PART IV: PHYSICAL ENVIRONMENT
REGIONAL CUMULATIVE EFFECTS ASSESSMENT
PART IV
PHYSICAL ENVIRONMENT
TABLE OF CONTENTS

**4.0 PHYSICAL ENVIRONMENT** ................................................................. 4-1

**4.1 INTRODUCTION** .............................................................................. 4-1

**4.2 WATER REGIME** ............................................................................ 4-2

**4.2.1 Zone 1 - Outlet Lakes Area** ....................................................... 4-6

- **4.2.1.1 Manitoba Hydro Operations** .............................................. 4-6
- **4.2.1.2 Data** .................................................................................. 4-7
- **4.2.1.3 Jenpeg Forebay** ................................................................. 4-7
- **4.2.1.4 Lake Winnipeg Total Outflow** .......................................... 4-8
- **4.2.1.5 Kiskitogisu Lake** ............................................................... 4-9
- **4.2.1.6 Playgreen Lake** ................................................................. 4-10
- **4.2.1.7 Nelson River East Channel** .............................................. 4-12
- **4.2.1.8 Kiskitto Lake** ................................................................. 4-12
- **4.2.1.9 Ice Conditions** ................................................................. 4-13

**4.2.2 Zone 2 - Cross Lake and Surrounding Area** .............................. 4-15

- **4.2.2.1 Manitoba Hydro Operations** .............................................. 4-15
- **4.2.2.2 Data** .................................................................................. 4-15
- **4.2.2.3 Cross Lake** ....................................................................... 4-15
- **4.2.2.4 Cross Lake Weir Project** ................................................. 4-16
- **4.2.2.5 Pipestone, Walker, and Duck Lakes** ............................... 4-17
- **4.2.2.6 Ice Conditions** ................................................................. 4-18

**4.2.3 Zone 3 - Sipiwesk Lake to Kelsey GS** ......................................... 4-20

- **4.2.3.1 Manitoba Hydro Operations** .............................................. 4-20
- **4.2.3.2 Data** .................................................................................. 4-20
- **4.2.3.3 Kelsey GS** ....................................................................... 4-21
- **4.2.3.4 Sipiwesk Lake** ................................................................. 4-22
- **4.2.3.5 Ice Conditions** ................................................................. 4-23

**4.2.4 Zone 4 - Leaf Rapids to Southern Indian Lake** ............................ 4-25

- **4.2.4.1 Manitoba Hydro Operations** .............................................. 4-25
- **4.2.4.2 Data** .................................................................................. 4-25
- **4.2.4.3 Southern Indian Lake** ...................................................... 4-25
- **4.2.4.4 Ice Conditions** ................................................................. 4-26
4.2.5 Zone 5 - Lower Churchill River ................................................................. 4-28
  4.2.5.1 Manitoba Hydro Operations .......................................................... 4-28
  4.2.5.2 Data .............................................................................................. 4-28
  4.2.5.3 Lower Churchill River Discharge .................................................. 4-28
  4.2.5.4 Churchill Weir ............................................................................. 4-28
  4.2.5.5 Ice Conditions ............................................................................. 4-28

4.2.6 Zone 6 - South Bay Channel to Notigi Control Structure ................. 4-31
  4.2.6.1 Manitoba Hydro Operations ........................................................ 4-31
  4.2.6.2 Data .............................................................................................. 4-31
  4.2.6.3 Isset Lake - Rat Lake - Notigi Forebay Area .................................. 4-31
  4.2.6.4 Ice Conditions ............................................................................. 4-31

4.2.7 Zone 7 - Notigi Control Structure to Early Morning Rapids ............. 4-35
  4.2.7.1 Manitoba Hydro Operations ........................................................ 4-35
  4.2.7.2 Data .............................................................................................. 4-35
  4.2.7.3 Footprint Lake .............................................................................. 4-35
  4.2.7.4 Ice Conditions ............................................................................. 4-35

4.2.8 Zone 8 - Early Morning Rapids to Wuskwatim GS ......................... 4-38
  4.2.8.1 Manitoba Hydro Operations ........................................................ 4-38
  4.2.8.2 Data .............................................................................................. 4-38
  4.2.8.3 Wuskwatim GS and Lake .............................................................. 4-38
  4.2.8.4 Ice Conditions ............................................................................. 4-38

4.2.9 Zone 9 - Wuskwatim GS to Split Lake Inlet ....................................... 4-40
  4.2.9.1 Manitoba Hydro Operations ........................................................ 4-40
  4.2.9.2 Data .............................................................................................. 4-40
  4.2.9.3 Manasan Fall Control Structure .................................................. 4-40
  4.2.9.4 Ice Conditions ............................................................................. 4-40

4.2.10 Zone 10 - Split Lake to Gull Rapids ............................................... 4-43
  4.2.10.1 Manitoba Hydro Operations ....................................................... 4-43
  4.2.10.2 Data .............................................................................................. 4-43
  4.2.10.3 Split Lake ..................................................................................... 4-43
  4.2.10.4 Ice Conditions ............................................................................. 4-44

4.2.11 Zone 11 - Stephens Lake to Limestone GS ...................................... 4-46
  4.2.11.1 Manitoba Hydro Operations ....................................................... 4-46
4.2.11.2 Data ................................................................................................. 4-46
4.2.11.3 Stephens Lake / Kettle Forebay .................................................. 4-46
4.2.11.4 Long Spruce Forebay .................................................................. 4-46
4.2.11.5 Limestone Forebay ..................................................................... 4-47
4.2.11.6 Ice Conditions ............................................................................. 4-47
4.2.12 Zone 12 - Limestone GS to Gillam Island ...................................... 4-50
4.2.12.1 Manitoba Hydro Operations ...................................................... 4-50
4.2.12.2 Data .............................................................................................. 4-50
4.2.12.3 Limestone to Gillam Island .......................................................... 4-50
4.2.12.4 Ice Conditions ............................................................................. 4-50
4.2.13 Scientific References ....................................................................... 4-52
4.3 EROSION AND SEDIMENTATION ....................................................... 4-54
4.3.1 Overview of Major Studies ............................................................... 4-57
  4.3.1.1 Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) ..................................................................................... 4-57
  4.3.1.2 Federal Ecological Monitoring Program (FEMP) ....................... 4-57
  4.3.1.3 Split Lake Cree - Manitoba Hydro Joint Studies ....................... 4-58
  4.3.1.4 Environmental Impact Statement Studies .................................. 4-58
  4.3.1.5 Coordinated Aquatic Monitoring Program (CAMP) .................. 4-58
4.3.2 Zone 1 - Outlet Lakes Area ............................................................... 4-59
  4.3.2.1 Area Overview ............................................................................. 4-59
  4.3.2.2 Erosion ....................................................................................... 4-59
  4.3.2.3 Sedimentation ........................................................................... 4-60
4.3.3 Zone 2 - Cross Lake and Surrounding Area ..................................... 4-63
  4.3.3.1 Area Overview ............................................................................. 4-63
  4.3.3.2 Erosion ....................................................................................... 4-63
  4.3.3.3 Sedimentation ........................................................................... 4-63
4.3.4 Zone 3 - Sipiwas Lake to Kelsey GS .................................................. 4-66
  4.3.4.1 Area Overview ............................................................................. 4-66
  4.3.4.2 Erosion ....................................................................................... 4-66
  4.3.4.3 Sedimentation ........................................................................... 4-67
4.3.5 Zone 4 - Leaf Rapids to Southern Indian Lake ................................... 4-69
  4.3.5.1 Area Overview ............................................................................. 4-69
  4.3.5.2 Erosion ....................................................................................... 4-69
4.3.5.3 Sedimentation................................................................. 4-71

