Manitoba

# Manitoba Water Stewardship
# Shoal Lakes Watershed Study
## FINAL REPORT
## October 2010

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Manitoba Water Stewardship
Water Branch
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ATTENTION: Mr. Fisaha Unduche, P. Eng.

RE: Shoal Lake Watershed Study
Final Report

Dear Mr. Unduche:

We are pleased to submit twenty printed copies and one digital pdf copy on CD-ROM of our final report for the Shoal Lakes Watershed Study.

Yours truly,

David S. Brown, P. Eng.
Senior Water Resources Engineer

DSB/sp
Enclosure

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## ACKNOWLEDGEMENTS

The Shoal Lakes Watershed study, as documented within this report, is the combined effort of many people from both KGS Group and North/South Consultants, as well as, members of both Manitoba Water Stewardship and Manitoba Conservation.

KGS Group carried out the engineering portion of the studies while North/South Consultants provided their input to the aquatic, avian, and water quality components of this study, including the completion of the water quality monitoring program and environmental assessment of the project.

The input to the study from the members of the Technical Advisory Committee and Manitoba Water Stewardship proved very valuable for the successful completion of this study. Members of Manitoba Conservation also provided valuable input to the study in terms of quantification of the environmental effects of the flood protection alternatives.

## EXECUTIVE SUMMARY

The Shoal Lakes are located within the southwestern portion of Manitoba's Interlake region approximately 15 kilometres east of Lake Manitoba. These lakes consist of three main bodies of water, West Shoal Lake, East Shoal Lake, and North Shoal Lake. Due to the topographic relief surrounding the Shoal Lakes, the system is generally a land-locked drainage basin with no natural outlet for the lakes. However, when the lakes are at high levels, there have historically been natural overflows to the east into the Sturgeon Creek and Grassmere drainage systems. In the past when these overflows have occurred, the local authorities have either raised the roads or closed the drainage paths to eliminate the overflow to the adjacent drainage basin. As a result, during years, or numbers of years, with higher than average rainfall, the water levels in the three lakes rise. Conversely, in times of drought, the levels in the lakes recede.

The characteristics of the land in the Shoal Lakes Watershed are such that there is very few defined natural drains in the watershed that convey runoff to the lakes. The general form of runoff to the lakes occurs from overland flow. During drier periods, much of the precipitation infiltrates directly into the ground and does not run off. However, in wet periods, the groundwater levels are high and water in the basin tends to pond on the swales with some of the excess water eventually flowing as overland flow towards the lakes.

The land use consists mainly of grasslands and open deciduous forest, with a number of areas being used as forage crops. The land use in the area between the normal water level of the lakes and the high flood levels experienced in recent years consists mainly of marsh and grasslands. The agricultural capability of the land within the Shoal Lakes Watershed consists mainly of Class 4 land. The area between the normal water level and the high flood levels of recent years has approximately 40 to 50% of Class 5 land, 50 to 60% of Class 7 land and about 5 to 10% of Class 4 land.

There is little information available on the existing fishery in the Shoal Lakes with exception of reports from the Fish Inventory and Habitat Classification System (FIHCS) database maintained by Manitoba Water Stewardship – Fisheries Branch. However, Manitoba Conservation states that the Shoal Lakes currently have severe limitations to fish productivity (Class 4 fishery).

The Shoal Lakes have been defined as a nationally important area for migratory bird habitat as the second most important site in Manitoba and the fourth most important site in the Prairie Provinces. A number of bird species are known to inhabit the Shoal Lakes area. Of particular interest is the persistent occurrence of the Piping Plover, an endangered species. Other species of interest include Western Grebe, Black-crowned Night Heron, American Pelican, Canada Geese, and Lesser Snow Geese.

Little information exists regarding the water quality on the Shoal Lakes. Therefore, as part of this study, North/South Consultants conducted a water quality-sampling program at Shoal Lakes in 2008 to provide a description of existing conditions.

The water quality of the Shoal Lakes, based on the water quality-sampling program indicated that with some minor exceptions, the water quality of Shoal Lakes was relatively similar across the lakes. In general, the Shoal Lakes can be described as relatively turbid and very hard, with high concentrations of nutrients, and slightly alkaline pH. Levels of TDS and conductivity are relatively high and the lakes would be considered "slightly saline" according to the CCREM. Sodium was the dominant cation present in the lakes, with magnesium, calcium, and potassium present in lower concentrations. On the basis of total phosphorus concentrations, North Shoal Lake would be classified as eutrophic while the east and west basins would be classified as hypereutrophic according to the CCME phosphorus guidance.

In recent years, there has been an excess of precipitation and the water levels in the lakes have risen to the highest levels since water levels have been recorded on the lakes. During these periods of high water, agricultural land adjacent to the lakes, primarily utilized as pasture land for cattle as well as hay production land, is flooded. A number of Rural Municipalities within the Shoal Lakes drainage basin are impacted by this flooding including the R.M. of St. Laurent, the R.M. of Armstrong, the R.M. of Woodlands, the R.M. of Coldwell, and the R.M. of Rockwood.

As a result of this recent flooding, Manitoba Water Stewardship (MWS) retained KGS Group to evaluate the flooding issues within the Shoal Lakes Watershed and develop and assess flood mitigation measures. These mitigation measures, as prescribed in the Request for Proposal (RFP) by MWS outlining the project, include:

- The construction of a diversion / outlet channel from the Shoal Lakes to Lake Manitoba. Two alternate alignments of the diversion channel were defined by MWS and include:
    - A diversion channel along the alignment of Wagon Creek connecting to the north end of West Shoal Lake (Two alternative configuration based on the connection of the channel to the West Shoal Lake)
    - A diversion channel along the alignment of both Roy's Drain and Boundary Drain connecting to the west end of West Shoal Lake
- Construction of upland storage with in the Shoal Lakes Watershed
- Purchase of flood prone lands

Other options that were not included in the scope of the project, as outlined in the RFP include the construction of a diversion channel to the southeast into either the Grassmere Creek or Sturgeon Creek systems, or the diversion of flows to the northwest into the Hatchery Drain. As these options were not part of the scope of the project they have not been addressed in this study.

Each of the flood mitigation alternatives were reviewed and designed to a feasibility level as part of this study.

A hydrologic/hydraulic model of the Shoal Lakes was developed that consisted of an Inflow-Available-for-Outflow based water balance model and was used to review the hydraulic effects, or potential to reduce flooding on the Shoal Lakes, for the various flood mitigation alternatives was reviewed as part of the study.

The hydraulic model assessment of the flood diversion channels indicated that the lake levels would be significantly reduced from the natural levels and would as a result be quite shallow in the drought periods. However, the channels would be more or less effective in controlling the maximum lake levels to near the target elevations. Outflows from West Shoal Lake would occur in 12 of the 34 years of record considered.

The greatest benefit to the reduction of water levels on the Shoal Lakes was the flood diversion channels. The upland storage option had a minor reduction of water levels on the lakes. The purchase of flood prone land had no effect on water levels on the lake, but would remove all potential flood damages associated with buildings and agricultural activities.

Flood damages were estimated for each year of the past 34 year of record for the existing conditions and for the conditions with each of the flood mitigation alternatives in place. The reduction of flood damages from those of existing conditions to those for each of the flood mitigation alternatives was considered to be the benefits associated with each of the alternatives.

Flood damages were considered to be:

- damages to agriculture crops and forages
- reduction in revenue from livestock, primarily cattle
- damages, or flood protection costs, at farm establishments that are directly affected by flood waters
- damages to government facilities, including roads, ditches, culverts and buildings
- increases in costs of transportation during flood events and during repairs to damaged transportation facilities

Each of these components have been examined, and numerical algorithms developed that relate the severity of flood to the predicted extent of damage. ***The intent has been to develop a damage "model" that can be used to quantitatively compare conditions with and without the proposed flood mitigation alternatives. The reduction in flood damages due to the flood mitigation alternatives would form the benefits from the construction and on-going operation and maintenance of the project.***

There are, of course, other damages that occur that are difficult to quantify, or are not quantifiable at all. They include:

- stress and anxiety of local residents that are directly affected by flooding in the area
- reduction in on-going values of land that is currently considered flood prone
- loss of potential for future development of flood–prone lands

In addition to those damages listed above, it could be argued that there are socio-economic benefits or damages that could result from any of the potential flood mitigation alternatives, including the economic activity generated by ranchers within the nearby communities.

Quantification of these benefits or damages would require an in-depth socio-economic study of the area as related to agricultural practices surrounding the Shoal Lakes. This type of analysis was not defined part of this study nor is it typically included in an economic analysis of flood mitigation measures.

An economic analysis was then completed which compared the present value of the cost for each alternative to the present value of the benefits of each alternative to determine the benefit / cost (B/C) ratio. A summary of the estimate costs, benefits, and B/C ratio is presented below.

| Flood Mitigation Alternative | Present Value of Costs | Present Value of Benefits | Benefit/Cost |
|---|---|---|---|
| **Flood Diversion Channels** | | | |
| Wagon Creek – Option A | $23,773,000 | $8,018,268 | 0.34 |
| Wagon Creek – Option B | $26,610,000 | $8,018,268 | 0.30 |
| Roy's / Boundary Drain | $31,546,000 | $8,018,268 | 0.25 |
| **Upland Storage Areas** | $4,550,000 | $1,580,487 | 0.35 |
| **Purchase of Flood Prone Land** | $11,361,000 | $7,580,698 | 0.67 |

Sensitivity assessments were also carried out to quantify the sensitivity to various factors including the unit rate of excavation, interest rate, and effects of recent raising of roads adjacent to the lakes.

An environmental screening level assessment was carried out for each of the flood mitigation alternatives. It was found that the reduction of the water levels associated with the implementation of the flood diversion channels would negatively affect both the existing fisheries and avian/waterfowl populations of the Shoal Lakes.

Most water quality parameters are present in higher concentrations in Shoal Lakes than Lake Manitoba. However, introduction of water from the Shoal Lakes to Lake Manitoba would not have a notable effect on the water quality of Lake Manitoba.

The environmental effects of the implementation of the flood diversion channels were quantified to determine its effect on the benefit/cost ratio. It was found that with the incorporation of the environmental effects the benefit/cost ratio of the flood diversion channels would be reduced to less than 0.15.

The most attractive flood mitigation alternative from an economic perspective, as assessed within this study is the purchase of the flood prone land surrounding the Shoal Lakes.

## 1.0 INTRODUCTION

The Shoal Lakes are located within the southwestern portion of Manitoba's Interlake region approximately 15 kilometres east of Lake Manitoba. These lakes consist of three main bodies of water, West Shoal Lake, East Shoal Lake, and North Shoal Lake. Due to the topographic relief surrounding the Shoal Lakes, the system is generally a land-locked drainage basin with no natural outlet for the lakes. However, when the lakes are at high levels, there have historically been natural overflows to the east into the Sturgeon Creek and Grassmere drainage systems. In the past when these overflows have occurred, the local authorities have either raised the roads or closed the drainage paths to eliminate the overflow to the adjacent drainage basin. As a result, during years, or numbers of years, with higher than average rainfall, the water levels in the three lakes rise. Conversely, in times of drought, the levels in the lakes recede.

In recent years, there has been an excess of precipitation and the water levels in the lakes have risen to the highest levels since water levels have been recorded on the lakes. During these periods of high water, agricultural land adjacent to the lakes, primarily utilized as pasture land for cattle as well as hay production land, is flooded. A number of Rural Municipalities within the Shoal Lakes drainage basin are impacted by this flooding including the R.M. of St. Laurent, the R.M. of Armstrong, the R.M. of Woodlands, the R.M. of Coldwell, and the R.M. of Rockwood.

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    - A diversion channel along the alignment of both Roy's Drain and Boundary Drain connecting to the west end of West Shoal Lake
- Construction of upland storage with in the Shoal Lakes Watershed
- Purchase of flood prone lands

The study was overseen by a Steering Committee selected by the Province of Manitoba and the five local R.M's at the commencement of the project, which included the following members:

| | |
|---|---|
| *Steve Topping* | *Manitoba Water Stewardship* |
| *Ron Kaatz* | *Manitoba Water Stewardship* |
| *Sheldon* Anderson | Manitoba Water Stewardship |
| *Garth Ball* | *Manitoba Conservation* |
| *Ralph Hazelton* | *RM of Armstrong* |
| *Jim Dyke* | *RM of Coldwell* |
| *Brian Sigfusson* | *RM of Coldwell* |
| *Lance Kennedy* | *RM of St. Laurent* |
| *Earl Zotter* | *RM of St. Laurent* |
| *Doug Oliver* | *RM of Woodlands* |
| *Bill Fleury* | *RM of Woodlands* |
| *Jack Grandmont* | *Farmers Rep. from RM of Woodlands* |

Subsequent to the issue of the draft report in August 2010, MWS provided recent water level records on each of the three Shoal Lakes from January 2008 to August 2010 and requested that the study be updated to include the recent data. As such, the information and study findings documented within this report are based on current information up to August 2010.

This report describes the work that was carried out to complete the Shoal Lakes Watershed Study. A description of the Shoal Lakes watershed is presented in Section 2.0, while a description of the associated surface water drainage network is described in Section 3.0. The flood mitigation measures that were assessed in this study are outlined in Section 4.0. Section 5.0 describes the hydrologic/ hydraulic model that was selected to assess each of the flood mitigation alternatives. The costs and benefits associated with each of the flood mitigation alternatives are described in Sections 6.0 and 7.0, respectively, while the benefit/cost assessment for these alternatives is presented in Section 8.0. Environmental considerations and assessment of the various flood mitigation alternatives are presented in Section 9.0. Conclusions and recommendations from this study are presented in Sections 10.0 and 11.0, respectively.

# 2.0 SHOAL LAKES WATERSHED

## 2.1 STUDY AREA

The Shoal Lakes drainage basin extends over two of the Province of Manitoba Designation of Drains drainage area maps, numbers 108 and 109, as shown in Plate 1. The study area that has been considered for this project consists of the drainage area associated with the Shoal Lakes complex and the local drainage areas contributing to the waterways that have been identified by the Steering Committee, for diversion channels (i.e. Wagon Creek and Roy's / Boundary Drains), as noted in Section 1.0. Plate 2 shows the drainage area for the Shoal Lakes, as well as, the local drainage area for both Wagon Creek and Roy's / Boundary Drains.

The study area also includes Lake Manitoba since this lake is the ultimate recipient of water diverted from the Shoal Lakes as one of the flood mitigation alternatives. Although Lake Manitoba is not within the drainage area of the Shoal Lakes watershed, its existing water quality, which is described in Section 2.7, will be used in the basis for the assessment of the environmental impacts of diverted water from the Shoal Lakes, as described later in this report in Section 9.0.

## 2.2 WATERSHED DESCRIPTION

***General Description***

The Shoal Lakes complex is located in the southwestern portion of Manitoba's Interlake region, approximately 15 kilometres east of Lake Manitoba and approximately 65 kilometres northwest of Winnipeg. The Shoal Lakes complex consists of three main bodies of water, West Shoal Lake, East Shoal Lake, and North Shoal Lake. Part of the Shoal Lakes Watershed consists of the Vestfold Complex, located to the northwest of North Shoal Lake. The Vestfold complex is a series of wetlands that is located at the north end of the North Shoal Lake. Ducks Unlimited developed the Vestfold complex in 1986 into a controlled wetlands consisting of four cells. A stoplog weir at the south end and a pump system were included to pump water out of the Vestfold towards Goulet Lake and Lake Manitoba. In recent times, the Vestfold complex has been abandoned and the control facilities are no longer being operated. During high levels on

Shoal Lake, the levels in the Vestfold complex are controlled by the water levels on North Shoal Lake.

The Shoal Lakes watershed is generally a closed system with a combined drainage area of 1155 $km^2$ that slopes toward Shoal Lakes from the surrounding area. Drainage in the watershed is confined to numerous swales that collect runoff from the ridges that slope toward the lakes. Due to the topographic relief surrounding the Shoal Lakes, the system is generally a land-locked drainage basin with no natural outlet for the lakes. However, when the lakes are at high levels, there have historically been natural overflows to the east of the Shoal Lakes into the Sturgeon Creek and Grassmere drainage systems and west to the Wagon Creek. The topography, as shown Plate 3 shows that there is a ridge that generally encompasses the lakes. The land to the west of the ridge drops rapidly from a peak elevation along the ridge of 265 m to 269 m to an elevation of about 248.5 m on Lake Manitoba - an elevation difference of about 20 metres over a distance of about 12 km. The land also slopes relatively steeply to the south of the Shoal Lakes towards the Netley Creek, Grassmere Creek, and Sturgeon Creek Watersheds (See Plate 1).

The topography illustrated in Plate 3, otherwise known as a Digital Elevation Model (DEM) was developed from several data sources that were available to KGS Group. These sources of data include:

- Lake bottom survey data provided by MWS
- Lake bottom survey sonar data obtained during KGS Group surveys
- Topography survey data obtained during KGS Group surveys
- Historical air photo and satellite imagery data sets from 1950 to 2004
- Recorded water levels provided by MWS
- National Resources Canada Topography Data
- Shuttle Radar Topography Mission (SRTM) LVL1 DEM

Areas below the 2005 lake levels were developed using bathymetry surveys and the historical air photo with the recorded water levels. This information was then expanded into a regional DEM by integrating the SRTM DEM and the Natural Resource Canada Topography data. The final regional DEM was checked against various KGS Group ground surveys along roads and ditches to insure the DEM was representative of the surveys.

The Shoal Lakes watershed is characterised by relatively flat ground, scarred with many shallow parallel undulations or ridges orientated in a northwest to southeast direction. This landscape feature tends to restrict the natural surface drainage of the area.

The characteristics of the land in the Shoal Lakes Watershed are such that there is very few defined natural drains in the watershed that convey runoff to the lakes. The general form of runoff to the lakes occurs from overland flow. During drier periods, much of the precipitation infiltrates directly into the ground and does not run off. However, in wet periods, the groundwater levels are high and water in the basin tends to pond on the swales with some of the excess water eventually flowing as overland flow towards the lakes.

Runoff is highest during the spring period during the snowmelt period and least during the summer when evaporation is the greatest. However, since there are no defined waterways draining the land towards the lakes, runoff to Shoal Lake from the watershed is ungauged and is therefore not quantified.

The high groundwater levels in the basin would be expected to produce significant groundwater flows especially when the lakes are low, however, this flow cannot be quantified. Conversely, infiltration of water to groundwater from the lakes is also not known but would vary with the lake level with highest infiltration occurring during the drought period when local groundwater levels are depressed.

Since the Shoal Lakes are generally a landlocked system the levels of the lake are mainly influenced by precipitation and evaporation to the lakes. There are no precipitation measuring stations within the Shoal Lake watershed boundary. The closest location to the Shoal Lakes is at the Grosse Isle station. The annual mean precipitation for the period of record from 1977 to 2000 is 507.4 mm. There are no records or estimates of evaporation from the Shoal Lakes, however evaporation has been computed at both Portage la Prairie and Winnipeg. Both locations are approximately equal distance to Shoal Lake, however, the average annual evaporation for the study period from 1977 to 2006 is shown to be somewhat different, with the evaporation at Portage la Prairie being 750 mm and the evaporation at Winnipeg being 830 mm. For purposes of this study the Portage la Prairie data has been adopted.

***Soils***

The soils in the Shoal Lakes Watershed are shown in Plate 4. The soils in the area of the Shoal Lakes mainly include Calcareous Loamy Till with some inter-disbursement of shallow organic fen peat. As shown in Plate 4, the soil conditions between the normal water level and the high flood levels of 2005 consist of both marsh and Calcareous Loamy Till. These soils are considered to be poorly to very poorly drained.

***Land Use***

The land use within the Shoal Lakes Watershed is shown on Plate 5. The land use consists mainly of grasslands and open deciduous forest, with a number of areas being used as forage crops. The land use in the area between the normal water level of the lakes and the high flood levels experienced in recent years consists mainly of marsh and grasslands.

***Agricultural Capability***

The agricultural capability of the land within the Shoal Lakes Watershed is based on the Canada Land Inventory seven class system, which groups soils according to the limitations and risk for agricultural use. The Classes, defined as 1 to 7, have progressively higher risks and limitations for agricultural use as defined below:

- Classes 1, 2, or 3 are considered to be suitable for suitable production of annual crops
- Class 4 land is considered to be marginal for annual crop production
- Class 5 is considered suitable for hay and pasture activities
- Class 6 land is capable of producing native hay as well as for pasture activities
- Class 7 land is considered not suitable for agricultural

The agricultural capability of the land within the Shoal Lakes Watershed shown on Plate 6 consists mainly of Class 4 land. Based on the information shown on Plate 6, the area between the normal water level and the high flood levels of recent years has approximately 40 to 50% of Class 5 land, 50 to 60% of Class 7 land and about 5 to 10% of Class 4 land.

## 2.3 HISTORY OF FLOODING ON THE SHOAL LAKES

As noted in Section 1.0, the water levels on the Shoal Lakes have recently has risen to record levels resulting in flooding of the adjacent lands. This flooding has resulted in a number of agricultural ranching activities to cease operation and the relocation of cattle to drier pastures. It has also resulted in the local Municipalities and the Province to raise the crests of the roads in the vicinity of the Shoal Lakes.

As shown on Figure 2.1,high levels similar to those of recent years have not occurred on the Shoal Lakes since the late 1970s. Recorded water levels on the North Shoal Lake from 1976 to 2010, and on the West and East Shoal Lakes from 1999 to 2010 are illustrated on Figure 2.1. The high lake levels in the 1970s were followed by a relatively dry period in the 1980s, which resulted in a continual lowering of the lake levels over that decade, into the early 1990s. The levels on North Shoal Lake dropped from a high of elevation 261.05 m in 1979 to a low of elevation 259.14 m in 1990. In the mid-1990s a sharp rise occurred on the lake levels due to significantly higher precipitation that which occurred in the 1990s. Since the rise in water levels in the mid-1990s the level in North Shoal Lake has continued to rise to peak levels of 261.25 m in 2001, 261.31 m in 2005, 261.52 m in 2009, and again to 261.78 m in the summer of 2010.

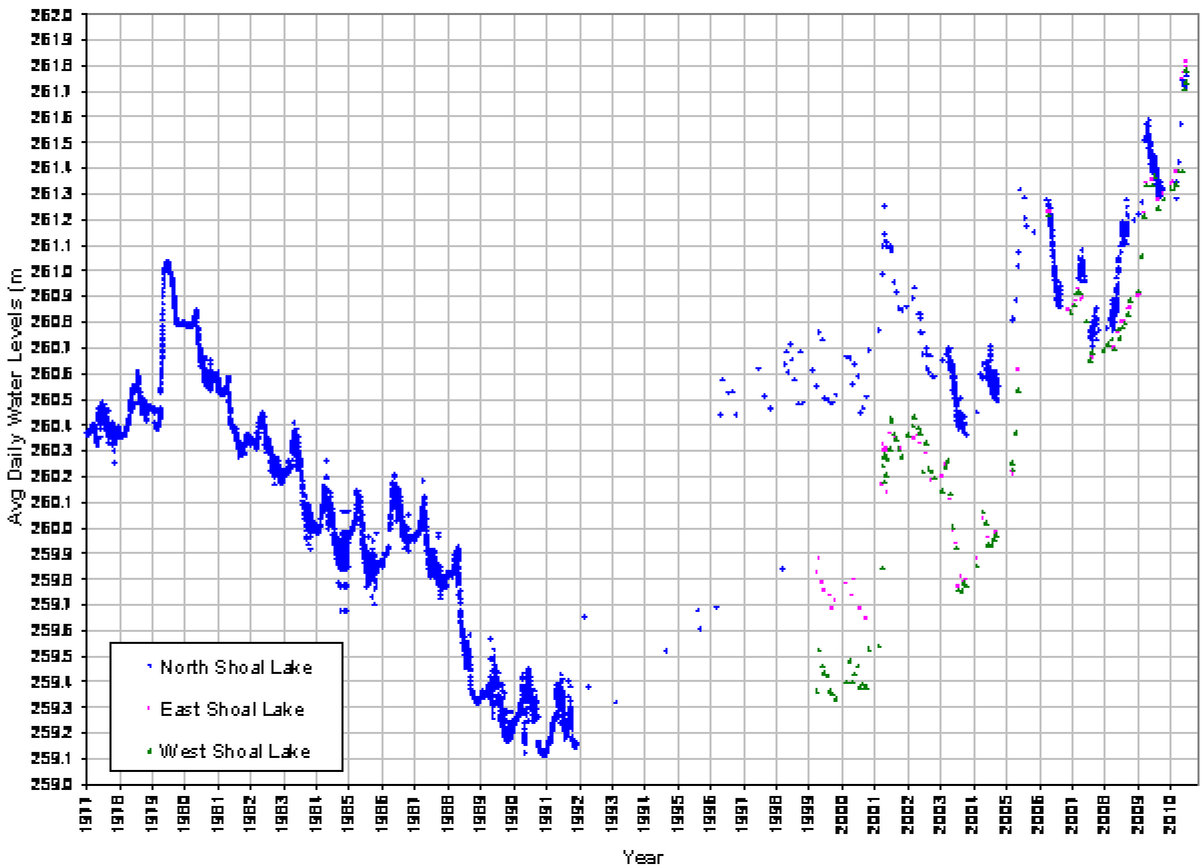


**Figure 2.1 – Recorded Water Levels on the Shoal Lakes**

The lake levels prior to 1976 were not available from MWS, as no records were taken prior to this time. There are historical records, however, that indicate that the water levels on the Shoal Lakes were higher than the levels experienced in recent times. A biological report on the Shoal Lakes Complex [Mowbray 1981] includes a map, (Figure 2.2), that shows that the water levels were high enough that there was no distinction between the West and East Shoal Lake with two connecting channels from the North Shoal Lake to the East Shoal Lake. The map also shows that the body of water consisted only of a single lake and not three distinct bodies of water.

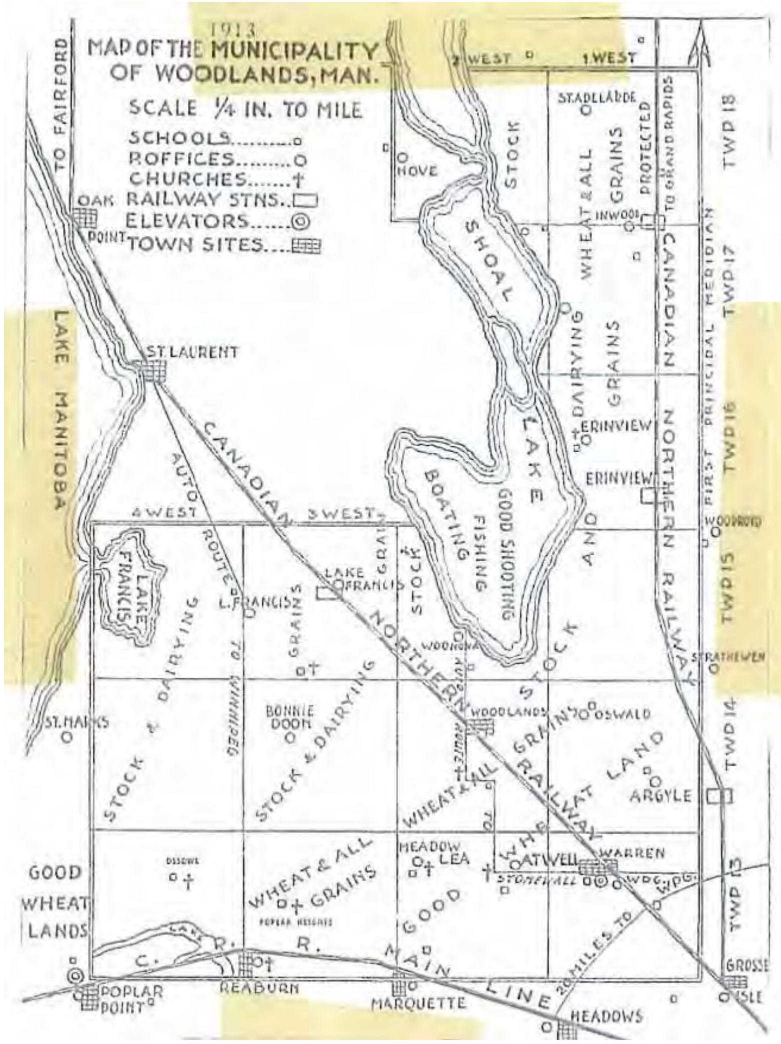


**Figure 2.2 – Map of the Shoal Lakes in the Early 1900s**

The Steering Committee members have also indicated that steamships were used on the Shoal Lakes in the early 1900s, coinciding with these high water levels illustrated on Figure 2.2.

## 2.4 AQUATIC HABITAT IN THE SHOAL LAKES

There is little information available on the existing fishery in the Shoal Lakes with exception of reports from the Fish Inventory and Habitat Classification System (FIHCS) database maintained by Manitoba Water Stewardship – Fisheries Branch. The database includes reports of fish species captured during scientific investigations, and also those collected by commercial or recreational fishers, however, dates of fish captures are not available. As the information is partially based on recreational fishers, caution is advised when interpreting the data and the reporting source(s) with respect to details such as species identification.

Manitoba Conservation states that the Shoal Lakes currently have severe limitations to fish productivity (i.e., Class 4 fishery; R. Janusz 1994, pers. comm., and K. Kristofferson, 1990, pers. comm.; FIHCS database). Ninespine stickleback and brook stickleback commonly occur in North Shoal Lake, and northern pike were stocked there between 1980 and 1986 (K. Kristofferson, 1990, pers. comm.; FIHCS database). The available information appears to have been collected prior to the mid-1990s; no recent surveys have been conducted and therefore, the current status of these populations is not known. There were no reports of fish in either East or West Shoal Lakes; however, winterkills of small fish were reported at East Shoal Lake (R. Janusz, 1994, pers. comm.; FIHCS database). It must be noted that the lack of fisheries information for East and West Shoal Lakes may merely represent the absence of records in the FIHCS database.

Reasons for the low productivity in the Shoal Lakes pertain to the water quantity and quality. The lakes are moderately saline and can only sustain species that are tolerant of such elevated salt concentrations. Also, the shallow depth (<3 m) and thick winter ice conditions (e.g., 0.8 - 0.9 m) particularly limit the area of habitat available to fish during winter. These conditions typically contribute to depleted oxygen concentrations in the lakes to the point that winterkills would inevitably reduce fish production, particularly of northern pike which have higher oxygen requirements than stickleback (Moore 1942 in Doudoroff and Shumway 1970; K. Kristofferson, 1990, pers. comm., FIHCS database; Stewart et al. 2007). Additionally, stickleback and pike typically migrate to avoid intolerable water quality conditions (i.e., low oxygen, high salinity, high temperature), but the isolation of the Shoal Lakes from other major water bodies negates that mobility, and likely increases the incidence of winterkills, which therefore reduces the productivity of the system (Magnuson et al. 1985; Stewart et al. 2007).

Under natural conditions, the depth of each lake ranges from 1.0 m in dry years to 4.0 m in very wet years, and based on the lake bathymetry, the area of each lake varies between approximately 1,500 ha and 8,000 ha.

## 2.5 WATERFOWL HABITAT IN THE SHOAL LAKES

A number of independent studies have documented the presence of birds at North, East, or West Shoal lakes (summarized by IBA 2004). Other reports and documentation of additional species may also be available at Manitoba Conservation or in the primary literature; however, an exhaustive search of the literature was not completed as part of this project as the IBA database provided sufficient information for this study. The information within the IBA database was developed between 1962 and 1995 (IBA 2004). The habitat and nesting requirements of each species were obtained from Godfrey (1966).

A number of bird species are known to inhabit the Shoal Lakes area (IBA 2004). Of particular interest is the persistent occurrence of the Piping Plover, an endangered species (SARA 2009). Between 1985 and 1996, an average of 46 nesting pairs (1.5 % of the Great Plains population) of plovers were observed in the Shoal Lakes area (IBA 2004). IBA (2004) also noted that the Shoal Lakes are an important avian area in Canada, with an abundance of nesting pelicans, grebes, and plovers as well as large congregations of migratory waterfowl. During the peak of the fall migration, upwards of 100,000 Canada Geese (or 30 % of the Tall Grass Prairie population) and 200,000 Lesser Snow Geese (or 6.6 % of the mid-continental population) were observed (IBA 2004). Other bird species of importance located in the Shoal Lakes as defined by Poston (Poston 1990) include:

- Western Grebe – The Shoal Lakes has the largest breeding population in the Prairies
- Black-crowned Night Herons – The Shoal Lakes are the only breeding population in the Prairies
- American Pelican – The Shoal Lakes are a nationally important area for breeding.

No recent assessments of avian habitat quality in the Shoal Lakes area have been reported. However, under natural conditions, the area of each lake varies between approximately 1500 ha and 8000 ha and therefore avails a substantial, contiguous parcel of wetland habitat to waterfowl, wading birds, and terrestrial birds. The broad expanses of open water are also important for staging ducks, geese, and wading birds, including those which may become resident (locally breeding) avian species and those which naturally move on to other breeding grounds further north (Murkin et al. 2000).

The Shoal Lakes have been defined as a nationally important area for migratory bird habitat as the second most important site in Manitoba and the fourth most important site in the Prairie Provinces (Poston, 1990).

## 2.6 WATER QUALITY IN THE SHOAL LAKES

### 2.6.1 Existing Water Quality Information

Little information exists regarding the water quality on the Shoal Lakes. Therefore, as part of this study, North/South Consultants conducted a water quality-sampling program at Shoal Lakes in 2008 to provide a description of existing conditions. This program would also provide information to facilitate an assessment of potential impacts associated with the proposed diversion of water to Lake Manitoba. There is sufficient water quality data that exists to characterize Lake Manitoba, as described in Section 2.7, so no sampling was required for this study on Lake Manitoba.

### 2.6.2 Water Quality Sampling Program

A summary of the sample sites, periods, methods, and results of the water quality sampling program are presented in the following sub-sections. Detailed results of the water quality sampling program are provided in the tables provided in Appendix A.

***Sampling Sites***

Samples were collected at one site near the centre of each lake (West, East, and North Shoal Lakes) to provide an overall representation of lake water quality (Figure 2.3 and Table 2.1). The winter sampling sites for the East and North Shoal Lakes were located closer to the northern and southern ends of each lake.

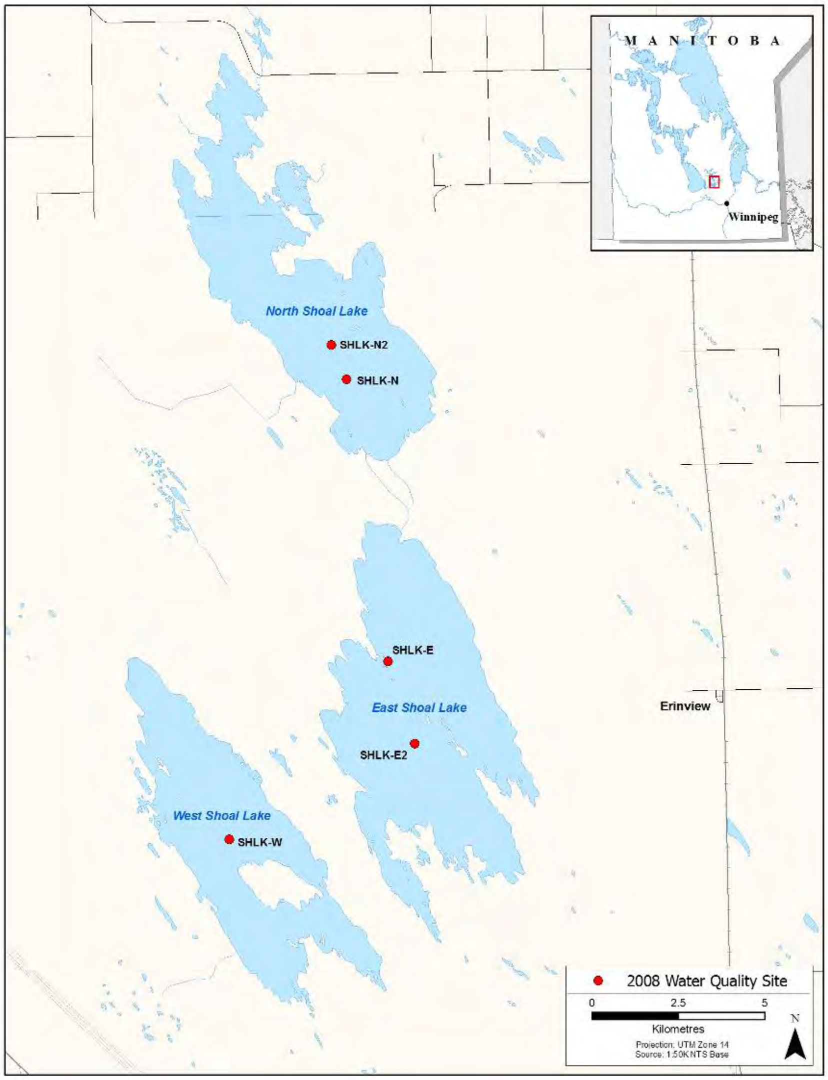


**Figure 2.3 – Water Quality Sampling Sites**

**TABLE 2.1**
**LOCATION OF THE SHOAL LAKES SAMPLING SITES**

| Sample Location | Location ID | Zone | Easting | Northing |
|---|---|---|---|---|
| North Shoal Lake | SHLK-N | 14 | 596 839 | 5590 332 |
| | SHLK-N2 | 14 | 596 402 | 5591 318 |
| East Shoal Lake | SHLK-E | 14 | 598 042 | 5582 171 |
| | SHLK-E2 | 14 | 598 807 | 5579 778 |
| West Shoal Lake | SHLK-W | 14 | 593 454 | 5577 014 |

***Sampling Periods***

Samples were obtained four times in the open-water season (June, July, August, and September) and once in the ice-covered season (March) to characterize the seasonal variability in water quality.

***Sample Collection and Field Measurements***

Sampling consisted of in-situ measurements throughout the water column (temperature, pH, specific conductance, turbidity, total dissolved solids, dissolved oxygen [DO], and oxidation reduction potential [redox]), measurements of Secchi disk depth (open-water season only), and collection of water samples for analysis at an accredited analytical laboratory.

***Chemical Analyses***

During the ice-covered season, the parameters measured at the laboratory were: pH, true colour, conductivity, alkalinity, bicarbonate, carbonate, hydroxide, dissolved ammonia, dissolved nitrate/nitrite, nitrogen as nitrate (dissolved), nitrogen as nitrite (dissolved), Total Kjeldahl Nitrogen (TKN), total and dissolved phosphorus, dissolved organic carbon (DOC), total dissolved solids, total suspended solids (TSS), turbidity, chlorophyll, and total metals and major ions.

During the open-water season, the water samples were analysed for a smaller subset of routine water quality variables, including: dissolved ammonia, dissolved nitrate/nitrite, TKN, total and dissolved phosphorus, total organic carbon (TOC), TSS, total dissolved solids, and turbidity.

***Methods of Sample Collection and In-Situ Measurements***

In-situ parameters were measured at each site using a Horiba W-22XD water quality meter. Measurements of in-situ variables were collected across depth at 0.5 or 1 m intervals. Secchi disk depth was measured at each site in the open-water season as an average of two measurements: the depth at which the Secchi disk was no longer visible when lowered through the water column and the depth at which the Secchi disk appeared when raised up through the water column. Site locations were recorded as Universal Transverse Mercator units (UTMs) using a hand-held Garmin eTrex Global Positioning System (GPS) unit. Ice depth was measured in winter using a metre stick. Sites were accessed by and sampled from a boat in the open-water season and by snowmobile in winter.

In the open-water season, grab samples of surface water were collected into the laboratory-supplied sample bottles and preserved as necessary. In winter, 10-inch holes were drilled in the ice using a gas-powered auger and grab samples of water were collected from below the ice surface.

***Data Analysis and Presentation***

Summary statistics, including mean ± standard error (SE) were derived for data collected during the open-water season. Raw data are provided for the ice-cover season. For the purposes of calculating the statistics, all measurements reported below the analytical detection limit (DL) were assigned a value of half the DL.

Data were compared to the Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs) to assess whether the conditions met the criteria for drinking water, irrigation of gardens or fields, livestock watering, and the protection of aquatic life.

The water quality sample program results are provided in the tables included in Appendix A.

### 2.6.3 Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs)

Provincial water quality objectives and guidelines have been generated for many water quality parameters for the purpose of protecting aquatic biota and wildlife, and for protecting water for various human usages including recreation, drinking, irrigation, and livestock watering. The Manitoba water quality objectives and guidelines were revised in 2002 (Williamson 2002) and are largely in accordance with national Canada Council of Ministers of the Environment (CCME) guidelines (CCME 1999; updated to 2009).

Water quality data collected from Shoal Lakes and Lake Manitoba were compared to the Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs; Williamson 2002) where available, and CCME guidelines where criteria were not available for Manitoba.

In general, the guidelines and objectives for the protection of aquatic life and wildlife are more stringent than the objectives for the protection of human health usages (i.e., drinking water; Williamson 2002). Objectives for ammonia were calculated based on the range of pH and water temperature observed in the study area during both the open-water and ice-covered seasons. Site-specific objectives were also calculated for cadmium, copper, chromium, lead, nickel, and zinc based on the range of water hardness measured in Shoal Lakes and Lake Manitoba.

Proposed Manitoba water quality objectives and guidelines for drinking water (Williamson 2002) were adopted from the federal Health Canada objectives (summarized in CCME 1999, updated to 2007). Drinking water quality objectives and guidelines are intended for application to treated or finished water as it emerges from the tap and “are not intended to be applied directly to source waters” (CCME 1999, updated to 2007). However, comparison of water quality in the Study Area to drinking water quality objectives is included to provide context; it is indicated in the proposed MWQSOGs (Williamson 2002) that: “All surface waters…are susceptible to uncontrolled microbiological contamination. It is therefore assumed that all raw surface water supplies will be disinfected as the minimum level of treatment prior to consumption.” Furthermore, it is indicated that Manitoba Drinking Water Quality Guidelines “apply to finished drinking water, but can be extrapolated to provide protection to raw drinking water sources”(Williamson 2002).

### 2.6.4 Description of Existing Water Quality Conditions

A summary of the surface water quality data collected during the ice-cover and open-water seasons of 2008 is presented in Tables B1, B2, and B3 provided in Appendix B. The following provides a general overview of these data.

With some minor exceptions, the water quality of Shoal Lakes was relatively similar across the lakes. In general, the Shoal Lakes can be described as relatively turbid and very hard, with high concentrations of nutrients, and slightly alkaline pH (Table B1). Levels of TDS and conductivity are relatively high and the lakes would be considered “slightly saline” according to the CCREM (1987). Sodium was the dominant cation present in the lakes, with magnesium, calcium, and potassium present in lower concentrations (Table B2). On the basis of total phosphorus concentrations, North Shoal Lake would be classified as eutrophic while the east and west basins would be classified as hypereutrophic according to the CCME phosphorus guidance framework (Table B4; CCME 1999, updated to 2009).

Each of the basins displayed weak thermal stratification in March and August 2008, although the thermocline was shallow. The basins were relatively well-oxygenated in the open-water season but exhibited oxygen depletion in the ice-cover season. DO concentrations were particularly low in the east and west basins in March 2008, and when stratified, DO concentrations decreased with depth.

The water quality of the lakes varied slightly across seasons and among the basins. As expected because of the connectivity of the lakes, West and East Shoal Lakes had very similar water quality except that mean turbidity was slightly lower and ammonia was slightly higher in West Shoal Lake than in the other basins (open-water season; Table B1). In contrast, during the ice-cover season, North Shoal Lake contained higher levels of total suspended solids but lower concentrations of total phosphorus and nitrate/nitrite than the other lakes. Further, during the open-water season, North Shoal Lake had lower levels of specific conductance, total dissolved solids, total phosphorus, and total nitrogen than in the east or west basins.

Most of the major ions and trace elements were only measured in the lakes during the ice-cover season and the concentrations of these compounds were generally similar across sites (Tables B2 and B3). The exception to this pattern was that North Shoal Lake had a slightly higher concentration of magnesium than East and West Shoal Lakes (Table B2). Sulphate and chloride were measured during both the open-water and ice-cover seasons and were consistently higher during winter than summer. Over both seasons, North Shoal Lake had the highest sulphate concentration of all basins but chloride concentrations were lowest in North Shoal Lake, moderate in East Shoal Lake, and highest in West Shoal Lake (Table B2).

***Comparison to Water Quality Objectives and Guidelines for the Protection of Aquatic Life***

Some water quality parameters were consistently within the Manitoba water quality guidelines and objectives for the protection of aquatic life including pH, ammonia, and most metals. In addition, all measurements of nitrate and nitrate/nitrite were below the CCME guideline for the protection of aquatic life.

Other water quality parameters, including TP, DO, aluminum, selenium, and silver (North Shoal Lake only), measured in Shoal Lakes exceeded the provincial water quality objectives and guidelines for the protection of aquatic life (Tables B1 and B3). TP exceeded the narrative guideline for the protection of aquatic life (0.025 mg/L) on all occasions and at all sites (Table B1). During the single sampling event in winter, some metals also exceeded the guidelines for the protection of aquatic life (Table B3). Aluminum and selenium were above the guidelines in each basin at this time and silver slightly exceeded the guideline in North Shoal Lake.

Dissolved oxygen concentrations were below the most stringent objective for the protection of cool-water species in the east and west basins in March and at depth in the west basin in August.

***Comparison to Water Quality Objectives and Guidelines for Irrigation***

Most water quality parameters measured in Shoal Lakes in 2008 were within the Manitoba water quality objectives and guidelines for irrigation, including aluminum, arsenic, beryllium, cadmium, copper, iron, lead, manganese, molybdenum, nickel, selenium, uranium, vanadium and zinc.

Conversely, all measurements of specific conductance and TDS exceeded the objectives for irrigation in greenhouses (1,000 µS/cm and 700 mg/L, respectively) and in parks and fields (1,500 µS/cm, 1000 mg/L, respectively; Table B1). Additionally, chloride exceeded the Manitoba irrigation guideline at all sampling times in West and East Shoal Lakes and in winter in North Shoal Lake (Table B2). Total chromium was at or near the guideline for irrigation in each basin in winter 2008. Boron also exceeded the lower range of the guidelines for irrigation in all samples.

***Comparison to Water Quality Objectives and Guidelines for Livestock Watering***

All substances for which there is Manitoba water quality objectives or guidelines for livestock watering were met in Shoal Lakes in 2008. This included TDS, nitrate/nitrite, calcium, sulphate and metals (Tables B1 to B3).

***Comparison to Water Quality Objectives and Guidelines for Recreation***

The only applicable water quality guideline for recreational usage (pH of 5-9) for the parameters measured in Shoal Lakes in 2008 was met at all sampling times.

***Comparison to Drinking Water Quality Guidelines***

Most water quality parameters measured in Shoal Lakes were within the Manitoba drinking water guidelines. Exceptions included:

- TDS exceeded the aesthetic guideline (500 mg/L) during all sampling periods and in all basins;
- pH of each lake exceeded the aesthetic guideline during the open-water season but not during the ice-cover season (Table B1).
- As the maximum acceptable concentration for turbidity in drinking water is only 1 NTU, all turbidity measurements from North, West, and East Shoal Lakes exceeded this guideline and many were in excess of the higher aesthetic guideline (5 NTU; Table B1); and
- Sodium exceeded the aesthetic guideline in all samples.

## 2.7 WATER QUALITY IN LAKE MANITOBA

### 2.7.1 Existing Water Quality Information

Lake Manitoba is the third largest lake in Manitoba (Last 1984) with a surface area of approximately 4,706 $km^2$. The south basin accounts for more than 70 % of the surface area of the lake, and has a volume of 14.1 $km^3$ (Last 1984). Although the south basin contains most of the water in the lake, the narrows between the north and south basins restrict the flow of water and exchange between the basins. Additionally, because both the major inflow (Waterhen River) and only outflow (Fairford River) for Lake Manitoba are in the north, the north basin has a much shorter residence time (2 years) than the south basin (28 years; Last 1984). Inflows to the south basin are from the Whitemud River (0.18 $km^3$/yr, or 6.0 % of total inflows to the lake), the Portage Diversion (0.30 $km^3$/yr or 11.0 % of total inflows), artificial drains, groundwater, and runoff (collectively 4.5 %; LMRRAC 2003). A number of stakeholders have expressed concern that the periodic inflows from the Portage Diversion (i.e., overflow from the Assiniboine River) have contributed to the deteriorating water quality in Lake Manitoba; however, water quality in the Lake and tributaries have not been studied sufficiently to validate such speculations (LMRRAC 2003).

MWS provided the raw water quality data for Lake Manitoba that was used in this study. Data was available for a nearshore location in the south basin (St. Ambroise Beach) and for some parameters at the Narrows. No data was available describing water quality in the offshore area of the south basin of Lake Manitoba.

***Sampling Periods, Locations, and Collections***

MWS provided data for samples collected from St. Ambroise Beach in June and August 2005, May, July, and August 2006, and during the ice-cover season in March 2006 and 2007. Water was collected for analysis of nutrients, temperature, turbidity, TSS, TDS, conductivity, and pH.

Additional samples were collected from the narrows (where Highway 68 crosses the lake) for analysis of metals. For the ice-cover season, samples were collected during January 2005, 2006, and 2007 as well as in November 2006. Samples from the open-water period were collected in April, June, and September 2004, 2005, and 2006, and in April, July, and August in 2007. Although this sampling location is distant from the studied location of the water diversion inflows to Lake Manitoba, it was assumed that the concentrations are representative of conditions in the entire lake.

***Chemical Analyses***

Samples from St. Ambroise Beach were analysed for dissolved ammonia, nitrate/nitrite, TKN, total nitrogen, particulate phosphorus, total dissolved phosphorus, and total phosphorus (TP). Water collected from the Narrows was analysed for total metals and major ions.

***Data Analysis and Presentation***

Metals data collected from the Narrows and routine data collected from St. Ambroise Beach were used for this analysis. Summary statistics, including mean ± SE, are presented for data collected during the ice-covered and open-water seasons for each of the two sites. For the purposes of calculating the statistics, all measurements reported below the detection limit were assigned a value of half the limit.

Data were compared to the MWQSOGs to assess whether the conditions met the criteria for drinking water, irrigation of gardens or fields, livestock watering, and the protection of aquatic life.

### 2.7.2 Description of Existing Water Quality Conditions

Minimal water quality data for Lake Manitoba were located. Summary statistics for key parameters measured at St. Ambroise Beach or the Narrows between 2004 and 2007 are presented in Tables B1 to B3 provided in Appendix B. The following is a discussion of these data.

Water quality of Lake Manitoba at St. Ambroise Beach can be broadly described as very hard, slightly alkaline in pH, and containing moderate-to-high levels of turbidity and nutrients (Table B1). Like Shoal Lakes, Lake Manitoba would be classified as "slightly saline," according to the TDS classification scheme presented in CCREM (1987). Sodium was the dominant cation present, with calcium, magnesium and potassium present in lower concentrations (Table B2). On the basis of total phosphorus concentrations, the lake would be classified as eutrophic according to the CCME phosphorus guidance framework (Table B4; CCME 1999, updated to 2009).

The available data indicate that conductivity, TDS, ammonia, and nitrate/nitrite concentrations were higher during the ice-cover season than the open-water season from 2004 to 2007 but that pH, TSS, turbidity, and total phosphorus were lower during winter.

The concentrations of metals measured at Lake Manitoba Narrows were similar across the ice-cover and open-water seasons, although only two samples were collected during the ice-cover.

