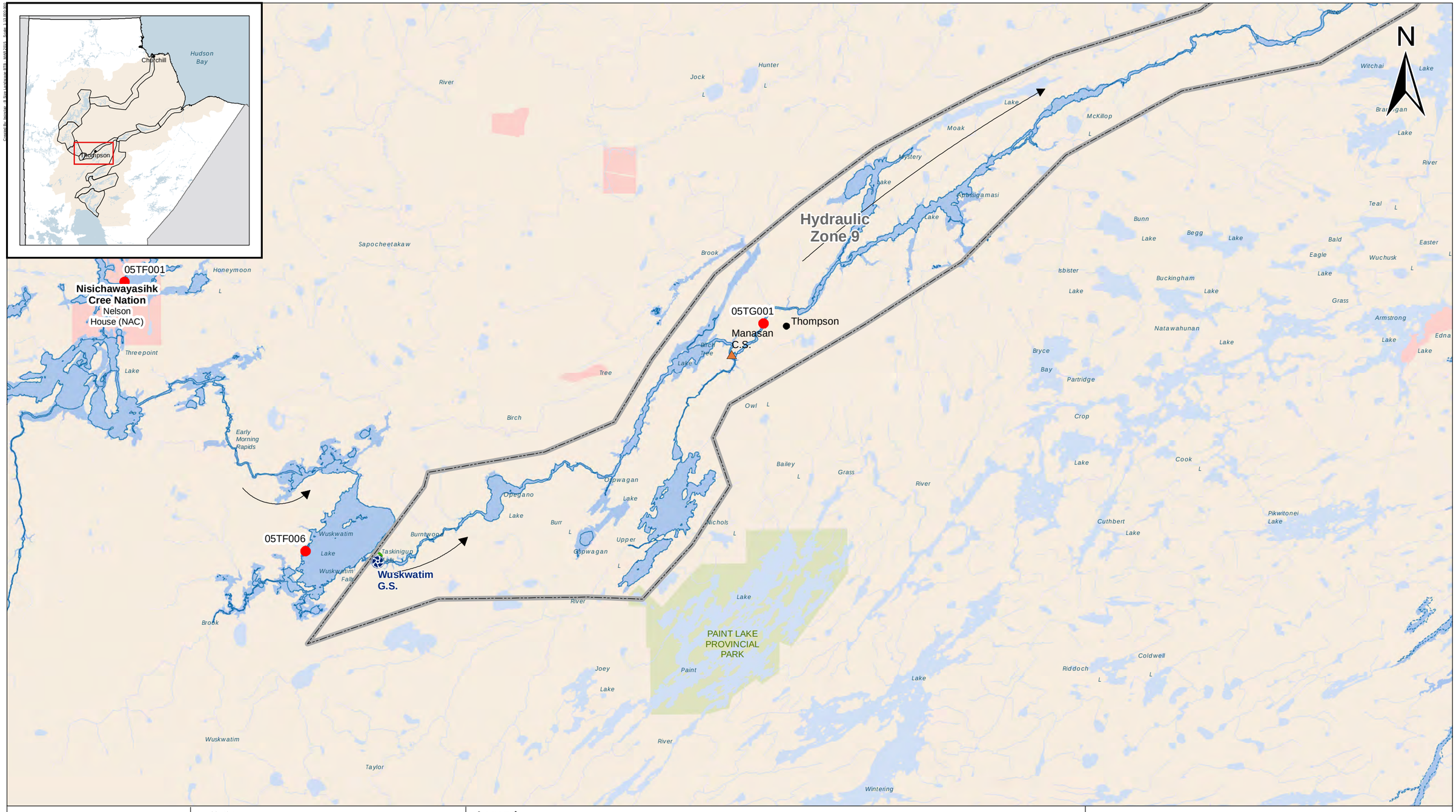


Regional Cumulative Effects Assessment

| | | | |
|---|---|---|---|
| **DATA SOURCE:** Manitoba Hydro; Government of Manitoba; Government of Canada | | | |
| **CREATED BY:** Manitoba Hydro - Hydraulic Operations | | | |
| **COORDINATE SYSTEM:** NAD 1983 UTM Zone 14N | **DATE CREATED:** 01-OCT-15 | **REVISION DATE:** 07-DEC-15 | |
| 0 4 8 Kilometres / 0 3 6 Miles | **VERSION NO:** 1.0 | **QA/QC:** | |

**Legend**

- Town
- Generating Station (Existing)
- Control Structure (Existing)
- Station Gauge
- Flow Direction
- Dyke
- First Nation Reserve
- Park (Provincial)
- Watercourse Boundary (Predevelopment)
- Watercourse Boundary (Predevelopment) Mapping Alignment Issue
- Watercourse (Existing)
- RCEA Hydraulic Zone

Notes:
- FOR ILLUSTRATIVE PURPOSES ONLY
- Northern Affairs Community (NAC)
- Watercourse Boundary Predevelopment - Mapping Alignment Issue See RCEA Phase II (PreambleSection 1.3.3) for more details.

# Hydraulic Zone 9

## Wuskwatim Generating Station to Split Lake Inlet

1 of 2

**Map 4.3.3-6**

**Regional Cumulative Effects Assessment**

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada

CREATED BY:
Manitoba Hydro - Hydraulic Operations

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 01-OCT-15 | 04-DEC-15 |
| 0 4 8 Kilometres / 0 3 6 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- Town
- Generating Station (Existing)
- Control Structure (Existing)
- Station Gauge
- Flow Direction
- Dyke
- First Nation Reserve
- Watercourse Boundary (Predevelopment)
- Watercourse Boundary (Predevelopment) Mapping Alignment Issue
- Watercourse (Existing)
- RCEA Hydraulic Zone

Notes:
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# Hydraulic Zone 9

## Wuskwatim Generating Station to Split Lake Inlet

2 of 2

**Map 4.3.3-6**

#### 4.3.3.7.2 Data

In this hydraulic zone WSC has operated flow station 05TG001 (Burntwood River near Thompson) since 1956.

#### 4.3.3.7.3 Key Hydraulic Features and Indicators

The effect of Wuskwatim cycling on water levels in this zone is described in Section 4.3.3.6.3. While there is no pre-CRD water level data for Opegano Lake, it is estimated based on simulated conditions with and without CRD, presented in Appendix 4.3C, that CRD increased the average water level by about 7.6 ft (2.3 m). Similarly, it is estimated that CRD and the Manasan Falls CS (described below) increased the average water level on Birch Tree Lake by about 18.4 ft, (5.6 m).

**BURTWOOD RIVER NEAR THOMPSON**

Based on the available record, CRD has increased flows at the Burntwood River near Thompson from a long-term average of approximately 4,000 cfs to 30,000 cfs (110 cms to 850 cms). Also, CRD has changed the seasonal flow pattern so that the highest flows typically now occur during the winter while flows used to peak during the summer (Figure 4.3.3-21). Figure 4.3.3-22 shows the average, historical range and upper and lower quartiles for daily discharge on the Burntwood River near Thompson from 1978 to 2014. Figure 4.3.3-22 also shows that discharge on the Burntwood River near Thompson during the 2003 drought and 2011 flood were fairly similar. In both cases, water flows were highest in the winter and reached extremely low levels during the open water season. In 2003 low levels were caused by low precipitation in the Churchill River drainage basin, while in 2011 low levels were caused by reduced outflow at Notigi CS to avoid aggravating flood conditions on the lower Nelson River.

**MANASAN FALLS CONTROL STRUCTURE**

The Manasan Falls CS is a passive control structure designed to reduce the risk of inundation due to ice on the Burntwood River in the City of Thompson. The project consists of an ice boom across the river upstream of a groin/gap structure, a by-pass channel with a concrete overflow weir and a flood channel protected with a fuse plug dyke. The project was initially constructed in 1976 followed by rehabilitation in 1986 and an incorporation of safety features in 1988. Based on simulated conditions with and without CRD it is estimated that the Manasan Falls CS, along with increased flows because of CRD, increased the average water level on Birch Tree Lake by about 18.4 ft (5.6 m).

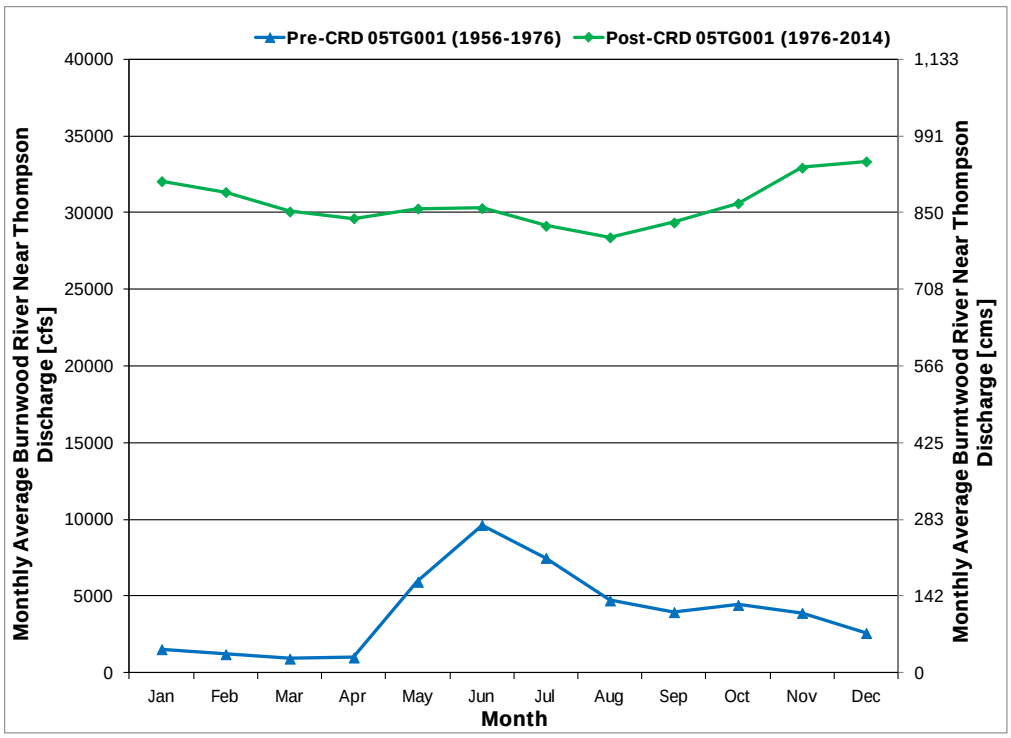
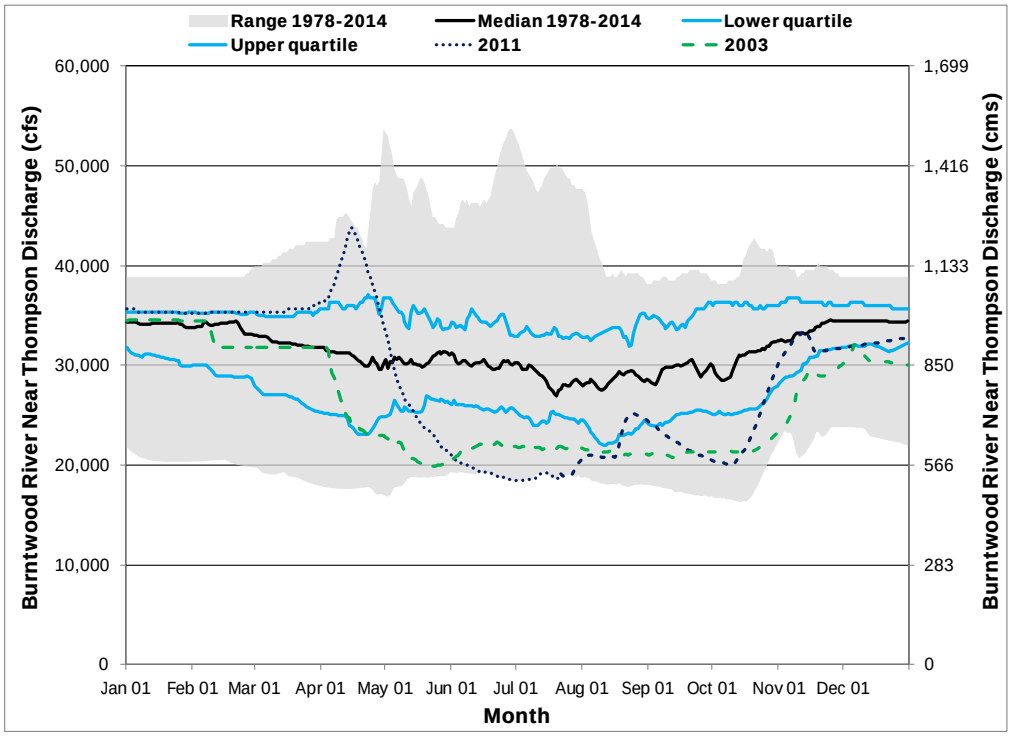



**Figure 4.3.3-21: Monthly Average Burntwood River near Thompson Discharge**




CRD = Churchill River Diversion.

**Figure 4.3.3-22: Daily Burntwood River near Thompson Discharge (Post-CRD)**

#### 4.3.3.7.4 Ice Conditions

The higher flows created by CRD in this hydraulic zone resulted in higher velocities along the Burntwood River, which may result in areas remaining ice free for longer periods. The present water regime consists of fast flowing reaches, which remain ice free, and connecting lakes or slow velocity reaches which freeze over early in the winter. Each year, a competent ice cover quickly forms on major lakes in this reach, including Opegano Lake and Birch Tree Lake. Other sections of the river remain open, and produce large volumes of frazil ice, which accumulates either on the leading edge of the downstream ice cover, resulting in advancement of the cover upstream, or deposits under the cover forming a hanging ice dam (Manitoba Hydro and NCN 2003). The Wuskwatim EIS contains a detailed description of ice conditions along the Burntwood River and any effects of the Wuskwatim GS on ice conditions.

## 4.3.4 Lake Winnipeg Regulation and Churchill River Diversion Influenced Zones

The RCEA ROI includes three hydraulic zones, which are influenced by both LWR and CRD. These are:

- Hydraulic Zone 10 – Split Lake to Gull Rapids;
- Hydraulic Zone 11 – Stephens Lake to Limestone GS; and
- Hydraulic Zone 12 – Limestone GS to Gillam Island.

Key hydraulic features within each hydraulic zone will be described within the appropriate sections below.

### 4.3.4.1 Typical Lake Winnipeg Regulation and Churchill River Diversion Operation

As discussed in the previous two sections, LWR and CRD operating decisions are made considering water supply conditions and other factors at the time. The following is a broad description of the influence of LWR and CRD operations on flows in the lower Nelson River over the course of a year. It is not meant to be a comprehensive guideline applicable to all possible conditions.

**WINTER**

Lake Winnipeg Regulation and Churchill River Diversion are both typically operated to maximize flows to the lower Nelson River to supply generation during the winter when Manitoba load is highest. Lake Winnipeg outflow is mainly dependent on the level of Lake Winnipeg and the ice constrictions between Lake Winnipeg and Jenpeg GS. Churchill River Diversion flow at Notigi CS is typically increased to the maximum possible if water supply permits, which is dependent on projected lake inflows and the water level of SIL.

**SPRING**

As spring approaches, LWR and CRD operations are planned based on current Lake Winnipeg and SIL water levels, storage levels elsewhere in the system, snowpack, and inflow forecasts. Generally, the objective for spring operation of LWR and CRD is to allow some refill of Lake Winnipeg and SIL with spring runoff while reducing flow on the lower Nelson River at a time when demand is lower. However, under above average or higher water supply conditions on Lake Winnipeg (*e.g.*, above average Lake Winnipeg levels and high expected snowmelt runoff), Lake Winnipeg outflows may continue to be maximized through the spring into the summer in an attempt to avoid Lake Winnipeg levels from rising close to or above 715 ft (217.9 m). In these cases, CRD diversion flow at Notigi CS may be further reduced to limit flooding on the lower Nelson River. This can result in SIL refilling more quickly with potentially higher Missi Falls CS outflows and higher flows along the lower Churchill River. In low water supply years, Lake Winnipeg and SIL outflows are reduced to conserve spring runoff to supply lower Nelson River generation at a later time.

**SUMMER**

Lake Winnipeg Regulation and Churchill River Diversion outflows during the summer are largely dependent on inflows at the time, which can vary greatly from year to year and can change relatively quickly due to precipitation in the respective basins. Inflows can transition from normal to flood inflows after only a few widespread, major rain events. Lake Winnipeg Regulation provides increased discharge capability to manage floods and this capacity can be used in response to an increase in inflows. There is a much wider range of Lake Winnipeg and Notigi CS outflows in summer. In comparison, the range of outflows during the winter months is smaller since outflows are almost always maximized. In years when SIL is full and inflows continue to be strong, excess water is spilled at Missi Falls CS. Also, in years when the Nelson River is experiencing flood conditions due to high Lake Winnipeg outflows, Notigi CS outflows are reduced to avoid aggravating flooding. This can also lead to higher outflows at Missi Falls CS.

**FALL**

During the fall, inflows to Lake Winnipeg and SIL typically begin to decrease. Lake Winnipeg Regulation and CRD outflows are generally less in the early fall than the summer because inflows are lower on average and because electrical demand is less in the early fall versus summer. Fall floods are not as common as spring and summer floods but they do occur. Lake Winnipeg and SIL levels typically decline through the fall, however when water supply conditions are low (*i.e.*, system storage and inflows are low), outflows will be reduced to conserve water for use in supplying winter demand and to protect against the possibility of drought. If Missi Falls CS outflows had been above minimum during the summer, they would typically be reduced during the fall to avoid drawing down SIL. Both Lake Winnipeg and Notigi CS outflows are typically increased prior to winter as described above to supply Nelson River generation.

Although extremely rare, there have been instances when generating stations have been shut down entirely for short periods. These include events such as emergencies and maintenance inspections. These events typically last for one to two hours or less. Manitoba Hydro monitors these events closely. These events have not caused water levels either upstream or downstream of the generating stations to fall outside the historical range of experience.

## 4.3.4.2 Hydraulic Zone 10 – Split Lake to Gull Rapids

Hydraulic Zone 10 covers the lower Nelson River, including Split Lake to just upstream of Stephens Lake (Map 4.3.4-1). Major lakes in this hydraulic zone are Split, Clark, and Gull lakes. Prior to 2014, there were no structures related to hydroelectric development in this hydraulic zone. As of July 16, 2014, the construction of the Keeyask GS began. The Keeyask GS will be located at the downstream end of this hydraulic zone at Gull Rapids.

### 4.3.4.2.1 Manitoba Hydro Operations

Manitoba Hydro's operation of CRD, LWR, and Kelsey GS influences inflows to this hydraulic zone. Lake Winnipeg Regulation changes the seasonal timing of Nelson River inflows to match seasonal load requirements at Manitoba Hydro's major generating stations along the lower Nelson River. The CRD increases the average inflow and influences the seasonal timing of inflows from the Burntwood River.

Kelsey GS had no effect on inflows to this hydraulic zone prior to 1976 because it was operated as a run-of-the-river plant. Starting in 1977, Kelsey GS operations were modified to more effectively utilize the reservoir of Kelsey GS's forebay on an infrequent basis to supplement flows over a period of about a month or so, or to increase the gradient out of Sipiwesk Lake to alleviate winter hydraulic restrictions. Kelsey GS operations can have short duration effects on Split Lake water levels and flows (Manitoba Hydro-Split Lake Cree Joint Studies 1996).

#### 4.3.4.2.2 Data

Water Survey Canada reports the daily average water level for Split Lake since 1954 at station 05UF003 (Split Lake at Split Lake).

#### 4.3.4.2.3 Key Hydraulic Features and Indicators

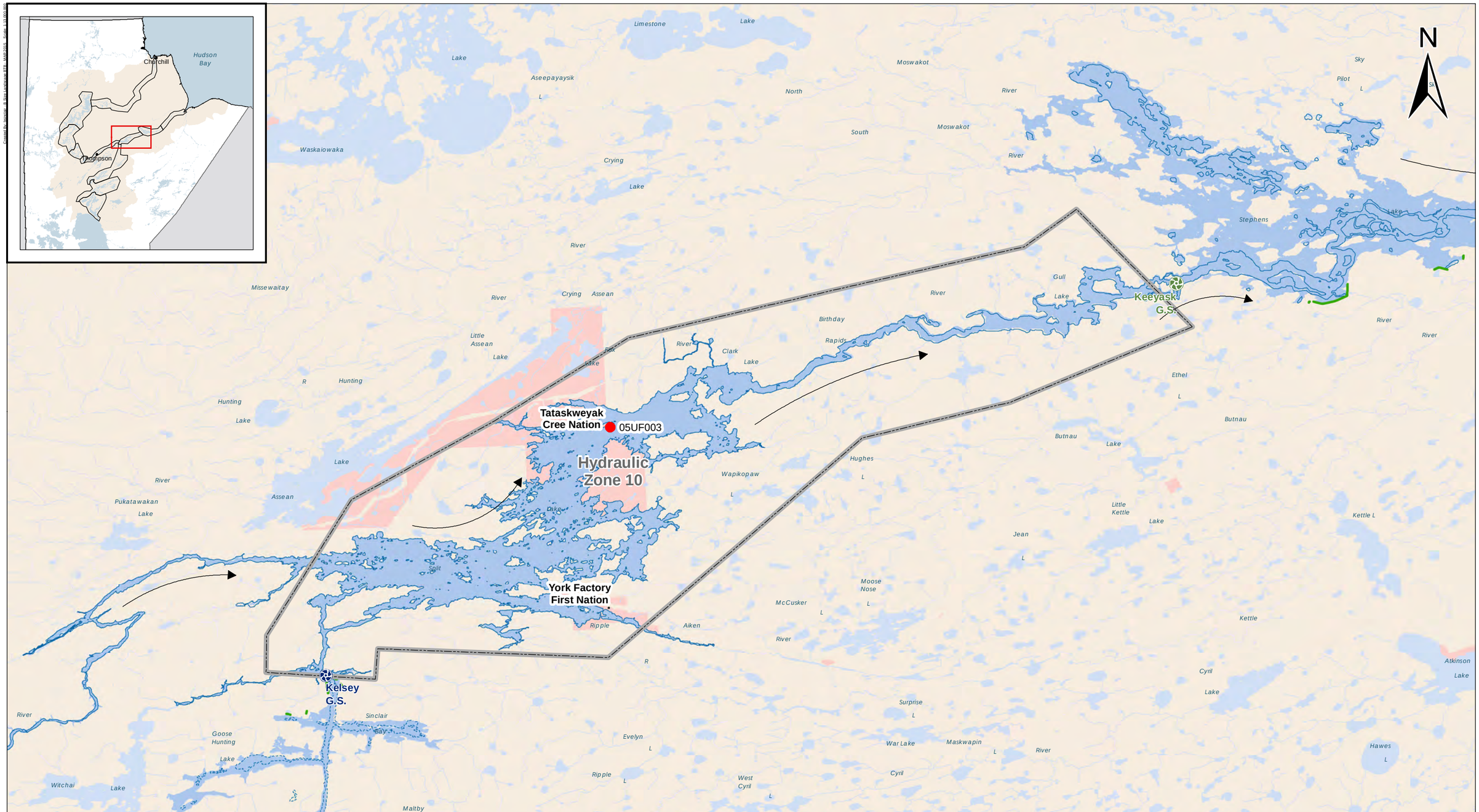
**SPLIT LAKE**

The Keeyask Hydropower Limited Partnership reports that Split Lake is relatively large with numerous small islands and an approximate surface area of 116 sq mi (300 $km^2$). Water levels are influenced by the amount of water flowing in to the lake and the narrow constriction at the outlet that controls the lake's discharge. The levels on Split Lake typically fluctuate between 545 ft and 551 ft (166.1 m and 167.9 m) in any given year, but water levels may vary greatly from one year to the next, depending on the water supply from the Nelson River drainage basin and CRD (Keeyask Hydropower Limited Partnership 2012).

The average Split Lake water level was 547.4 ft (166.8 m) pre-CRD/LWR. Post-CRD/LWR, the average Split Lake water level is 1.2 ft (0.4 m) higher at 548.6 ft (167.2 m). There was a seasonal reversal in water levels because average winter levels are typically higher than average summer levels (Figure 4.3.4-1). However, the overall peak water levels have still occurred in summer in association with high flood flows from the upper Nelson River. Figure 4.3.4-2 shows the average, historical range and upper and lower quartiles for daily water levels on Split Lake from 1976 to 2014. Water levels during the 2003 drought and 2011 flood are also included on the figure. The 2003 drought resulted in very low Split Lake water levels for most of the year, reaching record lows for the last few months of the year. The 2011 flood resulted in near record high Split Lake water levels for most of the year. Simulated Split Lake water levels without CRD and LWR presented in Appendix 4.3A estimate that severe flood events such as the floods of 2005 and 2011 are about 1.3 ft (0.4 m) higher with CRD and LWR. Also, the study estimates that the Burntwood River's contribution to the total inflow to Split Lake was 25% with CRD and would have been 3% without CRD in the period from 1978 to 2014.

Operation of LWR and CRD does not cause large hourly or daily water level variations on Split Lake. As shown in Table 4.3.4-1, the largest daily variations are typically less than a few inches. Table 4.3.4-1 also provides average and 95$^{th}$ percentile weekly and annual water level variations both pre and post-CRD.

From the outlet of Split Lake to Stephens Lake, which is located just below Gull Rapids, there are both lake and river sections which are described in more detail in the Keeyask EIS, along with the anticipated effects of the Keeyask GS (Keeyask Hydropower Limited Partnership 2012).




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada

CREATED BY:
Manitoba Hydro - Hydraulic Operations

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 01-OCT-15 | 04-DEC-15 |
| 0 4 8 Kilometres / 0 3 6 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- Generating Station (Existing)
- Generating Station (Under Construction)
- Station Gauge
- Flow Direction
- Dyke
- First Nation Reserve
- Watercourse Boundary (Predevelopment)
- Watercourse Boundary (Predevelopment) Mapping Alignment Issue
- Watercourse (Existing)
- RCEA Hydraulic Zone

Notes:
- FOR ILLUSTRATIVE PURPOSES ONLY
- Northern Affairs Community (NAC)
- Watercourse Boundary Predevelopment - Mapping Alignment Issue See RCEA Phase II (PreambleSection 1.3.3) for more details.

# Hydraulic Zone 10

## Split Lake to Gull Rapids

1 of 1

**Map 4.3.4-1**

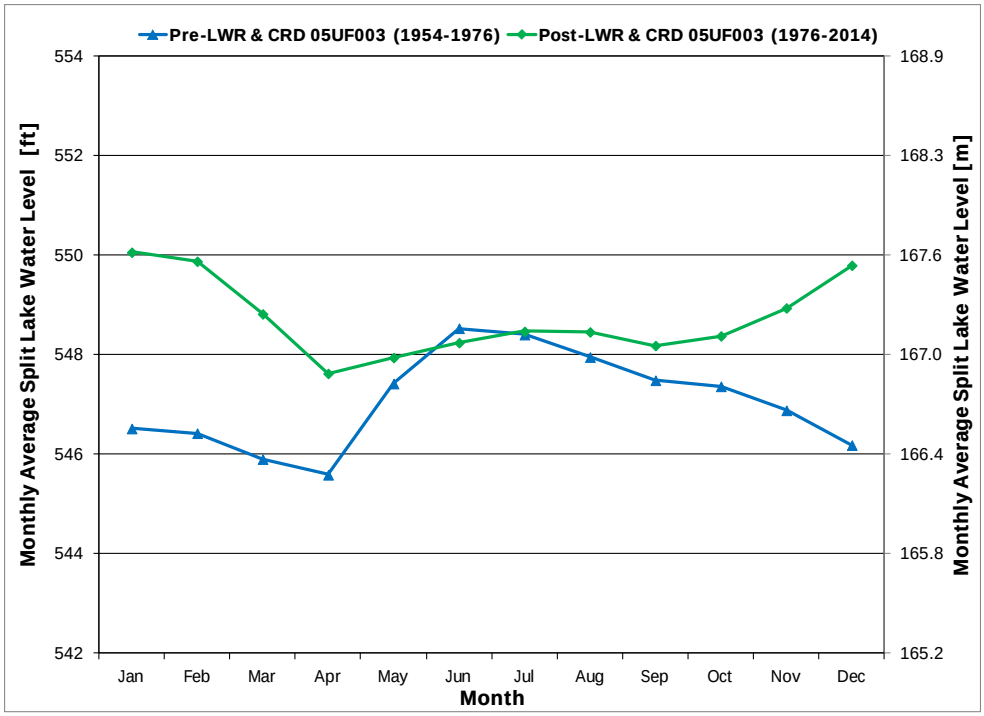
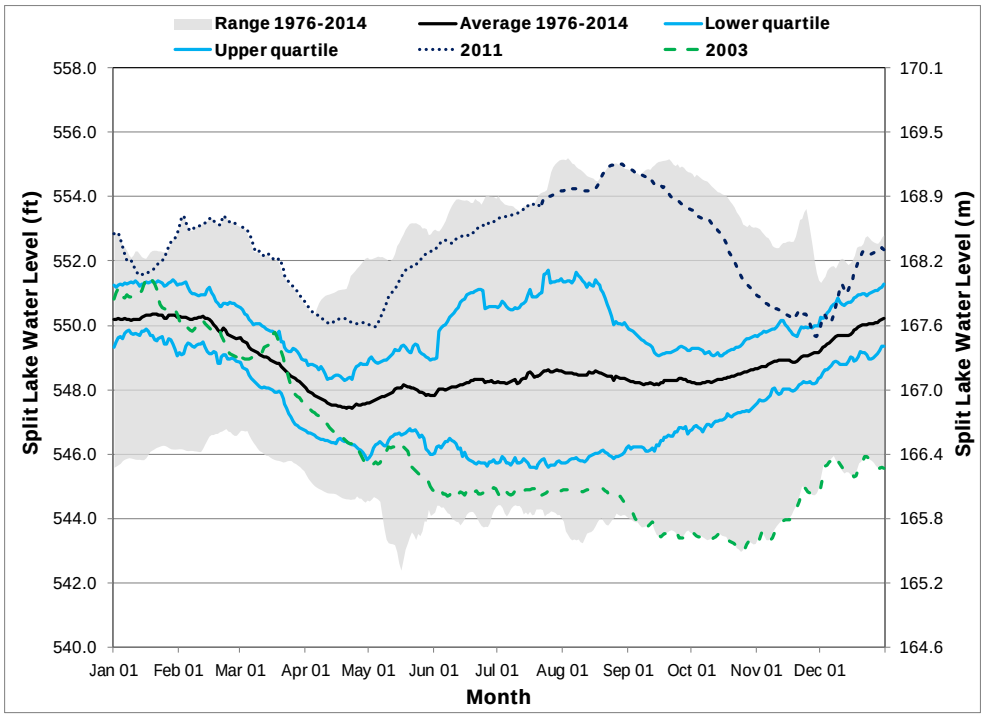



**Figure 4.3.4-1: Monthly Average Split Lake Water Levels**




CRD/LWR = Chuchill River Diversion/ Lake Winnipeg Regulation.