4.3.6 Zone 5 - Lower Churchill River............................................. 4-74
  4.3.6.1 Area Overview................................................................. 4-74
  4.3.6.2 Erosion .............................................................................. 4-74
  4.3.6.3 Sedimentation................................................................. 4-74

4.3.7 Zone 6 - South Bay Channel to Notigi Control Structure ........ 4-77
  4.3.7.1 Area Overview................................................................. 4-77
  4.3.7.2 Erosion .............................................................................. 4-77
  4.3.7.3 Sedimentation................................................................. 4-77

4.3.8 Zone 7 - Notigi Control Structure to Early Morning Rapids .... 4-80
  4.3.8.1 Area Overview................................................................. 4-80
  4.3.8.2 Erosion .............................................................................. 4-80
  4.3.8.3 Sedimentation................................................................. 4-82

4.3.9 Zone 8 - Early Morning Rapids to Wuskwatim GS ............... 4-85
  4.3.9.1 Area Overview................................................................. 4-85
  4.3.9.2 Erosion .............................................................................. 4-85
  4.3.9.3 Sedimentation................................................................. 4-87

4.3.10 Zone 9 - Wuskwatim GS to Split Lake Inlet ....................... 4-90
  4.3.10.1 Area Overview............................................................... 4-90
  4.3.10.2 Erosion ............................................................................. 4-90
  4.3.10.3 Sedimentation............................................................... 4-91

4.3.11 Zone 10 - Split Lake to Gull Rapids ................................. 4-95
  4.3.11.1 Area Overview............................................................... 4-95
  4.3.11.2 Erosion ............................................................................. 4-95
  4.3.11.3 Sedimentation............................................................... 4-96

4.3.12 Zone 11 - Stephens Lake to Limestone GS ....................... 4-100
  4.3.12.1 Area Overview............................................................... 4-100
  4.3.12.2 Erosion ............................................................................. 4-100
  4.3.12.3 Sedimentation............................................................... 4-101

4.3.13 Zone 12 - Limestone GS to Gillam Island ......................... 4-104
  4.3.13.1 Area Overview............................................................... 4-104
  4.3.13.2 Erosion ............................................................................. 4-104
  4.3.13.3 Sedimentation............................................................... 4-106
4.3.14 Scientific References ................................................................. 4-109
  4.3.14.1 Erosion References ............................................................... 4-109
  4.3.14.2 Sedimentation References .................................................... 4-116
LI ST OF TABLES

Table 4-1: Summary of Hydroelectric Developments along the Churchill and Nelson Rivers................. 4-3

LI ST OF FIGURES

Figure 4-1: Jenpeg Forebay Daily Water Level Duration Curve............................................................ 4-8
Figure 4-2: Monthly Average Lake Winnipeg Total Outflow ................................................................. 4-9
Figure 4-3: Monthly Average Kiskittogisu Lake Water Levels............................................................... 4-10
Figure 4-4: Correlation Between Water Levels at Stations 05UB001 and 05UB005................................. 4-11
Figure 4-5: Monthly Average Nelson River East Channel at Norway House Water Levels................ 4-11
Figure 4-6: Kiskitto Lake Daily Water Level Duration Curve Compared to Natural Range from LWCNRSB 1975 Report ...................................................................................................... 4-12
Figure 4-7: Monthly Average Cross Lake Water Levels........................................................................ 4-16
Figure 4-8: Monthly Average Cross Lake Water Levels During High Flow Years................................ 4-17
Figure 4-9: Kelsey Forebay Daily Water Level Duration Curve.............................................................. 4-21
Figure 4-10: Monthly Average Kelsey Discharge .................................................................................. 4-22
Figure 4-11: Monthly Average Sipiwes Lake Water Levels................................................................. 4-23
Figure 4-12: Monthly Average Southern Indian Lake Water Levels...................................................... 4-26
Figure 4-13: Monthly Average Churchill River Below Fidler Lake Discharge ........................................ 4-29
Figure 4-14: Monthly Average Churchill River Above Red Head Rapids Discharge............................ 4-29
Figure 4-15: Monthly Average Notigi Forebay Water Levels............................................................... 4-32
Figure 4-16: Monthly Average Notigi Discharge .................................................................................. 4-32
Figure 4-17: Notigi Discharge Duration Curve ..................................................................................... 4-33
Figure 4-18: Monthly Average Footprint Lake Water Levels.................................................................. 4-36
Figure 4-19: Footprint Lake Water Level Duration Curve ................................................................. 4-36
Figure 4-20: Monthly Average Burntwood River Near Thompson Discharge ...................................... 4-41
Figure 4-21: Monthly Average Split Lake Water Level ........................................................................ 4-44
Figure 4-22: Kettle Forebay Daily Water Level Duration Curve ......................................................... 4-47
Figure 4-23: Long Spruce Forebay Daily Water Level Duration Curve .............................................. 4-48
Figure 4-24: Limestone Forebay Daily Water Level Duration Curve ................................................ 4-48
# LIST OF MAPS

