Manitoba
INFRASTRUCTURE AND TRANSPORTATION

ASSINIBOINE RIVER & LAKE MANITOBA BASINS FLOOD MITIGATION STUDY

KGS GROUP
CONSULTING ENGINEERS

Executive Summary

12-0300-011 | January 2016

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1. BACKGROUND

The flood of 2011 was the largest flood in more than one hundred years in both the Assiniboine and Souris Rivers. Similarly, extreme water levels were experienced on Lakes Manitoba and St. Martin. The flood of 2011 highlighted several potential weak links in the existing flood control systems. The shortcomings of the system were emphasized again in 2014.

Studies by the 2011 Flood Review Task Force and the Lake Manitoba and Lake St. Martin Regulation Review have both recently provided broad perspectives on this unprecedented flood event and offered a variety of opinions and recommendations on possible improvements that could reduce damages in the future. The Province of Manitoba retained KGS Group to undertake engineering analyses of a wide range of measures that could mitigate floods of a similar magnitude to 2011 and larger. The study was requested to be at a conceptual level of analysis, and intended to identify and assess potential options to reduce flood risk for communities and major infrastructure along the Assiniboine River, Souris River, Qu'Appelle River, Dauphin Lake, Lake Manitoba, Fairford River, Lake St. Martin, Dauphin River and Shoal Lakes. This report provides a detailed account of the work carried out, the findings, and the conclusions / recommendations.

The study process involved the deployment of the usual Steering and Technical Committees comprised of staff from MIT, Manitoba Conservation and Water Stewardship (C&WS), University of Manitoba, and Manitoba Agriculture, Food and Rural Development (MAFRD). It also included input from a Study Liaison Committee (SLC) that had a broader perspective than the engineering focus of the Steering and Technical Committees. In addition to the representation previously identified, the SLC also included representatives from various key towns, cities and municipalities (e.g., Winnipeg and Brandon), as well as from other organisations and local citizen groups (e.g., Emergency Measures Organization (EMO), Manitoba Métis Federation (MMF), Ducks Unlimited, Association of Lake Manitoba Stakeholders (ALMS), and more).

The study commenced with review and familiarization of a large compendium of previous reports. Over 185 reports were examined, dating back as far as the 1950s. A summary of all the reviewed reports is provided in this report. **Since the 1950 Flood, Manitoba has developed an extensive flood protection system. This integrated strategy has worked well and has avoided billions of dollars in damages.**

The study terms of reference required identification of all major flood vulnerabilities throughout the study area. The process to confirm vulnerabilities that were initially identified in this study was based on a technical workshop developed jointly by the Manitoba Infrastructure & Transportation (MIT) Steering Committee and KGS Group. Approximately 75 technical representatives with diverse experience in Manitoba floods were invited from various government and non-government sectors. The purpose of the workshop was to provide a mechanism for input from the attendees prior to KGS Group completing their comprehensive conceptual-level studies.

2. VULNERABILITIES

A wide range of vulnerabilities were identified and are described in detail in this report. In the context of the process of identification, the threshold of minimum acceptable protection against floods was defined by the three criteria promoted by the Province of Manitoba, which were:

1. The 1:200 year event, as recommended by the Lake Manitoba and Lake St. Martin Regulation Review Committee and the 2011 Flood Review Task Force, which was greater than the previous 1:100 year standard as discussed further below.
2. The highest flood on record if greater than the 1:200 year event.
3. A greater flood event that could be justified in an economic analysis that considered costs and benefits.

More than 100 vulnerabilities were identified and classified by a rating system that varied from low to high. The three most important vulnerabilities are summarized as follows:

1. The maximum safe discharge capacity of the Lower Assiniboine River from Portage la Prairie to Winnipeg combined with the Portage Diversion is less than the minimum criteria for flood protection promoted by the Province. This vulnerability became evident during the 2011 Flood when extensive emergency measures were necessary on the Portage Diversion and on the Lower Assiniboine River to convey peak flows.

2. The shorelines of Lakes Pineimuta and St. Martin are vulnerable to flooding. This has been a chronic problem for decades and requires urgent attention.

3. Although the response to the 2011 Flood effectively addressed major problems, and decisions were made in a timely and purposeful fashion, many decisions were made under duress and were based on less than full knowledge of optimum reactions. Existing emergency preparedness and response plans to address extreme floods have been pushed to the limits and would greatly benefit from being updated and expanded.

The flood mitigation alternatives analysed in the study addressed a significant number of the vulnerabilities that were identified including the first two most important vulnerabilities mentioned above. The remaining vulnerabilities, including the third most important vulnerability identified above, were not specifically addressed in this study as they were outside the study scope. Nevertheless, these were also provided to the Province of Manitoba with the report.

3. OPEN HOUSES

Three rounds of public open house events were held for the study. The first round occurred from June 18 to 20, 2013 in Dauphin, Brandon and Portage la Prairie and communicated as much information as possible regarding the scope of the study. Another open house event was held in Ashern on September 18, 2014 and provided information specific to the Lake Manitoba and Lake St. Martin outlet channels. The final round occurred from December 8 to 10, 2014 in Dauphin, Brandon and Portage la Prairie and provided an opportunity for feedback on the preliminary results of the study prior to the development of the final report. Feedback received at the open house has been incorporated into the report.

4. BASIN HYDROLOGY

The hydrology of the Assiniboine River and Lake Manitoba drainage basins has been studied extensively as a basis for addressing possible improvements in the flood protection works. Flood frequency analyses were provided by MIT for most relevant rivers and streams in the region, and were supplemented with other analyses as required for specific study needs. The statistics of all rivers were focussed on the characteristics derived from the full hydrometric record for each site, which for example, dates back more than 100 years for the Assiniboine River at Holland. Flood probabilities were identified across the region as a basis for assessing the need and justification for upgrades in flood protection. Use of the full historical period in the statistical analyses reflects an assumption that the hydrological characteristics of the watersheds will remain essentially the same in the future as they have persisted in the past. For example, 1:200 year flood peaks were estimated to be the following for key locations in the watershed, based on the existing published records of river flow:

- Assiniboine River near Holland – 1,617 m^3/s (57,100 cfs).
- Assiniboine River at Brandon – 1,198 m^3/s (42,300 cfs).
- Souris River at Melita – 790 m^3/s (27,900 cfs).
- Lake Manitoba still water level – El 248.9 m (El 816.6 ft).

It was recognized in this study that there is a growing belief that climate change is already affecting the statistical characteristics of flood potential in the region, compounded in some areas by changes in land use. However, the consensus of the engineering community represented at the Workshop held on February 6, 2013, was that there is no solid understanding of the means to predict future trends at this point in time. It was agreed at the Workshop and subsequently confirmed with MIT that the full historical period of hydrometric records should be used as a basis of analysis. However, it was also agreed that sensitivity analyses should be conducted to explore what the effects would be if shorter records using only recent high flood peaks were considered. This is discussed further later in this summary, and details are provided in the report.