**Figure 4.3.4-2: Daily Split Lake Water Levels (Post-CRD/LWR)**

**Table 4.3.4-1: Daily, Weekly and Annual Split Lake Water Level Variation at Gauge 05UF003**

| Variation | Pre-CRD/LWR [1] Mean (ft) 1954–1976 | Post-CRD/LWR Mean (ft) 1977–2014 | Pre-CRD/LWR 95th Percentile (ft) 1954–1976 | Post-CRD/LWR 95th Percentile (ft) 1977–2014 |
|---|---|---|---|---|
| Daily | 0.1 | 0.1 | 0.2 | 0.2 |
| Weekly | 0.3 | 0.4 | 0.8 | 0.9 |
| Annual | 3.9 | 5.7 | 5.6 | 8.2 |

Annual variation is max-min in each year June–May.

1. CRD/LWR = Churchill River Diversion/Lake Winnipeg Regulation.

#### 4.3.4.2.4 Ice Conditions

On Split Lake, water level fluctuations have the potential to create thin ice, slush ice, and earlier breakup. A detailed description of existing ice conditions from Split Lake to Stephens Lake is contained in the Keeyask EIS, which indicates that higher velocities in this reach have a substantial impact on overall ice formation processes (Keeyask Hydropower Limited Partnership 2012). Hydroelectric development caused higher winter flows and velocities, which may result in areas remaining ice free for longer periods.

### 4.3.4.3 Hydraulic Zone 11 – Stephens Lake to Limestone Generating Station

Hydraulic Zone 11 covers Stephens Lake and the lower Nelson River downstream to the Limestone GS. This zone includes Manitoba Hydro's three biggest generating stations, Kettle GS, Long Spruce GS and Limestone GS, and their associated forebays (Map 4.3.4-2). The Kettle GS is located at the outlet of Stephens Lake near the town of Gillam and was completed in 1974. The Long Spruce GS is located 10 mi (16 km) downstream from Kettle GS and was completed in 1979. The Limestone GS is located 14 mi (23 km) downstream from Long Spruce GS and was completed in 1992.

#### 4.3.4.3.1 Manitoba Hydro Operations

Operation of Kettle GS, Long Spruce GS, and Limestone GS controls water levels in this hydraulic zone regardless of inflows to Stephens Lake. The level of Stephens Lake is controlled for optimum energy production within the Manitoba Hydro system through operation of Kettle GS. This includes a daily and weekly cycling pattern that allows Manitoba Hydro to match energy production to consumption patterns. Flows are increased each morning during the workweek and maintained until late afternoon or evening when they are decreased to reach lowest levels overnight. There is a similar daily pattern on the weekend although flows are lower because there is less energy demand. On a weekly cycle, Stephens Lake is generally drawn down during the workweek when energy demand is higher and the lake is re-filled over the weekend. Long Spruce GS and Limestone GS are operated as run-of-the-river generating stations, with flow patterns matching releases from Kettle GS.

Hydraulic Zone 11

Conawapa G.S.

Fox Lake Cree Nation

Limestone G.S.

Long Spruce G.S.

Kettle G.S.

Keeyask G.S.

Gillam

WILDLIFE MANAGEMENT AREA

N

Regional Cumulative Effects Assessment

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada

CREATED BY:
Manitoba Hydro - Hydraulic Operations

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 01-OCT-15 | 04-DEC-15 |
| 0 4 8 Kilometres / 0 3 6 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- Town
- Generating Station (Existing)
- Generating Station (Under Construction)
- Generating Station (Potential)
- Flow Direction
- Dyke
- First Nation Reserve
- Wildlife Management Area
- Watercourse Boundary (Predevelopment)
- Watercourse (Existing)
- RCEA Hydraulic Zone

Notes:
- FOR ILLUSTRATIVE PURPOSES ONLY
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- Watercourse Boundary Predevelopment - Mapping Alignment Issue See RCEA Phase II (PreambleSection 1.3.3) for more details.

# Hydraulic Zone 11

Stephens Lake to Limestone Generating Station
1 of 1

**Map 4.3.4-2**

#### 4.3.4.3.2 Data

There is no continuous water level data available in this hydraulic zone prior to hydroelectric development. Manitoba Hydro has records of forebay water levels and discharge at Kettle GS, Long Spruce GS, and Limestone GS since the stations were completed. Discharge data is also available through WSC.

#### 4.3.4.3.3 Key Hydraulic Features and Indicators

**STEPHENS LAKE / KETTLE GENERATING STATION FOREBAY**

The Kettle GS increased water levels on the Nelson River immediately upstream by approximately 103.3 ft (31.5 m) (Manitoba Hydro-Split Lake Cree Joint Studies 1996) and flooded approximately 85.3 sq mi (221 $km^2$) of land, creating what is now known as Stephens Lake. The part of Stephens Lake just upstream from Kettle GS is known as the forebay. The current normal maximum forebay elevation is 463 ft (141.1 m), while the minimum operating level is 453 ft (138.1 m), although 95% of the time the forebay elevation is above 457 ft (139.3 m) as (Figure 4.3.4-3). To avoid wind and wave damage to Kettle GS dams the forebay was rarely operated above 461 ft (140.5 m) prior to 1996. At this time the dams were upgraded including the installation of large concrete blocks as wave barriers to allow the forebay to be operated between 461 and 463 ft (140.5 and 141.1 m) more frequently during the open water period. Average and 95$^{th}$ percentile daily, weekly, and annual water level variations in the Kettle GS forebay are provided in Table 4.3.4-2.

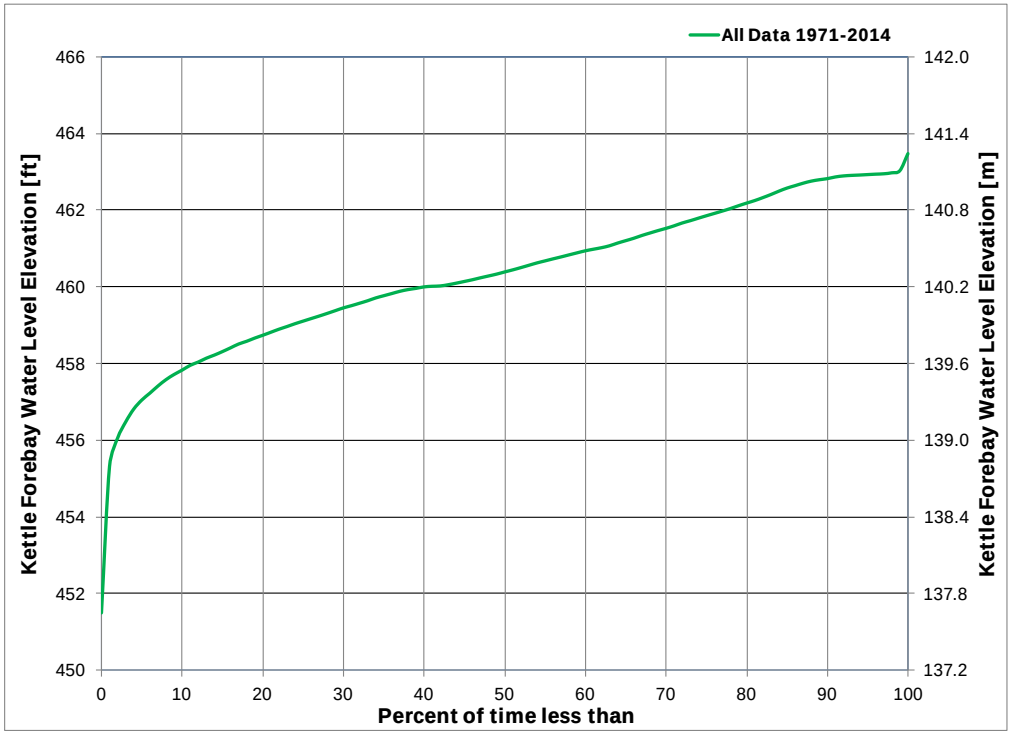



**Figure 4.3.4-3: Kettle Generating Station Forebay Daily Water Level Duration Curve**

**Table 4.3.4-2: Daily, Weekly and Annual Kettle Generating Station Forebay Water Level Variation**

| Variation | Post-CRD/LWR [1] Mean (ft) 1977–2014 | Post-CRD/LWR 95th Percentile (ft) 1977–2014 |
|---|---|---|
| Daily | 0.3 | 0.8 |
| Weekly | 1.3 | 2.9 |
| Annual | 7.5 | 9.4 |

Note: Annual variation is max-min in each year June–May.
1. CRD/LWR = Churchill River Diversion/Lake Winnipeg Regulation.

## LONG SPRUCE GENERATING STATION FOREBAY

Impoundment of the Long Spruce GS forebay was mostly contained within the natural banks of the Nelson River and flooded approximately 5.6 sq mi (14.5 km$^2$) to just downstream from Kettle GS. The forebay is typically operated at just below 361 ft (110.0 m) during the open water period and just below 362 ft (110.3 m) during the winter. Water levels remain above 359 ft (109.4 m) in the forebay 95% of the time (Figure 4.3.4-4).

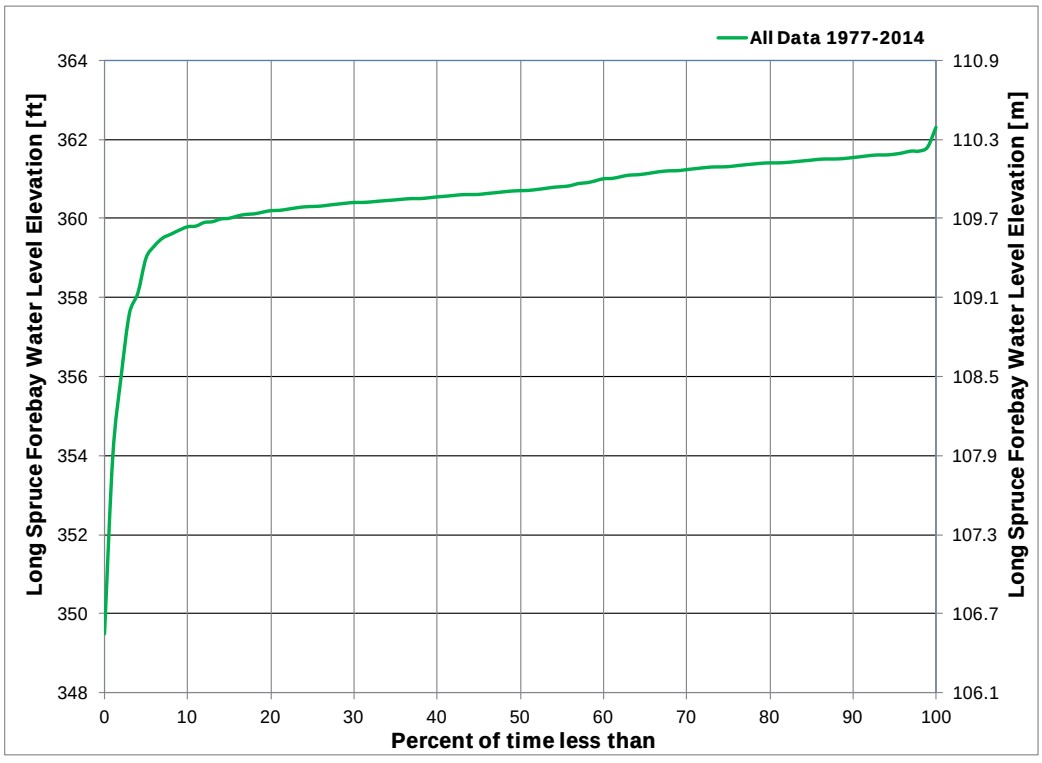



**Figure 4.3.4-4: Long Spruce Generating Station Forebay Daily Water Level Duration Curve**

## LIMESTONE GENERATING STATION FOREBAY

The majority of the Limestone GS forebay is contained by the natural banks of the Nelson River. The project flooded 0.8 sq mi (2.2 $km^2$) of land, affecting water levels to just downstream of Long Spruce GS. The Limestone GS forebay is typically operated between 278 ft and 280 ft (84.7 m and 85.3 m) (Figure 4.3.4-5).

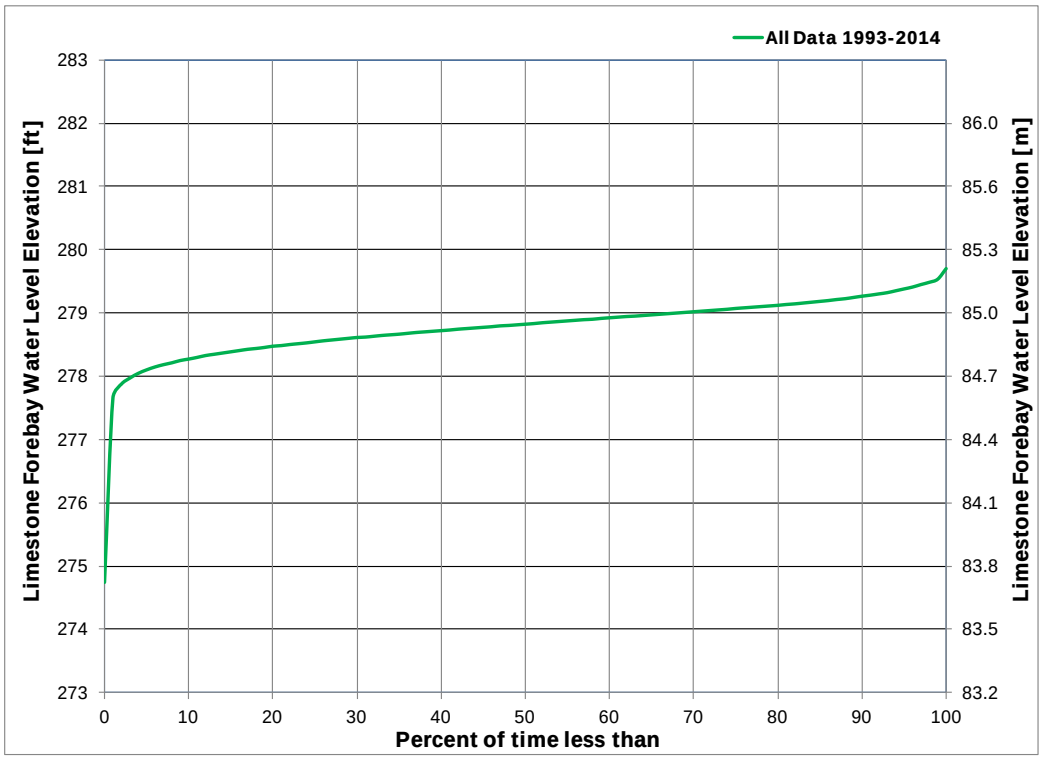



**Figure 4.3.4-5: Limestone Generating Station Forebay Daily Water Level Duration Curve**

## LOWER NELSON RIVER CYCLING

Cycling operation at the lower Nelson generating stations is described above in Section 4.3.4.3.1. Long Spruce GS and Limestone GS are operated as run-of-the-river generating stations, with flow patterns matching releases from Kettle GS. The exact pattern of cycling depends on a number of factors including energy demand, export price, and amount of other available generation. Figures 4.3.4-6 to 4.3.4-11 provide a snapshot of the effects of cycling on the forebay and tailrace water levels at the three lower Nelson River generating stations from July 2002. This period was selected because discharge variation from the daytime peak to the overnight low was near the highest on record during this month and therefore provides an estimate of the greatest water level variations in this hydraulic zone because of cycling. All figures show that during the entire month of July, discharge at each of the three stations reached a daytime high of between about 140,000 and 180,000 cfs (3,964 to 5,097 cms), and reached an overnight low of about 20,000 to 60,000 cfs (566 to 1,699 cms). The figures also show that discharge each day is about the same at Kettle GS, Long Spruce GS, and Limestone GS.

Figure 4.3.4-6 shows that the cycling operation generally resulted in the weekly pattern described above except during the last week of the month when re-ponding of Stephens Lake did not occur over the weekend. The water level variation in the immediate forebay and on Stephens Lake in the northwest arm was typically less than 0.5 ft (0.15 m) within any given day, while up 3 ft (0.9 m) in water level variation was observed throughout the month of July in 2002.

Figure 4.3.4-7 shows that water levels fluctuated about 4 ft (1.2 m) immediately downstream from Kettle GS because of the cycling operation. Figures 4.3.4-8, 4.3.4-9, and 4.3.4-10 show that water levels were maintained within a 2 to 3 ft (0.6 to 0.9 m) range in the Long Spruce GS forebay and tailrace, as well as the Limestone GS forebay throughout the entire month of July in 2002. Figure 4.3.4-11 shows that water level variations were largest just downstream from Limestone GS at about 6 ft (1.8 m) between the maximum and minimum each day.

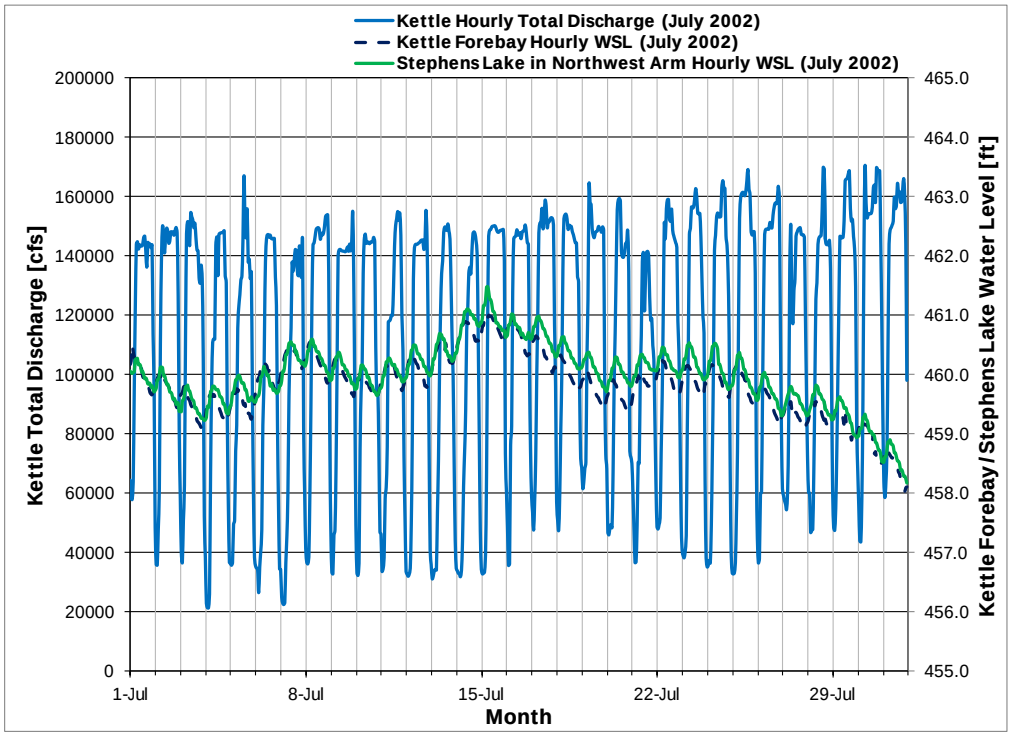



**Figure 4.3.4-6: Total Discharge and Forebay Water Level at Kettle Generating Station during Cycling Operation in July 2002**

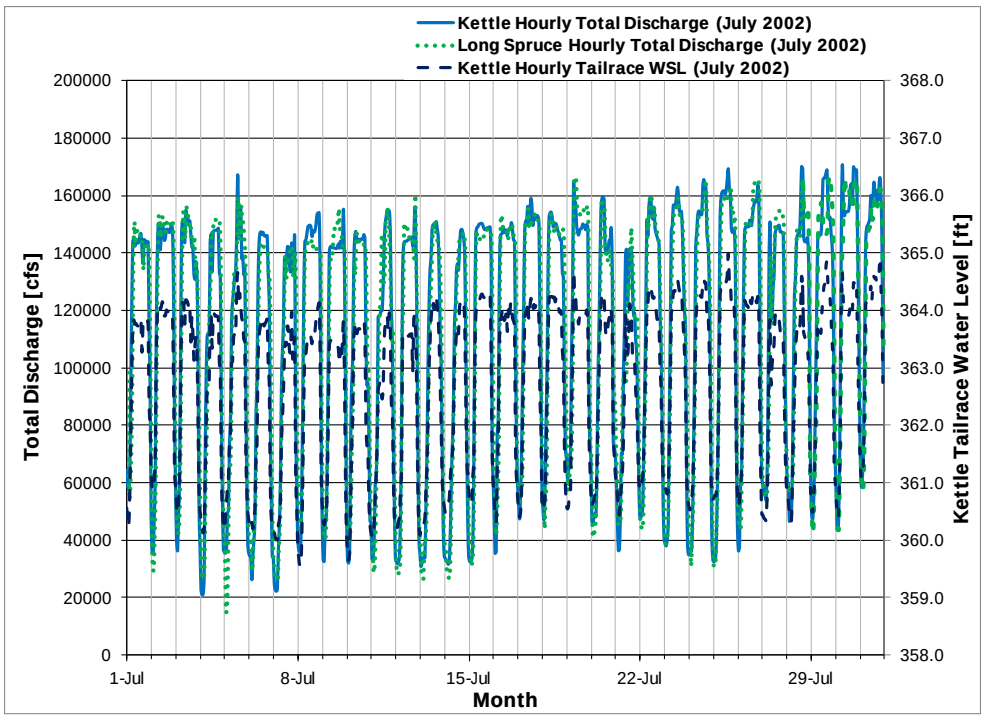



**Figure 4.3.4-7: Total Discharge and Tailrace Water Level at Kettle Generating Station during Cycling Operation in July 2002**

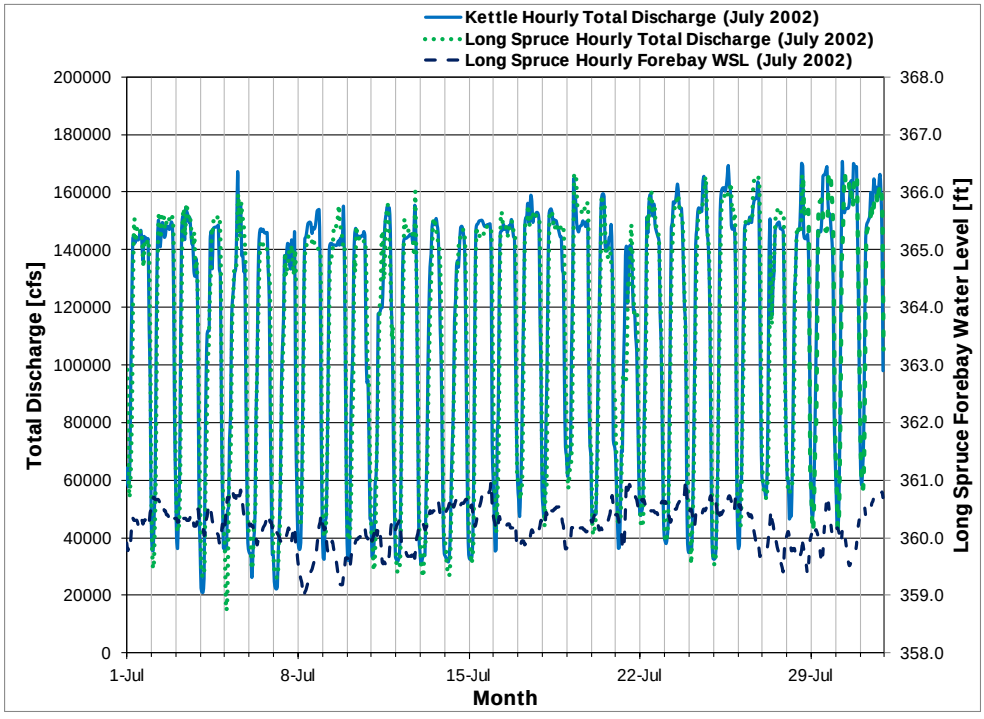



**Figure 4.3.4-8: Total Discharge and Forebay Water Level at Long Spruce Generating Station during Cycling Operation in July 2002**

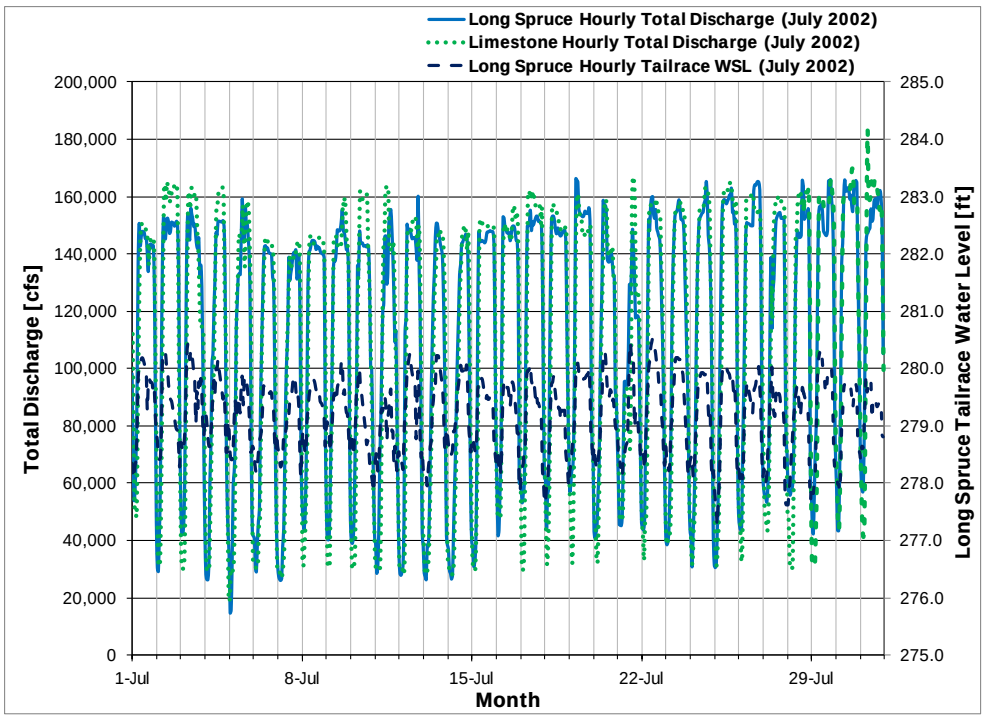



**Figure 4.3.4-9: Total Discharge and Tailrace Water Level at Long Spruce Generating Station during Cycling Operation in July 2002**