<table>
<thead>
<tr>
<th>Map 4-1:</th>
<th>RCEA Hydraulic Zones</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map 4-2:</td>
<td>Zone 1 - Outlet Lakes Area - RCEA Area 1</td>
<td>4-14</td>
</tr>
<tr>
<td>Map 4-3:</td>
<td>Zone 2 - Cross Lake and Surrounding Area - RCEA Area 1</td>
<td>4-19</td>
</tr>
<tr>
<td>Map 4-4:</td>
<td>Zone 3 - Sipiwesk Lake to Kelsey G.S. - RCEA Area 1</td>
<td>4-24</td>
</tr>
<tr>
<td>Map 4-5:</td>
<td>Zone 4 - Leaf Rapids to Southern Indian Lake - RCEA Area 3</td>
<td>4-27</td>
</tr>
<tr>
<td>Map 4-6:</td>
<td>Zone 5 - Lower Churchill River - RCEA Area 4</td>
<td>4-30</td>
</tr>
<tr>
<td>Map 4-7:</td>
<td>Zone 6 - South Bay to Notigi Control Structure - RCEA Area 3</td>
<td>4-34</td>
</tr>
<tr>
<td>Map 4-8:</td>
<td>Zone 7 - Notigi Control Structure to Early Morning Rapids - RCEA Area 3</td>
<td>4-37</td>
</tr>
<tr>
<td>Map 4-9:</td>
<td>Zone 8 - Early Morning Rapids to Wuskwatim G.S. - RCEA Area 3</td>
<td>4-39</td>
</tr>
<tr>
<td>Map 4-10:</td>
<td>Zone 9 - Wuskwatim G.S. to Split Lake Inlet - RCEA Area 3</td>
<td>4-42</td>
</tr>
<tr>
<td>Map 4-11:</td>
<td>Zone 10 - Split Lake to Gull Rapids - RCEA Area 2</td>
<td>4-45</td>
</tr>
<tr>
<td>Map 4-12:</td>
<td>Zone 11 - Stephens Lake to Limestone G.S. - RCEA Area 2</td>
<td>4-49</td>
</tr>
<tr>
<td>Map 4-13:</td>
<td>Zone 12 - Limestone G.S to Gillam Island - RCEA Area 2</td>
<td>4-51</td>
</tr>
<tr>
<td>Map 4-14:</td>
<td>RCEA Erosion and Sedimentation Zones</td>
<td>4-56</td>
</tr>
<tr>
<td>Map 4-15:</td>
<td>RCEA Erosion and Sedimentation Zone 1</td>
<td>4-62</td>
</tr>
<tr>
<td>Map 4-16:</td>
<td>RCEA Erosion and Sedimentation Zone 2</td>
<td>4-65</td>
</tr>
<tr>
<td>Map 4-17:</td>
<td>RCEA Erosion and Sedimentation Zone 3</td>
<td>4-68</td>
</tr>
<tr>
<td>Map 4-18:</td>
<td>RCEA Erosion and Sedimentation Zone 4</td>
<td>4-73</td>
</tr>
<tr>
<td>Map 4-19:</td>
<td>RCEA Erosion and Sedimentation Zone 5</td>
<td>4-76</td>
</tr>
<tr>
<td>Map 4-20:</td>
<td>RCEA Erosion and Sedimentation Zone 6</td>
<td>4-79</td>
</tr>
<tr>
<td>Map 4-21:</td>
<td>RCEA Erosion and Sedimentation Zone 7</td>
<td>4-84</td>
</tr>
<tr>
<td>Map 4-22:</td>
<td>RCEA Erosion and Sedimentation Zone 8</td>
<td>4-89</td>
</tr>
<tr>
<td>Map 4-23:</td>
<td>RCEA Erosion and Sedimentation Zone 9</td>
<td>4-94</td>
</tr>
<tr>
<td>Map 4-24:</td>
<td>RCEA Erosion and Sedimentation Zone 10</td>
<td>4-99</td>
</tr>
<tr>
<td>Map 4-25:</td>
<td>RCEA Erosion and Sedimentation Zone 11</td>
<td>4-103</td>
</tr>
<tr>
<td>Map 4-26:</td>
<td>RCEA Erosion and Sedimentation Zone 12</td>
<td>4-108</td>
</tr>
</tbody>
</table>
## ACRONYMS, ABBREVIATIONS AND UNITS

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<thead>
<tr>
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<th>Term/Unit</th>
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<tr>
<td>%</td>
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</tr>
<tr>
<td>AEMP</td>
<td>Aquatic Effects Monitoring Plan</td>
</tr>
<tr>
<td>CAMP</td>
<td>Coordinated Aquatic Monitoring Program</td>
</tr>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>cms</td>
<td>cubic metres per second</td>
</tr>
<tr>
<td>CRD</td>
<td>Churchill River Diversion</td>
</tr>
<tr>
<td>CS</td>
<td>Control Structure</td>
</tr>
<tr>
<td>DFO</td>
<td>Department of Fisheries and Oceans</td>
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<tr>
<td>EIS</td>
<td>Environmental impact statement</td>
</tr>
<tr>
<td>et al.</td>
<td>and others</td>
</tr>
<tr>
<td>FEMP</td>
<td>Federal Ecological Monitoring Program</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GS</td>
<td>Generating Station</td>
</tr>
<tr>
<td>i.e.</td>
<td>in other words</td>
</tr>
<tr>
<td>km</td>
<td>kilometre</td>
</tr>
<tr>
<td>km²</td>
<td>square kilometre</td>
</tr>
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<td>LWCNRSB</td>
<td>Lake Winnipeg, Churchill and Nelson Rivers Study Board</td>
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</tr>
<tr>
<td>m</td>
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</tr>
<tr>
<td>m/y</td>
<td>metre per year</td>
</tr>
<tr>
<td>m³</td>
<td>cubic metre</td>
</tr>
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<td>cubic metre per metre</td>
</tr>
<tr>
<td>MB</td>
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</tr>
<tr>
<td>MCWS</td>
<td>Manitoba Conservation and Water Stewardship</td>
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<td>MEMP</td>
<td>Manitoba Ecological Monitoring Program</td>
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<tr>
<td>MW</td>
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</tr>
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<td>Northern Flood Agreement</td>
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<td>NHP</td>
<td>National Hydrometric Program</td>
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<tr>
<td>PEMP</td>
<td>Physical Environment Monitoring Program</td>
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<td>Term/ Unit</td>
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<td>-----------------------</td>
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<tr>
<td>RCEA</td>
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<td>Total Suspended Solids</td>
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<td>WPLP</td>
<td>Wuskwatim Power Limited Partnership</td>
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</tr>
</tbody>
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4.3 EROSION AND SEDIMENTATION

This section summarizes the available studies to date on the effect of hydroelectric development on shoreline erosion and sedimentation processes in the RCEA Region of Interest.

The RCEA Region of Interest covers an area known as the outlet lakes (downstream of the Lake Winnipeg outlet), the Rat/ Burntwood River system and parts of the Churchill and Nelson rivers watersheds. The water regime in these areas was affected by the construction of hydroelectric generating stations and the LWR and the CRD projects. Flooding and changes to the water regime (water depth and velocity) can initiate scouring, slumping, nearshore downcutting, peatland disintegration, and shoreline recession at locations that are susceptible to shoreline erosion processes (i.e., shoreline is not bedrock controlled). As the eroded and disintegrated mineral and organic material and the resurfaced peat enter the waterway, they contribute to sedimentation processes, which includes entrainment, transportation, deposition and compaction of sediment in the waterway.

The RCEA Region of Interest for erosion and sedimentation is divided into 12 zones, similar to the water regime study area, because changes to the water regime are the primary drivers for changes to the erosion and sedimentation regime. These 12 zones are shown in Map 4-14. Zones 1, 2 and 3 are within the RCEA Area 1; zones 10, 11 and 12 are within the RCEA Area 2; zones 4, 6, 7, 8 and 9 are within the RCEA Area 3; and zone 5 is in the RCEA Area 4 (see Map 1-4).