***Comparison to Water Quality Objectives and Guidelines for Protection of Aquatic Life***

Most water quality parameters measured in Lake Manitoba were within the Manitoba water quality objectives and guidelines for the protection of aquatic life, including: pH, ammonia, and with a single exception, metals and metalloids. In addition, nitrate/nitrite concentrations were within the CCME guideline for nitrate.

As observed in Shoal Lakes, TP concentrations in Lake Manitoba were above the narrative guideline of 0.025 mg/L for lakes and averaged 0.070 mg/L for the open-water season.

Mean metal concentrations of samples collected from Lake Manitoba between 2004 and 2007 were all below the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002), including: aluminum; arsenic; cadmium; chromium; copper; iron; lead; molybdenum; nickel; selenium; silver; thallium; and zinc (Tables B2 and B3). As for individual samples, only the guideline for aluminum (0.100 mg/L) was exceeded (0.110 mg/L; Table B3) and this only occurred during a single sampling event in winter.

***Comparison to Water Quality Objectives and Guidelines for Irrigation***

As observed for Shoal Lakes, all measurements of conductivity and total dissolved solids measured in Lake Manitoba from 2005 to 2007 exceeded the objectives for greenhouse irrigation (1,000 µS/cm and 700 mg/L, respectively); samples collected during the ice-covered season also exceeded the higher objectives for field and park irrigation (1,500 µS/cm and 1,000 mg/L, respectively). Although irrigation does not occur during winter months, the latter comparison is made for perspective. Additionally, all measurements of chloride exceeded the lowest water quality guideline for irrigation (note: a range is indicated for the guideline depending on the crop). Most metals were within the irrigation guidelines; the exception was that the maximum concentration for chromium, which occurred in winter, was at the guideline limit for irrigation (Table B3).

***Comparison to Water Quality Objectives and Guidelines for Livestock Watering***

All parameters for which there are livestock watering guidelines were within the respective guidelines including TDS, sulphate, nitrate/nitrite, and metals.

***Comparison to Water Quality Objectives and Guidelines for Recreation***

The only applicable water quality guideline for recreational usage (pH of 5-9) for the parameters measured in Lake Manitoba was met at all sampling times.

***Comparison to Water Quality Objectives and Guidelines for Drinking Water***

Although most water quality variables measured in Lake Manitoba met the provincial guidelines for drinking water quality (including nitrate/nitrite, sulphate, and metals/metalloids), there were a few exceptions, as follows:

- TDS was above the aesthetic guideline for drinking water in all samples (500 mg/L; Table B1)
- pH was above the upper range for the aesthetic drinking water quality guideline in the open-water season
- as the maximum acceptable concentration for turbidity in drinking water is only 1 NTU, all measurements of turbidity in Lake Manitoba exceeded this guideline, and summer measurements also exceeded the higher aesthetic guideline (5 NTU; Table B1)
- all measurements of chloride exceeded the aesthetic guideline
- some measurements of sodium were above the aesthetic drinking water guidelines in Lake Manitoba (Table B2)

# 3.0 SURFACE WATER DRAINAGE NETWORK

## 3.1 DRAINAGE NETWORK

As noted in Section 2.2, there are very few defined drains that convey flow into the Shoal Lakes system. Drainage areas adjacent to the lakes drain directly to the lakes. There are, however, a number of drains to the west of the ridge that separates the Shoal Lakes from Lake Manitoba, as well as a series of drains that convey flow away from PTH 6.

There are also drains that connect the Shoal Lakes including the channel that connecting North Shoal Lake to East Shoal Lake, and the channel that connects Swamp Lake to the West Shoal Lake. There is no defined channel connecting the East and West Shoal Lakes. However during flood periods, the land connecting the two lakes is submerged and flow between the lakes occurs freely.

Two drains have been identified as locations for the alignment of the potential diversion channels from Shoal Lake, including Wagon Creek, and Boundary Drain, which flows into Roy's Drain to the west of PTH 6.

As noted in Section 1.0, due to the topographic relief surrounding the Shoal Lakes, the system is generally a land-locked drainage basin with no natural outlet for the lakes. However, we understand as based on discussions with members of the Steering Committee that when the lakes are at high levels, there have historically been natural overflows to the east into the Sturgeon Creek and Grassmere drainage systems. Typically, when these overflows have occurred, there is a tendency for the local authorities to raise the roads or closed the drainage paths to eliminate the overflow to the adjacent drainage basins. Recent information obtained by MWS however, suggests that the elevations of the roads in the south end of the basin are situated at elevations lower than the surrounding topography. This would suggest that even if the roads were overtopped, that the floodwaters would not flow into the adjacent drainage basins.

## 3.2 CONDITION OF DRAINS

As part of the work, KGS Group carried out a visual inspection of the drains, summarized in Section 3.1, including Boundary Drain, Roy's Drain, Wagon Creek, and the channels that connect North and East Shoal Lakes as well as the drain that connects Swamp Lake to West Shoal Lake. A description of the conditions of these drains, as well as photographs that show the typical drain conditions are presented in the following sub-sections. The condition assessment was completed in the spring and summer of 2008 and may not be representative of the conditions in the drain at the present time.

### 3.2.1 Boundary / Roy's Drain

***Boundary Drain along Edmoudos/Boundary Road between PR 518 and PTH 6 –*** This reach is about 8.6 km in length where the drain is generally heavily overgrown with dense vegetation with trees and shrubs sporadically along the ditch on both the side slopes and base of the channel (Photo 3.1). In some areas due to poor grading, the drain acts as a pond and as a results heavy marshland vegetation is present. Similarly, most of the culverts along the reach are half buried and/or blocked by dense vegetation growth. The exception is the portion of the drain near PTH 6 that appears to have been recently maintained and is in comparatively good condition, with limited vegetation and virtually free of trees, shrubs and dense vegetation (Photo 3.2).

**Photo 3.1 – Drain along South side of the Edmoudos/Boundary Rd**

***Roy's Drain along the East Side of PTH 6 –*** This reach is about 3.1 km in length where the drain exists on East side of the road. The drain is full of dense weed growth and the culverts are half buried and/or blocked by dense vegetation growth (Photo 3.3) similar to the upper reaches of the Boundary Drain.

**Photo 3.2 – Drain along South side of the Edmoudos/Boundary Rd near PTH 6**

**Photo 3.3 – Drain along East side of the PTH 6**

***Roy's Drain Between PTH 6 and Lake Manitoba –*** This reach is about 6.1 km in length. The section of the drain just downstream of PTH 6 does not appear to have been maintained and is in poor condition. Portions of the drain have either silted in or have eroded. The erosion and siltation has resulted in a channel that is poorly drained that consists of a number of ponded areas where the associated marshland is shown (Photo 3.4). The remainder of the drain in this reach is in comparatively better condition with only some relatively minor silting and erosion. Substantial vegetation growth on the banks of the channel has occurred, however, but the base of the channel is relatively vegetation free (Photo 3.5). Similarly, the upstream and downstream ends of most of the culverts in this reach are clear from the heavy vegetation growth.

**Photo 3.4 – Drain downstream of the PTH 6**

**Photo 3.5 – Drain between PTH 6 and Lake Manitoba**

### 3.2.2 Wagon Creek Drain

***Along Gaudry Road between PR 518 and the Location where the Drain leaves the Gaudry Road –*** This reach is about 4.0 km in length. The existing prairie elevations are comparatively higher than the bottom of the ditch in this reach. The drain is generally quite heavily overgrown with trees and shrubs along the banks and inside the channels. In some areas, the drains are acting as ponds with associated marsh vegetation comprised of dense weed growth. Most of the culverts in this reach are half buried and/or blocked by dense vegetation growth (Photo 3.6). The area further South of the Gaudry Road and West of the PR 518 is comprised mostly of marshland with no defined drainage systems

***Between Gaudry Road and Stony Ridge Road –*** This reach is about 12.0 km in length. The area is mostly marshland and the drain is full of dense weed growth (Photo 3.7). The culverts in this reach are half buried and/or blocked by dense vegetation growth.

***Between Stony Ridge Road and PTH 6 along Wagon Creek Road –*** This reach is about 8.3 km in length. The drain has been silted in to some extent and most of the sections have a heavy vegetation growth along the banks and along the bottom of the channel. The farmland South of Wagon Creek Road is subject to periodic flooding from the Wagon Creek Drain. Low-lying swales along the south side of the drain allow water to enter into the fields during periods of high water levels (Photo 3.8). During spring, runoff water entering through the culverts under PTH 6, is most likely often blocked by the snow and by ice-filled culvert crossings located just upstream, approximately 130 m east from the PTH 6.

**Photo 3.6 – Culvert crossing and Marshland along North side of Gaudry Rd**

**Photo 3.7 – Drain and Marshland between Gaudry Rd and Stony Ridge Rd**

**Photo 3.8 – Drain along South side of Wagon Creek Rd**

***Between PTH 6 and Lake Manitoba –*** This reach is about 1.3 km in length. The drain is heavily overgrown with dense vegetation along the banks and inside the channel. In addition, the drain has been silted in to some extent. In some areas, the drain is acting as a pond and associated marshland is growing resulting a dense weed growth. Most of the culverts in this reach are half buried and/or blocked by dense vegetation growth. Spring runoff water is most likely often blocked by the snow and ice-filled culvert crossing located close to Lake Manitoba (Photo 3.9).

**Photo 3.9 – Drain and Culvert near Lake Manitoba**

### 3.2.3 Swamp Lake Drain

***Between PR 518 and West Shoal Lake –*** This drain has not been maintained and some portions have been silted in or eroded and/or acting as ponds. The drain is heavily overgrown with vegetation (Photo 3.10).

**Photo 3.10 – Swamp Lake Drain (between PR 518 and West Shoal Lake)**

### 3.2.4 Drain between North and East Shoal Lakes

The North and East Shoal Lakes are connected through large marshy areas on both sides of PR 415. A relatively undefined drainage channel connects the two lakes through this area (Photo 3.11).


**Photo 3.11 – Connection between North and East Shoal Lakes**

## 3.3 SURVEYS

MWS provided a number of surveys of cross sections and profiles of the roads and drains in the watershed, as well, as four cross sections taken across each of the North, East, and West Shoal Lakes. This data was insufficient to develop feasibility level designs of the diversion channels along the Wagon Creek, Roy's Drain or the Boundary Drain. The interconnecting channels between the lakes were also not surveyed. KGS Group carried out a survey program to obtain the required information, as part of this study. Plate 7 shows a summary of the survey data that was available from MWS at the start of the study, as well as a list of the information that was obtained by KGS Group in the spring of 2008.

The cross section information of the Shoal Lakes that was provided by MWS is shown on Plate 7, and consisted of four cross sections of each lake. This information was used together with the adjacent land contours to produce bathymetric contours of the lakes as shown on

Plate 8. The bathymetric contours were used to compute the elevation-surface area and elevation-storage volume relationships of the lakes. This information was used to determine net inflows to the lakes for use in the hydraulic model of the Shoal Lakes, as documented in Section 5.0. It should be noted that all of the results presented in this study, used the surface area and volume of the lakes based entirely on the four cross sections for each lake. The area and volumes computed are therefore considered to be approximate. It is recommended that a more detailed bathymetric survey program be carried out to more accurately represent the bathymetry of each of the lakes if further studies are undertaken.

# 4.0 FLOOD MITIGATION ALTERNATIVES

## 4.1 GENERAL

A number of flood mitigation alternatives have been reviewed as part of past studies for potential options to alleviate the flooding concerns on the Shoal Lakes. Most notably, the "Shoal Lakes Water Management – Preliminary Investigation" study dated August 2002, in which three flood diversion / outlet channels were reviewed at a feasibility level (two channels connected to North Shoal Lakes and one channel connected to West Shoal Lake). That study recommended further consideration of an outlet channel connecting to the East Shoal Lake.

As defined in the project scope in the RFP, the current watershed study has defined a number of flood mitigation alternatives for assessment. These alternatives include:

- The construction of a diversion / outlet channel from the Shoal Lakes to Lake Manitoba. Two alternate alignments of the diversion channel were defined and include:
  - A diversion channel along the alignment of Wagon Creek connecting to the north end of West Shoal Lake
  - A diversion channel along the alignment of both Roy's Drain and Boundary Drain connecting to the west end of West Shoal Lake
- Construction of upland storage in the Shoal Lakes Watershed
- Purchase of flood prone lands

Other options that were not included in the scope of the project, as outlined in the RFP include the construction of a diversion channel to the southeast into either the Grassmere Creek or Sturgeon Creek systems, or the diversion of flows to the northwest into the Hatchery Drain. As these options were not part of the scope of the project they have not been addressed in this study.

Each of the flood mitigation alternatives were reviewed and designed to a feasibility level as part of this study. Costs, and benefits of the reduction of flooding were also evaluated. The development of each alternative is described in further detail in the following Sections.

## 4.2 FLOOD DIVERSION CHANNELS

### 4.2.1 Flood Diversion Channel Alternatives

The routes for each of the two diversion channels (Wagon Creek Option and the Roy's / Boundary Drain Option) were defined by the Steering Committee are shown in Plate 9. For the Wagon Creek Drain Option, two alternatives were considered for the location of the start of the Wagon Creek drain at West Shoal Lake - Option A that follows Gaudry Road and connects to the north end of West Shoal and Option B that follows the lower topography and connects to the middle section of the West Shoal Lake.

### 4.2.2 General Design Considerations

The purpose of the diversion / outlet channels is to divert excess floodwaters from the Shoal Lakes to Lake Manitoba when the water levels in the lakes exceed the target levels. The target water level on each of the three lakes refers to the maximum desirable lake level. The target levels, as prescribed by the Steering Committee, for the each of the Shoal Lakes are:

- North Shoal Lake = 260.45 m
- East Shoal Lake = 259.70 m
- West Shoal Lake = 259.70 m

The design criteria that were adopted for the preliminary design of the flood diversion channels include:

- The channel was designed to convey flow from the West Shoal Lake to Lake Manitoba by gravity flow only, without the inclusion of pump or pipeline structures, as defined by the Steering Committee. A gated control structure was included at the entrance to the channel to limit the flow of water to periods only when the water level exceeded the target level on West Shoal Lake

- The diversion channel cross section from West Shoal Lake was designed with a trapezoidal shape.

- The channels were designed with a grass cover such that the flow shear stresses at the surface of the channel are below that which would cause erosion under the design flow conditions.

- The channels were designed as non-aggrading to prevent sediment deposition in the channel that would result in loss of discharge capacity.
- A channel bed slope of 0.01 % was chosen to minimize excavation quantities in the channel. A steeper gradient would reduce the base width but would also increase the depth of cut and result in increased excavation quantities due to the flat side slopes and high elevation of the land along the channel alignment
- Design water level at a minimum of 0.3 metres below the adjacent prairie level.

The diversion channel was also considered to operate during the winter period. Therefore, the sizing of the channel was determined to prohibit the potential for frazil ice formation.

The design of the spoil embankments for the flood channels have been based on Manitoba Infrastructure and Transportation's (MIT) standard design criteria for drainage channels, as well as KGS Group's experience with the type of soil materials along the alignment of the channels. The preliminary design criteria for the spoil dikes include:

- Minimum top width not less than 2.5 m
- Side slopes of 1 vertical on 3 horizontal
- Minimum setback distance of 5.5 m (from top of the channel)

In areas where there is not an existing road adjacent to the channel, spoil embankments were placed on both sides of the excavated channel except when the channel was located along side a road in which case the all of the spoil material was assumed to be placed on the side of the channel opposite the road.

The side slopes for the channels and spoil embankments were based on MIT's standard design criteria for drainage channels and on KGS Group's experience. The design side slopes are listed below:

- For channels, 1 vertical on 4 horizontal
- For spoil dikes, 1 vertical on 3 horizontal

Geotechnical investigations (i.e. soils testing) were not carried out as part of this study. Should this project proceed to subsequent phases of design, it is recommended that soil surveys should be carried out to confirm the soil types along the channel alignments.

The diversion channel capacity was selected based on a review of water levels and estimated inflow derived from the change in water levels for the period when the water levels were at or above the target level. A preliminary optimization of the channel size based on excavation volumes, maximum channel velocity related to bed erosion and ice cover formation concluded that the channel capacity be approximately 10 $m^3/s$ when the water level on West Shoal Lake was above elevation 260.20 m. The channel capacity for water levels other than 260.20 m is based on normal depth of flow using Manning's formula. At the target level of East Shoal Lake of 259.70 m the discharge is approximately 6 $m^3/s$, but the discharge increases to approximately 22 $m^3/s$, when the West Shoal Lake level is 261.00 m. The stage discharge rating curve for the channel is shown on Figure 4.1.

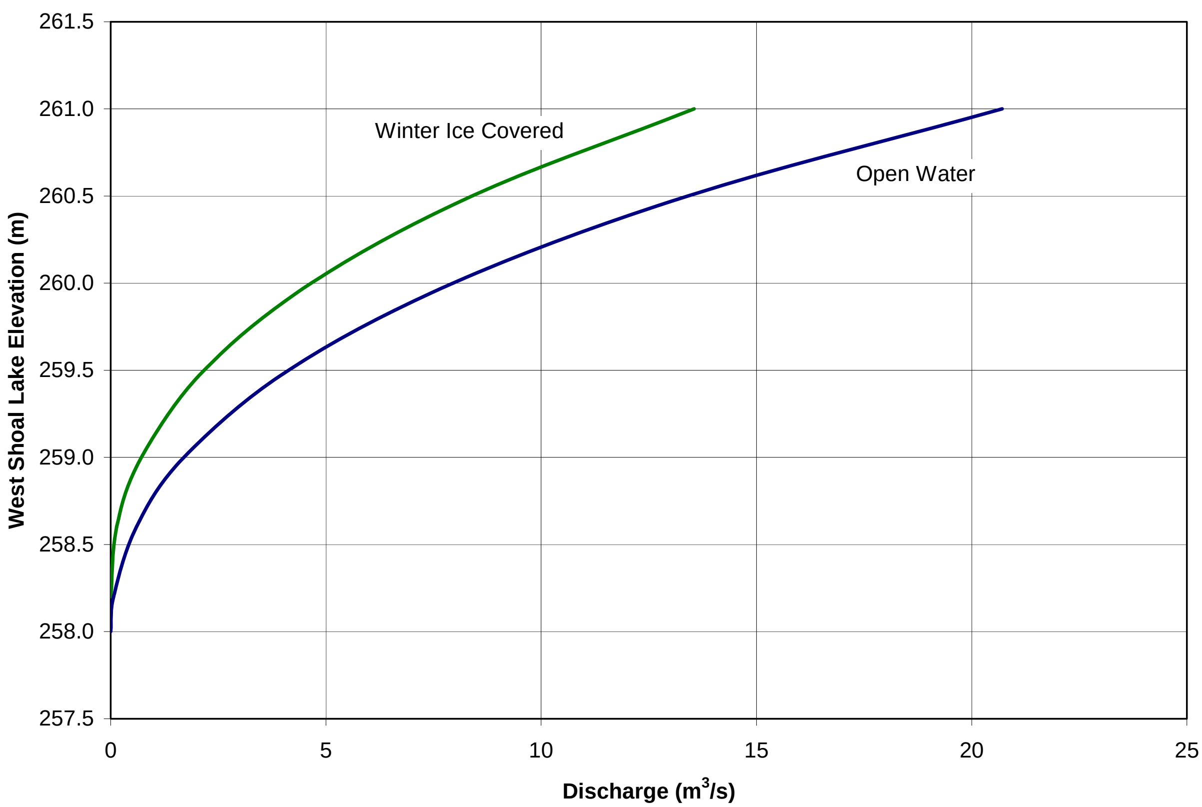


**Figure 4.1 – Discharge Channel Stage-Discharge Relationship**

Since the flow into the diversion channel is governed by the control structure and the elevation of the lake and the adjacent topography, each channel alternative was designed with the same flow capacity. In addition to the flow diverted from the West Shoal Lake, the channel associated with each route was also designed to convey the local discharge associated with a 10 year flood event.

As noted above the channel capacity has been selected based on a cursory examination of inflows to satisfy the design criteria listed above. If this study proceeds to subsequent levels of design a detailed optimization for the channel capacity is recommended in which alternative channels having a range in capacities are compared. That assessment should include the development of detailed cost estimates compared to the effects or incremental benefits related to lowering of the target level on the Shoal Lakes.

The designs have also considered the incorporation of a perimeter drain along the outside toe of the spoil embankment. The design of the perimeter drain has been based on MIT's standard design criteria for drainage channels and KGS Group's experience with the type of soil materials along the alignment of the channels. The preliminary design criteria for the perimeter drains include:

- A trapezoidal channel section with base width of 1 m and depth of 1 m
- Side slopes of 1 vertical on 3 horizontal
- Minimum setback distance of 3 m (from toe of the spoil dike)

The large drop in the land elevation in the lower one-third length of each channel between the ridge and Lake Manitoba required a number of drop structures to limit the flow velocities in this reach. The purpose of the drop structures is to allow the dissipation of the energy to prevent erosion of the soil in the channel bed. The least expensive alternative for the drop structures using riprap for the drop structures have been selected for all the three flood channel options. Riprap drop structures are defined as short channel reaches of the drain (10 to 15 metres in length) that have a steep gradient and a vertical elevation drop of 1.0 m or 1.5 m in the channel bed.

Road crossings for this study were designed as corrugated steel pipe culverts with projecting type inlets. Design discharges for the determination of the culvert sizes consisted of the diversion flow with a peak diversion flow of 10 $m^3/s$ plus the runoff from the local drainage to the channel. The local flow component was selected as the 2% flood for Provincial Trunk Highways

(PTH) and the 3% flood for Provincial Roads (PR) and Municipal roads. The culverts were sized to convey the design flow with the headwater level at or below the top of the culvert under inlet control conditions and a maximum headloss of 0.3 metres under outlet control conditions

A manually operated gated control structure was assumed at the upstream end of each channel alternative at West Shoal Lake, in order to control the flow entering the diversion channel. The control structure for each alternative would consist of an undershot radial gate structure having 2 bays (each 3 m wide) and 2 gates (each 3m x 2.2m). The structure would be fully opened when West Shoal lake levels are above the target levels. The gates would be closed fully if the lake levels drops below the target levels to prevent the diversion of flow from the Shoal Lakes system. The elevation of the upstream end of the channel was chosen elevation 258.0 m to coincide with the elevation of the West Shoal lake bottom at the diversion location.

Interconnecting channels between both the North Shoal Lake and East Shoal Lake and between East Shoal Lake and West Shoal Lake were also incorporated in the design of the diversion channel alternative. The elevation of the lake bottom near the shoreline governed the design invert levels of the interconnecting channel. Stage discharge relationships for each of the interconnecting channels are shown in Figures 4.2 and 4.3. These stage discharge relationships are formed of a series of relationships that relate the discharge through the channel, in either upstream or downstream direction, based on the water level in both the upstream and downstream lakes. The water level for the upstream lake is shown on the y-axis and the water level on the downstream lake is represented by the series of blue lines.

An invert of El. 258.0 m was selected for the interconnecting channel between North Shoal Lake and East Shoal Lake, while the invert level of the interconnecting channel between East Shoal Lake and West Shoal Lake was selected as El. 257.0 m. A gated control structure was assumed for the channel between North and East Shoal Lakes. This gated control structure would be similar to that as described above between the West Shoal Lake and the diversion channel, but would consist of only one 3 m wide bay. The purpose of the control structure was to limit outflows from North Shoal Lake to only when the target level on North Shoal Lake was exceeded.

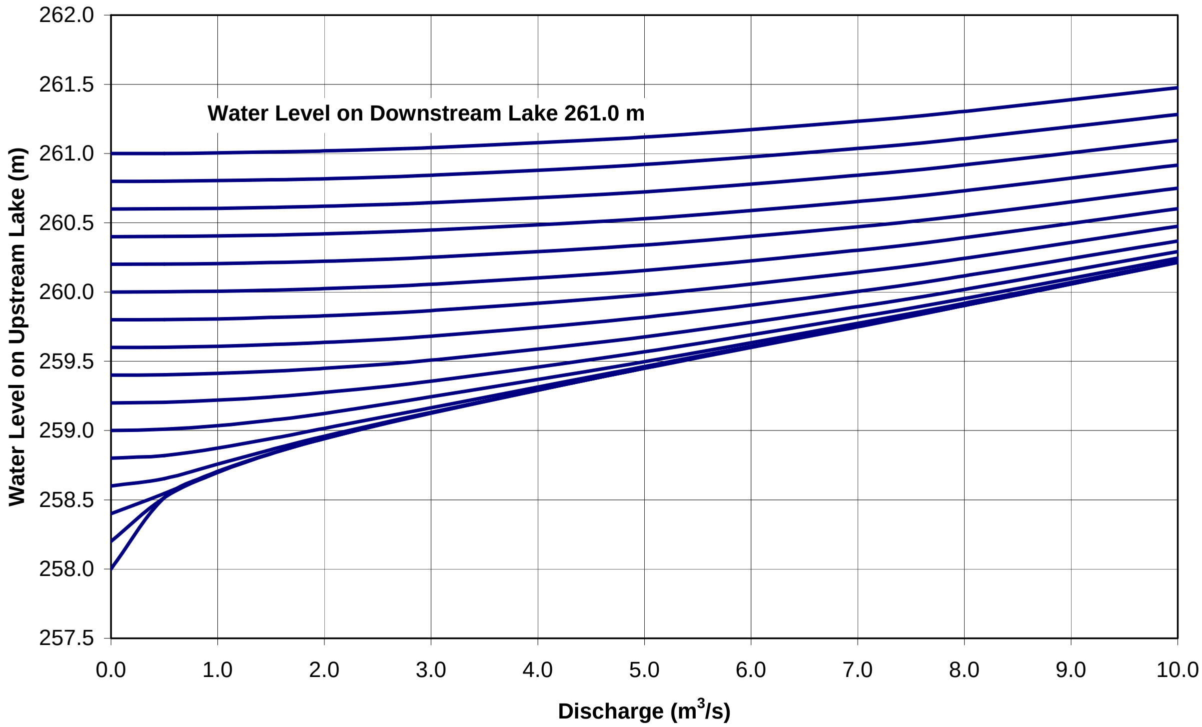


**Figure 4.2 –Stage-Discharge Relationship for Interconnecting Channel between the North and East Shoal Lakes**

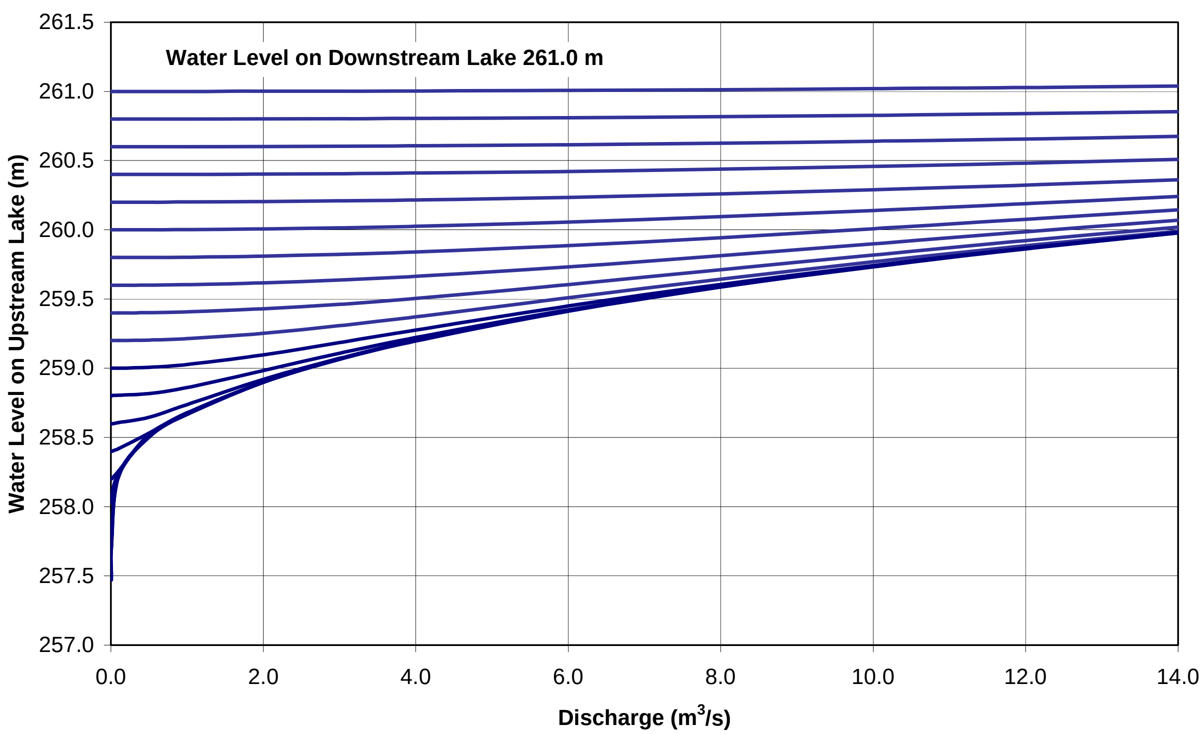


**Figure 4.3 – Stage-Discharge Relationship for Interconnecting Channel between the East and West Shoal Lakes**

Optimization of the geometry for the discharge channels was not undertaken as part of this study, however, should the flood diversion channels be selected for further study, an optimization review should be carried out to determine the most cost efficient bed elevation, design discharge capacity and target elevation on the lakes.

### 4.2.3 Design Description of Channels

A variety of channel profiles and combination of drop structures were assessed for each flood diversion channel option to develop an optimum configuration, based on the data at hand. The relative cost of excavation of the in-situ soils materials governs the optimum channel configuration. The assumed unit price for excavation was assumed to be $5.50/m³, based on KGS Group's interpretation of the soils from existing soil maps, as well as our knowledge of the soil conditions in the area. Test excavations to confirm soil conditions are recommended for the next level of study to confirm the estimated unit price.

The dominant factors that govern the channel design parameters:

- The ridge near the Shoal Lakes that lies in the upper two-third length of each flood diversion channel
- The steep slope of the land between the ridge and Lake Manitoba, which requires a number of riprap drop structures.

The final design of the channel was based on standard-step backwater calculations using a Manning's n-value of 0.03 for the channel bed. The assumed roughness value is representative of well-maintained grass-lined channels, (i.e. mowed), as well as representative of snow-flattened vegetation. The latter condition could occur in the spring runoff season if the vegetation had not been cut in the previous growing season. The velocity of flow and the depths of water within the channels associated with the design flows, as well as the flow conditions through the culverts and over the drop structures were determined with the use of the MIKE 11 model.

The model "MIKE 11" was developed by DHI Water and Environment for the modelling of rivers and channels. The model has the following capabilities, which make it a suitable modelling tool for the flood channels upgrade design for this study:

- MIKE 11 is a 1D model that can model both steady and unsteady state flow conditions
- The model can solve water levels in channels under subcritical and supercritical flow conditions
- The model can simulate flow through complex control structures

Specific design details for each of the diversion channel alternatives are summarized in the following sub-sections. Optimization of each channel design has not been carried out in this study; however, it should be considered should this project proceed to subsequent stages of design.

***Design Description of Wagon Creek – Option A Diversion Channel***

The alignment for Option A consists of a diversion channel along Wagon Creek, this channel is approximately 25.5 km in length, as shown in Figure 4.4. The profile shows the existing ground level along the channel, the channel invert, and the design water level associated with the discharge capacity of 10 $m^3/s$ when the water level on West Shoal Lake is above the target elevation. Typical cross sections in the lower and upper reaches of the diversion channel are shown on Figures 4.5 and 4.6.

The depth of flow in the diversion channel at the design flow is typically 2.2 metres with a velocity ranging from 0.35 m/s to 0.45 m/s along the upstream reach of the channel. The depth of flow decreases to about 1.5 m along the steep downstream portion of the channel with a velocity of 0.65 m/s between the drop structures and 0.75 m/s over the drop structures.

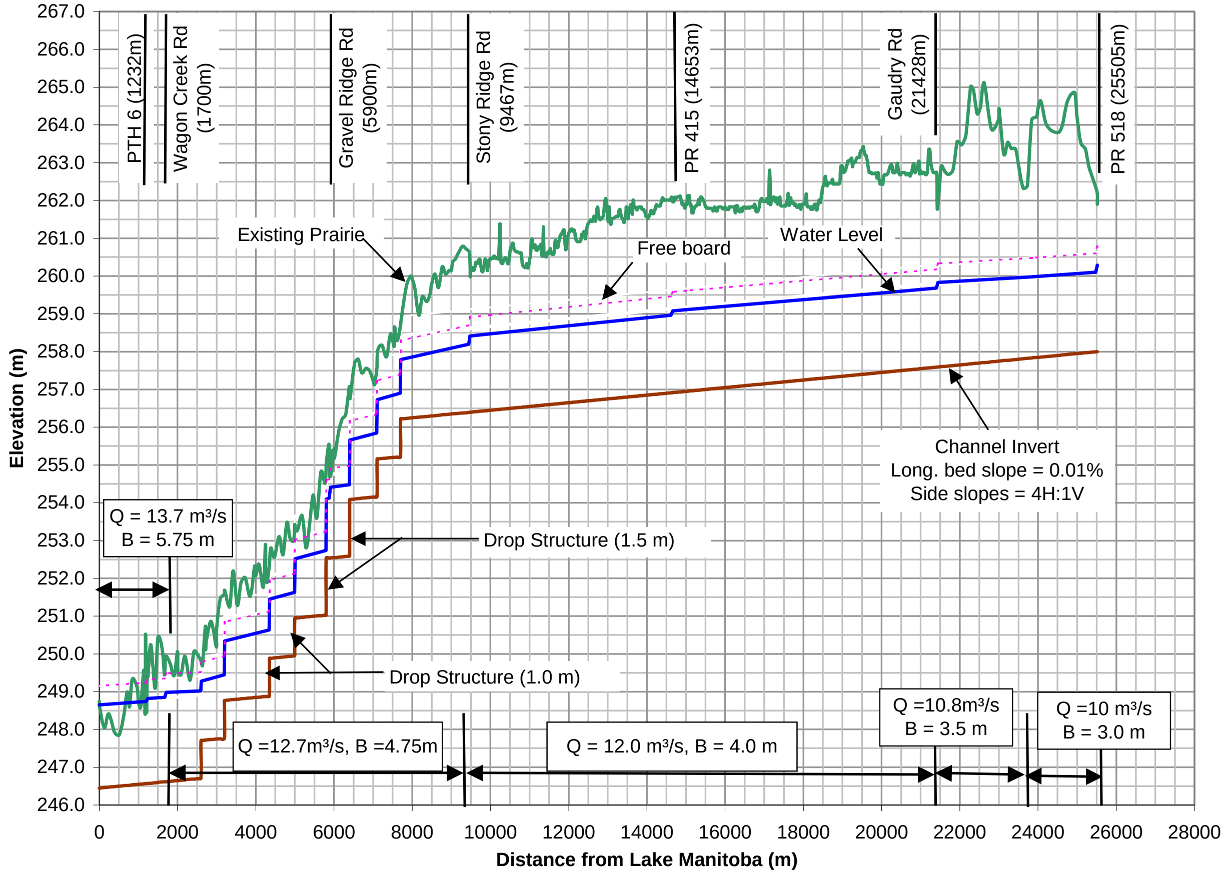


**Figure 4.4 – Profile for Wagon Creek – Option A**

As shown in Figure 4.4, the maximum depth of excavation is up to 8 metres in some areas. The total drop in the water level elevation from West Shoal Lake to Lake Manitoba is 12 metres. The downstream 8 km includes a total drop of about 9.5 metres, which requires the use of eight drop structures ranging in height between 1.0 and 1.5 metres.

A total of seven road crossings are required along channel for the Wagon Creek – Option A channel alignment. A design summary of the crossings is provided in Table 4.1.

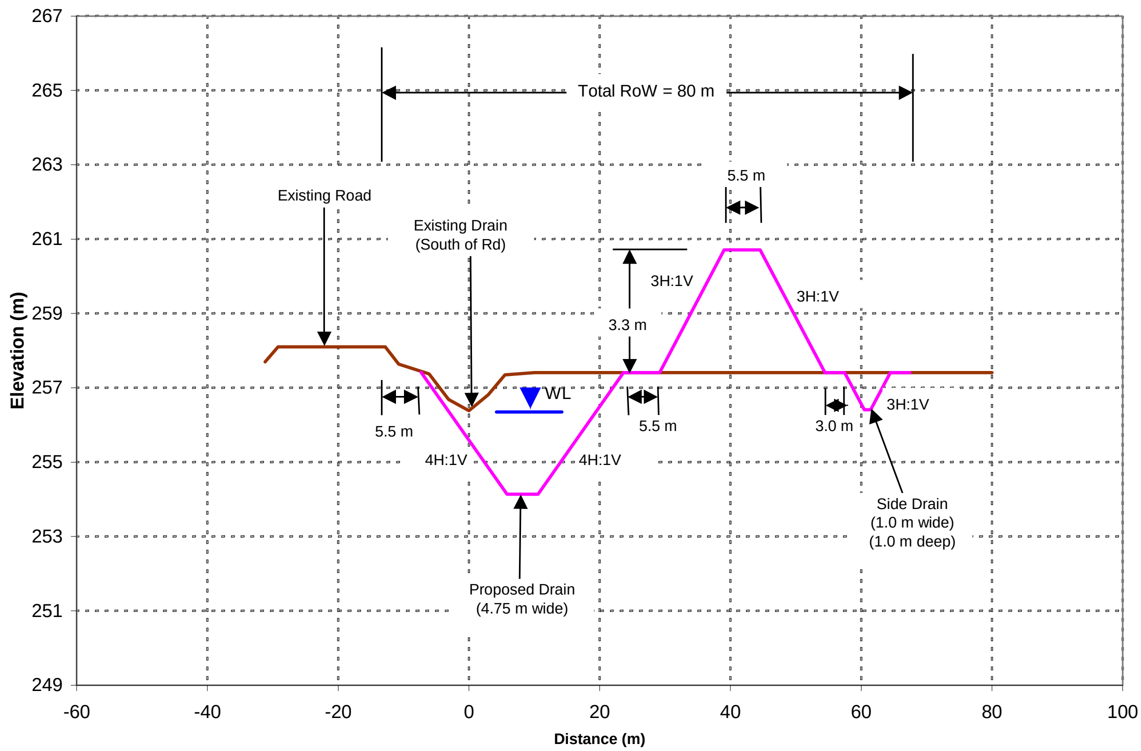


**Figure 4.5 – Typical Cross Section in Lower Reach of Wagon Creek Option A Diversion Channel**

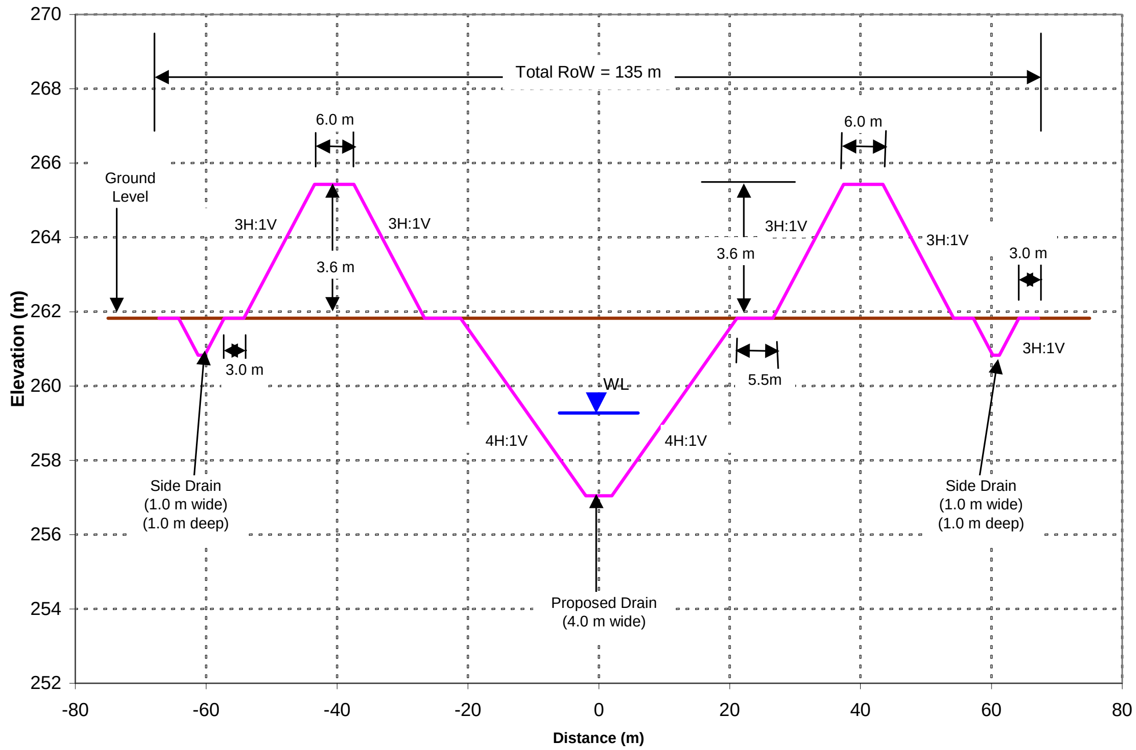


**Figure 4.6 – Typical Cross Section in Upper Reach of Wagon Creek Option A Diversion Channel**

**TABLE 4.1**
**CULVERT CROSSINGS FOR WAGON CREEK – OPTION A**

| Road Crossing | Design Flow ($m^3/s$) | Culvert Size | | | Velocity (m/s) | Headloss (m) |
|---|---|---|---|---|---|---|
| | | Number of Barrels | Diameter (m) | Length (m) | | |
| PR 518 | 10.0 | 2 | 2.0 | 20 | 1.5 | 0.3 |
| Gaudry Rd | 12.0 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| PR 415 | 13.7 | 3 | 2.0 | 30 | 1.5 | 0.3 |
| Stony Ridge Rd | 12.7 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| Gravel Ridge Rd | 12.7 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| Wagon Creek Rd | 13.7 | 3 | 2.0 | 15 | 1.6 | 0.3 |
| PTH 6 | 18.6 | 4 | 2.0 | 30 | 1.5 | 0.3 |

***Design Description of Wagon Creek – Option B Diversion Channel***

A profile of the diversion channel along Wagon Creek – Option B alignment is shown in Figure 4.7, covering a distance of approximately 29.1 km. Figure 4.7 shows the existing ground level along the channel, the channel invert, and the design water level. Typical cross sections of the diversion channel for Option B are the same as those for Option A shown in Figures 4.5 and 4.6.

The depth of flow in the diversion channel for Option B is similar to that of Option A ranging from 1.5 m to 2.2 metres with a velocity ranging from 0.35 m/s in the upper reaches of the channel to 0.75 m/s over the drop structures.

As shown in Figure 4.7, the maximum depth of excavation of up to 8 metres is required. The total drop in the water level from West Shoal Lake to Lake Manitoba is 12 metres, which includes a total drop of about 9.5 metres in the downstream 7.8 km. Eight drop structures ranging between 1.0 and 1.5 metres drop each are required.

There are a total of seven road crossings along the alignment of Wagon Creek – Option B channel. A design summary of the crossings is provided in Table 4.2.

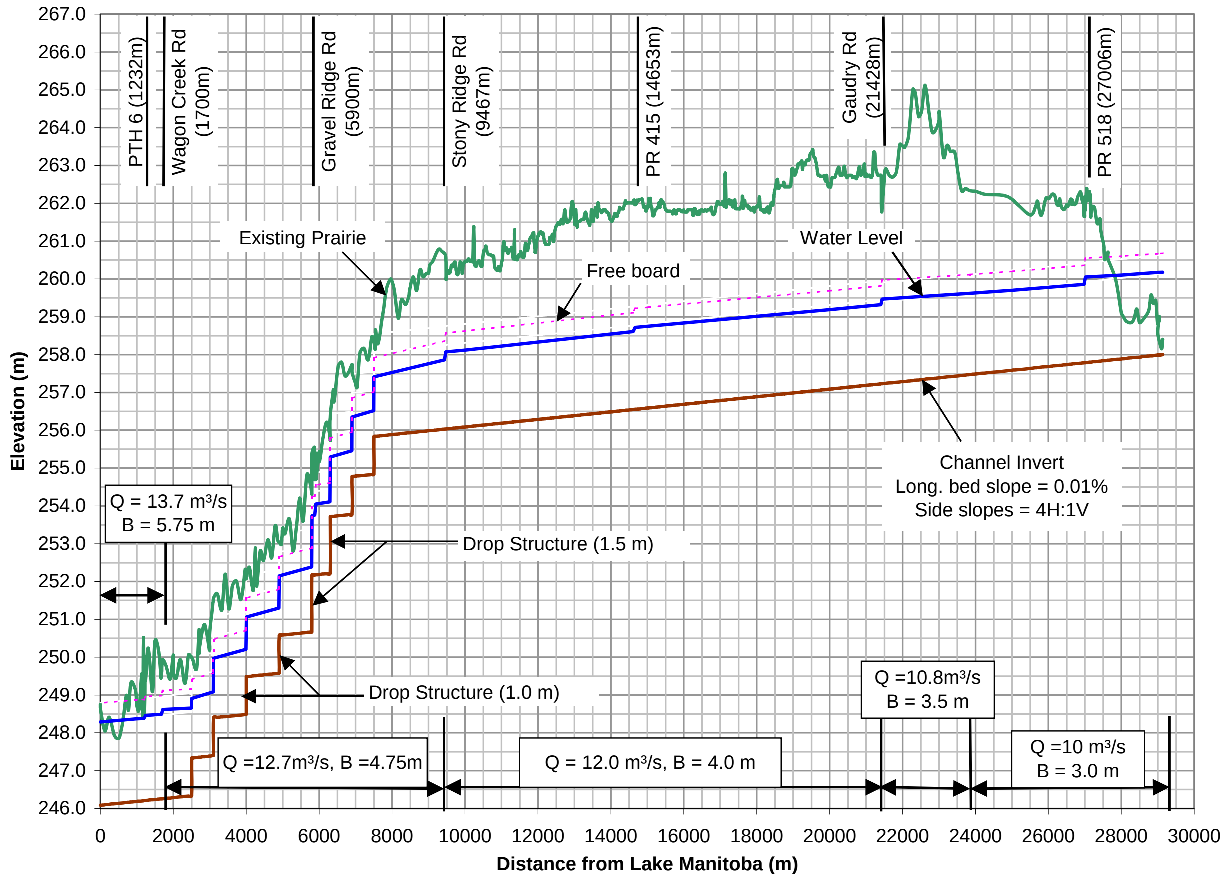


**Figure 4.7 – Profile for Wagon Creek – Option B**

## TABLE 4.2
## CULVERT CROSSINGS FOR WAGON CREEK – OPTION B

| Road Crossing | Design Flow ($m^3/s$) | Culvert Size | | | Velocity (m/s) | Headloss (m) |
|---|---|---|---|---|---|---|
| | | Number of Barrels | Diameter (m) | Length (m) | | |
| PR 518 | 10.0 | 2 | 2.0 | 20 | 1.5 | 0.3 |
| Gaudry Rd | 12.0 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| PR 415 | 13.7 | 3 | 2.0 | 30 | 1.5 | 0.3 |
| Stony Ridge Rd | 12.7 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| Gravel Ridge Rd | 12.7 | 2 | 2.2 | 15 | 1.6 | 0.3 |
| Wagon Creek Rd | 13.7 | 3 | 2.0 | 15 | 1.6 | 0.3 |
| PTH 6 | 18.6 | 4 | 2.0 | 30 | 1.5 | 0.3 |



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### *Design Description of Roy's / Boundary Drain Diversion Channel*

A profile of the diversion channel along Roy's / Boundary Drain alignment, which is approximately 17.8 km in length, is shown in Figure 4.8. This profile shows the existing ground level, the channel invert, and the design water level. Typical cross sections of the diversion channel in the lower and upper reaches are shown in Figures 4.9 and 4.10, respectively.

The depth of flow in Roy's / Boundary Drain diversion channel is similar to that of the Wagon Creek alternative and ranges from 1.5 m to 2.2 metres with a velocity of 0.35 m/s in the upper reaches of the channel and 0.75 m/s over the drop structures.