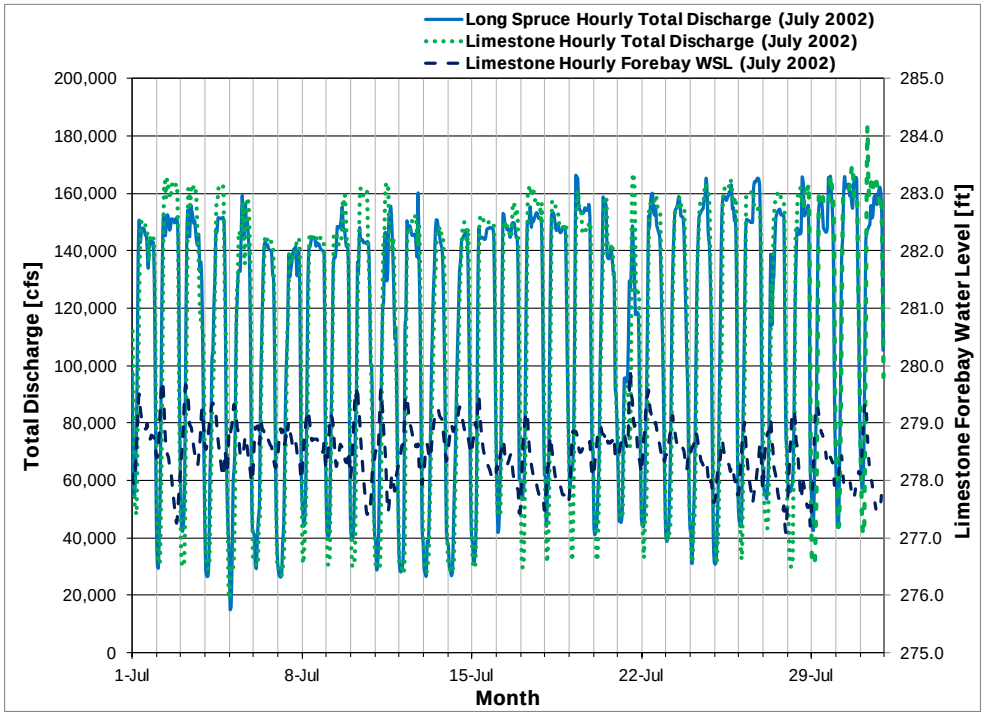



**Figure 4.3.4-10: Total Discharge and Forebay Water Level at Limestone Generating Station during Cycling Operation in July 2002**

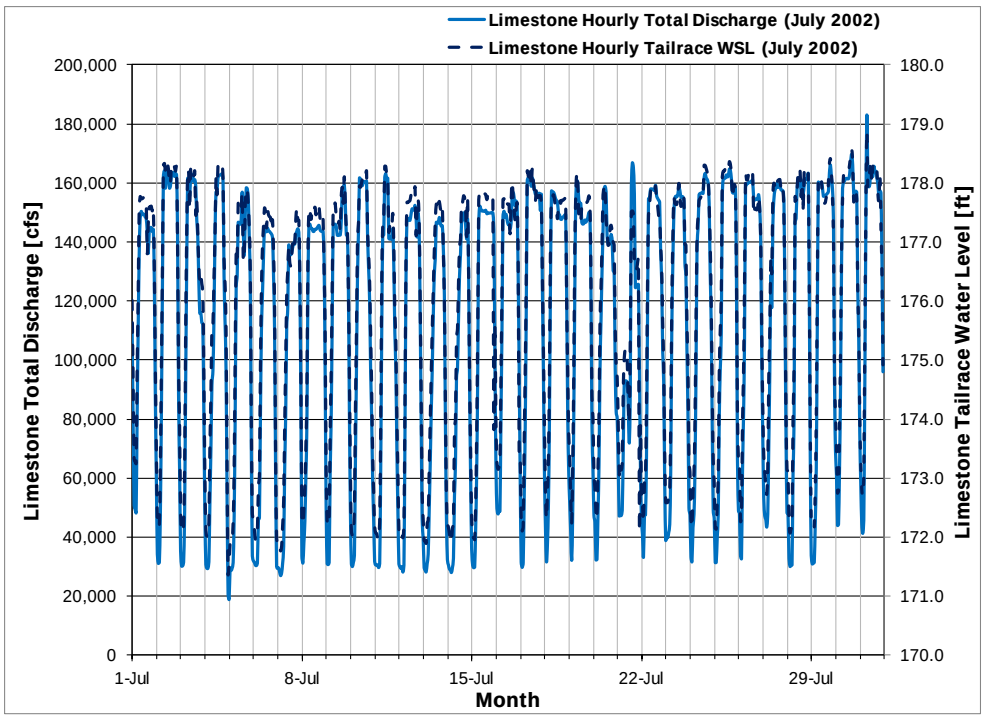


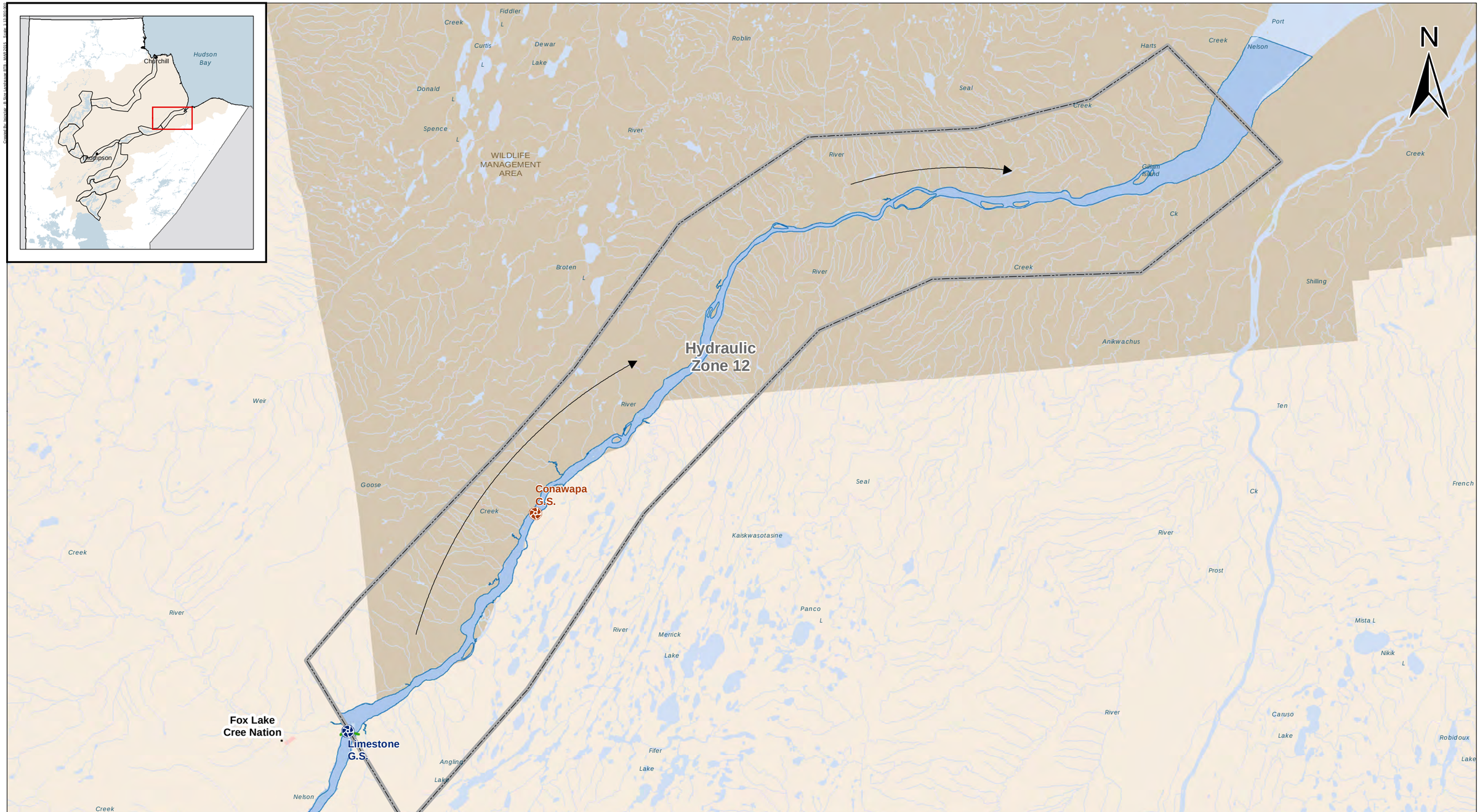

**Figure 4.3.4-11: Total Discharge and Tailrace Water Level at Limestone Generating Station during Cycling Operation in July 2002**

#### 4.3.4.3.4 Ice Conditions

Prior to hydroelectric development, ice generated along the fast flowing Nelson River resulted in an ice cover generally progressing upstream from the Nelson River estuary. The ice accumulated upstream through a process of ice jam progression upriver resulting a very thick and rough ice cover and typically water level increases of about 33 ft (10 m) (Carson 1982). Impoundments created by the three generating stations in this hydraulic zone reduced water velocities and allowed most of the forebay areas, including Stephens Lake, to freeze over with stable and much flatter thermal ice covers. The areas immediately downstream from the generating stations typically remain open for a short distance because of higher water velocities and turbulence.

### 4.3.4.4 Hydraulic Zone 12 – Limestone Generating Station to Gillam Island

Hydraulic Zone 12 covers the lower Nelson River from the Limestone GS to Gillam Island (Map 4.3.4-3).There are no lakes in this hydraulic zone. Gillam Island is the upstream extent of tidal influence from the Nelson River estuary. There are currently no hydroelectric structures located in this hydraulic zone although the potential Conawapa GS would be located approximately 18 mi (29 km) downstream from the Limestone GS.




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada

CREATED BY:
Manitoba Hydro - Hydraulic Operations

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 01-OCT-15 | 04-DEC-15 |
| 0 4 8 Kilometres / 0 3 6 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- Generating Station (Existing)
- Generating Station (Potential)
- Flow Direction
- Dyke
- First Nation Reserve
- Wildlife Management
- Watercourse Boundary (Predevelopment)
- Watercourse (Existing)
- RCEA Hydraulic Zone

Notes:
- FOR ILLUSTRATIVE PURPOSES ONLY
- Northern Affairs Community (NAC)
- Watercourse Boundary Predevelopment - Mapping Alignment Issue See RCEA Phase II (PreambleSection 1.3.3) for more details.

# Hydraulic Zone 12

Limestone Generating Station to Gillam Island

1 of 1

**Map 4.3.4-3**

#### 4.3.4.4.1 Manitoba Hydro Operations

Operation of CRD, LWR, and the three generating stations along the Lower Nelson River affect water levels and flows in this hydraulic zone. The CRD and LWR affect the magnitude and seasonal pattern of flows, while short-term fluctuations are caused by operations at Kettle GS, Long Spruce GS, and Limestone GS.

Prior to June 2004, Manitoba Hydro periodically cycled the lower Nelson River generating stations such that only one of the ten generating units at Limestone GS was operated for part of the overnight period. Between June 1990 when the Limestone GS flow record starts and the end of 2004, there were about 180 out of 5,290 days when the flow was reduced to one unit for several hours overnight or about 3.4% of the days. After 2004, Manitoba Hydro now limits the overnight reduction in flow along the lower Nelson River to a minimum of two generating units in operation at Limestone GS.

#### 4.3.4.4.2 Data

There is no continuous water level data in this hydraulic zone available prior to hydroelectric development. Manitoba Hydro measures the discharge at Limestone GS, which is the primary inflow to the hydraulic zone, and the water level immediately downstream from the generating station since 1990. Manitoba Hydro has also measured water levels for a number of seasons at several locations in this hydraulic zone as part of baseline studies for the potential Conawapa GS.

#### 4.3.4.4.3 Key Hydraulic Features and Indicators

##### LIMESTONE GENERATING STATION TO GILLAM ISLAND

Manitoba Hydro development has increased daily water level fluctuations and average flows and water levels in this hydraulic zone. Flows are also higher in the winter than under natural conditions and water level variations are increased due to flow releases at Limestone GS. Figure 4.3.4-12 and 4.3.4.13 provide a breakdown of the magnitude and frequency of hourly and daily (max-min hourly water level in any given day) water level variations in the open water season over the entire reach from Limestone GS to Gillam Island based on hydraulic modeling (Manitoba Hydro 2012).

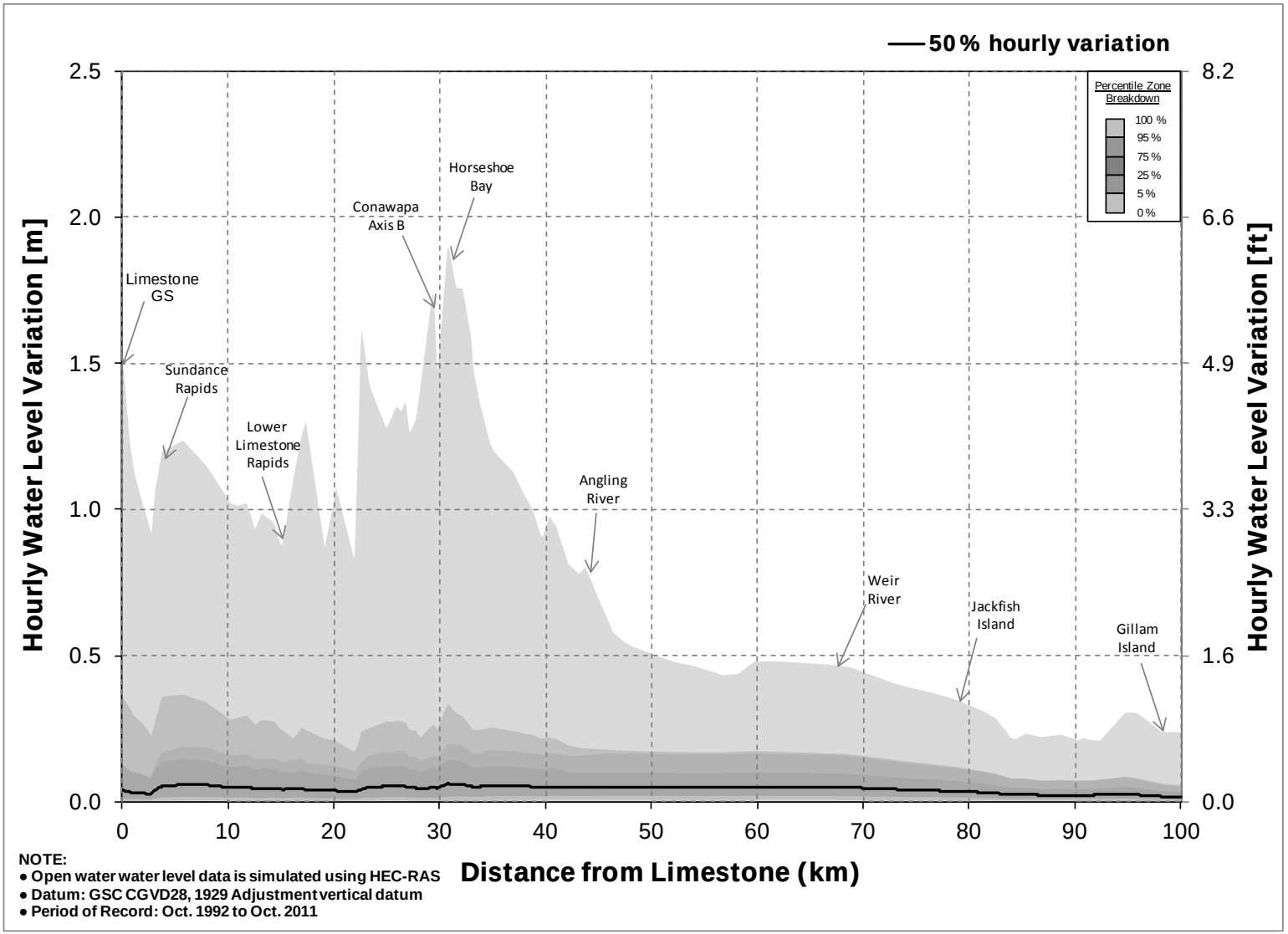
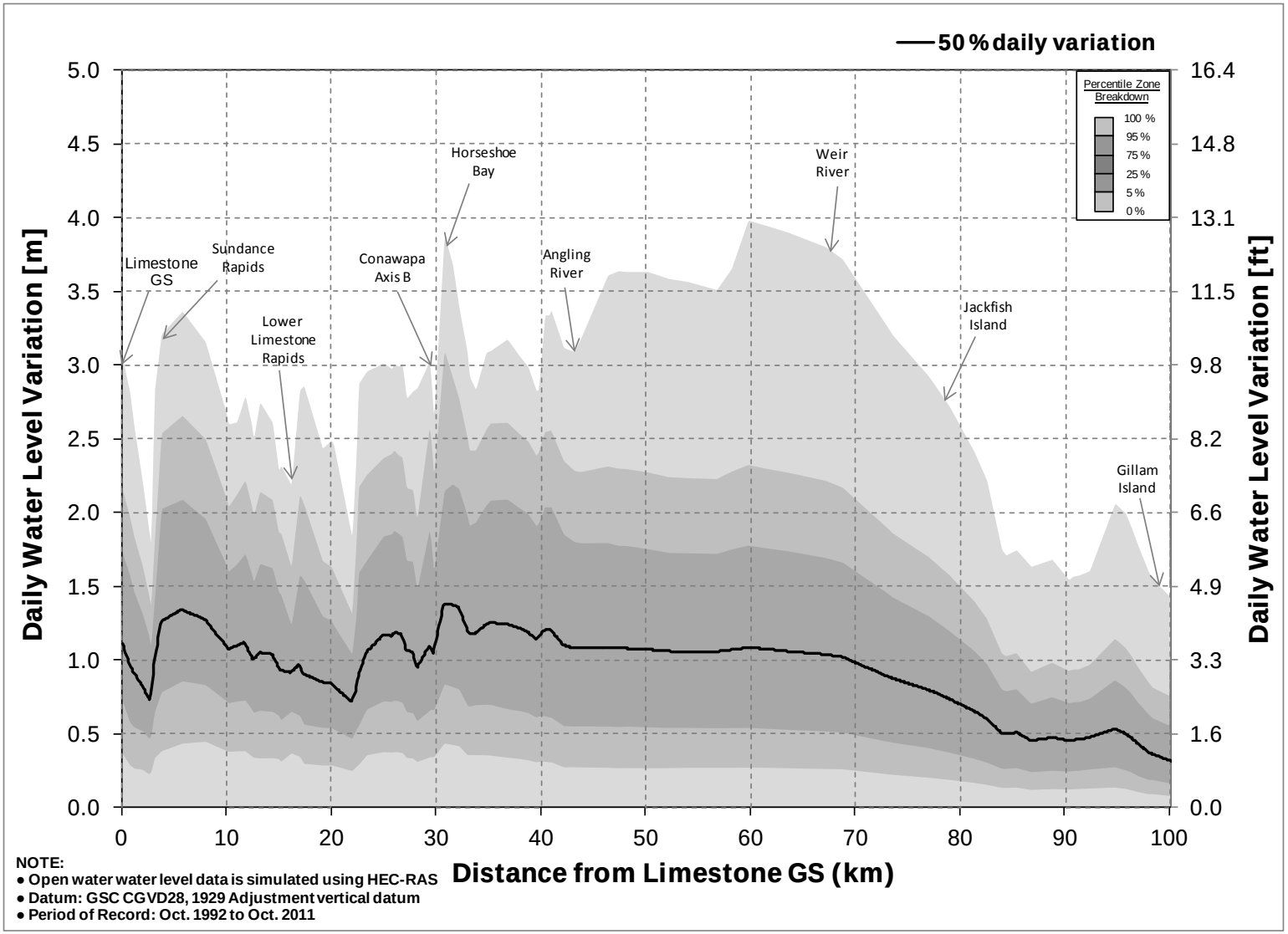



**Figure 4.3.4-12: Hourly Water Level Variations from Limestone Generating Station to Gillam Island (Open Water)**




NOTE:
- Open water water level data is simulated using HEC-RAS
- Datum: GSC CGVD28, 1929 Adjustment vertical datum
- Period of Record: Oct. 1992 to Oct. 2011

**Figure 4.3.4-13: Daily (max-min) Water Level Variations from Limestone Generating Station to Gillam Island (Open Water)**

#### 4.3.4.4.4 Ice Conditions

Prior to hydroelectric development, the ice cover generally progressed upstream from the Nelson River estuary. This process was the result of ice accumulation at the leading edge, shoving and thickening with ice generated from the fast flowing upstream open water river sections. The process resulted in a very thick and rough ice cover and typically caused water level increases of about 33 ft (10 m) (Carson 1982). The thick ice cover resulted in ice scouring and erosion of the shoreline. While this process still occurs, the amount of time required for the ice cover to progress upstream has typically increased. Forebay impoundments created by hydroelectric development reduced the amount of fast flowing river sections that generated ice and contributed to the ice cover progression. Hydroelectric development also increased water level fluctuations during the ice-covered period and this can affect the strength and stability of the ice cover and change surface ice conditions (Environment Canada, Department of Fisheries and Oceans Canada 1992b).

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# 4.4 Erosion and Sedimentation

## 4.4.1 Introduction

### 4.4.1.1 Background

The water regime in the Regional Cumulative Effects Assessment (RCEA) Region of Interest (ROI) has been and continues to be affected by the construction and operation of hydroelectric generating stations, control structures, and the Lake Winnipeg Regulation (LWR) and the Churchill River Diversion (CRD) projects. Flooding and changes to the water regime associated with these developments can alter upstream and downstream erosion and sedimentation processes. Impoundment of reservoirs upstream of structures floods terrestrial areas, creating new shorelines that become subject to erosion processes that cause shoreline recession through slumping, near shore downcutting due to waves, mass slope failures, and disintegration of flooded and shoreline peatlands. Changes to downstream flow conditions can similarly alter processes of shoreline erosion because of flow cycling or flow increases due to diversion. While changes to erosion may add sediment into the water, reservoirs can also reduce sediment levels by reducing flow velocities, causing sediment to deposit within the impounded areas. Changes to the erosion and sedimentation regimes are often most pronounced during the early years after a development occurs and an initially high recession rate and sediment loading may decline over time to a lower rate similar to that, which existed prior to development.

For the purposes of conducting the erosion and sedimentation assessment, the RCEA ROI has been divided into four broad areas affected by the operation of, CRD/LWR and these areas are further subdivided into hydraulic zones (see Water Regime, Map 4.3.1-1) based primarily on the locations of hydraulic structures:

- **Area 1** covers the upper Nelson River from its origin at the outlet from Lake Winnipeg and extends downstream to the Kelsey Generating Station (GS) just upstream of Split Lake. The water regime in Area 1 has been altered by LWR and the area includes two generating stations, Jenpeg and Kelsey. This area has been subdivided into three hydraulic zones (Hydraulic Zones 1, 2 and 3):
    - **Hydraulic Zone 1** extends from the Lake Winnipeg outlet to the Jenpeg GS and Control Structure (CS), encompassing a reach commonly referred to as the outlet lakes area;
    - **Hydraulic Zone 2** extends from below the Jenpeg GS to just downstream of Cross Lake, encompassing Cross Lake and Walker Lake; and
    - **Hydraulic Zone 3** extends from just below Cross Lake to the Kelsey GS just upstream of Split Lake, encompassing Sipiwesk Lake.
- **Area 2** covers the lower Nelson River from Kelsey GS on the Nelson River and from the inlet of the Burntwood River, extending downstream to the Nelson River estuary at Hudson Bay. The water regime in this area is affected by LWR as well as flow increases resulting from CRD. This area has been subdivided into three hydraulic zones (Hydraulic Zones 10, 11 and 12).

  - **Hydraulic Zone 10** encompasses Split Lake and the downstream reach of the Nelson River to just upstream of Stephens Lake at Gull Rapids, where the new Keeyask GS is currently under construction.
  - **Hydraulic Zone 11** extends downstream from Gull Rapids to Limestone GS, encompassing three reservoir areas: Stephens Lake, which is the reservoir formed upstream of the Kettle GS, and the reservoirs for the Long Spruce GS and Limestone GS downstream of Kettle.
  - **Hydraulic Zone 12** extends from below the Limestone GS to the Nelson River estuary.
- **Area 3** covers Southern Indian Lake (SIL), which was impounded for the CRD development, and extends downstream along the diversion route from SIL along the Rat and Burntwood rivers up to Split Lake. The water regime in Area 3 was altered by CRD and the area includes the Notigi CS and the recently constructed Wuskwatim GS. The area has been divided into five hydraulic zones:
  - **Hydraulic Zone 4** encompasses SIL and a portion of the Churchill River just upstream to Leaf Rapids;
  - **Hydraulic Zone 6** includes the diversion channel from South Bay on SIL and extends up to the Notigi CS, which regulates the amount of flow diverted downstream;
  - **Hydraulic Zone 7** covers the reach from Notigi to Early Morning Rapids just upstream of Wuskwatim Lake;
  - **Hydraulic Zone 8** covers the reach from Early Morning Rapids to the Wuskwatim GS; and
  - **Hydraulic Zone 9** covers the remainder of the Burntwood River from below the Wuskwatim GS to the inlet to Split Lake.
- **Area 4** has only one hydraulic zone, **Hydraulic Zone 5**, which covers the entire reach of the lower Churchill River from the Missi CS at the natural outlet from SIL up to the estuary at Hudson Bay. The water regime in Area 4 has been changed due to the diversion of the bulk of the Churchill River flows, which has resulted in lower water levels in Area 4.

This section of the RCEA presents information on erosion and sedimentation for historical conditions, including conditions prior to LWR and CRD, as well as more contemporary information that has been collected through more recent studies. The erosion section also presents the results of new analyses conducted for the RCEA involving the use of historical and recent satellite imagery and aerial photographs to identify shoreline erosion throughout the RCEA ROI. The following section discusses the methods and approach taken for the erosion and sedimentation investigations while subsequent sections present the findings.

## 4.4.1.2 Approach and Methods

### 4.4.1.2.1 Erosion

The erosion results are organized into zone-by-zone descriptions. Each zone description begins with a literature review section and most zones include a data analysis section, which presents new erosion-related data generated in the present study through analysis of Landsat images and/or air photos. At the end of the zone description, a summary of erosion-related findings is presented. The text below provides details on the methods used to complete the erosion portion of the study.

## LITERATURE REVIEW

The literature review for each zone provided here in the Phase II document has been revised and in many cases expanded from the version presented in the Phase I document.

For each zone, a basic description of the terrain and shoreline characteristics is presented under the heading “Terrain and shoreline characteristics” based largely on information presented in the Physical Impact Study (Water Resources Branch 1974). This description includes a summary of shoreline types identified in the natural state prior to hydroelectric development. In cases where hydroelectric development did not involve a major increase in water level, the description of natural state shorelines provides a reasonable estimate of post-hydroelectric development shorelines. In other cases, increased water levels will have transferred shorelines into new materials. Where available, information on post-hydroelectric development shoreline classification has been provided.

The information compiled for each zone under the heading “Review of Information on Erosion” represents a concise summary of the available information on erosion prior to any analysis of Landsat images or air photos conducted in the current study, with emphasis on collection of erosion rate data. Shoreline or top of bank recession rates represent simple metrics that can be tracked across zones to obtain an indication for the degree of sediment production occurring and to assess whether shorelines have become more or less stable in time. The literature review illustrated that the available erosion data are generally limited in several ways, and it was found that some of these limitations could be addressed by conducting new analysis using readily available satellite imagery and historical air photos.

## DATA ANALYSIS

After reviewing the available information on erosion across the RCEA ROI, it was found that a considerable amount of information had not yet been generated in many areas, including data on total erosion since development, pre- versus post-hydroelectric development erosion rates, and trends in post-hydroelectric development erosion rates. Preliminary experimentation revealed that Landsat imagery and historical air photos had potential to generate a considerable amount of new information on the nature, magnitude and spatial distribution of erosion. Any new results generated through the analysis of Landsat imagery or historical air photos are presented in each zone description under the heading “Data Analysis.” The following two subsections provide details on the methods used to analyze Landsat imagery or historical air photos.

### Landsat Analysis

Landsat images were analyzed in some zones to identify areas where at least approximately 90 m (300 ft) of erosion had occurred since hydroelectric development. Landsat analysis was carried out as a rapid, first-pass analysis to identify major areas of erosion across the zone. In many cases, Landsat analysis facilitated selection of areas for detailed air photo follow-up analysis. In most cases, Landsat analysis was also effective at distinguishing areas of peatland disintegration versus mineral erosion. The text below describes details of the approach used in mapping erosion from Landsat images. Details on the Landsat analyses conducted in any specific zone are provided in the respective zone descriptions.

Landsat image selection mainly involved finding two cloud-free images, one from the 1970s, the other from between 2010 and 2015, both portraying approximately equal water levels in the main water body represented in the images. In each Landsat image comparison made, it was possible to find images with water levels that matched to within 10 cm (4 in). Therefore, the influence of differing water levels on shoreline position was minimized.

An approximate 90 m (300 ft) detection limit was assumed in the Landsat analysis, and therefore, only locations showing at least 90 m (300 ft) of erosion were presented on maps. This detection limit is a function of image resolution and of errors as discussed in the following paragraphs.

In each comparison, the earlier Landsat image had a resolution of 60 m (200 ft), while that of the recent image was 30 m (100 ft). The early image was aligned to the recent image using a spline transformation function based on at least ten control points, and then the realigned image was saved at a resolution of 30 m (100 ft). However, even after improving the alignment of the earlier images, it was impossible to remove all errors associated with misalignment.