The drainage basin of the study area is vast, covering more than 246,000 km^2 (95,000 mi^2). The Assiniboine River is also a tributary of the Red River and forms more than 82,000 km^2 (32,000 mi^2) of the total area of 285,000 km^2 (11,000 mi^2) at Winnipeg. It was recognized that floods in one region do not necessarily correspond to simultaneous floods in another region. For example, floods in the Assiniboine River may or may not occur in parallel with inflow floods to Lake Manitoba. Similarly, floods in the Assiniboine River may or may not occur simultaneously with floods in the Red River. This diversity within the overall watershed had to be understood and reflected appropriately in the statistical characteristics of flood events. Special statistical techniques were devised to address the diversity of the streams and were used to quantify flood probabilities with and without upgrades to flood protection works, as well as to form a basis for economic calculations of benefits due to flood reduction. Details of this approach have been provided within the report, but the key basis for the studies of diversity across the watershed was the application of the principles of synthetically generated flood peaks and volumes for a large number of hypothetical years in the future. The statistical generation of this data followed in all cases the existing known statistical characteristics of individual rivers and streams within the study area. This technique, often called a Monte Carlo approach by practitioners, permits examination of the inter-dependencies of flood flows within the region. It is widely accepted by practitioners and has formed the basis for studies of the basin-wide flood potential, particularly for the Assiniboine / Lake Manitoba / Red River catchments.

The assembled statistical characteristics of floods throughout the study area permitted the identification of zones where the flood potential exceeded the existing capability of flood protection works and, therefore, formed the basis of the vulnerability to floods. The only zone where flood protection does not meet the basic standard of either the flood of record or the 1:200 year flood was found to be the Lower Assiniboine River between Portage la Prairie and Headingley. **The level of protection for the Lower Assiniboine River area, including the Portage Diversion, is deficient with an estimated level of protection of 1:55 years**.

In other areas of the basin, there have already been significant strides towards upgrading the flood protection system. **A number of related flood mitigation studies and projects are ongoing or have been recently completed within the Assiniboine River and Lake Manitoba Basins. Many areas are, therefore, already protected to the highest flood on record.**

5. FLOOD PROTECTION MEASURES AND ECONOMIC ANALYSES

A wide variety of flood protection measures were considered as potential upgrades to existing facilities, as well as new works that could assist in averting flood damages. **A massive amount of data and technical input has been assessed and over 70 mitigation options have been evaluated**. The options included all the classic measures such as dikes, reservoirs, diversion channels, channel improvements, modifications to land use, as well as the purchase of vulnerable properties where protection measures were not practical. The report provides considerable detail on each option considered, and the improvements in flood protection that could be provided by the options, both as stand-alone schemes, or in some cases selected combinations.

The economics of the various options were assessed using guidelines that were developed for the study and vetted by representatives of MIT and the Study Liaison Committee. The details of the guidelines are extensive and are described in the report. Key features included:

- Benefits were estimated on the basis of the averted flood damages in the future. These damages would include:
  - Cost of pre-emptive works or actions that would be deployed if the protection measure were not implemented.
  - Repairs / replacements for direct physical damages to residential, commercial and industrial buildings and contents, as well as damages to adjacent developments.
  - Temporary relocation and subsistence costs for affected residents.
  - Temporary services that may be required until direct physical damages are repaired (e.g., hauled water or septic).
  - Repair / replacement of damaged vehicles that could not be removed from the inundated zone in time.
  - Agricultural losses.
  - Miscellaneous damage to crops or arable land.
  - Miscellaneous impacts on farm infrastructure including, for example:
    - Effects on timely access to non-flooded fields.
    - Loss of income from off-farm jobs.
    - Relocation costs of the affected farm.
    - Emergency care of livestock, if located within the ring dike.
    - Repair / replacement of damaged public infrastructure.

- A depth-damage relationship was used to estimate damages on partially submerged buildings, and was modelled after similar relationships devised in previous extensive studies of flood protection in the City of Winnipeg.
- Expected Annual Damages (EAD) were estimated with and without a protection option and the calculation incorporated the full spectrum of flood probabilities up to and exceeding the 1:500 year flood.
- A time horizon of 50 years was the basis of the economic calculations, and present valuations were based on this period.
- Costs of the various options were based on preliminary estimates of the construction details, using a set of pre-selected unit prices that would represent conditions in the study area in 2014 (i.e., all cost estimates are in 2014$).
- Rates of interest and inflation assumed the following basic values:
  - Interest – 7% per year.
  - Inflation – 3 % per year.
  - Future Growth of Population and Economic Activities in the region – 1% per year.
- Sensitivity analyses were undertaken in cases where the economic indicators would be affected significantly by the assumed parameters listed above.

6. NUMERICAL MODELS

A broad spectrum of numerical models were developed and applied during the course of the study. These included:

- Flood routing models for a range of key lakes and river reaches.
- Backwater models were either developed from cross sectional data or based on existing models provided by MIT.
- Wind and wave generation models for Lake Manitoba.
- Models to permit synthetic generation of river flows in the Upper and Lower Assiniboine River, inflow to Lake Manitoba, and flows in the Red River.
- Flood damage models that incorporated depth-damage relationships / topographic information and water levels with and without flood protection works under consideration.

All major models were documented and prepared for transfer to MIT as “legacy tools” for use in future studies of the region.

7. FLOOD PROTECTION MEASURES

A summary of the measures and issues that were considered for each of the geographic areas of the region follows.

A. UPPER ASSINIBOINE RIVER

Agricultural land located along the Upper Assiniboine River at the bottom of the valley is prone to flooding and at times has been negatively impacted by operation of the Shellmouth Dam. The 2011 Flood Review Task Force recommended that three alternative means to prevent or reduce flood damages on the Assiniboine River downstream of Shellmouth Dam should be investigated. These options were evaluated for the study and are summarized below:

1. The effects of the installation of gates on the spillway at the Shellmouth Dam, and specifically whether they could be relied on to reduce flood potential was reviewed in

considerable detail. A previous numerical model developed by the Province of Manitoba (Assiniboine River Water Management Model) was mobilized and used to assess the merits of gates in the context of flood mitigation. **It has been concluded that the gates on the Shellmouth Dam could have moderating effects at modest flood magnitudes, however, they would essentially provide no significant improvement for above normal to extreme floods** without changes to the existing operating guidelines for the structure. Even the modest benefits for minor floods would only be available locally near the Shellmouth Dam and would attenuate significantly further downstream.

2. Options for protecting agricultural interests along the Assiniboine River Valley between the Shellmouth Dam and Brandon were considered. Diking proved to be very expensive, ranging between approximately $73 million to $471 million depending on the options, which provided a flood protection level of 1:5 year to 1:50 year, and was not practical in comparison with the estimated benefits that could be gained. It was also recognized, but not evaluated specifically, that diking along the valley would exacerbate flooding in Brandon and downstream due to an increase in flow from the loss of floodplain storage in the protected area.
3. An alternative option in the Upper Assiniboine River is the purchase of flood prone land. The option consisted of purchasing land affected by flooding between the Shellmouth Dam and St. Lazare at a flow of 85 m^3/s (3,000 cfs). The cost of the option was estimated to equal approximately $24 million. **Due to various issues related to the linear diking scheme identified in the report and the lower cost of the land purchase option, it was concluded that purchase of the flood prone land option was preferred over linear diking and that it should be considered further.**

A selection of possible large reservoirs including the Holland Dam and the Alexander Dam on the Assiniboine River, the Zelena Dam on the Shell River, and the Victor Dam on the Qu'Appelle River were studied and found to provide varying extents of reduction in flood conditions, but with considerable cost, ranging between $104 million for the Zelena Dam Project, to $591 million for the Alexander Dam project. The environmental effects on the surrounding area would be substantial, ranging from loss of agricultural land, loss of First Nation reserve land, to the blocking of fish passage, altering of fish habitat associated with the change in flow regime and impeding navigation of the rivers. These impacts are expected to render these options difficult to implement. **Therefore, it has been concluded that large dams on the Upper Assiniboine River should not be considered further due to the significant environmental and operational concerns, as well their relatively high costs compared to other flood mitigation solutions**. These conclusions are consistent with the comments and advice received at the technical workshop that was undertaken at the beginning of this study.