The effect of hydroelectric development on shoreline erosion and sedimentation processes in the RCEA Region of Interest will be assessed in two phases. The purpose of Phase I is to inventory the studies on erosion and sedimentation in each zone and to provide some indication as to the types and extent of physical impacts associated with hydroelectric development. Efforts have been made to include all relevant studies, but in some cases, there may be additional studies that have not been reviewed at the time of submitting the Phase I report. The Phase I report consists of the review of erosion and sedimentation information available in the RCEA Region of Interest and provides a synthesis of the existing studies in this area. The Phase I study methodology consists of the following steps:

- Develop an inventory of the existing studies that may contain useful sedimentation and erosion data. The sources consisted of fieldwork reports, laboratory reports, shoreline monitoring reports, water quality studies, and academic research conducted by Manitoba Hydro and its consultants, universities, individuals, and federal/provincial organizations;
- Review the reports for their relevance to the sedimentation and erosion component of the RCEA; and
- Create a document that details a zone-wise chronologic account of studies that can be used in Phase II of this study.

Phase II will involve further analysis of the results from the available studies combined with compilation and analysis of existing data (e.g., monitoring data, air photos) to generate information on physical impacts. The further compilation and analysis in Phase II will be primarily focused at selected sites of interest. The sites would be selected based on a review of the Phase I results and through a discussion.
with the project team. Priorities will be identified by Manitoba Hydro and the provincial government taking into consideration the availability of data and the feasibility to conduct the analysis at these locations. The Phase II report will include a summary and synthesis of the findings on the impacts of erosion and sedimentation processes associated with hydroelectric development. In this phase, the information gaps identified through the synthesis will also be identified. The Phase II study methodology consists of the following steps:

- Develop a complete electronic inventory of the existing erosion and sedimentation data. The data sources compiled in Phase I will be revisited, and additional studies that have not been reviewed at the time of submitting the Phase I report will be added;

- Develop sediment/turbidity and erosion monitoring station maps in a GIS environment that will include all the monitoring locations from pre-development to present. For each station, a summary of the erosion and sedimentation data including the period of measurements and measured parameters will be developed;

- Assess (to the extent possible) changes in the erosion and sedimentation regime associated with the existing hydroelectric development based on available information for pre- and post-development;

- Present the current trends and rates of shoreline erosion and sedimentation to the extent that is feasible with the available information; and

- Identify gaps in the data and information and develop plans to address the gaps.
Legend

Zones

Existing Generating Stations (G.S.)

Control Structures (C.S.)

Zones

Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12

DATA SOURCE: Manitoba Hydro
DATE CREATED: 27-MAY-14
CREATED BY: 23-MAY-14
VERSION NO: 1.0
REVISION DATE: 10-JUN-14
QA/QC: 10-JUN-14
COORDINATE SYSTEM: UTM NAD 1983 Z15N

RCEA
Erosion and Sedimentation Zones

Map 4-14
4.3.1 OVERVIEW OF MAJOR STUDIES

Erosion and sedimentation processes in the RCEA Region of Interest have been the focus of several studies including the Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB), Federal Ecological Monitoring Program (FEMP), Split Lake Cree-Manitoba Hydro Joint Studies, and Environmental Impact Statement (EIS) studies for pre- and post-hydroelectric development in northern Manitoba.

Most of the water quality studies conducted in the RCEA Region of Interest also reported sediment data including suspended sediment and turbidity. The majority of these studies were conducted as a part or follow-up to the LWCNRSB, FEMP, and MEMP (Manitoba Ecological Monitoring Program) studies. A more recent aquatic monitoring program initiated by Manitoba Hydro in partnership with the Province of Manitoba is the Coordinated Aquatic Monitoring Program (CAMP). There is also ongoing water quality monitoring conducted by MCWS (Manitoba Conservation and Water Stewardship) which includes Total Suspended Solids (TSS) and turbidity at a number of sites. 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.

Each of these studies mentioned above may cover the entire RCEA Region of Interest or a portion of it. A brief description of these studies is presented in the following sections to avoid duplicating information in each of the zones.

4.3.1.1 LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD (LWCNRSB)

In 1971, prior to developments associated with the CRD and LWR, Manitoba and Canada initiated the LWCNRSB to determine the effects that LWR, the CRD and the development of hydroelectric power along the CRD route would have on other water-related resource uses. The study took over three years to complete. The results were compiled in eight technical appendices, one technical report (LWCNRSB 1975) and a summary report.

The Physical Impact Study (Water Resources Branch 1974) represents the most comprehensive erosion and sedimentation study covering the RCEA Region of Interest. The study deals with the physical impacts on shorelines and inundated terrain along the Churchill and Nelson rivers resulting from the CRD and LWR.

4.3.1.2 FEDERAL ECOLOGICAL MONITORING PROGRAM (FEMP)

In 1986, Environment Canada and the Department of Fisheries and Oceans (DFO) coordinated a five-year monitoring program in northern Manitoba. This program was directed towards meeting some of the federal obligations under the Northern Flood Agreement (NFA), a four-party agreement concerned with the effects of large-scale hydroelectric development on the local inhabitants of the impacted area. Environment Canada and DFO published the findings of the five-year monitoring and research program as a series of ecological reports.
The main erosion-related research was conducted by Kellerhals Engineering Services Ltd. (1987, 1988), a two-phase study investigating how the CRD and LWR have affected river and lake morphology. Phase I was a detailed review of previous studies combined with a brief field inspection (Kellerhals Engineering Services Ltd. 1987). The study identified the main areas of concern for sediment, erosion, and deposition along with monitoring recommendations on a region-by-region basis. The study area for Phase II of this program (Kellerhals Engineering Services Ltd. 1988) was restricted primarily to the CRD route downstream of the Notigi control structure (CS), with a brief look at the lower Churchill River using maps and air photos to quantify morphologic changes.

4.3.1.3 **Split Lake Cree - Manitoba Hydro Joint Studies**

The primary objective of these studies was to establish an environmental baseline by assessing the impacts of past hydroelectric development on the Split Lake Cree and extending this knowledge to anticipate the impacts of future hydroelectric developments and evolving environmental conditions in the study area. The study area comprised of an estimated 48,500 km² (12 million acres) of land and waters around Split Lake and extended past the Churchill River to the north, to Fidler Lake on the west, the CN rail line to the east and Sipiwesk Lake to the south.

Manitoba Hydro and Split Lake Cree undertook the environmental review jointly. Phase I of this study included a review of environmental impacts of hydroelectric development observed by the Split Lake Cree, scientific literature and identification of knowledge/data gaps. A major part of this study was to quantify the effect of erosion, subsequent nearshore sediment deposition, and substrate changes on the water quality parameters. Phase II provided the conclusions and a summary of above investigations.

4.3.1.4 **Environmental Impact Statement Studies**

Manitoba Hydro conducts EIS studies as key requirements of the preliminary planning of hydroelectric projects to meet federal and provincial regulatory requirements ever since the Environment Act became enacted. The process includes identification and extensive study of potential effects on the environment and people along with the development of follow-up monitoring programs.