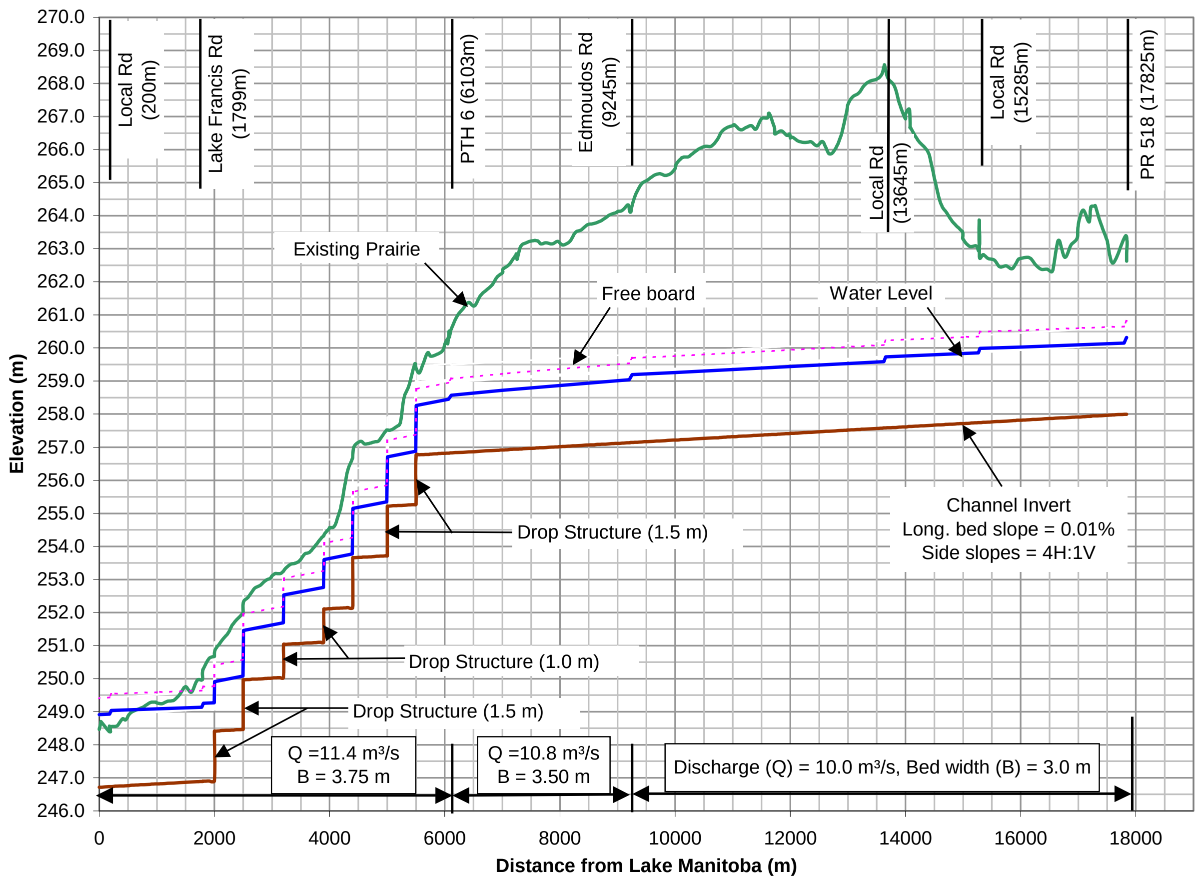



**Figure 4.8 – Profile for Roy's / Boundary Drain Option**

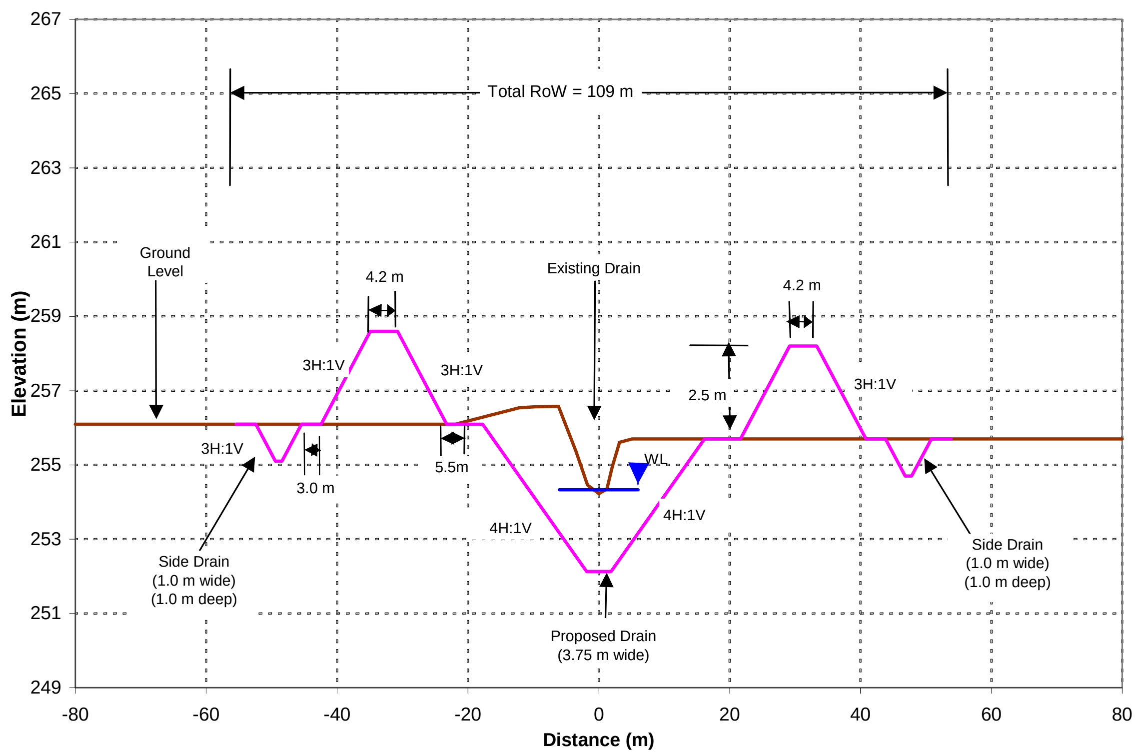



**Figure 4.9 – Typical Cross Section in Lower Reach of Roy's / Boundary Drain Diversion Channel**

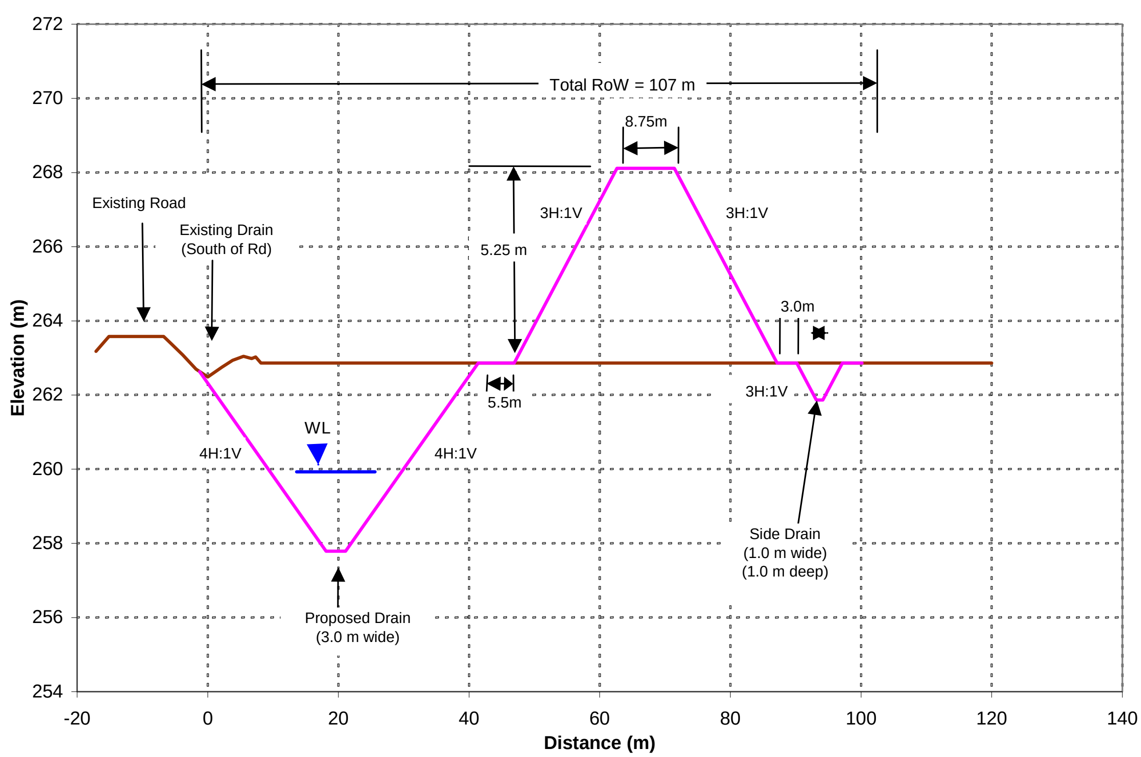



**Figure 4.10 – Typical Cross Section in Upper Reach of Roy's / Boundary Drain Diversion Channel**

As shown in Figure 4.8, the maximum depth of excavation of up to 11 metres is required to convey the flow by gravity. The total drop in elevation from West Shoal Lake to Lake Manitoba is 11.5 metres, which includes a total drop of about 10 metres in the downstream 5.5 km. Seven drop structures ranging in height of between 1.0 and 1.5 metres are required.

A total of seven road crossings are required along the alignment of the Roy's/Boundary Drain channel. A design summary of the crossings is provided in Table 4.3.

**TABLE 4.3**
**CULVERT CROSSINGS FOR ROY'S/BOUNDARY DRAIN OPTION**

| Road Crossing | Design Flow ($m^3/s$) | Culvert Size | | | Velocity (m/s) | Headloss (m) |
|---|---|---|---|---|---|---|
| | | Number of Barrels | Diameter (m) | Length (m) | | |
| PR 518 | 10.0 | 2 | 2.0 | 20 | 1.5 | 0.3 |
| Local Rd | 10.0 | 2 | 2.0 | 15 | 1.6 | 0.3 |
| Local Rd | 10.0 | 2 | 2.0 | 15 | 1.6 | 0.3 |
| Edmoudos Rd | 10.8 | 2 | 2.2 | 30 | 1.5 | 0.3 |
| PTH 6 | 13.1 | 3 | 2.0 | 30 | 1.5 | 0.3 |
| Lake Francis Rd | 11.4 | 2 | 2.2 | 15 | 1.7 | 0.3 |
| Local Rd | 11.4 | 2 | 2.2 | 15 | 1.7 | 0.3 |

## 4.3 INCREASED UPSTREAM STORAGE

### 4.3.1 Design Considerations

As part of the assessment of flood mitigation alternatives for the Shoal Lakes, increased upstream storage was considered.

The design of increased upstream storage was based on the following design considerations:

- Storage sites are situated in low lying areas that allow storage based on topography
- Since limited detailed topography is available and due to the relatively flat terrain in the uplands of the Shoal Lakes, it was assumed that the storage sites could capture one metre depth of storage over the assumed storage area.
- No consideration to landowner / land type
- No perimeter dyking was assumed to be required, i.e. use the land topography.
- Channels would be constructed or existing channel would be upgraded from the storage area to the Shoal Lakes to allow the flow of water from the storage areas to the lakes.
- A gated outlet structure was assumed for each storage area with
  - 1 m diameter culvert
  - Earthfill dam with concrete headwall
  - Manual operated screw gate

### 4.3.2 Description of Upstream Storage Areas

Due to the topographic relief in the uplands of the Shoal Lakes watershed, few areas lend themselves to the creation of upland storage areas. Five areas have been identified and considered as upland storage areas and are shown on Plate 10. A summary of the surface area and total storage capacity of the storage areas is provided in the Table 4.4.

**TABLE 4.4**
**SUMMARY OF UPLAND STORAGE RESERVOIRS**

| Storage Area Name | Lake Contributing to | Surface Area (ha) | Storage Volume ($m^3$) |
|---|---|---|---|
| E1 | East Shoal Lake | 350 | 3,450,000 |
| E2 | East Shoal Lake | 120 | 1,190,000 |
| W1 | West Shoal Lake | 850 | 8,520,000 |
| N1 | North Shoal Lake | 240 | 2,390,000 |
| N2 | North Shoal Lake | 120 | 1,150,000 |

## 4.4 PURCHASE OF FLOOD PRONE LANDS

### 4.4.1 Design Considerations

The purchase of flood prone lands was considered as a flood mitigation alternative, as prescribed in the RFP, as a means of reducing flood damages by buying out any property that could be affected by flooding.

The purchase of flood prone lands adjacent to the Shoal Lakes was based on the following criteria:

- Land would be purchased if the property is affected by the highest recorded flood level (for the period from 1977 to 2010). In addition, to consider the potential for increased water levels, above the peak experienced within the period of record, all property within a buffer zone equivalent to 0.6 m in elevation above the peak recorded water level was also considered for the land purchase.
- No dividing of land parcels / properties

Land that would be purchased as part of this flood mitigation option could be leased back to the local farmers in periods of low water level, or alternatively could be converted into a Wildlife Management Area. The end use of any land purchased would have to be determined by the various levels of government involved as well as the various stakeholders involved. The definition of the end use of the purchased land was not part of the scope of this study.

The 0.6 m buffer zone above the 2010 peak water level was estimated based on the digital elevation model described in Section 2.2, and was based on the available information at the time of the study. Ground truth surveys of the land adjacent to the high water levels were not completed as part of this study. It would be recommended, should the purchase of flood prone lands option be selected for further study that a survey program be carried out to confirm the extents of the area encompassed by the 0.6 m buffer zone above the 2010 peak water level.

No consideration has also been included in this assessment to address the potential for viability of those landowners for which only a portion of their land would be purchased under the buyout. Quantification of these considerations would require an in-depth socio-economic analysis, which was not defined as part of this study.

### 4.4.2 Description of Land Required for Purchase

Land ownership maps for the R.M. of St. Laurent, the R.M. of Armstrong, the R.M. of Woodlands and the R.M. of Coldwell were used to determine land ownership (privately owned lands, leased crown lands or crown lands) and the number of owners or lessees in and around the Shoal Lakes. The Government of Manitoba – Property Assessment website [Manitoba 2010] was used to determine the numbers, locations of any buildings, as well as the current values of the properties/buildings for use in the cost estimation as described in Section 6.0.

The total area of the properties and types of properties that would be affected by flooding are listed in Table 4.5 and shown graphically on Plate 11. The total area includes only full properties that are affected by flooding as outlined in Section 4.4.1, and does not consider the sub-division of property area if only a portion of the property is flooded. Sub-division of lands would reduce the total number of hectares that would be required to be purchased but there would be increased legal costs to sub-divide the properties.

The first column of the Table 4.5 provides a summary of the total privately owned land that would have to be purchased, as well as the number of owners and the number of properties with at least one building. The second and third columns show the number of hectares of crown land, of which about one third of the crown land is leased by a total of 39 lessees.

Changes to the lease terms associated with the leased crown land have not been considered in this assessment, since the end use of the land is uncertain at this time and would require involvement by the various levels of government involved as well as the various stakeholders involved. However, should the option of land purchase be considered for further study, the terms of the leases and changes to those leases should be considered.

**TABLE 4.5**
**PURCHASE OF FLOOD PRONE LANDS**

| Privately Owned Lands | Leased Crown Lands | Crown Lands | Total |
|---|---|---|---|
| 16,893 ha | 8,819 ha | 16,809 ha | 42,521 ha |
| 117 Owners | 39 Leases | | |
| 54 Properties with at least 1 building | | | |

# 5.0 HYDROLOGIC / HYDRAULIC MODEL OF SHOAL LAKES

## 5.1 SELECTION OF HYDROLOGIC/HYDRAULIC MODEL

The selection of the hydrologic model has been based partly on the quality of the data available. As noted in Section 2.2, there is little recorded information available in the Shoal Lakes watershed that defines the precipitation, runoff, stream flow, groundwater flow, and evaporation.

Commonly used computer software that could be used to model the hydrology of the Shoal Lakes includes HEC-HMS or the hydrology component of MIKE11. These watershed models compute runoff based on the hydrologic processes in a watershed. The modelled flows are then compared to measured flows on a watercourse. This then allows parameters in the model to be adjusted so that the modelled flows are either increased or decreased to match the recorded flows. Additional inflow, aside from runoff due to precipitation, are typically much smaller and are not included in the runoff estimate within the model or they are sufficiently small compared to the runoff volume and can be neglected. Or if those other inflows are included, the error in the estimate of the parameter is not that important when compared to the runoff.

In the case of the Shoal Lakes watershed, direct runoff from the catchment is not measured and occurs as inflow from numerous local swales. The inflow sources that are minor in most watersheds (precipitation, evaporation, groundwater inflow) are the dominant sources of inflow for Shoal Lakes. A review of the available precipitation data at the Atmospheric Environment Services (AES) station in Grosse Isle, evaporation at Portage la Prairie, and the recorded lake levels on the Shoal Lakes, indicated that there was no clear relationship between the three components.

The application of a runoff model for the Shoal Lakes watershed is complicated by the fact that runoff during the winter season is less certain. Much of the precipitation that falls in the form of snowfall accumulates during the winter season and occurs as runoff only during the snowmelt period. The runoff model for snowmelt has a number of additional parameters that affects the amount of runoff including antecedent basin conditions in the late summer and autumn period, the depth of frost based on snow cover and air temperature during the snowmelt period, of which each of these parameters would vary from year to year.

The change in water level in the Shoal Lakes occurs only as a response to the net inflow as the difference between the outflow source, mainly evaporation and all inflow sources including precipitation, runoff, and groundwater inflow. As previously noted, runoff is not measured in the watershed and the runoff to the Shoal Lakes can be highly variable, both during the year and for succeeding years. Seasonably, winter precipitation in the form of snow runs off in the spring snowmelt period, the timing of which depends on the air temperature. Runoff timing due to snowmelt of the accumulated winters' snowfall would be difficult to estimate with any reliability. Antecedent conditions that occurred in the previous year would have to be estimated for the snowmelt runoff estimate. In addition estimated runoff from precipitation would require an accounting of the antecedent moisture conditions prior to the rain event.

The determination or separation of the inflow sources could only be done using the observed water levels on each lake in the Shoal Lakes complex. Water levels on Shoal Lakes, by themselves, however, are not that reliable for this purpose. As noted in Section 2.2, water levels on North Shoal Lake have been observed almost continuously since 1977, however water levels on the East and West Shoal Lakes have only been observed since 1999 and even then they are sporadic recordings. A continuous water level hydrograph for each of the three lakes has been estimated based on interpolation and correlation (further discussed in Section 5.2) of the known water level record. The use of water levels to calibrate the model for missing input values is therefore judged to have a significant error in the estimate of the value of each of the model variables.

Due to the complex nature of the Shoal Lakes relative to the various inflow and outflow components described above, the determination of input parameters for a watershed model is therefore judged to be difficult to apply to the Shoal Lakes with any degree of accuracy.

Use of the HEC-HMS or MIKE11 was therefore discounted for this study. Rather the model that was considered and adopted for this study was an in-house computer model written specifically for the Shoal Lakes using inflow-available for outflow computed from observed and estimated water levels on Shoal Lake. The reservoir routing model is a continuous reservoir routing model based on combining all inflow and outflow sources into one term called net inflow or inflow available for outflow. This net inflow is computed from recorded changes in lake levels over a given time period and defined reservoir storage curves. This model routes the inflow and outflow through the lakes to determine the change in lake level and does not require that inflow sources such as precipitation, runoff, infiltration and evaporation be explicitly known.

Another component of the daily routing model that is important to Shoal Lakes is how the model would determine the exchange of flow between each of the lakes. Due to the closeness in the water levels on each of the lakes, the outflows from each lake occur, for the most part, under conditions of backwater from the downstream lake. Under certain circumstances, disproportionate outflow can have a reversal of flow occurring with flow being transferred from the downstream lake to the upstream lake. The commercially available programs (HEC-HMS and MIKE11) do not have the capability of handling these backwater outflow relationships and flow reversal conditions. The daily flood routing program used in this study was written specifically to handle these situations and is the only model available to do so.

## 5.2 OVERVIEW OF SHOAL LAKES WATER BALANCE MODEL

### 5.2.1 Model Overview and Description

As noted in Section 5.1, the model that was adopted for this study was a continuous reservoir routing model of the Shoal Lakes that was based on Inflow-Available-for-Outflow or IAO. For this model, an inflow cycle was developed based on the principle that the net inflow, defined by the rate of change in the total of all inflow and outflow sources, is equal to the rate of change in the reservoir storage. The reservoir storage used in the model was determined from stage-storage curves developed from lake surface area relationships. The bathymetry of each of the Shoal Lakes, defined by four cross sections per lake as described in Section 3.3, was used to define the storage in the lakes. Figure 5.1 shows the stage storage curves that were adopted for each of the lakes.

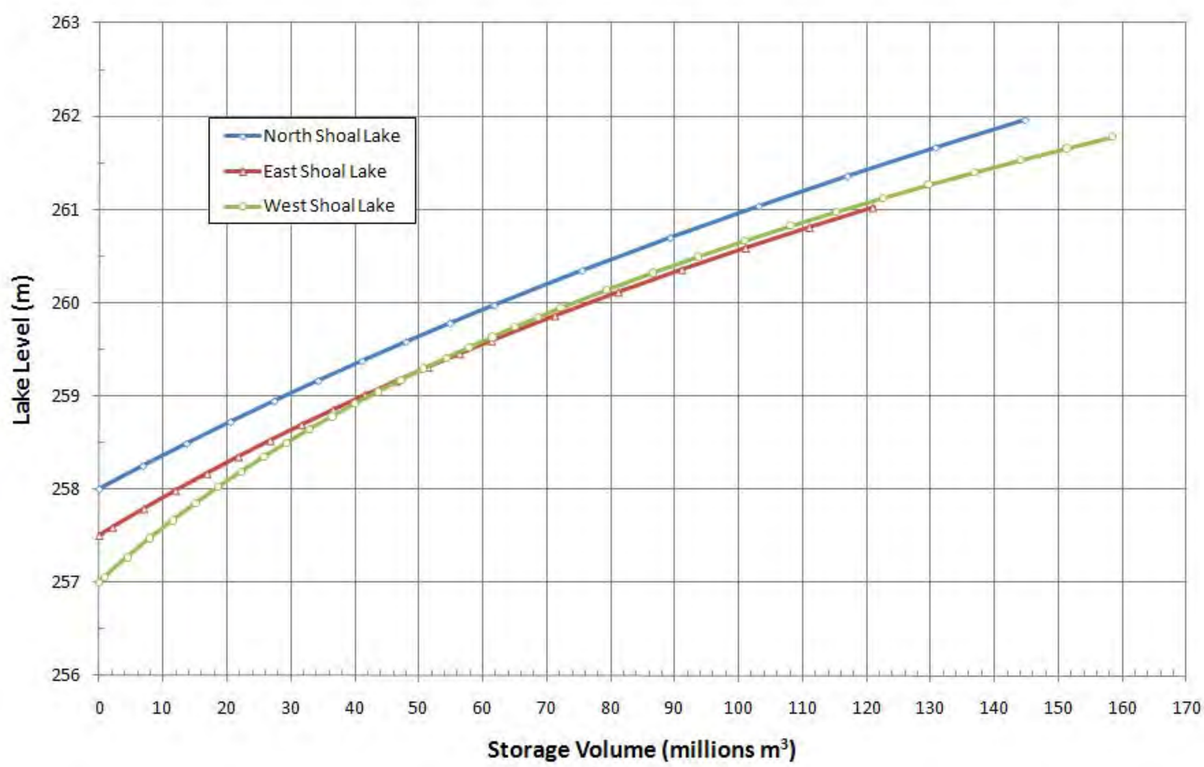



**Figure 5.1– Shoal Lakes Stage-Storage Relationships**

As shown on Figure 5.1, the bottom of each the North, East, and West Shoal Lakes are El. 258.0 m, El. 257.5 m, and El. 257.0 m, respectively. It can also be shown that one metre of storage between El. 260 m and El. 261 m on all three lakes is approximately 124 million cubic metres.

The net inflow in this routing method is referred to as the Inflow-Available-for-Outflow or IAO. When used in conjunction with the reservoir storage curve (Figure 5.1), only the observed rate of change in water level over time is required to determine the net inflow. This method is a preferred method of analysis when only the lake level is known, because the individual components of the inflow and outflow are not measured nor do they have to be determined. This fact, as noted in Section 5.1, eliminates any potential errors in the estimates of each hydrologic component.

Reservoir routing is typically based on the conservation of mass principle, which states:

$$I_{(t)} - O_{(t)} = dS/dt$$ *Equation 1*

Where:

$I_{(t)}$ is equal to the Inflow as a function of time

$O_{(t)}$ is equal to the outflow as a function of time

dS/dt is equal to the change in storage as a function of time

In Equation 1, inflow includes stream flow runoff from the surrounding watershed, groundwater inflow and precipitation in the form of rainfall and snowfall. Since there were no outlet channels from the complex for the water levels that have been experienced, the outflow is comprised of evaporation from the surface of the lakes and transpiration from marsh vegetation, as well as, groundwater infiltration.

As noted in Section 5.1, since neither inflow (runoff, precipitation, groundwater infiltration) nor outflow (evaporation) is known explicitly, the solution to the standard routing formula for the Shoal Lake complex (Equation 1) is indeterminate. For that reason it is considered to be less uncertain to combine all the inflow and outflow parameters into one parameter referred to as IAO. The routing equation therefore becomes:

$$IAO = dS/dt$$ *Equation 2*

The change in storage (dS/dt) can be determined from the change in lake level for a given period of time and using lake storage curves developed from lake bathymetry to produce the IAO sequence.

The recorded water levels shown in Figure 2.1 were used to define the historic lake levels. However, the water level record was not continuous for the entire period of record from 1977 to 2010. Water levels on North Shoal Lake have been observed continuously on a monthly basis from 1976 to 1992 and from 1996 to 2006. Between 1992 and 2006, only discontinuous water levels were available. The discontinuous water level measurements for North Shoal Lake levels were used to estimate a continuous record from 1992 to 1996 by interpolation between measured values.

The water levels on the East and West Shoal Lakes have been observed on a monthly basis from 1999 to 2010. No data for these lakes was recorded for the period prior to 1999. The recorded data from the period from 1999 to 2007 was used to create a correlation relationship between the historic North Shoal Lake levels with those for the East and West Shoal Lake levels for that period. The relationship was then used to estimate the historic lake levels on East and West Shoal Lakes between 1977 and 1999 using known water levels on North Shoal Lake. The discontinuous record between 1999 and 2007 was used to estimate a continuous water level record in the same manner as for North Shoal Lake described above. The complete record of water levels that was adopted for use in this study and for the determination of the IAO for the period from 1977 to 2010 is presented in Figure 5.2.

The computed total monthly mean IAO sequence was derived from the historic (recorded and estimated) water levels for all the Shoal Lakes is shown in Figure 5.3. The IAO forms the basis for all the water level calculations in the model of the Shoal Lakes for both the simulation of the existing conditions and each of the alternative diversion channels.

As illustrated on Figure 5.2, the historic Shoal Lake levels have exhibited a dry and wet cycle. For this study, the computed sequence of water levels based on historical levels was assumed to be representative of the future hydrologic cycle that could occur on Shoal Lakes. This sequence of water levels was used to compare the change in water levels on the lakes associated with the incorporation of the flood mitigation measures to those that would be associated with the flood mitigation alternatives. The dry and wet cycle that has historically occurred will represent effects of the flood mitigation measures both in the extreme wet and extreme dry conditions, which is considered to represent the worst conditions that could occur in the future. If the water level trend were less severe than historically occurred, the effects of the flood mitigation measures would be lessened.

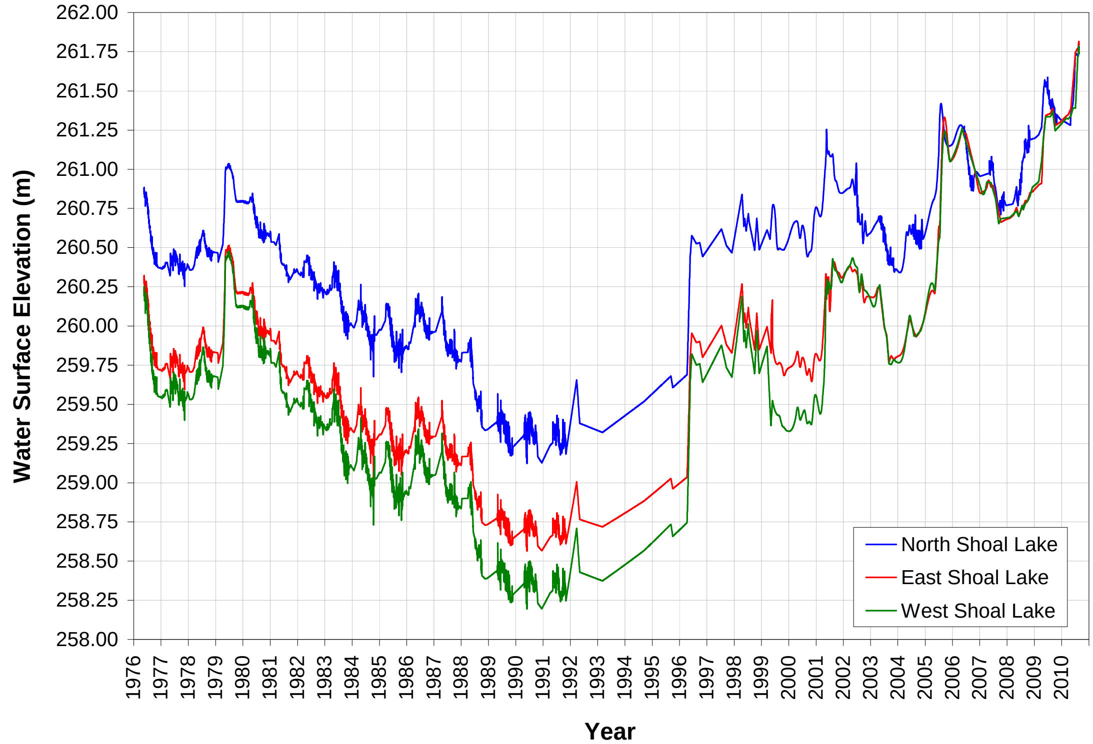



**Figure 5.2 – Adopted Historic Water Levels on the Shoal Lakes (1977 to 2010)**

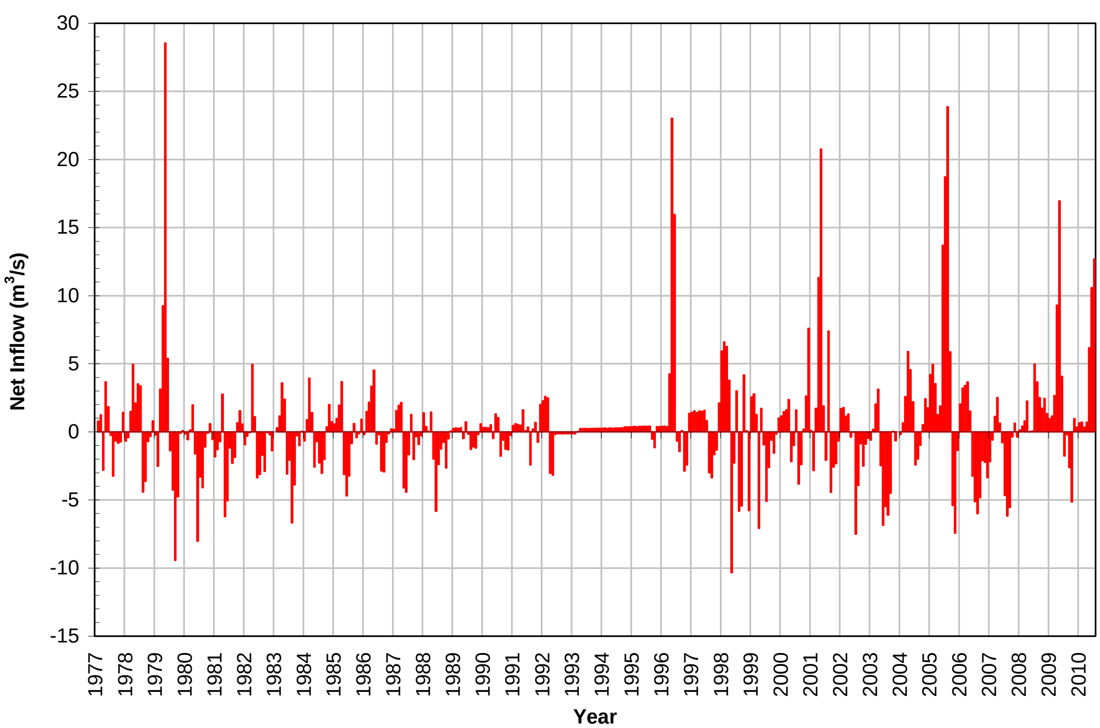



**Figure 5.3 – Monthly Inflow Available for Outflow**

The basis of the computations for the simulations of natural conditions and for the simulations with the excavated channels between the lakes and the diversion channels from West Shoal Lake was the iteration of the water levels on each of the lakes on an hourly time step by trial and error with the given IAO to that lake. The total inflow to each lake includes not only the IAO for the time period under review but also flow that occurs from the upstream and downstream lakes computed from the stage discharge rating curves for the iterated water levels.

The difference between total inflow from the lakes and the computed outflows in a given time step based on assumed lake water levels is equal to the change in storage at the end of the time step for each lake. The end of period storage based on assumed water levels was then used to solve for the end of period water level from the stage-storage curve for each lake. The water level iteration was solved when the assumed end of period water level agreed with the computed end of period water level, within the specified tolerance for the solution of the water level iteration.

Since the lakes are generally a land-locked system, evaporation rates dictate the amount of change in the lake levels during periods of drought. Under most reservoir routing analyses, the reduction in lake surface area is small and the lake level variation do affect the estimated IAO. The normal modelling approach uses the assumption that the relative surface areas of the lakes do not vary significantly. This, for the Shoal Lakes, is not the case. Due to the shallow depths of water on the lakes, changing levels of the lakes (historically up to 3 metres) produces significant changes in the surface area of the lake. The variation of the surface area will affect the magnitude of the IAO for the same time step if the water levels in the lake are different from natural.

To account for the effects of this changing lake surface area, the computed IAO was adjusted using the daily evaporation for Shoal Lakes as described below. The IAO was corrected for the reduced evaporation based on the change in surface area from the corresponding natural level times the known evaporation for that day using computed evaporation rates for Portage la Prairie. A relationship that illustrates the surface area of each lake relative to the water surface elevation is shown in Figure 5.4.

The correction to the IAO considered the fact that not all the change in the water level could be attributed to evaporation. Monthly evaporation rates for June, July and August were compared with the change in lake level that occurred under natural condition. The summer months were chosen for this comparison since the effect of groundwater flow and runoff would be small when evaporation rates were highest compared to the spring and fall periods when runoff would more likely to be predominate in the IAO. Figure 5.5 shows the percentage change to lake level that has been related to evaporation based on the period of record.

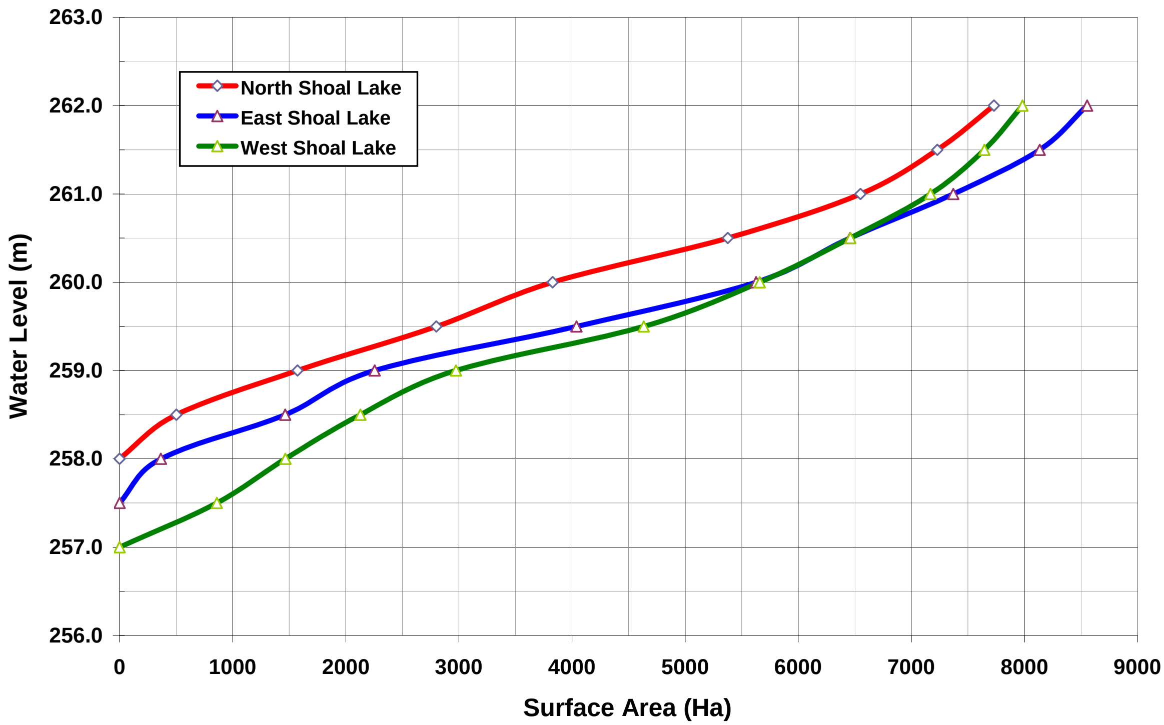



**Figure 5.4 – Shoal Lakes Stage-Surface Area Relationships**

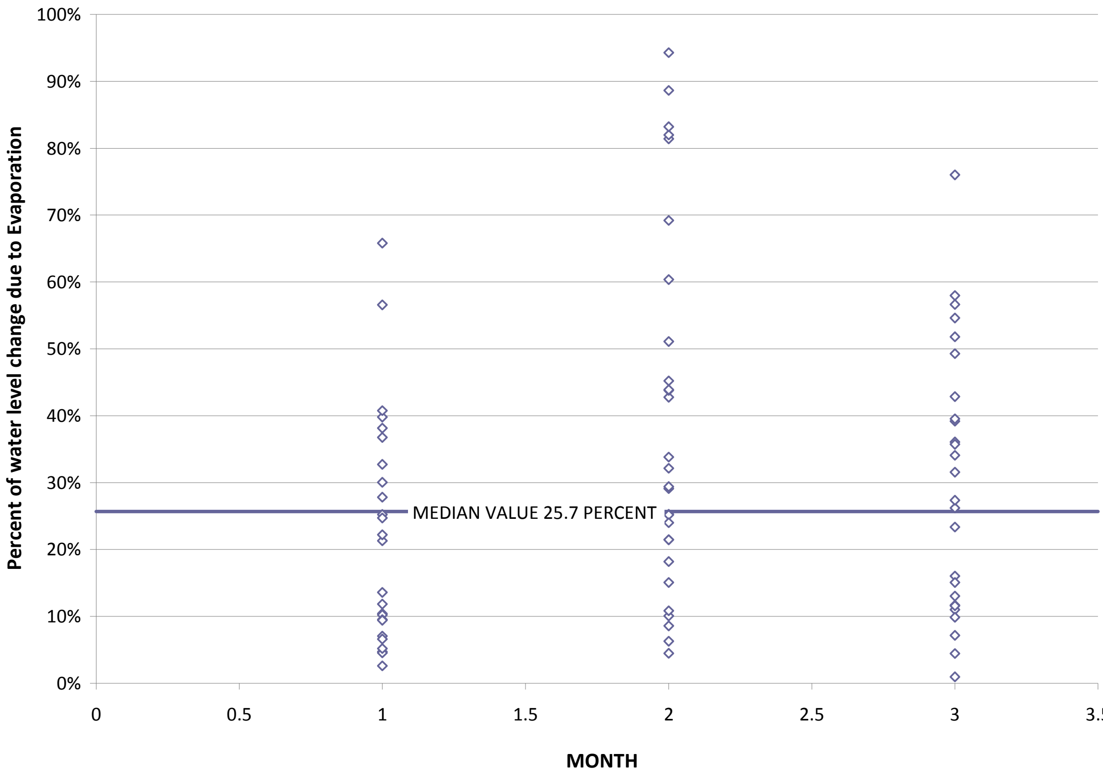



**Figure 5.5 – Percent of Water Level Change due to Evaporation**

As indicated on Figure 5.5, the computed ratio of change in water level to evaporation varies significantly. However, for application to the model it was assumed that only 25.7% of the change in lake level could be explained by evaporation. The IAO were adjusted using the area reduction factor each time in the iteration process for the estimation of end of period elevations and outflows from each lake.

## 5.3 MODEL CALIBRATION / VERIFICATION

Model calibration of an IAO model is not completely straightforward. Since the IAO is developed from the recorded water levels and storage volume, there are no parameters to adjust to calibrate the model. That being said, the model can be “verified” by making minor adjustments to the model inputs (rating curves between the basins) and comparing those model results to the historic water levels. The model verification therefore consisted of simulating the model with the incorporation of the stage-discharge relationships representing the interconnecting channels between the lakes, and then simulating the model to reproduce the historic lake levels for the study period from 1977 to 2007.

The computed IAO sequence was based on the assumption that under existing conditions, the lakes level changes on each lake were based on external inflow sources and that inter-lake transfer of flow was relatively small due to the restriction to flow caused by the land separating the lakes. This assumption was generally valid for most historic levels except under extreme flood conditions when the submergence of the land was assumed to permit some flow to occur. The IAO from all three lakes was summed to produce the total IAO to the Shoal Lakes complex. The IAO to each lake was then apportioned based on lake surface area and drainage area.

As noted in Section 4.2.2, the stage-discharge relationships for the interconnecting channels between the lakes were determined based on estimated topographic levels from surveys conducted on the lakes to define the surface areas of each of the lakes. The computed natural rating curves are therefore considered to be an approximation of the true rating curves.

The results of the model verification are shown on Figures 5.6, 5.7, and 5.8. The comparison of the recorded natural lake levels and the computed water levels in Figures 5.6, 5.7, and 5.8 show a close agreement. There is however a slight difference in the lake levels from natural conditions with the modelled levels on North Shoal Lake and East Shoal Lake generally being lower than natural and West shoal Lake being higher than natural. These differences are attributed to the fact that the stage discharge relationships that define the interconnecting channels are not completely representative of the existing channel capacities. Nevertheless, the computed water levels for the existing conditions confirm that the model represents the hydrologic and hydraulic processes in the Shoal Lakes reasonably well. The model calibration was not updated to include the recent data to 2010, as the calibration based on the data up to 2007 illustrated that the model provided a reasonably good estimate.

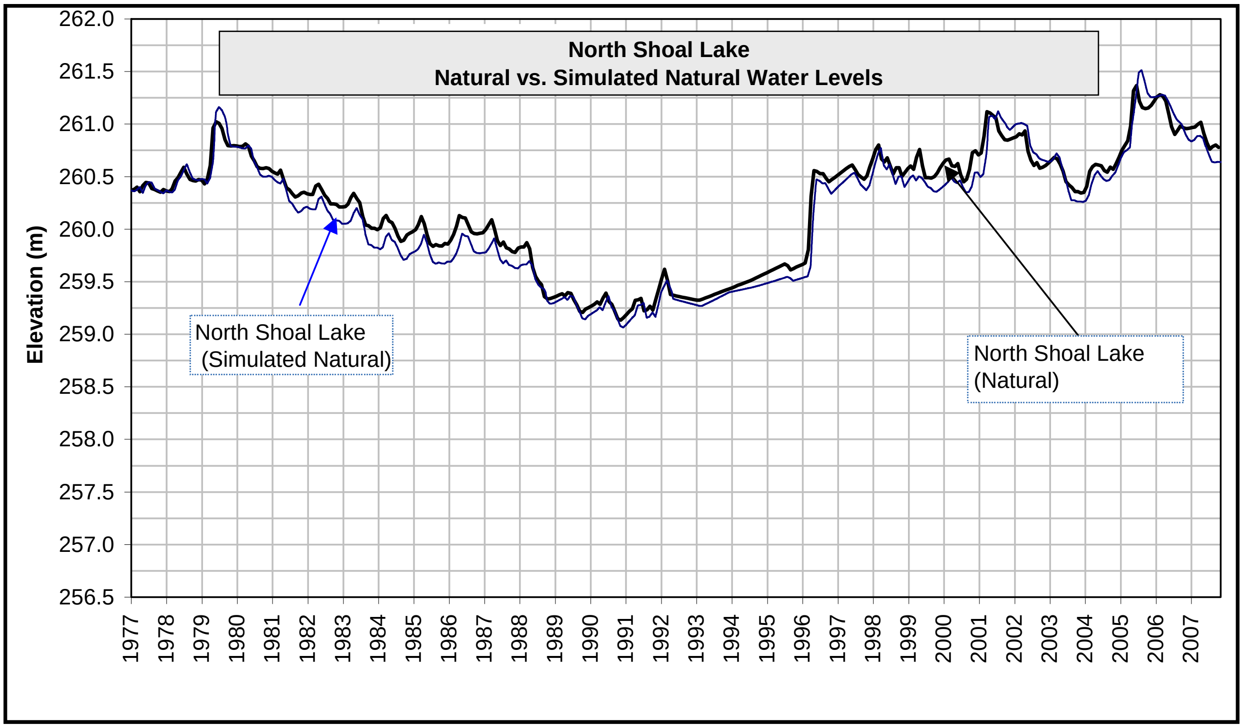



**Figure 5.6 – Comparison of Historic and Modelled Lake Levels in the North Shoal Lake**

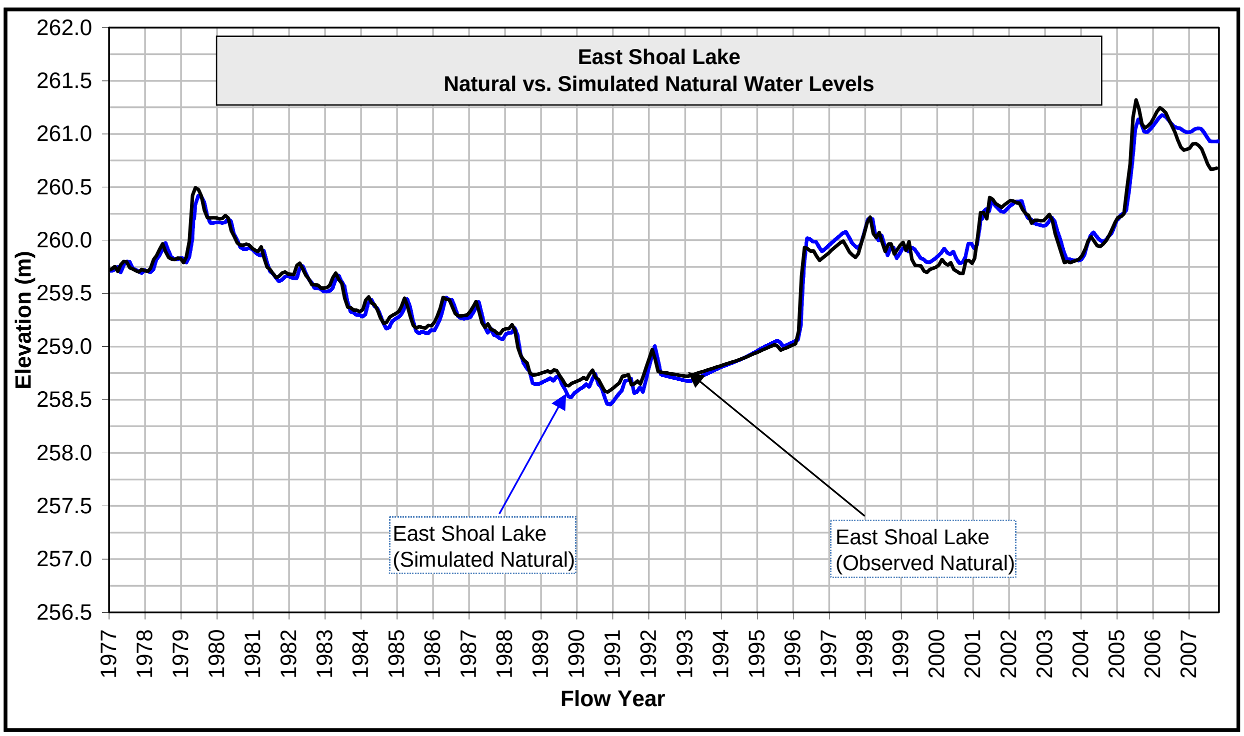



**Figure 5.7 – Comparison of Historic and Modelled Lake Levels in the East Shoal Lake**

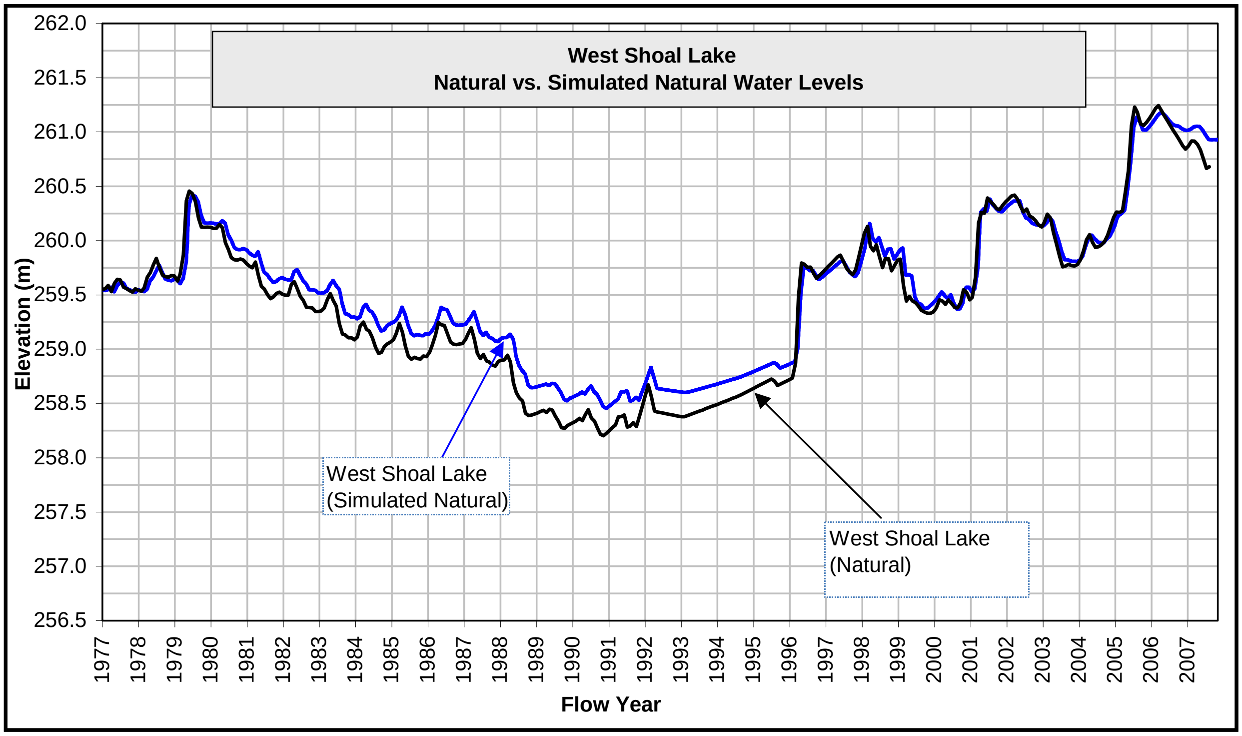



**Figure 5.8 – Comparison of Historic and Modelled Lake Levels in the West Shoal Lake**

## 5.4 ASSESSMENT OF FLOOD MITIGATION ALTERNATIVES

### 5.4.1 Flood Diversion Channels

Three alternatives for flood diversion channel have been investigated as described in Section 4.0. As noted in Section 4.0, the functionality of the diversion channels and their effect on the lake levels will be the same regardless of the channel alignment or alternative. Therefore, the model results presented in this section are representative of all the flood diversion channel alternatives.

To assess the effects of the diversion channel on the Shoal Lakes, the model as described in Section 5.2, was simulated by incorporating a discharge rating curve for the diversion channel that would divert water from West Shoal Lake when the water level in that lake is at or above the target level.

The computed IAO values for the study period from 1977 to 2010 were routed through the lakes using the daily flood routing program. The IAO was adjusted for the decreasing surface area of the lakes as explained in Section 5.2.

Control gates were used on the diversion channel and on the interconnecting channel between North and East Shoal lakes in order to retain water on the lakes when the water level fell below the target level.

Assuming a repeat sequence of IAO, as occurred historically between 1977 and 2010, the effect of the diversion channel on the lake levels, as compared to natural, are shown in Figures 5.9, 5.10, and 5.11 for North, East and West Shoal Lakes, respectively. The flow hydrograph discharges into the diversion channel conveyed to Lake Manitoba are shown in Figure 5.12.