The land-water interface in each Landsat image was established using a threshold value on whichever multispectral band provided the best contrast between land and water. The best bands in this respect were near-infrared and shortwave-infrared bands. Thresholding involved dividing the range of values in the band into two classes, with values below the threshold representing water and larger values representing land. For each comparison, the thresholds for the early and recent images were arrived at through a process of trial and error aimed at ensuring that the extents of off-system lakes and ponds were approximately equal. Because the bands and threshold values used may differ between locations, the specific bands used and threshold values selected are reported in the hydraulic zone descriptions.

Following image alignment and thresholding, the image overlay was used to isolate the areas showing at least 90 m (300 ft) of erosion. These areas were then interpreted using the multispectral and panchromatic Landsat imagery and any available high-resolution aerial imagery. The areas were interpreted as to whether the erosion mechanism was dominantly mineral erosion or peatland disintegration. Air photos taken a short time after development often revealed the dominant erosion mechanism. For example, areas undergoing peatland disintegration would show partially flooded land with standing dead trees and floating or inundated vegetation. As historical air photos were not always available, this distinction in some cases had to be made based largely on whether the site represented a low-gradient shore zone that was flooded partially during development or a high-gradient shore zone situated in a high-energy setting like a point or promontory. In cases where it was impossible to determine the dominant erosion mechanism with confidence, the erosion areas were left unclassified.

In zones where Landsat analysis was conducted, the total areas showing peatland disintegration or mineral erosion were reported to the nearest hectare. These area estimates should be regarded as minimums due to the coarse scale of the imagery and because areas showing less than 90 m (300 ft) of erosion were excluded. For example, in Hydraulic Zone 8 where peatland disintegration had been previously mapped using air photos, the extent of peatland loss estimated from air photo mapping was 1,695 ha (4,188 ac), whereas a much smaller value of 391 ha (966 ac) was obtained through the Landsat analysis. The mapping of peatland disintegration using Landsat imagery is particularly subject to error. This is because the largest errors associated with Landsat analysis are to be found in low-gradient shore

zones where peatland disintegration is the dominant erosion process, whereas in steeper shore zones where mineral erosion is more common, the errors are generally smaller. Larger errors in low-gradient shore zones are mainly due to slight differences in water level between images and to differences in definition of the land-water interface using the threshold technique described above. Despite these challenges, Landsat analysis proved valuable for providing a coarse image of where and what type of erosion occurred throughout the zone, and the uniform approach used to estimate the amount of erosion within a zone allowed for comparison between zones.

Landsat analysis could not be used to assess erosion prior to hydro development, as the earliest Landsat images are from 1972, and given that LWR and the CRD occurred less than 10 years later, this period was of insufficient length for a measurable amount of erosion to occur. Similarly, due to the short associated time intervals, it was impossible to use Landsat images to establish trends in post-hydroelectric development erosion rates. Air photos were needed to assess pre-hydroelectric development erosion rates and trends in post-hydroelectric development erosion rates.

### Air Photo Analysis

Historical air photos were used in conjunction with recent high-resolution aerial imagery in many of the zones. In many cases, air photos were used in locations of major erosion identified through Landsat analysis to constrain recession amounts more accurately or to establish pre- versus post-hydroelectric development erosion rates or trends in post-hydroelectric development erosion rates. In other cases, they were used to quantify erosion in areas where erosion was less than what could be measured reliably using Landsat imagery. Air photos were also used to interpret the nature of the erosion indicated through Landsat analysis. The discussion below provide general information on the methods used to map erosion from historical air photos. Details on the analysis conducted in any given zone can be found in the respective zone descriptions.

Air photo selection was based primarily on photo location, acquisition date and scale. Photo scales ranging from 1:15,000 to 1:60,000 were used, with acquisition dates ranging from 1928 and 1992. Most photos were obtained from the National Air Photo Library, supplied as digital images scanned at 300 dpi from the contact prints.

The historical air photos were aligned to the best available high-resolution aerial imagery recently collected by Manitoba Hydro. Each air photo was aligned using a spline transformation function based on at least ten control points. Generally, air photos were aligned to an accuracy of about 5 m (16 ft). In the worst cases, alignment errors were as high as about 10 m (33 ft), and in these cases, the lower accuracy was noted in the text.

Erosion was quantified in different ways depending mainly on typical erosion amounts and shoreline types within that zone. In cases where erosion was dominantly close to or below the detection limit, the typical procedure was to map shorelines from the recent high-resolution imagery over some distance and then compare these visually with those shown in the historical image to obtain an indication of the amount of erosion. In these cases, because the historical shoreline was generally positioned within measurement errors of the recent shoreline, it was impossible to characterize accurately an average erosion amount given that the actual erosion amount in most locations was smaller than what can be detected using air

photos. Thus, in these areas, only a statement of maximum erosion is provided. On the other hand, in cases where continuous stretches of shoreline had shown measurable erosion, both the historical and recent shorelines were mapped over some distance along the shore, and then recession distances were computed between shorelines at intervals of 20 m (66 ft) and summary statistics were calculated. In these cases, the average stated from the measurements is reported after excluding any measurements less than the detection limit. In cases where the shorelines were mixed between bedrock-controlled shorelines and overburden shorelines, rather than mapping both historical and recent shorelines to obtain an average erosion amount, only the maximum erosion is recorded from the most erosion-prone overburden shorelines. Details of the approach taken to quantify erosion in any given zone are provided in the data analysis section of the appropriate zone descriptions.

#### 4.4.1.2.2 Sedimentation

**OVERVIEW OF DATA SOURCES**

The approach taken in this component of the RCEA is to provide a summary and discussion of historical sedimentation studies extending back to the early 1970s and earlier. While historical studies were conducted prior to and after CRD/LWR and the development of several generating stations, the amount of information for the pre-hydro period in the 1970s or earlier is generally limited. Also, while early studies reported on parameters relevant to sedimentation, the studies tended to more often focus on water quality in general rather than specifically investigating sedimentation processes related to sources, transport and deposition. Three of the main sources for historical data are from studies that were conducted for the Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) prior to CRD/LWR, the Federal Ecological Monitoring Program (FEMP), and the Manitoba Ecological Monitoring Program (MEMP).

More recently, since about the year 2000, a number of more intensive environmental monitoring studies have been undertaken on both the Burntwood River and the lower Nelson River. On the Burntwood, monitoring programs were initiated to collect baseline data and support the preparation of an environmental impact assessment for the Wuskwatim GS project. Monitoring programs were carried out prior to and during construction while monitoring for effects during operation has been taking place since the GS began operating in 2012. Similarly, environmental baseline monitoring was carried out for the Keeyask Generation Project (GP) to support the preparation of the project's environmental impact statement, and monitoring during construction has been ongoing since work began in 2014. Until recently, intensive environmental monitoring was also being performed on the lower Nelson River downstream of the Kettle GS to obtain baseline data to support an environmental assessment for the potential Conawapa GP. These studies were suspended when the development of this project was put on hold. Together, the monitoring programs for these three studies have obtained more contemporary data on sediment conditions in the lower reaches of Area 3, in Hydraulic Zones 8 and 9, and through all of Area 2, in Hydraulic Zones 10, 11, and 12.

In addition to the monitoring programs carried out for the environmental impact assessments noted above, Manitoba Hydro in partnership with the Province of Manitoba has also initiated the Coordinated Aquatic Monitoring Program (CAMP). The CAMP has conducted monitoring at various locations throughout the RCEA ROI since 2007. There is also ongoing long-term water quality monitoring

conducted by Manitoba Conservation and Water Stewardship (MCWS). Not all of the water quality studies where suspended sediment and/or turbidity has been measured are cited in the erosion and sedimentation section of this report since a comprehensive list of these studies are provided in the Water Quality sections.

## SEDIMENTATION PARAMETERS CONSIDERED

The main parameter considered in the sedimentation section is suspended sediment concentrations. Suspended sediment concentrations are routinely tested for whenever water quality sampling is performed as it is an important water quality indicator that is relevant to different types of studies beyond just sediment monitoring. For this reason, data on suspended sediment concentrations are the most widely available data relevant to sedimentation from both the historical studies and contemporary investigations. Within the data sources considered for this study, suspended sediment concentrations have been reported as either Non-filterable Residue (NFR) or Total Suspended Solids (TSS), both of which report the concentration in the units of milligrams per litre (mg/L). NFR is a term that was previously used in older studies whereas TSS is the current term. Both are measured in a laboratory by passing a known volume of water through a filter and then determining the mass of material retained on the filter, which represents the mass of suspended sediment in the sample. Dividing the mass retained on the filter by the known volume of sample tested gives the concentration of suspended sediment. Smaller particles that pass through the filter are considered to be dissolved solids. The comparison of results from different periods may be confounded if testing methods change (*e.g.*, use of filters with different pore size openings). However, for the purpose of this assessment, the values from different testing programs are assumed to be comparable.

TSS represents sediment that is carried in suspension and that may be transported away from where it originates. The amount and size of sediment particles that can be held in suspension depends primarily on flow velocity. Larger, heavier particles require higher flow velocities to be transported in suspension. Thus, a fast flowing river may carry larger sediment particles downstream. Sediment particles may be deposited when flow velocities decrease and the flow cannot keep them in suspension.

In addition to TSS, turbidity is another parameter that is routinely measured as a part of many types of water quality studies. Turbidity measures the amount of light that passes through the water compared with the amount of light that reflects off particles in the water and is thus is an indicator of its murkiness. As the amount of sediment in the water increases, less light passes through the water and more is reflected off the sediment particles, resulting in higher turbidity values. Turbidity is regularly measured in the lab along with TSS. However, unlike TSS, which requires laboratory testing, turbidity is relatively easy to measure in the field using hand held electronic sensors. While turbidity increases as TSS increases, dissolved solids in the water also cause cloudiness that may affect turbidity.

There are several measures of turbidity, which can make it difficult to compare results from different testing programs. From the review of historical and current data, the more common unit of reference for turbidity is the Nephelometric Turbidity Unit (NTU), although Formazin Turbidity Units (FTU) are also used. Results reported in different units are not directly comparable as they are not equivalent, although higher values in either system generally indicate higher concentrations of sediment. Additionally, measurements reported in the same units also may not be comparable as different types of measuring

devices can produce different results despite the fact the same units are used. Although turbidity is not a direct measure of sediment mass in the water, it is an indicator of sediment conditions that can be used to identify changes in the sediment regime.

Another measurement influenced by water clarity is Secchi disk depths, which are obtained to measure the depth to which light penetrates into the water column rather than specifically being a measure of how turbid the water is due to sediment. Secchi depths are obtained in the field by lowering a marked, standardized Secchi disk into the water until it is no longer visible from the surface. The depth at which it is no longer visible is recorded as the Secchi depth. The murkier the water the smaller the depth in which the disk is visible: therefore, smaller Secchi depth values may indicate murkier conditions. However, because Secchi disk readings are a measure of light penetration, small Secchi depths can occur in clear water conditions if light penetration is obscured by something other than sediment such as aquatic vegetation. Despite this potential confounding effect, Secchi depths have been considered as an indicator of the amount of sediment in the water that can provide an indication of changes in sediment conditions.

The sedimentation section of the RCEA presents information on TSS, turbidity and Secchi depths reported in historical and contemporary data sources. The information is presented chronologically, generally summarizing the data based on the overall ranges and averages of observed conditions that were reported both before and after development.

The Regional Study Component “Water Quality” (Water Part V, Chapter 5.2) also considers TSS, turbidity, and Secchi disk depth as key metrics of interest with respect to water clarity. While the same metrics are used for both water clarity and sedimentation, data sets and analyses undertaken for the water quality and sedimentation assessments differed. Specifically, the water quality assessment focused upon detailed analysis of raw data (including previously unpublished data) for key sites, notably those with long-term records, to support a statistical assessment of changes in water quality over time. The rationale for the sites and data sets used in the water quality analysis is discussed in Part V. Due to differences in data sets and analyses undertaken for these two components/assessments on the same waterbodies, results reported for the same metrics are at times different. However, these differences reflect the appropriate approach in both Chapters 4.4 and 5.2. For example, the water quality assessment is based on sites that are generally representative of water in the main flow of the river while the sedimentation analysis also considered locations more distributed through the waterbodies (*e.g.*, in closer proximity to areas of erosion/deposition).

Earlier historical and contemporary studies have reported on substrate conditions within a number of water bodies in the RCEA ROI. Historical studies reported on substrates throughout SIL as well as substrate sampling in different parts of the study region. More recently, environmental studies for the Keeyask GP and Conawapa GP have contributed significantly to the mapping of substrates in large segments of the lower Nelson River while CAMP has contributed to mapping substrates at the upper end of the upper Nelson River. However, studies investigating post-hydroelectric development effects with respect to changes in sediment deposition and changes in substrates are generally limited. Where substrate data is available, the information is summarized while substrate maps prepared for studies such as those for Keeyask and Conawapa are also reproduced.

## DATA NOT CONSIDERED

The assessment considers discrete turbidity measurements obtained in the lab from water samples or collected in the field for both historical and contemporary studies. Discrete sampling results represent the conditions at the specific point in time when the sample or measurement was obtained. More recently, since about 2007, Manitoba Hydro has monitored *in situ* turbidity using electronic sensors that remain in the water for extended periods (*e.g.*, over a summer) and continuously measure turbidity at a high frequency (*e.g.*, intervals as short as every minute or less). This type of continuous monitoring has been done as a part of monitoring programs for the Wuskwatim, Keeyask and Conawapa GPs, and more recently for CAMP. Many sites have been monitored at various times and over different time frames at locations along the Burntwood River and the lower Nelson River, in Hydraulic Zones 8 through 12, as well as Hydraulic Zones 1 and 4 (Outlet Lakes and SIL). However, to date, little of this data has been reported on and a comprehensive review and analysis of data collected under multiple monitoring programs has not been done. There are no comparable historical records to which this data could be compared; therefore, continuous data obtained recently is of little value in assessing how past alterations like LWR and CRD affected sedimentation.

A decision was made not to report the continuous turbidity data in the RCEA. The data are currently being analyzed as part of the CAMP implementation and will be reported on in the future through that process, therefore the results of that analysis are not available to report on for RCEA.

## STUDY LIMITATIONS

The ability to assess cumulative effects of hydropower development on erosion and sedimentation processes is limited by the availability of historical data prior to and immediately after the LWR and CRD projects, and even more so for the earlier Kelsey and Kettle GSs. While a number of historical studies were conducted and reported on in the available literature, these studies were generally limited both spatially and temporally. Spatially, some areas such as Southern Indian Lake were studied in relatively greater detail in contrast to other regions like Sipiwesk Lake where fewer studies were done. In addition, some early studies were performed over a few years before and after CRD/LWR but then no further monitoring took place for an extended period of time.

The erosion portion of the RCEA addresses the lack of reported historical erosion data such as actual erosion measurements through the comparison of historical and contemporary satellite and aerial images, as discussed in Section 4.4.2.1. The shoreline erosion analysis provides a good indication of the areas where the larger amounts of erosion have occurred but it is limited in the level of detail that can be resolved depending on the quality of available imagery, as discussed in 4.4.2.1. For the sedimentation studies, the data limitations generally cannot be addressed through alternative means since much of the data of interest, such as suspended sediment concentrations, must come from *in situ* monitoring at a specific point in time. With respect to limited historical data on sediment deposition and substrate composition, some more recent studies have investigated historical rates of sediment deposition based on detailed analyses of sediment cores (*e.g.*, as noted for the Wuskwatim GP in Section 4.4.3.8). However, the ability to evaluate historical deposition and substrate is very much dependent on site-specific conditions.

For sedimentation parameters like turbidity and suspended sediment, the historical monitoring typically occurred about once a month during open water periods and, if winter monitoring was done, it often only occurred once per winter. Because of the limited frequency of sampling, the historical data does not allow for the characterization of suspended sediment conditions during short events like wind or rain storms and temporal changes as sediment is transported with the flow. While it is impossible to fill this gap in the historical record, more recent turbidity monitoring (*e.g.*, for CAMP, Wuskwatim, and Keeyask) using *in situ* electronic probes will help investigate shorter duration events and develop a better understanding of sediment transport, but only for existing conditions.

While more detailed erosion or sedimentation studies could be conducted to further investigate historical conditions, the performance of such studies is beyond the scope of RCEA. This report does not make any conclusions regarding erosion or sedimentation studies that might be investigated in the future. Rather, as was the case for the Wuskwatim and Keeyask GPs, the need for and scope of any future studies would be entirely dependent upon the purposes for which data are required and would only be defined as and when required based on the specific needs of those studies.

# 4.4.2 Description of Erosion and Sedimentation Zones

## 4.4.2.1 Hydraulic Zone 1 – Outlet Lakes

### 4.4.2.1.1 Hydraulic Zone 1 Overview

Hydraulic Zone 1 in RCEA Area 1 encompasses the area from the outlets of Lake Winnipeg at the natural mouth of the Nelson River and the entrance to Two-Mile Channel downstream to the Jenpeg GS and to the east arm of the Nelson River just upstream of Pipestone Lake (Map 4.4.2-1). In this zone, the Nelson River splits into east and west channels before rejoining at Cross Lake, however the bulk of the river's flow occurs along the west channel. The main lakes along the west channel of the river are Playgreen, which has south and north basins separated by a more riverine section, Kiskittogisu and Kiskitto. Little Playgreen Lake lies along the east channel of the river just downstream of Playgreen Lake.

This reach includes the major works that were constructed to regulate Lake Winnipeg (see Hydroelectric Development Project Description in the ROI, Appendix 2D). This includes three channels built to bypass natural flow restrictions, specifically:

- Two-Mile Channel, which increased outflow capacity from Lake Winnipeg;
- Eight-Mile Channel between Playgreen Lake and the south end of Kiskittogisu Lake; and
- Ominawin Bypass Channel to improve outflow at the north end of Kiskittogisu Lake.

The Jenpeg GS is downstream of Kiskittogisu Lake, lying across the west channel of the Nelson River where it enters Cross Lake. While the primary purpose of the Jenpeg GS is to regulate Lake Winnipeg outflow, allowing for water storage on and withdrawal from Lake Winnipeg, it also utilizes the water level drop at the station to generate electricity.

In addition to these major works, an earth dam and a series of dykes were constructed at Kiskitto Lake to prevent the Nelson River from backing up into the lake as a result of increased water levels behind the Jenpeg GS. The lake's outflow was redirected from the Nelson River to an adjacent creek that drains into the Minago River, which empties into Cross Lake. Levels on Kiskitto Lake are regulated within its natural pre-LWR range.

### 4.4.2.1.2 Erosion

#### TERRAIN AND SHORELINE CHARACTERISTICS

Based on surface area, Hydraulic Zone 1 is the second largest zone in the RCEA ROI, with an approximate water surface area of 1,406 $km^2$ (543 sq mi) and shoreline 3,196 km (1,986 mi) long. The zone consists of several large lakes, including the north and south basins of Playgreen Lake, Little Playgreen Lake, Kiskittogisu and Kiskitto lakes, and the Jenpeg forebay. In addition, it includes Two-Mile and Eight-Mile channels, and the East and West channels of the Nelson River.

Jenpeg G.S.

PIPE STONE LAKE

OMINIWIN BY-PASS CHANNEL

Kiskitto Control Structure

KISKITTO LAKE

KISKITTOGISU LAKE

EIGHT MILE CHANNEL

KISKITTOGISU RIVER

LITTLE PLAYGREEN LAKE

Norway House

Norway House Cree Nation

Norway House (NAC)

PLAYGREEN LAKE

LAKE WINNIPEG

TWO MILE CHANNEL

N

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE: Government of Manitoba, Government of Canada, Manitoba Hydro

CREATED BY: Water Resources Engineering

COORDINATE SYSTEM: NAD 1983 UTM Zone 14N

DATE CREATED: 23-MAY-15

REVISION DATE: 03-DEC-15

0 5.5 11 Kilometres

0 4.5 9 Miles

VERSION NO: 1.0

QA/QC:

**Legend**

- RCEA Hydraulic Zones
- RCEA Region of Interest
- First Nation Reserve
- Manitoba Provincial Park
- Transmission Line (Existing)

# Hydraulic Zone 1

**Map 4.4.2-1**

From the north end of Lake Winnipeg, the Nelson River flows through thick deposits of glacial Lake Agassiz silts and clays, which are covered by thick organic deposits in some areas. Throughout Playgreen, Kiskittogisu and Kiskitto lakes, bedrock shorelines are irregular and form promontories while erodible organic and granular shorelines form sweeping arcs. Rock outcrops become increasingly common towards the northeast within these lakes, illustrated by highly irregular shorelines and a great abundance of islands. In these rocky areas, silt and clay deposits are present mainly in local depressions. Shorelines along the southwest shore of the south basin of Playgreen Lake from Two-Mile to Eight-Mile channels are dominated by treed muskeg, low willow, and fen, which represent highly erodible shorelines underlain by lacustrine silts and clays.

## REVIEW OF INFORMATION ON EROSION

### Two-Mile Channel

Galay (1971) anticipated a greater load of suspended sediment to be transported into Playgreen Lake through Two-Mile Channel than what entered into the lake prior to regulation via Warren Landing. Littoral transport of suspended sediment originating from eroding shorelines along the north shore of Lake Winnipeg was expected to make the greatest contribution to the sediment flux through the channel. Considerable erosion due to wind-generated waves was also expected at the entrance of Two-Mile Channel (Baracos and Galay 1972). Suspended sediment transport through the channel would be maximized during strong onshore wind events (Koshinsky 1973). Baracos and Galay (1972) suggested that any material eroded from the channel or carried through from Lake Winnipeg would be transported downstream on the Nelson River to still-water areas such as the Jenpeg and Kelsey reservoirs.

Erosion monitoring has been conducted along Two-Mile Channel since it was constructed in 1978 (Manitoba Hydro 1985a, 1989, 1990, 1991, 1994a, 1997a). Initial monitoring consisted of three transects across the channel, with the monitoring being extended in 1982 to include sounding at the channel entrance and exit. The most recent monitoring report (Manitoba Hydro 2011) presents results for five transects across the channel (1978–2010) and eight offshore transects divided evenly between the channel entrance and exit (1982–2010).

The location with the greatest shoreline recession observed up to 1993 was at the channel entrance (site 30+48; Manitoba Hydro 1994a), where banks are exposed to wave attack from Lake Winnipeg. This site has not been monitored since 1988, as erosion had removed the original benchmarks used for survey control. In 1993, it was estimated that in excess of 46 m (151 ft) of shoreline recession had occurred up to that time (Manitoba Hydro 1994a), representing an average rate of 3.1 m/y (10 ft/y) over the 15-year monitoring period. The lack of recent monitoring means that recent rates of erosion at this site are unknown. However, as survey crews had indicated that considerable erosion continued to occur here, it was suggested in 2011 that monitoring of this site be restarted in 2012 (Manitoba Hydro 2011), however data from later surveys has not yet been reported.

Aside from the anomalous site described above, the site displaying the next greatest amount of shoreline recession was located on the right bank at the channel exit, associated with a slight bend in the channel. Rates here declined significantly after an initial 4-year period of rapid erosion. Examination of transect data presented in the 1997 monitoring report (Manitoba Hydro 1997a) indicated that the period from 1978

to 1982 recorded 9.7 m (32 ft) of recession (2.4 m/y [7.9 ft/y]) at this site, while from 1982 to 1997, only 4.8 m (15.7 ft) of recession was observed (0.3 m/y [1.0 ft/y]). A strong decline in recession rates was also exhibited at the next transect upstream from the channel exit, where rates went from 1.9 m/y (6.2 ft/y; 1978–1982) to 0.1 m/y (0.3 ft/y; 1982–1997).

In terms of erosion of the channel floor and lakebed, difficulties have been experienced in maintaining horizontal survey control during sounding operations (Manitoba Hydro 1994a), resulting in erroneous horizontal shifting in some transects, and sounding data generally display abundant noise. For survey data up to 1993, the transect located 300 m (984 ft) into Playgreen Lake showed the greatest amount of bed erosion. It was reported to display an average of 0.85 m (2.8 ft) of bed lowering between 1982 and 1993 (Manitoba Hydro 1994a), and careful examination of transect surveys for this site indicates a maximum amount of bed erosion of about 1.6 m (0.15 m/y [5.2 ft; 0.5 ft/y]). This site was also noted in the most recent monitoring report (Manitoba Hydro 2011) to be the site with the greatest amount of bed lowering. From 1982 to 2010, the maximum amount of bed erosion shown in transect data presented in the appendix of the monitoring report at this site was about 2.2 m (7.2 ft), indicating a decline in erosion rate since 1993.

**Eight-Mile Channel**

Erosion monitoring at Eight-Mile Channel began in 1979 with nine transects along the channel, and seven offshore transects were added to the program in 1982 (Manitoba Hydro 2011): four near the channel entrance and three near the exit. In addition, six lakeshore transects were added in 2009 along the north shore of Playgreen Lake near the channel entrance. Several monitoring reports have been completed to date (Manitoba Hydro 1985a, 1990, 1997b, 2011).

Volumetrically, the greatest amount of erosion along Eight-Mile Channel has occurred at the entrance, where the channel has migrated about 50 m (164 ft) to the right and degraded its bed by as much as 8.5 m (28 ft [Manitoba Hydro 2011]). The anomalous erosion here is related to the peculiar alignment of the channel at the entrance and to the presence of a granular deposit that the channel passes through at the entrance. The offshore portion of the channel within Playgreen Lake is offset to the right somewhat from the main part of the channel, a misalignment apparently introduced into channel design after rock outcrops were found in the bed of Playgreen Lake during construction (Gill 1973). The alignment directs flow toward the right bank at the entrance, which induces channel migration. Because of the highly erodible fine sand deposit near the entrance, the first 5 km (3.1 mi) of the channel had to be widened during construction to reduce flow velocities. The granular materials are part of one of the many northeast trending ridge-like littoral deposits in this area, which were formed at the margin of glacial Lake Agassiz. Beyond the widened section at the entrance, the rest of the channel is dominantly formed in cohesive clays.

Data on historical shoreline recession along Eight-Mile Channel was generated in the current study by examining transect surveys presented in the appendix of the most recent monitoring report (Manitoba Hydro 2011). Shoreline recession has amounted to as much as 20 to 30 m (66–98 ft) from 1979 or 1982 to 2010 (0.6–1.1 m/y [2.0–3.6 ft]), occurring most significantly at the channel entrance and at bends in the channel downstream of the Kiskittogisu River. Where the channel bends, the receding shoreline has extended into the narrow dykes that form the left bank of the channel, which have narrowed considerably

since construction. Rates of shoreline recession have declined in many locations, whereas significant recession has been recorded in recent years at others. Minimal shoreline recession has been recorded on transects located in the straight section of channel downstream of the entrance.

Channel bed erosion has been pronounced throughout Eight-Mile Channel. Apart from the extreme migration-related erosion and deposition noted at the entrance, other channel transects typically show a simpler pattern dominated by degradation, with a typical maximum amount of bed lowering of about 1.8 m (5.9 ft) for several transects observed in survey data presented in the appendix of the most recent monitoring report (Manitoba Hydro 2011). Rarely are there examples of declining rates of bed degradation through time, and an absence of decline or, more commonly, an increase in rates appears to be the norm, with typical maximum bed lowering rates of 0.05 m/y (1.6 ft/y) leading up to 2003 and then 0.10 m/y (0.3 ft/y) after 2003.

The lakeshore transects near the entrance of Eight-Mile Channel show variable amounts of shoreline recession. Three of the six transects show negligible erosion. One of the four transects north of the channel shows no shoreline recession but about 2 m (6.6 ft) of top of bank retreat over the monitoring period (2009–2010), while the two transects south of the channel show 1.0 to 4.7 m (3.3–15.4 ft) of shoreline recession.

### Playgreen and Little Playgreen Lakes

Although Lake Winnipeg Regulation has had minimal effect on the average water level on Little Playgreen Lake and the south basin of Playgreen Lake (Manitoba Hydro 2014a), regulation has resulted in a modified seasonal water level regime. The changes associated with the altered timing and variability of water levels and flows in this area were expected (Kellerhals Engineering Services Ltd. 1988a) to produce changes in shoreline vegetation, particularly in flat organic terrain, but this would result in minimal shoreline erosion.

MacLaren Plansearch Inc. (1985a) assessed the effects of LWR on the commercial fishery of Playgreen Lake. The study assessed the pre- and post-LWR shoreline stability of Playgreen Lake and the north shore of Lake Winnipeg. The study also assessed rates of sedimentation and types of bottom sediments throughout Playgreen Lake. On Playgreen Lake, a comparative analysis of air photos dating back to 1946 for eight sites showed highly variable bank retreat rates ranging from 1.34 to 11.6 m/y (4.4–38 ft/y [MacLaren Plansearch Inc. 1985a]). The site on Playgreen Lake displaying the highest rate of erosion, known as Peat Point, showed 440 m (1,443 ft) of shoreline recession from 1946 to 1984 (11.6 m/y [38 ft]), and no changes in erosion rates attributable to LWR could be detected at this site. As erosion rates were computed at only eight sites on Playgreen Lake, it was suggested that rates should be calculated at additional sites. Erosion rates for the inlet of Two-Mile Channel were not calculated, but it was observed that erosion rates there were markedly higher than at other locations along the north shore of Lake Winnipeg. J.D. Mollard and Associates Limited (JDMA 1994) used air photo to search for changes in the Norway House Reserve area before and after LWR. Ten different sets of air photos were examined ranging in scale from 1:6,000 to 1:63,000, acquired between 1955 and 1990. No shore erosion could be identified along lakeshores or river channels near the Norway House settlement. The most visible shoreline changes were in land use, with an increase in the number of houses and docks observed from 1973 to 1990.