Manitoba Hydro has submitted these assessments for the previously developed Limestone and Wuskwatim GSs as well as the proposed Keeyask Generating Station. An EIS study is also underway for the planned Conawapa Generating Station. Numerous sediment and erosion studies are available in the reaches affected by these developments.

4.3.1.5 **Coordinated Aquatic Monitoring Program (CAMP)**

Manitoba Hydro, in partnership with the Province of Manitoba, initiated a long-term monitoring program with a mandate to track aquatic ecosystem health using scientifically defensible methods to monitor the environmental effects associated with hydroelectric development in Manitoba. Water and sediment sampling are essential parts of this program and provide data consisting of turbidity, TSS, and sediment composition and deposition processes within a water body. An extensive amount of data has been accumulated since the inception of CAMP in 2007.
4.3.2  **ZONE 1 – OUTLET LAKES AREA**

**4.3.2.1  AREA OVERVIEW**

The outlet lakes area includes the East and West channels of the Nelson River as shown in Map 4-15. The West Channel covers a distance of approximately 60 mi (100 km) from the outlet of Lake Winnipeg to the Jenpeg GS and includes Playgreen Lake, Kiskittogisu Lake, Kiskitto Lake, and the Jenpeg forebay. The Nelson River East Channel begins at Little Playgreen Lake and covers 60 mi (100 km) until reaching Pipestone Lake just upstream from Cross Lake.

**4.3.2.2  EROSION**

The LWCNRCSB divided Zone 1 into several reaches, which were classified into ten shoreline types (Water Resources Branch 1974). In general, throughout this zone bedrock shorelines are irregular and form promontories while erodible organic and granular shorelines form continuous sweeping arcs.

Kellerhals Engineering Services Ltd. (1987) summarized the erosion studies done to that date within the outlet lakes area. Little erosion monitoring work has been completed in this area since their review. One exception is the work undertaken by Bill Straight in 2003 as part of a woody debris and bank recession study in the Jenpeg forebay, which was later updated in 2012 (J. Tutkaluk, pers. comm. 2014).

Baracos and Galay (1972) discussed the construction and operation of the Two-Mile and Eight-Mile channels. Erosion due to wind-generated waves on Lake Winnipeg and Kiskittogisu Lake were expected to be substantial at the south end of the Two-Mile channel and north end of the Eight-Mile Channel, respectively. Any material eroded from the channels was expected to be dominantly clay, which would be transported downstream on the Nelson River to stillwater areas such as the Jenpeg and Kelsey reservoirs.

Galay and Baracos (1974) conducted follow-up work on the Eight-Mile Channel. Their work dealt with the present and future condition of dykes along the channel and dealt with the role that high water levels on Kiskittogisu Lake would have on shoreline displacement along the south end of the lake. It was recommended that dykes paralleling the south shore of Kiskittogisu Lake be constructed to prevent the southward displacement of the shore due to erosion by wind-induced waves.

According to Kellerhals Engineering Services Ltd. (1987), Manitoba Hydro was monitoring the Eight-Mile and Two-Mile channels annually with approximately five cross sections monitored at each channel, and some soundings were collected in the outlet areas. Substantial erosion was reported to have occurred during the first two years of operation, but much less since. Cross sections of both channels have been surveyed every two years since the project was completed and the results are published in summary reports.

Kellerhals Engineering Services Ltd. (1987) indicates that a broad environmental assessment of project effects on Playgreen Lake was conducted by MacLaren Plansearch Inc. (1985). The study was mainly concerned with the effects of LWR on the commercial fishery of Playgreen Lake. The study determined the pre- and post-project shoreline stability of Playgreen Lake and of the northern end of Lake Winnipeg. 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. No changes in shore erosion rates attributable
to LWR could be detected on either the Lake Winnipeg north shore or on Playgreen Lake. Large erosion rates were observed at the entrance to the Two-Mile Channel.

Kellerhals Engineering Services Ltd. (1987) discussed the predominance of low, flat organic terrain surrounding Kiskittogisu Lake. They indicated that the effects of the increased water levels associated with regulation had not yet been monitored along this lakeshore.

Northwest Hydraulic Consultants Ltd. (1987) considered the Lake Winnipeg outlet channels as one of the top three main sources of increased sediment due to hydroelectric development. Shoreline erosion on Southern Indian Lake and bank erosion along the Burntwood River route of the diversion were the other two main sediment sources.

J.D. Mollard and Associates Ltd. assessed whether there were any identifiable changes in air photos in the Norway House Reserve area before and after the regulation of Lake Winnipeg (JDMA 1994). 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 using air photos taken before and after LWR. The most visible shoreline changes were in land use, with an increase in the number of houses and docks observed from 1973 to 1990.

4.3.2.3 SEDIMENTATION

The LWCNRSB documented the baseline sediment conditions prior to the CRD and LWR within the study area (LWCNRSB 1975a). In this study, sediment and water quality data collected by federal and provincial agencies prior to 1972 were utilized along with the data collected in 1972 and 1974 in Two-Mile Channel, Playgreen Lake, Eight-Mile Channel, Norway House, Kiskitto Lake, Kiskittogisu Lake, Kisipacheuwuk Rapids, Warren Landing, and in the area of the Jenpeg GS (Morelli 1975). Koshinsky (1973) studied limnology and fisheries of the outlet lakes area and compared water quality and suspended sediment in the outlet lakes area and compared water quality and suspended sediment in the outlet lakes and Lake Winnipeg.

Prior to LWR, suspended sediment data was collected by Manitoba Hydro in the area of Warren Landing and at the entrance and exit of Two-Mile and Eight-Mile Channel locations in Lake Winnipeg, and Playgreen and Kiskittogisu lakes. 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, b).

A report prepared by Manitoba Hydro (1985a) presented the 1984 sedimentation program sampling results for the Playgreen Lake area and provided a comparison to previous historic data. The 1984 bedload measurements conducted in Two-Mile and Eight-Mile channels were presented in a Manitoba Hydro report (Manitoba Hydro 1985b). In 1985, MacLaren Plansearch Inc. completed a comprehensive study of South Playgreen Lake to assess the impacts of LWR on the commercial fishery on Playgreen Lake. As part of this study, comparison of the pre- and post-regulation sediment regime was undertaken using sediment cores, grab samples, suspended sediment concentration, and satellite images. The rate of sedimentation and type of bottom sediments throughout most of Playgreen Lake were also assessed (MacLaren Plansearch 1985a, b, c).
The Nelson River near Norway House has been monitored since 1972 for a variety of water quality parameters including TSS and turbidity (currently monitored by Manitoba Water Conservation and Water Stewardship). Assessments of changes resulting from hydroelectric development, including analysis of TSS and/or turbidity, have also periodically been undertaken (Morelli 1975; Playle 1986; Playle and Williamson 1986; Duncan and Williamson 1988; Grapentine et al. 1988; Playle et al. 1988; Baker and Davies 1991; Ramsey 1991; Williamson and Ralley 1993).

