roads removed) conditions with other scenarios. The modelled scenarios included the removal of all roads (i.e., natural conditions), removal of the border road/dyke, removal of North Dakota County Road 55, and compared the existing and “natural” scenarios with hypothetical situations including a floodway, a set-back dyke, diversions, and cuts in the border road/dyke. The model provided a general estimate of flooded area and flood duration (flooded area multiplied by flood duration).

The LPRFTT has consulted throughout the three phases of the project with key stakeholders on the different phases of the model and the scenarios modelled. Those consulted included the Pembina River Basin Advisory Board, the Pembina County Water Resource District, the Red River Basin Commission, and the IRRB. Results of the study’s Phase 2 were presented to the IRRB September 2010 meeting by the LPRFTT. Phase 2 results were also presented to the Pembina River Basin Advisory Board and Pembina County Water Resource District, at the January 2011 Annual Red River Basin and Water International Summit Conference, and at the June 2011 Canadian Water Resources Conference. Mostly recently, preliminary Phase 3 results were presented at the January 2012 Annual Red River Basin and Water International Summit Conference, to the IRRB January 2012 meeting, and to the Pembina River Basin Advisory Board.

2 Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac2D Hydrodynamic Model Phase 3

The Phase 3 report provides results for each scenario tested and a comparison of aerial extent of flooding with existing or other conditions. Specifically, the NRC was asked to model scenarios that removed all roads (i.e., natural conditions), removed the border road/dyke, removed ND County Road 55, and compared the existing and “natural” scenarios with hypothetical situations including a floodway, set-back dykes, diversions, and cuts in the border road/dyke. The model results were analyzed to provide general estimates of maximum areal extent of flooding (km^2) and a Flood-duration factor (km^2-days), which is the duration in days multiplied by the area flooded, for each simulation.

The Phase 3 report presents in Table 18 the Flood-duration factor for every simulation. This factor is an effort to extrapolate a magnitude of the problem related to both flooded area and flood duration. As noted in the report, the flood maps show the maximum extent of the flood waters but cannot convey any information on the timing or the duration of the flood event. The "Flood duration" *factor was developed as a parameter to characterize the combination of extent of the flood and its duration. It is calculated as the area flooded, times the duration of the local flooding so that it characterizes both flood extent and duration. For instance, if 20 km^2 are flooded for 5 days, it will have a factor of 100 km^2-days; the same factor as an area of 10 km^2 flooded for 10 days. Its units are km^2-days.* (NCR: page 69) This flood duration factor for the 2006 flood under existing conditions was 224 km^2-days in Canada and 692 km^2-days in the US. The need to take into account duration (and timing of the flood) for compensation is important. However, in this flood duration calculation, if 1 km^2 of agriculture land is flooded for ten days, it may kill the crop. If 10 km^2 is flooded for one day, it may have little effect on some crops. Both scenarios, however, would have a value of 10 km^2-days value.

The LPRFTT concludes that the Phase 3 modelled results present a fairly accurate representation of actual flood events in the Lower Pembina River floodplains and can be used, given awareness of its parameters and assumptions, to simulate flood events and to compare the impact of different structural mitigation measures. It is the Task Team's view that this model meets the IRRB's key objective of creating a hydrodynamic model that can both act as a basis for developing a scientific understanding of the flooding of the lower Pembina River floodplains under existing conditions and can act as a tool for further work to assess and compare the benefits and problems with specific flood mitigation measures.

The Task Team endorses the conclusions of *the Simulations of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac2D Hydrodynamic Model Phase 3* report. The report accurately summarizes what the model produced in each of the various scenarios. Pending approval of the IJC, the model results should be displayed on the IJC website and if possible have an interactive interface. Due to the size and complexity of the model and the size of the data files, a copy of the model and data will also be provided to a number of key agencies: USACE and Manitoba Conservation and Water Stewardship. It may be advantageous to have further work undertaken by the NRC.

The Task Team notes that some key considerations should be taken into account when reviewing flood scenarios in this report or when further using the model. These points include:

- The model is focused on the flooding of the Pembina River. While it includes some local runoff information, it was not developed to address locally generated flood events or provide insights for their mitigation.

-- The model's "natural conditions" scenario results from the mathematical removal of all roads by lowering the roads to the elevation of the surrounding landscape.

-- The model may not adequately simulate the Red River overflows into the Aux Marais River as illustrated by the 2009 and 2011 flood simulations.

2.1 Improved Understanding of Current Flooding

The model results can be used to better understand the flooding situation under current conditions in the lower Pembina River floodplain and to better understand the influence of existing roads and structures on the propagation of flooding. The model's "existing conditions scenario" was compared to the "natural conditions" scenario as well as scenarios with some roads removed or other modifications. After reviewing the model scenarios with these comparisons, the Task Team concludes that:

-- All roads impact how water flows north-south and east-west.

-- The border road/dyke along the international boundary increases flooding in North Dakota for all simulated events.   Its influence on flooding is highest along the border road/dyke.

-- Removal of the border road/dyke would greatly increase the extent and duration of flooding throughout Manitoba along the Aux Marais River and Buffalo Creek.

-- CR 55 increases flooding to its north and only impacts water levels along the U.S. - Canadian border for a one mile section during the 1:10 year and less frequent flood scenarios. This was determined by comparing the removal of CR 55 scenarios to the existing conditions scenarios. CR 55 also prevents breakout flows from entering Buffalo Creek west of Gretna.