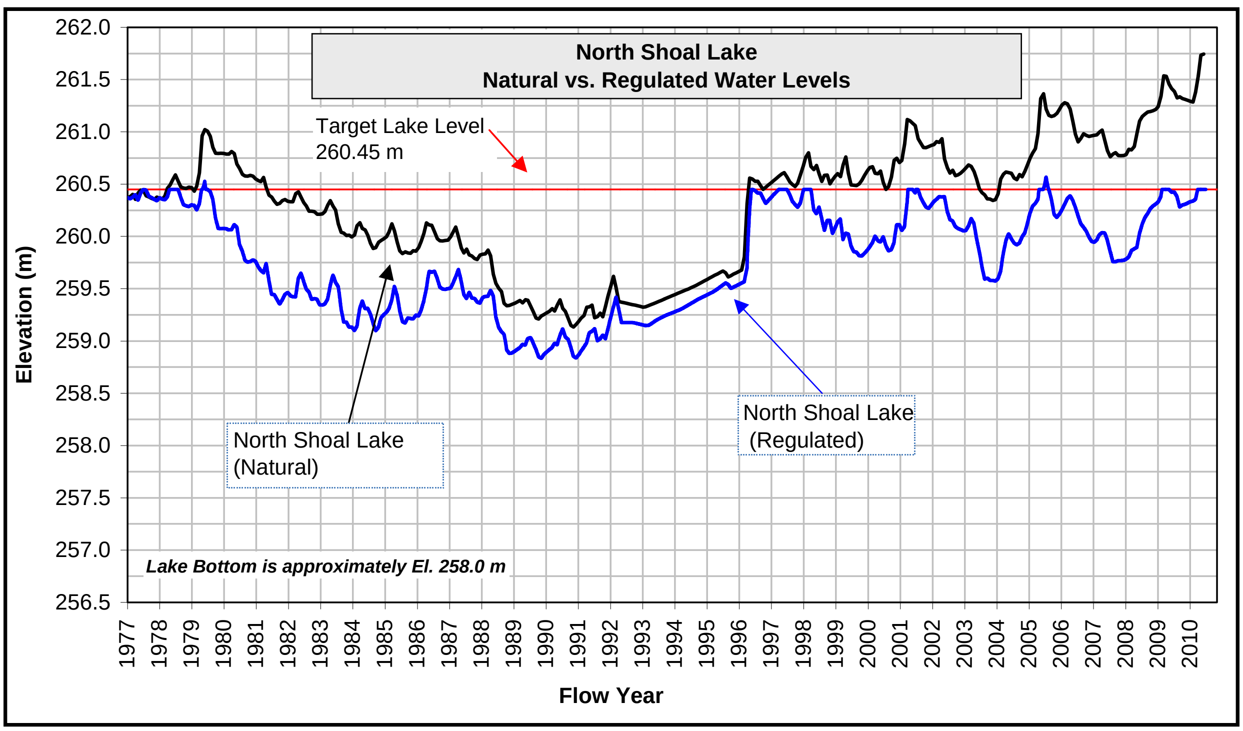



**Figure 5.9 – North Shoal Lake – Natural and Regulated Water Levels**

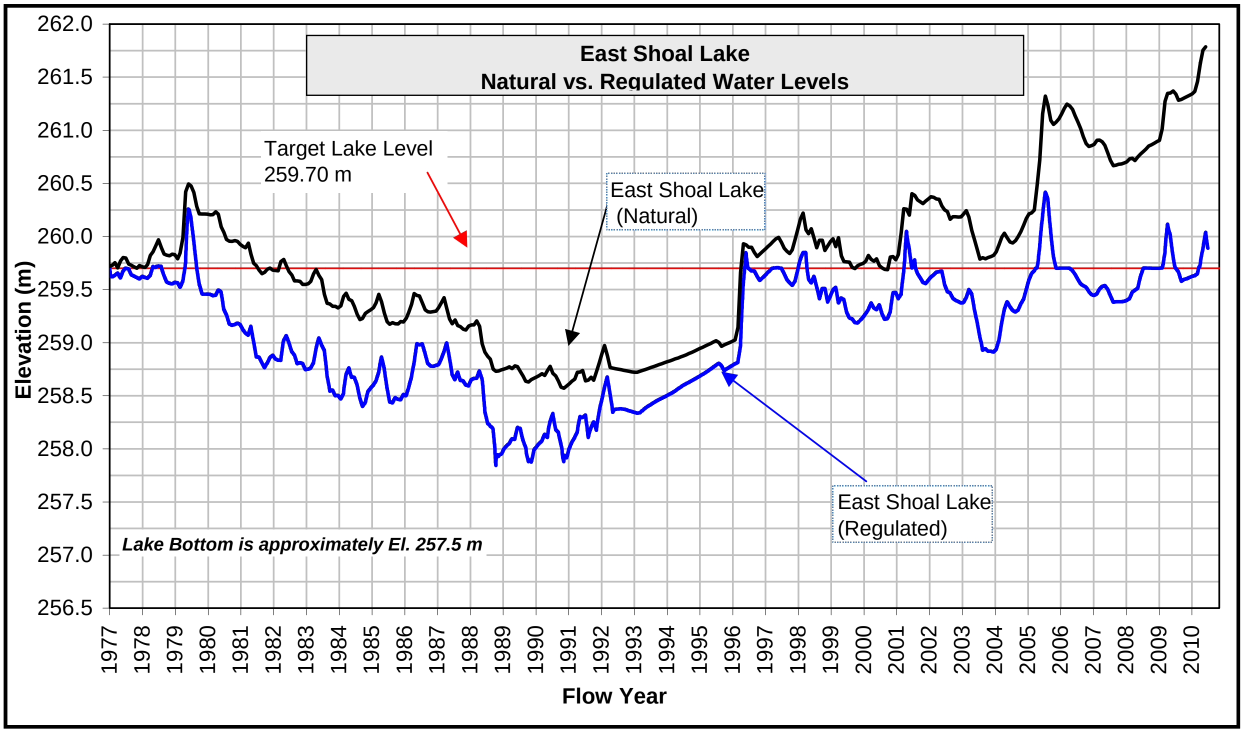



**Figure 5.10 – East Shoal Lake – Natural and Regulated Water Levels**

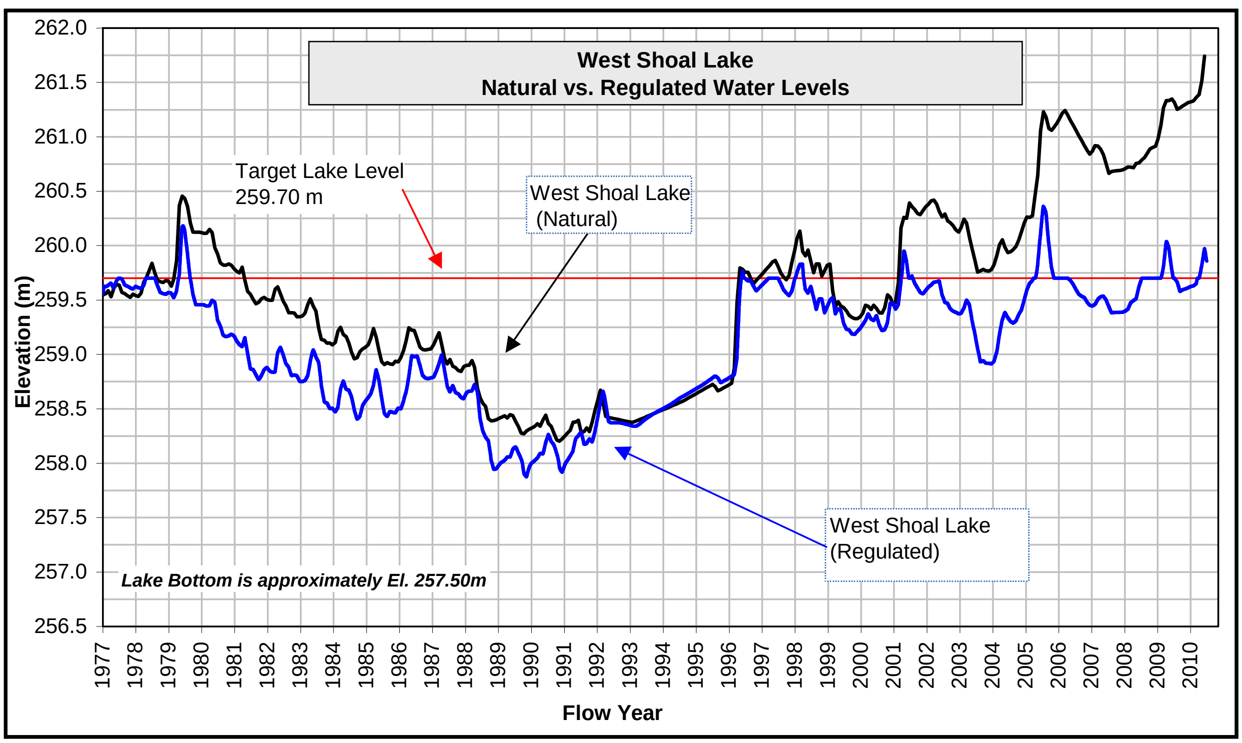



**Figure 5.11 – West Shoal Lake – Natural and Regulated Water Levels**

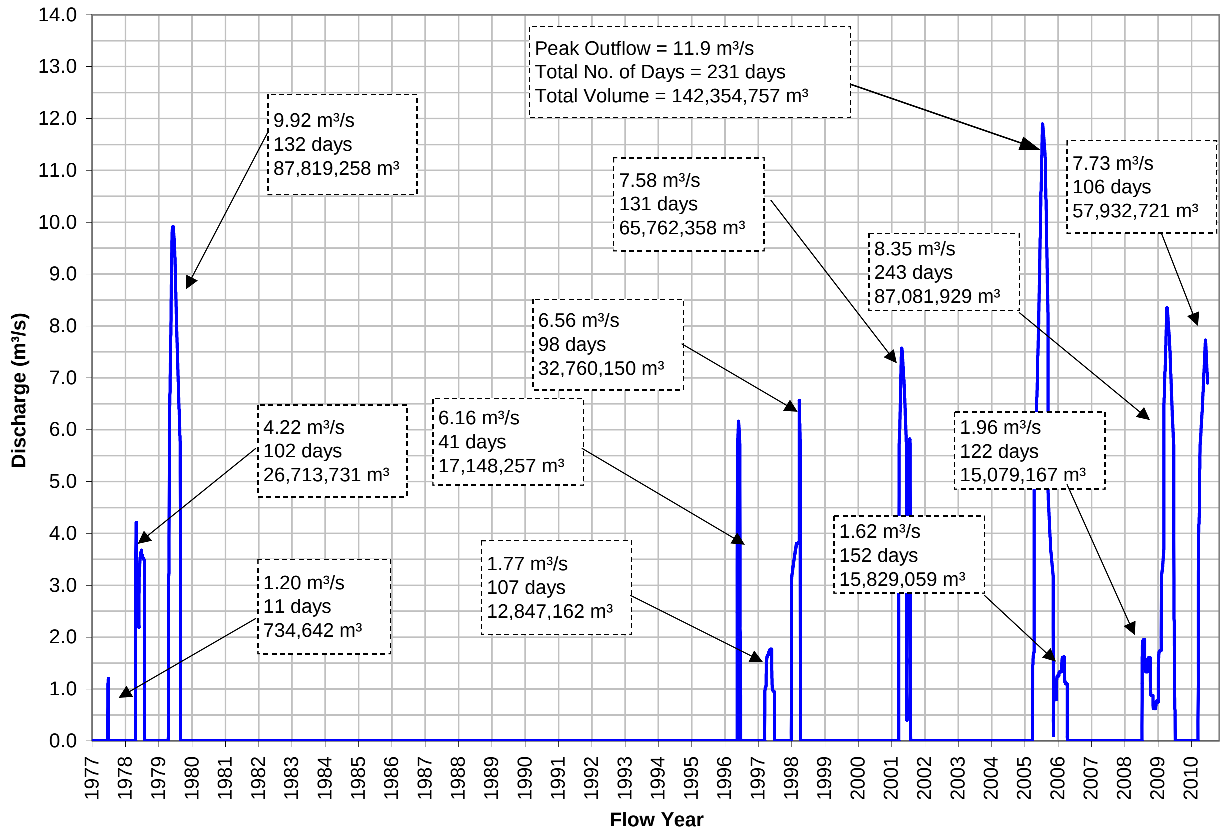



**Figure 5.12 – West Shoal Lake Outflows Diverted to Lake Manitoba**

The model results showed that the water levels on the lakes for natural or existing conditions exceeded the target level in the years 1977 to 1981 and in years 1996 to 1999 and from years 2001 to 2010. With the diversion channel the regulated water level on North Shoal Lake is controlled at or below the target level for most of the flood years except in year 1979 and year 2005. Peak water levels in these years were reduced significantly from the natural level, however they are above the target level since the discharge in the diversion channel is less than the rate of inflow in those years. Similarly, the flooding on East and West Shoal Lakes was reduced with lake levels exceeding the target levels in years 1979, 1998, 2001, 2005, 2009, and 2010

As shown in Figure 5.12, the diversion channel conveys flow to Lake Manitoba in 12 of the 34 years.

The diversion of flood volumes during the wet periods also resulted in the minimum levels on the lakes being lowered. The minimum levels and water depths in each of the lakes for both the natural and regulated conditions are listed in Table 5.1.

**TABLE 5.1**
**MINIMUM LAKE LEVELS AND DEPTHS – NATURAL AND REGULATED**

| Lake Condition | Minimum Water Level (1977 – 2007) | | |
|---|---|---|---|
| | North Shoal Lake | East Shoal Lake | West Shoal Lake |
| Natural | 259.13 m (1.13 m) | 258.57 m (1.07m) | 258.20 m (1.20 m) |
| Regulated | 258.84 m (0.84 m) | 257.84 m (0.34 m) | 257.88 m (0.88 m) |

*Note: Depths shown in brackets.*

Outflow from North Shoal Lake is controlled independent of the levels on East and West Shoal Lakes by control gates on the inter-connecting channel between North and East Shoal Lake. Minimum level on North Shoal Lake reached 258.84 m., which is approximately 0.8 m above the channel invert level while the minimum level on East Shoal Lake reached 257.84 m, which is near the bottom of the lake. However, because the level on North Shoal Lake was below the target level of 260.45 m, no additional water could be released downstream to alleviate the low water level on East Shoal Lake in accordance with the operating rule assumed. Additional water could be released from North Shoal Lake if the channel design and the operating rules were optimized and operated differently than assumed in this study. This optimization of gate operation and channel capacities, however, was not considered at this level of study, but should be considered should this project proceed to subsequent stages of design.

As noted previously, the sequence of IAO as historically occurred was retained for the assessment of the effects of the flood diversion channel alternatives Sensitivity assessments were carried out for different starting water levels in the lakes (low and high) to test the effect of the starting water level on the change in lake levels. The historic sequence represents only one of many possible sequences based on the initial time reference for the start of the analysis. This analysis showed that changing the starting level of the lakes had little effect to the changes in water levels and discharge conveyed to Lake Manitoba via the diversion channel between the natural condition and the regulated conditions.

### 5.4.2 Upland Storage

The effects of the increase upland storage areas, as described in Section 4.3, were also assessed. It was assumed, for the hydraulic assessment that during periods when the water levels on the lakes exceeded the target levels, water was retained in the upland storage reservoirs up to the capacity of the storage reservoir. Once the reservoirs are filled with water, it could not be released from storage to the Shoal Lakes until the water level in the Shoal Lakes recedes to below the target level.

Since the periods of high flows and high lake levels typically extended over a number of years, in which upland storage would be most effective at attempting to reach the target levels, there is no potential for storing additional water in subsequent years. At this point, any inflow to these storage areas would have to be passed to the Shoal Lakes.

Figures 5.13, 5.14, and 5.15 illustrated the effect of the storage on the water levels on the lakes. These curves show that there is only a slight reduction in the lake levels at the times when the water levels in the lakes are above the target levels. This slight reduction is due to the relative small volume available for storage in the watershed.

The upland storage areas for the Shoal Lakes watershed do not function as a typical storage reservoir as would on a run of the river watershed. In the run of river watershed, water can be retained in storage until the flows in the river downstream of the reservoir subside. In the Shoal Lakes watershed, the water from the reservoirs would have to be released to the Shoal Lake. Once flooded in a period of sustained flood conditions, the flood levels persist for a number of years. Water cannot be released from the storage reservoirs until the lake levels drop below the target operating level. The result is that the volume of storage can only be used once in a given flood period.

The release of water from the storage reservoir or the volume of water remaining in the storage reservoir is also affected by excessive evaporation in a similar manner that the lake levels drops following the peak level being attained. The retention of water over several years duration would result in evaporation of much of the water that was initially stored in the storage reservoir. For this study, it is assumed that there would be no storage water remaining when the lake level fell below the target level.

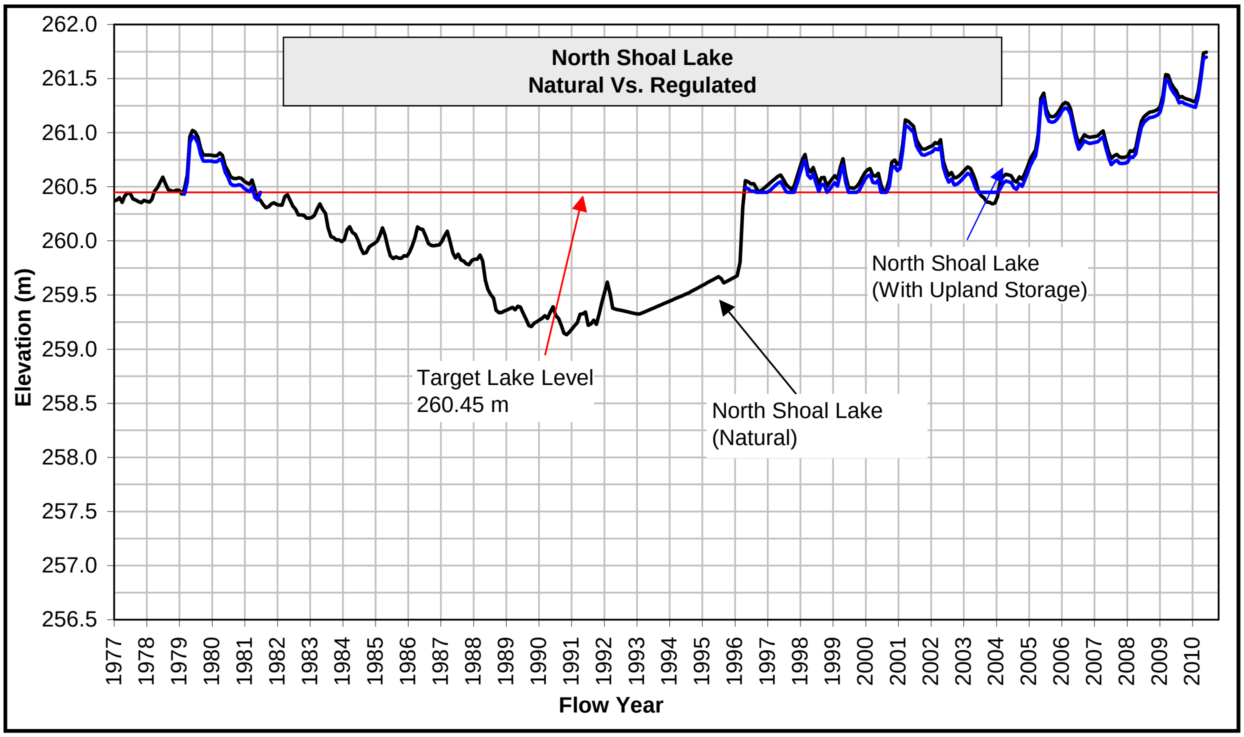



**Figure 5.13 – North Shoal Lake**
**Natural and Regulated Water Levels with Upland Storage**

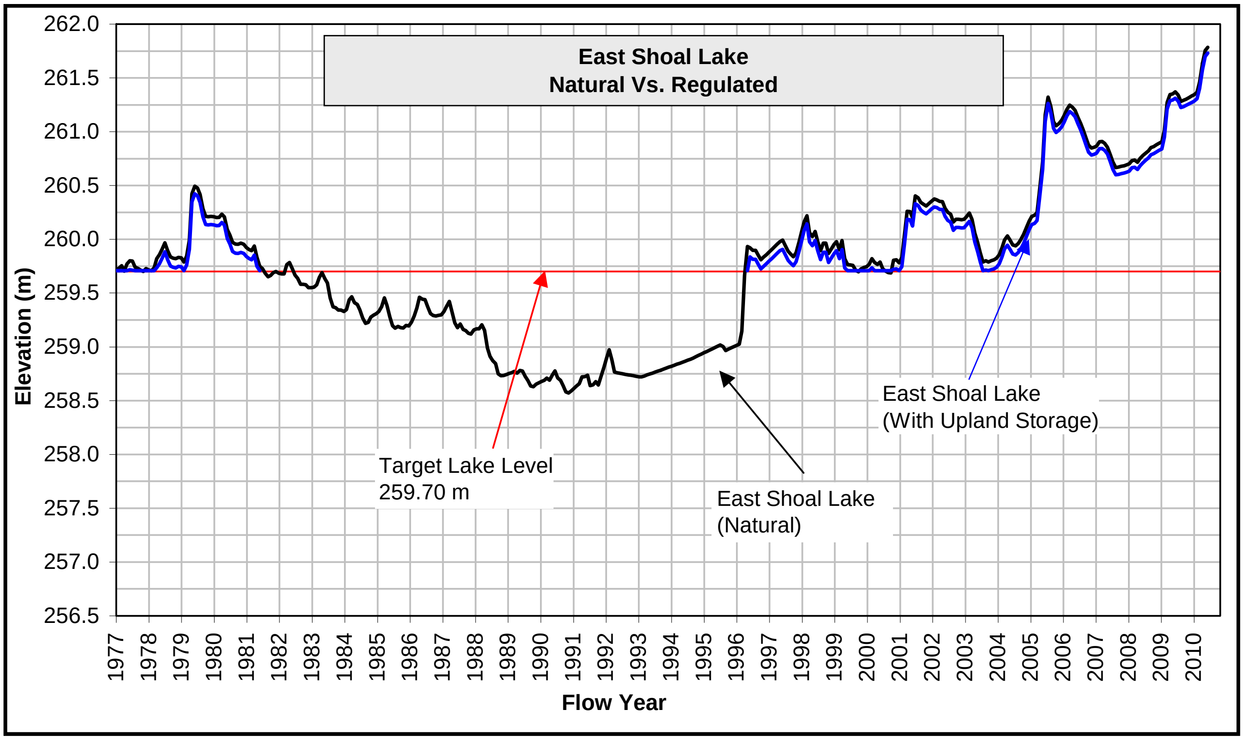



**Figure 5.14 – East Shoal Lake**
**Natural and Regulated Water Levels with Upland Storage**

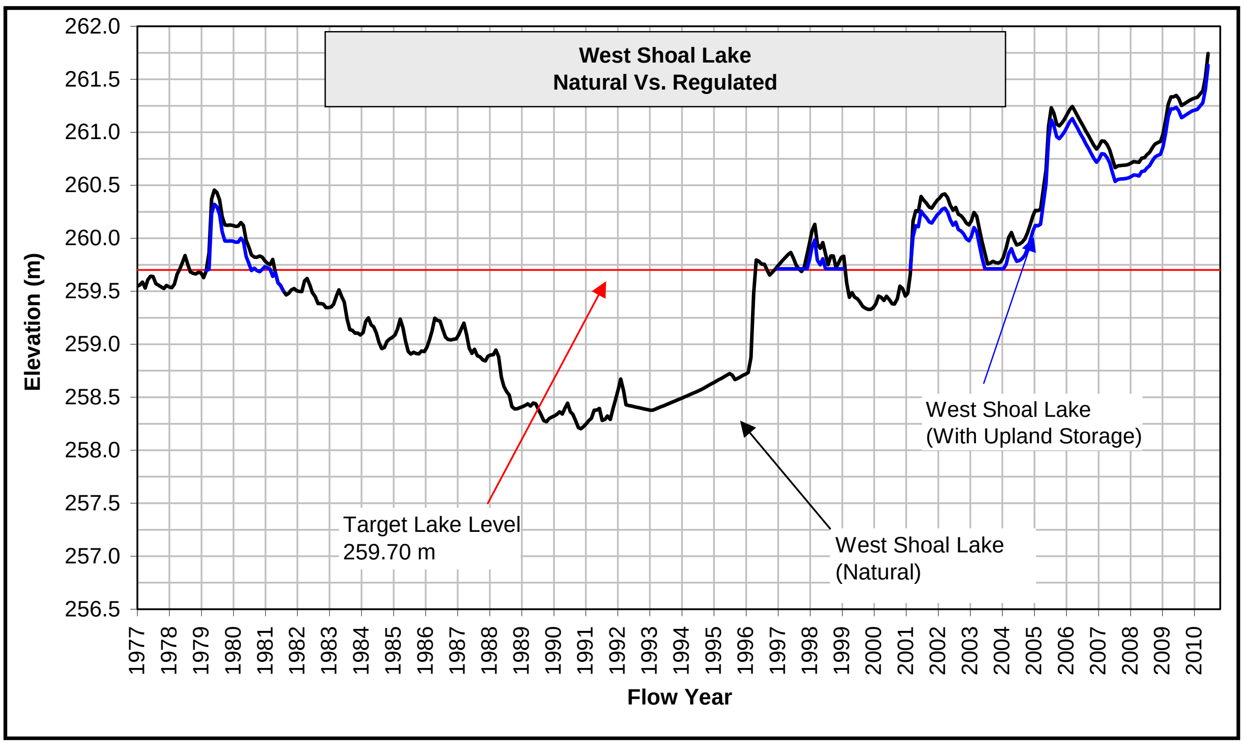



**Figure 5.15 – West Shoal Lake**
**Natural and Regulated Water Levels with Upland Storage**

# 6.0 COST ESTIMATION OF FLOOD MITIGATION ALTERNATIVES

## 6.1 BASIS FOR COST ESTIMATION

The estimated costs for the flood mitigation alternatives are based on KGS Group's recent experience with similar projects throughout southern Manitoba. The estimated costs associated with the flood mitigation alternatives are considered to be in 2009 dollars.

A contingency allowance of 20% of the direct costs has been included in the cost estimates of each alternative. This contingency is a factor that is normally included in feasibility level studies to account for:

- Items of cost that are likely to arise that cannot be quantified accurately at this level of study without detailed engineering work to do so
- Unforeseen items that ultimately increase the cost of the project
- Uncertainties in the soil materials which could affect the excavation costs
- Uncertainties such as foundation conditions that affect cost but are normally only resolved during the construction process

Cost estimates for each of the diversion channel alternatives, as well as the upland storage option include an allowance of 10% of the direct costs for engineering design and construction management of the project. This percentage has been proven to be representative of the costs for this critical function in the execution of the project.

No allowance for interest during construction has been included since the construction period for each of the channel options would be a maximum of two years, and the interest would be relatively small.

## 6.2 UNIT PRICES

### 6.2.1 Flood Diversion Channels

***Excavation***

Excavation costs are based on the information shown on the soils map and KGS Group's knowledge of the conditions in the area. Predominantly the soil materials that require excavation consist of extremely calcareous loamy till (black chernozems, brunisols and dark gray chernozems) and highly calcareous loamy till (gelysols). For excavation of these types of soil materials a unit price of $5.50/m³ was assumed. This estimated unit price includes the cost of excavation as well as the placement of excavated material in the embankments.

The price is moderately higher than would be expected for shallow, less complicated excavation work in this area. Local contractors with experience only in such favourable conditions may consider this price to be unrealistically high. However, this has been chosen to reflect:

- a market condition wherein the excavation industry is moderately busy, and inordinately low price that is not sustainable in the long run would not be bid
- the difficulty of excavating a channel to a depth of as much as 11 m (for Boundary/Roy's Drain) and 8 m (for Wagon Creek Option A & B), while dealing with potential groundwater inflows, blowouts, artesian pressure, and unknown amounts of rock encountered in the excavation
- the fact that the estimation of soil types in the area has been based only on the soil classification map, and no proper subsurface investigation has been done

Greater certainty in the unit price would be possible if the project proceeds and extensive subsurface investigations are undertaken. These investigations would be highly recommended, and should also be accompanied by test excavations to establish the ability to move material, should one of the diversion channel alternatives be pursued to the next level of study.

It is possible that ***if*** the soil conditions turn out to be favourable, with very competitive market conditions, with little or no complications due to ground water or artesian pressures, and if excavation of the calcareous loamy till can be done with scrapers and conventional equipment, the unit price of excavation for the channel could be lower than currently estimated. A reduction of as much as 50% ***may*** be possible. In recognition of this possibility, a sensitivity analysis of the influence of lower prices on the channel economics has been done and is included in Section 8.0.

***Drop Structures***

To make the drop structures economical, riprap drop structures have been considered in the design for all three flood channel options. The cost for the drop structures consists of the supply and placement of riprap material. A gravel filter layer beneath the riprap layer has also been included in the design and cost estimate. The unit price for the supply and placement of riprap material is estimated to be $\$65.00/m^3$. A unit price of $\$50.00/m^3$ was assumed for the supply and placement of clean crushed gravel.

***Road Crossings / Culverts***

For road crossings, corrugated steel pipe culverts with projecting type ends were considered in the design for all the three flood diversion channels. All the culverts crossings have multiple barrels consisting of 2.0 m or 2.2 m diameter pipes. The cost estimate for the culverts consists of the supply and installation of Galvanized HEL-COR Pipes (corrugation profile of 125mm x 25mm and wall thickness of 3.5mm). The unit prices for the supply and installation of 2.0 m and 2.2 m diameter pipes were estimated as $2,100/m and $2,300/m respectively.

***Land Acquisition***

Land acquisition costs were based on the land assessed values for various quarter sections along the channel using the Government of Manitoba – Property Assessment website [Manitoba 2009] and KGS Group's recent experience with projects requiring land acquisition. The unit price for land acquisition was estimated as $2,000/ha for this study. This estimated unit price accounts for all costs associated with the land acquisition process, such as: legal surveys, land value, legal fees, and compensation to the owner for fragmenting his remaining fields.

***Re-Vegetation***

Based on KGS Group's knowledge of the conditions in the area and recent experience with projects requiring re-vegetation, the unit price for re-vegetation was estimated as $750/ha. This estimated unit price accounts for all costs associated with the re-vegetation process.

***Control Structure at West Shoal Lake***

The cost of the control structures at West Shoal Lake and between the North and East Shoal Lakes was based KGS Group's knowledge of the construction costs associated with concrete gated control structures. The cost was estimated based on the approximate quantities for the excavation, concrete, gates, and miscellaneous steel that would be required to construct the control structures.

***Maintenance Costs***

Annual maintenance costs were also considered for the flood diversion channels based on information from MWS as included in other flood studies and include the following:

- ***Drain Mowing and Clean Out*** – This includes the cost of cutting the grass and weeds within the drain and a minor amount of rain clean out. This cost is estimate to be approximately $650 per km. Typically in Manitoba, the drains are often quite wet, and therefore on average drains are mowed once in every fourth year. Assuming that the flood diversion channels would be mowed once every four years, the annual cost of this maintenance would be $163/km/year.

- ***Major Channel Maintenance*** – This would consist of more rigorous ditch maintenance than stated above, and include the possible drainage realignment, grading, and bed restoration. This more significant drain maintenance would occur on average every 15 to 20 years at a cost of approximately $5000 per km. Assuming that the flood diversion channels receive major maintenance every fifteen years, this cost would be $333/km/year.

- ***Culvert and Control Structure Maintenance*** – This would consist of routine maintenance of the culvert crossings and control structures, as well as routine testing of the gates at the control structures to ensure that the structures continue to function. This type of maintenance would occur approximately every five years at a cost of $25,000. Assuming that this maintenance would occur every five years, this cost would be $5,000/year.

### 6.2.2 Increased Upstream Storage

The cost estimate for the increased upstream storage includes the following:

- Purchase of land for storage areas: For this purpose, privately owned lands would be purchased at assessed value (determined from the Government of Manitoba – Property Assessment website) plus an additional 20% to account for market prices that may be greater than the assessed value. Legal fees of $1000 per property were also included in the estimated cost.
- Construction of any required dams / outlet works at storage sites: For this purpose, the lump sum cost for the control structure (at each storage site) was estimated as $50,000.
- Excavation / upgrade of outlet channels from storage sites to Shoal Lakes: For the excavation purpose, the unit price of $5.50/m$^3$ was estimated.

The cost estimates for the increased upstream storage does not include any costs for the loss of the land that is used for the storage area should that land be utilized for agricultural activities (i.e. loss of grazing land).

Annual maintenance costs were also considered for the upstream storage areas and have been assumed to be equal to those adopted for the flood diversion channels.

### 6.2.3 Purchase of Flood Prone Lands

The purchase cost of the flood prone lands was based on the following criteria:

- Privately owned lands would be purchased at assessed value (determined from the Government of Manitoba – Property Assessment website [Manitoba 2010]) plus an additional 20% to account for market prices that may be greater than the assessed value. To be consistent with the cost estimates, the 2010 property values were pro-rated back to 2009 dollars.
- Buildings would be purchased at assessed value (determined from the Government of Manitoba – Property Assessment website) plus an additional 20% to account for market prices that may be greater than the assessed value.
- Crown land and Leased Crown land would not be purchased. The leased land, however, would require new lease rules. Costs for changing the terms of the leases have not been included in this study.
- Legal fees of $1000 per property would be included in the estimated cost.

As noted in Section 4.4, changes to the existing land leases for crown-leased lands have not been considered in this assessment. Potential alternatives could include, the land being leased back to the farmers in times of low water on the lakes or the land being converted into a wildlife management area. If the land was leased back to the farmer in times of low water levels, it is possible that the current lease rules would remain unchanged, and therefore, there would be no additional cost associated with this alternative. Should, however, the land be converted into a wildlife management area, there would be a loss of revenue from the leases, but there would likely be increased benefits for other aspects associated with the wildlife management area.

## 6.3 ESTIMATED COST OF FLOOD MITIGATION ALTERNATIVES

### 6.3.1 Flood Diversion Channel – Wagon Creek – Option A

The estimated costs for the construction of the Wagon Creek – Option A are summarized in Table 6.1. A more detailed breakdown of costs is provided in Appendix C.

**TABLE 6.1**
**ESTIMATED COSTS FOR FLOOD DIVERSION CHANNEL – WAGON CREEK – OPTION A**

| Item | Description | Total Cost |
|---|---|---|
| ***Direct Costs*** | | |
| 1.0 | Excavation | $14,933,000 |
| 2.0 | Drop Structures | $720,000 |
| 3.0 | Culvert Crossings | $860,000 |
| 4.0 | Land Acquisition (Right of Way) | $520,000 |
| 5.0 | Re-Vegetation | $225,000 |
| 6.0 | Control Structures | $650,000 |
| ***Indirect Costs*** | | |
| 7.1 | Contingency (20%) | $3,582,000 |
| 7.2 | Engineering and Construction Supervision (10%) | $1,791,000 |
| **Total Estimated Costs** | | **$ 23,281,000** |
| **Annual Maintenance Costs** | | **$17,650** |

### 6.3.2 Flood Diversion Channel – Wagon Creek – Option B

The estimated costs for the construction of the Wagon Creek – Option B are summarized in Table 6.2. A more detailed breakdown of costs is provided in Appendix C.

**TABLE 6.2**
**ESTIMATED COSTS FOR FLOOD DIVERSION CHANNEL – WAGON CREEK – OPTION B**

| Item | Description | Total Cost |
|---|---|---|
| ***Direct Costs*** | | |
| 1.0 | Excavation | $17,039,000 |
| 2.0 | Drop Structures | $720,000 |
| 3.0 | Culvert Crossings | $860,000 |
| 4.0 | Land Acquisition (Right of Way) | $540,000 |
| 5.0 | Re-Vegetation | $240,000 |
| 6.0 | Control Structures | $650,000 |
| ***Indirect Costs*** | | |
| 7.1 | Contingency (20%) | $4,010,000 |
| 7.2 | Engineering and Construction Supervision (10%) | $2,005,000 |
| **Total Estimated Costs** | | **$26,064,000** |
| **Annual Maintenance Costs** | | **$19,540** |

### 6.3.3 Flood Diversion Channel – Roy's / Boundary Drain Option

The estimated costs for the construction of the Roy's / Boundary Drain Option are summarized in Table 6.3. A more detailed breakdown of costs is provided in Appendix C.

### 6.3.4 Upland Storage

The estimated costs for the increased upland storage are summarized in Table 6.4. A more detailed breakdown of costs is provided in Appendix C.

The costs for the land acquisition are based the assessed value (determined from the Government of Manitoba – Property Assessment website [Manitoba 2010]). It should be noted that the costs for the land acquisition are larger per hectare than those cost to purchase the land surrounding the Shoal Lakes as the land further away from the lakes is generally assessed at a higher value.

**TABLE 6.3**
**ESTIMATED COSTS FOR FLOOD DIVERSION CHANNEL – ROY'S / BOUNDARY DRAIN**

| Item | Description | Total Cost |
|---|---|---|
| ***Direct Costs*** | | |
| 1.0 | Excavation | $21,434,000 |
| 2.0 | Drop Structures | $655,000 |
| 3.0 | Culvert Crossings | $650,000 |
| 4.0 | Land Acquisition (Right of Way) | $400,000 |
| 5.0 | Re-Vegetation | $180,000 |
| 6.0 | Control Structures | $650,000 |
| ***Indirect Costs*** | | |
| 7.1 | Contingency (20%) | $4,794,000 |
| 7.2 | Engineering and Construction Supervision (10%) | $2,397,000 |
| **Total Estimated Costs** | | **$ 31,160,000** |
| **Annual Maintenance Costs** | | **$13,830** |

**TABLE 6.4**
**ESTIMATED COSTS FOR UPLAND STORAGE**

| Item | Description | Total Cost |
|---|---|---|
| ***Direct Costs*** | | |
| 1.0 | Excavation | $688,000 |
| 2.0 | Gated Control Structures | $250,000 |
| 3.0 | Land Acquisition (Right of Way) | $2,241,000 |
| ***Indirect Costs*** | | |
| 4.1 | Contingency (20%) | $636,000 |
| 4.2 | Engineering and Construction Supervision (10%) | $318,000 |
| **Total Estimated Costs** | | **$ 4,133,000** |
| **Annual Maintenance Costs** | | **$14,920** |

### 6.3.5 Purchase of Flood Prone Lands

The estimated costs for the purchase of flood prone lands are summarized in Table 6.5.

**TABLE 6.5**
**ESTIMATED COSTS FOR THE PURCHASE OF FLOOD PRONE LANDS**

| Item | Description | Total Cost |
|---|---|---|
| ***Direct Costs*** | | |
| 1.0 | Total Value of Land to Purchase | $6,048,000 |
| 2.0 | Total Value of Buildings to Purchase | $3,325,000 |
| ***Indirect Costs*** | | |
| 4.1 | Market Premium (20%) | $1,875,000 |
| 4.2 | Legal Fees ($1000 per property) | $113,000 |
| **Total Estimated Costs** | | **$11,361,000** |

# 7.0 BENEFITS FROM FLOOD PROTECTION

## 7.1 BASIS FOR ESTIMATION OF BENEFITS

Flood events in and around the Shoal Lakes have caused a variety of damages. The main quantifiable impacts have included:

- damages to agriculture crops and forages
- reduction in revenue from livestock, primarily cattle
- damages, or flood protection costs, at farm establishments that are directly affected by flood waters
- damages to government facilities, including roads, ditches, culverts and buildings
- increases in costs of transportation during flood events and during repairs to damaged transportation facilities

Each of these components have been examined, and numerical algorithms developed that relate the severity of flood to the predicted extent of damage. ***The intent has been to develop a damage "model" that can be used to quantitatively compare conditions with and without the proposed flood mitigation alternatives. The reduction in flood damages due to the flood mitigation alternatives would form the benefits from the construction and on-going operation and maintenance of the project.*** The benefits and costs are discussed and compared in Section 8.0.

There are, of course, other damages that occur that are difficult to quantify, or are not quantifiable at all. They include:

- stress and anxiety of local residents that are directly affected by flooding in the area
- reduction in on-going values of land that is currently considered flood prone
- loss of potential for future development of flood–prone lands

In addition to those damages listed above, it could be argued that there are socio-economic benefits or damages that could result from any of the potential flood mitigation alternatives, including the economic activity generated by ranchers within the nearby communities.

Quantification of these benefits or damages would require an in-depth socio-economic study of the area as related to agricultural practices surrounding the Shoal Lakes. This type of analysis was not defined part of this study nor is it typically included in an economic analysis of flood mitigation measures.

Environmental impacts associated with the project are also a factor that is difficult to quantify. Nevertheless, an approach to quantify the environmental effects has been developed and discussed in Section 9.0.

## 7.2 ESTIMATION OF FLOOD DAMAGES

### 7.2.1 Characterization of Flooded Area for Flood Damage Calculations

For estimation of flood damages, the area in and around the lakes has been divided into four portions namely the Vestfold Complex, North Shoal Lake, East Shoal Lake and West Shoal Lake. For each portion, the relationships between the flood levels and the areas of flooded land for various land use types (agriculture, forage, grassland, mixed forest, roads/trails, marsh and water or waterbodies) have been developed. Similarly the relationships between the flood levels and the lengths of flooded roads (provincial and secondary roads) have been developed. These relationships are shown in Figures 7.1 to 7.8. The topography that was used to develop these relationships is shown in Plate 3, as previously described in Section 2.2. The methodology that has been used to estimate the quantifiable agricultural and infrastructure flood damages are described in subsections 7.2.2, 7.2.3, and 7.2.4.

It should be noted that the information presented in Figures 7.5 to 7.8 is based on the topographic and survey data that was available at the start of this project and also includes the information obtained from the KGS Group surveys carried out in the spring of 2008. Any construction activities that have resulted in raising the elevation of the roads in the area since the spring of 2008 will not be considered in this assessment.