The City of Brandon is currently in the process of upgrading their flood protection system to be able to withstand a repetition of the 2011 and 2014 floods. **It has been concluded that linear diking is the most feasible means to increase the level of protection for Brandon**. Current hydrological analyses that include both the 2011 and 2014 floods suggest that the 2011 Flood is approximately a 1:140 year flood event. The study assessed requirements to increase that protection to a 1:300 year flood event. The proposed diking now underway would have to be raised by 0.8 m (2.6 ft), at an estimated additional cost of $11 million.

The communities of St. Lazare and Sioux Valley are protected to the highest flood on record, which exceeds the provincial flood protection level target of a 1:200 year flood event.

B. LOWER ASSINIBOINE RIVER

The existing provincial linear diking system on the Assiniboine River downstream of Portage la Prairie was able to convey a flow of about 510 m^3/s (18,000 cfs) for two months in 2011, and again for approximately two weeks in July 2014. Although the dikes held in 2011, significant repairs and ongoing inspection and maintenance were required, with temporary top up, to safely pass the flood during the extended flood period. **Based on an assessment of the existing diking system and experience from the 2011 Flood, the current reliable flow capacity of the provincial Assiniboine River linear dikes has been estimated to be 425 m^3/s (15,000 cfs)**.

Conceptual designs and cost estimates were prepared for three improvement schemes for the existing dikes between Portage la Prairie and approximately Baie St, Paul. The schemes consisted of:

- Option 1a – Upgrading the existing dikes generally in their current location.
- Option 1b – A major setback of the dikes to adjacent roadways.
- Option 1c – A combination of existing dike upgrades and major setbacks to adjacent roadways.

Different capacities were considered for the options, which when combined with upgrades to the Portage Diversion, would provide a flood protection level of at least 1:200 years. The cost for Option 1a was estimated to range between approximately $153 million and $392 million for design flows of 510 m^3/s (18,000 cfs) to 793 m^3/s (28,000 cfs). **Option (1a) was considered the most feasible option to increase the capacity of the Assiniboine River between Portage la Prairie to approximately Baie St. Paul as the estimated costs for Option 1b and Option 1c were estimated to be two to three times more.**

Downstream of the provincial linear diking system, from approximately Baie St. Paul to the City of Winnipeg limits in Headingley, minimal damages occurred during the 2011 and 2014 floods, although temporary flood mitigation measures were implemented to protect vulnerable properties from flooding. The following two options were considered for permanent protection in this area:

1. Option 2a – Extend the existing dike to the City of Winnipeg limits in Headingley.
2. Option 2b – Combination of individual flood proofing, neighbourhood diking and the purchase of vulnerable properties severely affected by flooding.

The most feasible option to increase the capacity of the Assiniboine River between approximately Baie St. Paul and the City of Winnipeg limits in Headingley is Option 2b, where the cost was estimated to range between approximately $21 million to $123 million for design flows of 510 m^3/s (18,000 cfs) to 793 m^3/s (28,000 cfs). The cost for option 2a is higher and estimated to range between $114 million and $197 million for the same flows.

Diversion of excess flood waters in 2011 at the Hoop and Holler Bend of the Assiniboine River was achieved by excavating a portion of the south bank of the Assiniboine River to release some flow into the La Salle River watershed. Review by the Task Force on the 2011 Flood led to a recommendation that the overflow could be a viable future emergency measure if more permanent works could be developed to contain the overflow and avoid excessive flooding along the diversion route.

The study examined several options for the capability of having a permanent mechanism for release of excess floodwaters at Hoop and Holler. It was found that, to affect a significant release of excess flood flow, significant permanent works including extensive excavation of a channel would be required. The costs of such works were estimated to range upwards of $110 million for a 99 m^3/s (3,500 cfs) capacity, and are considerably more expensive than other options considered later. **A permanent wasteway at Hoop and Holler is not feasible due to economics, increased flood risk downstream, as well as significant opposition from local stakeholders**. However, the option could still be considered as an emergency option for flood relief, but only under dire circumstances; and the effectiveness would be dependent on the situation at the time. Careful planning would be required before execution could be justified.

An alternative solution for mitigating flood damages in the Lower Assiniboine River area consists of protecting the homes and communities individually (similar to what is done within the Red River Basin) rather than increasing the capacity of the Assiniboine River. The cost of this scheme has been estimated to range between approximately $255 and $310 million. Without linear dikes, there would be widespread flooding in the Lower Assiniboine River area, which would spill into the La Salle River system. **Individual and community flood protection in the Lower Assiniboine River area is not a feasible solution due to the potential negative impacts and added costs of damages resulting from widespread flooding**. The transportation network would be severely affected, communities and individuals would need to be evacuated, and agricultural land, which is currently protected by the existing linear diking system, would now be routinely flooded.

C. PORTAGE DIVERSION

The original design of the Portage Diversion (PD channel) included a segment along the downstream end of the west embankment that would allow overtopping and spillage onto the adjacent land to the west if diversion flows exceeded 425 m^3/s (15,000 cfs). This zone was called the “Failsafe”. Since completion of the channel in 1969, the Failsafe has been overtopped on numerous occasions. The damages associated with the overflow are considered unacceptable to local stakeholders.

The study considered options to reduce the damages due to overtopping of the Failsafe:

- Elimination of the Failsafe by raising the East and West dikes in the PD channel along the lower reach. The Failsafe is currently estimated to be overtopped at flows less than 425 m^3/s (15,000 cfs). Costs are estimated to range from $3.6 million to $11 million , for increases of that threshold flow at activation of the Failsafe to 510 m^3/s (18,000 cfs) and to 708 m^3/s (25,000 cfs), respectively.
- The purchase of vulnerable property subject to flooding. Costs are estimated to be relatively high for this option, at about $37 million.
- The constructing of dikes to protect agricultural land from flooding. This was estimated to cost about $12 million.
- Constructing dikes along Cram Creek to control PD overflows through the Failsafe. Two extents of diking were considered, ranging in cost from approximately $7 million to $16 million.

Subsequent sections of this report will reveal that expansion of the Portage Diversion is a leading option for reducing flood potential in the region. Regardless of what form that expansion would involve, it would be logical to incorporate the elimination of the Failsafe within it. Due to

the relatively low cost of eliminating the Failsafe compared to the overall cost of increasing the Portage Diversion capacity, as well as due to the re-occurring economic, environmental and social impacts of flooding that has occurred in recent years from activation of the Failsafe, **it has been concluded that any upgrades to the Portage Diversion should inherently eliminate the Failsafe**.