--The 1:50 and 1:100 year flood scenarios overwhelm the existing storage and channel capacities of the basin resulting in broad areas of inundation of the floodplain. See Plates 4 and 5 for existing conditions and Plates 75 and 78 for natural conditions. See Table 1 for a comparison of metrics for both cases. A visual comparison of the plates and the numerical metrics indicates the magnitude of the impact roads have on the redistribution of waters within the basin.

-- The relationship between flooding of the lower Pembina River and the Red River is quite complex, with the flooding on the Red River causing increased flooding within the lower Pembina River floodplain.

Table 1 a   Base Case – "Existing Conditions"

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Existing	L74	3	1:10	9.4	49.3	157.2	534.6
Existing	L44P	4	1:50	55.4	103.8	821.1	1413.1
Existing	L46Q	5	1:100	80.0	129.1	1186.6	1758.0

Table 1 b   Base Case – "Natural Conditions"

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Natural	L73	72	1:10	38.5	35.4	606.2	415.4
Natural	L85	75	1:50	129.6	80.2	1603.1	1058.1
Natural	L69	78	1:100	159.6	99.7	2296.7	1454.5

2.2 Structural Flood Mitigation Scenarios

Based on stakeholder input, certain structural flood mitigation scenarios were modelled for the 1:10, 1:20 (summer), 1:50 and 1:100 year annual flood events. Each scenario with key comments is listed below. In addition, the Task Team noted that the model's application, as documented in the Phase 3 report, focused solely on structural scenarios. Non-structural mitigation measures, such as compensation and buy-outs should also be evaluated. The optimal solution may involve a combination of both structural and non-structural measures. The Task Team performed an exploratory, high-level analysis of some of these mitigation measures, which are reported herein.

2.3 Modelled Scenarios

2.3.1 Floodway: The impact of two floodways, one deemed "long" and another "short", were modelled for various design capacities as well as for four different flood events.

2.3.1.1 Long – The "long" option was a floodway from 8 km upstream of Neche (upstream of the first breakout) to the Red River downstream of Emerson. The estimated area flooded (km^2) for the different floodway capacities (50 m^3/s to 210 m^3/s; 1,770 cfs to 7,420 cfs) and for 1:10 and 1:50 flood events are shown in Table 2, with data taken from Table 18 of the Phase 3 report. For the 1:10 event and a channel capacity of 50 m^3/s (1,770 cfs), the maximum flooded area is slightly higher than what occurs during natural conditions for the US portion of the study area (37.2 km^2 as compared to 35.4 km^2), while the flood duration factor is less than would have occurred during natural conditions (375.2 km^2-days as compared to 415.4 km^2-days). This infers that a long floodway with a capacity of 50 m^3/s (1,770 cfs) would be similar metrics for the US portion of the basin as would have occurred under natural conditions. Results for the 1:50 year event indicate that a floodway capacity in excess of 119 m^3/s (4,200 cfs) would be required to attain a flood-duration factor similar to that which would occur under natural conditions for the US portion of the basin. Magnitudes of floodway capacity are likely far in excess of 210 m^3/s (7,420 cfs) and are required to attain a maximum areal extent of flooding similar to natural conditions for the US portion of the basin. The amount of area flooded is the same in Canada for all events and capacities; however the flood-duration factor decreases in comparison to existing conditions for each event as the magnitude of the capacity of the floodway increases. In summary, there are benefits to be derived from the creation of a floodway, but the capacities tested do not resolve the issue (e.g., area flooded in the US portion of the basin) for the 1:50 year event, unless capacities were to be further increased beyond 210 m^3/s (7,420 cfs). Further modelling would be required to establish a more precise estimate of the floodway capacity in such cases.

Based on a study done by the USACE in 2007 ([1]), the cost of a 50 m^3/s (1,770 cfs) capacity floodway assuming the floodway outlet is at Pembina, North Dakota would be in the order of $20 million (2012 USA dollars). A 210 m^3/s (7,420 cfs) capacity floodway with an outlet at Pembina was estimated to cost roughly $80 to $100 million (2012 USA dollars). A floodway with an outlet downstream of Emerson would be longer but the additional earth work may not be that substantial as the route would follow the natural slope of the land. Another cost saving measure would be to reduce the capacity of the floodway in an upstream direction.

2.3.1.2 Short – The "short" option was from the border-road dike crossing #6 (where the Pembina River overflows the border about seven miles east of Gretna and enters the Aux Marais watershed, see Appendix 1) to the Red River downstream of Emerson. The shorter floodway route would produce more flooding during the 1:50 event in both Canada and the US than would occur with the longer floodway. Potential cost savings due the shortened route, may make this option more attractive, however overall performance in reducing impacts versus cost savings would need to be assessed. A comparison of the 1:50 metrics for the long and short floodways in Table 2 illustrates the performance issues related to the shortened floodway. In essence, its capacity would need to be increased to obtain results similar or better than resulting from the longer floodway option. See Scenarios 14 and 14A Plates 26-61.