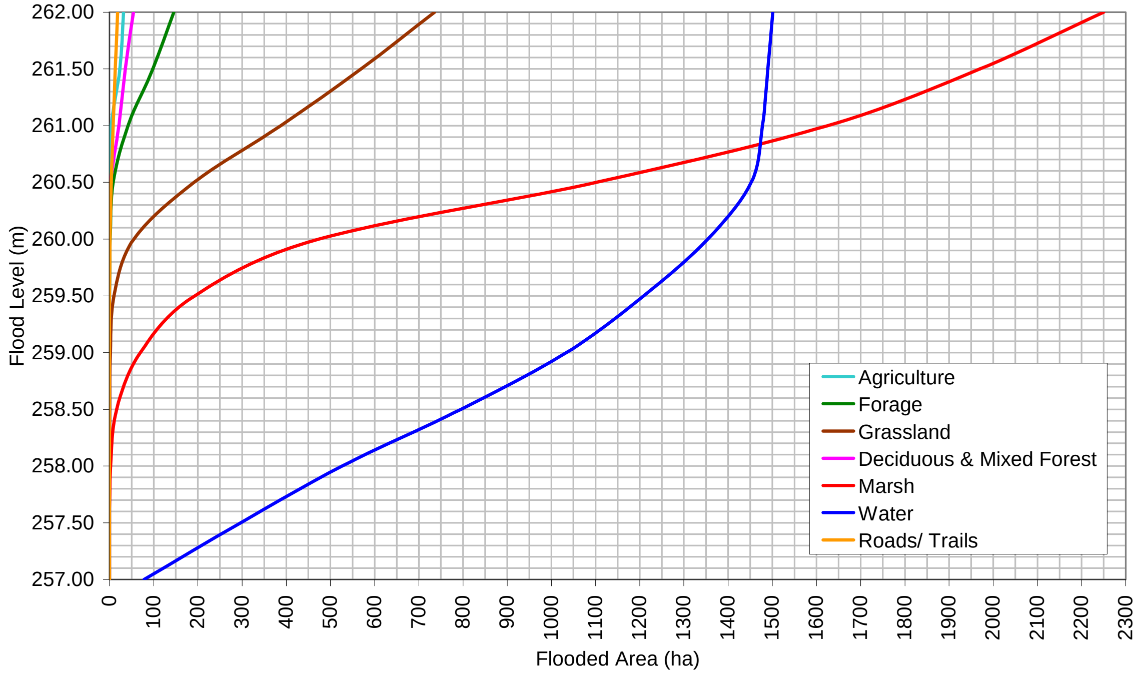



**Figure 7.1 – Flooded Land Use for the Vestfold Complex**

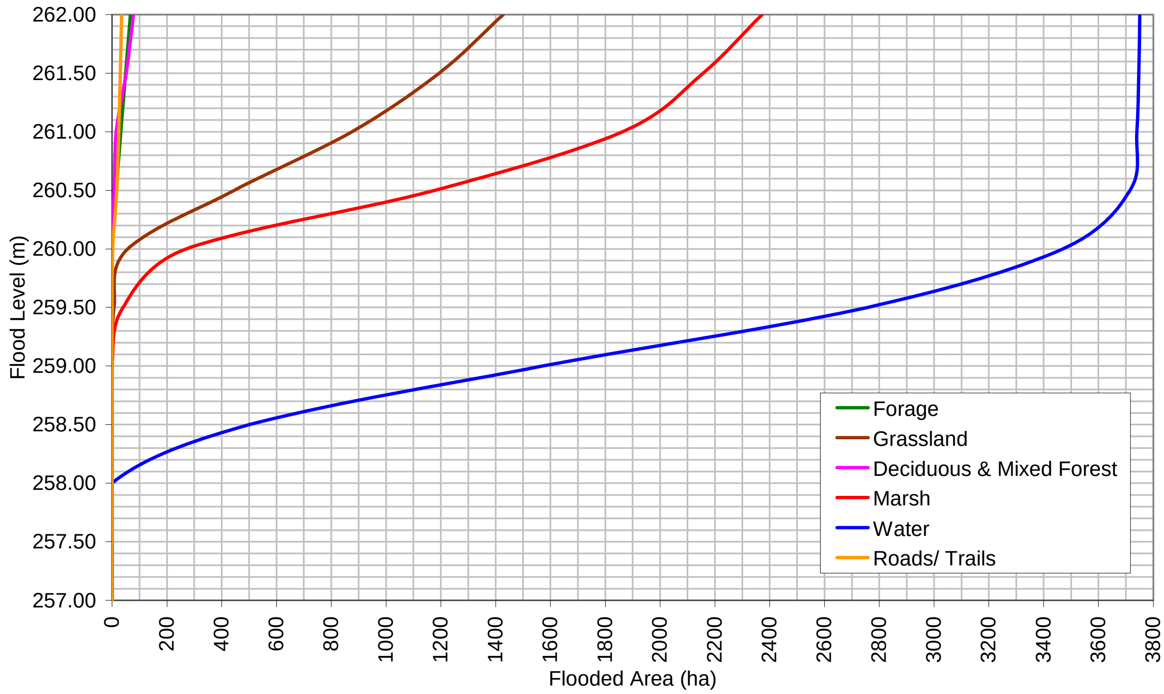



**Figure 7.2 – Flooded Land Use for North Shoal Lake**

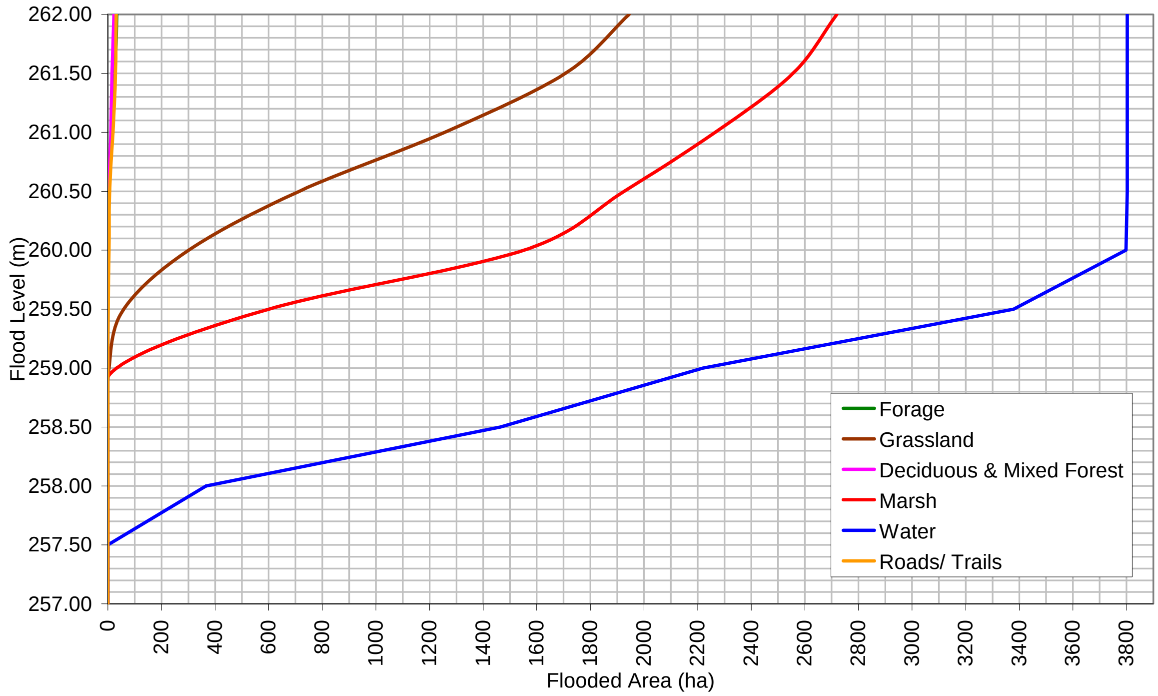



**Figure 7.3 – Flooded Land Use for East Shoal Lake**

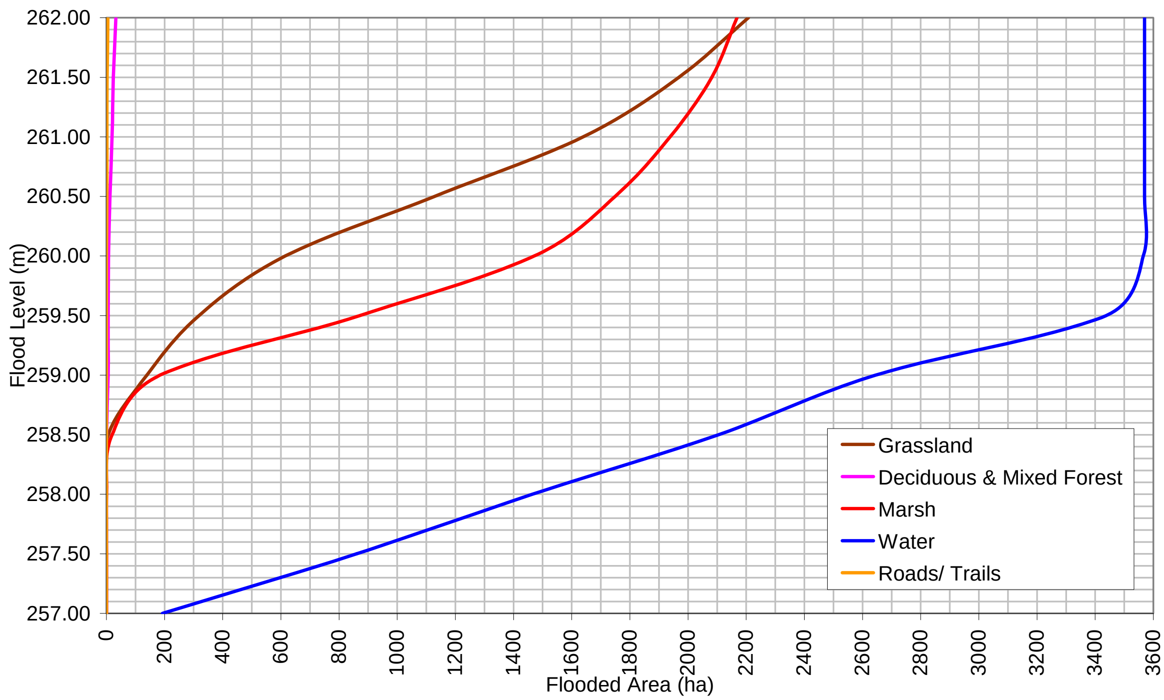



**Figure 7.4 – Flooded Land Use for West Shoal Lake**

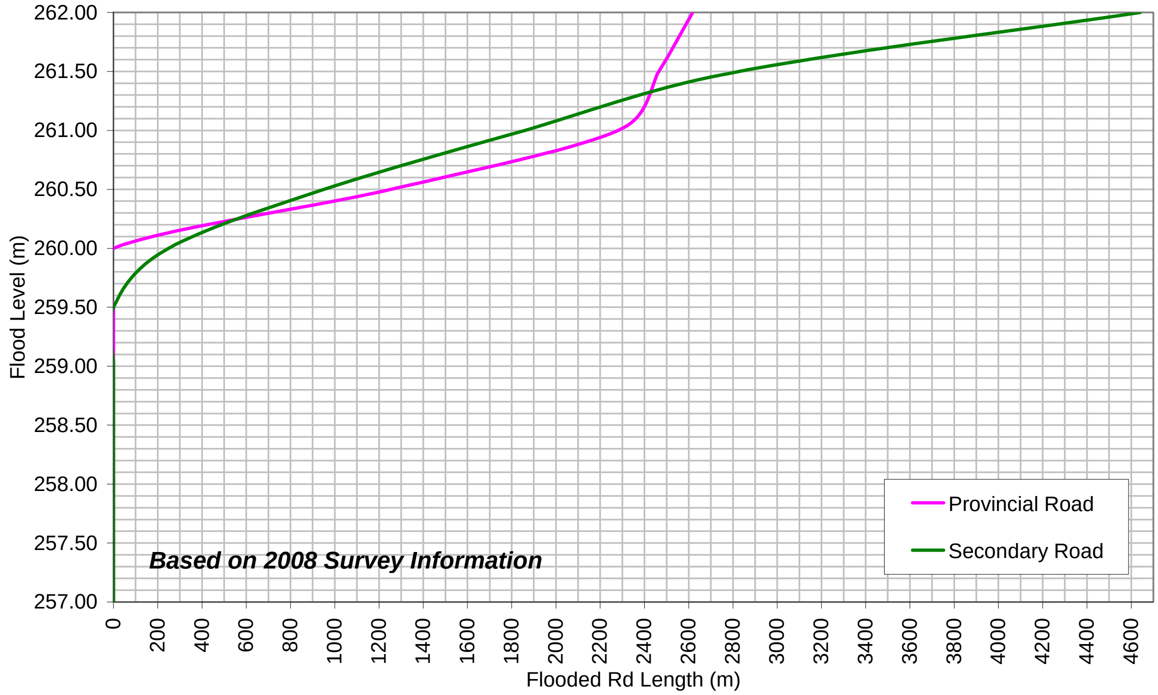



**Figure 7.5 – Flooded Road Lengths for the Vestfold Complex**

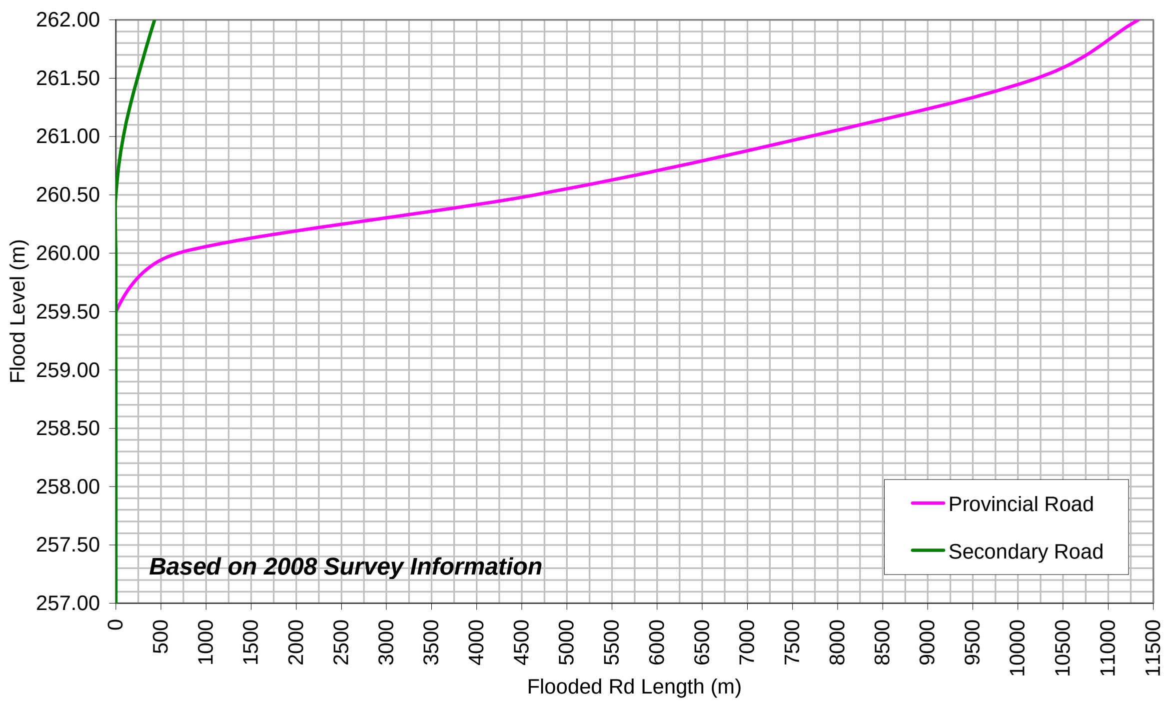



**Figure 7.6 – Flooded Road Lengths for North Shoal Lake**

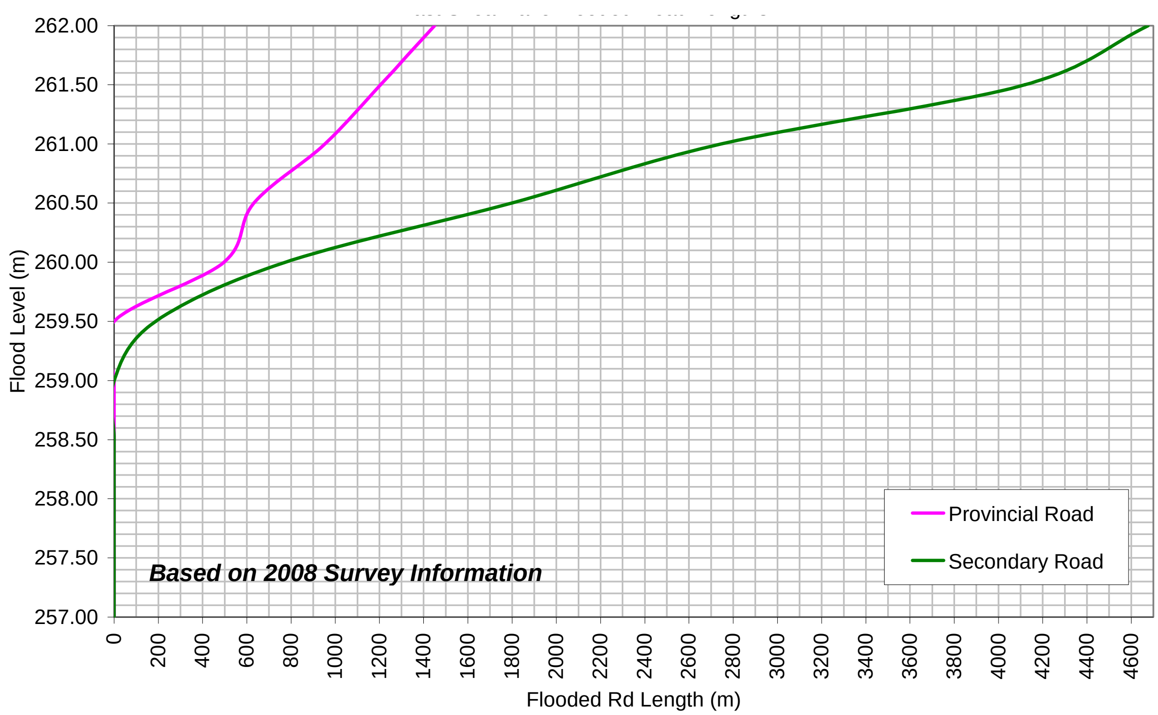



**Figure 7.7 – Flooded Road Lengths for East Shoal Lake**

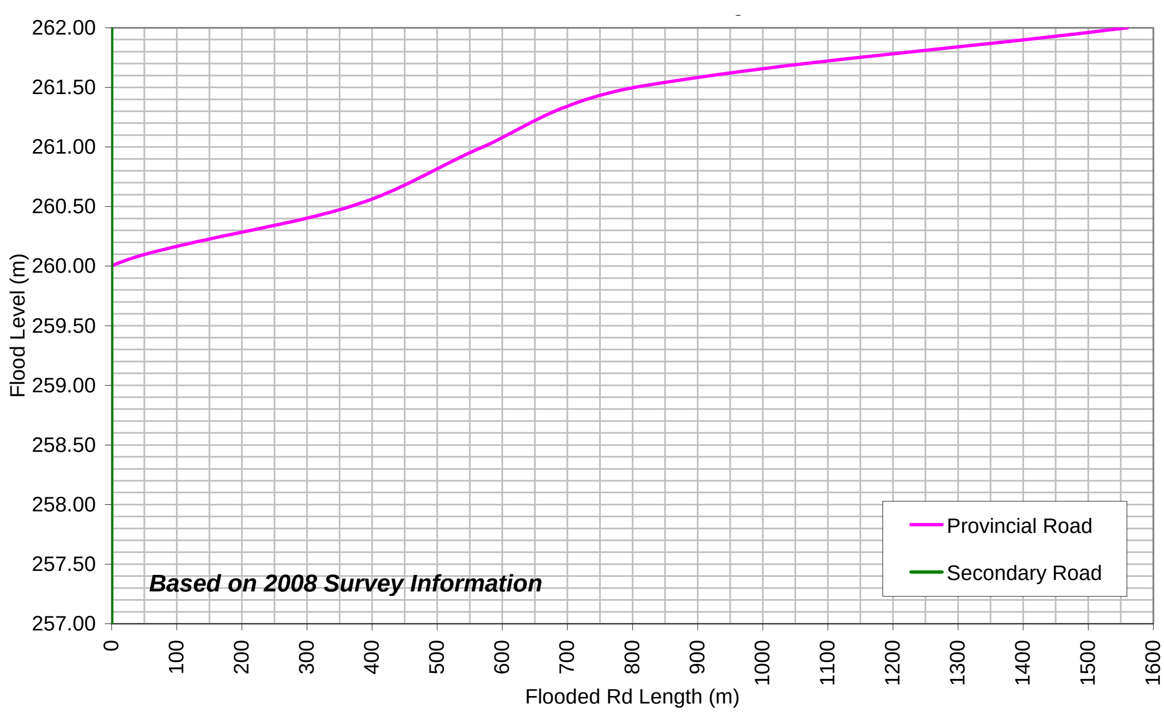



**Figure 7.8 – Flooded Road Lengths for West Shoal Lake**

### 7.2.2 Losses to Crops

Flood damages to crops consist of losses to both annual crops and forage crops. The agricultural land (annual or forage crops) within the flooded area was defined based on the land use and is shown in Figures 7.1 to 7.4.

***Annual Crops Losses***

As shown in Figures 7.1 to 7.4, flood damages to annual crops only would occur in the Vestfold Complex, as that is the only basin of the Shoal Lakes system that has annual cropping practiced. The relationships shown in Figure 7.1 were used to estimate the flooded area of agricultural land during a flood event in the Vestfold Complex basin.

It was assumed that if agricultural land were flooded in any year, it would be unusable for the entire season resulting in a total loss of annual crops (no crops at all). If the land would not be flooded, it was assumed that the farmers could plant their crops by May 1$^{st}$, and no damages would be incurred.

Since accurate annual cropping information for the Vestfold Complex did not exist, it has been assumed that Red Spring Wheat and Argentine Canola are the most common annual crops that are grown within the area. This assumption is based on typical annual grain crops known to be grown in this area of Manitoba. The estimation of annual crops losses due to floods was therefore based on estimated damages to these two dominant crops. Based on information from Manitoba Agricultural Services Corporation (MASC), the total area of land with annual crop production was assumed to have 70% Red Spring Wheat and 30% Argentine Canola. It is recognized that some other crops are grown, but detailed inclusion of their value was not warranted. It is expected that the hypothesis of only wheat/canola would result in conservatively high estimated flood damages.

The relationship between the crop seeding date and relative crop yield is shown in Figure 7.9. These “yield curves” are based on MASC data for a period of record from 1980 to 2001, and are assumed to account for the prime variables that can affect crop production, such as:

- spring flooding
- precipitation
- frost
- other weather conditions that have an adverse effect on crop yield
- the risk associated with disease resulting from delayed seeding (particularly fusarium head blight).

Relative yield (% of average) for wheat and canola for no flooding delay (May 1st seed date) as determined from Figure 7.9 are 112% and 114%, respectively.

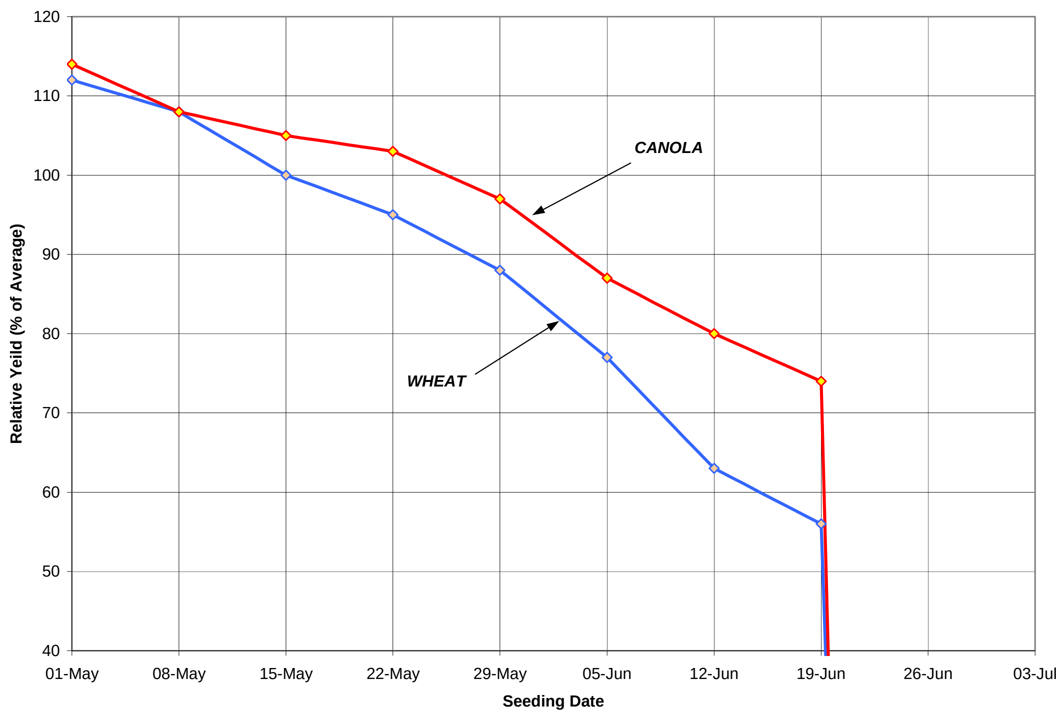



**Figure 7.9 – Relationship between Seeding Date and Relative Yield**

The long term average annual yields are based on the MASC soil classifications and are as published by MCIC. The long term average annual yields for Red Spring Wheat and Argentine Canola are summarized in Table 7.1. The average soil type for the Vestfold Complex was assumed to be "E", which is typical for this land type adjacent to the Vestfold and Shoal Lake, which corresponds to the long term average annual yield values of 2.49 tonne/ha and 1.61 tonne/ha for Red Spring Wheat and Argentine Canola.

**TABLE 7.1**
**LONG TERM AVERAGE ANNUAL YIELDS FOR RED SPRING WHEAT & ARGENTINE CANOLA**

| Soil Classification | Red Spring Wheat (tonne/ha) | Argentine Canola (tonne/ha) |
|---|---|---|
| A | 2.96 | 1.92 |
| B | 2.96 | 1.87 |
| C | 2.74 | 1.68 |
| D | 2.62 | 1.65 |
| E | 2.49 | 1.61 |
| F | 2.18 | 1.38 |
| G | 2.00 | 1.35 |
| H | 1.84 | 1.22 |
| I | 1.80 | 1.13 |
| J | 1.47 | 0.68 |

The price per tonne of each crop was determined based on Manitoba Agriculture data for typical average prices for wheat and canola. The average prices for wheat and canola used for this study are:

- $185/tonne for #1 Red Spring Wheat, 13.5% protein
- $345/tonne for #1 grade Argentine Canola

The damage function for the annual crops is:

$$D_{annual} = \sum_{portion}\left[\sum_{crop}\left(RY_{NF} \times CP \times A \times Y_{LT} \times P_{\#1}\right)\right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*
$\sum_{crop}$ = *symbol for "summation of … for each crop type"*
$D_{annual}$ = *annual crop damages (\$)*
$RY_{NF}$ = *relative yield for no flooding delay (May 1st seed date)*
$CP$ = *percentage of crop*
$A$ = *flooded area (ha)*
$Y_{LT}$ = *long term average annual yield (function of soil classification)(tonne/ha)*
$P_{\#1}$ = *average price for grade #1 crop (\$/tonne)*

### *Forage Crop Losses*

The relationships shown in Figures 7.1 to 7.4 were used to estimate the flooded area of forage land during a flood event. It was assumed that if a forage land were flooded in any year, it would be unusable for the entire year resulting in a total loss of forage crops (no crops at all). If the land would not be flooded, it was assumed that the farmers could grow two forage crops per year (with 45 days of crop maturity), and no damages would be incurred.

The long term average yield for forage crops is 4500 kg per hectare (4.5 tonne/ha), regardless of the soil classification. The price per tonne for forage crop was determined based on Manitoba Agriculture data for average price for hay. The average price for forage used for this study is $62/tonne.

The damages for forage crops are calculated as:

$$D_{forage} = \sum_{portion} \left[ A \times Y_{LT} \times P_{\#1} \right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*
$D_{forage}$ = *forage crop damages ($)*
$A$ = *flooded area (ha)*
$Y_{LT}$ = *long term average yield (tonne/ha)*
$P_{\#1}$ = *average price for top quality crop ($/tonne)*

### *Miscellaneous Losses*

Miscellaneous losses that are not directly accounted by the algorithms described above have been represented as a percent of the total losses to annual and forage crops. In KGS Group's best judgement, an amount of $30 per hectare has been included to account for such flood related damages as:

- denitrification of the fields due to standing water
- clean up costs as a result of the flooded fields

### 7.2.3 Livestock Losses

The relationships shown in Figures 7.1 to 7.4 were used to estimate the flooded area of grassland during a flood event. It was assumed that if grassland were flooded in any year, it would not be available for pasture for that year. In addition to the land not being useable during the year of flooding, it was also assumed that the land would be unusable for the following year, due to the extensive damage to the grasslands that would occur from the flooding the previous year and the time for grass to re-establish to allow for grazing to resume.

The total numbers of livestock in each portion of the watershed is difficult to quantify because there is a limited data on the livestock populations and types. As a result, approximate method has been devised for this purpose. The number of cows in the flooded area was based on a relationship of 0.50 head of cows per hectare. This is believed to be a conservatively high estimate.

Losses of revenue from livestock have been assumed to consist of four main components:

1. Damages related to the pasture renting as a result of unavailability of grazing land due to flooding.
2. Damages related to the transportation i.e. cost of moving cows (to and from the rented pasture) and rancher's monitoring.
3. Damages related to the amount of taxes paid for the unused flooded land.
4. Damages related to the loss of hay production as a result of flooding in the grassland.

***Cost to Rent Pasture***

Damages in this category were estimated to be those costs required to rent pasture as a result of unavailability of grazing land due to flooding. On average, the community pastures are opened for grazing in the 3rd week of May. For a flooding year, it was assumed that the number of days for renting the pasture consist of entire grazing season from May 25th to October 15th (144 days).

It was assumed that if the flooded area of grassland in any year were less than 40 hectare, the farmer would not rent pasture for that year, and that no damages would be incurred. On the other hand, if the flooded area of grassland were more than 40 hectare, the farmer would rent pasture equal to 50% of the flooded area. The total cost to rent pasture was estimated as $15 per hectare per season.

The damages were calculated as:

$$D_{RP} = \sum_{portion} \left[ A \times Rate \right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*

$D_{RP}$ = *cost to rent pasture ($)*

*A = pasture area need to be rented, assumed 50% of the total flooded grassland (ha)*

*Rate = rate to rent pasture ($/ha/season)*

***Cost for Transportation***

Damages in this category are estimated to be equal to the total cost for transportation, i.e. the cost of moving cows (to and from the rented pasture) and the costs for the rancher to routinely travel to monitor their livestock. It was assumed that if the flooded area of grassland in any year were less than 40 hectare, the farmer would not rent pasture for that year, and no transportation costs would be incurred.

The total one-way cost of moving cows was estimated as $14 per cow. This cost was based on the assumption that 25 cows could be transported in one semi-trailer truck. The truck's rent and driver's wage were considered as $100 and $20 per hour, respectively. The total time to load, transport and unload the cows was assumed as three hours.

The rancher's monitoring cost was estimated based on the number of ranchers travelling once a week to the rented pasture. For this purpose, one rancher was assumed per 100 number of cows. The total one-way distance travelled by the rancher was estimated as 20 km at the rate of $0.50 per km.

The damages were calculated as:

$$D_{TR} = \sum_{portion} 2\left[(N_c \times Rate_1) + (N_r \times W \times D \times Rate_2)\right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*
$D_{TR}$ = *total cost for transportation ($)*
$N_c$ = *number of cows to be moved*
$Rate_1$ = *unit cost to move cows in one direction ($/cow)*
$N_r$ = *number of ranchers travelling per week*
$W$ = *number of weeks per grazing season*
$D$ = *distance travelled by the rancher in one direction (km)*
$Rate_2$ = *unit cost for rancher's travelling ($/km)*

***Cost of Taxes***

Damages in this category are estimated to be equal to the amount of taxes paid for the unused flooded land. The cost of taxes was estimated as $5.50 per hectare per year (based on the actual amount of taxes being paid for various quarter sections within the watershed as per personal conversations with Mr. Jack Grandmont).

The damages were calculated as:

$$D_{TX} = \sum_{portion} \left[A \times Rate\right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*
$D_{TX}$ = *cost of taxes ($)*
$A$ = *flooded area (ha)*
$Rate$ = *tax rate ($/ha/year)*

***Loss of Hay Production***

Damages in this category were estimated to be equal to the loss of hay production as a result of flooding in the grassland. If the grassland would not be flooded, it was assumed that the farmers could use 50% of the grassland for hay production and 50% for grazing, and no damages would be incurred.

The long term average yield for hay production is assumed as 4.5 tonne per hectare (same as for the forage crop), regardless of the soil classification. The average price for hay used for this study is $40 per tonne.

The damages due to the loss of hay production are calculated as:

$$D_{HP} = \sum_{portion} \left[ A \times Y_{LT} \times P \right]$$

where,

$\sum_{portion}$ = *symbol for "summation of … for each land portion"*
$D_{HP}$ = *damages due to the loss of hay production ($)*
$A$ = *flooded hay producing area, assumed 50% of the total flooded grassland (ha)*
$Y_{LT}$ = *long term average yield (tonne/ha)*
$P$ = *average price for hay ($/tonne)*

### 7.2.4 Infrastructure Damages

Infrastructure damages mainly consist of damages to building/farm infrastructures, impacts on government facilities and impacts on transportation as described below.

***Damages to Building & Farm Infrastructures***

Damages in this category were difficult to quantify because there is limited data on the topography, farm practices, and locations, numbers and values of buildings and other facilities. For each portion of the watershed, the Government of Manitoba – Property Assessment website [Manitoba 2010] was used to determine locations and values of buildings. The damages due to floods would typically consist of structural damages to the buildings, contents and yards, and associated evacuation and cleanup costs, or of costs required to protect the farm complex. The latter has been adopted for the purposes of this study to identify costs that could be avoided if high water levels in Shoal Lakes could be reduced. Protection to the farm homes, buildings and yards (herein identified as farm "complexes") has been considered to be most effectively accomplished by providing a specially constructed ring dike, and installation and operation of pumps to manage seepage. This ring dike would also provide a location to house livestock until the fields dry adequately for grazing.

The estimated cost to construct a temporary earthen dike around a typical complex of farm buildings was $80,000. This cost is based on the construction of a temporary earthen dike 1 metre high that would be 1 km in length, which would surround the farm complex. A cost of $10,000 has been included for the installation and operation of pumps to manage seepage during the flood. In cases where the assessed value of the buildings was less than $5,000, it was assumed that the farm complex would not be protected and thus the complex would require replacement after the flood event. The assessed value was used as the replacement cost for such buildings.

***Impacts on Government Facilities***

The only government facilities that are impacted in the area are roads, culverts and ditches. The potential damages have been estimated using a relationship between the length of flooded roads in the area and the resulting costs of repairs. The total flood damages to government facilities were estimated using a value of $500,000 and $50,000 per km of flooded road for raising of provincial road and fixing up secondary road respectively.

The relationships shown in Figures 7.5 to 7.8 were used to estimate the lengths of flooded roads (provincial and secondary) during a flood event. The main roads that would be affected due to the raising waters in Shoal Lakes that would require these repairs and effect traffic around and across the Shoal Lakes include PR 229, PR 415, PR 416, and PR 518.

***Impacts on Transportation***

Flooded roads would require traffic to detour and follow a more circuitous route than normal, thereby incurring significant additional travel time and distances.

There is no information on traffic flow in this area, so a pro-ration system based on KGS Group's best judgement has been used to represent this flood damage. It is estimated that damages in this category would be linked to whether damages would occur to roads, as discussed in under the sub-section "Impacts on Government Facilities". A 20% increase in the damages to government facilities has been adopted to represent impacts to transportation.

## 7.3 ESTIMATION OF BENEFITS

Benefits of the construction of the flood mitigation alternatives can be measured by the reduction of future flood damages that would be attributed to the implementation of that alternative. The procedure that has been used in this study is summarized as follows:

1. Flood damages were estimated for each year of the 34 year period of record for the natural conditions. The flood damages were estimated for each sub-basin of the Shoal Lakes Complex (Vestfold, North Shoal Lake, East Shoal Lake, and West Shoal Lake). The estimated flood damages for the natural conditions are summarized in Table 7.2.
2. Total damages were summed for the 34 year period of record for the natural conditions.
3. The average annual flood damages were then determined based on the total damages over the 34 year period of record.
4. The flood damages were then estimated for each year of the 34 year period of record for the alternative with the flood mitigation measures incorporated (i.e. diversion channel or upland storage areas). Steps 2 and 3 were then repeated for the conditions with the flood mitigation alternative. The estimated flood damages for the various flood mitigation alternatives are summarized in Sections 7.3.1, 7.3.2, and 7.3.3.
5. The average annual benefits attributed to the flood mitigation alternative are then represented by the difference between the average annual damages for the natural conditions and those for the conditions with the flood mitigation alternative. The estimated average annual benefits for each of the various flood mitigation alternatives are summarized in Sections 7.3.1, 7.3.2, and 7.3.3.

### 7.3.1 Flood Diversion / Outlet Channel

The benefits associated for each of the flood diversion channels will be the same, as each channel is designed to function the same in terms of water withdrawal from the Shoal Lakes. The estimated flood damages for the conditions with the incorporation of the flood diversion channel are summarized in Table 7.3. The average annual benefit associated with the flood diversion channel is $373,252.

### 7.3.2 Upland Storage Areas

The estimated flood damages for the conditions with the incorporation of upland storage areas are summarized in Table 7.4. The average annual benefit associated with the upland storage areas is $73,572.

### 7.3.3 Purchase of Flood Prone Lands

The estimated flood damages for the purchase of flood prone land is somewhat different than that estimated for the diversion channels and the upland storage areas. The flood damages for the purchase of flood prone land would not include any damages to agricultural or building damages as those lands would have been purchased. Damages would only be associated with the infrastructure damages, since damages to roads would still occur. The estimated flood damages for the conditions with the purchase of flood prone lands are summarized in Table 7.5. The average annual benefit associated with the purchase of flood prone land is $352,883.

**TABLE 7.2**
**SUMMARY OF FLOOD DAMAGES FOR NATURAL CONDITIONS**

| Watershed Sub-Basin | Agricultural Damages | | | | Building Damages | Roads, Infrastructure, Transportation Damages * | Total Flood Damages |
|---|---|---|---|---|---|---|---|
| | Annual Crops | Forage Crops | Livestock | Misc. Farm | | | |
| Vestfold Complex | $83,393 | $526,758 | $1,082,150 | $32,860 | $804,800 | $1,766,337 | $4,296,298 |
| North Shoal Lake | $0 | $373,879 | $2,338,236 | $20,101 | $560,000 | $6,524,286 | $9,816,501 |
| East Shoal Lake | $0 | $83,386 | $2,063,146 | $4,483 | $560,000 | $1,084,534 | $3,795,549 |
| West Shoal Lake | $0 | $0 | $2,979,619 | $0 | $485,200 | $741,849 | $4,206,668 |
| **Total Flood Damages** | **$83,393** | **$984,023** | **$8,463,150** | **$57,444** | **$2,410,000** | **$10,117,006** | **$22,115,016** |

** Note: The damages for roads are based on the 2008 survey information.*

**TABLE 7.3**
**SUMMARY OF FLOOD DAMAGES FOR CONDITIONS WITH THE FLOOD DIVERSION CHANNEL**

| Watershed Sub-Basin | Agricultural Damages | | | | Building Damages | Roads, Infrastructure, Transportation Damages * | Total Flood Damages |
|---|---|---|---|---|---|---|---|
| | Annual Crops | Forage Crops | Livestock | Misc. Farm | | | |
| Vestfold Complex | $1,915 | $70,957 | $423,534 | $3,919 | $320,200 | $1,012,812 | $1,833,338 |
| North Shoal Lake | $0 | $108,939 | $915,073 | $5,857 | $240,000 | $3,040,742 | $4,310,611 |
| East Shoal Lake | $0 | $5,417 | $685,789 | $291 | $160,000 | $615,936 | $1,467,432 |
| West Shoal Lake | $0 | $0 | $1,492,306 | $0 | $161,500 | $159,282 | $1,813,088 |
| **Total Flood Damages** | **$1,915** | **$185,313** | **$3,516,702** | **$10,067** | **$881,700** | **$4,828,771** | **$9,424,469** |

** Note: The damages for roads are based on the 2008 survey information.*

## TABLE 7.4
## SUMMARY OF FLOOD DAMAGES FOR CONDITIONS WITH THE UPLAND STORAGE AREAS

| Watershed Sub-Basin | Agricultural Damages | | | | Building Damages | Roads, Infrastructure, Transportation Damages * | Total Flood Damages |
|---|---|---|---|---|---|---|---|
| | Annual Crops | Forage Crops | Livestock | Misc. Farm | | | |
| Vestfold Complex | $67,129 | $466,173 | $1,031,123 | $28,717 | $320,200 | $1,746,850 | $3,660,192 |
| North Shoal Lake | $0 | $351,913 | $2,245,631 | $18,920 | $240,000 | $6,411,281 | $9,267,745 |
| East Shoal Lake | $0 | $74,539 | $1,944,469 | $4,007 | $160,000 | $1,044,242 | $3,227,257 |
| West Shoal Lake | $0 | $0 | $2,694,197 | $0 | $161,500 | $602,696 | $3,458,394 |
| **Total Flood Damages** | **$67,129** | **$892,624** | **$7,915,420** | **$51,645** | **$881,700** | **$9,805,069** | **$19,613,587** |

** Note: The damages for roads are based on the 2008 survey information.*

## TABLE 7.5
## SUMMARY OF FLOOD DAMAGES FOR CONDITIONS WITH THE FLOOD PRONE LAND PURCHASE

| Watershed Sub-Basin | Agricultural Damages | | | | Building Damages | Roads, Infrastructure, Transportation Damages * | Total Flood Damages |
|---|---|---|---|---|---|---|---|
| | Annual Crops | Forage Crops | Livestock | Misc. Farm | | | |
| Vestfold Complex | $0 | $0 | $0 | $0 | $0 | $1,766,337 | $1,766,337 |
| North Shoal Lake | $0 | $0 | $0 | $0 | $0 | $6,524,286 | $6,524,286 |
| East Shoal Lake | $0 | $0 | $0 | $0 | $0 | $1,084,534 | $1,084,534 |
| West Shoal Lake | $0 | $0 | $0 | $0 | $0 | $741,849 | $741,849 |
| **Total Flood Damages** | **$0** | **$0** | **$0** | **$0** | **$0** | **$10,117,006** | **$10,117,006** |

** Note: The damages for roads are based on the 2008 survey information.*

# 8.0 BENEFIT/COST ANALYSIS

## 8.1 GENERAL

The procedures used in this study are generally consistent with the principles promoted by the Government of Canada in their documents "Federal Guidelines for the National Flood Damage Reduction Program" dated 1985, and "Benefit-Cost Analysis Guide" dated 1998. In accordance with these documents, secondary and tertiary benefits that may be derived from the project have not been included in the analysis. Examples of such exclusion are:

- Project-induced development
- Economic "multiplier effects" due to enhanced disposable income for local farmers and residents
- Business losses that could be compensated by increased production by companies in other jurisdictions
- Future speculative changes in land use that may affect the watershed.

## 8.2 ECONOMIC METHODOLOGY AND PARAMETERS

For a flood protection work to be cost effective, the direct benefits that would be accrued should equal, or preferably exceed, the cost of constructing and operating/maintaining the works. The test that is normally applied is whether the benefit/cost ratio (B/C) for the project exceeds 1.0. A project with a B/C less than 1.0 is one in which the costs exceed the benefits, and unless there are strong intangible benefits that could support the project, it would be difficult to justify.

The procedure used in this study consisted of:

1. Estimation of the present value of the average annual benefits using the following:
   - interest rate of 7% per year
   - inflation rate for the value of future costs and benefits, 3% per year
   - 50 year economic life
2. Estimation of the present value of the cost for each channel option.

3. Computation of B/C as the result of item #1 divided by the result of item #2 (for each flood mitigation option).

## 8.3 RESULTS

The results of the B/C analysis are summarized in Table 8.1. It is evident that none of the options have B/C ratios that would support an economic justification to construct. In fact, using the conservatively high estimates of the benefits that have been adopted throughout this study, the costs of the diversion channel would still be more than 4 times the damages that could be avoided by building the channel.

**TABLE 8.1**
**SUMMARY OF BENEFIT/COST ANALYSIS**

| Flood Mitigation Alternative | Present Value of Costs | Present Value of Benefits | Benefit/Cost |
|---|---|---|---|
| **Flood Diversion Channels** | | | |
| Wagon Creek – Option A | $23,773,000 | $8,018,268 | 0.34 |
| Wagon Creek – Option B | $26,610,000 | $8,018,268 | 0.30 |
| Roy's / Boundary Drain | $31,546,000 | $8,018,268 | 0.25 |
| **Upland Storage Areas** | $4,550,000 | $1,580,487 | 0.35 |
| **Purchase of Flood Prone Land** | $11,361,000 | $7,580,698 | 0.67 |

## 8.4 SENSITIVITY ANALYSIS

The estimates of excavation costs adopted for the cost estimates of the diversion channel alternatives are approximate, however, they comprise a significant component of the cost estimate. The costs that would ultimately be incurred if the project were constructed could vary widely depending on the actual soil conditions that may be encountered, and on market conditions. This sensitivity analyses considered the effect of this variation on the economic viability of the project. The unit price for excavation has been varied from about 50% to 150% of the basic value of $5.50/m³ adopted for the "best estimate". The total costs of the channel options have been adjusted accordingly, and are summarized in Table 8.2.

**TABLE 8.2**
**SUMMARY OF VARIATIONS IN COST OF CHANNELS DUE TO VARIATIONS IN UNIT PRICE OF EXCAVATION**

| Assumption of Unit Prices | Capital Cost of Wagon Creek – Option A | Capital Cost of Wagon Creek – Option B | Capital Cost of Roy's / Boundary Drain |
|---|---|---|---|
| 50% of best estimate | $14,066,000 | $15,534,000 | $17,614,000 |
| 75% of best estimate | $18,920,000 | $21,072,000 | $24,579,000 |
| 100% of best estimate | $23,773,000 | $26,610,000 | $31,546,000 |
| 125% of best estimate | $28,626,000 | $32,148,000 | $38,511,000 |
| 150% of best estimate | $33,479,000 | $37,684,000 | $45,477,000 |

The impact of variation in the unit price of excavation on the benefit / cost ratios is summarized in Figure 8.1. The sensitivity analysis shows that if the unit price was to be 50 % of the current "best estimate", the B/C ratio would rise to 0.57 from about 0.34 for the Wagon Creek – Option A diversion channel. Even under this very optimistic scenario, the costs would still be almost twice the direct benefits from the protection works.

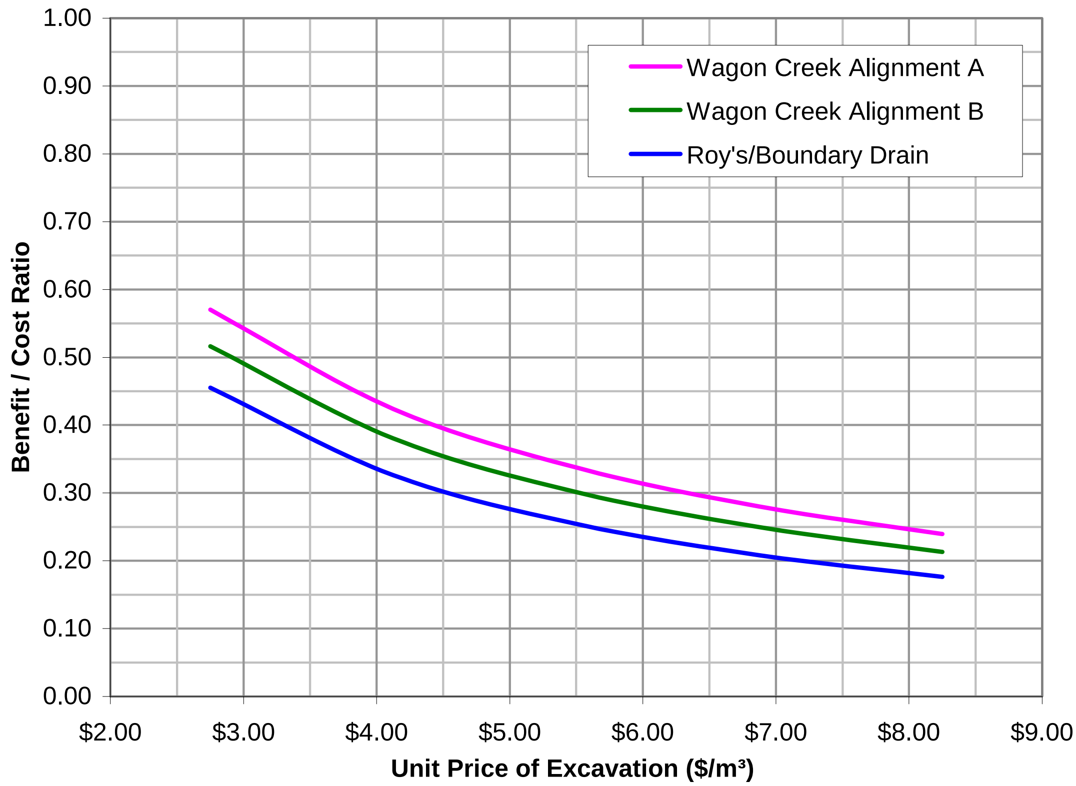



**Figure 8.1 – Impact of Variation of Unit Price of Excavation on Benefit/Cost Ratios**

A sensitivity assessment of the interest rate that was adopted for the economic assessment was also completed. As noted in Section 8.2 an interest rate of 7% per year and an inflation rate of 3% per year, giving an effective discount rate of 4% was adopted for the assessment. The sensitivity to the B/C ratio for varying the interest rate from 5% to 9% (i.e. discount rate from 2% to 6) for each of the flood mitigation alternatives is shown in Table 8.3.

**TABLE 8.3**
**IMPACT OF VARIATIONS IN INTEREST RATE ON BENEFIT/COST RATIO**

| Flood Mitigation Alternative | Interest Rate 5% (Discount Rate 2%) | Interest Rate 7% (Discount Rate 4%) | Interest Rate 9% (Discount Rate 6%) |
|---|---|---|---|
| **Flood Diversion Channels** | | | |
| Wagon Creek – Option A | 0.49 | 0.34 | 0.25 |
| Wagon Creek – Option B | 0.44 | 0.30 | 0.22 |
| Roy's / Boundary Drain | 0.37 | 0.25 | 0.19 |
| **Upland Storage Areas** | 0.51 | 0.35 | 0.25 |
| **Purchase of Flood Prone Land** | 0.98 | 0.67 | 0.49 |

As shown in Table 8.3, with a lower interest rate the B/C ratio for the flood diversion channel options increases to near 0.50, while the B/C ratio for the purchase of flood prone lands nears 1.0.

As noted in Section 7.2.1, the road and transportation damages were based on survey data current at the time of the start of the study in 2008. Since that time, some of the roads surrounding the Shoal Lakes have been raised. Inclusion of the road elevations as of 2010 was not possible for this study; however, higher road elevations would lead to the estimated damages to transportation being less than that shown in Tables 7.2 to 7.5. A sensitivity assessment was carried out, however, to illustrate the potential effect of the raised roads on the resulting B/C ratios presented in Table 8.1. Table 8.4 shows the results of this sensitivity assessment.  The results show that the B/C ratios would be slightly reduced or remain the same if the estimated road damages were either 75% or 50% of those presented in Tables 7.2 to 7.5.

**TABLE 8.4**
**IMPACT OF REDUCED ROAD DAMAGES ON BENEFIT/COST RATIO**

| Flood Mitigation Alternative | Road Damages 100% of Estimated | Road Damages 75% of Estimated | Road Damages 50% of Estimated |
|---|---|---|---|
| **Flood Diversion Channels** | | | |
| Wagon Creek – Option A | 0.34 | 0.30 | 0.27 |
| Wagon Creek – Option B | 0.30 | 0.27 | 0.24 |
| Roy's / Boundary Drain | 0.25 | 0.23 | 0.20 |
| **Upland Storage Areas** | 0.35 | 0.34 | 0.33 |
| **Purchase of Flood Prone Land** | 0.67 | 0.67 | 0.67 |

Sensitivities of the economic analysis to variation in benefits were not tested. The general philosophy that has been used in this study of estimating all benefits at the upper end of a range of justifiable values precludes the need for sensitivity analysis for this aspect. It is considered so unlikely that the benefits could be more than as estimated in this study, that there would be no point in speculating how the B/C ratio would improve if the benefits were even higher than estimated in Section 8.3.

# 9.0 ENVIRONMENTAL ASSESSMENT OF FLOOD MITIGATION ALTERNATIVES

## 9.1 EFFECTS TO AQUATIC AND WATERFOWL HABITAT

***Aquatic Habitat***

The assessment focuses on fish habitat due to its importance to fish, and addressing requirements under the federal Fisheries Act. Section 35 of the Act prohibits the harmful alteration, disruption, or destruction of fish habitat. Fish habitat is defined in the Fisheries Act as "spawning grounds and nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly in order to carry out their life processes."

The only flood mitigation alternative that would affect the aquatic habitat in the Shoal Lakes would be the flood diversion channels.

Removing water from the Shoal Lakes via the diversion channels has the potential to lead to basins that are critically dewatered compared to the natural conditions as illustrated in Section 5.0 (from the perspective of biota that would otherwise inhabit them). The proposed lake regulation would also reduce the flooded area of the basins and disrupt the vegetation dynamics currently established in the system. After the basins reach a significantly low elevation (i.e., under natural and/or human influences), they require a lengthy period of recharge (which can extend over >1 year) to recover to normal water levels. During this period, vegetation dynamics will change; the ultimate state of the vegetation is uncertain, but the risk of disruption is certain. Therefore, seasonal dewatering of the basins by artificial means will impact habitats (e.g., water depth, dissolved oxygen levels, food diversity and availability, and vegetation distribution) relied upon by biota requiring a purely aquatic environment (i.e., fish), but also of biota that require a close association with aquatic environments (e.g., amphibians). The likely result will be a general reduction in habitat area, and destruction of habitat and fish stocks during very low water level years.

Although the very low lake levels that would occur during droughts would eliminate all fishes and fish habitats, subtler impacts will also occur as the lake levels decline to these lower elevations. The reduction in the volume and surface area of the lakes would expose the sediments on which aquatic macrophytes (e.g., cattail; bulrush; sedge) grow. This process occurs naturally during dry years and is essential for seed germination and the maintenance of a healthy wetland environment. Under a natural hydrologic condition, the normally inundated areas typically recover as water levels are indirectly recharged from overland runoff, and directly recharged from precipitation events (complete recovery may require >1 year under natural conditions). However, under the regulated hydrologic condition, the potential exists to move the vegetated area down-slope from the existing shoreline and closer to the centre of each basin. The net result may then be an overall decline in lake areas, but also the potential for macrophytes to encroach and dominate the entire basin when maximum depths become less than 1.0 m, especially where soil and seedbed conditions are supportive (the fertility and extent of seedbed in the basins are currently unknown; this effect may not be completely realized where fertility is low and seed availability has been depleted).

The dominance of a vegetated state (instead of the concurrent existence of some open water areas interspersed with the vegetation) would eliminate the open-water habitats and the cooler, deeper waters preferred by some aquatic biota. Additionally, a shallower water column is more likely to freeze completely to the bottom, resulting directly in mortalities of biota (e.g., fish and amphibians) during the ice-covered season. Overall, the proposed lake level regulation would result in degradation and loss of spawning and over-wintering habitats.

A secondary effect, although extremely unlikely based on the design of the diversion channels and the incorporation of the drop structures, is the potential introduction of fishes from Lake Manitoba into the Shoal Lakes. The fishery in Lake Manitoba has a high capability for fish production (Class 1; K. Kristofferson, 1990, pers. comm.; FIHCS database) and construction of a drain between Shoal Lakes and Lake Manitoba could cause fish from Lake Manitoba to migrate into the Shoal Lakes if the drop structures are not designed to prohibit fish movement up the diversion channel. Such introductions would alter the community assemblage and ecosystem in Shoal Lakes, specifically if the new fish were predators of stickleback. Additionally, if water levels in Shoal Lakes declined after the migration event and were sufficiently low to prohibit access to the drain for downstream fish movement, this would result in fish stranding and potential mortality of species intolerant to over-wintering hypoxia.

Although likely a relatively temporary occurrence, erosion of soil along the diversion channel could increase the turbidity, locally, in the receiving waters. This could result in populations of fishes that are visual feeders or use visual displays during breeding to be negatively impacted in these localized areas of potentially increased turbidity.

***Waterfowl Habitat***

Maintenance of the habitat along migration routes and in the staging and breeding grounds is essential to the survival of many avian species (SARA 2009). Specifically, wetlands provide water, food, protective cover, and breeding and staging areas for a variety of waterfowl species. The presence of islands or rocky areas can also be important for certain birds. Potential impacts of regulation of the Shoal Lakes in terms of reducing the surficial area of the lakes, and thus altering the presence or abundance of staging and breeding habitats for avian species known to be present in the Shoal Lakes area, are discussed within this section.

As with the fish and fish habitat, the degree to which the surface area of the lakes changes will be the largest factor determining the level of impact on avian species. Many of the birds that breed in the Shoal Lakes area create nests in aquatic areas concealed by vegetation, or use plant material to line nests formed in depressions on the ground. Changes in the vegetation dynamics (e.g., the surficial area of macrophyte beds) of this aquatic system could negatively impact the breeding populations of those species. Additionally, reducing the surface area of the lakes will reduce the area available to staging waterfowl and wading birds that migrate through the area.

Although it is acknowledged that periodic dry-down or dewatering of the basins is essential for habitat maintenance (Murkin et al. 2000), anthropogenically-influenced dewatering (constructed drainage) typically disrupts local hydrology, and often leads to the conversion of such regions to land use skewed towards agricultural production rather than mutual benefits for wildlife and agriculture (Goldsborough pers. comm. 2009).

Similar to concerns regarding fish habitat, the extent of change in the surface area of the lakes, change in the system's vegetation dynamics, and (especially for waterfowl and wading birds) the change in the distribution of aquatic vegetation areas and open water areas will be the largest factor determining the level of impact on avian species. Changes of this nature will negatively impact the breeding populations of avian species known to use the Shoal Lakes region.

## 9.2 EFFECTS ON WATER QUALITY IN LAKE MANITOBA

The proposed drainage channel options would flow from West Shoal Lake into the southeast portion of Lake Manitoba, near the communities of Oak Point and St. Laurent. The Province periodically assesses water quality at St. Ambroise Beach, a provincial park in the south-eastern portion of the lake. Water quality at the beach and at a sampling point in the narrows has been used to infer the degree to which the quality of Lake Manitoba waters could change if the Shoal Lakes diversion channel is implemented.

The following sub-sections provide an overview of the approach and methods used to assess the potential impacts of diversion of surface water from Shoal Lakes to Lake Manitoba on water quality.

### 9.2.1 Approach

Key water quality parameters were identified for consideration in the impact assessment and included those variables measured during the water quality sampling program conducted in Shoal Lakes in 2008. The general approach taken for assessing impacts to water quality involved:

- A direct comparison between the water quality of Shoal Lakes and Lake Manitoba,
- An assessment of the potential effect of key parameters on the south basin of Lake Manitoba using a mass-balance modelling approach, and
- A comparison of the estimated loads of nutrients that would be introduced to Lake Manitoba from the Project, relative to existing loads.

***Comparison between Shoal Lakes and Lake Manitoba Water Quality: Screening Assessment***

A direct comparison of water quality conditions between Shoal Lakes and Lake Manitoba was conducted to identify those parameters with the potential to adversely affect water quality in Lake Manitoba. Specifically, this comparison was used first to identify those parameters that were higher in Shoal Lakes relative to Lake Manitoba and therefore could theoretically adversely affect water quality (Step 1) and second, of these parameters, which would be predicted to cause or contribute to exceedences of water quality objectives and guidelines in the nearshore environment of Lake Manitoba (Step 2).

As diversion would occur during the open-water season, nutrient concentrations, chloride, sulphate and in situ conditions measured in the waterbodies are compared for this time period. Although metals were only measured in Shoal Lakes during the ice-cover, it was assumed that seasonal trends in metal concentrations in Shoal Lakes were similar to those observed in Lake Manitoba (i.e., that winter concentrations were representative of the concentrations that occur throughout the year).

It is cautioned that direct comparisons of these data must be interpreted with caution as the data were collected during different years and with different sampling frequencies. In addition, the quantity of data is limited and may not capture the ranges encountered over longer periods.

Parameters that indicated the potential to adversely affect water quality in Lake Manitoba through this screening exercise were retained for the next phase of assessment (i.e., the mass-balance modelling approach). These substances are hereafter referred to as substances of potential concern (SOPCs). Parameters identified in Step 1 but for which there are no MWQSOGs, were also identified as SOPCs.

***Mass-Balance Modelling Approach***

The second approach for assessing impacts was the use of a mass-balance model to determine the impact of the full volume of diverted water on water quality in the south basin of Lake Manitoba. To evaluate the overall range of potential effects of the diversion on water quality, the minimum and maximum discharge volumes predicted from the hydrological assessment (Section 5.0) were used to estimate the range of loads of water quality substances. It is noted, that the actual range of annual inputs from the proposed diversion channels would range from zero in years where no discharges would occur.