Suspended sediment and turbidity were also collected as part of the FEMP water quality data collection program from 1987 to 1989 (Environment Canada and DFO 1992a, b). To more effectively utilize the sediment data collected by different agencies, an annotated atlas of sediment sampling stations in the LWCNR area was prepared (Environment Canada and DFO 1989b). This atlas describes the key characteristics (location, period of record, and frequency of sampling) of the stations of federal, provincial and Manitoba Hydro. Kellerhals Engineering Services Ltd. conducted a study to synthesize the existing knowledge at the time to determine the location, extent, and significance of river morphological changes in the FEMP study area (Kellerhals Engineering Services Ltd. 1987, 1988). Field survey data, aerial photo interpretation, and analysis of data available in 1987 formed the basis for this assessment. Northwest Hydraulic Consultants Ltd. was also hired under the FEMP studies to assess the sediment effects resulting from the LWCNR hydroelectric projects. The study included assessment of sediment type, sediment sources, transport routes and depositional sites, and sediment mixing (Northwest Hydraulic Consultants Ltd. 1988a, b). Temporal changes in turbidity and suspended solids were assessed in Playgreen Lake/ Norway House and Kiskittogisu Lake for 1973-1977, 1972-1999, and 1987-1997 (Northwest Hydraulic Consultants Ltd. 1988a).

MCWS has been monitoring water quality at the Jenpeg GS since 2001 (unpubl. data).

A more recent ongoing sediment monitoring program was initiated by Manitoba Hydro on South Playgreen Lake under the CAMP. Sediment data including TSS, discrete and continuous turbidity, bedload, and bed material have been collected in the open water season of 2013 and winter 2013/2014 (CAMP 2014a). Since 2009, water quality, including TSS and turbidity, has been monitored in Playgreen and Little Playgreen lakes every three years under the CAMP (CAMP 2014b, CAMP unpubl. data). Ongoing water quality monitoring is also conducted at the Jenpeg GS as a cooperative undertaking by Manitoba Hydro and MCWS.
4.3.3  ZONE 2 – CROSS LAKE AND SURROUNDING AREA

4.3.3.1  AREA OVERVIEW
This zone begins just downstream of the Jenpeg G S at Cross Lake and extends further downstream along
the Nelson River to just upstream of Sipiwesk Lake as shown in Map 4-16. Duck Lake, which is a lake
along an arm of the Nelson River just upstream of Sipiwesk Lake, is also in this zone. Other lakes in the
zone include Pipestone Lake, which is between the Nelson River East Channel and Cross Lake, and
Walker Lake, which is a tributary to Cross Lake. The Cross Lake Weir is the only Manitoba Hydro in-
stream structure in this zone.

4.3.3.2  EROSION
Cole (1974) assessed the anticipated effects of LWR on shorelines at Cross Lake. At strategic sites
throughout the Cross Lake community, 20 shore profiles were surveyed and presented along with
descriptions of the shore materials and vegetation. Most of the shoreline was classified as bedrock-
controlled with shallow overburden. It was determined that project-related changes to water levels and
flows, although changed seasonally, would not be of sufficient magnitude to cause substantial soil erosion
from such low bedrock shorelines. The limited fetch across the east channel of the Nelson River in this
area was also expected to limit the amount of erosion.

The effects of LWR on shoreline stability were predicted to be minimal by the LWCNRSB (1975), and
no erosion problems had been reported up to 1987 according to Kellerhals Engineering Services Ltd.
(1987). The main predicted physical changes associated with LWR were expected to be changes to
shoreline vegetation initiated by the modified seasonal water level regime. However, considerable shore
remediation has been carried out in recent years on Cross Lake (J. Tutkaluk, pers. comm. 2014).

4.3.3.3  SEDIMENTATION
Morelli (1975) summarized pre-development suspended sediment and turbidity data collected from 1972
to 1974 in Cross Lake, Eve Falls, Minago River mouth, and Bladder Rapids areas. The effects of the
LWCNCR hydroelectric projects on Cross Lake sediment regime were predicted by the LWCNRSB
(1975a). In a limnology and fisheries study report, Koshinsky (1973) compared turbidity in the east basin
of Cross Lake with that section of the lake receiving the Nelson River discharge.

Turbidity values, as an indication of suspended sediment concentration in water, collected in Cross Lake
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 1986).

Water quality data collection for Walker Lake was conducted in 1981 (Gaboury and Patalas 1981, 1982).
Suspended sediment and turbidity were also collected as part of the FEMP water quality data collection
program from 1987 to 1989 (Environment Canada and DFO 1992a, b). Kellerhals Engineering Services
Ltd. conducted a study to synthesize the existing knowledge at the time to determine the location, extent,
and significance of river morphological changes through the FEMP study area (Kellerhals Engineering

Northwest Hydraulic Consultants Ltd. assessed the sediment effects resulting from the LWCNR hydroelectric projects. The study included assessment of sediment type, sediment sources, transport routes and depositional sites, and sediment mixing. Temporal changes in turbidity and suspended solids were assessed for the periods 1975-1984 and 1970-1999 (Northwest Hydraulic Consultants Ltd. 1988a, b).

Water quality data including suspended sediment and turbidity for Walker Lake and Cross Lake near the community have been monitored under CAMP (CAMP 2014b, CAMP unpub. data).
4.3.4 **ZONE 3 – SIPIWESK LAKE TO KELSEY GS**

4.3.4.1 **AREA OVERVIEW**

This zone includes Sipiwesk Lake and the Nelson River from the outlet of Sipiwesk Lake to the Kelsey GS as shown in Map 4-17. Some of the other lakes in this zone include Landing, Hunting, Prud’homme, Cauchon, and Goose Hunting lakes, which are all tributaries to the Nelson River. The Kelsey GS was constructed to supply the International Nickel Company’s mining and smelting operations and to supply electricity to the City of Thompson.

4.3.4.2 **EROSION**

As part of the Physical Impact Study, the impact of altered water regimes was surveyed at Sipiwesk Lake and the Kelsey forebay (Water Resources Branch 1974). The summaries in the two paragraphs below are based on information provided in Section 7 of the Physical Impact Study.

The construction of the Kelsey GS impounded the shoreline of Sipiwesk Lake in 1960. The readjustment process involved shoreline vegetation being impacted to the maximum water level along with increased shoreline erosion and nearshore sedimentation. About 5% of the shoreline was predominantly steep bedrock outcrop where no impact was observed. Over about 10% of the shoreline, impacts were slight and consisted of a narrow band of dead trees. Moderate impacts were observed over about 35% of the shoreline and consisted of vegetation being impacted. Severe erosion was observed over about 50% of the shoreline, characterized by erosion and flooding extending inland.