Table 2 Potential Floodways

Scenario (Diversion Capacity)	Run	Plate	Flood Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Long – 50 m^3/s	L87	26	1:10	9.4	37.2	143.8	375.2
Long – 74 m^3/s	L121	28	1:10	9.4	30.5	142.1	322.3
Long – 96 m^3/s	L122	30	1:10	9.4	23.7	140.7	271.6
Short – 50 m^3/s	L128	40	1:10	9.4	40.2	145.9	409.2
Short - 67 m^3/s	L129	42	1:10	9.4	39.7	142.2	405.2
Long – 74 m^3/s	L125	44	1:50	55.0	101.2	765.6	1209.3
Long – 96 m^3/s	L126	46	1:50	54.9	99.8	756.1	1143.0
Long – 119 m^3/s	L127	48	1:50	54.8	98.0	745.2	1072.4
Long - 210 m^3/s	L84	50	1:50	54.5	88.2	714.6	860.6
Short – 74 m^3/s	L131	54	1:50	55.2	103.1	768.1	1352.3
Short – 96 m^3/s	L132	56	1:50	55.2	102.6	755.8	1348.2
Short – 142 m^3/s	L133	58	1:50	55.1	101.2	747.8	1340.3
Short – 181 m^3/s	L135	60	1:50	55.2	100.3	746.4	1337.0

2.3.2 Set Back Dykes: Two set back dyke alternatives were considered along the lower Pembina River. Both were simulated with the 1:10 and 1:50 annual flood events. One scenario, termed long, had the tie back dykes extending south from the confluence with the Tongue River to the north bank of the Tongue River cutoff. The second scenario, short set-back dykes, ended with the south dike at the confluence with the Tongue River and did not extend south along the Tongue River. Both of the set back dyke scenarios would dramatically reduce flooding in the areas within North Dakota that are located upstream of the Tongue River confluence, for both the 1:10 and 1:50 flood events. The set back dykes, though, would have increased flood impacts in the area near the confluence with the Tongue River and extending east to HWY I-29, compared to existing conditions. The model did not show an increase in water elevation on the east side of HWY I-29 and at the town of Pembina. This may have been due to the assumption that the timing of the peak flow, and elevation, on the Pembina River and Red River did not coincide. An analysis of model results indicated the need of approximately a 2.7 metre dyke for a 1:50 event, not including freeboard. If designing for a 1:10 event, and not including freeboard, a 1.8 metre dyke would be required. Right of way would need to be negotiated, farmsteads and roads would have to be protected and an enlarged crossing for HWY I-29 may be required (would reduce the impacts near the Tongue River confluence).

Table 3 Set Back Dykes

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Long set back dykes	L70	62	1:10	9.4	17.2	131.4	234.5
Long set back dykes	L71	66	1:50	54.4	36.8	693.1	738.0
Short set back dykes	L112	64	1:10	9.4	17.3	131.4	235.2
Short set back dykes	L120	68	1:50	54.4	33.7	694.8	650.6

2.3.3 Diversions: The Diversions scenario creates five diversions that would move water into Buffalo Creek east and west, the Aux Marais River, Rosebud Coulee and Louden Coulee. (See Scenario 19, Plates 94-106). Diversion distribution of 53% north and 47% south was based on the distribution observed during "natural conditions". This diversion of water floods all receiving channels during the 1:10 event even with the minimum diversion of 50 m^3/s (1,770 cfs). The diversion to the Rosebud Coulee could flood the town of Bathgate. Due to local runoff there is limited additional capacity in the receiving channels and the requirements for environmental approval to increase conveyance capacity in these channels complicate this option. Although, the ability to develop this mitigation measure in stages would be an advantage, the need for improved bridges, culverts, channel capacity, and other mitigation measures downstream would increase the difficulty and expense. Thoughts are that this mitigation measure may be two to three times the cost of a floodway.

Table 4 Diversions into 5 Receiving Streams

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Diversion of 210 m^3/s	L78	94	1:10	26.8	28.4	350.7	387.2
Diversion of 190 m^3/s	L82	97	1:10	25.0	27.7	343.6	379.0
Diversion of 142 m^3/s	L83	99	1:10	20.8	28.8	327.2	379.4
Diversion of 50 m^3/s	L86	102	1:10	13.4	41.8	222.7	475.9

2.3.4 Breach in Border Road: The model was used to simulate a breach in the border road at two locations: West of Gretna (flow into East Branch of Buffalo Creek) and Border-road dyke at Crossing #6 (flow into Aux Marais River). This scenario increased flooding along Aux Marais

River and east Buffalo Creek compared to existing conditions. It reduces, although only somewhat, flooding along the border up to Crossing #6. Generally, bridges along the streams restrict conveyance more so than the channel capacity. Also, in some reaches, limited stream capacity and the requirements for environmental approval to increase conveyance capacity in these streams complicate this option. This mitigation measure is only considered a partial solution.

Table 5 Removal of Portions of Border-Road Dyke

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
2 Breaches	L102	20	1:10	19.3	37.6	256.8	388.2

2.3.5 Storage: This scenario considers upstream detention site(s) in both the U.S. and Canada. This scenario has major positive impacts during the 1:10 event (see Run L103, Plate 107) although it does not have much impact for the 1:50 year flood event (see Run L104, Plate 109). The model runs shown projected an amount of storage roughly equivalent to the 51,000 acre-ft (62,900 dam^3) storage that the Red River Basin Commission recommends for the Pembina River in order to obtain a 20% reduction of the 1997 peak flow on the Red River at Emerson. Upstream storage would enhance any of the other structural or non-structural options that could be considered. (Red River Basin, Long Term Flood Solutions, Barr Engineering Co., September 30, 2011) The general average rule of thumb for estimating detention storage used has been $1,000 per acre-ft so the anticipated cost for this storage is in the neighborhood of $51 M (2012 U.S. dollars).