The mass balance modelling focused specifically on the compounds where concentrations in Shoal Lakes were higher than those measured in Lake Manitoba (i.e., SOPCs), as identified through the first phase of the assessment. Loads of SOPCs associated with the water diversion were calculated as the product of the mean concentration measured across Shoal Lakes and the discharge rates. The mass-balance model incorporated background loads of SOPCs in Lake Manitoba to determine the overall additive effect of the Project. Background loads for Lake Manitoba were calculated using the volume of the south basin of the lake and mean concentrations of SOPCs measured in the open-water season as described in the previous sections. Lake volume (14.625 $km^3$) for the south basin was calculated from the mean lake depth (4.5 m) and surface area (3,250 $km^2$) for the south basin reported, as in Last (1984).

Mass-balance concentrations for Lake Manitoba were compared to the MWQSOGs to assess whether the resulting water in Lake Manitoba would be suitable for drinking water, irrigation of gardens and fields, livestock watering, and aquatic life.

***Comparison of Nutrient Loading***

A third approach was used to evaluate the potential effects of the Project on nutrients in Lake Manitoba as the issue of nutrient enrichment of aquatic ecosystems is a critical one in Manitoba as it is elsewhere. This entailed the comparison of the predicted loads of nutrients that would be released to Lake Manitoba as a result of the Project, relative to the loads of nutrients introduced to the south basin of Lake Manitoba from the Whitemud River and the Portage Diversion, as reported in Bourne et al (2002). The mean annual loads of TP and TN to Lake Manitoba were calculated as the product of the mean concentration across Shoal Lakes measured in 2008 and the total anticipated volume of diverted water, divided by the number of years on record.

These loading rates were then compared to current loading rates to Lake Manitoba from the Whitemud River and the Portage Diversion, as well as current in-lake loads of nutrients.

### 9.2.2 Screening Assessment

With few exceptions, mean concentrations of in situ parameters, routine variables, and metals were higher in Shoal Lakes than in Lake Manitoba (Table 9.1). Exceptions include: chloride; barium; calcium; manganese; and molybdenum. The remaining substances would therefore have the potential to cause localized increases in the immediate receiving environment of Lake Manitoba and potentially over the entire basin. The magnitude and the spatial extent of these increases would in turn, depend upon the degree of difference between the concentrations measured in the diversion outflow (i.e., estimated from Shoal Lakes water quality conditions) and Lake Manitoba, the overall volume of diverted water, and mixing properties in the lake.

Of the parameters that are higher in Shoal Lakes than Lake Manitoba as indicated in Table 9.1, a number are currently present at concentrations below Manitoba water quality objectives and guidelines for various water usages in Shoal Lakes, including:

- Ammonia
- Nitrate/nitrite
- Sulphate
- Antimony
- Arsenic
- Beryllium
- Cadmium
- Copper
- Iron
- Lead
- Nickel
- Thallium
- Uranium
- Vanadium
- Zinc

Although introduction of these substances to Lake Manitoba would result in a localized increase in concentrations, the diversion would not be expected to cause or contribute to exceedences of water quality objectives or guidelines for these substances.

The following variables were identified as SOPCs as they are both higher in Shoal Lakes and currently above water quality objectives or guidelines in Shoal Lakes:

- pH (above the aesthetic drinking water quality guideline in both lakes);
- specific conductance (above the guidelines for irrigation);
- TDS (above the guidelines for irrigation and the aesthetic drinking water quality guideline);
- TP (above the narrative guideline for eutrophication);
- Aluminum (above the guideline for the protection of aquatic life);
- Boron (above the guideline for irrigation);
- Chromium (above the guideline for irrigation);
- Selenium (above the guideline for the protection of aquatic life); and
- Silver (above the guideline for the protection of aquatic life).
- Sodium (above the aesthetic drinking water quality guideline);

**TABLE 9.1**
**COMPARISON OF MEAN ROUTINE AND METAL CONCENTRATIONS IN SHOAL LAKES AND LAKE MANITOBA**

| Parameter | Unit | Shoal Lakes | Lake Manitoba |
|---|---|---|---|
| **Routine: Open-water** | | | |
| Ammonia | mg N/L | 0.046 | 0.030 |
| Nitrate/Nitrite | mg N/L | 0.059 | <0.01 |
| DO | mg/L | 8.2 | - |
| pH | - | **8.87** | **8.62** |
| Conductivity | uS/cm | **1949** | **1285** |
| Total Dissolved Solids | mg/L | **1233** | **826** |
| Total Phosphorus | mg/L | **0.110** | **0.070** |
| Total Nitrogen | mg/L | 2.4 | 2.1 |
| Turbidity | NTU | **53** | **20.6** |
| Total Suspended Solids | mg/L | 26 | 17 |
| Sulphate | mg/L | 267 | 145 |
| Chloride | mg/L | 110 | 306 |
| **Metals: Winter** | | | |
| Hardness (as $CaCO_3$) | mg/L | 950 | 312 |
| Aluminum | mg/L | **0.147** | 0.047 |
| Antimony | mg/L | <0.001 | 0.0005 |
| Arsenic | mg/L | 0.0066 | 0.0026 |
| Barium | mg/L | 0.042 | 0.064 |
| Beryllium | mg/L | <0.001 | <0.0002 |
| Boron | mg/L | **0.91** | 0.15 |
| Calcium | mg/L | 28.9 | 38.6 |
| Cadmium | mg/L | 0.00007 | <0.00004 |
| Chromium | mg/L | **0.005** | 0.0003 |
| Copper | mg/L | 0.003 | 0.001 |
| Iron | mg/L | 0.13 | 0.07 |
| Lead | mg/L | 0.0012 | 0.0002 |
| Magnesium | mg/L | 213 | 50.4 |
| Manganese | mg/L | 0.0055 | 0.0079 |
| Mercury | mg/L | <0.00005 | - |
| Molybdenum | mg/L | 0.0014 | 0.0026 |
| Nickel | mg/L | 0.005 | 0.001 |
| Potassium | mg/L | 74.7 | 14.2 |
| Selenium | mg/L | **0.003** | <0.0004 |
| Silver | mg/L | **0.0002** | <0.00002 |
| Sodium | mg/L | **346** | 193 |
| Thallium | mg/L | 0.0002 | <0.0002 |
| Uranium | mg/L | 0.0033 | 0.0023 |
| Vanadium | mg/L | 0.006 | 0.0016 |
| Zinc | mg/L | 0.02 | 0.002 |

Note: Parameters indicated in blue are higher in Shoal Lakes than Lake Manitoba; parameters in **bold red** exceed the Manitoba water quality objectives and guidelines (see Tables B1 to B3 in Appendix B).

As there are no water quality guidelines for TN, potassium, magnesium, and hardness but all are higher in Shoal Lakes, these substances were also identified as SOPCs for further consideration. In addition, as the objectives for TSS refer to a relative change from background, this parameter was also considered an SOPC.

### 9.2.3 Potential Effects of SOPCs on the Water Quality of the South Basin of Lake Manitoba

The mass of SOPCs that would be transferred from Shoal Lakes to Lake Manitoba as a result of the diversion channel is outlined in Table 9.2.

Although the mass of SOPCs transferred into Lake Manitoba will be quite large during years of discharge (only 9 in the 31 year period of record assessed), the addition of these compounds is expected to have a relatively small effect on the water quality in Lake Manitoba after dilution throughout the south basin (i.e., in the fully mixed condition; Table 9.2). The relative increase in SOPCs in the fully mixed condition would be less than 10% above background conditions. For most SOPCs, the percent increase above background is predicted to be <1% and would likely not be detectable.

Mass-balance modelling indicates that the release of the diversion water would not result in exceedences of water quality objectives or guidelines in the fully mixed condition that are currently met in Lake Manitoba. pH, conductivity, TDS, and TP are currently above guidelines and are predicted to remain above guidelines with the diversion of Shoal Lakes water at concentrations that would be relatively unchanged from current levels.

**TABLE 9.2**
**ESTIMATED CONCENTRATIONS OF SOPC IN LAKE MANITOBA RESULTING FROM DIVERSION PROJECT**

| Parameter | Discharge Concentration (mg/L) | Background Concentration (mg/L) | Estimated Whole Lake Concentration (mg/L) | Difference (%) |
|---|---|---|---|---|
| **Minimum Discharge** | | | | |
| Hardness | 950 | 312 | 312.029 | 0.01 |
| Total Nitrogen | 2.4 | 2.1 | 2.100 | 0.00 |
| Boron | 0.91 | 0.15 | 0.150 | 0.02 |
| Aluminum | 0.147 | 0.047 | 0.047 | 0.01 |
| Chromium | 0.005 | 0.0003 | 0.00030 | 0.05 |
| Conductivity | 1949 | 1285 | 1285 | 0.00 |
| Magnesium | 213 | 50.4 | 50.406 | 0.01 |
| Nitrogen | 2.4 | 2.055 | 2.055 | 0.00 |
| pH | 8.87 | 8.62 | 8.62 | 0.00 |
| Phosphorus | 0.11 | 0.07 | 0.070 | 0.00 |
| Selenium | 0.003 | 0.0002 | 0.00020 | 0.05 |
| Silver | 0.0002 | 0.00001 | 0.00001 | 0.06 |
| Total Dissolved Solids | 1233 | 826 | 826 | 0.00 |
| Potassium | 74.7 | 14.2 | 14.2 | 0.02 |
| Total Suspended Solids | 26 | 17 | 17 | 0.00 |
| Turbidity | 31 | 20.6 | 20.6 | 0.00 |
| Sodium | 346 | 193 | 193 | 0.01 |
| **Maximum Discharge** | | | | |
| Hardness | 950 | 312 | 316 | 1.17 |
| Total Nitrogen | 2.4 | 2.1 | 2.102 | 0.08 |
| Boron | 0.91 | 0.15 | 0.154 | 2.85 |
| Aluminum | 0.147 | 0.047 | 0.048 | 1.22 |
| Chromium | 0.005 | 0.0003 | 0.00033 | 8.31 |
| Conductivity | 1949 | 1285 | 1289 | 0.30 |
| Magnesium | 213 | 50.4 | 51.3 | 1.83 |
| Nitrogen | 2.4 | 2.055 | 2.057 | 0.10 |
| pH | 8.87 | 8.62 | 8.62 | 0.01 |
| Phosphorus | 0.11 | 0.07 | 0.070 | 0.33 |
| Selenium | 0.003 | 0.0002 | 0.000216 | 7.49 |
| Silver | 0.0002 | 0.00001 | 0.000011 | 9.90 |
| Total Dissolved Solids | 1233 | 826 | 828.355 | 0.28 |
| Potassium | 74.7 | 14.2 | 14.550 | 2.41 |
| Total Suspended Solids | 26 | 17 | 17.052 | 0.31 |
| Turbidity | 31 | 20.6 | 20.660 | 0.29 |
| Sodium | 346 | 193 | 193.885 | 0.46 |

### 9.2.4 Comparison of Nutrient Loading to Lake Manitoba

The Whitemud River and Portage Diversion currently drain into the south basin of Lake Manitoba and deliver over 250 times more nutrients (as a load) than would be transferred to the lake as a result of the Project. The average nutrient load in the Whitemud River between 1994 and 2001 was 418,000 kg TN/yr and 30,000 kg TP/yr (Bourne et al. 2002). The diversion of water from the Assiniboine River into Lake Manitoba via the Portage Diversion results in a substantial input of nutrients into the south basin of the lake: 3,297,000 kg TN/yr and 542,000 kg TP/yr (Bourne et al. 2002). Under the low water level target, the Shoal Lake Diversion would introduce between 26,119 and 172,864 kg TN/yr and between 1,197 and 7,923 kg TP/yr (Table 9.3). Under the moderate water level target, the Shoal Lake Diversion would introduce between 1,065 and 204,247 kg TN/yr and between 49 and 9,361 kg TP/yr (Table 9.3). These loads represent <2% of the current annual average TP loads and <6% of the current annual average TN loads introduced to the south basin of Lake Manitoba from the Whitemud River and Portage Diversion. In addition, the estimated loading from the Shoal Lakes Diversion represent less than 1% of the TN and TP loads present in the south basin of Lake Manitoba.

**TABLE 9.3**
**DISCHARGE CONCENTRATIONS, VOLUMES, AND LOADING RATES IN LAKE MANITOBA RESULTING FROM DIVERSION PROJECT**

| Parameter | Discharge Concentration (mg/L) | Discharge ($m^3$/year) | Loads (kg/yr) |
|---|---|---|---|
| **Minimum)** | | | |
| Total Nitrogen | 2.4 | 443638 | 1065 |
| Total Phosphorus | 0.11 | 443638 | 49 |
| **Maximum** | | | |
| Total Nitrogen | 2.4 | 85103101 | 204247 |
| Total Phosphorus | 0.11 | 85103101 | 9361 |

### 9.2.5 Summary of Water Quality Impact Assessment

Most water quality parameters are present in higher concentrations in Shoal Lakes than Lake Manitoba and would be expected to affect water quality conditions in the mixing zone in the lake. However, with the exception of pH, TDS, conductivity, TP, turbidity, boron, sodium, aluminum, boron, chromium, silver, and selenium (SOPCs), all variables, including those that are higher in Shoal Lakes, would not be expected to cause or contribute to exceedences of water quality objectives or guidelines as they are currently within these criteria in Shoal Lakes. Diversion of water from the Shoal Lakes may cause or contribute to exceedences of water quality objectives and guidelines in the mixing zone for the aforementioned parameters.

Mass-balance modelling indicates that most SOPCs would generally cause a change of <1% above background in the fully mixed condition in the south basin of Lake Manitoba. The highest relative increases in concentrations estimated with this model are for selenium (7% increase) and silver (10% increase) but these increases are not expected to result in an exceedance of the water quality guidelines in the fully mixed condition. In general, the estimated increases in SOPCs in the south basin as a whole would not be expected to be detectable.

Overall, the Project is expected to cause localized increases in pH, TDS, conductivity, TN, TP, turbidity, TSS, ammonia, nitrate/nitrite, hardness, aluminum, antimony, arsenic, boron, cadmium, chromium, copper, iron, lead, magnesium, nickel, potassium, selenium, silver, sodium, thallium, uranium, vanadium, and zinc in Lake Manitoba near the inflow from Shoal Lakes but not measurably in the south basin as a whole. As the estimated mass-balance concentrations of TN and TP with the Project are not expected to cause a detectable change in the lake concentrations, trophic status of the overall south basin of Lake Manitoba is not expected to be altered by the Project. However, given that TP is notably higher in Shoal Lakes than Lake Manitoba, local nutrient enrichment effects near the location of inflow to Lake Manitoba may occur.

## 9.3 QUANTIFICATION OF ENVIRONMENTAL EFFECTS

As noted in Section 7.1, environmental impacts associated with a project are difficult to quantify in terms of benefits or dis-benefits to a project. However, an approach to quantify the environmental effects has been developed.

As described in Sections 9.1 and 9.2, there are negative environmental effects that would be associated with the implementation of a flood diversion channel to regulate the Shoal Lakes water levels.

The water quality assessment, described in Section 9.2, noted that the diversion of Shoal Lakes water to Lake Manitoba is expected to cause localized increases a number of parameters, however, those increases are not considered to be significant. As well, these increases in the various parameters would only be evident in Lake Manitoba near the source of the outflow from the Shoal Lakes diversion channel, but would not be measurably noticeable within the south basin as a whole. If the parameters were considered to have a significant effect on the water quality in Lake Manitoba, a filter system would be required to "clean" the water from Shoal Lakes prior to its introduction to Lake Manitoba. Since the introduction of the Shoal Lakes water does not have a notable effect on Lake Manitoba there is no requirement for a water filter, and therefore we have not included a cost for such a system in this study.

The environmental assessment related to fishes, birds, and waterfowl, presented in Section 9.1, concluded that there would be a negative impact to both fishes in the Shoal Lakes, as well as, a negative impact to the breeding populations of avian species known to use the Shoal Lakes region. Since the Shoal Lakes have been recognized as national importance to the avian species, this environmental impact is considered to be significant.

Quantification of the value of the Shoal Lakes to the aquatic and avian population is quite difficult. Information documented in the Environment Canada reference, "The Importance of Nature to Canadians: The Economic Significance of Nature Related Activities" defines the value of nature related activities to Canadians. These nature related activities include outdoor activities such as camping, hiking, boating, etc., wildlife viewing, recreational fishing, as well as hunting. This report defines that residents of Manitoba spent a total of $427.6 million on nature-related activities during 1996. The report defines the proportion of this money that was spent on the various activities; however, there is no indication of the spatial distribution of where this money was spent. Therefore, this information is difficult to apply to this study to quantify the environmental effects of the flood mitigation alternatives.

If the population of waterfowl were negatively affected as a result of the project, as the environmental assessment would conclude, this would in turn lead to a reduction in outdoor activities within the Shoal Lakes area such as hunting. One quantifiable effect to the project would be the loss of revenue to the area related to hunting. This however, is an activity that is typically not included in an economic assessment, as any hunting activities that would be reduced in the Shoal Lakes areas would likely transfer to other areas in Manitoba. The net effect to the Province on the revenues from hunting activities would therefore remain unchanged. As well, noted above, Environment Canada (2000) quantified the total amount of money spent on hunting activities, but there is no indication of where that money is spent.

A more relevant reference that provides information to quantify the value of the loss of wetlands habitat as it related to avian and aquatic wildlife is the "Wetlands Habitat Compensation Plan" that was developed by the Province of Manitoba in 2005 for the upgrades to the PTH 1 in western Manitoba. The upgrades to PTH 1 included twinning of the highway, which resulted in the alteration and destruction wetlands within the internationally recognized North American Waterfowl Management Plan Target Area. As a result, the Province developed a value of the affected wetlands and provided a monetary contribution to secure and protect additional wetlands, as well as, construct improvements to existing wetlands. The PTH 1 upgrades resulted in an alteration / destruction of 53.9 hectares of wetlands. The monetary value applied to this area was $304,000, or a cost of $5,640 per hectare in 2005 dollars.

The implementation of the Shoal Lakes diversion channel has the potential to negatively affect a significant area that is used as wetlands habitat. The total area of wetlands negatively affected from the project could be determined using one of two different methods, as described below.

- Method 1: The area that would be permanently changed over the period of record for both the high and low levels of each lake. That is, the summation of the difference in the flooded area at the peak water level on each lake for the natural and regulated case plus the difference in the flooded area at the minimum lake levels for each lake for the natural and regulated conditions. This would yield a permanent change in flooded area of approximately 6,600 hectares.

- Method 2: The difference in average flooded areas for each lake over the period of record between the natural and regulated conditions. This would yield a permanent change in flooded area of approximately 4,600 hectares.

If a similar monetary value of the wetlands that was adopted for the PTH 1 upgrade project (inflated to 2009 dollars) was applied to the area of affected wetlands in the Shoal Lakes estimated from both methods described above, the value of this would range from $30 to $44 million.

If the cost associated with the negatively affected area of wetlands ($30 to $44 million) were included in the benefit / cost assessment for the flood diversion channels, outlined in Section

8.0, then the B/C ratio associated with the flood diversion channel projects would be reduced to 0.11 to 0.15 for each of the alternate flood diversion channels. Any environmental effects, not described above, would only further reduce the B/C ratio for the projects.

The other flood mitigation alternatives considered in this study, upland storage areas and purchase of flood prone lands, were shown in Section 5.0 not to affect the lake levels much (upland storage) or at all (purchase of flood prone land).

There would be some negative environmental damages to lands used for upland storage due to the flooding of land used for the storage areas. These damages have not been quantified but would not be that significant and would only add to the damages and reduce the B/C ratio for this alternative. Therefore, there has been no consideration for quantifying the environmental effects associated with those alternatives as has been done for the flood diversion channels.

As noted in Section 4.4.1, the land that would be purchased as part of this flood mitigation option could be leased back to the local farmers in periods of low water level, or alternatively could be converted into a Wildlife Management Area. The end use of any land purchased would have to be determined by the various levels of government involved as well as the various stakeholders involved. The definition of the end use of the purchased land was not part of the scope of this study. If the land was leased back to the farmers in drier times, the environmental effects would be expected to be similar to what has occurred over history, therefore there would be no change and no expected benefit or damages. However, if the land were converted into a wildlife management area, there would be expected to be a number of environmental benefits. Since the end use of the land is uncertain at this time, there has been no effort to quantify these benefits for this study.

# 10.0 CONCLUSIONS

The following conclusions can be made based on the findings of the Shoal Lakes watershed study as documented within this report:

- The Shoal Lakes complex consists of three main bodies of water, West Shoal Lake, East Shoal Lake, and North Shoal Lake. Due to the topographic relief surrounding the Shoal Lakes, the system is generally a land-locked drainage basin with no natural outlet for the lakes. However, when the lakes are at high levels, there have historically been natural overflows to the east into the Grassmere drainage system. In the past when these overflows have occurred, the local authorities have either raised the roads or closed the drainage paths to eliminate the overflow to the adjacent drainage basin.

- The land in the vicinity of the Shoal Lakes, between the normal levels and the flood levels of 2010 consists of 50 to 60% of Class 7 land, which is considered not suitable for agricultural purposes, 40 to 50% of Class 5 land, which is considered to be suitable for hay and pasture activities, and about 5 to 10% of Class 4 land which is considered to be marginal for annual crop production

- There is little information available regarding the hydrologic and hydraulic characteristics of the Shoal Lakes and associated watershed, with the exception of recorded water levels on the North Shoal Lake from 1977 to 2010 and East and West Shoal Lakes from 1999 to 2010.

- The high water levels of current times are not unprecedented on the Shoal Lakes. A map illustrating the lake levels circa early 1900s (Mowbray 1981) indicates that the lake levels were higher than they are currently.

- There is little information available on the existing fishery in the Shoal Lakes with exception of reports from the Fish Inventory and Habitat Classification System (FIHCS) database maintained by Manitoba Water Stewardship – Fisheries Branch. However, Manitoba Conservation states that the Shoal Lakes currently have severe limitations to fish productivity (Class 4 fishery).

- The Shoal Lakes have been defined as a nationally important area for migratory bird habitat as the second most important site in Manitoba and the fourth most important site in the Prairie Provinces. A number of bird species are known to inhabit the Shoal Lakes area. Of particular interest is the persistent occurrence of the Piping Plover, an endangered species. Other species of interest include Western Grebe, Black-crowned Night Heron, American Pelican, Canada Geese, and Lesser Snow Geese.

- Little information exists regarding the water quality on the Shoal Lakes. Therefore, as part of this study, North/South Consultants conducted a water quality-sampling program at Shoal Lakes in 2008 to provide a description of existing conditions.

- The water quality of the Shoal Lakes, based on the water quality-sampling program indicated that with some minor exceptions, the water quality of Shoal Lakes was relatively similar across the lakes. In general, the Shoal Lakes can be described as relatively turbid and very hard, with high concentrations of nutrients, and slightly alkaline pH. Levels of TDS and conductivity are relatively high and the lakes would be considered “slightly saline” according to the CCREM. Sodium was the dominant cation present in the lakes, with magnesium, calcium, and potassium present in lower concentrations. On the basis of total phosphorus concentrations, North Shoal Lake would be classified as eutrophic while the east and west basins would be classified as hypereutrophic according to the CCME phosphorus guidance.

- A number of flood mitigation alternatives were assessed in this study and include:
  - Construction of a diversion / outlet channel from the Shoal Lakes to Lake Manitoba. Two alternate alignments of the diversion channel were defined and include:
  - A diversion channel along the alignment of Wagon Creek connecting to the north end of West Shoal Lake, or alternately connecting to the west side of the West Shoal Lake.
  - A diversion channel along the alignment of both Roy’s Drain and Boundary Drain connecting to the west end of West Shoal Lake
  - Construction of upland storage within the Shoal Lakes Watershed
  - Purchase of flood prone lands
- The flood diversion channel(s) have been designed to regulate the lakes to the maximum target water levels as defined by the Steering Committee which are:
  - North Shoal Lake = 260.45 m
  - East Shoal Lake = 259.70 m
  - West Shoal Lake = 259.70 m
- The diversion channels have been designed to convey a discharge of 10.0 $m^3/s$ and designed to convey the flow by gravity alone. (i.e. no pumping).
- The natural outlets from North Shoal Lake and East Shoal Lake have very little flow capacity at flood levels at least 1 metre above the target lake level. As a result channels through both outlets have been designed to convey water to the downstream lake. The connection between the North and East Shoal Lakes would include a control structure, while the connection between the East and West Shoal Lakes would include an uncontrolled channel.
- A gated control structure on the outlet channel at West Shoal Lake has been provided to limit channel flows to only the period when the water level on West Shoal Lake is above the target level of elevation 259.7 m.
- The cost of the diversion channels is quite high, as the channels must be excavated through a high ridge of land that lies between the Shoal Lakes and Lake Manitoba. The capital cost of each channel ranges between $23,281,000 and $31,160,000.

- Due to the topographic relief in the uplands of the Shoal Lakes watershed, few areas lend themselves to the creation of upland storage areas. Five areas have been identified and considered as upland storage areas. The cost of construction of these storage areas is estimated to be $4,133,000.

- The effectiveness of the storage reservoirs is limited due to the fact that the storage volume can only be used once during an extended flood period that can extend over a number of years.

- The purchase of flood prone lands was considered as a flood mitigation alternative, as prescribed in the RFP, as a means of reducing flood damages by buying out any property that could be affected by flooding. This would involve the purchase of approximately 16,900 ha of land from 117 different owners for an estimated cost of $11,361,000.

- A hydrologic/hydraulic model of the Shoal Lakes was developed that consisted of an Inflow-Available-for-Outflow based water balance model. This type of model was considered most appropriate to assess the hydraulic conditions of the land and the effects of the flood mitigation alternatives mainly due to the limited hydrologic and hydraulic records within the basin.

- The hydraulic model assessment of the flood diversion channels indicated that the lake levels would be significantly reduced from the natural levels and would as a result be quite shallow in the drought periods. However, the channels would be more or less effective in controlling the maximum lake levels to near the target elevations. Outflows from West Shoal Lake would occur in 12 of the 34 years of record considered.

- Sensitivity analyses on the model assumptions (i.e. starting water level) showed little difference from the base assumptions adopted in the analysis.

- The hydraulic model assessment of the upland storage areas showed that there was little hydraulic benefit to the incorporation of upland storage areas and would not reduce the lake levels to the target elevations.

- Benefits associated with each of the flood mitigation alternatives were estimated and considered the potential reduction in the loss of agricultural and infrastructure damages.

- The benefit / cost ratios for the various flood mitigation alternative are:

  - Flood diversion channels B/C = 0.25 to 0.34
  - Upland Storage Areas B/C = 0.35
  - Purchase of Flood Prone Land B/C = 0.67

- A sensitivity analysis on the effect of excavation costs (the largest component of the cost estimate for the flood channels) showed that the benefit / cost ratios for the various flood diversion channels could range from 0.57 to 0.17.

- The reduction of the water levels associated with the implementation of the flood diversion channels would negatively affect both the existing fisheries and avian/waterfowl populations of the Shoal Lakes.

- Most water quality parameters are present in higher concentrations in Shoal Lakes than Lake Manitoba. However, introduction of water from the Shoal Lakes to Lake Manitoba would not have a notable effect on the water quality of Lake Manitoba.

- The environmental effects of the implementation of the flood diversion channels were quantified to determine its effect on the benefit/cost ratio. It was found that with the incorporation of the environmental effects the benefit/cost ratio of the flood diversion channels would be reduced to less than 0.15.

- The most attractive flood mitigation alternative from an economic perspective, as assessed within this study is the purchase of the flood prone land surrounding the Shoal Lakes.

# 11.0 RECOMMENDATIONS

The following recommendations can be made based on the findings of the Shoal Lakes watershed study as documented within this report.

- The results of this report should be reviewed to determine if any intangible benefits that are not included in the assessment outlined in this report would justify the construction of either of the flood diversion channels.

- If considered justifiable, a pre-commitment level of field investigations and preliminary design should be carried out to refine the cost estimates for this project. In this further study, it would be recommended to carry out the following:

    - Review / optimize the target levels considered for the Shoal Lakes. It is possible that higher target levels would reduce the both the environmental effects and costs associated with the flood diversion channel.

    - Review / optimize the channel size, invert elevation, and discharge capacity. It would also be prudent to consider a pump system. This pump system could avoid the high costs of excavation associated with the relatively deep diversion channel.

- If this study proceeds to subsequent levels of design, a comprehensive bathymetric survey of the lakes should be carried out to more accurately define the surface area and storage volume of the lakes. The studies documented in this report have shown that implementation of a diversion channel significantly reduces the levels on the lake, which is quite sensitive to the bathymetric conditions of the lakes.

- As described in Section 4.4, the 0.6 m buffer zone above the 2010 peak water level was estimated based on the digital elevation model that was based on the topographic information available at the time of the study. Ground truth surveys of the land adjacent to the high water levels were not completed as part of this study. It would be recommended, should the purchase of flood prone lands option be selected for further study that a survey program be carried out to confirm the extents of the area encompassed by the 0.6 m buffer zone above the 2010 peak water level.

## 12.0 REFERENCES

1. Bourne, A., N. Armstrong, and G. Jones. 2002. “A preliminary assessment of total nitrogen and total phosphorus loading to streams in Manitoba, Canada: .Manitoba Conservation Report 2002-04. 49 pp.

2. Caux, P.-Y., D.R.J. Moore, and D. MacDonald. 1997. “Ambient water quality guidelines (criteria) for turbidity, suspended and benthic sediments.” Technical Appendix. Prepared for BC Ministry of Environment, Lands and Parks. 82 pp.

3. Canadian Council of Ministers of the Environment (CCME). 1999, updated to 2009. “Canadian environmental quality guidelines”. Canadian Council of Ministers of the Environment, Winnipeg. 9 pp.

4. Canadian Council of Resource and Environment Ministers (CCREM). 1987. “Canadian water quality guidelines”. Canadian Council of Resource and Environment Ministers, Winnipeg, MB.

5. Crooks, 2002. “Shoal Lakes Water Management – Preliminary Investigation”. A report prepared for the Shoal Lakes Water Management Investigation Ad Hoc Study Group, August 2002.

6. Environmental Canada, 2000. “The importance of Nature to Canadians: The Economic Significance of Nature Related Activities”.

7. Horne, A.J. and C.R. Goldman. 1994. “Limnology”. Second Edition. McGraw-Hill, Inc. New York, USA. 576 pp.

8. Important Bird Areas of Canada (IBA) 2004. http://www.ibacanada.com/

9. Last, W.M. 1984. “Modern sedimentology and hydrology of Lake Manitoba, Canada”. Environmental Geology 5(4): 177-190.

10. Lake Manitoba Regulation Review Advisory Committee (LMRRAC). 2003. “Regulation of water levels on Lake Manitoba and along the Fairford River, Pineimuta Lake, Lake St. Martin and Dauphin River and related issues. Volume 2: Main Report”. A report to the Manitoba Minister of Conservation. 99 pp.

11. Manitoba, 2010. “Manitoba Assessment Online – Property Search”, Manitoba Local Government. http://web5.gov.mb.ca/public/search_select.aspx.

12. Mowbray S., 1981. “Preliminary Biological Report on Vestfold – Shoal Lakes Complex: Waterfowl Production Potential and Management Recommendations”. 138 pp.

13. Murkin, H.R., B.D.J. Batt, P.J.Caldwell, J.A. Kadlec, and A.G. Van Der Valk. 2000. “Introduction to the Marsh Ecology Research Program.” In Murkin, H.R., A.G. Van Der Valk, And W.R. Clark (Eds). Prairie Wetland Ecology; The Contribution of the Marsh Ecology Research Program. Iowa State University Press, Ames.

14. Poston et al. 1990. “Priority Migratory Bird Habitats of Canada’s Prairie Provinces”.

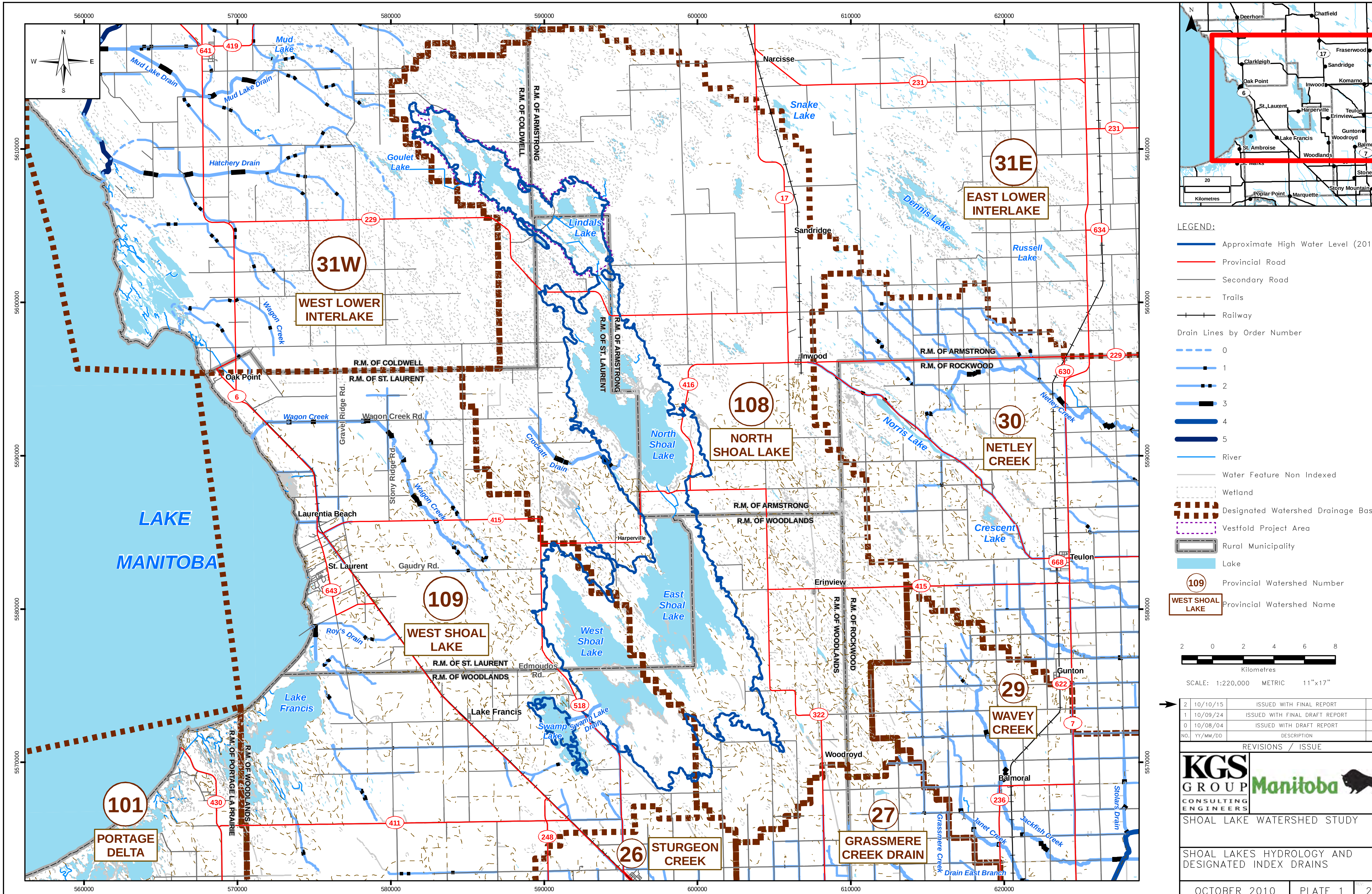
15. Province of Manitoba, 2005. “Wetland Compensation Plan associated with the Provincial Trunk Highway (PTH) 1 Upgrade from the Saskatchewan Boarder to 1.9 km West of the West Junction of the Provincial Trunk Highway 83.”

16. Species at Risk Act (SARA) 2009. www.sararegistry.gc.ca.

17. Wetzel, R.G. 1983. “Limnology”. Second Edition. New York. Saunders College Publishing. 767 pp.

18. Williamson, D.A. 2002. “Manitoba Water Quality Standards, Objectives, and Guidelines”. Manitoba Conservation Report 2002-11. Final Draft: November 22, 2002, 76 pp.

**PLATES**



LAKE MANITOBA
31W WEST LOWER INTERLAKE
31E EAST LOWER INTERLAKE
108 NORTH SHOAL LAKE
109 WEST SHOAL LAKE
30 NETLEY CREEK
29 WAVEY CREEK
27 GRASSMERE CREEK DRAIN
26 STURGEON CREEK
101 PORTAGE DELTA
R.M. OF COLDWELL
R.M. OF ST. LAURENT
R.M. OF ARMSTRONG
R.M. OF ROCKWOOD
R.M. OF WOODLANDS
R.M. OF PORTAGE LA PRAIRIE
Mud Lake
Mud Lake Drain
Hatchery Drain
Goulet Lake
Lindals Lake
Snake Lake
Dennis Lake
Russell Lake
North Shoal Lake
East Shoal Lake
West Shoal Lake
Swamp Lake
Swamp Lake Drain
Lake Francis
Crescent Lake
Norris Lake
Netley Creek
Wagon Creek
Crockatt Drain
Roy's Drain
Janet Creek
Jackfish Creek
Stolars Drain
Grassmere Creek
Drain East Branch
Narcisse
Sandridge
Inwood
Oak Point
Laurentia Beach
St. Laurent
Harperville
Erinview
Teulon
Gunton
Woodroyd
Balmoral
Lake Francis
Wagon Creek Rd.
Gravel Ridge Rd.
Stony Ridge Rd.
Gaudry Rd.
Edmoudos Rd.
LEGEND:
Approximate High Water Level (2010)
Provincial Road
Secondary Road
Trails
Railway
Drain Lines by Order Number
0
1
2
3
4
5
River
Water Feature Non Indexed
Wetland
Designated Watershed Drainage Basin
Vestfold Project Area
Rural Municipality
Lake
Provincial Watershed Number
Provincial Watershed Name
Kilometres
SCALE: 1:220,000 METRIC 11"x17"
2 10/10/15 ISSUED WITH FINAL REPORT
1 10/09/24 ISSUED WITH FINAL DRAFT REPORT
0 10/08/04 ISSUED WITH DRAFT REPORT
NO. YY/MM/DD DESCRIPTION BY
REVISIONS / ISSUE
KGS GROUP CONSULTING ENGINEERS
Manitoba
SHOAL LAKE WATERSHED STUDY
SHOAL LAKES HYDROLOGY AND DESIGNATED INDEX DRAINS
OCTOBER 2010
PLATE 1
2
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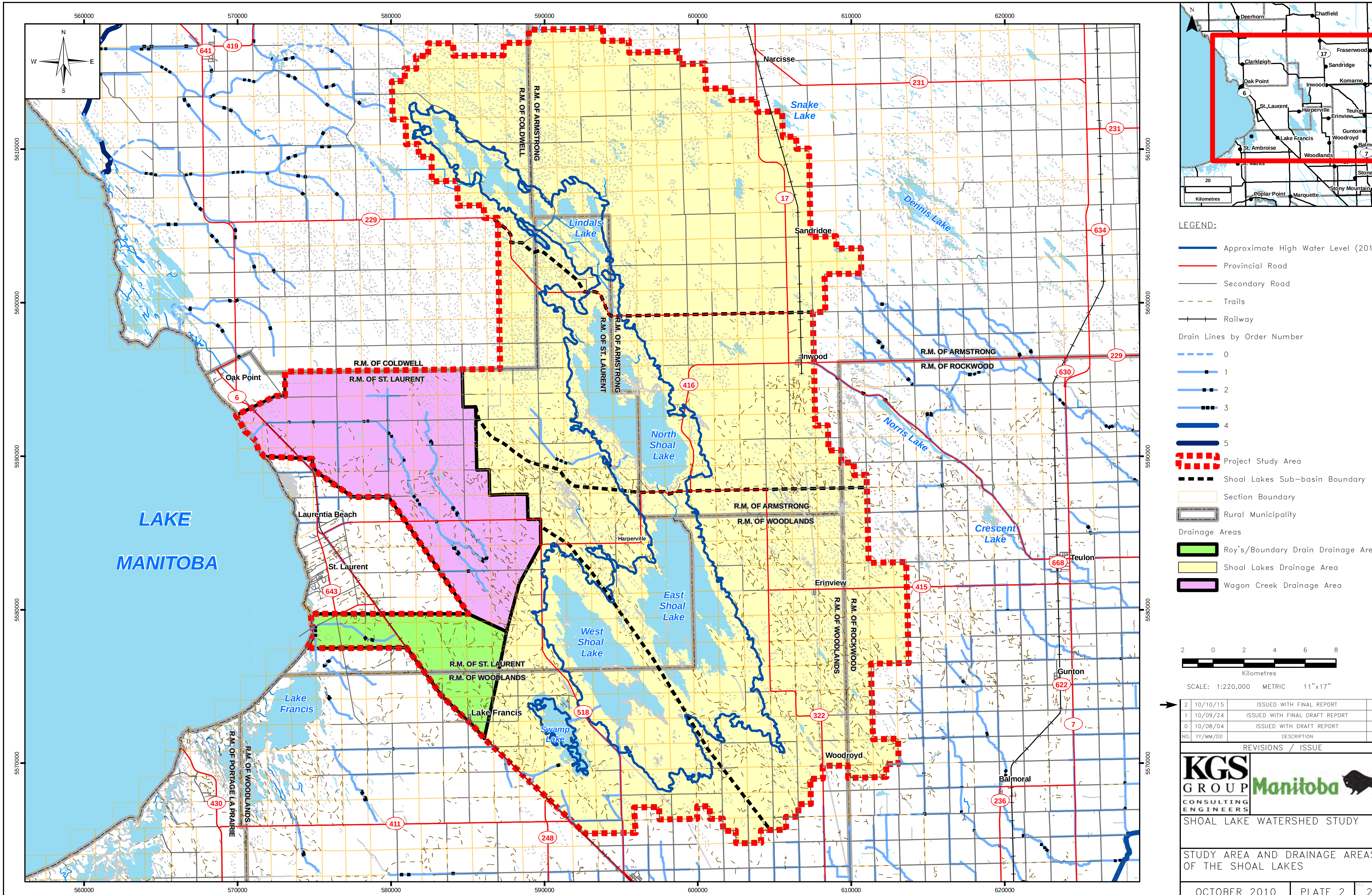
LAKE MANITOBA
Snake Lake
Lindals Lake
North Shoal Lake
East Shoal Lake
West Shoal Lake
Swamp Lake
Lake Francis
Dennis Lake
Norris Lake
Crescent Lake
Narcisse
Sandridge
Inwood
Oak Point
Laurentia Beach
St. Laurent
Harperville
Lake Francis
Erinview
Woodroyd
Teulon
Gunton
Balmoral
R.M. OF COLDWELL
R.M. OF ARMSTRONG
R.M. OF ST. LAURENT
R.M. OF WOODLANDS
R.M. OF ROCKWOOD
R.M. OF PORTAGE LA PRAIRIE
Deerhorn
Chatfield
Fraserwood
Clarkleigh
Sandridge
Oak Point
Inwood
Komarno
St. Laurent
Harperville
Teulon
Erinview
Gunton
Woodroyd
Lake Francis
St. Ambroise
Balmoral
Woodlands
St. Marks
Stonewall
Poplar Point
Marquette
Stony Mountain
Kilometres
LEGEND:
Approximate High Water Level (2010)
Provincial Road
Secondary Road
Trails
Railway
Drain Lines by Order Number
0
1
2
3
4
5
Project Study Area
Shoal Lakes Sub-basin Boundary
Section Boundary
Rural Municipality
Drainage Areas
Roy's/Boundary Drain Drainage Area
Shoal Lakes Drainage Area
Wagon Creek Drainage Area
Kilometres
SCALE: 1:220,000 METRIC 11"x17"
2 10/10/15 ISSUED WITH FINAL REPORT
1 10/09/24 ISSUED WITH FINAL DRAFT REPORT
0 10/08/04 ISSUED WITH DRAFT REPORT
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SHOAL LAKE WATERSHED STUDY
STUDY AREA AND DRAINAGE AREAS OF THE SHOAL LAKES
OCTOBER 2010
PLATE 2
2
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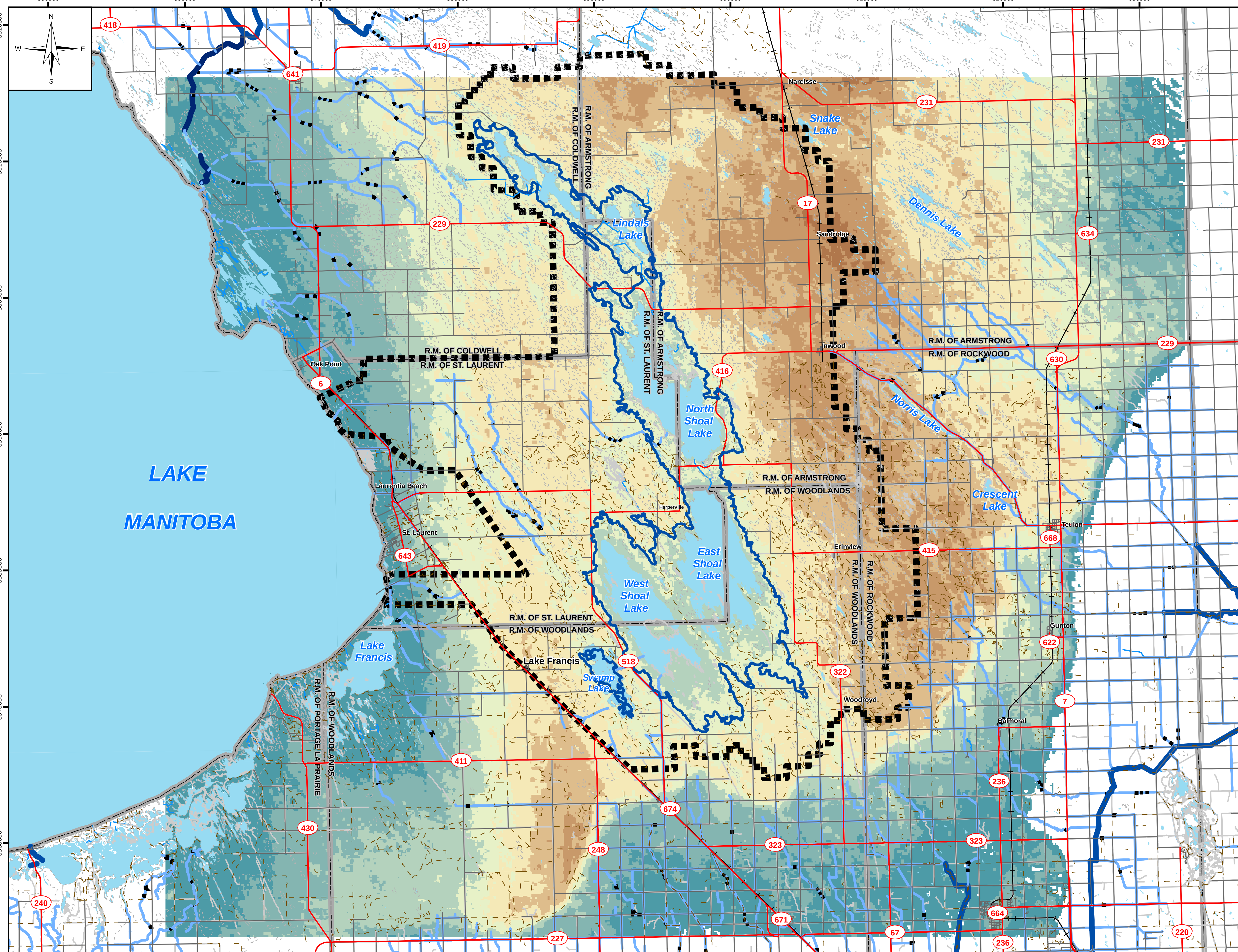


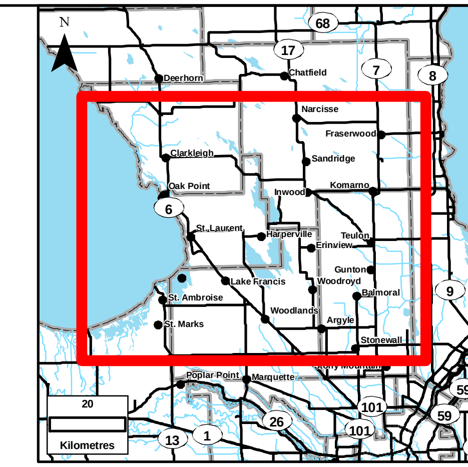


LEGEND:

- Approximate High Water Level (2010)
- Provincial Road
- Secondary Road
- Trails
- Railway

Drain Lines by Order Number

- 0
- 1
- 2
- 3
- 4
- 5
- Water Feature Non Indexed
- Wetland
- River
- Project Study Area
- Rural Municipality
- Lake

DEM

Elevation in Metres

- 280 – 285
- 275 – 280
- 270 – 275
- 265 – 270
- 260 – 265
- 255 – 260
- 250 – 255
- 245 – 250

NOTES:

1. Source of Digital Elevation Model is KGS Group (Various Multiple Sources).

2.5 0 2.5 5 7.5 10
Kilometres

SCALE: 1:275,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS

Manitoba

SHOAL LAKE WATERSHED STUDY

TOPOGRAPHY IN THE REGION OF THE SHOAL LAKES

OCTOBER 2010 | PLATE 3 | 2

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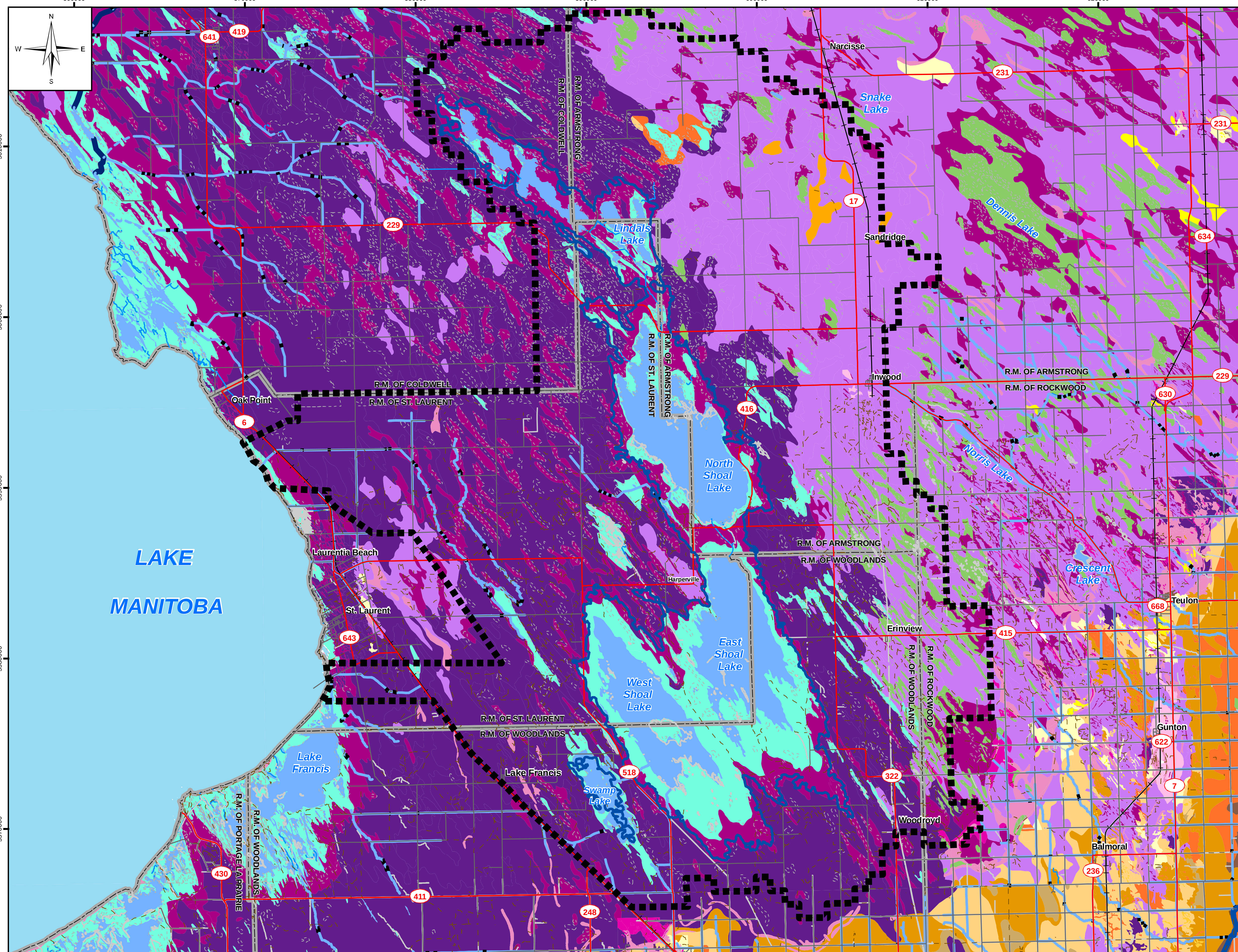