It is clear that mitigation of floods on the Lower Assiniboine River could be achieved by increasing the amount of flow that can be diverted through the PD into Lake Manitoba. Three concepts were considered in this study:

1. Widening the PD Channel.
2. Construction of an additional channel parallel and to the west of the existing PD.
3. Upgrades to the existing PD, or the "retrofit" option.

In addition to these three alternatives, a "do nothing" option was also considered.

The Portage Diversion Reservoir during flood conditions is a body of water that could cause serious damage if released suddenly through a breach in the retaining structures. The Canadian Dam Association (CDA) has issued widely accepted guidelines for assessing acceptable risks at such structures. It is understood that a Dam Safety Review of the Portage Diversion has not been carried out to ascertain the extent to which this project complies with the CDA Dam Safety Guidelines. Undertaking such a review was not practical within the current study. As a result, it was difficult to speculate on changes to the project that would be acceptable, and changes that could violate the principles of dam safety currently accepted in Canada. The options considered in this study were, as a result, considered conceptual and must be refined after a full dam safety review has been carried out. This review is not anticipated to substantially change the conclusions of the study, however, the results must be considered at the next stage of design.

Widening of the channel was considered for a design discharge increased from 708 m^3/s (25,000 cfs) to 960 m^3/s (34,000 cfs). The conceptual scheme devised included expansion of the inlet control structure and the drop structures, replacement of the outlet structure and river control structure, excavation of approximately 16.7 million cubic metres (21.8 million cubic yards) of earth, with revegetation of disturbed areas, and new bridges. The cost is estimated to be $615 million.

Construction of a parallel channel for a total design discharge of 960 m^3/s (34,000 cfs) would require excavation of approximately 3.5 million cubic metres of earth (46 million cubic yards), revegetation of disturbed areas, a new inlet control structure, along with drop structures and an outlet structure, and new bridges. The cost was estimated to be $265 million. However, as outlined below, the parallel channel option was independent of the existing Portage Diversion and, therefore, would also have to consider the "do nothing" costs.

The "retrofit" option 960 m^3/s (34,000 cfs) would require increased dike heights, dike improvements, modifications and upgrades to the existing control and drop structures, rehabilitation of the river control structure and outlet structure, new bridges and revegetation of disturbed areas. The cost is estimated to be $373 million.

Even if none of the above options were pursued, or if the parallel channel option was selected, there would still be substantial costs required to maintain the existing Portage Diversion in working order for secure future flood protection. This would include refurbishment of the inlet

control structure and drop structures, rehabilitation of the river control structure and outlet structure and future upgrades or replacement of bridges, estimated to amount to a total cost of $136 million

At this level of concept design, the retrofit option was identified as the preferred alternative to upgrade the Portage Diversion capacity, since it had the lowest cost. The cost is estimated to be $237 million more than the "do-nothing" option, but is $28 million less than the combined cost of the parallel channel option and the "do-nothing" option. However, the Retrofit Option requires careful consideration of the dam safety issues and the additional risk associated with this option in the overall decision making process. Additionally, the parallel channel will almost certainly have greater environmental and socio-economic impacts. This is primarily due to the additional land acquisition requirements and expansion of the overall project foot print.

The Province is currently evaluating some of the issues associated with the "retrofit" that have been identified in the report, such as the adequacy of the Portage Diversion dikes that were raised in 2011. Should the Province wish to pursue the retrofit option, this would best be done at a functional design stage where the criteria for the preferred options could be established and a more robust comparison of the alternatives could be undertaken, including consideration of maintenance and operating costs.

D. SOURIS RIVER

There have been many studies of options to control flooding along the Souris River. The most comprehensive report was prepared in the late 1970s for the Souris River Basin Board. The findings from that study were used by KGS Group to guide updates and new studies. The most promising options included reservoirs and diking upgrades at the principal communities along the river at Melita, Souris and Wawanesa.

The reservoirs identified for updated planning studies were the High Souris Dam and the Nesbitt Dam, both located on the Souris River. The High Souris Dam would cost approximately $131 million, and would potentially reduce significant flood peak flows by only 3 to 5% at Portage la Prairie. The Nesbitt Dam would cost approximately $238 million and would potentially reduce significant flood peak flows by only 3 to 6% at Portage la Prairie.

Both the High Souris and Nesbitt Dams would have significant environmental impacts that would include flooding and loss of agricultural land, blocking of fish passage, altering fish habitat associated with the change in flow regime and impeding navigation of the rivers. The loss of agricultural land would receive substantial opposition that would almost certainly delay or possibly ultimately stop the approval process. **Therefore, it has been concluded that large dams on the Souris River should not be considered further due to the significant environmental and operational concerns, as well their relatively high costs compared to other flood mitigation solutions**. Furthermore, it has been concluded from analyses of these sites that similar options elsewhere in the area would also not form viable solutions.

Flood protection projects are currently underway at Souris and Melita to provide flood protection to the highest flood on record (the 2011 Flood) at a cost of approximately $8 to $10 million. **Linear diking has been selected as the most feasible means of flood protection for communities on the Souris River**. The ongoing projects at Melita and Souris will provide a flood protection level approximately equivalent to a return period of 1:180 years and 1:150 years, respectively. The study also evaluated options to increase the flood protection in

these communities to the 1:200 years and the 1:500 years events. The proposed diking now underway would have to be raised by 0.1 m (0.3 ft) to 0.7 m (0.9 ft) in Melita at an estimated cost of approximately $177,000 to $1,300,000. In Souris, the dikes would have to be raised by 0.5 m (1.6 ft) to 2.4 m (7.9 ft) at an estimated cost of $1,645,000 to $3,935,000. In Wawanesa, the dikes constructed in 2011 are higher and the community is protected to the flood of record and the 1:200 year flood. The dikes would have to be raised by 0.2 m to 0.8 m (0.7 ft to 2.5 ft) for 1:500 year protection at an estimated cost of $1,492,000.

E. DAUPHIN LAKE

Dauphin Lake is located about 10 km (6.2 mi) due east of Dauphin, Manitoba. The lake is about 42 km (26 mi) long with a width that varies from 8 km (5 mi) to 18 km (11 mi).The lake has a surface area of approximately 500 km^2 (193 mi^2). Since about the mid-1960s, lake levels have seldom been allowed to fall below El 260.0 m (El 852.8 ft) with water levels below that threshold occurring only for a few days each year – the recorded minimum lake levels are approximately El 259.7 m (El 852 ft). Lake levels have exceeded El 261.5 m (El 857.94 ft) in five separate years since the mid-1960s. The maximum recorded water level on Dauphin Lake of El 262.47 m (El 861.1 ft) occurred during the 2011 Flood and was estimated to have a return period of 1:110 years.

Water levels on Dauphin Lake are regulated by Mossy Dam, which is located on the Mossy River about 150 m (492.0 ft) downstream of the outlet from the lake. During severe inflow events, such as in 2011, all the stoplogs would be removed from this structure to promote as much outflow as possible. During dry years and during the winter period the stoplogs would be installed to limit outflow and maintain water levels as high as would be appropriate.