Table 6 Upstream Storage

Scenario	Run	Plate	Event	Maximum Flooded Area (km^2)		Flood-duration Factor (km^2-days)	
				Canada	US	Canada	US
Upstream storage	L103	107	1:10	9.4	13.3	137.2	183.4
Upstream storage	L104	109	1:50	55.0	73.3	743.0	1195.9

2.3.6 Non Structural Options: Land acquisition and compensation for flooding or water storage could be considered as a part of any structural solution, but they should also be considered a non-structural solution option on their own. Given a credible analysis of the increased flooding with the border road/dyke versus the “natural” conditions (i.e., no roads and no border road/dyke) could be used as basis to assess the impact of the border road/dyke and evaluate the need for specific compensation or land acquisition measures which given the flooding patterns and history may be a solution over building major infrastructure. This option, however, would not do anything to alleviate the flooding anywhere in the basin. Land acquisition values have been estimated in Table 8. Compensation would be based on the individual damages to crops and the land sustained during specific flood events. This would require the development of a compensation program specifically for the area impacted by the border road/dyke.

Table 7 US Land Acquisition

Flood Event	Flooded Area in the US					Incremental Costs ($ M) at $5,000 per acre	
	Natural Conditions – no Roads (km^2)	Existing Conditions (km^2)	With Border Road Dyke Removed (km^2)	Existing minus Natural (acres)	With Border Road Dyke Removed minus Natural (acres)	Existing minus Natural	With Border Road Dyke Removed minus Natural
1:10	35.4	49.3	34.8	3435	Negative	17.2	Negative
1:50	80.2	103.8	88.0	5832	1927	29.2	9.6
1:100	99.7	129.1	116.7	7265	4201	36.3	21.0

2.4 Cost Benefit Analysis

To move the process forward towards deciding on a mitigation solution, the Task Team notes that a feasibility study including a cost benefit analysis should be done on the preferred options both structural and non-structural. The result of the net benefit analysis, however, will depend on what base condition is used for the cost and benefit comparisons. In principle, the comparison should be based on the no border road/dyke and no roads condition, which is also referred to as the natural condition. Also, ideally no solution should make the flooding worse than existing conditions in the basin north of the border, nor worse than the without border road/dyke condition south of the border. However, benefits (or other impacts) on both sides of the border should be taken into account for each scenario considered, thus the true cost-benefit analysis and final ratio would be a bi-national assessment.

In addition, the plan formulation would also need to take into account to what degree the governments are prepared to provide flood protection for agricultural land, farmsteads, roads and towns. A preliminary survey of the area flooded by the border dyke/road would establish a range for the extended future benefit analysis and could provide important perspective to the consideration of structural and non-structural solutions.

Thus, in looking at a net benefit analysis, the choice of the base scenario for comparison either the model's "natural conditions" (no roads or border road/dyke) or no border road/dyke, or existing conditions will make a difference on the final net benefit ratio. So within a net benefit analysis, the basic status would need to be defined and perhaps compared across multiple scenarios. In addition, the projected desired flood mitigation level would need to be adjusted between agricultural land, farmsteads, roads and towns.

3 Task Team Observations on Flooding and Mitigation Solutions

The Task Team makes the following general observations and conclusions about flooding in the Lower Pembina River basin and the possible mitigation solutions. Again the Task Team would like to emphasize that the best overall solution may not result from only one mitigation measure but from a combination of a number of mitigation measures. The goal is that flooding should be no worse than existing conditions north of the border in Manitoba and no worse than natural conditions south of the border in North Dakota.

- The results of this study, including simulations and conclusions, can be useful as background material for feasibility assessments of potential flood mitigation alternatives in the lower Pembina River floodplains.

- Much of the analysis that has been conducted is focused on determining the extent of impact of the border dyke road in North Dakota, with the implementation of the structural alternatives.

- Upstream storage would enhance all the structural and non-structural options considered. Storage options in both Canada and the U.S. should continue to be pursued.

- All structural mitigation measures would require compensation and or buy outs / acquisition of land for implementation. Compensation and buy-outs should be considered as possible stand-alone non-structural mitigation measures.

- Working together and across the border may lead to solution options that have not been previously considered or may change aspects of previously considered options and make them more feasible. For example, a floodway could be constructed across the border, or a combination of measures would be implemented working in conjunction across the border. Cross border considerations could improve on previous marginal net benefit calculations.

- The benefits of any project to mitigate the impact of the border road/dyke should include the benefits that accrue to Canada of keeping the border road/dyke in place and thus would increase the bi-national cost/benefit ratio of the new structural project. The floodway net benefit would increase if natural conditions are used as the base and reduced flooding in Canada is taken into account in the benefits analysis.

- Given the negative impacts of some flood mitigation measures considered, public awareness of the impact of the options throughout the basin is important. The model helps to illustrate those impacts in a clear visual manner.

- Finally the working group notes that it does not seem to be economically feasible to eliminate all impacts of flooding in the lower Pembina River floodplains during major events such as the 1:100 year flood.