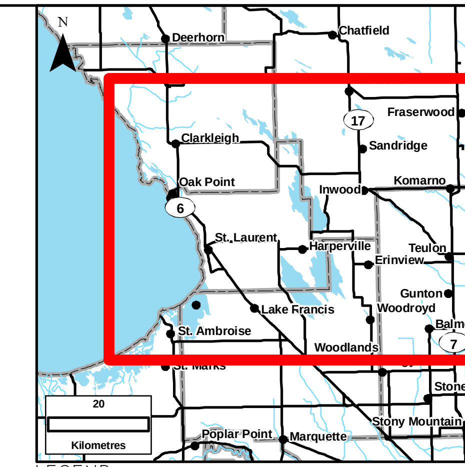


LEGEND:

- Approximate High Water Level (2010)
- Provincial Road
- Project Study Area

Agriculture Capability

- Clayey Lacustrine (Gleysols)
- Clayey Lacustrine (Black Chernozems)
- Clayey Lacustrine (Luvisols and Dark Gray Chernozems)
- Extremely Calcareous Loamy Till (Black Chernozem)
- Extremely Calcareous Loamy Till (Brunisols and Dark Gray Chernozem)
- Highly Calcareous Loamy Till (Gelysols)
- Sand and Gravel (Gleysols)
- Sand and Gravel
- Highly Calcareous Loamy Till (Black Chernozem)
- Loam Lacustrine (Gleysols)
- Loamy Lacustrine
- Limestone Bedrock
- Sandy Loam Lacustrine (Gleysols)
- Sandy Loam Lacustrine
- Sandy Lacustrine (Gleysols)
- Sandy Lacustrine
- Shallow Organic Fen Peat
- Marsh
- Water
- Variable Textured Alluvium (Gleysols)

2 0 2 4 6 8
Kilometres
SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |

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SHOAL LAKE WATERSHED STUDY

AGRICULTURE CAPABILITY

OCTOBER 2010 | PLATE 4 | 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F04_REV2.mxd
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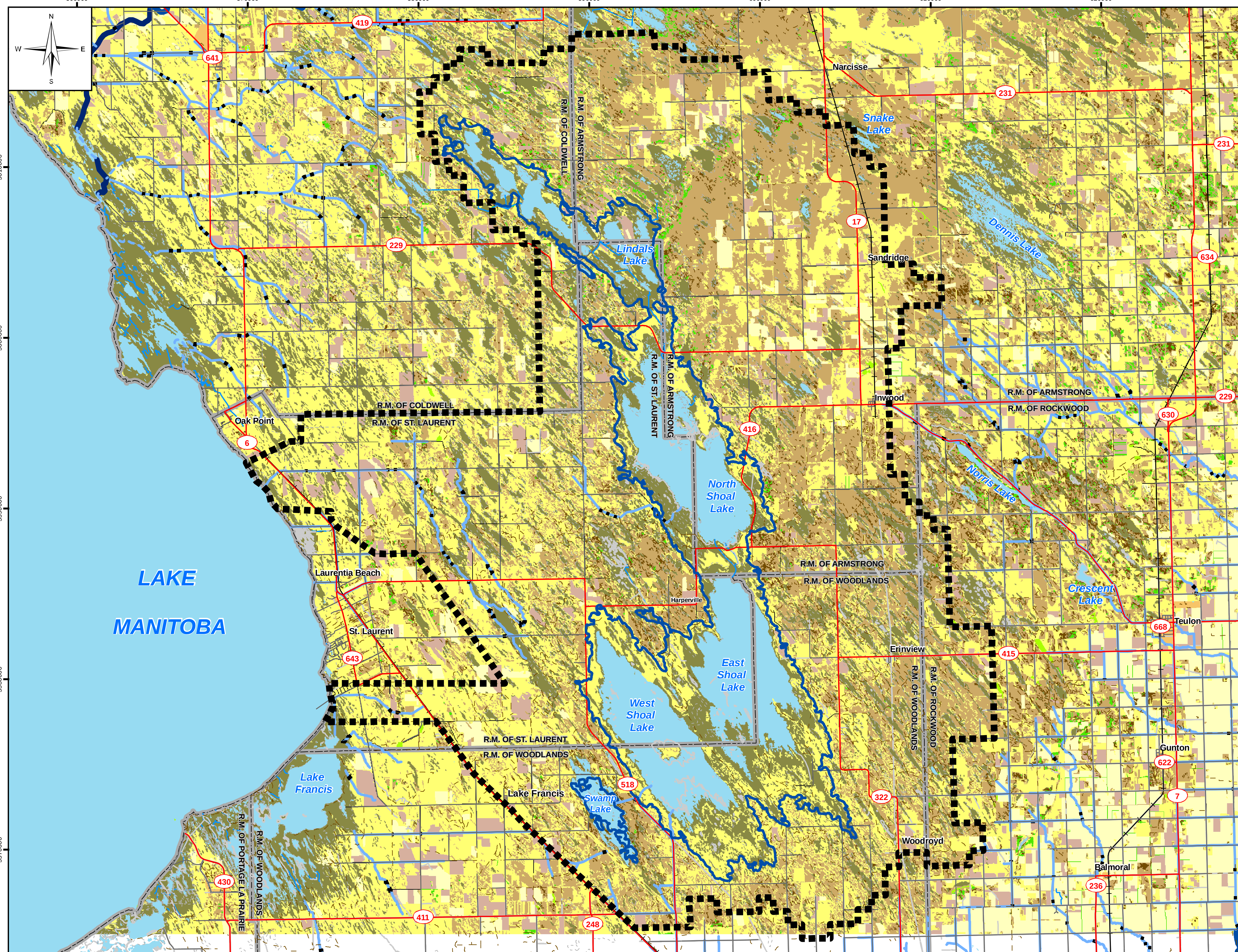


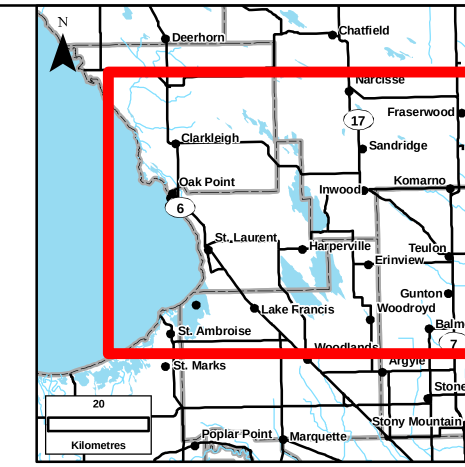


LEGEND:

- Approximate High Water Level (2010)
- Provincial Road
- Secondary Road
- Project Study Area

Landuse 2001/2002

- Agriculture
- Deciduous Forest
- Water
- Grassland
- Mixedwood Forest
- Marsh
- Bogs
- Treed Rock
- Conifer Forest
- Burns
- Open Deciduous Forest
- Forage Crops
- Cultural
- Forest Cutblocks
- Bare rock/sand/gravel
- Roads/Trails
- Lake

2 0 2 4 6 8
Kilometres

SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

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SHOAL LAKE WATERSHED STUDY

LANDUSE

OCTOBER 2010 | PLATE 5 | 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F05_REV2.mxd
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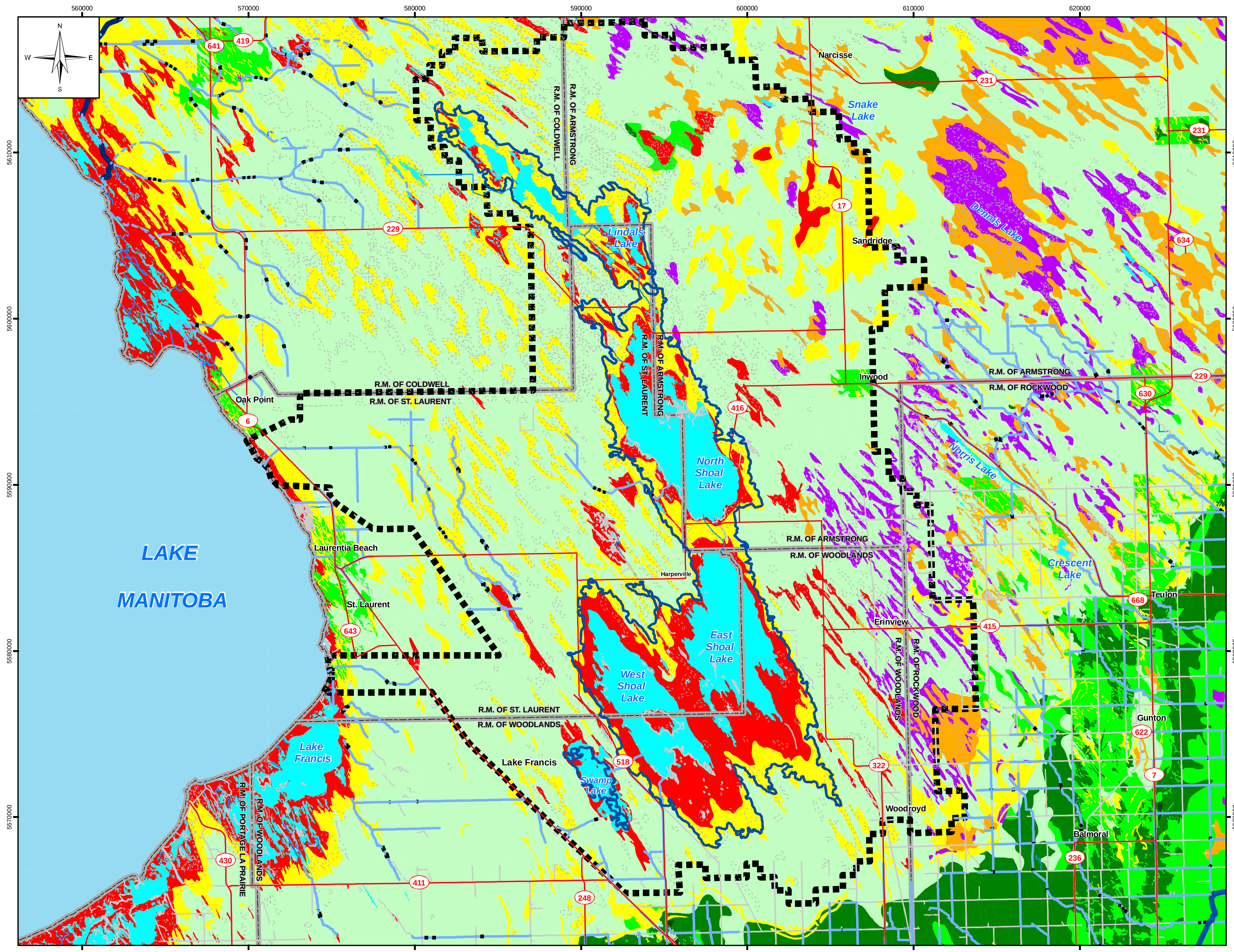


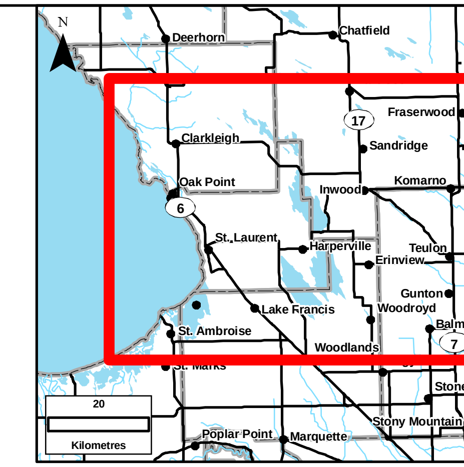


LEGEND:

- Approximate High Water Level (2010)
- Provincial Road

Drain Lines by Order Number

- 0
- 1
- 2
- 3
- 4
- 5
- Project Study Area
- Rural Municipality

Agriculture Capability

- Class 1
- Class 2
- Class 3
- Class 4
- Class 5
- Class 6
- Class 7
- Organic
- Unclassified
- Water

2 0 2 4 6 8
Kilometres

SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

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SHOAL LAKE WATERSHED STUDY

AGRICULTURE CAPABILITY

OCTOBER 2010 | PLATE 6 | 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F06_REV2.mxd
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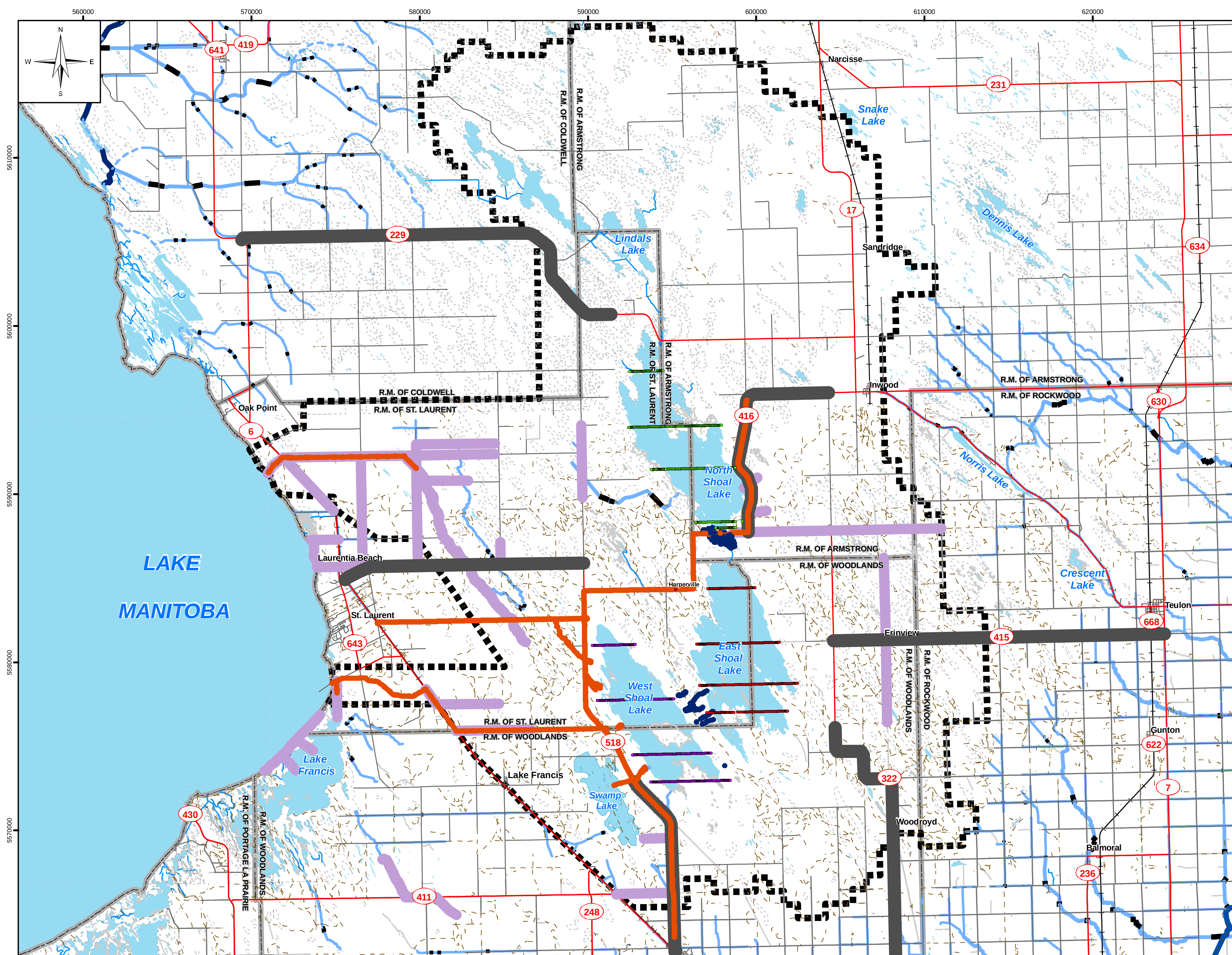


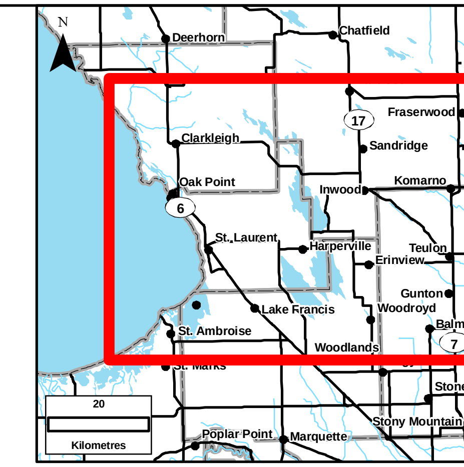


LEGEND:

- North Shoal Lake Topo (MWS)
- West Shoal Lake Topo (MWS)
- East Shoal Lake Topo (MWS)
- KGS Topograhic Survey
- KGS Bathymetric Survey

Existing Survey Data

- DRAIN PROFILES
- ROAD PROFILES
- Provincial Road
- Secondary Road
- Trails
- Railway
- Project Study Area
- Lake Intermittent
- Rural Municipality

2 0 2 4 6 8
Kilometres

SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

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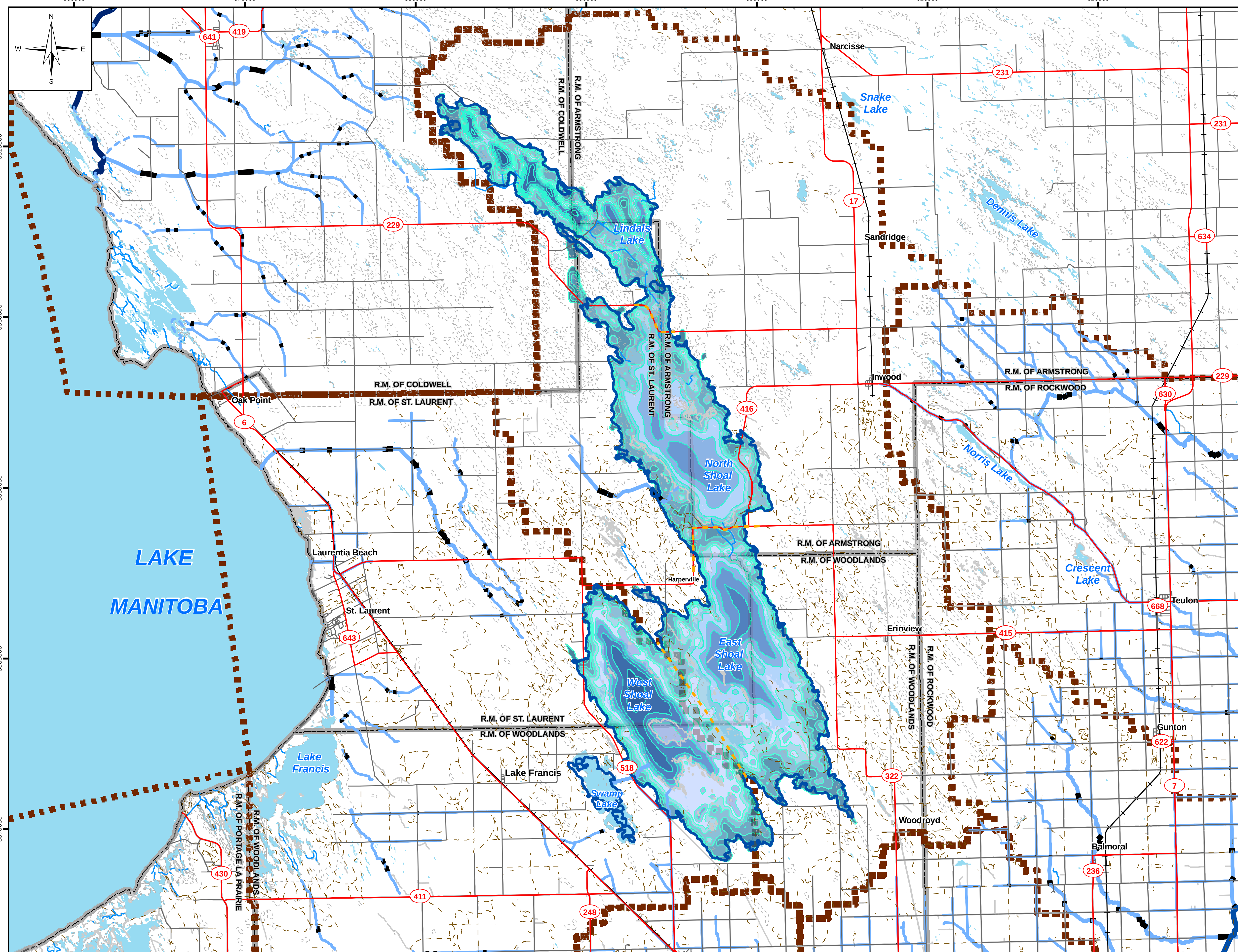
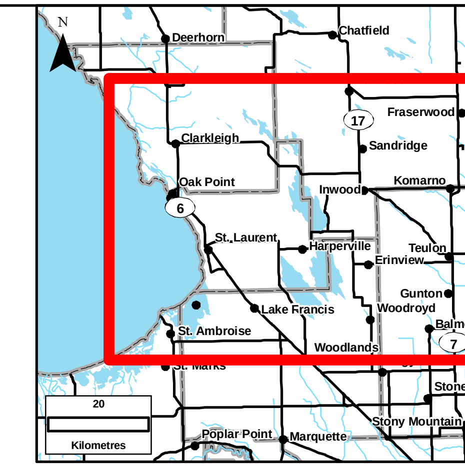
SHOAL LAKE WATERSHED STUDY

SURVEY DATA

OCTOBER 2010 | PLATE 7 | 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F07_REV2.mxd
11"x17" PLOT SCALE 1:1




LEGEND:

- Approximate High Water Level (2010)
- Lake Division Line
- Provincial Road
- Secondary Road
- Trails
- Railway
- Rural Municipality

Lake Bathymetry

- 257 m
- 257.5 m
- 258 m
- 258.5 m
- 259 m
- 259.5 m
- 260 m
- 260.5 m
- 261 m
- 261.5 m
- 262 m

2 0 2 4 6 8
Kilometres

SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

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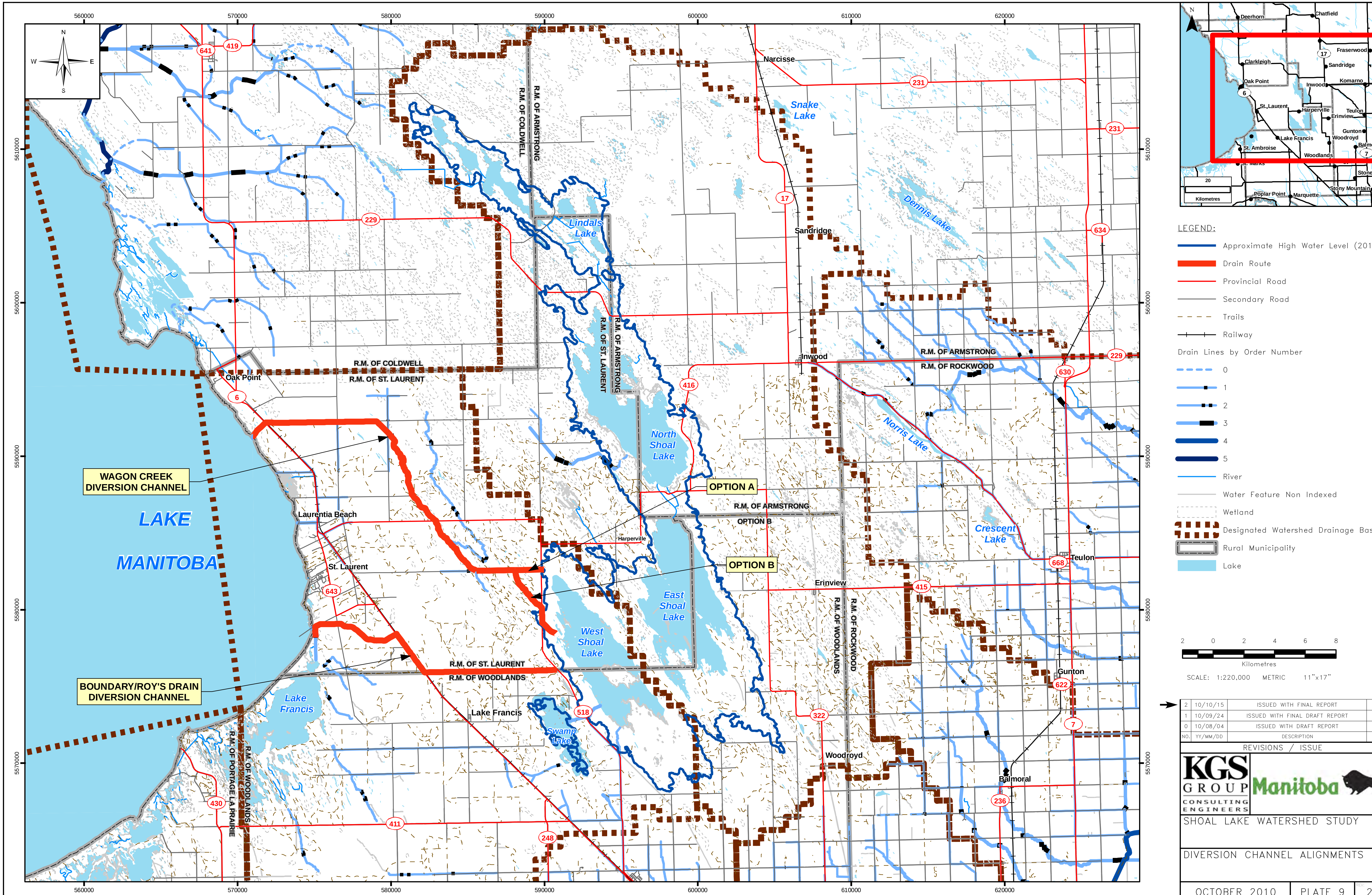
SHOAL LAKE WATERSHED STUDY

BATHYMETRY OF SHOAL LAKES

OCTOBER 2010 | PLATE 8 | 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F08_REV2.mxd
11"x17" PLOT SCALE 1:1

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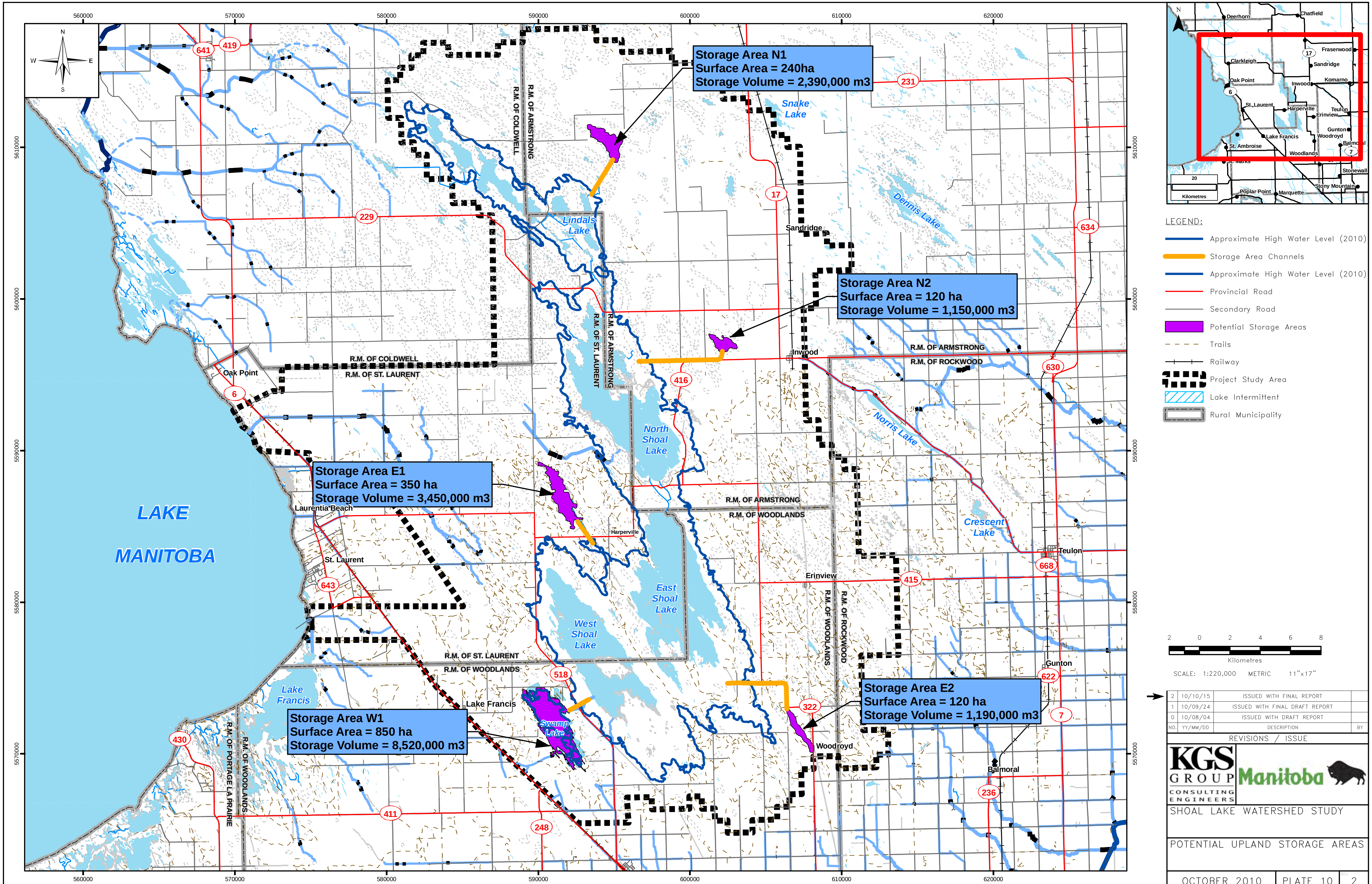
11"x17" PLOT SCALE 1:1


Storage Area N1
Surface Area = 240ha
Storage Volume = 2,390,000 m3
Storage Area N2
Surface Area = 120 ha
Storage Volume = 1,150,000 m3
Storage Area E1
Surface Area = 350 ha
Storage Volume = 3,450,000 m3
Storage Area W1
Surface Area = 850 ha
Storage Volume = 8,520,000 m3
Storage Area E2
Surface Area = 120 ha
Storage Volume = 1,190,000 m3
LAKE MANITOBA
Snake Lake
Lindals Lake
Dennis Lake
North Shoal Lake
East Shoal Lake
West Shoal Lake
Norris Lake
Crescent Lake
Lake Francis
Swamp Lake
Sandridge
Inwood
Oak Point
Laurentia Beach
St. Laurent
Harperville
Erinview
Teulon
Gunton
Woodroyd
Balmoral
Lake Francis
R.M. OF COLDWELL
R.M. OF ST. LAURENT
R.M. OF ARMSTRONG
R.M. OF ROCKWOOD
R.M. OF WOODLANDS
R.M. OF PORTAGE LA PRAIRIE
LEGEND:
Approximate High Water Level (2010)
Storage Area Channels
Approximate High Water Level (2010)
Provincial Road
Secondary Road
Potential Storage Areas
Trails
Railway
Project Study Area
Lake Intermittent
Rural Municipality
SCALE: 1:220,000 METRIC 11"x17"
Kilometres
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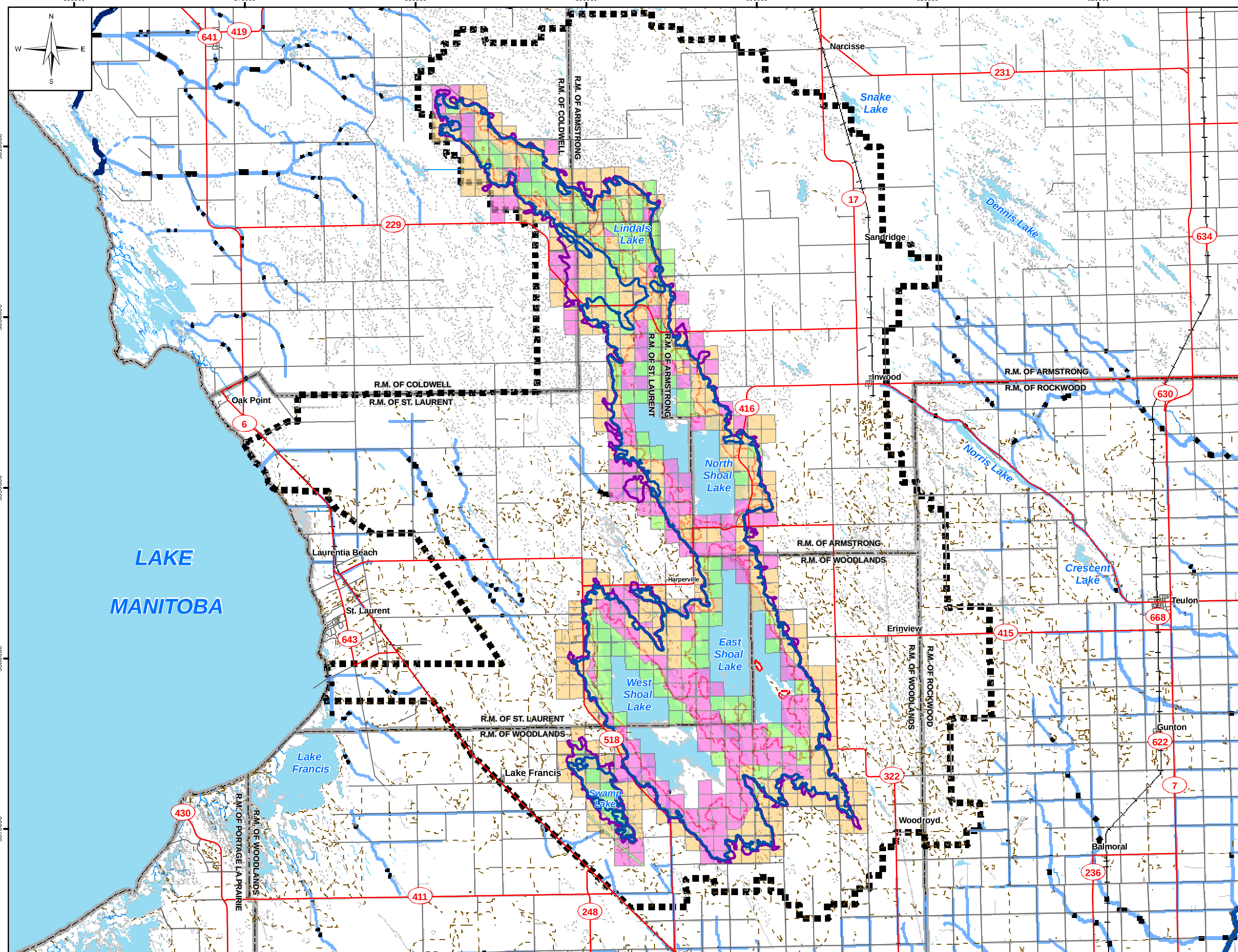
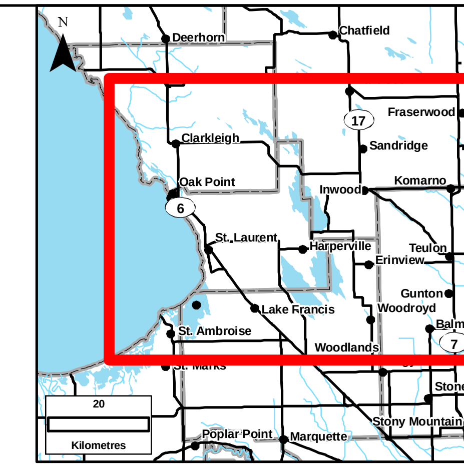
2 10/10/15 ISSUED WITH FINAL REPORT
1 10/09/24 ISSUED WITH FINAL DRAFT REPORT
0 10/08/04 ISSUED WITH DRAFT REPORT
NO. YY/MM/DD DESCRIPTION BY
KGS GROUP CONSULTING ENGINEERS
Manitoba
SHOAL LAKE WATERSHED STUDY
POTENTIAL UPLAND STORAGE AREAS
OCTOBER 2010
PLATE 10
2
FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F10_REV2.mxd
11"x17" PLOT SCALE 1:1




LEGEND:

- Approximate High Water Level (2010)
- Buffer Zone Above High Water Level (2010)
- Provincial Road
- Secondary Road

Section Ownership

- Crown Land
- Crown Leased Land
- Private Land
- Target
- Trails
- Railway
- Project Study Area
- Lake Intermittent
- Rural Municipality

Kilometres

SCALE: 1:220,000 METRIC 11"x17"

| NO. | YY/MM/DD | DESCRIPTION | BY |
|---|---|---|---|
| 2 | 10/10/15 | ISSUED WITH FINAL REPORT | |
| 1 | 10/09/24 | ISSUED WITH FINAL DRAFT REPORT | |
| 0 | 10/08/04 | ISSUED WITH DRAFT REPORT | |

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SHOAL LAKE WATERSHED STUDY

FLOOD PRONE LAND PURCHASE

OCTOBER 2010 PLATE 11 REV: 2

FileName: P:\Projects\2008\08-0311-01\GIS\MXDs\REV2\08-0311-01_F11_REV2.mxd
11"x17" PLOT SCALE 1:1

# APPENDICES

# APPENDIX A

# SHOAL LAKES WATER QUALITY SAMPLING PROGRAM RESULTS

**Table A1 – Water quality parameters measured *in situ* in North Shoal Lake during the Shoal Lakes water quality program 2008**

| Sample Location | Location ID | Sample Date | Total Depth | Ice Thickness | Effective Depth [1] | Sampling Depth | Temperature | Dissolved Oxygen | |
|---|---|---|---|---|---|---|---|---|---|
| | | | (m) | (m) | (m) | (m) | (°C) | (mg/L) | (% Saturation) |
| North | SHLK-N | 24-Mar-08 | 2.4 | 0.8 | 1.6 | 0.0 | 0.3 | 6.42 | 48 |
| Shoal Lake | | | | | | 0.5 | 1.6 | 6.32 | 48 |
| | | | | | | 1.0 | 2.9 | 6.83 | 54 |
| | SHLK-N2 | 10-Jun-08 | 2.5 | - | - | 0.3 | 15.8 | 9.49 | 97 |
| | | | | | | 0.5 | 15.7 | 9.48 | 97 |
| | | | | | | 1.0 | 15.7 | 9.46 | 96 |
| | | | | | | 1.5 | 15.7 | 9.44 | 96 |
| | | | | | | 2.0 | 15.5 | 9.48 | 96 |
| | SHLK-N2 | 10-Jul-08 | 2.5 | - | - | 0.3 | 19.4 | 9.50 | 104 |
| | | | | | | 0.5 | 19.3 | 9.46 | 104 |
| | | | | | | 1.0 | 19.3 | 9.39 | 103 |
| | | | | | | 1.5 | 19.3 | 9.36 | 103 |
| | | | | | | 2.0 | 18.9 | 9.06 | 99 |
| | SHLK-N2 | 7-Aug-08 | 2.6 | - | - | 0.3 | 24.0 | 8.40 | 101 |
| | | | | | | 1.0 | 21.8 | 8.44 | 97 |
| | | | | | | 1.5 | 21.5 | 7.31 | 84 |
| | | | | | | 2.0 | 21.5 | 7.09 | 81 |
| | | | | | | 2.5 | 21.4 | 6.82 | 78 |
| | SHLK-N2 | 11-Sep-08 | 2.8 | - | - | 0.3 | 15.4 | 8.80 | 89 |
| | | | | | | 1.0 | 15.2 | 8.59 | 87 |
| | | | | | | 2.0 | 15.0 | 8.31 | 84 |

**Table A1 – Continued**

| Sample Location | Location ID | Sample Date | Sampling Depth (m) | Specific Conductance [2] (S/m) | Conductivity [2] (S/m) | Turbidity (NTU) | pH | TDS (g/L) | ORP (mV) | Secchi Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| North Shoal Lake | SHLK-N | 24-Mar-08 | 0.0 | 0.30 | 0.16 | 6 | 8.34 | 2.0 | 155 | |
| | | | 0.5 | 0.30 | 0.17 | 8 | 8.32 | 1.9 | 154 | |
| | | | 1.0 | 0.31 | 0.18 | 12 | 8.27 | 2.0 | 155 | |
| | SHLK-N2 | 10-Jun-08 | 0.3 | 0.19 | 0.16 | 63 | 8.94 | 1.2 | 202 | 0.30 |
| | | | 0.5 | 0.19 | 0.16 | 64 | 8.92 | 1.2 | 202 | |
| | | | 1.0 | 0.19 | 0.16 | 66 | 8.90 | 1.2 | 203 | |
| | | | 1.5 | 0.19 | 0.16 | 65 | 8.86 | 1.2 | 205 | |
| | | | 2.0 | 0.19 | 0.16 | 66 | 8.84 | 1.2 | 206 | |
| | SHLK-N2 | 10-Jul-08 | 0.3 | 0.19 | 0.17 | 77 | 8.93 | 1.2 | 174 | 0.25 |
| | | | 0.5 | 0.19 | 0.17 | 74 | 8.93 | 1.2 | 171 | |
| | | | 1.0 | 0.19 | 0.17 | 74 | 8.92 | 1.2 | 169 | |
| | | | 1.5 | 0.19 | 0.17 | 74 | 8.89 | 1.2 | 169 | |
| | | | 2.0 | 0.19 | 0.17 | 75 | 8.85 | 1.2 | 170 | |
| | SHLK-N2 | 7-Aug-08 | 0.3 | 0.17 | 0.17 | 41 | 8.89 | 1.1 | 151 | 0.45 |
| | | | 1.0 | 0.18 | 0.17 | 41 | 8.85 | 1.1 | 156 | |
| | | | 1.5 | 0.17 | 0.16 | 42 | 8.77 | 1.1 | 160 | |
| | | | 2.0 | 0.18 | 0.17 | 44 | 8.76 | 1.1 | 163 | |
| | | | 2.5 | 0.18 | 0.17 | 42 | 8.76 | 1.1 | 162 | |
| | SHLK-N2 | 11-Sep-08 | 0.3 | 0.17 | 0.14 | 48 | 9.00 | 1.1 | 196 | 0.40 |
| | | | 1.0 | 0.17 | 0.14 | 47 | 9.00 | 1.1 | 195 | |
| | | | 2.0 | 0.17 | 0.14 | 45 | 8.92 | 1.1 | 199 | |

[1] Effective depth = total depth - ice thickness
[2] Specific conductance was measured; conductivity was calculated using the water temperature

**Table A2 – Water quality parameters measured *in situ* in East Shoal Lake during the Shoal Lakes water quality program 2008**

| Sample Location | Location ID | Sample Date | Total Depth (m) | Ice Thickness (m) | Effective Depth [1] (m) | Sampling Depth (m) | Temperature (°C) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% Saturation) |
|---|---|---|---|---|---|---|---|---|---|
| East Shoal Lake | SHLK-E | 24-Mar-08 | 2.7 | 0.9 | 1.9 | 0.0 | 0.7 | 1.67 | 13 |
| | | | | | | 0.5 | | | |
| | | | | | | | 2.0 | 1.59 | 12 |
| | | | | | | 1.0 | 2.9 | 1.59 | 13 |
| | | | | | | 1.5 | 3.5 | 0.84 | 7 |
| | SHLK-E2 | 10-Jun-08 | 3.0 | - | - | 0.3 | 16.3 | 9.92 | 102 |
| | | | | | | 0.5 | 16.3 | 9.81 | 101 |
| | | | | | | 1.0 | 16.3 | 9.76 | 101 |
| | | | | | | 1.5 | 16.3 | 9.73 | 100 |
| | | | | | | 2.0 | 16.3 | 9.70 | 100 |
| | | | | | | 2.5 | 16.1 | 9.69 | 100 |
| | SHLK-E2 | 10-Jul-08 | 3.0 | - | - | 0.3 | 19.2 | 9.10 | 100 |
| | | | | | | 0.5 | 19.2 | 9.08 | 99 |
| | | | | | | 1.0 | 19.2 | 9.04 | 99 |
| | | | | | | 1.5 | 19.2 | 8.98 | 98 |
| | | | | | | 2.0 | 19.1 | 8.98 | 98 |
| | | | | | | 2.5 | 19.0 | 8.92 | 97 |
| | SHLK-E2 | 7-Aug-08 | 3.0 | - | - | 0.3 | 23.4 | 7.47 | 89 |
| | | | | | | 1.0 | 22.4 | 7.35 | 86 |
| | | | | | | 1.5 | 21.5 | 6.46 | 74 |
| | | | | | | 2.0 | 21.4 | 6.50 | 74 |
| | | | | | | 2.5 | 21.4 | 6.53 | 75 |
| | | | | | | 3.0 | 21.3 | 6.04 | 69 |
| | SHLK-E2 | 11-Sep-08 | 3.1 | - | - | 0.3 | 14.8 | 8.30 | 83 |
| | | | | | | 1.0 | 14.8 | 8.01 | 80 |
| | | | | | | 2.0 | 14.7 | 7.96 | 80 |

**Table A2 – Continued**

| Sample Location | Location ID | Sample Date | Sampling Depth (m) | Specific Conductance [2] (S/m) | Conductivity [2] (S/m) | Turbidity (NTU) | pH | TDS (g/L) | ORP (mV) | Secchi Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| East Shoal Lake | SHLK-E | 24-Mar-08 | 0.0 | 0.29 | 0.16 | 3 | 8.30 | 1.9 | 170 | |
| | | | 0.5 | 0.28 | 0.16 | 2 | 8.31 | 1.8 | 169 | |
| | | | 1.0 | 0.28 | 0.16 | 5 | 8.29 | 1.8 | 168 | |
| | | | 1.5 | 0.29 | 0.17 | 7 | 8.24 | 1.8 | 128 | |
| | SHLK-E2 | 10-Jun-08 | 0.3 | 0.20 | 0.17 | 46 | 8.93 | 1.3 | 190 | 0.35 |
| | | | 0.5 | 0.20 | 0.17 | 46 | 8.92 | 1.3 | 191 | |
| | | | 1.0 | 0.20 | 0.17 | 45 | 8.88 | 1.3 | 194 | |
| | | | 1.5 | 0.20 | 0.17 | 46 | 8.84 | 1.3 | 196 | |
| | | | 2.0 | 0.20 | 0.17 | 48 | 8.83 | 1.3 | 198 | |
| | | | 2.5 | 0.20 | 0.17 | 49 | 8.83 | 1.3 | 198 | |
| | SHLK-E2 | 10-Jul-08 | 0.3 | 0.20 | 0.18 | 68 | 8.95 | 1.3 | 151 | 0.35 |
| | | | 0.5 | 0.20 | 0.18 | 70 | 8.95 | 1.3 | 149 | |
| | | | 1.0 | 0.20 | 0.18 | 67 | 8.94 | 1.3 | 147 | |
| | | | 1.5 | 0.20 | 0.18 | 68 | 8.91 | 1.3 | 148 | |
| | | | 2.0 | 0.20 | 0.18 | 68 | 8.88 | 1.3 | 150 | |
| | | | 2.5 | 0.20 | 0.18 | 66 | 8.86 | 1.3 | 151 | |
| | SHLK-E2 | 7-Aug-08 | 0.3 | 0.20 | 0.19 | 52 | 8.90 | 1.3 | 135 | 0.35 |
| | | | 1.0 | 0.20 | 0.19 | 55 | 8.89 | 1.2 | 132 | |
| | | | 1.5 | 0.19 | 0.18 | 56 | 8.79 | 1.2 | 137 | |
| | | | 2.0 | 0.19 | 0.18 | 55 | 8.71 | 1.2 | 143 | |
| | | | 2.5 | 0.19 | 0.18 | 54 | 8.71 | 1.2 | 143 | |
| | | | 3.0 | 0.19 | 0.18 | 70 | 8.70 | 1.2 | 143 | |
| | SHLK-E2 | 11-Sep-08 | 0.3 | 0.19 | 0.15 | 53 | 9.00 | 1.2 | 202 | 0.39 |
| | | | 1.0 | 0.19 | 0.15 | 60 | 8.98 | 1.2 | 200 | |
| | | | 2.0 | 0.19 | 0.15 | 56 | 8.96 | 1.2 | 200 | |

[1] Effective depth = total depth - ice thickness
[2] Specific conductance was measured; conductivity was calculated using the water temperature

**Table A3 – Water quality parameters measured *in situ* in West Shoal Lake during the Shoal Lakes water quality program 2008**

| Sample Location | Location ID | Sample Date | Total Depth (m) | Ice Thickness (m) | Effective Depth [1] (m) | Sampling Depth (m) | Temperature ($^oC$) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% Saturation) |
|---|---|---|---|---|---|---|---|---|---|
| West Shoal Lake | SHLK-W | 24-Mar-08 | 3.8 | 0.8 | 3.0 | 0.0 | 0.7 | 2.41 | 18 |
| | | | | | | 0.5 | 1.8 | 2.39 | 18 |
| | | | | | | 1.0 | 2.1 | 2.56 | 20 |
| | | | | | | 1.5 | 2.4 | 4.92 | 38 |
| | | | | | | 2.0 | 2.4 | 3.06 | 24 |
| | | | | | | 2.5 | 2.8 | 2.78 | 22 |
| | SHLK-W | 10-Jun-08 | 3.6 | - | - | 0.3 | 15.1 | 8.88 | 89 |
| | | | | | | 0.5 | 15.1 | 8.85 | 89 |
| | | | | | | 1.0 | 15.0 | 8.84 | 89 |
| | | | | | | 1.5 | 15.0 | 8.83 | 89 |
| | | | | | | 2.0 | 15.0 | 8.82 | 89 |
| | | | | | | 2.5 | 15.0 | 8.83 | 89 |
| | | | | | | 3.0 | 15.0 | 8.76 | 88 |
| | SHLK-W | 10-Jul-08 | 3.6 | - | - | 0.3 | 19.3 | 8.08 | 89 |
| | | | | | | 0.5 | 19.3 | 8.08 | 89 |
| | | | | | | 1.0 | 19.3 | 8.06 | 88 |
| | | | | | | 1.5 | 19.3 | 8.02 | 88 |
| | | | | | | 2.0 | 19.3 | 8.01 | 88 |
| | | | | | | 2.5 | 19.2 | 8.01 | 88 |
| | | | | | | 3.0 | 19.2 | 7.94 | 87 |