Shoreline conditions have been assessed at several sites around Playgreen Lake during the development of setback lines for the Norway House First Nation Settlement Agreement Land Selections (Manitoba Hydro 2014b). Locations examined include Norway House South, Flett Island, Whiskey Jack Narrows, Playgreen Point, Pine Creek and Sandy Bar Point. Very little erosion has been observed at most sites, with descriptions of the degree of erosion ranging from no observed signs of active erosion with stability indicated by well-vegetated shorelines to some evidence of minor erosion (Manitoba Hydro 2006a, 1995a, b, c, d). Out of six sites examined, two sites showed a slightly higher degree of erosion. At Sandy Bar Point, bank undercutting resulted in numerous trees leaning towards the water at the eastern end of the site (Manitoba Hydro 1995b). At Whiskey Jack Narrows, shoreline recession was noted on local clay shorelines located between bedrock-controlled promontories (Manitoba Hydro 1995d).

### Kiskitto and Kiskittogisu Lakes

In contrast to the minimal change in average water level observed since regulation on the south basin of Playgreen Lake (Manitoba Hydro 2014a), Kiskittogisu Lake is situated at a lower elevation and therefore its mean water level has increased more noticeably.

Kellerhals Engineering Services Ltd. (1987) discussed the predominance of low, flat organic terrain surrounding Kiskittogisu Lake and pondered the effects of increased water levels due to LWR in such flat organic terrain. The effects had not been monitored at that time, and no further information has been found to indicate that such monitoring has been carried out to date.

Increased water levels on Kiskittogisu Lake were expected to result in accelerated wave erosion along the south shore of the lake. If left unchecked, this was postulated to have the potential to threaten dykes along the north part of Eight-Mile Channel and cause erosion of the extensive peatlands surrounding the channel (Baracos and Galay 1972; Unies Ltd. 1973). To avoid this potential release of floating peat, peat islands and forest debris into the lake, dykes along the south shore of the lake were recommended (Galay and Baracos 1974).

The regulation of Kiskitto Lake was expected to result in erosion within the Kiskitto-Minago Channel and along the Black Duck Creek for some distance downstream before the channel widens (Dickson 1974; Koshinsky 1973). Kellerhals Engineering Services Ltd. (1987) was unaware of any substantial erosion along the Kiskitto-Minago Channel or along lower Black Duck Creek, but he suggested that an inspection of this area would be needed to confirm the lack of erosion.

Manitoba Hydro has not monitored erosion rates on either Kiskitto or Kiskittogisu lakes, but parts of the west-shore of Kiskittogisu Lake were classified during easement line delineation for the Norway House Cree Nation treaty land entitlement selection (Manitoba Hydro 2004). Signs of ongoing erosion were found at most sites examined, except at bedrock-controlled, sheltered or well-vegetated sites.

### Jenpeg Forebay

Flooding associated with construction of the Jenpeg GS resulted in a transition from a fluvial to a lacustrine environment for a large area above the generating station. As over half of the flooded land was forested and 42% was treed muskeg (Water Resources Branch 1974a), there has been a history of woody debris transport from eroding shorelines into the forebay.

Erosion monitoring associated with debris management work on Jenpeg has been carried out on the forebay since 2003 (Haines and Straight 2012), as about 75% of the forebay shorelines are susceptible to erosion, particularly at high water levels. Since 1998, Manitoba Hydro has been involved with the Cross Lake First Nation in developing and implementing programs to remove and manage forebay debris to improve navigation safety. In 2002, both Manitoba Conservation and the Department of Fisheries and Oceans (DFO) raised concerns about accelerating bank recession within the forebay due to removal of woody debris from shorelines, and the DFO was concerned about debris removal, because the debris could be valuable fish habitat. In 2003, Manitoba Hydro initiated an experimental debris removal and shoreline-monitoring program to study the effects of debris removal on erosion rates. The initial results of this program were reported on by Manitoba Hydro (2009), with the most up to date results presented by Haines and Straight (2012).

TetrES Consultants Inc. (2002) mapped and classified the Jenpeg forebay shorelines into seven different classes, three of which were most erosion prone: clay beaches topped by small bluffs (class 3), wave-cut banks (class 4) and bedrock shores capped by soil (class 5). By far, clay beaches topped by small bluffs were the most common of these erosion-susceptible shoreline classes. Erosion monitoring has been carried out since 2003 on 75 randomly selected forebay sites, 25 from each of the three erosion-prone shoreline types.

Haines and Straight (2012) summarized erosion and debris mobilization monitoring results from 2003 to 2012. The erosion parameters measured in this monitoring program are the horizontal distances to the leading edge (crest) and bottom of the bank from a benchmark established some distance back from the shoreline, usually on a tree. Average bank recession rates for the three more erodible shoreline classes from 2003 to 2012 were 0.05 m/y (0.16 ft/y; class 3), 0.23 m/y (0.75 ft; class 4), and 0.02 m/y (0.07 ft/y; class 5). The wave-cut banks showed the greatest erosion, with up to 6.7 m (22 ft) of recession over the 9-year period. A direct relationship was found between the amount of bank recession and total loss of woody debris. A set of 16 sites were identified that were responsible for most of the bank recession and woody debris mobilization observed.

## DATA ANALYSIS

This section summarizes results obtained from the analysis of Landsat images and historical air photos within Hydraulic Zone 1.

### Landsat Analysis

Two Landsat images were used to map erosion within Hydraulic Zone 1. The historical image used was a Landsat 2 image acquired on 10 August 1979, whereas the recent image was a Landsat 8 image from 31 October 2014. Aside from the gauge at Kiskitto Lake, the only gauge with water level data available for both dates is the gauge at Norway House, where daily average water levels were 217.58 m (713.8 ft) when both images were acquired. Water levels on Kiskitto Lake were 43 cm (17 in) higher in the historical image. The 1979 image was georeferenced to the 2014 image to improve alignment. For the historical image, a near-infrared band (Band 7) with a threshold value of 28 was used to delineate the land-water interface; this band covers a wavelength of 0.8 to 1.1 µm with a resolution of 60 m (200 ft). For the recent image, a shortwave-infrared band (Band 7) with a threshold value of 5220 was used to delineate the land-

water interface; this band covers a wavelength of 2.1 to 2.3 µm with a resolution of 30 m (100 ft). After comparing the two images, the areas showing at least 90 m (300 ft) of recession were isolated. The erosion areas were then checked against the 2011 Lake Winnipeg Regulation 50 cm aerial imagery and historical air photos for quality control. The erosion areas were then classified based on whether the erosion was interpreted to have involved dominantly mineral erosion or peatland disintegration.

Landsat analysis suggested three main areas of pronounced erosion within Hydraulic Zone 1: the north shore of Lake Winnipeg and entrance of Two-Mile Channel; the west shore of South Playgreen Lake near Peat Point; and the south shore of Kiskittogisu Lake and exit of Eight-Mile Channel. Additional areas of pronounced erosion include the island offshore from Weasel Point in South Playgreen Lake and the entrance of Eight-Mile Channel.

MacLaren Plansearch Inc. (1985a) surveyed four transects along the north shore of Lake Winnipeg at the entrance of Two-Mile Channel between 1984 and 1985. They suggested that the extreme erosion in this location should be further documented and that rates would be better calculated over a longer period of observation. Landsat analysis suggests that as much as approximately 190 m (623 ft) of recession has occurred at the entrance of Two-Mile Channel from 1979 to 2014 (5.4 m/y [17.7 ft/y]).

Considerable erosion is also suggested along the Lake Winnipeg north shore within 15 km (9.3 mi) north of Two-Mile Channel (Map 4.4.2-2), where as much as about 100 to 130 m (328–427 ft) of shoreline recession is suggested between 1979 and 2014 (2.8 to 3.7 m/y [9.2–12.1 ft/y]). Note that MacLaren Plansearch Inc. (1985a) mapped shorelines shown in 1946 and 1978 air photos at six sites along the Lake Winnipeg north shore, reflecting pre-hydroelectric development conditions. The site showing the highest erosion rate on the north shore (Site A), which is located in the same general area as the zone of pronounced erosion delineated using Landsat imagery in this study, showed a recession rate of 3.5 m/y (11.5 m/y) between 1946 and 1978. Thus, the available evidence suggests that erosion rates have not changed following LWR along this portion of the Lake Winnipeg north shore.

The site showing the largest amount of shoreline recession in the Hydraulic Zone 1 is located on the southwest shore of South Playgreen Lake, near Peat Point (Map 4.4.2-3). The zone of elevated shore recession extends along a stretch of shoreline about 6 km (3.7 mi) long extending south from near Peat Point. Landsat analysis suggests that as much as approximately 415 m (1,362 ft) of shoreline recession has occurred between 1979 and 2014 (11.9 m/y [39 ft/y]). Further discussion of erosion rates at this site is provided below based on air photo analysis.

Sporadic areas of at least 90 m (300 ft) of shoreline recession are suggested along the south shore of Kiskittogisu Lake within about 8 km (5 mi) east and west of Eight-Mile Channel (Map 4.4.2-4). The greatest recession along the south shore occurs at Eight-Mile Channel and the Kiskittogisu River, where Landsat imagery suggest approximately 175 m (5.0 m/y [574 ft; 16.4 ft/y]) of erosion between 1979 and 2014. Only a few areas of peat or mineral erosion exceeding 90 m (300 ft) were mapped in Kiskitto Lake and the northern part of Kiskittogisu Lake (Map 4.4.2-5)

Another site of marked erosion in Hydraulic Zone 1 is the island offshore from Weasel Point (Map 4.4.2-2) in South Playgreen Lake. Weasel Point is referred to as Ermine Point on some maps. The southern tip of this island showed as much as about 110 m (361 ft) of recession between 1979 and 2014

(3.1 m/y [10.2 ft/y]), while at Weasel Point, as much as about 95 m (2.7 m/y [312 ft; 8.9 ft/y]) of recession was indicated.

Landsat analysis identified no areas showing at least 90 m (300 ft) of recession in Little Playgreen Lake, along the eastern shore of South Playgreen Lake or in North Playgreen Lake (Map 4.4.2-2, Map 4.4.2-3, Map 4.4.2-6, and Map 4.4.2-7). Much of the shoreline in these areas is bedrock-controlled, and the abundance of rocky islands tends to limit wave energy. In some of these areas, shoreline conditions have been assessed in the field during development of setback lines for the Norway House First Nation Settlement Agreement Land Selections (Manitoba Hydro 2014b). The degree of erosion observed at most sites ranged from no observed signs of active erosion to some evidence of minor erosion (Manitoba Hydro1995a,b,c,d, 2006a), consistent with the lack of erosion exceeding 90 m (300 ft) suggested by the Landsat analysis.

The four sites with at least 90 m (300 ft) of recession found in the Jenpeg forebay (Map 4.4.2-7) are suspected to relate dominantly to peatland disintegration rather than mineral erosion. There are also some similar sites of suspected peatland disintegration in the Kisipachewuk Channel (Map 4.4.2-7).

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

**Erosion Monitoring Site**

MacLaren Plansearch (1985)

**Erosion 1979-2014 (≥90 m)**

Mineral Erosion

Erosion Transect

**Historical Shoreline**

2009

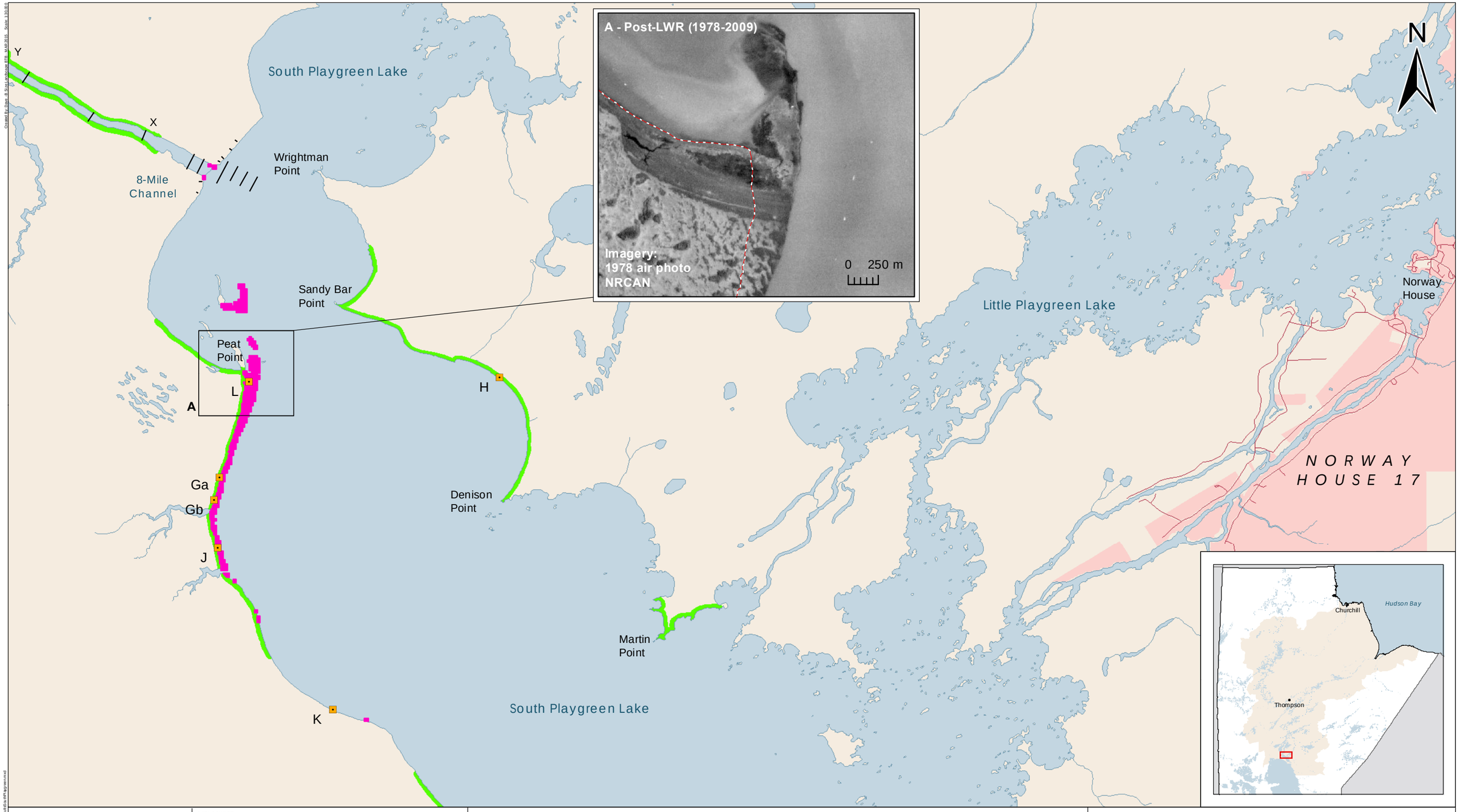
# Erosion Analysis Results

Hydraulic Zone 1

Lake Winnipeg And

South Playgreen Lake

**Map 4.4.2-2**




Manitoba Hydro

Regional Cumulative Effects Assessment

| | | | |
|---|---|---|---|
| **DATA SOURCE:** United States Geological Survey; Government of Canada; Manitoba Hydro; Province of Manitoba | | | |
| **CREATED BY:** J.D. Mollard and Associates Limited | | | |
| **COORDINATE SYSTEM:** NAD 1983 UTM Zone 14N | **DATE CREATED:** 11-MAY-15 | **REVISION DATE:** 30-AUG-15 | |
| 0 1 2 Kilometres; 0 0.95 1.9 Miles | **VERSION NO:** 1.0 | **QA/QC:** | |

**Legend**

- Air Photo Mapping
- **Erosion Monitoring Site**
  - MacLaren Plansearch (1985)
- **Erosion 1979-2014 (≥90 m)**
  - Mineral Erosion
- Erosion Transect
- **Historical Shoreline**
  - 2009
- First Nation Reserve
- Highway

# Erosion Analysis Results

## Hydraulic Zone 1
## Little Playgreen And South Playgreen Lakes

**Map 4.4.2-3**

Kiskitto gisu Lake

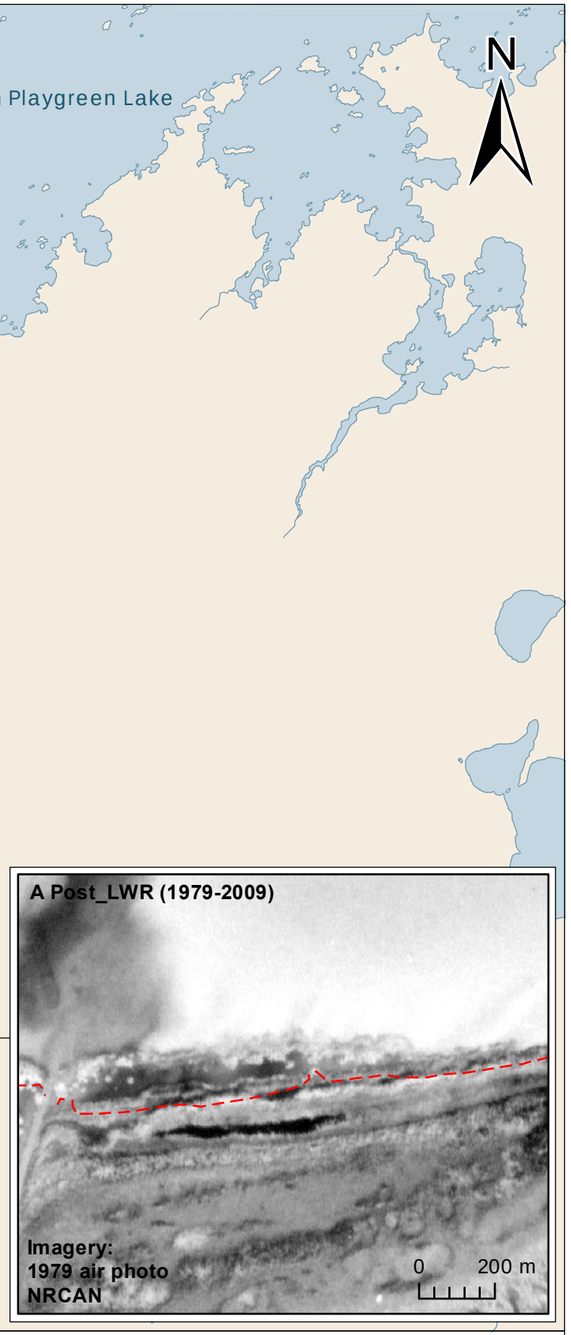
North Playgreen Lake

South Playgreen Lake

A

Z

Y




Manitoba Hydro

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DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

Erosion Transect

**Erosion 1979-2014 (≥90 m)**

Mineral Erosion

Peatland Disintegration

**Historical Shoreline**

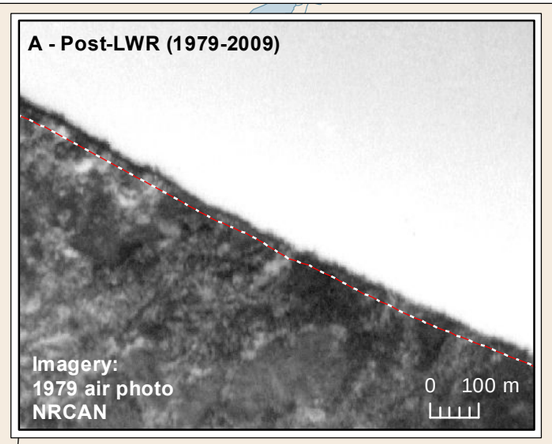
2009

# Erosion Analysis Results

## Hydraulic Zone 1

## South Part of Kiskittogisu Lake

**Map 4.4.2-4**




Kiskitto Minago Channel

Kiskitto Dam

Kiskitto Lake

Kiskitto gisu Lake

Kisipachewuk

N

A

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
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| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

**Erosion Monitoring Site**

Haines and Straight (2012)

**Historical shoreline**

2009

**Erosion 1979-2014 (≥90 m)**

Mineral Erosion

Peatland Disintegration

Control Structure

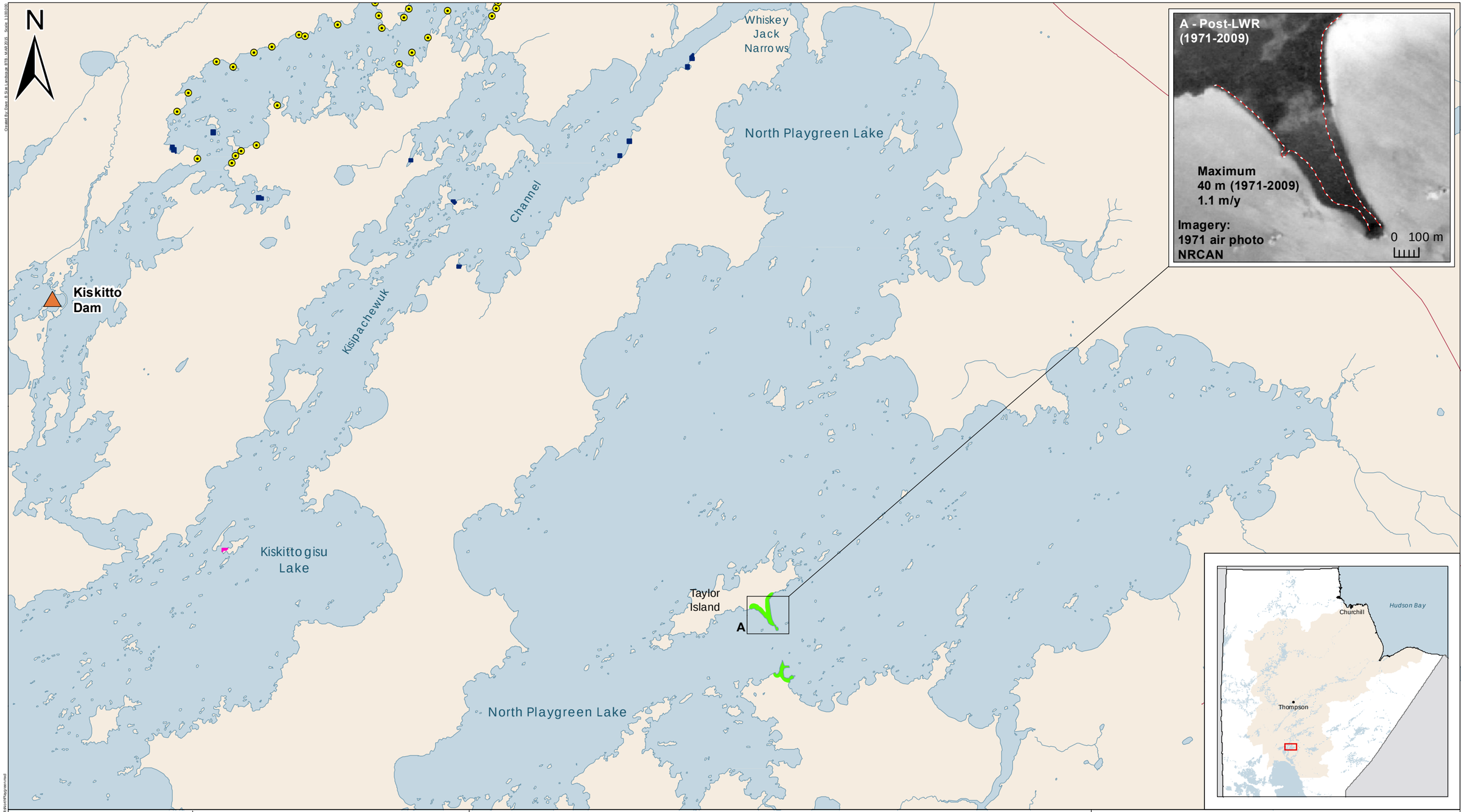
# Erosion Analysis Results

## Hydraulic Zone 1

## Kiskitto Lake and Northern Kiskittogisu Lake

**Map 4.4.2-5**

File Location: N:\Cumulative\Mapping\RH_RCEA_PE_Erosion_Zone1\Erosion\Results\Kiskitto.mxd




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

**Erosion Monitoring Site**

Haines and Straight (2012)

**Historical Shoreline**

2009

**Erosion 1979-2014 (≥90 m)**

Mineral Erosion

Peatland Disintegration

Highway

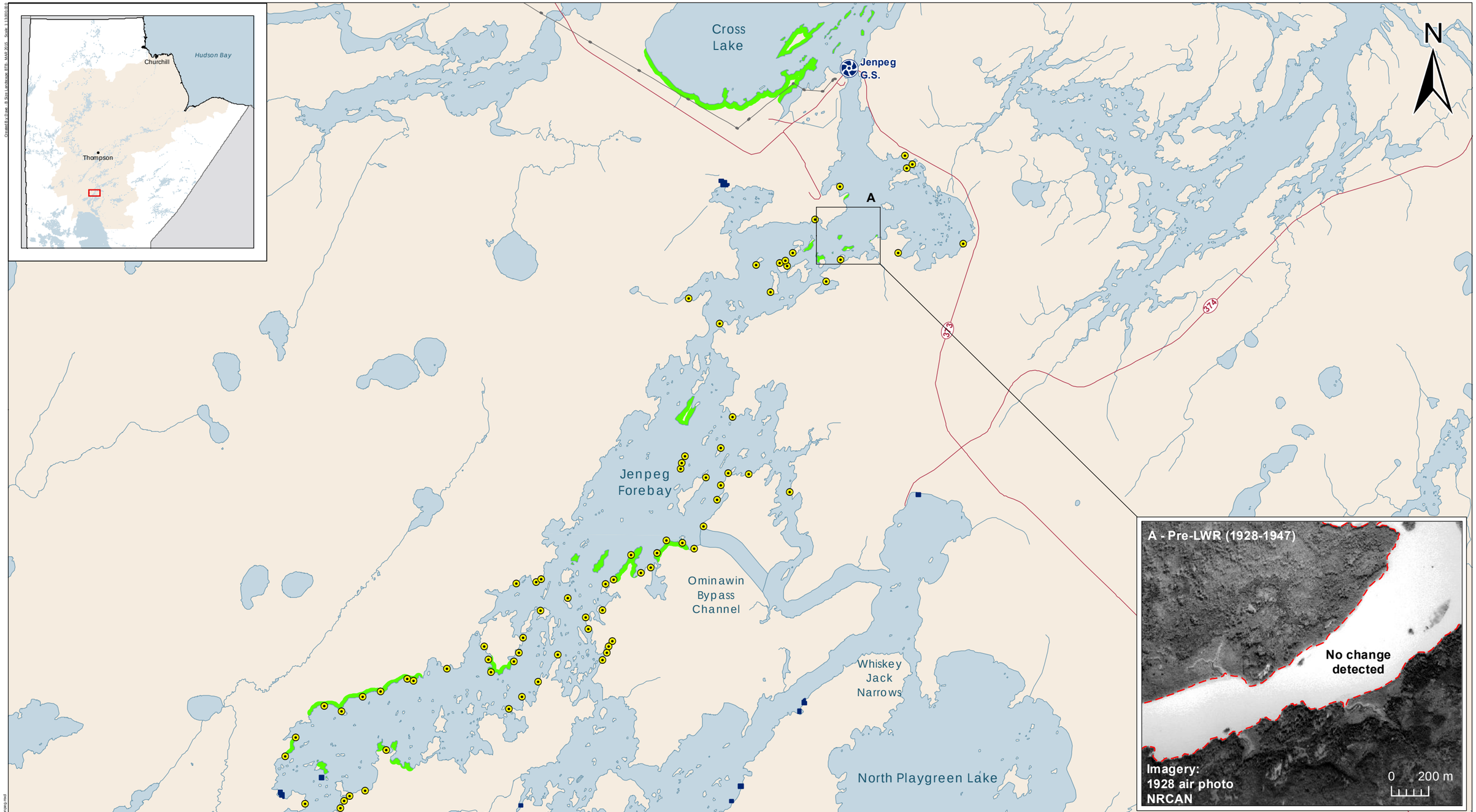
Control Structure

# Erosion Analysis Results

Hydraulic Zone 1

North Parts of Playgreen And Kiskittogisu Lakes

**Map 4.4.2-6**




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

**Erosion Monitoring Site**

Haines and Straight (2012)

**Erosion 1979-2014 (≥90 m)**

Peatland Disintegration

**Historical Shoreline**

1947

Generating Station (Existing)

Transmission Line (Existing)

Highway

# Erosion Analysis Results

Hydraulic Zone 1

Jenpeg Forebay

**Map 4.4.2-7**

**Air Photo Analysis**

Within the part of South Playgreen Lake located near Peat Point, 10.9 km (6.8 mi) of shoreline was mapped on both the east and west shores from a georeferenced 1978 air photo and the 2009 LWR imagery (21.8 km (13.5 mi) in total). Recession distances were computed between the two shorelines at intervals of 20 m (66 ft), resulting in 1,088 measurement points.