4 Recommendations for next steps for IRRB

The Task Team recommends that:

a) The International Red River Board (IRRB) approve this report and the Phase 3 NRC report and forward these reports and model of the lower Pembina River floodplain to the IJC for approval and release to the public.

b) The IRRB should publish this report and the Phase 3 NRC report and post them on the web for public discussion.

c) Once approval from the IJC is received, the IRRB should proceed to host or participate in public meetings in the lower Pembina River basin to discuss the model results and flood mitigation measures, possibly at the January 2013 IRRB public meeting as well as venues in the Pembina River basin.

d) The IJC should inform the governments of Manitoba and North Dakota, and related federal agencies about the results of the modeling and the findings of the Task Team.

e) Pending approval of the IJC, the model results should be displayed on the IJC website and if possible have an interactive interface. Due to the size and complexity of the model and the size of the data files, a copy of the model and data will also be provided to a number of key agencies: USACE and Manitoba Conservation and Water Stewardship.

Appendices:

1) Map 1 – NRC report Figure 1 from page 14

2) Map 2 – NRC report Figure 55 from page 70

3) Conclusions from the Phase 3 report from pages 109-112

Attachment: *Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac 2D Hydrodynamic Model Phase 3,* Thierry Faure*,* National Research Council, Canada, 2012

Conversion Units:

Length: 1 millimetre (mm) = 0.039370 inches
1 meter = 3.28 feet
1 kilometre = 0.62 miles

Area: 1 square kilometres ($km^{2)}$ = 0.38610 mi^2
1 Hectare (ha) = 2.47 acres

Volume: 1 cubic decametre ($dam^{3)}$ = 0.8107 acre-ft

Flow: 1 cubic metre per second (m^3/s = 35.315 ft^3/s

References:

1) Phase I: Preparation of a two-dimensional Hydrodynamic Model of the Lower Pembina River Flood Plains
Controlled Technical Report CHC-CTR-093, July 2009

http://www.ijc.org/rel/boards/watershed/report_Pembina_CHC_July_2009.pdf

2) Phase II: Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the 2D Hudrodynamic Model
Controlled Technical Report CHC-CTR-106, June 2010

http://www.ijc.org/rel/boards/watershed/report_Pembina_CHC_June_2010.pdf

3) Simulation of Flood Scenarios on the Lower Pembina River Flood Plains with the Telemac 2D Hydrodynamic Model Phase 3, Thierry Faure, National Research Council, Canada, 2012

To be published on IJC website www.ijc.org

4) Red River Basin, Long Term Flood Solutions, Barr Engineering Co., September 30, 2011 http://www.redriverbasincommission.info/RRB%20Long%20Term%20Flood%20Solutions%20Appendices/Appendix%20A-Maps/App%20A-Maps%20Text.pdf

5) US Army Corps of Engineers, PEMBINA RIVER BASIN RECONNAISSANCE STUDY, Section 905(b) Analysis, (Water Resources Development Act (WRDA) of 1986), North Dakota, JANUARY 2007