The Kelsey forebay was impounded during the summer of 1960 by the Kelsey GS. The readjustment process took several forms: erosion of till banks where the water level had risen well above the previous stable shoreline, severe undercutting of banks near the upper end of the channel, impacting shoreline vegetation to maximum water level, increased shoreline erosion with resulting increased nearshore sedimentation, and rapid erosion of mid-stream islands. Impacts were slight over 20% of the shoreline where dead vegetation was the main impact. Moderate impacts occurred over 40% of the shoreline where impacts took the form of dead vegetation and erosion. Severe impacts were observed on over 40% of the shoreline, where dead vegetation, erosion, severe bank undercutting were observed.

In addition to the summaries above, descriptions and photographs illustrating erosion impacts on Sipiwesk Lake and the Kelsey forebay were provided in several sections of the Physical Impact Study (Water Resources Branch 1974). These two areas were used several times throughout the text to illustrate examples of disappearing islands, floating peat islands and other floating peat features (e.g., islands 120 m by 150 m across still intact five years after flooding). The extreme water level fluctuations on Sipiwesk Lake were thought to be the main reason for the fen destruction observed throughout the lake.

JDMA (1992b) measured shoreline erosion rates around Sipiwesk Lake using historical air photos. The Sipiwesk Lake erosion measurements were also presented by JDMA (1992c). Pre-Kelsey forebay erosion measurements were made by comparing air photos acquired in 1930, 1946 and 1950, with average rates of erosion of 0.5 m/ y. In this pre-development period, about half of the shoreline displayed erosion rates up to 0.5 m/ y, while the other half showed rates between 0.5 and 1.0 m/ y. Post-development erosion
rates were measured between air photos dated from 1971 and 1978. The overall average rate of erosion was 3.3 m/y. However, some concerns were expressed regarding the accuracy of the post-development measurements, particularly related to photo scale, photo quality, challenges with identifying the shoreline at some locations, and changes in water level between photo acquisition dates.

4.3.4.3 SEDIMENTATION

Sediment data for the Grass River are limited to the Manitoba Hydro survey programs on the Grass River upstream of Kelsey GS for the open water season from 1969 to 1972 (Manitoba Hydro 1970, 1971, 1973). During August 1972, a limnological survey of Kettle reservoir and the Nelson River between Prud'homme Lake and Kelsey was conducted (Crowe 1973). The purpose of the survey was to document physical, chemical and biological characteristics of the two reservoirs and to compare a new reservoir (Kettle) with an established one (Kelsey). Hecky and Harper (1974) reported suspended sediment concentrations collected in Sipiwas Lake and the Grass River in the open water season of 1973.

Suspended sediment and turbidity data collected in the Kelsey reservoir and Sipiwas Lake between 1972 and 1974 was reported by Morelli (1975). Pre-LWR suspended sediment and turbidity in Sipiwas were studied Lake by the LWCNR (1975a). A comparison was made between turbidity, as an indication of magnitude of suspended sediment in water, in Sipiwas Lake for the periods of 1972-1976 (before development) and 1976-1984 (after development) to investigate the effects of LWR and the CRD on water quality (Playle and Williamson 1986).

Suspended sediment and turbidity were also collected in Sipiwas Lake and Kelsey reservoir area as part of the FEMP water quality data collection from 1987 to 1989 (Environment Canada and DFO 1992a, b). Turbidity and suspended sediment collected in Sipiwas Lake between 1972 and 1973 were compared with data for the period of 1986-1987 (Ramsey et al. 1989).

Northwest Hydraulic Consultants Ltd. assessed the sediment effects resulting from the LWCNR hydroelectric projects. The study included assessment of sediment type, sediment sources, transport routes and depositional sites, and sediment mixing (Northwest Hydraulic Consultants Ltd. 1988a, b).

Suspended sediment and turbidity in Sipiwas Lake and the Nelson River upstream of Kelsey GS are monitored every three years under CAMP (CAMP unpublished data). The historical water quality monitoring site located near the outlet of Sipiwas Lake continues to be monitored three times per year by MCWS.
4.3.5  ZONE 4 – LEAF RAPIDS TO SOUTHERN INDIAN LAKE

4.3.5.1  AREA OVERVIEW

This zone includes the upper Churchill River from Leaf Rapids to Southern Indian Lake as shown in Map 4-18. Starting from Leaf Rapids, the Churchill River runs approximately 20 mi (32 km) before reaching O pachuanau Lake which is connected to Southern Indian Lake.

Two of the three main components of the CRD are located in this zone. The Missi Falls CS controls the outflow at the natural outlet of Southern Indian Lake and raised the water level on the lake. The South Bay Diversion Channel is an excavated channel from the South Bay of Southern Indian Lake to Issett Lake and creates a new outlet to allow Churchill River water to flow into the Rat River and Burntwood River system.

4.3.5.2  EROSION

The LWCNRSB divided Zone 4 into nine reaches, which were classified into 14 different shoreline types (Water Resources Branch 1974). In general, low lacustrine relief and the occurrence of granular material characterized the northern portion of Southern Indian Lake, whereas the southern reaches were characterized by the high occurrence of bedrock-controlled shorelines.

The Freshwater Institute of Fisheries and Oceans Canada carried out a detailed, long-term monitoring study of the effects of the CRD on Southern Indian Lake. Results up to about 1982 were published in a special issue of the Canadian Journal of Fisheries and Aquatic Sciences (Vol. 41, No. 4, April 1984). As background for the other studies in the special issue, Newbury et al. (1984) provide a brief summary of hydroelectric development, geography of the Southern Indian Lake region, and changes in the hydraulic regime of the Churchill River and Southern Indian Lake. Satellite images of Southern Indian Lake acquired before and after impoundment were used to illustrate how the eroded materials were suggested to have dramatically increased the turbidity of the lake.

Newbury and McCullough (1984) summarized the results of an erosion study on Southern Indian Lake. The study was aimed at the quantification of observed erosion rates over the entire lake shoreline to obtain an estimate of the total weight of mineral materials added to the lake annually and to predict the total period of shoreline instability. Results of the study were also published by Newbury et al. (1978), Newbury and McCullough (1982, 1983) and McCullough and Newbury (1985). Permafrost is widespread in the lacustrine clay and glacial till shorelines surrounding the lake, and since impoundment, the combined processes of permafrost melt and wave erosion have caused considerable shoreline retreat. Seventeen sites on Southern Indian Lake were selected in 1975 for erosion monitoring during and following impoundment. Each site was surveyed on several cross-sectional lines running perpendicular to the shoreline and extending 50 m inland. Acoustic and line soundings were taken at each site to a distance of 500 m offshore. The volume of eroded material at each site was obtained from the change in the surveyed cross sections. Shorelines formed in fine-grained overburden contributed large amounts of suspended sediment to the main body of the lake, with long plumes of sediment observed moving from the eroding shorelines into the main body of the lake. In general, it was suggested that the creation of
stable shorelines and the reduction of sediment input to the lake to pre-impoundment conditions would require many decades in the large basins and centuries in the less exposed regions of the lake.