Currently, the strategy for regulating water levels on Dauphin Lake and the existing structure and channel are unable to achieve the passage of large runoff events quickly enough to prevent large increases in lake levels. Methods to improve the regulation of Dauphin Lake fall into two broad categories, both of which were considered for the study:

1. Reduce and delay the inflow volume into the lake by temporarily storing runoff in the headwaters. This method was analyzed by assessing the existing upstream storage and comparing the typical flood volumes of Dauphin Lake's tributaries to what could realistically be stored in the headwater areas. It clearly demonstrated that this option is impractical and would require an unrealistically large number of new reservoirs. Costs would be very large, and the social and environmental impacts would be unacceptable.

2. Increase the capability to release water from the lake. Two options were assessed:

    a) Construction of a separate diversion channel with a control structure to increase the potential for outflow from Dauphin Lake. A variety of diversion channels were considered, but the costs were found to be high (ranging from $144 million to $323 million), and the potential for reduction of lake levels during floods would be modest.
    b) Increase the conveyance of the Mossy River by excavation in conjunction with an enlarged control structure at the lake outlet. This option has the potential to achieve the desired performance, but the costs are uncertain at this level of study. They are at present believed to be less than $105 million for excavation up to 1 m (3.3 ft) in depth along the river. However, the environmental impacts from excavating in or

beside the Mossy River would be significant, and mitigation of these undesirable effects could eventually cause the cost of the option to expand as studies into the details of the impact evolve.

It is important to recognize that efforts to control rises in levels of Dauphin Lake during flood events would theoretically have an adverse effect on downstream water courses, including Lake Winnipegosis. However, numerical modelling was carried out in this study to show that reductions in peak water levels on Dauphin Lake by 1 m (3.3 ft), for example, would result in a rise of only about 8 to 10 cm (0.25 to 0.3 ft) on the much larger Lake Winnipegosis.

The study also investigated the concern from the public that the lake bottom is infilling with sediment at a rate that would soon reduce the already low capacity to absorb floods. Review of previous measurements of sediment concentrations in the main tributaries showed that the rate of sediment inflow is very small relative to the size of the lake. No significant impact on flood storage is expected for several hundred years.

It was concluded that protection to the highest flood on record through development controls and individual flood proofing initiatives would be the most viable means to improve flood protection at Dauphin Lake.

F. LAKE WINNIPEGOSIS

Outflow from Lake Winnipegosis typically contributes about three quarters of the inflow to Lake Manitoba. The study addressed several possible options to reduce the potential flood outflow from Lake Winnipegosis.

Occasional diversion of water north from Lake Winnipegosis could be achieved over a distance of about 5.9 km (3.7 mi) to Cedar Lake where the excess flow supplied to the Saskatchewan River might be used for additional generation of energy at Manitoba Hydro's Grand Rapids Generating Station. This concept was found to require an expensive channel excavation through the high ground between Lake Winnipegosis and Cedar Lake, and a pump facility would be required to overcome the fact that Cedar Lake is typically at least 1.5 m (4.9 ft) higher than Lake Winnipegosis, even during flood events. The attraction of additional energy generation at the Grand Rapids Plant was investigated. The analyses showed that the power benefits on average were a negligible amount compared to the large annual costs required to pay for the construction of the option. The capital cost of developing a system that could divert up to 283 m^3/s (10,000 cfs) to Cedar Lake was found to be approximately $325 million. If this project had been operational in the 2011 Flood, the peak water levels on Lake Winnipegosis and Lake Manitoba could have been 0.8 m (2.8 ft) and 0.4 m (1.4 ft) lower than what was experienced. On the other hand, there would be disadvantages:

- The environmental impacts of inter-basin transfer of water could be significant, to the extent that ultimate approval to construct would be slow and maybe not even possible.
- The effectiveness of the scheme would be dependent on diligent maintenance of a complex pumping facility that may be operated very infrequently, possibly with several decades between uses.
- The cost of the pump station was approximate only and detailed design of this uncommonly large pump facility could cause cost increases that have not been completely represented by the contingency allowance currently incorporated into the cost estimate.

- The diversion from Lake Winnipegosis would have limited effectiveness for future floods that could emanate from the southern portion of the watershed supplying runoff to Lake Manitoba, including diversions from extraordinary isolated floods in the Assiniboine River.

Occasional diversion of excess water east from Lake Winnipegosis could be achieved over a distance of about 54 km (34 mi) to Lake Winnipeg. Unfortunately, the difference in lake levels between these two water bodies is about 38 m (125 ft) and is not conducive to economical diversion of water. The cost of channel excavation, drop structures to dissipate excess energy, and other facilities amounts to more than $1.3 billion, and was not considered a feasible solution to flooding in Lake Manitoba.

While controversial, the option of controlling outflow from Lake Winnipegosis by constructing a control structure at the outlet of the lake on the Waterhen River would be an effective means of limiting flood inflow to Lake Manitoba. A structure that could hold back adequate water to reduce the peak water level in Lake Manitoba in a 2011 magnitude of flood could be constructed for a capital cost of approximately $58 million. This would include the estimated cost of mitigating environmental effects; but such effects are only approximated in this level of study; and it is possible that other impacts could arise on further more detailed study. As a general approximation, a targeted 0.5 m (1.6 ft) lowering of the peak water level on Lake Manitoba in an extreme flood such as 2011 could cause a 1.0 m (3.2 ft) rise in water level on Lake Winnipegosis. Given the history in Manitoba of aversion to such schemes where downstream benefits are accrued at the expense of upstream damages, this scheme was considered unlikely to be acceptable and was not considered beyond examination of the concept.

The alternatives for diverting water from Lake Winnipegosis to Cedar Lake or to Lake Winnipeg, as well as for controlling outflow from Lake Winnipegosis with a control structure on the Waterhen River are not viable solutions due to the relative costs compared to other alternatives for mitigating flooding on Lake Manitoba, and the environmental impacts associated with these alternatives.

There appears to be a modest potential for control of outflow from Swan Lake (located upstream of Lake Winnipegosis) through the development of a storage reservoir and to reduce flood flows downstream. However, the effect would be small because the watershed upstream of Swan Lake is limited; and its contribution to flood inflows to Lake Winnipegosis is relatively small. In addition, the environmental impact of temporarily storing excess flood water, thereby flooding shoreline on Swan Lake, is expected to be significant.

G. LAKE MANITOBA AND LAKE ST. MARTIN

Increase in discharge capacity from Lakes Manitoba and St. Martin is a viable and direct means to limit rises in lake level in flood conditions on both lakes. The scope of work for the report contained herein includes assessment of this concept. Subsequent to the start of the studies reported herein, KGS Group was retained by MIT to develop a two-stage process to advance the conceptual designs. The first phase of the adjusted study scope (called Stage 1) was similar to what was originally included in the terms of reference for the overall study of the Assiniboine River & Lake Manitoba Basins. However, it included additional effort to expedite this portion of the work and increase the level of detail.

The scope of work and methodology for Stage 1 included:

- Identify Outlet Options for Lake Manitoba & Lake St. Martin.
- Develop Screening Level Designs and Cost Estimates.
- Economic Assessment.
- Stage / Damage Relationships.
- Summary Report.
- Public Open House Event.