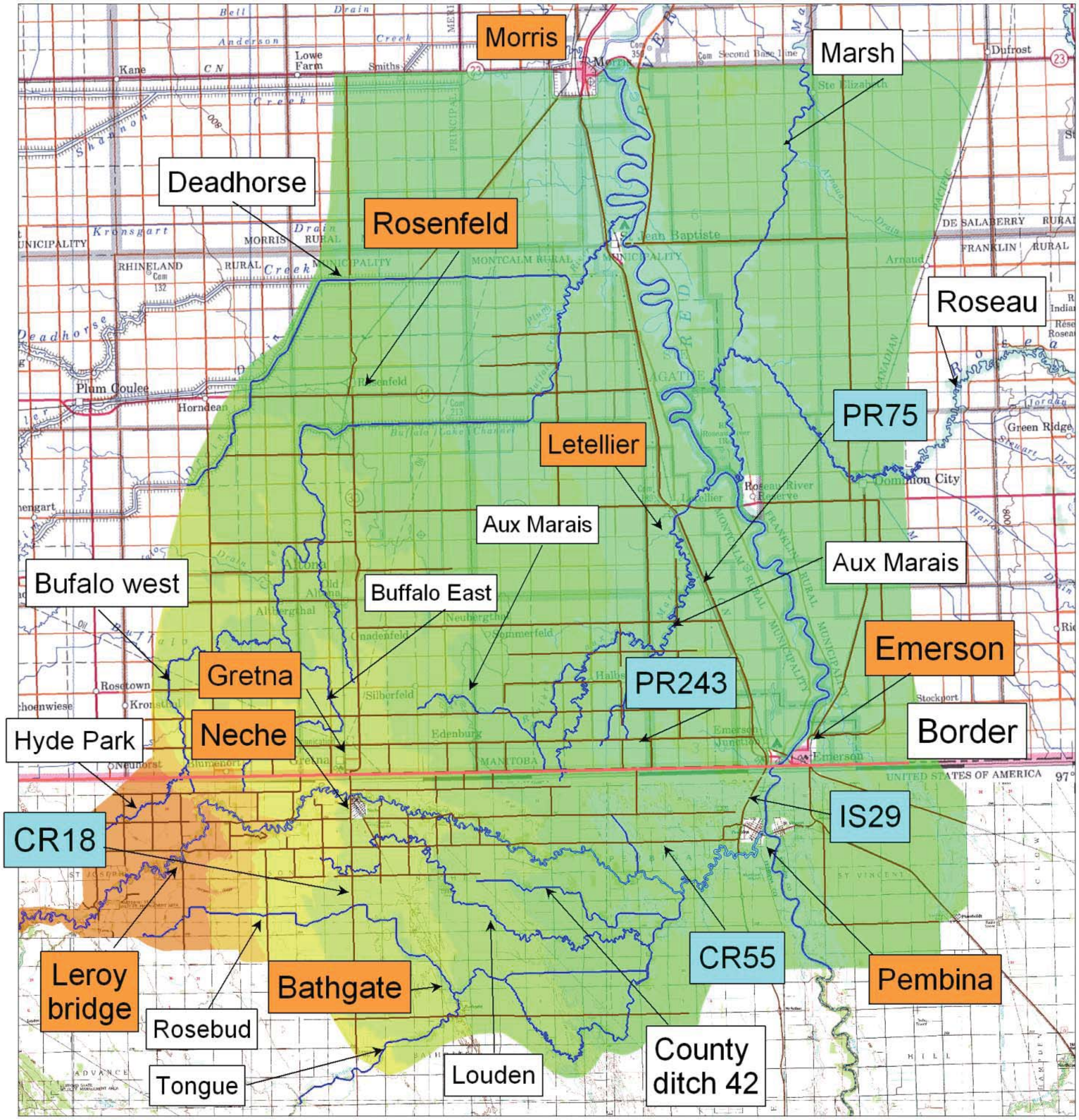

Figure 1 - General layout of phase 3 model

In most cases the simulations were run for 25 days. The 2006 event was run for 30 days and the summer event for 18 days only.

The comparison of two scenarios can be done be comparing their flood-duration factors. Within the same area, a positive difference between two scenarios indicates that the first one exhibits more flood extent, or is flooded for a longer period, than the second scenario. A negative difference indicates that the first scenario provides less flood extent within the same area. The factors are shown on Table 18.
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As a reference, the two areas have the following total surface area:

Canadian: 666 km^2
US: 388 km^2

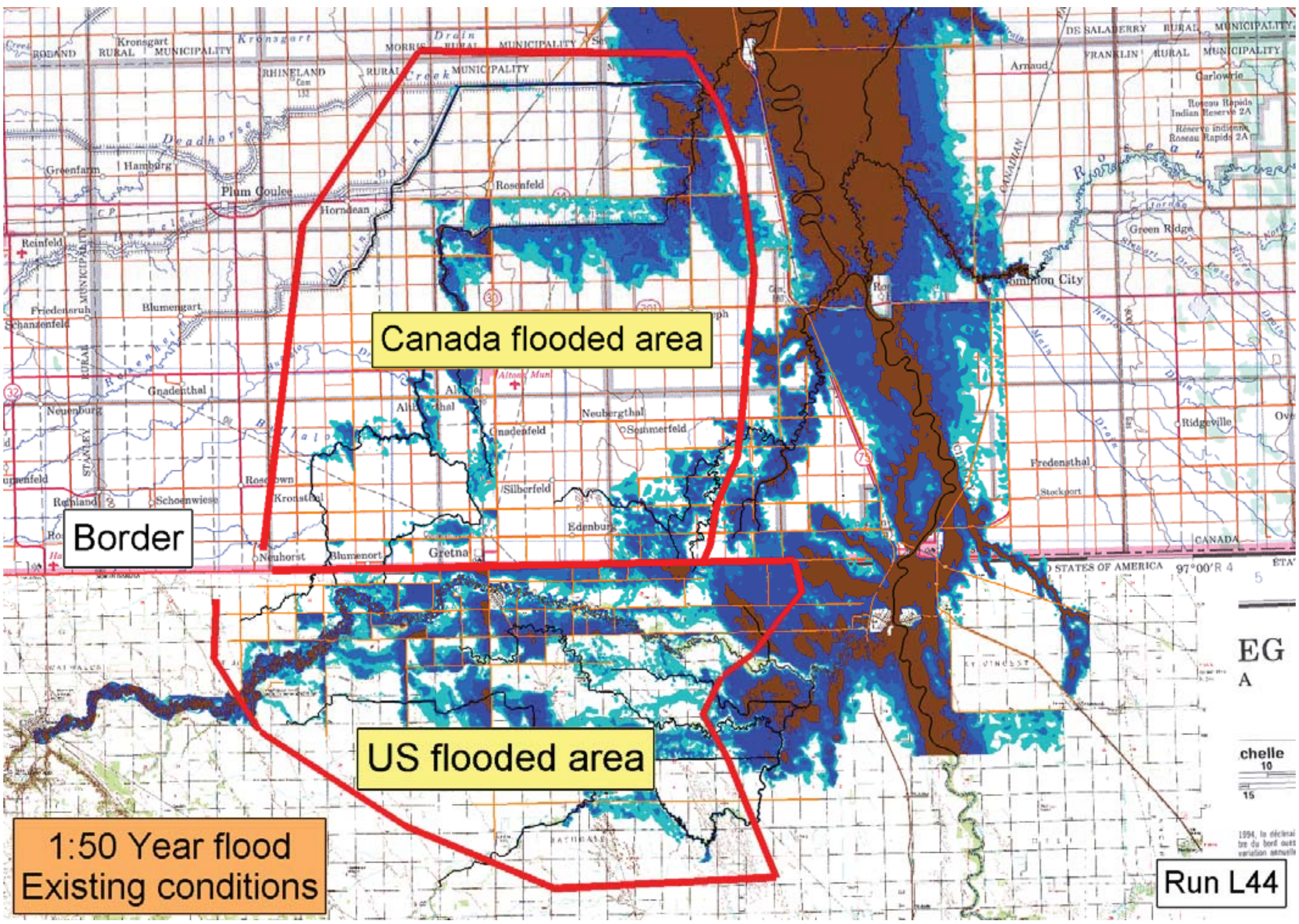

Figure 55 - Delineation showing the two areas used to calculate the flood-duration factor

Of particular interest is the flooding around Rosenfeld (shown on Figure 1) which is protected by the Buffalo dykes against local runoff.