Along the east shore, 10.9 km (6.8 mi) of shoreline was mapped from north of Sandy Bar Point south to Denison Point. The 1978 and 2009 shorelines were within 5 m (16.4 ft) of each other over 42.7% of this distance. Over the rest of the mapped shoreline, the average and maximum recession amounts were 13.7 m (0.4 m/y [45 ft; 1.3 ft/y]) and 42.1 m (1.4 m/y [138 ft; 4.6 ft/y]), respectively. MacLaren Plansearch Inc. (1985a) found that their Site H between Sandy Bar and Denison points (Map 4.4.2-3) had retreated with an average rate of 1.3 m/y (4.3 ft/y) from 1946 to 1978, suggesting that erosion rates have not changed following LWR along this shoreline.

Along the west shore, 10.9 km (6.8 mi) of shoreline was mapped west and south of Peat Point. The 1978 and 2009 shorelines were within 5 m (16.4 ft) of each other over only 5.1% of this distance. Over the rest of the mapped shoreline, average and maximum recession amounts were 97.3 m (3.1 m/y [319 ft; 10.2 ft/y]) and 390 m (12.6 m/y [100 ft; 41 ft/y]), respectively. Over the first 4 km (2.5 mi) south of Peat Point, the average recession amount was 172.2 m (5.6 m/y [565 ft; 18.4 ft/y]).

MacLaren Plansearch Inc. (1985a) analyzed air photos from 1946, 1953, 1955, 1971, 1977, 1978 and 1984 and found a maximum of 440 m (1,444 ft) of shoreline recession south of Peat Point over the 38 years from 1946 to 1984 (11.6 m/y [38.1 ft/y]). The pre-hydroelectric or LWR development rate they calculated from 1946 to 1971 was 12.8 m/y (42 ft/y), while their post-hydroelectric development rate was 13.1 m/y (43 ft/y), calculated from 1977 to 1984, pointing towards erosion rates not having changed following LWR. Furthermore, the maximum rate of 12.6 m/y (41.3 ft/y) calculated above using air photos (1978–2009) and the maximum rate of 11.9 m/y (39 ft/y) calculated from Landsat images (1979–2014) are similar to the long-term (1946–1984) and pre-LWR (1946–1971) rates calculated by MacLaren Plansearch Inc. (1985a). Therefore, there is no evidence to suggest that erosion rates have changed following LWR at this site.

Near Weasel Point along the south shore of South Playgreen Lake, 12.3 km (7.6 mi) of shoreline was mapped from a 1978 georeferenced air photo and from the 2009 LWR imagery. Recession was measured between the two shorelines at intervals of 20 m (66 ft). Recession distances were less than 5 m (16.4 ft) along 15% of the shoreline. Over the rest of the mapped shoreline, the average and maximum recession amounts were 20.9 m (0.7 m/y [69 ft; 2.3 ft/y]) and 136.0 m (4.4 m/y [446 ft; 14.4 ft/y]), respectively. The maximum recession was observed at the tip of Weasel Point. At the island offshore from Weasel Point, as much as 111.7 m (3.6 m/y [367 ft; 11.8 ft/y]) of recession was observed, with an average of 56.1 m (1.8 m/y [184 ft; 5.9 ft/y]). Along the north shore of the lake in this area, near Martin Point, rock outcrops are abundant along the shoreline and form small islands offshore. No erosion was detected along the 4.2 km (2.6 mi) of shoreline mapped in this area.

Along the south shore of Kiskittogisu Lake, 16.3 km (10.1 mi) of shoreline was mapped from the 1979 air photo and from the 2009 LWR imagery, including a small portion of Eight-Mile Channel near its exit, resulting in 813 measurements at an interval of 20 m (66 ft). The 1979 and 2009 shorelines were within

5 m (16.4 ft) of each other over 4.5% of this distance. Over the rest of the mapped shoreline, average and maximum recession amounts were 52.4 m (1.8 m/y [172 ft; 5.9 ft/y]) and 168.5 m (5.6 m/y [553 ft; 18.4 ft/y]), respectively. The greatest amounts of erosion were observed at the exit of Eight-Mile Channel and along the south shore of the lake near the Kiskittogisu River, while the maximum observed recession of 168.5 m (553 ft) was observed at the exposed points at the exit of Eight-Mile Channel.

The 1979 air photo acquired to cover the south shore of Kiskittogisu Lake did not cover the southernmost portion of Eight-Mile Channel (no coverage south of transect at station 45+35.47). Thus, it is impossible to comment on rates at the channel entrance, where the channel margins are formed in erodible fine sands and transect surveys have shown considerable erosion historically. Downstream of the channel entrance, recession distances were below detection along the straight section of channel formed in cohesive clays extending between transects at stations 45+35.47 and 89+29.52. This finding is consistent with historical data from transect surveys along this portion of the channel. Further downstream, the left dyke within Eight-Mile Channel where the channel bends near station 122+78.94 was mapped over a distance of 1.0 km (0.6 mi). The 1979 and 2009 shorelines were within 5 m (16.4 ft) of each other over 0.8% of this distance. Over the rest of the mapped shoreline, average and maximum recession amounts were 21.5 m (0.7 m/y [71 ft; 2.3 ft/y]) and 31.7 m (1.1 m/y [104 ft; 3.6 ft/y]), respectively. As discussed above, considerable erosion was observed at the exit of Eight-Mile Channel.

Pre-LWR erosion rates were assessed along the south shore of Kiskittogisu Lake using 1955 and 1971 air photos. Shorelines were mapped over a distance of 6.2 km (3.9 mi) and then measurements were made between them at an interval of 20 m (66 ft). The 1955 and 1971 shorelines were within 5 m (16.4 ft) of each other over 55.7% of this distance. Over the remainder of the mapped shoreline, average and maximum recession amounts were 9.1 m (0.6 m/y [30 ft; 2 ft/y]) and 25.9 m (1.6 m/y [85 ft; 5.2 ft/y]), respectively.

Along the east shore of Kiskittogisu Lake, shorelines were mapped from a 1979 air photo and from the 2009 LWR imagery over a distance of 11.3 km (7 mi). Average and maximum recession amounts were 30.3 m (1.0 m/y [99 ft; 3.3 ft/y]) and 89.1 m (3.0 m/y [292 ft; 9.8 ft/y]), respectively.

Along the southwest shore of Kiskitto Lake, 10.2 km (6.3 mi) of shoreline was mapped from a 1979 air photo and from the 2009 LWR imagery. The 1979 and 2009 shorelines were within 5 m (16.4 ft) of each other over 10.7% of this distance. Over the remainder of the mapped shoreline, average and maximum recession amounts were 22.3 m (0.7 m/y [73 ft; 2.3 ft/y]) and 48.5 m (1.6 m/y [159 ft; 5.2 ft/y]), respectively.

In North Playgreen Lake (Map 4.4.2-6) and Little Playgreen Lake (Map 4.4.2-3), bedrock controls the shorelines largely and the great abundance of rocky islands serves to limit the fetch. To assess the magnitude of erosion observed in these generally rocky areas, a 1971 air photo covering the central part of North Playgreen Lake (Map 4.4.2-6) was georeferenced and compared with the 2009 LWR imagery. Erosional changes to rocky islands and mainland shorelines in this area are generally below detection. The greatest amount of shoreline recession found in this photo was along a peninsula on the south shore of Taylor Island, where about 40 m (131 ft) of recession was observed between 1971 and 2009 (1.1 m/y [3.6 ft/y]). Landsat analysis suggested that this peninsula showed the greatest erosion of any site in North Playgreen Lake. Based on the above discussion, it is suspected that the most erosion prone

shorelines in North Playgreen Lake have been characterized by erosion rates generally less than 1.1 m/y (3.6 ft/y) since the 1970s.

Two air photos from 1979 covering the central part of the Jenpeg forebay were acquired and aligned to the 2009 LWR imagery. The 2009 shorelines were mapped in selected locations (15.3 km [9.5 mi] total) throughout the forebay, and then these lines were compared with the 1979 shorelines. Erosion was generally smaller than measurement uncertainties, which in some locations were as high as 10 m (33 ft) due to difficulties in defining shorelines. The largest erosion magnitudes were observed at exposed points, where 10–20 m of recession (0.3 to 0.7 m/y [33–66 ft; 1.0–2.3 ft/y]) represented a typical upper bound and the upper limit appeared to be about 30 m (1.0 m/y [100 ft; 3.3 ft/y]).

Haines and Straight (2012) monitored 75 sites in the Jenpeg forebay and reported that average bank recession rates for the three more erodible shoreline classes from 2003 to 2012 were 0.05 m/y (0.16 ft/y; class 3), 0.23 m/y (0.75 ft/y; class 4), and 0.02 m/y (0.07 ft/y; class 5).

Air photos from 1928 and 1947 covering a part of the Jenpeg forebay near the Jenpeg GS were aligned to the 2009 LWR imagery. No measurable changes were observed in the positions or shapes of the shorelines over the 6.4 km (4.0 mi) of shoreline covered by the 1928 photo. Therefore, the maximum pre-LWR erosion rates must have been less than about 0.3 m/y (1.0 ft/y).

**SUMMARY**

Based on surface area, Hydraulic Zone 1 is the second largest zone in the RCEA ROI, with an approximate water surface area of 1,406 $km^2$ (543 sq mi) and a shoreline of 3,196 km (1,986 mi) long. The zone consists of several large lakes, including North, South and Little Playgreen lakes, Kiskittogisu and Kiskitto lakes, and the Jenpeg forebay. It also includes Two-Mile and Eight-Mile channels, and the East and West channels of the Nelson River.

From the north end of Lake Winnipeg, the Nelson River flows through thick deposits of glacial Lake Agassiz silt and clay, locally covered by thick organic deposits. Along the southwest shore of South Playgreen Lake, highly erodible silt and clay shorelines are dominant. Bedrock shorelines become increasingly common towards the northeast within South Playgreen, Kiskittogisu and Kiskitto lakes.

Historically, most of the erosion monitoring in Hydraulic Zone 1 has been carried out through transect surveys along Eight-Mile and Two-Mile channels, through air photo analysis at selected sites in South Playgreen and Little Playgreen lakes, and through field surveys around the Jenpeg forebay.

Analysis of Landsat images from 1979 and 2014 revealed three main areas of pronounced erosion within this zone: the north shore of Lake Winnipeg near Two-Mile Channel, the west shore of South Playgreen Lake near Peat Point, and the south shore of Kiskittogisu Lake near Eight-Mile Channel. Air photos were used to quantify erosion in these areas, and in areas of lesser erosion elsewhere.

The analysis found as much as about 190 m (623 ft) of recession had occurred at the entrance of Two-Mile Channel from 1979 to 2014 (5.4 m/y [17.7 ft/y]). A similar erosion rate was obtained from 1979 to 2009 aerial image analysis. Elsewhere along Two-Mile Channel, erosion has been considerably less, with strong declines in erosion rates since the early 1980s suggested by transect surveys.

The analysis also suggested a large amount of erosion along the Lake Winnipeg north shore north of Two-Mile Channel, with as much as 100 to 130 m (328–427 ft) of shoreline recession between 1979 and 2014 (2.8 to 3.7 m/y [9.2–12.1 ft/y]). Previously reported 1946 to 1978 air photo analysis along this shore showed a maximum pre-LWR erosion rate of 3.5 m/y (11.5 ft/y). Thus, erosion rates have not changed following LWR along this portion of the Lake Winnipeg north shore.

The site showing the largest amount of erosion in the Hydraulic Zone 1 is located on the southwest shore of South Playgreen Lake, near Peat Point, where air photo analysis from 1978 to 2009 over a shoreline 10.9 km (6.8 mi) long indicated average and maximum recession amounts of 97.3 m (3.1 m/y [319 ft; 10.2 ft/y]) and 390 m (12.6 m/y [1,280 ft; 41.3 ft/y]), respectively. Previously reported air photo analysis at this site revealed a maximum erosion rate from 1946 to 1971 of 12.8 m/y (42 ft/y). Thus, erosion rates at this site have not changed following LWR.

Sporadic areas of at least 90 m (300 ft) of erosion were also indicated along the south shore of Kiskittogisu Lake east and west of Eight-Mile Channel. Air photo analysis from 1979 to 2009 along 16.3 km (10.1 mi) of the south shore indicated average and maximum recession amounts of 52.4 m (1.8 m/y [172 ft; 5.9 ft/y]) and 168.5 m (5.6 m/y [553 ft; 18.4 ft/y]), respectively. The greatest erosion was observed at Eight-Mile Channel and near the Kiskittogisu River. Pre-LWR air photo analysis from 1955 to 1971 around the mouth of the Kiskittogisu River indicated a maximum recession amount of 25.9 m (1.6 m/y [85 ft; 5.2 ft/y]). Thus, there was a clear increase in erosion rates following LWR in this part of the Kiskittogisu Lake south shore.

Air photo analysis from 1978 to 2009 in parts of South Playgreen Lake other than near Peat Point indicated maximum rates of 1.4 m/y (4.6 ft/y) along the east shore from around Sandy Bar Point to Denison Point, and 4.4 m/y (14.4 ft/y) along the southwest shore near Weasel Point. Along the north shore of the lake near Martin Point, rock outcrops are abundant and no measurable erosion was observed along the 4 km (2.5 mi) of shoreline examined.

In North Playgreen and Little Playgreen lakes, shorelines are dominantly bedrock-controlled, and the abundance of rocky islands serves to limit fetch. Air photo analysis from 1971 to 2009 in the central part of North Playgreen Lake indicated that erosion was generally less than 5 m (16.4 ft). The greatest amount of erosion was observed along a peninsula on the south shore of Taylor Island, where about 40 m (131 ft) of recession was observed (1.1 m/y [3.6 ft/y]).

Air photo analysis from 1979 to 2009 along 10.2 km (6.3 mi) of the southwest shore of Kiskitto Lake indicated average and maximum recession amounts of 22.3 m (0.7 m/y [73.2 ft; 2.3 ft/y]) and 48.5 m (1.6 m/y [159 ft; 5.2 ft/y]), respectively. Landsat analysis suggested that this was the part of the lake showing the largest amount of erosion.

Air photo analysis from 1979 to 2009 in the central part of the Jenpeg forebay indicated low erosion rates, with maximums of 0.3 to 1.0 m/y (1.0–3.3 ft/y). Haines and Straight (2012) monitored 75 sites in the Jenpeg forebay from 2003 to 2012 and reported similarly low recession rates of 0.02 to 0.23 m/y (0.07-0.75 ft/y) for the most erosion prone sites. Air photo analysis from 1928 and 1947 covering part of the Jenpeg forebay indicated no measureable erosion over the 6.4 km (4.0 mi) of shoreline examined. Therefore, there has been an increase in erosion rates following LWR, but the increase is difficult to

quantify with accuracy due to the low erosion rates post-LWR and because pre-LWR erosion rates were not measurable.

#### 4.4.2.1.3 Sedimentation

**REVIEW OF INFORMATION ON SEDIMENTATION**

The earliest identified documentation regarding the sedimentation environment of the Outlet Lakes region relating to Lake Winnipeg Regulation is found in a report by V. J. Galay detailing the shoreline processes of Lake Winnipeg, Playgreen Lake and Kiskittogisu Lake as they relate to the future Two Mile and Eight Mile channels (Galay 1971). The findings of the report are based primarily on observations made during a brief field trip to the region. Concerning sedimentation the report predicted that large amounts of clay eroded from the north shore of Lake Winnipeg would be introduced into the Outlet Lakes through Two-Mile Channel. The report noted that the natural outlet of Lake Winnipeg does not introduce a significant amount of sediments into Playgreen Lake however, the focus of the report is on macro-level concerns such as potential future deposition of sand becoming a hazard to navigation. The report does not assess or comment on water quality of suspended sediment.

Prior to LWR, suspended sediment data were collected by Manitoba Hydro in the area of Warren Landing and off the ends of Two Mile Channel and Eight Mile Channel in Lake Winnipeg, Playgreen Lake, and Kiskittogisu Lake. Manitoba Hydro documented suspended sediment, light penetration, wave action, wind velocity and direction and flow in the outlet lakes area from 1971 to 1977 in several reports (Manitoba Hydro 1974, 1975, 1977a, 1977b), however these could not be located for this assessment.

The LWCNRSB documented the baseline sediment conditions within the Hydraulic Zone 1 and findings of these studies, relevant to this zone, were presented by Koshinsky (1973) and Morelli (1975). Koshinsky (1973) summarized the limnological data from earlier investigations and concluded that water in the Outlet Lakes is less transparent than Lake Winnipeg, indicating re-suspension of suspended sediments by wind and current action on the glaciolacustrine shore and bottom deposits. The Secchi disk depth values in Playgreen Lake varied from 0.15 to 1.43 m (0.5–4.7 ft) with a mean value of 0.54 m (1.8 ft). The Secchi disk depth in Kiskittogisu Lake was similar to Playgreen Lake, varying from 0.21 to 1.46 m (0.7–4.8 ft) with a mean value of 0.53 m (1.8 ft). Kiskitto Lake was the most turbid with Secchi disk depths ranging from 0.18 to 0.34 m (0.6–1.1 ft) and a mean value of just 0.21 m (0.7 ft). Morelli (1975) reported the pre-LWR water quality data collected in the Outlet Lakes area from 1972 to 1974. The range and mean values of turbidity and NFR for these water bodies are summarized in Table 4.4.2-1.

A report prepared by Manitoba Hydro (1985b) presented the 1984 sedimentation program sampling results for the Playgreen Lake area and a comparison with previous historic data. The report concluded that bedload movement in 1984 had declined and remained a minor source of sediment transfer. The 1984 bedload measurements conducted in Two Mile and Eight Mile channels were presented in a Manitoba Hydro report (Manitoba Hydro 1985c), however the present study has been unable to obtain this report.

**Table 4.4.2-1: Summary of 1972–1974 Lake Winnipeg, Churchill and Nelson River Study Board (LWCNRSB) Water Quality Data for Outlet Lakes**

| Sampling Location | Turbidity (NTU) | | Non-filterable Residue (mg/L) | |
|---|---|---|---|---|
| | Range (min–max) | mean | Range (min–max) | mean |
| Nelson River @ Warren landing | 2.2–35.0 | 9.2 | 3.2–25.2 | 14.2 |
| Nelson River @ Norway House | 2.8–20.0 | 8.4 | 1.2–22.4 | 8.7 |
| Playgreen Lake south | 5.5–75.0 | 28.7 | 5.0–50.0 | 20.0 |
| Playgreen Lake north | 5.0–45.0 | 17.5 | 5.0–50.0 | 13.6 |
| Kiskittogisu Lake | 3.5–85.0 | 26.3 | 5.0–70.0 | 22.7 |
| Kiskitto Lake | 63.0–320.0 | 129.2 | 50.0–240.0 | 113.3 |
| Kisipachewuk Rapids | 5.4–28.0 | 15.4 | 0.8–27.2 | 10.6 |
| Jenpeg | 3.2–140.0 | 20.0 | 0.1–28.0 | 11.6 |

1. NTU = Nephelometric Turbidity Units.

In 1985, MacLaren Plansearch Inc. completed a comprehensive study of South Playgreen Lake to assess the impacts of LWR on the commercial fishery of Playgreen Lake (MacLaren Plansearch Inc. 1985a, b, c). Water samples were collected during 1984/85 to compare with the pre- and post-LWR water quality data. The findings of this comparison are summarized as follows:

- Playgreen Lake had undergone a small but statistically significant chemical enrichment due to LWR. There is a statistically significant difference in water quality between water in the plume.
- The pre-LWR mean turbidity levels near the outlet of Two Mile Channel, inlet of Eight-Mile Channel and south basin of Playgreen Lake were reported to be 22.2, 22.3 and 29.9 NTU respectively, with the latter value being similar to the mean from the LWCNRSB data in Table 4.4.3-1. Maclaren Plansearch results for sampling in summer 1984 did not report turbidity.
- The pre-LWR mean NFR concentrations were reported to be 16.4,19.6 and 7.4 mg/L, near the outlet of Two Mile Channel, inlet of Eight Mile Channel, and the south basin of Playgreen Lake, respectively. NFR concentrations from sampling the south basin in July and September 1984 ranged from 5–54 mg/L and averaged about 19.6 mg/L, similar to the pre-LWR results from LWCNRSB in Table 4.4.3-1.

Several lake bottom grab and core samples were taken from the Playgreen Lake in 1984/85 to assess the sedimentary regime of lake's bottom and identify the effects of LWR on sedimentation process within the lake. Main conclusions of sediment core analysis are:

- No apparent differences attributable to LWR exist in the sediment layers and the degree of difference in Playgreen Lake's sedimentary environment since LWR is not quantifiable.
- The bottom sediments are generally silty with a significant amount of fine sand.

- Most of the sediment originating from Lake Winnipeg and Playgreen Lake remains in suspension and is flushed through the Lake.
- Some coarser sand, presumably derived from Lake Winnipeg shorelines and conveyed by flood flows, was found in the middle of Playgreen Lake.
- Sediment from Playgreen Lake itself is relatively thinly and discontinuously distributed due to energy conditions within the lake and to the fine-grained nature of majority of source material.

The Maclaren Plansearch Inc (1985a,b,c) study also included a qualitative comparison of the pre- and post-LWR sediment regime using satellite and aerial images. Results indicated the supply of sediment to the south basin of Playgreen Lake was seasonal and episodic and the higher water levels after-LWR may have increased episodes of sediment entrainment. It also indicated that suspended sediment that might otherwise have settled in Lake Winnipeg was transported downstream through Two Mile Channel, however this sediment is fine and appeared to flush through Playgreen Lake. The imagery also revealed sediment plumes arising from erosion of the south and west shores of the lake both before and after regulation. Limited downstream attenuation of sediment concentrations in plumes observed in 1984 suggested either there was little deposition of sediment, maintenance of the concentration by internal shoreline erosion, or a combination of the two. Near-surface sediment concentrations in Playgreen Lake, as inferred from satellite imagery analysis, appeared not to have been affected significantly by regulation, at this time (Maclaren Plansearch Inc. 1985a, b, c).

Turbidity values, as an indication of concentration of suspended sediment in water, collected in Norway House for the periods of 1972–1976 before development and 1976–1984 after development were compared to investigate the effects of LWR on water quality (Playle and Williamson 1986a). The study calculated an increase in the average turbidity at Norway House from 5.3 NTU before July 1976 to 7.2 NTU after. The report deemed this change statistically significant based on a student t-test. It was presumed that the increase is a result of the construction of Two Mile Channel.

The FEMP was initiated in 1986 and Northwest Hydraulic Consultants was hired to provide a review of potential physical and ecological effects of increased sediment resulting from the CRD and LWR. Phase I of RCEA reviewed the pre and post-LWR sedimentation regime. The findings of this study (Northwest Hydraulic Consultants Ltd. 1988) relevant to RCEA Hydraulic Zone 1 are summarized below:

- The Lake Winnipeg outlet channels and the glaciolacustrine shoreline of Playgreen Lake act as major sediment sources on Nelson River route from Lake Winnipeg to Jenpeg GS.
- Playgreen Lake, Kiskittogisu Lake and Jenpeg GS forebay act as major sediment sinks on the Nelson River route from Lake Winnipeg to Jenpeg GS.
- Sediment input to Nelson River system has not been substantially increased. Any increase in sediment from LWR is believed to be transported through Playgreen Lake, but its contribution to Lower Nelson River system is believed to be very small as compared to that of the CRD.
- A small amount of information appears to be available on grain size distributions of bottom samples from Playgreen Lake.

Strange (1990a) reported on the suspended sediment and turbidity data collected as part of the FEMP (1986–1989) at two sites on the east channel of the Nelson River upstream and downstream of Norway House. Sampling occurred in winter and summer seasons and data collected over the period is

summarized in Table 4.4.2-2. In general, turbidity and NFR values were somewhat lower in winter than in summer.

Baker and Davies (1991) summarized the impacts of LWR and CRD on physical, chemical, and biological resources of the affected aquatic environment. The effects were qualitatively summarized after a comprehensive review of historic documents. The study found negligible difference in erosion and sedimentation between pre- and post-regulation periods in the Norway House area.

More recently, the CAMP initiated an ongoing sediment monitoring program on Playgreen Lake and Little Playgreen Lake. Sediment data including suspended sediment concentration, discrete and continuous turbidity, bedload, and bed material have been collected every three years at both lakes. The CAMP monitoring data from 2008 to 2011 is provided in the 2014 CAMP report (CAMP 2014). A summary of relevant data is given in Table 4.4.2-3.

Sediment samples were collected in Playgreen Lake in 2009 to provide a general characterization of sediment type in nearshore and offshore aquatic habitats. At Playgreen Lake, silty clay comprised the majority of the sediments collected from the nearshore areas while sandy loam comprised the majority of the offshore sediments.

In Little Playgreen Lake, offshore samples were collected in 2010 and silty clay loam comprised the majority of sediments. The nearshore bed consisted of cobbles and boulders with exposed bedrock, and therefore could not be sampled for the particle size analysis.

The results of particle size analysis of collected samples are summarized in Map 4.4.2-8. Similar data has been collected in subsequent years, more recently during the open water season of 2013 and winter 2013/2014, however this data is not yet available and remains to be published. CAMP studies in 2012 also mapped substrates (habitat) within areas of Playgreen Lake, however these maps are not reproduced here because the information is still in draft format and is yet to be finalized.

**Table 4.4.2-2: Summary of 1986–1989 Federal Ecological Monitoring Program (FEMP) Sediment Data Collected in Nelson River East Channel**

| | Jack River downstream of Norway House station no. 00MA05-UB0013 | | Below Sea River Falls station no. 00MA05-UB0006 | |
|---|---|---|---|---|
| | **Range (min–max)** | **mean** | **Range (min–max)** | **mean** |
| *In situ* Turbidity (NTU [1]) | 5.0–34.0 | 10.4 | 6.0–16.0 | 9.6 |
| Laboratory Turbidity (NTU) | 3.0–26.0 | 8.7 | 4.0–13.0 | 8.4 |
| Non-filterable Residue (mg/L) | 2.0–20.0 | 6.5 | 5.0–20.0 | 9.4 |

1. NTU = Nephelometric Turbidity Units.

**Table 4.4.2-3: Summary of 2008–2011 Coordinated Aquatic Monitoring Program (CAMP) Sediment Data on Playgreen Lake and Little Playgreen Lake**

| | Playgreen Lake | | Little Playgreen Lake | |
|---|---|---|---|---|
| | Range (min–max) | mean | Range (min–max) | mean |
| *In situ* Turbidity (NTU [1]) | 4.9–22.0 | 12.8 | 14.0–21.1 | 18.2 |
| Laboratory Turbidity (NTU) | 4.1–15.0 | 9.8 | 3.5–11.7 | 8.3 |
| Secchi disk depth (m) | 0.6–0.92 | 0.8 | 0.6–0.81 | 0.7 |
| Total Suspended Solids (mg/L) | <2.0–18.2 | 11.2 | 3.6–14.0 | 9.4 |

1. NTU = Nephelometric Turbidity Units.

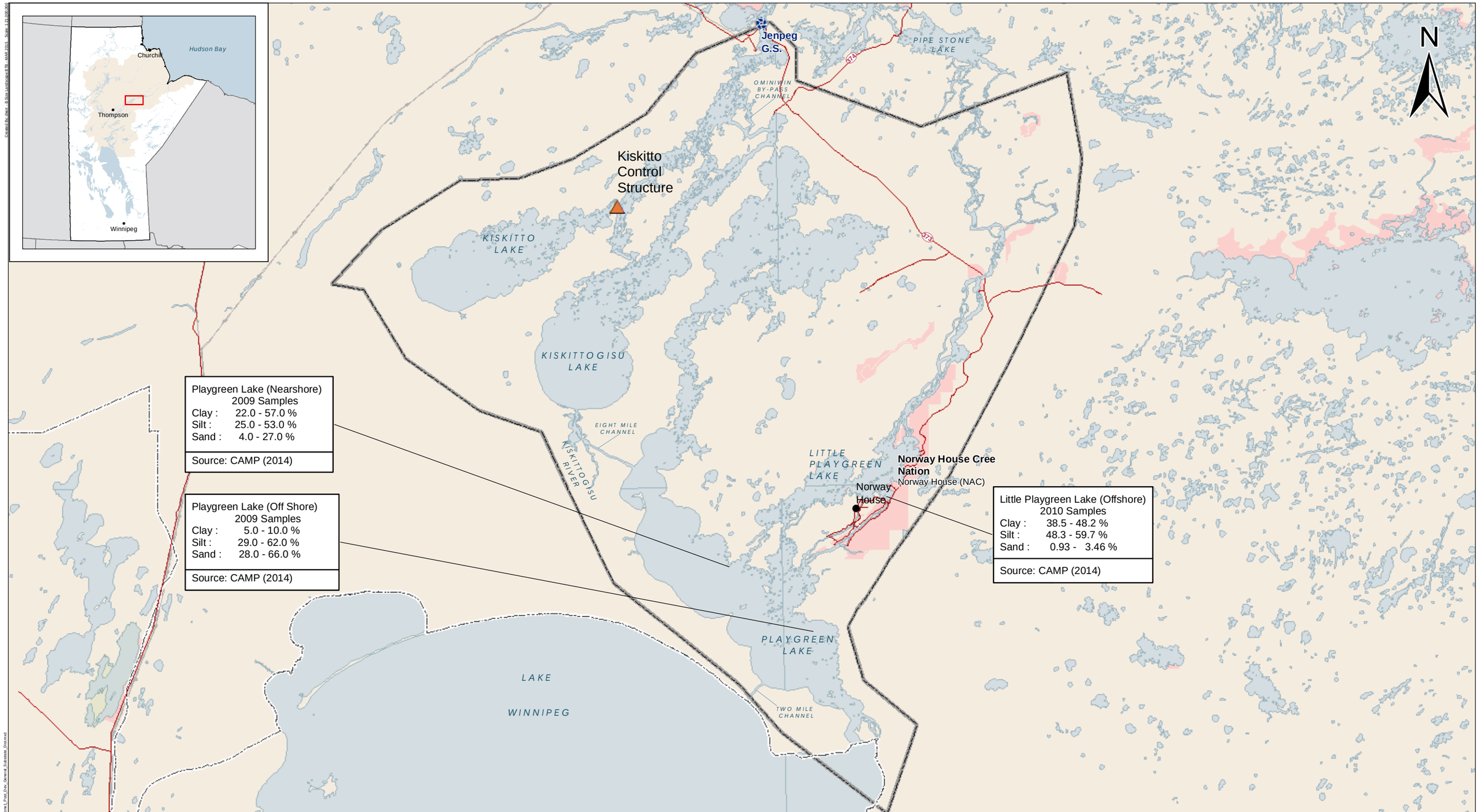
**SUMMARY**

Most of the water quality and sediment data for the outlet lakes in Hydraulic Zone 1, was collected as part of three large studies: LWNCRSB (1972–1974), FEMP (1987–1989) and CAMP (since 2008). A few other studies including FEMP used available pre and post-regulation data to assess the effects of LWR on the water quality within this zone. More recently under CAMP, substrate (habitat) mapping and sedimentation monitoring in 2013–2014 were performed; however, this information was not included in RCEA as it is still a draft pending assessment of the results and publication of a formal report and conclusions. A comparison of the most recent CAMP data and pre-LWR conditions along with review of previous assessments lead to the following general conclusions.