The work done in Stage 1 is addressed in this report. In this conceptual level of study, six Lake Manitoba outlet channel options (Option A to Option F) and two Lake St. Martin outlet channel options (Option JB and Option WP) were developed:

- Option A – Twinning the Fairford River.
- Option B – Channel south of Pinaymootang First Nation.
- Option C – Channel slightly less south of Pinaymootang First Nation.
- Option D – Channel following Birch Creek.
- Option E – Bypass channel north of the Fairford River Water Control Structure (FRWCS).
- Option F – Expansion of the Fairford River and FRWCS.
- Option JB – Reach 1, Reach 2 and Reach 3 to Johnson Beach.
- Option WP – Reach 1, Reach 2 and Reach 3 east of Willow Point.

Discharge capacities for the outlet channels from Lake Manitoba to Lake St. Martin ranging from zero (do nothing) to 425 m^3/s (15,000 cfs) have been considered. Discharge capacities for the outlet channels from Lake St. Martin to Lake Winnipeg ranging from 113 m^3/s (4,000 cfs) to 540 m^3/s (19,000 cfs) have been considered. A description of the channel options and a plan showing their conceptual alignments have been included in this report.

Based on recommendations from the Lake Manitoba and Lake St. Martin Regulation Review Committee and the Manitoba 2011 Flood Review Task Force, the governing principle for the design of the outlet channels from Lake Manitoba and Lake St. Martin was that there should be no net increase in flow to Lake St. Martin above the base condition of the existing channel built in 2011, which has a discharge capacity of 113 m^3/s (4,000 cfs).

A statistical analysis was conducted to generate combined flood volumes for the Assiniboine River and local Lake Manitoba inflow, given the limited hydrometric records and limited information on the correlation between floods in the two drainage basins. A numerical flood routing model was also developed to estimate peak water levels on Lake Manitoba and on Lake St. Martin, with and without outlet channels, for a range of combinations of flood volumes. For the 1:200 year flood event, based on the results of the flood routing model and the statistical analysis, the peak still water level on Lake Manitoba without an outlet channel was determined to be approximately El 248.9 m (El 816.6 ft). For the 200-year event, outlet channels with discharge capacities of 142 m^3/s (5,000 cfs) and 283 m^3/s (10,000 cfs) would reduce the peak water level on Lake Manitoba by approximately 0.24 m (0.8 ft) and 0.43 m (1.4 ft), respectively. On Lake St. Martin, the peak still water level without an outlet channel was determined to be approximately El 245.5 m (El 805.4 ft) for a 1:200 year flood event, and the outlet channel would reduce the peak water level by approximately 0.8 m (2.7 ft).

A cost estimate was prepared for each of the alternatives investigated. The Lake Manitoba outlet channel with the lowest estimated cost was Option E ($30 million) for 106 m^3/s (3750 cfs)). However, the hydraulic capacity of this option is limited, and it increases downstream water levels locally. Costs for Lake Manitoba outlet channels that considered greater hydraulic capacities ranged from $101 million (Option A for 142 m^3/s (5,000 cfs)) to $462 million (Option B for 425 m^3/s (15,000 cfs)). Costs for Lake St. Martin outlet channels ranged from $107 million (Option JB for 113 m^3/s (4,000 cfs)) to $330 million (Option WP for 538 m^3/s (19,000 cfs)).

Each outlet channel from Lake Manitoba and Lake St. Martin is viable from a constructability perspective. However, a discharge capacity for an outlet channel that would be sufficient to avoid flooding due to a 2011-sized event would be greater than 425 m^3/s (15,000 cfs). The high cost of construction of such an option makes this unjustifiable.

Each outlet channel option for Lake Manitoba, as well as the inlet to Reach 1 of each of the Lake St. Martin options, should incorporate a control structure to regulate outflows. Also, all outlet channel options for Lake St. Martin should incorporate a permanent access road to facilitate construction, maintenance and operation.

All outlet channel options should consider improvement of fish passage directly at the FRWCS. Improving fish passage at the FRWCS with the construction of a new external fishway would provide an opportunity to decommission the existing fishway, which is located within one of the FRWCS bays. This could improve the hydraulic capacity of the structure at a relatively low cost and could be implemented in a fairly short time frame.

A description of the general environmental concerns has been provided in the report, along with a relative ranking of the channel options. For all options, utilization of the lower portion of Buffalo Creek to pass flow on a permanent basis would have significant environmental impacts and increased potential for flooding of the Dauphin River communities. Opposition from stakeholders was expected to be strong, and this option was not recommended for these reasons.

On Lake Manitoba, the combined biophysical and social environment rankings of the options were the lowest for Option A and the highest for Option C. It has been concluded that Options A and F should not be considered further due to the significant environmental and social concerns. **Furthermore, the Lake Manitoba Outlet Channel Options C and D were preferred due to their cost effectiveness and the positive environmental rankings**.

On Lake St. Martin, the combined biophysical and social environment rankings of the options were equivalent for both Option JB and Option WP; and, therefore, both should proceed to the next stage of study. **However, due to the social environment concerns with having the Reach 3 outlet located at Johnson Beach, the Willow Point option of the Lake St. Martin outlet channel was the preferred alternative**.

Based on the concept designs, the estimated costs and environmental assessment, the following recommendations were developed:

- Lake Manitoba channel discharge capacities in the range of 142 to 283 m^3/s (5,000 to 10,000 cfs) should be considered for further review since lesser capacities will not adequately reduce lake levels and greater capacities are not justifiable due to the high cost.

- The Lake St. Martin Emergency Outlet Channel should be made permanent with a base discharge capacity of 113 m^3/s (4,000 cfs) to control Lake St. Martin levels.
- Additional discharge capacity to the Lake St. Martin Outlet Channel in the range of 142 to 283 m^3/s (5,000 to 10,000 cfs) should be considered for further review to match a Lake Manitoba outlet channel to ensure that flooding will not be aggravated on Lake St. Martin.

Based on the results of the study, later discussed in the report, and available funds, the Province has decided to proceed with preliminary design for the preferred alternatives with outlet channel capacities of 212 m^3/s (7,500 cfs) on Lake Manitoba, and of 326 m^3/s (11,500 cfs) on Lake St. Martin. The estimated costs of the projects are $230 million and $220 million, respectively.

A proposed scope for the next phase of planning (Stage 2) has been included in the report. The focus of Stage 2 will be to complete the preliminary design of the preferred alternatives allowing the next phase of design to proceed to the detailed design stage.

H. EFFECTS FROM SHOAL LAKES

The Shoal Lakes Watershed Study conducted by KGS Group investigated three alternative measures to mitigate flooding issues within the lakes: construction of a diversion / outlet channel from the Shoal Lakes to Lake Manitoba; construction of upland storage within the Shoal Lakes watershed; and, purchase of flood prone lands.

The alternative which had the greatest reduction of water levels on the Shoal Lakes was the system of flood diversion channels. **However, it has been concluded that the most attractive option from an economic perspective was the purchase of flood prone lands, which is currently being pursued by the Province**. The latter would have virtually no effect on water levels on Lake Manitoba, and the former would have only a very small, almost immeasurable effect. The implementation of channel diversions was estimated to cause at most a 3 cm (0.1 ft) rise in water level on Lake Manitoba during severe floods.