12. Conclusions

- During flood events roads have a huge temporal and spatial impact on the distribution of water within the lower Pembina River flood plains. The relationship between the lower Pembina River basin and adjacent basins, including the Red River, is quite complex. As presented in this report, the Phase 3 TELEMAC model does an exceptional job at replicating historic events, and as a result, is a useful tool for assessing the impacts of various alternative mitigation measures that are structural in nature. Such measures include evaluating the impacts on the landscape of:

  - the removal of one of more roads that act as barriers to the flow of water;
  - the upstream storage of water that reduces the magnitude of the flood peak on the lower Pembina River;
  - a floodway having various conveyance capacities;
  - multiple diversions of water from the Pembina River to various other stream systems;
  - set-back dykes along both sides of Pembina Rive to contain its spreading, and;
  - breaching the border road at two locations.

- For the 10-year event, the only location that County Road (CR) 55 impacts the level of flood waters along the Border is for about one mile (1.6 km), east of the Border Road Crossing 6 (Plate 87). It does not appear that there would be any change north of the border at this site. This location would experience reduced water levels by about 5 cm during the 10-year flooding if CR 55 did not impair the movement of water towards south-east (while all other roads remain in place).
- County Road 55 runs in an east-west direction. It crosses Pembina River 9.6 km (6 miles) west of Neche, and then runs north of the River instead of south. It therefore affects the breakouts on the left bank of the river as they move north. For the 50-year and 100-year events, if CR55 is removed, the break outs on the north side of Pembina River, which was contained by CR55, is now free to progress toward the border and into Buffalo Creek, causing strong flooding along the creek. At the same time since more water is released into Buffalo Creek, there is a reduction of flow into Aux Marais, as seen on (Plate 89).

- CR 55 also significantly alters the distribution of water within the US portion of the model domain, channeling water in an east-west direction north of the road rather than allowing it to flow in a south-eastward direction. It was overtopped during large recent flood events. Plate 87 shows that CR 55 increases water levels north of CR 55 and lowers levels south of it. Conversely, a large area north of the road and south of the Pembina River would generally experience reduced flood levels during flooding while south of the road would experience increased water levels during flooding if CR 55 did not impair the movement of water in a north-south direction. The widening of the existing bridges and culverts, or the creation of new ones under CR55 (east and west of CR18), would reduce flooding on the north side of CR55. This must be undertaken under controlled situation where water is guided downstream into channels with sufficient capacity such as the downstream portions of Louden and Rosebud Coulee, and County ditch 42.

- The Border Road reduces flooding in Canada from waters overflowing the banks of the lower Pembina River in the United States, while causing more flooding in the U.S.. (Plate 3 and 7)

- If the Border Road did not impair the south-north movement of water, there would be significant flood reduction in the United States while at the same time significant increased flooding in Canada, which would be closer to the conditions that would occur with natural conditions. Natural receiving streams in Manitoba are the east and west branch of Buffalo Creek and Aux Marais River (Plate 72, 75, 78 and Table 23). It is to be noted that the model was prepared with four east-west roads which impeded the south-north natural flow direction: the road 1/2 mile south of the border, the border road itself, PR243 located 1 mile north of the border, and the next road 1 mile north. If only the border road was removed, the flood water would still be directed by the other east-west roads towards Aux Marais (Plate 10), even though Aux Marais is not the main natural drainage (Plate 75). With the border road removed, peak flow in Aux Marais (42 m^3/s, for the 1:10 event) would be higher than in natural conditions (29 m^3/s) and than in existing conditions (10 m^3/s)

- The removal of the border road must be accompanied by the modification of the other east-west roads (widening of the existing bridges and culverts, creation of new ones), to create passages (along with new drains and channels) which would guide water towards its natural drainage: mostly Buffalo Creek and to a lesser extent Aux Marais River.

- Upstream basin storage (above Walhalla), as promoted by the Red River Basin Commission to reduce the Red River main stem 1997 peak flows by 20%, would have broad benefits to the lower Pembina flood plain. It is evident from a comparison of Plate 107 that upstream storage reduces overall flooding more than what occurs under either existing conditions (Plate 3) or natural conditions (Plate 72), for the 10-year event. Upstream storage also has dramatic reductions in flood extent and flood duration factors similar to the floodway scenario having a capacity of 142 m^3/s (5,000 cfs) (Plate 34). The timing and quantity of the water placed in storage was assumed to be nearly perfect, taking the entire volume off the highest portion of the flood hydrograph even for the small 1:10 event.