Recent and historical studies on Playgreen Lake have found that the supply of suspended material to the south basin of the lake is seasonal and episodic. Higher water levels due to LWR may have increased the frequency of sediment entrainment. The increased flow through Two Mile Channel has negatively affected water clarity in Playgreen Lake by passing increased sediment load from Lake Winnipeg into Playgreen Lake. The increased flows also tended to dilute the suspended sediment concentration in Playgreen Lake with an exception of Two-Mile and Eight-Mile channels. Most of the sediment originating from Lake Winnipeg and Playgreen Lake remains in suspension and is flushed through and out of the Lake.

The study of sediment cores in 1985 found no distinguishable boundary between sediment layers that would demark the pre and post-LWR periods. This suggests there has been no significant change in sedimentation processes or sediment types in Playgreen Lake since LWR. The study found bottom sediments were generally silty clay in nearshore areas while sandy sediments were found offshore and the same general distribution was observed in 2009 under CAMP.

Negligible sedimentation changes were observed between pre- and post-LWR periods on the east channel of Nelson River.




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
Government of Manitoba, Government of Canada, Manitoba Hydro

CREATED BY:
Water Resources Engineering

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 23-MAY-15 | 03-DEC-15 |
| 0 5 10 Kilometres / 0 4.5 9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- RCEA Hydraulic Zones
- RCEA Region of Interest
- First Nation Reserve
- Manitoba Provincial Park
- Transmission Line (Existing)

# Hydraulic Zone 1

Post-Hydroelectric Development

General Substrate Distribution

**Map 4.4.2-8**

## 4.4.2.2 Hydraulic Zone 2 – Cross Lake and Surrounding Area

### 4.4.2.2.1 Hydraulic Zone 2 Overview

The upstream end of the Nelson River in Hydraulic Zone 2 is at the Jenpeg GS on the west channel where it enters Cross Lake and the Nelson River east channel just upstream of Pipestone Lake (Map 4.4.2-9). This zone extends downstream of Cross Lake to where the river enters Sipiwesk Lake in two separate channels. The major lakes within Hydraulic Zone 2 are Pipestone, Cross and Duck lakes, which lie on the Nelson River flow path. Walker Lake, which is sometimes influenced by Cross Lake depending on water levels and drains into the eastern end of Cross Lake. The hydraulic zone also extends upstream along the Minago River, which empties into the southwest end of Cross Lake.

Water levels and flows on Cross Lake are affected by the regulation of outflows at the Jenpeg GS. Operation of LWR altered water levels on Cross Lake. This resulted in a decrease in average summer levels, an increase in winter levels, a wider range of variation, and rapid changes in level in response to Jenpeg outflow changes. In 1991, Manitoba Hydro constructed the Cross Lake Weir and other channel modifications at the lake's outlet that were designed to increase water levels, reduce the range of water level variation, and provide more stable water level conditions as inflow varies.

### 4.4.2.2.2 Erosion

#### TERRAIN AND SHORELINE CHARACTERISTICS

Hydraulic Zone 2 has an approximate water surface area of 895 $km^2$ (346 sq mi) and a shoreline 4,613 km (2,866 mi) long. The zone includes Cross Lake, Pipestone Lake, Walker Lake and Duck Lake. The Cross Lake shoreline is particularly irregular, with large islands separating the lake into numerous basins and interconnecting channels. The lakeshore is dominated by low bedrock shorelines, some of which contain backshore overburden occasionally a few metres thick. The few overburden shorelines present on Cross Lake are characterized by alluvial silts deposited around small rock cores or lacustrine clays found in small bays.

#### REVIEW OF INFORMATION ON EROSION

Lake Winnipeg Regulation changed the seasonal water level regime on Cross Lake, resulting in generally higher winter levels and lower summer levels, and increased the water level range in this area. The Cross Lake Weir was constructed at the lake's outlet in 1991 in an attempt to reduce the overall water level range by reducing peak levels and increasing minimum levels, and to increase levels at lower flows. However, by raising the average water level, the weir may have increased erosion rates on erodible shorelines (Manitoba Hydro 2014b), which are erosion-susceptible at high water levels.

Manitoba Hydro

Regional Cumulative Effects Assessment

**DATA SOURCE:**
Government of Manitoba, Government of Canada, Manitoba Hydro

**CREATED BY:**
Water Resources Engineering

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 23-MAY-15 | 01-DEC-15 |
| 0 5 10 Kilometres / 0 4.5 9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- RCEA Hydraulic Zones
- First Nation Reserve
- Transmission Line (Existing)
- Rail

# Hydraulic Zone 2

**Map 4.4.2-9**

File Location: M:\RCEA\GIS\MXD\Phase_II\FINAL\RCEA_R_Phase1_Hydraulic_Zone2.mxd

Cole (1974) forecasted the effects of LWR on shorelines at the Cross Lake settlement, which extends 7 km (4.3 mi) along the channel separating Cross Island from the mainland and another 3 km (1.9 mi) along the shore of Cross Lake. Shore profiles were presented with descriptions of shore materials and vegetation. Most of the shoreline is bedrock-controlled with shallow overburden in the backshore. Bedrock-controlled shorelines with overburden beaches capped by a low clay bluff are present locally between rock promontories. Given the bedrock-controlled shorelines and limited fetch along the channel in this area, it was anticipated that regulated changes in water levels and flows would be of insufficient magnitude to cause substantial erosion.

The main physical changes expected after LWR predicted in the Physical Impact Study (Water Resources Branch 1974a) were changes to shoreline vegetation due to the modified seasonal water level regime, and no erosion problems had been reported up to 1987 (Kellerhals Engineering Services Ltd. 1987). Cole (1974) noted that the causeways within the Cross Lake settlement required raising and riprap for erosion protection, as their levels at the time would not have withstood high water levels under natural or regulated conditions.

Record high water levels were recorded at Cross Lake in 2005 and then in 2011, with considerable erosion impacts in the Cross Lake area resulting from the 2011 high water levels due to high runoff in the drainage basin (Manitoba Hydro 2014b). Between June 2011 and fall 2012, Manitoba Hydro implemented a shore protection program that protected 4.4 km (2.7 mi) of waterfront at the Cross Lake settlement. High water levels in 2011 also resulted in a new channel being formed at Duck Rapids, the outlet from Duck Lake, which was expected to result in the introduction of considerable sediment and debris into Sipiwesk Lake (Manitoba Hydro 2014b).

Shoreline conditions at five sites located between the mouth of the Minago River and the Cross Lake settlement were assessed in 2006 during the development of setback lines (Manitoba Hydro 2006b, c, d), with minimal erosion reported from any of these sites. Along a silt-clay beach between Jenpeg and the Minago River, most of the nearshore trees and vegetation appeared unhealthy or dead, likely due to high water levels in 2005, but no signs of active erosion were reported (Manitoba Hydro 2006c). No information on erosion rates or magnitudes was reported from this work.

## DATA ANALYSIS

### Landsat Analysis

Two Landsat images were used to map erosion within Hydraulic Zone 2. The historical image used was a Landsat 2 image acquired on 10 August 1979, whereas the recent image was a Landsat 8 image from 20 May 2015. Water levels on Cross Lake were 207.6 m (681.1 ft) on the dates that both images were acquired. The 1979 image was georeferenced to the 2015 image to improve alignment. For the historical image, a near-infrared band (Band 7) with a threshold value of 38 was used to delineate the land-water interface; this band covers a wavelength of 0.8 to 1.1 µm with a resolution of 60 m (200 ft). For the recent image, a shortwave-infrared band (Band 7) with a threshold value of 6100 was used to delineate the land-water interface; this band covers a wavelength of 2.1 to 2.3 µm with a resolution of 30 m (100 ft). After comparing the two images, the areas showing at least 90 m (300 ft) of recession were isolated. The erosion areas were then checked against the 2011/2013 Nelson River Forestry imagery where available

for quality control. The areas considered in the analysis of Hydraulic Zone 2 are shown in Map 4.4.2-10 through Map 4.4.2-14.

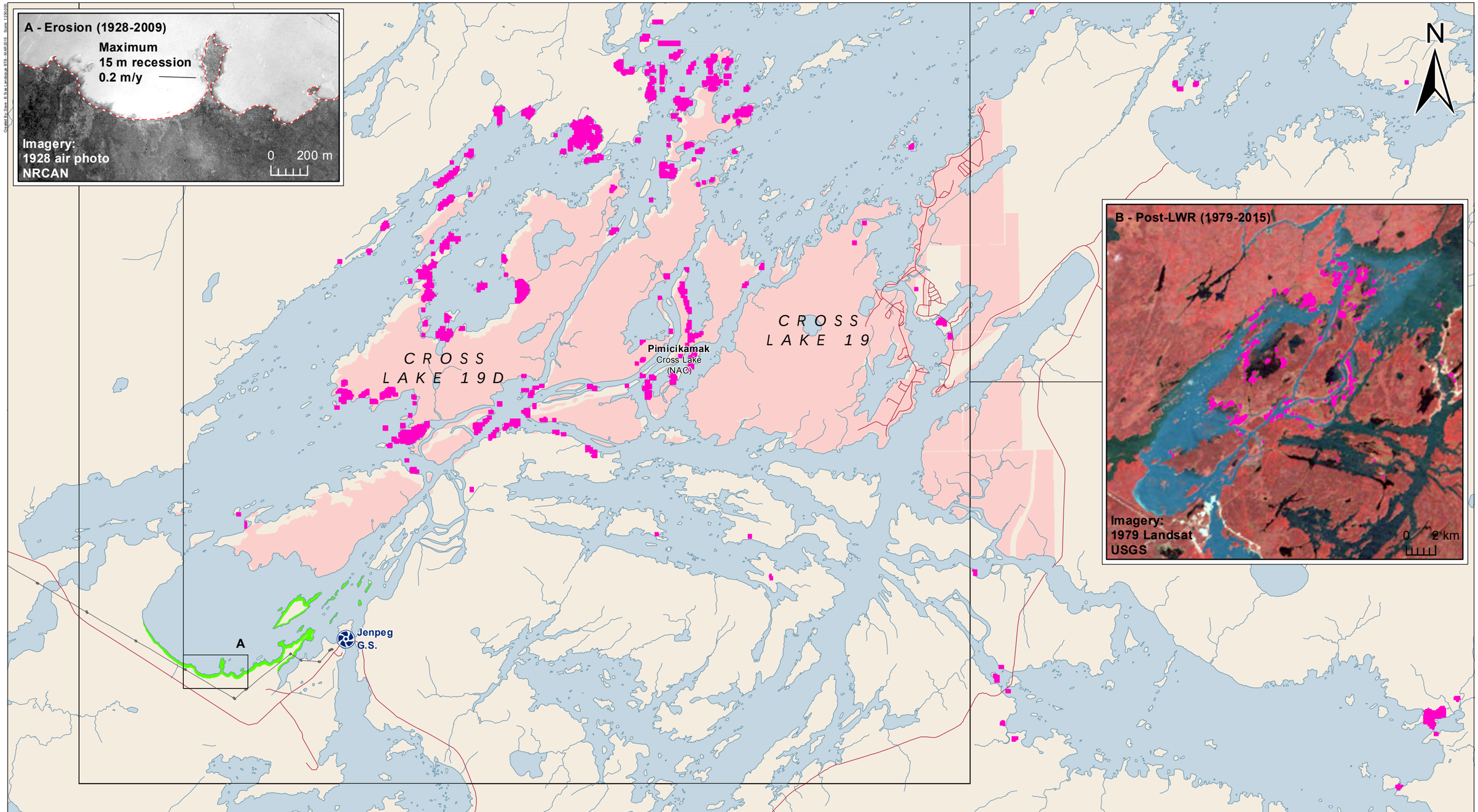
All of the areas showing at least 90 m (300 ft) of erosion in Hydraulic Zone 2, except for one site, are located in wetland areas that are flooded periodically depending on lake levels. These erosion areas were dominantly terrestrial in the 1979 image, while at the same water level in the 2015 image, these areas were dominantly aquatic. It is interpreted that in these areas there has been a removal of vegetation and perhaps peat and soil from the ground surface between 1979 and 2015. Examination of a 1979 air photo revealed that these areas were unforested and represented areas of either low vegetation or mineral soil. The one site of mineral erosion found in Hydraulic Zone 2 is located near Duck Rapids (Map 4.4.2-14), where a new channel was noted to have formed along the Nelson River in association with record high water levels in 2011 (Manitoba Hydro 2014b). The eroded area associated with the new channel formed near Duck Rapids is approximately 190 by 180 m (623–591 ft) in extent, covering an area of 3.24 ha (8 ac).

The main areas of erosion suggested through Landsat analysis are located in the southern part of Cross Lake in a broad zone about 8 by 12 km (5.0 x 7.5 mi) in extent situated in the general path of the West Channel of the Nelson River (Map 4.4.2-10). The location of this broad zone of eroded land in the path of the West Channel of the Nelson River could suggest that flow velocities played a role in the removal of this material. The extent of the zone of flow associated with the West Channel can be seen in a 1979 multispectral Landsat image as an area of increased suspended sediment concentration. The areas of erosion suggested from Landsat analysis are closely aligned with this zone of flow.

**Air Photo Analysis**

Air photos from 1928 and 1954 covering the southern shore and islands of Cross Lake west of the Jenpeg GS were aligned to the 2009 LWR imagery (Map 4.4.2-10). The shorelines shown in the 1954 photo were mapped over a distance of 19.5 km (12.1 mi) and then were compared visually with those shown in the 2009 LWR imagery and the 1928 air photo. No measurable changes were observed between the 1954 and 2009 shorelines. No measurable changes were noted between the 1928 and 2009 shorelines, except for localized places where as much as 10 to 15 m (33–49 ft) of erosion (0.1–0.2 m/y [0.3–0.7 ft]) was observed.

Shorelines shown in the Nelson River Forestry imagery (based on 2011 air photos in this area) were mapped over a length of 16.3 km (10.1 mi) around a set of islands near the north shore of Cross Lake near the outlet (Map 4.4.2-11). These shorelines were compared visually with those shown in a 1979 air photo. Apart from some localized possible erosion up to 10 m (0.3 m/y [33 ft; 1 ft/y]) in magnitude, no other changes were detected between the 1979 and 2011 shorelines. Shorelines from the Nelson River Forestry imagery were also mapped in the central part of Cross Lake, north of Wapaskatkakow Narrows (Map 4.4.2-11). Shorelines were mapped over 14.2 km (8.8 mi) from the 2011 imagery on the north and south shores and on islands in this area. These shorelines were compared visually with those shown in a 1979 air photo. No changes were detected in the positions of the shorelines.




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 09-SEP-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Air Photo Mapping

**Erosion 1979-2015 (≥90 m)**

Erosion 1979-2015 (≥90 m)

**Historical shoreline**

2009

Generating Station (Existing)

First Nation Reserve

Transmission Line (Existing)

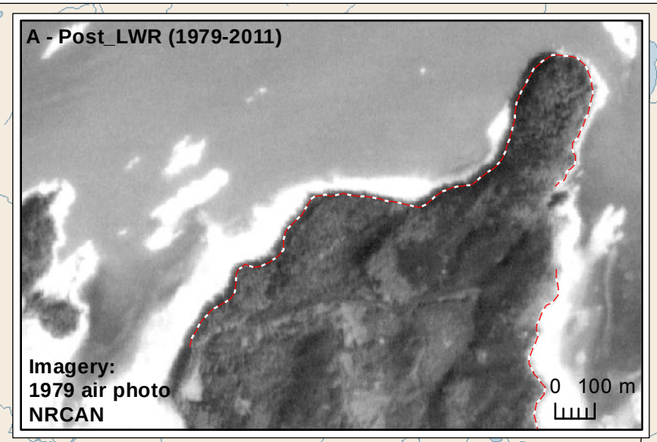
Highway

# Erosion Analysis Results

Hydraulic Zone 2

South Part of Cross Lake

**Map 4.4.2-10**




N

A

Cross Lake

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Erosion 1979-2015 (≥90 m)
First Nation Reserve
Air Photo Mapping

**Historical Shoreline**

2011

# Erosion Analysis Results

## Hydraulic Zone 2

## Central Part of Cross Lake

**Map 4.4.2-11**

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
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| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

Erosion 1979-2015 (≥90 m)

# Erosion Analysis Results

Hydraulic Zone 2

Walker Lake Area

**Map 4.4.2-12**

Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

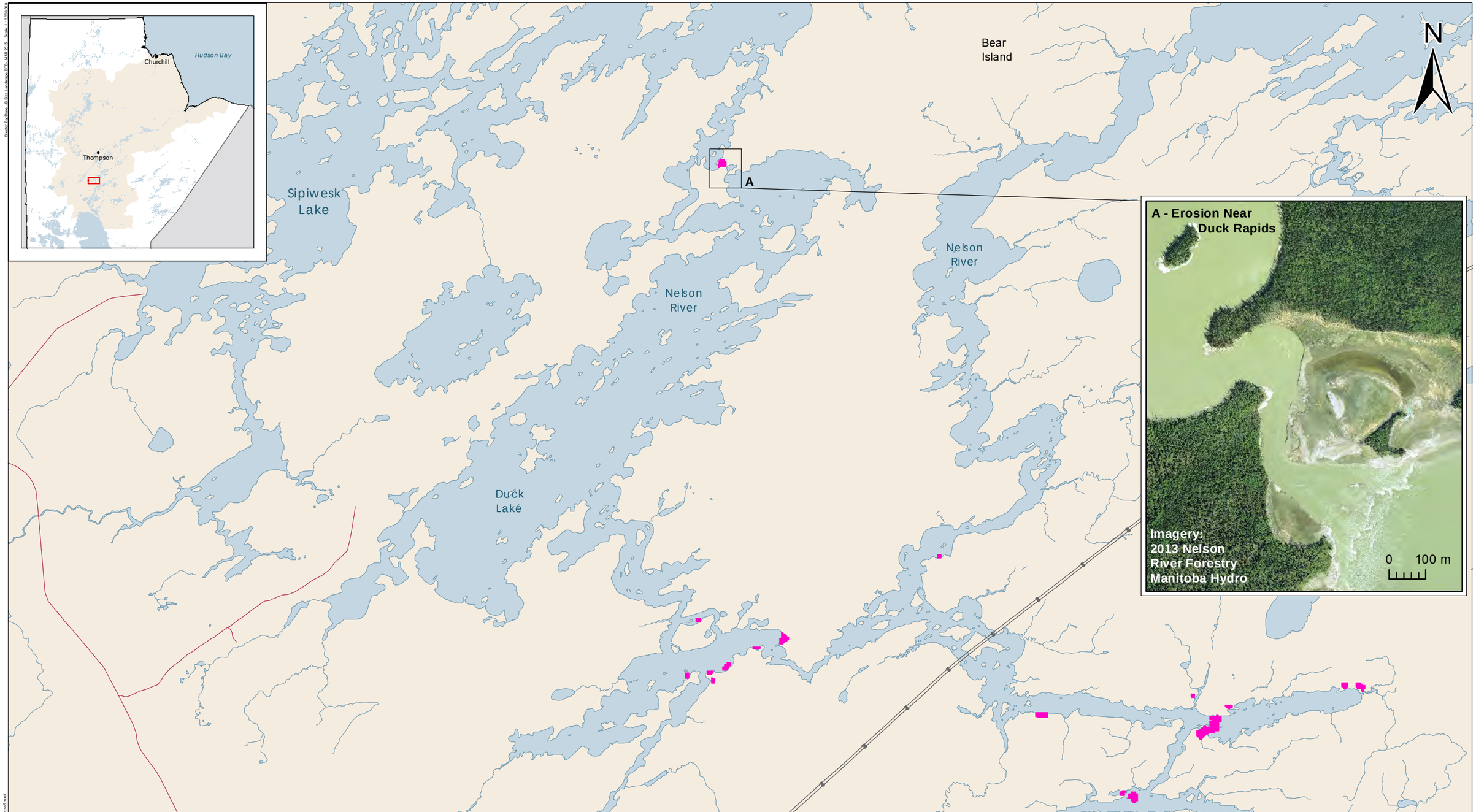
Erosion 1979-2015 (≥90 m)

# Erosion Analysis Results

Hydraulic Zone 2

North Part of Cross Lake

**Map 4.4.2-13**




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
United States Geological Survey
Government of Canada
Manitoba Hydro
Province of Manitoba

CREATED BY:
J.D. Mollard and Associates Limited

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 11-MAY-15 | 30-AUG-15 |
| 0 1 2 Kilometres / 0 0.95 1.9 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- Erosion 1979-2015 (≥90 m)
- Transmission Line (Existing)
- Transmission Line (Under Construction)
- Highway

# Erosion Analysis Results

## Hydraulic Zone 2

## Duck Lake Area

**Map 4.4.2-14**

**SUMMARY**

Hydraulic Zone 2 has an approximate water surface area of 895 $km^2$ (346 sq mi) and a shoreline of 4,613 km (2,866 mi) long. The zone includes Cross Lake, Pipestone Lake, Walker Lake and Duck Lake. The Cross Lake shoreline is particularly irregular, with large islands separating the lake into numerous basins and interconnecting channels. The lakeshore is dominated by low bedrock shorelines, some of which contain backshore overburden occasionally a few metres thick. The few overburden shorelines present on Cross Lake are characterized by alluvial silts deposited around small rock cores or lacustrine clays found in small bays.

Changes in water levels and flows in Cross Lake associated with LWR were expected to be insufficient to cause substantial erosion, and the main physical impacts expected after LWR were changes to shoreline vegetation due to the modified seasonal water level regime. No erosion problems had been reported up until record high water levels were observed in 2005, and then in 2011, when considerable erosion impacts resulted from the 2011 flood. Between June 2011 and the fall of 2012, Manitoba Hydro implemented a shore protection program along 4.4 km (2.7 mi) of waterfront at the community of Cross Lake.

Landsat analysis from 1979 and 2015 revealed a broad zone around the West Channel of the Nelson River where there has been a removal of low vegetation and perhaps mineral soil within a large number of low gradient shore zones. The only mineral erosion observed in Hydraulic Zone 2 from Landsat was at Duck Rapids, where a new channel was formed along the Nelson River.

Air photo analysis from 1928 to 2009 along the southern shore and islands of Cross Lake west of the Jenpeg GS indicated no measureable erosion except for localized places where as much as 10 to 15 m (33–49 ft) of erosion (0.1–0.2 m/y [0.3–0.7 ft]) was observed. Air photo analysis from 1979 to 2011 in the central part of Cross Lake indicated no measureable erosion apart from very localized places where as much as 10 m (0.3 m/y [33 ft; 1 ft/y]) was observed.

### 4.4.2.2.3 Sedimentation

**REVIEW OF INFORMATION ON SEDIMENTATION**

The data available for this zone is mostly obtained from the water quality studies conducted to meet the program requirements of LWCNRSB (1971–1975), FEMP (1986–1992), and most recently as a part of Coordinated Aquatic Monitoring Plan (CAMP, since 2007). It is apparent from the timeline of these studies that the available data is marked with temporal gaps of a decade or more.

Driver and Doan (1972) provided the earliest account of water transparency measurements in Cross Lake. Manitoba department of Mines, Resources and Environmental Management measured Secchi disk depths in 1965. The values ranged from 0.3 to 1.4 m (1.0–4.6 ft), with a mean value of 0.76 m (2.5 ft). Koshinsky (1973) noted that this average transparency in Cross Lake was higher than in outlet lakes farther upstream. However, he noted that considerably higher Secchi disc values were observed in the eastern portion of Cross Lake. The eastern portion of the lake is less subject to the influence of the Nelson River, which flows through the western end of the lake, and its shorelines are primarily bedrock-controlled. The average Secchi depth in the west part of the lake was lower, averaging about

0.53 m (1.7 ft (Morelli 1975)), closer to the values observed in the Outlet Lakes upstream. The average turbidity values in 1972 at Cross Lake and Eve's Rapids were 22 and 28 NTU respectively. The average NFR values in 1972 at Cross Lake and Eve's Rapids were 8.6 and 21.8 mg/L respectively.

Cleugh (1974) provided the results of measurements at Cross Lake in 1972–1973. The Secchi disk depths were in range of 0.3 to 0.7 m (1.0–2.3 ft) with a mean value of 0.5 m (1.6 ft). The TSS values ranged from 11 to 17 mg/L with a summer mean value of 14.8 mg/L. The peak TSS values were observed during July and August sampling periods.

Morelli (1975) summarized the pre-LWR development water quality data collected from 1972 to 1974. The turbidity at Cross Lake (Minago River mouth) varied from 2.5 to 27 NTU, with the exception of a high value of 110 NTU. The NFR values in Cross Lake varied from 0.1 to 36 mg/L, with a couple of very high values of 110 and 290 mg/L. The average turbidity and NFR values for Cross Lake, excluding non-characteristic high values, were 27 NTU and 36 mg/L respectively. The turbidity at Eve's Falls, at the outlet of Cross Lake, varied from 7.1 to 36 NTU with a mean value of 18.8 NTU, while the NFR concentrations varied from 0.1 to 27 mg/L with a mean value of 13.1 mg/L. The turbidity and NFR values were somewhat lower downstream at Bladder Rapids, with turbidity varying from 7.9 to 16 NTU and having a mean value of 13.0 NTU, while the NFR value varied from 5.5 to 14.4 mg/L with a mean value of 10.0 mg/L.

Gaboury and Patalas (1981) reported changes in turbidity of Cross Lake. The eastern basin of Cross Lake became less clear with a decrease in Secchi disk depth from 0.76 m (2.5 ft) in 1965 to 0.45 m (1.5 ft) in 1980, whereas the western part of Cross Lake became clearer with an increase in Secchi disk depth from 0.53 m (1.7 ft) in 1965 to 0.67 m (2.2 ft) in 1980. The authors attributed the higher turbidity in the east basin to the wind action re-suspending bottom sediments in this shallow basin (resulting from LWR), while the lower turbidity in west basin was attributed to the decreased flushing rate under Jenpeg regulation.

Gaboury and Patalas (1982) provided the mean Secchi disk and TSS values for the lakes in this zone during summer of 1981. The Secchi disk depth of 0.70 m (2.3 ft) on Cross Lake was somewhat less than the 0.83 m (2.7 ft) Secchi disk depth on Pipestone Lake, which is just upstream on the east reach of the Nelson River. On Walker Lake upstream from the east basin of Cross Lake, the Secchi disk depth was much greater at 2.78 m (9.1 ft). Whiskey Jack basin in west Cross Lake was an exception in this part of the lake with an average Secchi disk depth of 1.69 m. The TSS concentration in West Cross Lake ranged from 6–20 mg/L, while it was 34 mg/L in east Cross Lake, 23 mg/L in Pipestone Lake and less than 5 mg/L in Walker Lake.