I. COMBINATIONS OF SMALL DAMS

A combination of small dams on tributaries of the Assiniboine and Souris rivers in Manitoba was considered as an option for flood mitigation. These dams would be operated strategically to reduce peak flood flows in the Assiniboine and Souris rivers. A combination of 21 small dams was studied to explore the possibilities of this concept.

The impact of operating these 21 small dams showed that the reduction in peak flood flows on the Assiniboine and Souris Rivers ranged between approximately 3% and 13%, depending on the location and size of flood. The reduction in peak flows on the Assiniboine River near Holland was optimistically estimated to be approximately 8%.

Operation of the dams to reduce peak flows on the tributaries was not a preferred flood mitigation strategy, as it would not provide optimal benefits downstream on the mainstem rivers. However, the dams could have relatively small local benefits that could justify further review in the future.

The estimated capital cost of the 21 dam sites is approximately $482 million. With such a high cost, potential environmental impacts, relatively small reductions in flood peak flows, and difficulties in effective operation to achieve the maximum benefits, **it was concluded that flood mitigation with a multitude of small dams was not a feasible solution when compared to other options**.

J. DEVELOPMENT CONTROLS AND LAND USE PLANNING

Manitoba's development controls to minimize the risk of flood damages were reviewed and compared to other jurisdictions. The review identified areas for improvement in the Province's development review and control strategy to minimize the risk of flood damages. In addition, the findings and recommendations presented in the 2011 Manitoba Flood Review Task Force Report and the Lake Manitoba, Lake St. Martin Regulation Review Report have been carefully considered. **The Flood Protection Level should be the 1:200 year flood or Flood of Record, whichever was greater, as is being adopted by the Province of Manitoba for the Province as a whole**. A higher level of protection could be justified on a risk based assessment.

The Lower Assiniboine River, Lake Manitoba and Lake St. Martin, as well as Dauphin Lake were recommended as candidates where designated flood areas should be considered. Following the development of updated flood control works, consideration should also be given to establishment of designated flood areas for the communities along the Souris River, and along the Upper Assiniboine River protected by linear diking systems. **Where there is no designated flood area, flood development controls should be more rigorously enforced by Planning Districts and Municipalities.** Additional support and mechanisms should also be considered for the Planning Districts and Municipalities to help improve enforcement.

K. ADJUSTMENT TO PRACTICES IN LAND USE

Provincial initiatives to reduce flood risk through land use policies and regulations have focused on wetland preservation. Recent practices associated with Forest Management Plans by the Province of Manitoba have been successful to a large extent. However, consideration should be given to policies and regulations to control conversion of grasslands, woodlands and marginal lands to cultivation. Additionally , incentive programs to convert high-runoff land uses to low-runoff uses should be considered.

Integrated Watershed is an approach that helps reduce the land's runoff potential as it relies on the application of multiple strategies. There is a need for better linkages between Integrated Watershed Management Plans (IWMP) and Land Use Planning to ensure the IWMP recommendations related to riparian and shoreline protection, flooding and surface water management are adequately considered and adopted into land use plans.

Manitoba's Surface Water Management Strategy endorses the principles associated with managing land use for the purpose of reducing runoff, and it focuses on regulatory approaches for wetlands. **Other land use changes associated with cultivation of grasslands and deforestation should also be emphasized**.

L. EXPANSION OF WETLANDS FOR FLOOD ATTENUATION

Quantification of the attenuating effects of prairie wetlands on varying magnitudes of floods is complex. This is particularly true for the Assiniboine River. A statistical analysis of long-term

precipitation and stream flow records in the Assiniboine River Basin did not find statistically significant effects of drainage on peak flows and annual flows. Early research indicated that the drainage of prairie wetlands had a relatively minor impact on the peak flows of low frequency flood events such as the 2011 Flood in the Assiniboine River and Lake Manitoba basins. However, the most recent modelling on the role of prairie wetlands on flooding by Pomeroy indicates that wetlands drainage may play a significant role in flooding. This work is unquestionably the best available tool for simulating the hydrology of prairie watersheds including intact and drained wetlands. However, the complexity of the wetland drainage issues demands more thorough basin-wide and geographically-based assessments to verify the model and Pomeroy's findings.

Based on Pomeroy's findings, a basin wide analysis was conducted to determine the viability of wetlands restoration as a flood mitigation solution. It was found that the estimated cost of wetland restoration to obtain a 20% to 30% reduction in flow on the Assiniboine River would range between $1.0 billion to $1.5 billion. **With such high costs, large scale wetland restoration was not identified as a cost effective mitigation option. However, smaller scale projects could be pursued as they arise.** Manitoba's surface Water Management Strategy endorses "no net loss" in wetlands and encourages water retention, which should continue to be promoted. **A multi-year pilot study on wetland restoration should be considered to determine the costs and benefits of wetland restoration on flood attenuation, and the cost would be in the range of $10 to $20 million.**

M. CONTROL OF DRAINAGE IN SASKATCHEWAN

Interprovincial drainage has been a long standing and very contentious issue between Manitoba and Saskatchewan, especially in the Upper Assiniboine River Basin. In the past number of years, Manitoba and Saskatchewan have cooperatively tried to resolve the interprovincial drainage issues. A resolution of the interprovincial drainage issue has been hampered by the lack of clear scientific understanding of the role prairie wetlands play on flood attenuation for varying flood magnitudes. This has contributed to the fact that no acceptable resolution has yet been reached. There is clearly a need for a better forum to resolve interprovincial water management issues such as drainage. Possibilities are to expand the mandate of the Prairie Provinces Water Board or Western Water Stewardship Council, or to establish an interprovincial commission or dispute board.

An analysis of streamflow data identified increasing trends in watershed response in the Upper Assiniboine River Basin. Hydrologic analysis of streamflow records indicated that both peak flows and runoff volumes appeared to be increasing. The difficulty was isolating and quantifying the impact of drainage practices from other land management practices. Changes in drainage practices were likely the predominate issue impacting the increasing runoff response of the watershed. Drainage practices generally resulted in gradual change, and as such, were not easily quantifiable and isolatable through the analysis of streamflow data. Ideally, it could take a paired watersheds assessment with the same land use practices, but with different drainage practices: one in a drained state, and the other in an undrained state, to provide more conclusive data.

Saskatchewan recognizes their growing problems with illegal drainage. However, there appears to be no immediate solution to the problem. Saskatchewan is proposing new legislation to address the illegal drainage activities that also impact Manitoba. Development and implementation of new legislation along with enforcement, however, will take time. **Through the**

Assiniboine River Basin initiative, Manitoba will have opportunities to express their concerns to all jurisdictions regarding the interprovincial drainage issue.

8. BASE ANALYSIS OF INDIVIDUAL OPTIONS AND PREFERRED MEASURES

The study initially addressed all of the options summarized above on an individual basis to determine which would upgrade protection in areas that do not currently meet the provincial standards for flood protection. **Based on the results of the analyses, application of the economic guidelines would not lead to the justification of flood protection for infrastructure in the study area that exceeded the basic requirements of either the 1:200 year flood or the flood of record**. This finding was applicable to all options and combinations of options devised in this study.