- Floodways having seven capacities between 50 m^3/s (1,770 cfs) and 210 m^3/s (7,420 cfs) were analyzed for the 1:10 event, while the 1:50 event was run for capacities between 74 m^3/s (2,610 cfs) and 210 m^3/s (7,420cfs). Results on the inundated area and flood duration factors are provided below for the 1:10 event (termed metrics) and illustrate the effect of the various floodway capacities on them. A shorter floodway having its intake at Crossing 6 is also shown. It should be noted that there is associated reductions in aerial extent of flooding and flood reduction factors not captured below due to the two zones wherein these metrics were calculated. There are reductions in these metrics outside the zones evident in the various Plates contained in this report. It is evident from the numerical results below that for the 1:10 event, within the American portion, there are decreasing reductions in the metrics as the size of the floodway increases (Plate 27, 29, 31, 33, 35, 37, 39), with minor changes on the Canadian side. Any significant increase in capacity would provide a level of protection that would have occurred without roads impairing the movement of water for the 1:10 magnitude design event. Larger capacities would also provide protection for events exceeding the 1:10 level and would have benefits associated with the additional capacity. Results from the 50 m^3/s (1,770 cfs) floodway capacity provide metrics that are very close to what would have occurred under natural conditions within the American portion of the analyzed area (Plate 45, 47, 49, 51).

Run	**Description all 1:10 event**	**Inundated area (km^2)**		**Flood-duration factor (km^2-days)**	
		Canada	US	Canada	US
L74	existing conditions	9.4	49.3	157.2	534.6
L73	Natural conditions	38.5	35.4	606.2	415.4
L87	Floodway 50 m3/s	9.4	37.2	143.8	375.2
L121	Floodway 74 m3/s	9.4	30.5	142.1	322.3
L122	Floodway 96 m3/s	9.4	23.7	140.7	271.6
L123	Floodway 119 m3/s	9.4	18.0	139.2	218.8
L75	Floodway 142 m3/s	9.4	14.1	135.9	182.1
L80	Floodway 190 m3/s	9.4	12.0	130.9	155.4
L81	Floodway 210 m3/s	9.4	12.0	131.1	151.7
L128	short Floodway 50 m3/s	9.4	40.2	145.9	409.2
L129	short Floodway 67 m3/s	9.4	39.7	142.2	405.2

- For events 1:50 and larger, the floodway does not reduce significantly the extent of flooding coming from Red River overflow, East of Switzer Ridge and at the Tongue confluence, but it reduces their depth, and their duration.
- In the conditions tested , there is a local increase in water level of up to 24 cm (9.4 inches) on Red River at the floodway outlet, but no increase in the peak levels on the Red for the 1:10 event, and minor peak level increase (2 to 4 cm) for the 1:50 event. But this effect is very sensitive to the timing of the peaks between Red River and Pembina River.

- A shorter floodway starting at Border Crossing 6 with a capacity of only 67 m^3/s (2370 cfs), during 1:10 event, would prevent any overtopping of Switzer Ridge and the subsequent filling from Pembina River of the area east of the ridge. A capacity of 181 m^3/s (6390 cfs) would be required for the 1:50 event. Much work is required to determine the most effective floodway route and the required capacity. As well, the capacity of the floodway could potentially decrease in an upstream direction if branching into it were included in the design.

- The diversion of some of Pembina River flow into five adjacent channels provides a scenario closest to natural conditions where water is allowed to flow according to natural slope of the land, in both northern and southern directions, instead of one artificially set direction (such as set-back dykes or floodway). It would provide additional flow capacity to the existing flood relief infrastructures such as border crossings 4, 5 and 6, and county ditch 42. The diversions being independent from each other could be designed according to the planned capacity of the receiving channels. Their implementation could be gradual, compared to the floodway or set-back dykes which must be fully completed before being operational. The model was run with one location for the diversion intake and outlet. Other locations, which may require less infrastructure modification (bridges) or channel improvement (where the model identified insufficient conveyance), should be investigated.

- There are issues around the mitigation approach of such diversions. They relate to the already estimated significant local flows that can occur during flood events along the receiving waterways, their timing, existing channel capacities and existing infrastructure (e.g. bridge restrictions, homes and farmyard locations). Cost of increasing channel capacities and undertaking bridge enhancements or extra culvert installations, should be undertaken on a one to one basis; Buffalo Creek has more capacity than Aux Marais, and some of the impeding bridges identified by the model may require only minor modifications. One must also consider the impact that channel enlargement (deepening or widening or simply clearing), would have on the environment. A constructed channel adjacent to the coulees, rivers and creeks, or additional drains, may reduce some of the environmental concerns, but may still have several of the other issues.

- Set-back dykes may be an absolute mitigation alternative. It prevents any flooding for a given design event. Right-of-way and compensation would be issues to consider (there are many farmsteads located close to the river edge). With the south side of the dyke along Pembina River ending at the confluence with the Tongue River, there is a dramatic reduction in both inundation area and flood-duration factor for both American and Canadian portions. The increase in water level is localized at the confluence with Tongue River and is minimal on the Pembina community dykes. This increase is sensitive to the timing of the peaks between Pembina River and Red River. (For an event similar to the 2006 flood, an increase along the Red River of up to 12 cm (4.7 inches) would be observed). This downstream impact must be mitigated for this option to be further considered, such as raising the dykes around the communities.

- Breaching the Border Road at the two identified locations, one located west of Gretna and the other at Border Road Crossing 6, is seen as only a partial solution. It must be accompanied by infrastructure enhancements such as the creation of channels which would guide water towards Buffalo and Aux Marais, bridge widening and farm yard protection. The scenario with diversions would be a better choice of mitigation.