Playle and Williamson (1986a) compared the turbidity data for the periods of 1972–1976 (before LWR) and 1976–1984 (after LWR). They concluded that the turbidity of Cross Lake increased from 5.7 to 8.4 NTU, whereas the NFR values decreased from 10 to 8 mg/L.

The FEMP was initiated in 1986 and Northwest Hydraulic Consultants were hired to provide a review of potential physical and ecological effects of increased sediment resulting from the CRD and LWR. Phase 1 of this two-phase study reviewed the pre and post-CRD/LWR sedimentation regime of its study area. The

findings of this study (Northwest Hydraulic Consultants Ltd. 1988) relevant to RCEA Hydraulic Zone 2 are given below:

- Cross Lake acts as one of the major potential sediment sinks on the Nelson River route between the Jenpeg and Kelsey GSs.
- Total sediment load transported from Lake Winnipeg to Cross Lake has not been greatly increased by LWR.
- No definitive information in historical studies on grain size distributions of suspended sediment or bedload.

Ramsey *et al*. (1989) compared pre and post-LWR water quality data including Secchi disk depths, turbidity and NFR values. The information obtained from this study relevant to RCEA is given below:

- The water clarity in terms of Secchi disk depths vary year to year. However, a generalized observation is a decrease in transparency after LWR. The Secchi disk depth varied from 0.45 m (1.5 ft) to 1.82 m (6 ft) with an average of 0.85 m (2.8 ft) after LWR, which is significantly less than the reported range of 1.5–2.5 m (4.9–8.2 ft) observed by Driver and Doan in 1965 (Driver and Doan 1972).
- Suspended sediment concentrations in 1985 and 1987 were at the low end of range measured in 1972–1973. The NFR measured in the mainstem of Cross Lake in 1985–1987 ranged from 7.7-8.8 mg/L as compared with a range of 8.6–14.8 mg/L in 1972–1973.
- Suspended sediment concentrations were much higher at the backwater stations (located in middle and eastern basin) than mainstem in 1985–1987.
- Turbidity measured in 1985–1987 ranged from 5.0–17.4 NTU with a mean value of 11.0 NTU.

The final FEMP water quality report by Ramsey (1991) provided a comprehensive assessment of changes in water quality parameters, including turbidity and suspended sediment concentrations as a result of LWR and CRD. This technical report concluded there were no significant changes in turbidity or NFR in Cross Lake when comparing the baseline data from 1972–1973 with the data collected as part of FEMP from 1987 to 1989 (Berger and Ramsey 1991).

Baker and Davies (1991) summarized the impacts of LWR and CRD on physical, chemical, and biological resources of the affected aquatic environment. The region of interest of this study comprised of the communities signatory to Northern Flood Agreement. The effects were qualitatively summarized after a comprehensive review of historic documents. The findings of this study relevant to the Cross Lake area are given below:

- No detailed pre-hydroelectric development information on sediment regime at Cross Lake is available.
- A fair amount of post-hydroelectric development information on sediment regime at Cross Lake is available.
- More rapid fluctuations in lake levels than would have occurred under natural conditions, and the effects of wind and wave action re-suspending sediments had, however, contributed to a higher sediment concentration in the water than existed prior to LWR.

A more recent ongoing sediment monitoring program was initiated on Walker Lake and Cross Lake near the community as part of the CAMP. Sediment data including suspended sediment load, discrete and

continuous turbidity, bedload, and bed material have been collected annually at Cross Lake and every three years at Walker Lake. The CAMP monitoring data from 2008 to 2011 is provided in the 2014 CAMP report (CAMP 2014). A summary of relevant data is given in Table 4.4.2-4.

Sediment samples were collected at Cross Lake from 2008 to 2010 to provide a general characterization of sediment type in nearshore and offshore aquatic habitats. At Cross Lake, sand comprised the majority of the sediments collected from the nearshore and silt comprised the majority of the offshore sediments.

**Table 4.4.2-4: Summary of 2008–2011 Coordinated Aquatic Monitoring Program (CAMP) Sediment Data on Cross Lake and Walker Lake**

| | Cross Lake | | Walker Lake | |
|---|---|---|---|---|
| | **Range (min–max)** | **mean** | **Range (min–max)** | **mean** |
| *In situ* Turbidity (NTU [1]) | 0.3–30.5 | 8.9 | 0.0–301.5 | 1.5 |
| Laboratory Turbidity (NTU) | 1.0–20.0 | 8.9 | 0.5–1.81 | 1.3 |
| Secchi disk depth (m) | 0.4–1.90 | 1.0 | 2.1–3.05 | 2.5 |
| Total Suspended Solids (mg/L) | 2.0–18.0 | 7.8 | <2.0-2.0 | 1.5 |

1. NTU = Nephelometric Turbidity Units.

In Walker Lake, offshore samples were collected in 2010 and sand comprised the majority of sediments. The nearshore bed consisted of cobbles and boulders with exposed bedrock, and therefore could not be sampled for the particle size analysis.

The results of particle size analysis of collected samples are provided in Map 4.4.2-15. Similar data has been collected in subsequent years; however this data has not yet been published.

## SUMMARY

Most of the water quality and sediment data for Hydraulic Zone 2, extending from Jenpeg GS to the just upstream of Sipiwesk Lake, was collected as part of three large studies: LWNCRSB (1972–1974), FEMP (1987–1989) and CAMP (since 2008). A few other studies collected data in the late 1970s and early 1980s to assess the effects of LWR on the water quality within this zone. A comparison of the most recent CAMP data and pre-LWR conditions along with review of previous assessments lead to the following general conclusions.

The average turbidity of overall Cross Lake increased from 5.7 NTU before LWR (1972–1976) to 8.9 NTU from (2008–2011). However, the east and west basins of Cross Lake had been affected in different ways as a result of LWR. Regulation caused a reduction in Cross Lake average open water levels. As a result, the shallower eastern basin became susceptible to the re-suspension of bottom sediments due to wind action causing reduced water clarity, whereas the flow regulation through Jenpeg decreased the flushing of sediment in west Cross Lake resulting in clearer west basin.The NFR values decreased after regulation having averaged 10 mg/L from 1972–1976 and 8 mg/L from 1976–1984 for Cross Lake. The TSS values collected from 2008–2011 averaged 7.8 mg/L.

Cross lake (Nearshore)

| | 2008 Samples | 2009 Samples | 2010 Samples |
|---|---|---|---|
| Clay : | 23.0 % | 28.0 - 31.0 % | 11.7 % |
| Silt : | 68.0 % | 66.0 - 71.0 % | 11.3 % |
| Sand : | 9.0 % | 1.0 - 6.0 % | 77.0 % |

Source: CAMP (2014)

Cross lake (Offshore)

| | 2010 Samples |
|---|---|
| Clay : | 28.0 - 44.0 % |
| Silt : | 54.2 - 63.8 % |
| Sand : | 1.36 - 8.18 % |

Source: CAMP (2014)

Cross lake (Offshore)

| | 2009 Samples |
|---|---|
| Cla | 23.0 - 25.0 % |
| Silt : | 65.0 - 75.0 % |
| Sand : | 3.0 - 10.0 % |

Source: CAMP (2014)

Cross lake (Offshore)

| | 2008 Samples |
|---|---|
| Clay : | 26.0 % |
| Silt : | 71.0 % |
| Sand : | 3.0 % |

Source: CAMP (2014)

Walker Lake (Offshore)

| | 2010 Samples |
|---|---|
| Clay : | 0.45 - 26.0 % |
| Silt : | 0.39 - 37.7 % |
| Sand : | 1.36 - 8.18 % |

Source: CAMP (2014)

N

Wabowden (NAC)
Wabowden
Ponton
Pimicikamak Cross Lake (NAC)
Cross Lake
Jenpeg G.S.
Kiskitto Control Structure
SIPIWESK LAKE
NELSON RIVER
CROSS LAKE
WALKER LAKE
PIPE STONE LAKE
KISKITTO LAKE
PLAYGREEN LAKE

Regional Cumulative Effects Assessment

DATA SOURCE: Government of Manitoba, Government of Canada, Manitoba Hydro

CREATED BY: Water Resources Engineering

COORDINATE SYSTEM: NAD 1983 UTM Zone 14N

DATE CREATED: 23-MAY-15

REVISION DATE: 03-DEC-15

VERSION NO: 1.0

QA/QC:

0 5 10 Kilometres
0 4 8 Miles

**Legend**

- RCEA Hydraulic Zones
- First Nation Reserve
- Transmission Line (Existing)
- Rail

# Hydraulic Zone 2

Post-Hydroelectric Development
General Substrate Distribution

**Map 4.4.2-15**

File Location: M:\RCEA\GIS\MXD\Phase_II\FINAL\RCEA_Phase_II_ES_Hydraulic_Zone2_Post_Dev_General_Substrate_Distrib.mxd

# 4.4.2.3 Hydraulic Zone 3 – Sipiwesk Lake to the Kelsey Generating Station

## 4.4.2.3.1 Hydraulic Zone 3 Overview

The upstream end of Hydraulic Zone 3 is where the two channels of the Nelson River enter Sipiwesk Lake and the zone extends downstream to the Kelsey GS, which was completed in 1961 just upstream of Split Lake. The major water body in this zone is Sipiwesk Lake. Although the Nelson River extends about 100 km (62 mi) from Sipiwesk to the Kelsey GS, flooding of the reservoir behind this dam raised upstream water levels as far upstream as Sipiwesk Lake. Thus, this zone was affected by hydroelectric development for about 15 years before LWR was implemented in 1976. Since LWR, this zone is influenced by the combined effects of upstream regulation at the Jenpeg GS and downstream regulation at the Kelsey GS.

## 4.4.2.3.2 Erosion

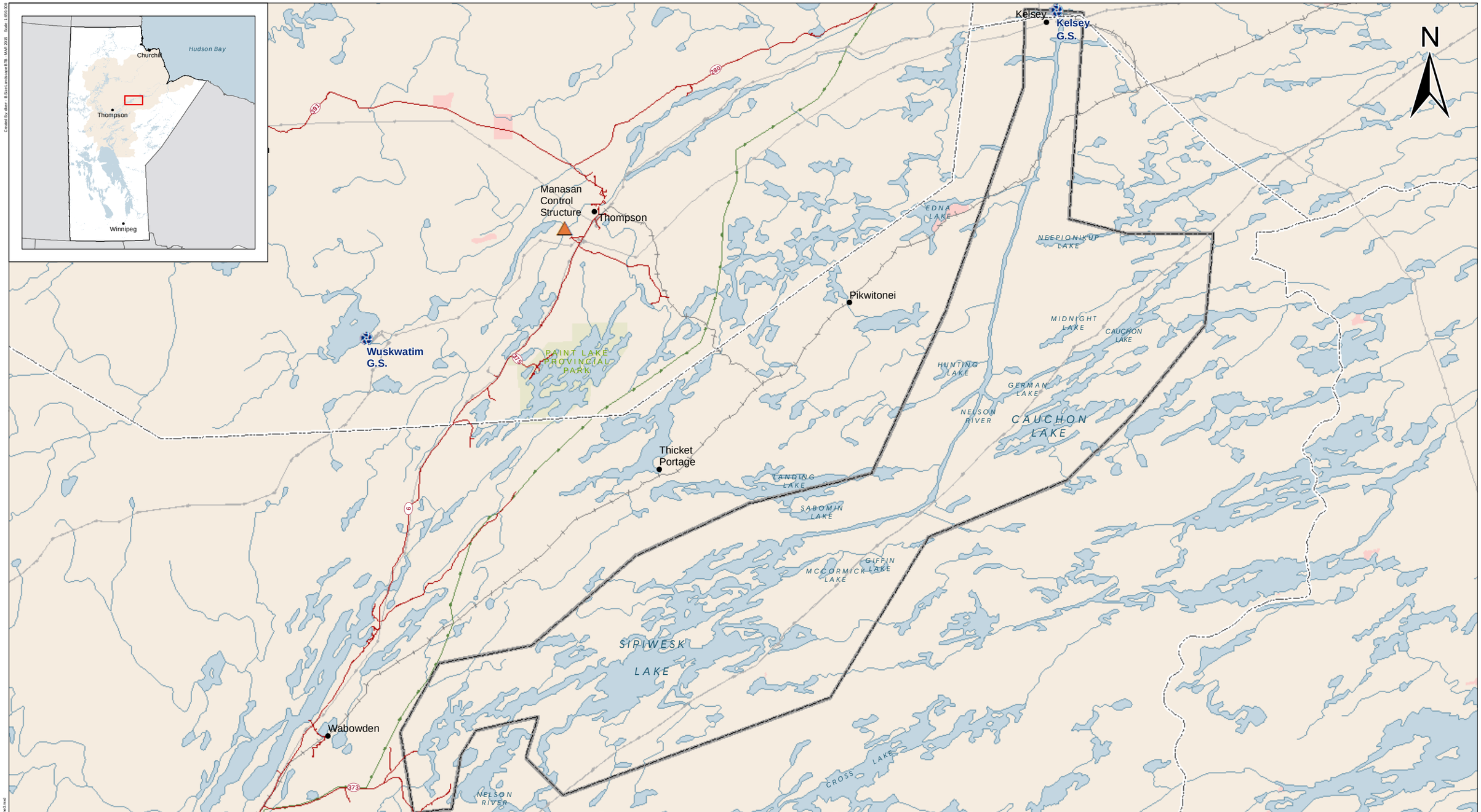
### TERRAIN AND SHORELINE CHARACTERISTICS

Hydraulic Zone 3 has an approximate water surface area of 869 $km^2$ (336 sq mi) and a shoreline 4,078 km (2,534 mi) long (Map 4.4.2-16). The zone is represented by Sipiwesk, Prud'homme and Cauchon lakes and the Kelsey forebay. The Kelsey forebay consists of the channel of the Nelson River, which follows a narrow, structurally controlled linear topographic low for 112 km (70 mi) upstream of the Kelsey GS. Prud'homme and Cauchon lakes connect with the Kelsey forebay about 65 km (40 mi) upstream of the generating station. Neither Sipiwesk Lake nor the Kelsey forebay were mapped during the LWCNRSB Physical Impact Study (Water Resources Branch 1974), but a mixture of bedrock, overburden and organic shorelines are present.

### REVIEW OF INFORMATION ON EROSION

The Kelsey GS impounded the Kelsey forebay and Sipiwesk Lake in the summer of 1960. Water levels on the Kelsey forebay were raised about 9.1 m (30 ft) while the average increase in water level on Sipiwesk Lake has been estimated between about 1.0–4.0 m (3.3–13.1 ft) depending on the information source (see Water Regime, Section 4.3.1.4.3).

The physical impacts around these waterbodies were observed in 1972 and reported on in Section 7 of the Physical Impact Study (Water Resources Branch 1974). The readjustment process on Sipiwesk Lake following construction of the Kelsey GS involved flooded vegetation and increased shoreline erosion and nearshore sedimentation, with erosion over about 50% of the shoreline. Readjustment of shorelines in the Kelsey forebay took several forms: erosion of till banks where the water had risen well above the previous stable shoreline, severe bank undercutting near the upper end of the channel, flooded vegetation, increased shoreline erosion with related nearshore sedimentation, and rapid erosion of mid-stream islands. Impacts were observed over 40% of the shoreline, where dead vegetation, erosion, and severe bank undercutting were observed. In addition, Sipiwesk Lake and the Kelsey forebay contained manyexamples of disappearing islands, floating peat islands and other floating peat features. The Physical Impact Study suggested that extreme water level fluctuations on Sipiwesk Lake were the main reason for the peatland disintegration observed throughout the lake (Water Resources Branch 1974).




Manitoba Hydro

Regional Cumulative Effects Assessment

DATA SOURCE:
Government of Manitoba, Government of Canada, Manitoba Hydro

CREATED BY:
Water Resources Engineering

| COORDINATE SYSTEM: | DATE CREATED: | REVISION DATE: |
|---|---|---|
| NAD 1983 UTM Zone 14N | 23-MAY-15 | 01-DEC-15 |
| 0 7.5 15 Kilometres / 0 6 12 Miles | VERSION NO: 1.0 | QA/QC: |

**Legend**

- RCEA Hydraulic Zones
- RCEA Region of Interest
- First Nation Reserve
- Manitoba Provincial Park
- Transmission Line (Existing)
- Rail

# Hydraulic Zone 3

**Map 4.4.2-16**

J.D. Mollard and Associates Limited (1992a) measured shoreline erosion rates around the farthest southwest bay of Sipiwesk Lake using historical air photos. Pre-hydroelectric development erosion measurements were made by comparing air photos acquired in 1930, 1946 and 1950. In this pre-hydroelectric development period, about half of the shoreline displayed erosion rates up to 0.5 m/y (1.6 ft), while the other half showed rates between 0.5 and 1.0 m/y (1.6–3.3 ft/y). Post-hydroelectric development erosion rates were measured between 1971 and 1978 air photos, with an average rate of 3.3 m/y (10.8 m/y). However, some concerns were expressed regarding the accuracy of post-hydroelectric development measurements, particularly regarding photo scale, photo quality, challenges with identifying the shoreline at some locations, and changes in water level between photos.

High water levels in 2011 are reported to have resulted in erosion on Sipiwesk Lake to a greater degree than on Cross Lake (Manitoba Hydro 2014b). This prompted Manitoba Hydro to undertake shore protection works at burial sites on Sipiwesk Lake in order to ensure that remains are not disturbed during high water events. Archaeological surveys have been underway in this area after a site believed to be the first trading post established by David Thompson while working for the Hudson's Bay Company was found on Sipiwesk Lake in 2010 (Redekop 2011).

## DATA ANALYSIS

### Landsat Analysis

The available Landsat images covering Sipiwesk Lake were inventoried and it was found that no cloud-free images from the 1970s and 2000s with equal water levels on Sipiwesk Lake could be found. An analysis was conducted using Landsat images from 1974 and 2014, but these images contained partial cloud cover and the erosion suggested in cloud-free areas was quite limited. Rather than formalizing the results of the Landsat analysis, a decision was made to proceed with air photo analysis. The air photo analysis summarized below, which covered west, central and east parts of Sipiwesk Lake, showed that maximum erosion was in the range of 40 to 60 m (131–200 ft) in the most actively eroding areas. In light of this finding, the need for a formal Landsat analysis was ruled out given its detection limit of 90 m. Note, however, that there are places around Sipiwesk Lake where the erosion of organic material has extended more than 90 m (300 ft) inland since the 1970s, and these areas could be delineated if a cloud-free recent image is eventually obtained that captures a water level that matches one of the cloud-free historical images. Also note that, since operation of the Kelsey GS began in summer 1960, Landsat analysis could not be used to document the erosion that occurred during the initial adjustment period in the first 10–12 years after development.

### Air Photo Analysis

Historical erosion was studied using air photos in the west, central and east parts of Sipiwesk Lake. The air photo analysis in the west part of the lake included pre- and post-Kelsey measurements, as well as measurements from post-LWR, whereas in the other two areas, no pre-hydroelectric development analyses were completed. Note that the development of the Kelsey GS would have played a much stronger role than LWR in initiating erosion in Hydraulic Zone 3. The historical air photos were aligned to the Nelson River Forestry imagery, which was based on air photos of two different ages. In the west part

of Sipiwesk Lake, the imagery was based on air photos from 2013, whereas the portion of the imagery covering the east part of the lake was based on 2011 air photos.

In the west part of Sipiwesk Lake (Map 4.4.2-17), air photos from 1930, 1954 and 1978 were analyzed. An air photo from 1954 was aligned to the 2013 imagery. Three air photos from 1930 were aligned to the georeferenced 1954 photo. The 1954 shorelines were mapped over a distance of 24.5 km (15.2 mi), and then were compared visually with those shown in the 1930 photos. As no changes were found between 1930 and 1954, the maximum rate of shoreline recession must have been less than about 0.2 m/y (0.7 ft/y) over this pre-hydroelectric development period. In the same area as described above, an air photo from 1978 was aligned to the 2013 imagery. Distances between the 2013 and the 1954 and 1978 shorelines were measured every 20 m (66 ft) along the 10.5 km (6.5 mi) of shoreline (526 measurement points). The 1978 and 2013 shorelines were within 5 m of one another at 14% of points, while at the remaining sites, average and maximum recession distances were 14.0 m (0.4 m/y [46 ft; 1.3 ft/y]) and 43.2 m (1.2 m/y [142 ft; 3.9 ft/y]), respectively. As construction of the Kelsey GS was completed in 1961, the analysis from 1978 to 2013 covers only a portion of the post-Kelsey period. To obtain an upper bound for the total amount of erosion that occurred in this area since development, the 1954 and 2013 shorelines were compared. The 1954 and 2013 shorelines were within 5 m (16.4 ft) of one another at 4% of measurement sites, while at the remainder, average and maximum recession distances were 24.0 m (0.4 m/y [79 ft; 1.3 ft/y]) and 64.8 m (1.1 m/y [213 ft; 3.6 ft/y]), respectively. In summary, the maximum shoreline recession rate observed from 1930 to 1954 must have been less than about 0.2 m/y (0.7 ft), while following impoundment the long-term erosion rates in this area have averaged around 0.4 m/y (1.3 ft) with a maximum of about 1.0 m/y (3.3 ft).

In the central part of Sipiwesk Lake (Map 4.4.2-18), air photo mapping of shorelines was carried out along channels north and south of Bear Island. In addition, a set of islands situated east of these channels was also analyzed to obtain an indication for erosion rates in an open part of the lake. Shorelines shown in the Nelson River imagery (based on 2011 and 2013 air photos) were mapped over a distance of 22.0 km (13.7 mi) along the channel north of Bear Island. These shorelines were compared visually with those shown in a georeferenced 1979 air photo. Essentially all of the changes were below detection. The few places where erosion was detected were located in the furthest east part of the channel, where the channel merges with an open part of the lake and where the maximum amount of erosion was about 20 m (66 ft) between 1979 and 2011 (0.6 m/y [2.0 ft/y]). Along the channel south of Bear Island, shorelines were mapped from the Nelson River Forestry imagery (based on 2011 and 2013 air photos) over a distance of 21.6 km (13.4 mi), and these shorelines were compared visually with those shown in a 1979 air photo. Over the majority of this area, the changes were below detection. Only at the eastern limit of this area where the channel spills into the lake were any measureable changes observed, with maximum recession amounts of about 30 m (100 ft) observed at exposed points between 1979 and 2011 (0.9 m/y [3.0 ft/y]). In the open part of the lake to the east of the channels mentioned above, shorelines around a set of islands were mapped from the 2011 imagery and from a 1976 air photo over a distance of 26.6 km (16.5 mi). Measurements were made between the two shorelines at intervals of 20 m (66 ft: 1,328 points). The shorelines were within 5 m (16.4 ft) of one another at 6% of points, whereas at the other points, mean and maximum recession amounts were 14.9 m (0.4 m/y [49 ft; 1.3 ft/y]) and 54.9 m (1.6 m/y [180 ft; 5.2 ft/y]), respectively. In summary, the air photo analysis in the central part of Sipiwesk Lake revealed that post-Kelsey erosion rates were below detection in the channels north and south of

Bear Island, whereas average erosion rates of 0.4 m/y (1.3 ft/y) were observed on a set of islands in an open part of the lake situated east of the channels.

In the east part of Sipiwesk Lake (Map 4.4.2-19), 34.1 km (21.2 mi) of shoreline around a set of islands in an open part of the lake were mapped from the 2011 imagery. Shorelines shown in a georeferenced 1976 air photo were also mapped, and measurements were made between the two shorelines at intervals of 20 m (66 ft; 1,680 points). At 6% of measurement points, shorelines were separated by less than 5 m (16.4 ft), whereas at the remaining points the mean and maximum recession amounts were 14.8 m (0.4 m/y [49 ft; 1.3 ft/y]) and 61.5 m (1.8 m/y [202 ft; 5.9 ft/y]), respectively. A band of standing dead trees was noted near the shoreline in many places within this set of islands in the September 2011 imagery. The most likely explanation for this band of dead trees would be the high water levels that occurred between July and October 2005. In addition, high water levels in January 2011, between June and September 2011, and in August and September 2014 likely contributed to the expansion of these bands of standing dead trees.

## SUMMARY

Hydraulic Zone 3 has an approximate water surface area of 869 $km^2$ (336 sq mi) and a shoreline 4,078 km (2,534 mi) long. The zone is represented by Sipiwesk, Prud'homme and Cauchon lakes and the Kelsey forebay. The Kelsey forebay is contained within the narrow, structurally controlled channel of the Nelson River for 112 km (70 mi) upstream of the Kelsey GS. Prud'homme and Cauchon lakes connect with the Kelsey forebay about 65 km (40 mi) upstream of the generating station. A mixture of bedrock, overburden and organic shorelines are present within the Kelsey forebay and Sipiwesk Lake.

The Physical Impact Study (Water Resources Branch 1974) provided a qualitative description of erosional impacts observed as of 1972 around Sipiwesk Lake and the Kelsey forebay. Shoreline erosion, flooded vegetation, floating peat islands and other floating peat features were observed throughout the area.

Pre-hydroelectric development air photos were analyzed in the westernmost part of Sipiwesk Lake. No measurable erosion was observed between 1930 and 1954 over the 24.5 km (15.2 mi) of shoreline examined. Air photo analysis from 1976, 1978 and 1979 to 2011 or 2013 over about 115 km (72 mi) of shoreline in the west, central and east parts of Sipiwesk Lake indicated an average erosion rate of 0.4 m/y (1.3 ft/y), with maximums ranging from 1.2 to 1.8 m/y (3.9–5.9 ft/y). Thus, there has been a clear increase in erosion rates following development of the Kelsey GS.

More recent high water levels have resulted in considerable erosion around Sipiwesk Lake, prompting Manitoba Hydro to undertake shore protection works at burial sites on the lake. Bands of dead standing trees near shorelines are visible in the September 2011 imagery, and it is suspected that these bands were caused by high water levels observed between July and October 2005. In addition, high water levels in January 2011, between June and September 2011, and in August and September 2014 likely increased the number of standing dead trees around Sipiwesk Lake.

### 4.4.2.3.3 Sedimentation

**REVIEW OF INFORMATION ON SEDIMENTATION**

Crowe (1973) conducted a limnological survey of Kettle reservoir and the Nelson River between Prud'homme Lake and Kelsey in 1972. Due to high silt load, the Secchi disk depth rarely exceeded 0.45 m (1.5 ft) and the turbidity values ranged from 13–15 NTU.

Cleugh (1974) provided the results of water quality measurements in the Nelson River measured at the outlet of Sipiwesk Lake and above Kelsey GS in 1972/73. The Secchi disk depth at the outlet of Sipiwesk Lake ranged from 0.3 to 0.7 m (1.0–2.3 ft) with a mean value of 0.5 m (1.6 ft), while the TSS values ranged from 7–16 mg/L with a mean of 9.4 mg/L. The mean TSS value in summer was 10 mg/L, which was somewhat higher than the mean of 7 mg/L in winter. The Secchi disk depths above Kelsey GS were similar to those at the outlet of Sipiwesk Lake, ranging from 0.2 to 0.9 m (0.7–3.0 ft) with a mean value of 0.5 m (1.6 ft). The TSS values, however, were higher and ranged from 10 to 25 mg/L with a mean annual value of 17.6 mg/L. The mean TSS values were higher in summer at 19.2 mg/L as compared with 13 mg/L in winter.

Hecky and Harper (1974) reported lower suspended sediment concentrations of 5 mg/L in Sipiwesk Lake during the open water season of 1973.

Morelli (1975) summarized the pre-LWR water quality data collected in the Kelsey reservoir and Sipiwesk Lake between 1972 and 1974. The turbidity in Sipiwesk Lake varied from 1.1–23 NTU with a mean value of 11.1 NTU, while the NFR value varied from 1.2–23.2 mg/L with a mean value of 10.9 mg/L. The turbidity in Kelsey forebay varied from 1.4–27 NTU with a mean value of 9.1 NTU, which was similar to the values on Sipiwesk Lake. The observed NFR values were lower, varying from 2.0–13.6 mg/L with a mean value of 6.5 mg/L.

Playle and Williamson (1986) investigated the effects of CRD and LWR on water quality by comparing the water chemistry data for the pre-LWR period from 1972–1976 and the post-LWR period from 1976–1984. The authors found there was no significant change in the turbidity of Sipiwesk Lake due to LWR. The turbidity value after mid-1976 averaged 8.6 NTU compared with 8.3 NTU before mid-1976.

The FEMP was initiated in 1986 and Northwest Hydraulic Consultants were hired to provide a review of potential physical and ecological effects of increased sediment resulting from CRD and LWR. The findings from Phase I of this report (Northwest Hydraulic Consultants Ltd. 1988) relevant to RCEA Hydraulic Zone 3 are given below:

- Sipiwesk Lake acts as one of the major potential sediment sinks on the Nelson River route between Jenpeg GS and Kelsey GS. There are no field observations of sediment deposition in Sipiwesk Lake.
- Sediment load transported from Lake Winnipeg to Sipiwesk Lake has not been greatly increased by Lake Winnipeg Regulation.

No definitive information on grain size distributions of suspended sediment or bedload was found.