This conclusion in turn provided a clear direction for the remainder of the study – **the best measures that could upgrade the level of flood protection for infrastructure, where necessary, should be planned for at least the 1:200 year flood, or the flood of record, whichever is greater, at all locations within the study area**. As discussed in the report, many areas of the Assiniboine River and Lake Manitoba basins already meet that standard. Although some areas meet the previous 1:100 years criteria and not the recent 1:200 years criteria, there have been significant strides towards upgrading flood protection such as the Individual Flood Proofing Initiative and the Community Flood Protection Program.

As a result of these comprehensive and in some cases, on-going, programs, focus was then directed towards a means to improve the level of protection on the Lower Assiniboine River, east of the Portage Diversion and west of the City of Winnipeg. **It was concluded that the protection along the Assiniboine River that would comply with the standard adopted by the Province of Manitoba would require the ability to safely pass the 1:200 year flood. That is a flood of approximately 1,620 m^3/s (57,100 cfs) at Holland, and exceeds the flood of record (2011 Flood) by about 10%.** It became obvious that no single option studied would satisfy the required upgrades, so the study then concentrated on combinations of the options with relatively high economic indicators (primarily benefit / cost ratios) that could provide the desired level of protection. They were as follows:

- Expansion of the Portage Diversion.
- Expansion of the outlet works at Lake Manitoba and Lake St. Martin.
- Enhancement of the dikes along the Lower Assiniboine River.

There are other options that could be interchangeable, such as the Holland Dam, within the above list, but would be far more costly or would have significant environmental and/or socio-economic impacts. The best combination and the extent of each of the above options has been derived through a logical process, as summarized below:

- The Portage Diversion can be readily expanded to nearly double the discharge capacity of its original design. However, as described in the report, the cost of increasing to a discharge capacity that exceeds approximately 960 m^3/s (34,000 cfs) increases sharply.
- The dike protection along the Lower Assiniboine River could be upgraded to reach river flows well in excess of 655 m^3/s (23,100 cfs); but the option was limited by the river flow that could be tolerated within the City of Winnipeg; and the cost was more than the cost of upgrades to the Portage Diversion.

- The outlets at Lake Manitoba and Lake St. Martin should consider an increase in discharge capacity in the range of 142 to 283 m^3/s (5,000 to 10,000 cfs) since lesser capacities will not adequately reduce lake levels and greater capacities were not justifiable due to the high cost.

Consideration of these limits has identified a preferred combination of options that provides the protection against a 1:200 year flood event. It consisted of the following:

- **Expansion of the Portage Diversion to reach a design discharge capacity of 960 m^3/s (34,000 cfs) at an estimated cost of $373 million for the Retrofit Option.**
- **Upgrades to the Lower Assiniboine River capacity to permit passage of a flow of 655 m^3/s (23,100 cfs) at estimated costs of $273 million for upgrades to the existing dikes in their current location and $63 million for a Combination of Individual Flood Proofing, Neighbourhood Diking and Purchase of Vulnerable Properties. This would be tolerable in the City of Winnipeg without any special upgrades to flood protection in that area.**
- **Construction of a new Lake Manitoba outlet with a capacity of 212 m^3/s (7,500 cfs) and making the Lake St. Martin outlet channel permanent with a capacity of 326 m^3/s (11,500 cfs), as committed to by the Province of Manitoba, at an estimated cost of $450 million for the preferred alternatives.**

Economic assessment of this combination has revealed that increasing the level of protection beyond this threshold would not be cost effective.

A hydraulic analysis of these combined measures has shown that water levels on Lake Manitoba could be lowered by approximately 0.7 m (2.4 ft) in a repeat 2011 Flood event, and could maintain water levels below flood stage for a repeat 2014 Flood event. This 0.7m (2.4 ft) reduction is more than the reduction provided by a Lake Manitoba Outlet Channel on its own due to the increased capacity of the Lower Assiniboine River, which can reduce the volume of water that is diverted to Lake Manitoba.

Key environmental and social impacts that could be of concern for each mitigation alternative have been presented in the report. It is anticipated that all three projects of the preferred alternative would require licencing under the *Manitoba Environment Act*, however, only the Lake Manitoba and Lake St. Martin outlet channels are anticipated to require approval by the Canadian Environmental Agency.

Examination of the effects of future trends in more frequent occurrences of major floods revealed that:

- **Use of only the historical record of recent decades of flood peaks would tend to increase the best estimate of the 1:200 year flood in most areas. The increase would vary over the study area.**
- **Estimates of damages averted by any specific improvement in flood protection would increase on an average annual basis and enhance the economic incentive to proceed.**

- **On the other hand, achieving a minimum protection of a 1:200 year flood that is determined based on only the historical record of recent decades of flood peaks rather than the full period of record, would require more extensive protection works and would become more expensive.**

9. RECOMMENDATIONS

Based on the study results and the public open house processes undertaken as a part of the study, the following recommendations are presented:

1. The Lower Assiniboine River has been identified as an area that has infrastructure vulnerable to floods much smaller than the highest flood on record. It is recommended that this area be protected to a target Flood Protection Level of 1:200 years, which is consistent with the 2011 Flood Review Task Force recommendations. This increased protection would consist of upgrading the Portage Diversion to 960 m^3/s (34,000 cfs), upgrading the Assiniboine River capacity to 655 m^3/s (23,100 cfs), constructing a new Lake Manitoba outlet with a capacity of 212 m^3/s (7,500 cfs) and a Lake St Martin outlet channel with a capacity of 326 m^3/s (11,500 cfs). The estimated cost for this recommended flood mitigation system is $1,159 million and is summarized in Table 23.1. Considering the current low standard of protection within the Lower Assiniboine River and the Province's current commitments for Lake Manitoba and Lake St. Martin, these areas should be given the highest priority.

Table 23.1
Summary of Estimated Cost of Preferred Measures for Upgrading Flood Protection for the Lower Assiniboine River

Flood Protection Infrastructure	Proposed Capacity	Preliminary Estimated Costs for Upgrade
Provincial Assiniboine Dikes	654 m^3/s (23,100 cfs)	$273 Million
Assiniboine River Baie St. Paul to Headingley	654 m^3/s (23,100 cfs)	$63 Million
Portage Diversion	963 m^3/s (34,000 cfs)	$373 Million
Lake Manitoba Outlet	212 m^3/s (7,500 cfs)	$230 Million
Lake St. Martin Outlet	326 m^3/s (11,500 cfs)	$220 Million
Total Estimated Cost		**$1,159 Million**

2. Development controls were considered as a means to restrict future development. Where there are no Designated Flood Areas (DFA) local municipalities and planning districts should more rigorously enforce flood protection levels in new developments and DFAs should be considered for the Lower Assiniboine River, Lake Manitoba and Lake St. Martin, as well as the Dauphin Lake areas.

3. The provincial flood protection policy should be revised to require flood protection to at least the 1:200 year flood, or the flood of record, whichever is greater, at all locations within the study area. This is consistent with recommendations from the Manitoba 2011 Flood Review Task Force Report.

4. The purchase of the flood prone land along the Upper Assiniboine River between Shellmouth Dam and St. Lazare was preferred over linear diking and should be considered further. The estimated cost was approximately $24 million for the flow of 85 m^3/s (3,000 cfs).

5. A multi-year pilot study on wetland restoration should be considered to determine the costs and benefits of wetland restoration on flood attenuation. The cost would be in the range of $10 to $20 million.