**Table A3 – Continued**

| Sample Location | Location ID | Sample Date | Total Depth (m) | Ice Thickness (m) | Effective Depth [1] (m) | Sampling Depth (m) | Temperature (°C) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (% Saturation) |
|---|---|---|---|---|---|---|---|---|---|
| West Shoal Lake | SHLK-W | 7-Aug-08 | 3.5 | - | - | 0.3 | 23.7 | 6.76 | 81 |
| | | | | | | 1.0 | 21.8 | 6.64 | 77 |
| | | | | | | 1.5 | 21.4 | 6.08 | 70 |
| | | | | | | 2.0 | 21.4 | 6.01 | 69 |
| | | | | | | 2.5 | 21.3 | 5.93 | 68 |
| | | | | | | 3.0 | 21.3 | 5.90 | 67 |
| | | | | | | 3.5 | 21.3 | 5.00 | 57 |
| | SHLK-W | 11-Sep-08 | 3.7 | - | - | 0.3 | 14.9 | 7.93 | 80 |
| | | | | | | 1.0 | 14.9 | 7.79 | 78 |
| | | | | | | 2.0 | 14.9 | 7.78 | 78 |
| | | | | | | 3.0 | 14.9 | 7.74 | 78 |

**Table A3 – Continued**

| Sample Location | Location ID | Sample Date | Sampling Depth (m) | Specific Conductance [2] (S/m) | Conductivity [2] (S/m) | Turbidity (NTU) | pH | TDS (g/L) | ORP (mV) | Secchi Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| West Shoal Lake | SHLK-W | 24-Mar-08 | 0.0 | 0.29 | 0.16 | 4 | 8.17 | 1.9 | 172 | |
| | | | 0.5 | 0.28 | 0.16 | 4 | 8.15 | 1.8 | 173 | |
| | | | 1.0 | 0.28 | 0.16 | 4 | 8.15 | 1.8 | 173 | |
| | | | 1.5 | 0.29 | 0.16 | 5 | 8.18 | 1.8 | 172 | |
| | | | 2.0 | 0.29 | 0.16 | 7 | 8.17 | 1.9 | 162 | |
| | | | 2.5 | 0.30 | 0.17 | 9 | 8.12 | 1.9 | 130 | |
| | SHLK-W | 10-Jun-08 | 0.3 | 0.20 | 0.16 | 55 | 8.86 | 1.3 | 210 | 0.30 |
| | | | 0.5 | 0.21 | 0.17 | 54 | 8.89 | 1.3 | 209 | |
| | | | 1.0 | 0.21 | 0.17 | 61 | 8.85 | 1.3 | 211 | |
| | | | 1.5 | 0.21 | 0.17 | 54 | 8.84 | 1.3 | 211 | |
| | | | 2.0 | 0.21 | 0.17 | 57 | 8.86 | 1.3 | 210 | |
| | | | 2.5 | 0.21 | 0.17 | 55 | 8.89 | 1.3 | 208 | |
| | | | 3.0 | 0.21 | 0.17 | 57 | 8.91 | 1.3 | 207 | |
| | SHLK-W | 10-Jul-08 | 0.3 | 0.21 | 0.19 | 47 | 8.93 | 1.3 | 172 | 0.35 |
| | | | 0.5 | 0.21 | 0.19 | 46 | 8.93 | 1.3 | 171 | |
| | | | 1.0 | 0.21 | 0.19 | 47 | 8.90 | 1.3 | 171 | |
| | | | 1.5 | 0.21 | 0.19 | 45 | 8.87 | 1.3 | 171 | |
| | | | 2.0 | 0.21 | 0.19 | 45 | 8.84 | 1.3 | 172 | |
| | | | 2.5 | 0.21 | 0.19 | 43 | 8.83 | 1.3 | 172 | |
| | | | 3.0 | 0.21 | 0.19 | 44 | 8.81 | 1.3 | 172 | |

**Table A3 – Continued**

| Sample Location | Location ID | Sample Date | Sampling Depth (m) | Specific Conductance [2] (S/m) | Conductivity [2] (S/m) | Turbidity (NTU) | pH | TDS (g/L) | ORP (mV) | Secchi Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| West Shoal Lake | SHLK-W | 7-Aug-08 | 0.3 | 0.21 | 0.20 | 34 | 8.92 | 1.3 | 193 | 0.4 |
| | | | 1.0 | 0.21 | 0.20 | 35 | 8.86 | 1.3 | 189 | |
| | | | 1.5 | 0.21 | 0.20 | 38 | 8.75 | 1.3 | 192 | |
| | | | 2.0 | 0.21 | 0.20 | 35 | 8.77 | 1.3 | 189 | |
| | | | 2.5 | 0.21 | 0.20 | 37 | 8.78 | 1.3 | 187 | |
| | | | 3.0 | 0.21 | 0.20 | 37 | 8.79 | 1.3 | 185 | |
| | | | 3.5 | 0.21 | 0.20 | 40 | 8.78 | 1.3 | 168 | |
| | SHLK-W | 11-Sep-08 | 0.3 | 0.21 | 0.17 | 47 | 9.04 | 1.3 | 203 | 0.43 |
| | | | 1.0 | 0.21 | 0.17 | 48 | 8.94 | 1.3 | 201 | |
| | | | 2.0 | 0.21 | 0.17 | 49 | 8.93 | 1.3 | 201 | |
| | | | 3.0 | 0.21 | 0.17 | 53 | 8.91 | 1.3 | 202 | |

[1] Effective depth = total depth - ice thickness
[2] Specific conductance was measured; conductivity was calculated using the water temperature

**Table A4 – Results of the routine water chemistry analyses collected during the Shoal Lakes water quality program, 2008**

| Sample Location | Sample ID | Sampling Date | Alkalinity | | | |
|---|---|---|---|---|---|---|
| | | | Total (as CaCO3) (mg/L) | Bicarbonate ($HCO_3$) (mg/L) | Carbonate ($CO_3$) (mg/L) | Hydroxide (OH) (mg/L) |
| **Analytical Detection Limit** | | | **1** | **2** | **0.6** | **0.4** |
| **Ice-cover season** | | | | | | |
| North Shoal Lake | SHLK-N | 24-Mar-08 | 1160 | 1210 | 97.2 | <0.4 |
| East Shoal Lake | SHLK-E | 24-Mar-08 | 1080 | 1100 | 110.0 | <0.4 |
| West Shoal Lake | SHLK-W | 24-Mar-08 | 1040 | 1110 | 80.8 | <0.4 |
| **Open-water season** | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jun-08 | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 10-Jun-08 | - | - | - | - |
| West Shoal Lake | SHLK-W | 10-Jun-08 | - | - | - | - |
| North Shoal Lake | SHLK-N2 | 10-Jul-08 | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 10-Jul-08 | - | - | - | - |
| West Shoal Lake | SHLK-W | 10-Jul-08 | - | - | - | - |
| North Shoal Lake | SHLK-N2 | 7-Aug-08 | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 7-Aug-08 | - | - | - | - |
| West Shoal Lake | SHLK-W | 7-Aug-08 | - | - | - | - |
| North Shoal Lake | SHLK-N2 | 11-Sep-08 | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 11-Sep-08 | - | - | - | - |
| West Shoal Lake | SHLK-W | 11-Sep-08 | - | - | - | - |
| **Field Blank** | SHLK-A | 24-Mar-08 | 2 | 2 | <0.6 | <0.4 |

**Table A4 – Continued**

| Sample Location | Sample ID | Sampling Date | Nitrogen | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dissolved Ammonia (mg/L N) | Dissolved Nitrate/ nitrite (mg/L N) | Dissolved Nitrate-N (mg/L) | Dissolved Nitrite-N (mg/L) | TKN (mg/L) | Organic Nitrogen [2] (mg/L N) | Total Nitrogen [3] (mg/L) | Dissolved Inorganic Nitrogen [4] (mg/L N) |
| **Analytical Detection Limit** | | | **0.003** | **0.005** | **0.01** | **0.01** | **0.2** | **-** | **-** | **-** |
| **Ice-cover season** | | | | | | | | | | |
| North Shoal Lake | SHLK-N | 24-Mar-08 | 0.008 | 0.261 | 0.26 | <0.01 | 2.7 | 2.692 | 2.961 | 0.269 |
| East Shoal Lake | SHLK-E | 24-Mar-08 | 0.007 | 0.515 | 0.52 | <0.01 | 2.8 | 2.793 | 3.315 | 0.522 |
| West Shoal Lake | SHLK-W | 24-Mar-08 | 0.004 | 0.542 | 0.54 | <0.01 | 2.8 | 2.796 | 3.342 | 0.546 |
| **Open-water season** | | | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jun-08 | 0.023 | 0.016 | - | - | 2.1 | 2.077 | 2.116 | 0.039 |
| East Shoal Lake | SHLK-E2 | 10-Jun-08 | 0.017 | 0.015 | - | - | 2.4 | 2.383 | 2.415 | 0.032 |
| West Shoal Lake | SHLK-W | 10-Jun-08 | 0.017 | 0.010 | - | - | 2.6 | 2.583 | 2.610 | 0.027 |
| North Shoal Lake | SHLK-N2 | 10-Jul-08 | 0.017 | 0.166 | - | - | 2.1 | 2.083 | 2.266 | 0.183 |
| East Shoal Lake | SHLK-E2 | 10-Jul-08 | 0.032 | 0.124 | - | - | 2.8 | 2.768 | 2.924 | 0.156 |
| West Shoal Lake | SHLK-W | 10-Jul-08 | 0.234 | 0.127 | - | - | 2.9 | 2.666 | 3.027 | 0.361 |
| North Shoal Lake | SHLK-N2 | 7-Aug-08 | 0.021 | <0.005 | - | - | 1.9 | 1.879 | 1.903 | 0.024 |
| East Shoal Lake | SHLK-E2 | 7-Aug-08 | 0.018 | 0.116 | - | - | 2.3 | 2.282 | 2.416 | 0.134 |
| West Shoal Lake | SHLK-W | 7-Aug-08 | 0.138 | 0.059 | - | - | 2.8 | 2.662 | 2.859 | 0.197 |
| North Shoal Lake | SHLK-N2 | 11-Sep-08 | 0.017 | 0.018 | - | - | 1.9 | 1.883 | 1.918 | 0.035 |
| East Shoal Lake | SHLK-E2 | 11-Sep-08 | <0.003 | 0.033 | - | - | 2.2 | 2.199 | 2.233 | 0.035 |
| West Shoal Lake | SHLK-W | 11-Sep-08 | 0.013 | 0.019 | - | - | 2.4 | 2.387 | 2.419 | 0.032 |
| **Field Blank** | SHLK-A | 24-Mar-08 | <0.003 | 0.010 | 0.01 | <0.01 | <0.2 | - | - | - |

**Table A4 – Continued**

| Sample Location | Sample ID | Sampling Date | Phosphorus | | | Nitrogen:Phosphorus Molar Ratios | | |
|---|---|---|---|---|---|---|---|---|
| | | | Dissolved (mg/L P) | Total (mg/L P) | Dissolved Fraction (%) | TN:TP | DIN:DP | DIN:TP |
| **Analytical Detection Limit** | | | **0.001** | **0.001** | **-** | **-** | **-** | **-** |
| **Ice-cover season** | | | | | | | | |
| North Shoal Lake | SHLK-N | 24-Mar-08 | 0.035 | 0.056 | 63 | 117 | 17 | 11 |
| East Shoal Lake | SHLK-E | 24-Mar-08 | 0.085 | 0.090 | 94 | 81 | 14 | 13 |
| West Shoal Lake | SHLK-W | 24-Mar-08 | 0.159 | 0.164 | 97 | 45 | 8 | 7 |
| **Open-water season** | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jun-08 | 0.028 | 0.096 | 29 | 49 | 3 | 1 |
| East Shoal Lake | SHLK-E2 | 10-Jun-08 | 0.031 | 0.096 | 32 | 56 | 2 | 1 |
| West Shoal Lake | SHLK-W | 10-Jun-08 | 0.035 | 0.146 | 24 | 40 | 2 | 0 |
| North Shoal Lake | SHLK-N2 | 10-Jul-08 | 0.035 | 0.096 | 36 | 52 | 12 | 4 |
| East Shoal Lake | SHLK-E2 | 10-Jul-08 | 0.076 | 0.119 | 64 | 54 | 5 | 3 |
| West Shoal Lake | SHLK-W | 10-Jul-08 | 0.057 | 0.139 | 41 | 48 | 14 | 6 |
| North Shoal Lake | SHLK-N2 | 7-Aug-08 | 0.029 | 0.057 | 51 | 74 | 2 | 1 |
| East Shoal Lake | SHLK-E2 | 7-Aug-08 | 0.043 | 0.126 | 34 | 42 | 7 | 2 |
| West Shoal Lake | SHLK-W | 7-Aug-08 | 0.064 | 0.130 | 49 | 49 | 7 | 3 |
| North Shoal Lake | SHLK-N2 | 11-Sep-08 | 0.030 | 0.072 | 42 | 59 | 3 | 1 |
| East Shoal Lake | SHLK-E2 | 11-Sep-08 | 0.038 | 0.109 | 35 | 45 | 2 | 1 |
| West Shoal Lake | SHLK-W | 11-Sep-08 | 0.039 | 0.132 | 30 | 41 | 2 | 1 |
| **Field Blank** | SHLK-A | 24-Mar-08 | <0.005 | 0.005 | - | - | - | - |

**Table A4 – Continued**

| Sample Location | Sample ID | Sampling Date | Organic Carbon (OC) | | Water Clarity | | |
|---|---|---|---|---|---|---|---|
| | | | TOC (mg/L) | DOC (mg/L) | Total Dissolved Solids (mg/L) | Total Suspended Solids (mg/L) | Turbidity (NTU) |
| **Analytical Detection Limit** | | | **1** | **1** | **5** | **2** | **0.05** |
| **Ice-cover season** | | | | | | | |
| North Shoal Lake | SHLK-N | 24-Mar-08 | - | 41 | 2000 | 14 | 7 |
| East Shoal Lake | SHLK-E | 24-Mar-08 | - | 40 | 1800 | 7 | 8 |
| West Shoal Lake | SHLK-W | 24-Mar-08 | - | 37 | 1700 | 4 | 7 |
| **Open-water season** | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jun-08 | 27 | - | 1200 | 38 | 36 |
| East Shoal Lake | SHLK-E2 | 10-Jun-08 | 29 | - | 1200 | 28 | 26 |
| West Shoal Lake | SHLK-W | 10-Jun-08 | 28 | - | 1200 | 37 | 29 |
| | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jul-08 | 25 | - | 1200 | 31 | 45 |
| East Shoal Lake | SHLK-E2 | 10-Jul-08 | 32 | - | 1300 | 36 | 40 |
| West Shoal Lake | SHLK-W | 10-Jul-08 | 33 | - | 1300 | 20 | 32 |
| | | | | | | | |
| North Shoal Lake | SHLK-N2 | 7-Aug-08 | 24 | - | 1100 | 13 | 21 |
| East Shoal Lake | SHLK-E2 | 7-Aug-08 | 23 | - | 1200 | 24 | 35 |
| West Shoal Lake | SHLK-W | 7-Aug-08 | 28 | - | 1400 | 10 | 25 |
| | | | | | | | |
| North Shoal Lake | SHLK-N2 | 11-Sep-08 | 27 | - | 1100 | 24 | 24 |
| East Shoal Lake | SHLK-E2 | 11-Sep-08 | 30 | - | 1300 | 24 | 31 |
| West Shoal Lake | SHLK-W | 11-Sep-08 | 31 | - | 1300 | 29 | 24 |
| **Field Blank** | SHLK-A | 24-Mar-08 | - | 1 | 40 | 3 | 0.1 |

**Table A4 – Continued**

| Sample Location | Sample ID | Sampling Date | pH | True Colour (TCU) | Conductivity umhos/cm | Algal Pigments: Chlorophyll *a* (ug/L) | Pheophytin (ug/L) | ODb/ODa |
|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | | **0.01** | **5** | **0.4** | **1** | **1** | **1** |
| **Ice-cover season** | | | | | | | | |
| North Shoal Lake | SHLK-N | 24-Mar-08 | 8.77 | 30 | 2870 | 9 | 3 | 1.51 |
| East Shoal Lake | SHLK-E | 24-Mar-08 | 8.64 | 30 | 2570 | 2 | 2 | 1.38 |
| West Shoal Lake | SHLK-W | 24-Mar-08 | 8.80 | 35 | 2670 | 2 | 3 | 1.33 |
| **Open-water season** | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jun-08 | - | - | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 10-Jun-08 | - | - | - | - | - | - |
| West Shoal Lake | SHLK-W | 10-Jun-08 | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 10-Jul-08 | - | - | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 10-Jul-08 | - | - | - | - | - | - |
| West Shoal Lake | SHLK-W | 10-Jul-08 | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 7-Aug-08 | - | - | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 7-Aug-08 | - | - | - | - | - | - |
| West Shoal Lake | SHLK-W | 7-Aug-08 | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | SHLK-N2 | 11-Sep-08 | - | - | - | - | - | - |
| East Shoal Lake | SHLK-E2 | 11-Sep-08 | - | - | - | - | - | - |
| West Shoal Lake | SHLK-W | 11-Sep-08 | - | - | - | - | - | - |
| **Field Blank** | SHLK-A | 24-Mar-08 | 5.56 | <5 | 0.9 | <1 | <1 | 1.00 |

**Table A5 –Results of the metal analyses collected during the Shoal Lakes water quality program, 2008**

| Sample Location | Sampling Date | Hardness as $CaCO_3$ (mg/L) | Aluminum Total (mg/L) | Antimony Total (mg/L) | Arsenic Total (mg/L) | Barium Total (mg/L) | Beryllium Total (mg/L) | Bismuth Total (mg/L) | Boron Total (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | **0.3** | **0.005** | **0.001** | **0.0005** | **0.0003** | **0.001** | **0.0002** | **0.03** |
| **Ice-cover season** | | | | | | | | | |
| North Shoal Lake | 24-Mar-08 | 1170 | 0.157 | <0.001 | 0.0058 | 0.0439 | <0.001 | <0.0002 | 0.94 |
| East Shoal Lake | 24-Mar-08 | 871 | 0.140 | 0.001 | 0.0068 | 0.0420 | <0.001 | <0.0002 | 0.82 |
| West Shoal Lake | 24-Mar-08 | 810 | 0.144 | <0.001 | 0.0072 | 0.0400 | <0.001 | <0.0002 | 0.96 |
| **Open-water season** | | | | | | | | | |
| North Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| North Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| North Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| North Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| **Field Blank** | 24-Mar-08 | <0.3 | <0.005 | <0.001 | <0.0005 | <0.0003 | <0.001 | <0.0002 | <0.03 |

**Table A5 – Continued**

| Sample Location | Sampling Date | Cadmium Total (mg/L) | Calcium Total (mg/L) | Cesium Total (mg/L) | Chloride Dissolved (mg/L) | Chromium Total (mg/L) | Cobalt Total (mg/L) | Copper Total (mg/L) | Iron Total (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | **0.00001** | **0.1** | **0.0001** | **9** | **0.001** | **0.0002** | **0.001** | **0.02** |
| **Ice-cover season** | | | | | | | | | |
| North Shoal Lake | 24-Mar-08 | 0.00007 | 31.0 | <0.0001 | 153 | 0.005 | 0.0020 | 0.004 | 0.14 |
| East Shoal Lake | 24-Mar-08 | 0.00009 | 28.5 | <0.0001 | 174 | 0.006 | 0.0021 | 0.003 | 0.13 |
| West Shoal Lake | 24-Mar-08 | 0.00004 | 27.2 | <0.0001 | 191 | 0.005 | 0.0021 | 0.002 | 0.13 |
| **Open-water season** | | | | | | | | | |
| North Shoal Lake | 10-Jun-08 | - | - | - | 80 | - | - | - | - |
| East Shoal Lake | 10-Jun-08 | - | - | - | 112 | - | - | - | - |
| West Shoal Lake | 10-Jun-08 | - | - | - | 129 | - | - | - | - |
| North Shoal Lake | 10-Jul-08 | - | - | - | 85 | - | - | - | - |
| East Shoal Lake | 10-Jul-08 | - | - | - | 122 | - | - | - | - |
| West Shoal Lake | 10-Jul-08 | - | - | - | 139 | - | - | - | - |
| North Shoal Lake | 7-Aug-08 | - | - | - | 78 | - | - | - | - |
| East Shoal Lake | 7-Aug-08 | - | - | - | 120 | - | - | - | - |
| West Shoal Lake | 7-Aug-08 | - | - | - | 143 | - | - | - | - |
| North Shoal Lake | 11-Sep-08 | - | - | - | 69 | - | - | - | - |
| East Shoal Lake | 11-Sep-08 | - | - | - | 110 | - | - | - | - |
| West Shoal Lake | 11-Sep-08 | - | - | - | 130 | - | - | - | - |
| **Field Blank** | 24-Mar-08 | <0.00001 | <0.1 | <0.0001 | <9 | 0.004 | *0.0017* | <0.001 | 0.03 |

**Table A5 – Continued**

| Sample Location | Sampling Date | Lead Total (mg/L) | Magnesium Total (mg/L) | Manganese Total (mg/L) | Mercury Total (mg/L) | Molybdenum Total (mg/L) | Nickel Total (mg/L) | Phosphorus (P) Total (mg/L) | Potassium Total (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | **0.0005** | **0.01** | **0.0003** | **0.00005** | **0.0002** | **0.002** | **0.05** | **0.1** |
| **Ice-cover season** | | | | | | | | | |
| North Shoal Lake | 24-Mar-08 | 0.0012 | 266 | 0.0047 | <0.00005 | 0.0016 | 0.005 | 0.11 | 72.2 |
| East Shoal Lake | 24-Mar-08 | 0.0016 | 194 | 0.0058 | <0.00005 | 0.0013 | 0.005 | 0.13 | 71.4 |
| West Shoal Lake | 24-Mar-08 | 0.0008 | 180 | 0.006 | <0.00005 | 0.0012 | 0.005 | 0.27 | 80.5 |
| **Open-water season** | | | | | | | | | |
| North Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - | - |
| | | | | | | | | | |
| North Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - | - |
| | | | | | | | | | |
| North Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - | - |
| | | | | | | | | | |
| North Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| East Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| West Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - | - |
| **Field Blank** | 24-Mar-08 | <0.0005 | 0.01 | <0.0003 | <0.00005 | <0.0002 | 0.002 | 0.07 | <0.1 |

**Table A5 – Continued**

| Sample Location | Sampling Date | Rubidium Total (mg/L) | Selenium Total (mg/L) | Silver Total (mg/L) | Sodium Total (mg/L) | Strontium Total (mg/L) | Sulphate Dissolved (mg/L) | Tellurium Total (mg/L) | Thallium Total (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | **0.0002** | **0.001** | **0.0001** | **0.03** | **0.0001** | **9** | **0.001** | **0.0001** |
| **Ice-cover season** | | | | | | | | | |
| North Shoal Lake | 24-Mar-08 | 0.0066 | 0.002 | 0.0004 | 318 | 0.294 | 475 | <0.001 | 0.0002 |
| East Shoal Lake | 24-Mar-08 | 0.0059 | 0.003 | <0.0001 | 338 | 0.186 | 314 | <0.001 | 0.0002 |
| West Shoal Lake | 24-Mar-08 | 0.0065 | 0.003 | <0.0001 | 383 | 0.158 | 293 | <0.001 | 0.0002 |
| **Open-water season** | | | | | | | | | |
| North Shoal Lake | 10-Jun-08 | - | - | - | - | - | 300 | - | - |
| East Shoal Lake | 10-Jun-08 | - | - | - | - | - | 260 | - | - |
| West Shoal Lake | 10-Jun-08 | - | - | - | - | - | 254 | - | - |
| North Shoal Lake | 10-Jul-08 | - | - | - | - | - | 300 | - | - |
| East Shoal Lake | 10-Jul-08 | - | - | - | - | - | 257 | - | - |
| West Shoal Lake | 10-Jul-08 | - | - | - | - | - | 253 | - | - |
| North Shoal Lake | 7-Aug-08 | - | - | - | - | - | 290 | - | - |
| East Shoal Lake | 7-Aug-08 | - | - | - | - | - | 251 | - | - |
| West Shoal Lake | 7-Aug-08 | - | - | - | - | - | 254 | - | - |
| North Shoal Lake | 11-Sep-08 | - | - | - | - | - | 284 | - | - |
| East Shoal Lake | 11-Sep-08 | - | - | - | - | - | 249 | - | - |
| West Shoal Lake | 11-Sep-08 | - | - | - | - | - | 251 | - | - |
| **Field Blank** | 24-Mar-08 | <0.0002 | <0.001 | 0.0001 | <0.03 | <0.0001 | <9 | <0.001 | <0.0001 |

**Table A5 – Continued**

| Sample Location | Sampling Date | Tin Total (mg/L) | Titanium Total (mg/L) | Tungsten Total (mg/L) | Uranium Total (mg/L) | Vanadium Total (mg/L) | Zinc Total (mg/L) | Zirconium Total (mg/L) |
|---|---|---|---|---|---|---|---|---|
| **Analytical Detection Limit** | | **0.0006** | **0.0009** | **0.0002** | **0.0001** | **0.001** | **0.01** | **0.0004** |
| **Ice-cover season** | | | | | | | | |
| North Shoal Lake | 24-Mar-08 | <0.0006 | 0.006 | <0.0002 | 0.0039 | 0.006 | 0.02 | 0.0004 |
| East Shoal Lake | 24-Mar-08 | <0.0006 | 0.0045 | <0.0002 | 0.0032 | 0.006 | 0.02 | <0.0004 |
| West Shoal Lake | 24-Mar-08 | <0.0006 | 0.0059 | <0.0002 | 0.0028 | 0.006 | 0.01 | 0.0004 |
| **Open-water season** | | | | | | | | |
| North Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jun-08 | - | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - |
| East Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - |
| West Shoal Lake | 10-Jul-08 | - | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - |
| East Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - |
| West Shoal Lake | 7-Aug-08 | - | - | - | - | - | - | - |
| | | | | | | | | |
| North Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - |
| East Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - |
| West Shoal Lake | 11-Sep-08 | - | - | - | - | - | - | - |
| **Field Blank** | 24-Mar-08 | 0.0011 | <0.0009 | <0.0002 | <0.0001 | 0.001 | <0.01 | <0.0004 |

**APPENDIX B**

**SHOAL LAKES WATER QUALITY DATA**

**Table B1 – Summary of key water quality parameters from the surface waters of Shoal Lakes (2008) and Lake Manitoba (2005-2007), and Manitoba Water Quality Guidelines and Objectives (Williamson 2002)**

| Parameter | | North Shoal Lake | | | | | | West Shoal Lake | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Open-water Season | | | | | Winter | Open-water Season | | | | |
| | | | Mean | SE | Min | Max | n | | Mean | SE | Min | Max | n |
| Specific Conductance | (µS/cm) | *3000* | *1803* | 56 | *1700* | *1900* | 4 | *2900* | *2068* | 24 | *2000* | *2100* | 4 |
| Total Dissolved Solids | (mg/L) | *2000* | *1150* | 29 | *1100* | *1200* | 4 | *1900* | *1300* | 0 | *1300* | *1300* | 4 |
| pH | - | 8.34 | **8.94** | 0.02 | **8.89** | **9.00** | 4 | 8.17 | **8.94** | 0.04 | **8.86** | **9.04** | 4 |
| Total suspended solids | (mg/L) | 14 | - | - | - | - | - | 7 | - | - | - | - | - |
| Turbidity | (NTU) | *6* | *57* | 8 | *41* | *77* | 4 | **4** | *46* | 4 | *34* | *55* | 4 |
| **Nutrients** | | | | | | | | | | | | | |
| Total Phosphorus | (mg/L) | **0.056** | **0.080** | 0.010 | **0.057** | **0.096** | 4 | **0.090** | **0.137** | 0.004 | **0.130** | **0.146** | 4 |
| Total Nitrogen | (mg/L) | 2.961 | 2.051 | 0.087 | 1.903 | 2.266 | 4 | 3.315 | 2.729 | 0.134 | 2.419 | 3.027 | 4 |
| Ammonia | (mg N/L) | 0.008 | 0.020 | 0.002 | 0.017 | 0.023 | 4 | 0.007 | 0.101 | 0.053 | 0.013 | 0.234 | 4 |
| Nitrate/Nitrite | (mg N/L) | 0.261 | 0.051 | 0.039 | 0.003 | 0.166 | 4 | 0.515 | 0.054 | 0.027 | 0.010 | 0.127 | 4 |

**Table B1 – Continued**

| Parameter | | East Shoal Lake | | | | | | Lake Manitoba[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Open-water Season | | | | | Ice-covered Season | | | | |
| | | | Mean | SE | Min | Max | n | Mean | SE | Min | Max | n |
| Specific Conductance | (µS/cm) | *2900* | *1978* | 23 | *1910* | *2000* | 4 | *1660* | 130 | *1530* | *1790* | 2 |
| Total Dissolved Solids | (mg/L) | *1900* | *1275* | 25 | *1200* | *1300* | 4 | *1050* | 0.00 | *1050* | *1050* | 2 |
| pH | - | 8.30 | **8.95** | 0.02 | **8.90** | **9.00** | 4 | 8.00 | 0.00 | 8.00 | 8.00 | 2 |
| Total suspended solids | (mg/L) | 4 | - | - | - | - | - | 1 | 0.00 | 1 | 1 | 2 |
| Turbidity | (NTU) | **3** | *55* | 5 | *46* | *68* | 4 | **2.1** | 0.0 | **2.1** | **2.1** | 2 |
| **Nutrients** | | | | | | | | | | | | |
| Total Phosphorus | (mg/L) | **0.164** | **0.113** | 0.007 | **0.096** | **0.126** | 4 | **0.025** | 0.002 | 0.023 | **0.027** | 2 |
| Total Nitrogen | (mg/L) | 3.342 | 2.497 | 0.149 | 2.233 | 2.924 | 4 | 1.76 | 0.25 | 1.51 | 2.01 | 2 |
| Ammonia | (mg N/L) | 0.004 | 0.017 | 0.006 | 0.002 | 0.032 | 4 | 0.08 | 0.00 | 0.08 | 0.08 | 2 |
| Nitrate/Nitrite | (mg N/L) | 0.542 | 0.072 | 0.028 | 0.015 | 0.124 | 4 | 0.11 | 0.10 | 0.01 | 0.21 | 2 |

**Table B1 – Continued**

| Parameter | | Lake Manitoba[1] | | | | |
|---|---|---|---|---|---|---|
| | | Open-water Season | | | | |
| | | Mean | SE | Min | Max | n |
| Specific Conductance | (µS/cm) | **1285** | 39 | **1160** | **1400** | 6 |
| Total Dissolved Solids | (mg/L) | **826** | 0.5 | **825** | **826** | 2 |
| pH | - | **8.62** | 0.04 | **8.5** | **8.74** | 6 |
| Total suspended solids | (mg/L) | 17 | 1 | 16 | 18 | 2 |
| Turbidity | (NTU) | *20.6* | 3.4 | *10.9* | *26.6* | 4 |
| **Nutrients** | | | | | | |
| Total Phosphorus | (mg/L) | **0.070** | 0.019 | **0.038** | **0.165** | 6 |
| Total Nitrogen | (mg/L) | 2.055 | 0.340 | 1.305 | 3.605 | 6 |
| Ammonia | (mg N/L) | 0.03 | 0.01 | <0.01 | 0.06 | 6 |
| Nitrate/Nitrite | (mg N/L) | <0.01 | 0.00 | <0.01 | 0.005 | 6 |

**Table B1 – Continued**

| Parameter | | MWQSOG | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Drinking Water | |
| | | PAL[2] | Recreation | Greenhouse Irrigation | Field/Park Irrigation | Livestock | Maximum Acceptable | Aesthetic |
| Specific Conductance | (μS/cm) | - | - | **1000** | *1500* | - | - | - |
| Total Dissolved Solids | (mg/L) | - | - | **700** | *1000* | 3000 | - | **500** |
| pH | - | 6.5-9.0 | 5.0-9.0 | - | - | - | - | **6.5-8.5** |
| Total suspended solids | (mg/L) | - [3] | - | - | - | - | - | - |
| Turbidity | (NTU) | - | - | - | - | - | **1** | *5* |
| **Nutrients** | | | | | | | | |
| Total Phosphorus | (mg/L) | **0.025** | - | - | - | - | - | - |
| Total Nitrogen | (mg/L) | - | - | - | - | - | - | - |
| Ammonia | (mg N/L) | 0.247-8.408 [4] | - | - | - | - | - | - |
| Nitrate/Nitrite | (mg N/L) | - | - | - | - | 100 | 10 | - |

[1]From Lake Manitoba St. Ambroise Beach. Data provided by MWS (2008).
[2]Protection of Aquatic Life
[3]The MWQSOG states that TSS should not increase more than 5 mg/L above the background concentration.
[4]Objectives calculated based on range of temperature and pH measured at Shoal Lakes (2008) and Lake Manitoba (2005-2007).

**Table B2 – Summary of major ions measured in Shoal Lakes (2008) and Lake Manitoba (2004-2007), and Manitoba Water Quality Guidelines and Objectives (Williamson 2002)**

| Parameter | Units | North Shoal Lake | | | | | | West Shoal Lake | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Open-Water Season | | | | | Winter | Open-Water Season | | | | |
| | | | Mean | SE | Min | Max | n | | Mean | SE | Min | Max | n |
| Calcium | mg/L | 31.0 | - | - | - | - | - | 28.5 | - | - | - | - | - |
| Magnesium | mg/L | 266 | - | - | - | - | - | 194 | - | - | - | - | - |
| Potassium | mg/L | 72.2 | - | - | - | - | - | 71.4 | - | - | - | - | - |
| Sodium | mg/L | **318** | - | - | - | - | - | **338** | - | - | - | - | - |
| Sulphate | mg/L | 475 | 294 | 4 | 284 | 300 | 4 | 314 | 253 | 1 | 251 | 254 | 4 |
| Chloride[3] | mg/L | **153** | 78 | 3 | 69 | 85 | 4 | **174** | **135** | 3 | **129** | **143** | 4 |

**Table B2 – Continued**

| Parameter | Units | East Shoal Lake | | | | | | Lake Manitoba[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Open-Water Season | | | | | Ice-covered Season | | | | |
| | | | Mean | SE | Min | Max | n | Mean | SE | Min | Max | n |
| Calcium | mg/L | 27.2 | - | - | - | - | - | - | - | - | - | - |
| Magnesium | mg/L | 180 | - | - | - | - | - | 56 | 4.5 | 45 | 67 | 4 |
| Potassium | mg/L | 80.5 | - | - | - | - | - | 16.0 | 1.0 | 14.2 | 18.6 | 4 |
| Sodium | mg/L | **383** | - | - | - | - | - | **215** | 20 | 167 | **263** | 4 |
| Sulphate | mg/L | 293 | 254 | 3 | 249 | 260 | 4 | 145 | 9 | 123 | 169 | 4 |
| Chloride[3] | mg/L | **191** | **116** | 3 | **110** | **122** | 4 | *349* | 13 | *315* | *379* | 4 |

**Table B2 – Continued**

| .Parameter | Units | Lake Manitoba[1] Open-Water Season | | | | | MWQSOG | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SE | Min | Max | n | PAL[2] | Recreation | Irrigation | Livestock | Drinking Water Aesthetic |
| Calcium | mg/L | 38.6 | - | - | - | 1 | - | - | - | 1000 | - |
| Magnesium | mg/L | 50.4 | 2.6 | 38.3 | 67.5 | 11 | - | - | - | - | - |
| Potassium | mg/L | 14.2 | 0.5 | 11.9 | 17.1 | 11 | - | - | - | - | - |
| Sodium | mg/L | 193 | 5 | 168 | **226** | 11 | - | - | - | - | **200** |
| Sulphate | mg/L | 145 | 24 | 96 | 371 | 11 | - | - | - | 1000 | 500 |
| Chloride[3] | mg/L | *306* | 8 | *280* | *371* | 11 | - | - | **100-700** | - | *≤250* |

[1]From Lake Manitoba Narrows. Data provided by MBWS (2008).
[2] PAL=Protection of Aquatic Life
[3]Foliar damage occurs at different concentrations for different plants. For example, damage occurs at 110 mg/L for strawberries, and at 178-355 mg/L for peppers, potatoes, and tomatoes (CCME 1999, updated 2007).

**Table B3 – Summary of selected metals (totals) measured in Shoal Lakes (2008) and Lake Manitoba (2004-2007), and Manitoba Water Quality Guidelines and Objectives (Williamson 2002)**

| Parameter | Units | North Shoal Lake | West Shoal Lake | East Shoal Lake | Lake Manitoba[1] Ice-covered Season | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Winter | Winter | Mean | SE | Min | Max | n |
| Aluminum | mg/L | **0.157** | **0.140** | **0.144** | 0.045 | 0.022 | 0.016 | **0.110** | 4 |
| Arsenic | mg/L | 0.0058 | 0.0068 | 0.0072 | 0.0028 | 0.0004 | 0.0021 | 0.0038 | 4 |
| Cadmium | mg/L | 0.00007 | 0.00009 | 0.00004 | <0.00004 | 0.0000 | <0.00004 | <0.00004 | 4 |
| Chromium | mg/L | *0.005* | *0.006* | *0.005* | 0.0003 | <0.0001 | 0.0003 | 0.0004 | 4 |
| Copper | mg/L | 0.004 | 0.003 | 0.002 | 0.0014 | 0.0001 | 0.0010 | 0.0017 | 4 |
| Iron | mg/L | 0.14 | 0.13 | 0.13 | 0.07 | 0.02 | 0.04 | 0.14 | 4 |
| Lead | mg/L | 0.0012 | 0.0016 | 0.0008 | 0.0003 | 0.0002 | 0.0001 | 0.0007 | 4 |
| Manganese | mg/L | 0.0047 | 0.0058 | 0.0060 | 0.0047 | 0.0006 | 0.0036 | 0.0063 | 4 |
| Mercury | mg/L | <0.00005 | <0.00005 | <0.00005 | - | - | - | - | - |
| Molybdenum | mg/L | 0.0016 | 0.0013 | 0.0012 | 0.0032 | 0.0002 | 0.0030 | 0.0038 | 4 |
| Nickel | mg/L | 0.005 | 0.005 | 0.005 | 0.0009 | 0.0002 | 0.0007 | 0.0014 | 4 |
| Selenium | mg/L | **0.002** | **0.003** | **0.003** | <0.0004 | 0.0000 | <0.0004 | <0.0004 | 4 |
| Silver | mg/L | **0.0004** | <0.0001 | <0.0001 | <0.00002 | 0.0000 | <0.00002 | <0.00002 | 4 |
| Zinc | mg/L | 0.02 | 0.02 | 0.01 | 0.004 | 0.0010 | 0.002 | 0.007 | 4 |

**Table B3 – Continued**

| Parameter | Units | Lake Manitoba[1] Open-water Season | | | | |
|---|---|---|---|---|---|---|
| | | Mean | SE | Min | Max | n |
| Aluminum | | 0.047 | 0.008 | 0.020 | 0.094 | 10 |
| Arsenic | mg/L | 0.0026 | 0.0001 | 0.0020 | 0.0031 | 11 |
| Cadmium | mg/L | <0.00004 | 0.0000 | <0.00004 | <0.00004 | 10 |
| Chromium | mg/L | 0.0003 | <0.0001 | 0.0002 | *0.0005* | 10 |
| Copper | mg/L | 0.0010 | <0.0001 | 0.0008 | 0.0013 | 10 |
| Iron | mg/L | 0.07 | 0.01 | 0.01 | 0.13 | 10 |
| Lead | mg/L | 0.0002 | <0.0001 | <0.0002 | 0.0003 | 10 |
| Manganese | mg/L | 0.0079 | 0.0008 | 0.0046 | 0.0110 | 10 |
| Mercury | mg/L | | | | | |
| Molybdenum | mg/L | 0.0026 | 0.0001 | 0.0022 | 0.0031 | 10 |
| Nickel | mg/L | 0.0010 | <0.0001 | 0.0007 | 0.0011 | 10 |
| Selenium | mg/L | <0.0004 | <0.0004 | <0.0004 | 0.0004 | 10 |
| Silver | mg/L | <0.00002 | 0.0000 | <0.00002 | <0.00002 | 10 |
| Zinc | mg/L | 0.002 | <0.001 | <0.001 | 0.004 | 10 |

**Table B3 – Continued**

| Parameter | Units | MWQSOG | | | | | |
|---|---|---|---|---|---|---|---|
| | | PAL[2,3] | | Irrigation | Livestock | Drinking Water | |
| | | Shoal Lakes | Lake Manitoba | | | Maximum Acceptable | Aesthetic |
| Aluminum | mg/L | **0.100** | | 5 | 5 | - | - |
| Arsenic | mg/L | 0.150 | | 0.1 | 0.025 | 0.025 [4] | - |
| Cadmium | mg/L | 0.0127-0.0170 | 0.0053-0.0073 | 0.0051 | 0.08 | 0.005 | - |
| Chromium | mg/L | 0.478-0.646 | 0.191-0.267 | *0.0049* | 0.05 | 0.05 | - |
| Copper | mg/L | 0.056-0.076 | 0.0215-0.303 | 0.2-1 | 0.5-5 | - | 1 |
| Iron | mg/L | 0.30 | | 5 | - | - | 0.3 |
| Lead | mg/L | 0.0456-0.0729 | 0.010-0.0184 | 0.2 | 0.1 | 0.01 | - |
| Manganese | mg/L | - | - | 0.2 | - | - | 0.05 |
| Mercury | mg/L | 0.0001 | | - | 0.003 | 0.001 | - |
| Molybdenum | mg/L | 0.073 | | 0.01-0.05 | 0.5 | - | - |
| Nickel | mg/L | 0.306-0.418 | 0.1190-0.1675 | 0.2 | 1 | - | - |
| Selenium | mg/L | **0.001** | | 0.02-0.05 | 0.05 | 0.01 | - |
| Silver | mg/L | **0.0001** | | - | - | - | - |
| Zinc | mg/L | 0.71-0.96 | 0.274-0.385 | 1-5 | 50 | - | 5 |

[1] From Lake Manitoba Narrows. Data provided by MBWS (2008).
[2] PAL=Protection of Aquatic Life
[3] Where two sets of objectives are presented, the values represent the ranges of calculated site-specific objectives for Shoal Lakes and Lake Manitoba, based on the range of water hardness measured in the lakes.
[4] Interim maximum acceptable concentration.

**Table B4 – Summary of the CCME trophic status classification scheme and open-water means of total phosphorus concentrations in the Shoal Lakes (2008) and Lake Manitoba (2005-2007)**

| | Lake Trophic Status | | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | Ultra-oligotrophic | Oligotrophic | Mesotrophic | Meso-eutrophic | Eutrophic | Hyper-eutrophic | |
| **Total Phosphorus (µg/L)** | | | | | | | |
| | < 4 | 4 - 10 | 10 - 20 | 20 - 35 | 35 - 100 | > 100 | CCME (1999) |
| North Shoal Lake | | | | | 80 | | This study |
| West Shoal Lake | | | | | | 137 | This study |
| East Shoal Lake | | | | | | 113 | This study |
| Lake Manitoba | | | | | 70 | | This study |

# APPENDIX C

# FLOOD MITIGATION ALTERNATIVE COSTS ESTIMATES

## Table C1 – Estimated Costs for Wagon Creek – Option A

| ITEM | DESCRIPTION | QTY. | UNIT | UNIT COST | TOTAL COST |
|---|---|---|---|---|---|
| | | | | | |
| **1.0** | **Excavation** | | | | |
| 1.1 | Diversion Channel | 2,629,000 | $m^3$ | $5.50 | $14,460,000 |
| 1.2 | Lakes Connecting Channels | 86,000 | $m^3$ | $5.50 | $473,000 |
| **2.0** | **Riprap Drop Structures** | | | | |
| 2.1 | Supply & Placement of Riprap | 8,000 | $m^3$ | $65 | $520,000 |
| 2.2 | Supply & Placement of Gravel Filter Material | 4,000 | $m^3$ | $50 | $200,000 |
| **3.0** | **Culverts** | | | | |
| 3.1 | Supply & Installation of 2.0 m Diameter Pipe | 300 | m | $2,100 | $630,000 |
| 3.2 | Supply & Installation of 2.2 m Diameter Pipe | 100 | m | $2,300 | $230,000 |
| **4.0** | **Land Acquisition (Right of Way)** | 260 | ha | $2,000 | $520,000 |
| **5.0** | **Re-Vegetation** | 300 | ha | $750 | $225,000 |
| **6.0** | **Control Structure (West Shoal Lake)** | | | | |
| | Excavation | 900 | $m^3$ | $5.50 | $5,000 |
| | Concrete | 270 | $m^3$ | $1,500 | $405,000 |
| | Gates | 2 | each | $15,000 | $30,000 |
| | Miscellaneous Steel | 1 | each | $10,000 | $10,000 |
| **7.0** | **Control Structure (North to East Shoal Lake)** | | | | |
| | Excavation | 400 | $m^3$ | $5.50 | $2,000 |
| | Concrete | 120 | $m^3$ | $1,500 | $180,000 |
| | Gates | 1 | each | $15,000 | $15,000 |
| | Miscellaneous Steel | 1 | each | $3,000 | $3,000 |
| | | | | | |
| | **Subtotal** | | | | **$17,908,000** |
| **8.0** | **Indirect Costs** | | | | |
| 8.1 | Contingency (20%) | | | | $3,582,000 |
| 8.2 | Engineering & Construction Supervision (10%) | | | | $1,791,000 |
| | | | | | |
| | **Subtotal** | | | | **$5,373,000** |
| | ***TOTAL*** | | | | ***$23,281,000*** |

## Table C2 – Estimated Costs for Wagon Creek – Option B

| *ITEM* | *DESCRIPTION* | *QTY.* | *UNIT* | *UNIT COST* | *TOTAL COST* |
|---|---|---|---|---|---|
| | | | | | |
| **1.0** | **Excavation** | | | | |
| 1.1 | Diversion Channel | 3,012,000 | $m^3$ | $5.50 | $16,566,000 |
| 1.2 | Lakes Connecting Channels | 86,000 | $m^3$ | $5.50 | $473,000 |
| **2.0** | **Riprap Drop Structures** | | | | |
| 2.1 | Supply & Placement of Riprap | 8,000 | $m^3$ | $65 | $520,000 |
| 2.2 | Supply & Placement of Gravel Filter Material | 4,000 | $m^3$ | $50 | $200,000 |
| **3.0** | **Culverts** | | | | |
| 3.1 | Supply & Installation of 2.0 m Diameter Pipe | 300 | m | $2,100 | $630,000 |
| 3.2 | Supply & Installation of 2.2 m Diameter Pipe | 100 | m | $2,300 | $230,000 |
| **4.0** | **Land Acquisition (Right of Way)** | 270 | ha | $2,000 | $540,000 |
| **5.0** | **Re-Vegetation** | 320 | ha | $750 | $240,000 |
| **6.0** | **Control Structure (West Shoal Lake)** | | | | |
| | Excavation | 900 | $m^3$ | $5.50 | $5,000 |
| | Concrete | 270 | $m^3$ | $1,500 | $405,000 |
| | Gates | 2 | each | $15,000 | $30,000 |
| | Miscellaneous Steel | 1 | each | $10,000 | $10,000 |
| **7.0** | **Control Structure (North to East Shoal Lake)** | | | | |
| | Excavation | 400 | $m^3$ | $5.50 | $2,000 |
| | Concrete | 120 | $m^3$ | $1,500 | $180,000 |
| | Gates | 1 | each | $15,000 | $15,000 |
| | Miscellaneous Steel | 1 | each | $3,000 | $3,000 |
| | | | | | |
| | **Subtotal** | | | | **$20,049,000** |
| **8.0** | **Indirect Costs** | | | | |
| 8.1 | Contingency (20%) | | | | $4,010,000 |
| 8.2 | Engineering & Construction Supervision (10%) | | | | $2,005,000 |
| | | | | | |
| | **Subtotal** | | | | **$6,015,000** |
| | ***TOTAL*** | | | | ***$26,064,000*** |

## Table C3 – Estimated Costs for Roy's / Boundary Drain

| ITEM | DESCRIPTION | QTY. | UNIT | UNIT COST | TOTAL COST |
|---|---|---|---|---|---|
| | | | | | |
| **1.0** | **Excavation** | | | | |
| 1.1 | Diversion Channel | 3,811,000 | $m^3$ | $5.50 | $20,961,000 |
| 1.2 | Lakes Connecting Channels | 86,000 | $m^3$ | $5.50 | $473,000 |
| **2.0** | **Riprap Drop Structures** | | | | |
| 2.1 | Supply & Placement of Riprap | 7,000 | $m^3$ | $65 | $455,000 |
| 2.2 | Supply & Placement of Gravel Filter Material | 4,000 | $m^3$ | $50 | $200,000 |
| **3.0** | **Culverts** | | | | |
| 3.1 | Supply & Installation of 2.0 m Diameter Pipe | 200 | m | $2,100 | $420,000 |
| 3.2 | Supply & Installation of 2.2 m Diameter Pipe | 100 | m | $2,300 | $230,000 |
| **4.0** | **Land Acquisition (Right of Way)** | 200 | ha | $2,000 | $400,000 |
| **5.0** | **Re-Vegetation** | 240 | ha | $750 | $180,000 |
| **6.0** | **Control Structure (West Shoal Lake)** | | | | |
| | Excavation | 900 | $m^3$ | $5.50 | $5,000 |
| | Concrete | 270 | $m^3$ | $1,500 | $405,000 |
| | Gates | 2 | each | $15,000 | $30,000 |
| | Miscellaneous Steel | 1 | each | $10,000 | $10,000 |
| **7.0** | **Control Structure (North to East Shoal Lake)** | | | | |
| | Excavation | 400 | $m^3$ | $5.50 | $2,000 |
| | Concrete | 120 | $m^3$ | $1,500 | $180,000 |
| | Gates | 1 | each | $15,000 | $15,000 |
| | Miscellaneous Steel | 1 | each | $3,000 | $3,000 |
| | | | | | |
| | **Subtotal** | | | | **$23,969,000** |
| **8.0** | **Indirect Costs** | | | | |
| 8.1 | Contingency (20%) | | | | $4,794,000 |
| 8.2 | Engineering & Construction Supervision (10%) | | | | $2,397,000 |
| | | | | | |
| | **Subtotal** | | | | **$7,191,000** |
| | ***TOTAL*** | | | | ***$31,160,000*** |

**Table C4 – Estimated Costs for Upland Storage**

| ITEM | DESCRIPTION | QTY. | UNIT | UNIT COST | TOTAL COST |
|---|---|---|---|---|---|
| **1.0** | **Channel Excavation** | 125,000 | $m^3$ | $5.50 | $688,000 |
| **2.0** | **Gated Control Structure** | 5 | each | $50,000 | $250,000 |
| **3.0** | **Land Acquisition (purchase of land for storage areas)** | 4300 | ha | Based on Property Assessment | $2,241,000 |
| | | | | **Subtotal** | **$3,179,000** |
| **4.0** | **Indirect Costs** | | | | |
| 4.1 | Contingency (20% of Direct Costs) | | | | $636,000 |
| 4.2 | Engineering & Construction Admin (10% of Direct Costs) | | | | $318,000 |
| | | | | **Subtotal** | **$954,000** |
| ***TOTAL*** | | | | | **$4,133,000** |