McCullough (1978) described the system of shoreline classification developed for Southern Indian Lake and he compared it with a biophysical land classification system developed for general ecological land classification applications. This shoreline classification system was developed for the LWCNRSB to map shorelines along the Nelson, lower Churchill and Rat-Burntwood rivers.

McCullough (1987) presented preliminary results of a study of nearshore sedimentation processes at Southern Indian Lake. The erosion portion of the study involved the use of 1970 and 1983 aerial photographs to plot shoreline maps and bank profiles at 17 sites. Seven to 16 profiles were drawn at each site equidistantly spaced to sample a reach of 0.5 to 1.0 km. From 15 to 84 m$^3$/m of shoreline was eroded at each site over the thirteen-year period.

McCullough (1990) discussed sedimentation and erosion within Southern Indian Lake and within the Notigi reservoir. Emphasis in the discussion was placed on the erosion of low energy shorelines. In the first years after the impoundment of Southern Indian Lake, erosion at low energy sites was negligible. Typically, several years were required to break apart the moss and root-fibre matte at the land-water interface. By 1980, minor toe erosion was more commonly apparent at the shoreline. It was suggested that substantial erosion of the more protected shorelines would begin only after the protective vegetation mat was destroyed, and would peak later in the life of the reservoir.

Hecky and McCullough (1984) examined the pre- and post-impoundment sediment balance of Southern Indian Lake and found that shoreline instability had increased the sediment input to the lake by a factor of 20, with most of the sediment deposited near the eroding shores. However, they also found evidence that these nearshore deposits could be temporary and that the sediment could eventually remobilize and become part of the lake’s general suspended load. They anticipated that this would cause unnaturally high lake turbidity to persist after the shorelines had become more stable. At one site where shore erosion ceased after encountering bedrock, the nearshore deposits disappeared over a period of three years.

Baracos and Galay (1974) investigated the channel connecting South Bay to Issett Lake. The Churchill River is diverted across the Churchill-Nelson divide along this channel. The excavation traversed a wide variety of materials ranging from bedrock to peat and silts with high organic content. Bedrock outcrops were expected to limit the tendency for the channel to shift where shoreline instability or erosion takes place. However, Kellerhals Engineering Services Ltd. (1987) noted that the South Bay Diversion Channel had seen little erosion monitoring, and the field reconnaissance in October 1986 indicated considerable shoreline instability, large areas of standing dead trees and many large floating fens.

Baracos and Galay (1973a) investigated the effects from raising the level of Southern Indian Lake due to the CRD on the shoreline at the settlement of South Indian Lake. Set-back lines were presented based on a consideration of flooding, erosion and bank stability assuming that no protective works were constructed. Topographical and soil information were obtained from 83 cross sections surveyed along shorelines near the settlement of South Indian Lake. Two cemeteries on the east shore had been located close to the lake for access, and in areas where the soil was easy to excavate. It was recommended that riprap protection or relocation be considered.
As part of the erosion monitoring program conducted by Manitoba Hydro along the CRD (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), two erosion monitoring sites on Southern Indian Lake and one on Opachuanau Lake were surveyed for several years beginning in 1981. The sites on Southern Indian Lake were located near the Missi Falls CS and near the settlement of South Indian Lake. However, as each of these sites was bedrock-controlled at the high waterline they were no longer surveyed. The available transect surveys for these sites have been compiled by Manitoba Hydro (2001b), with the final survey completed in 1992.

### 4.3.5.3 Sedimentation

Numerous water quality and shoreline erosion studies were conducted in Southern Indian Lake. These studies, although focused on water quality (in relation to aquatics) and shoreline erosion, provided an assessment of TSS in the pre- and post-CRD environments. A majority of these studies were conducted as a part or follow-up to the LWCNRSB or FEMP studies. A limited amount of sedimentation data is available for this zone in the form of turbidity, suspended sediment content and mapped deposition zones. A summary of the studies documenting these observations is given below.

Cleugh (1974) divided Southern Indian Lake into eight regions and included the pre-diversion conditions and presented his assessment of the diversion effects on the hydrography of each region. Afterwards, he established the baseline water quality parameters, including TSS and turbidity.

Hecky (1974) provided the Southern Indian Lake basin history and implications of inundations and diversion on the sedimentary environment of the lake. This study included information on the grain size distribution of sediments found at the lake bottom. In another study, Hecky et al. (1974) documented a few TSS measurements at selected stations and established a relationship between the Secchi disk depths and TSS. Hecky and Ayles (1974) surveyed Wood Lake, a relatively small lake draining into the Churchill River downstream of Southern Indian Lake in 1973, with the intention that it might serve in the future as a reference lake. Hecky et al. (1979) published the physical data, including suspended sediment concentration, collected at nine stations on Southern Indian Lake and neighboring lakes for the two years prior to diversion (1974 and 1975), for the year of impoundment and diversion (1976), and for two years after diversion. Hecky et al. (1981) created sediment budgets for Southern Indian Lake.

Manitoba Hydro (1982) conducted water sampling for suspended sediment and chemical analysis over the whole diversion route, including Southern Indian Lake in 1981.

Limited TSS data can be extracted from the work by Guildford (1985) on the depression in primary productivity due to the suspended sediment and dissolved humic matter in Southern Indian Lake. In an aquatic study, Fudge and Bodaly (1984) assessed the Lake Whitefish egg survival after determining the amount of sedimentation on post-impoundment spawning beds in Southern Indian Lake.

Hecky and McCullough (1984) discussed the effects of impoundment and diversion on the sediment budget of Southern Indian Lake. The lake was divided into six regions; each region had undergone different degrees of increase in suspended sediment. McCullough and Newbury (1985) measured the transient nearshore deposition and its effect on turbidity in Southern Indian Lake.
The effect of the CRD on water quality was investigated by comparing pre-development (1972-1976) and post-development (1976-1984) water chemistry data over the entire diversion route, including Southern Indian Lake. The findings of this comparison were published in water standards and studies report (Playle and Williamson 1986).

Penner et al. (1987) compiled a summary of all the suspended sediment and bed material data that had been collected up to 1985 in Manitoba by the Manitoba Water Resources Branch and Water Survey of Canada. Data collected by Freshwater Institute personnel was also referred to in this report.

Guildford et al. (1987) documented a few TSS values while evaluating the effect of eroding shorelines in Southern Indian Lake on depressed primary productivity and phytoplankton biomass due to reduced light penetration caused by the increased suspended sediments.

McCullough (1987) discussed shoreline evolution in Southern Indian Lake as a part of a Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the CRD. The preliminary results of nearshore sedimentation processes at Southern Indian Lake are documented in this report. Sediment cores were taken from the bed within 100 meters offshore to measure sediment deposition at representative locations along the shoreline. This information was used to estimate the weight of deposited material.

Bodaly et al. (1987) presented the results of sediment, fish and limnological sampling done in 1981-82, along the CRD route. The report presented the data and correlation between various quantities, including suspended sediments. This report was included as a technical appendix to the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the CRD. Jackson (1988) reported the grain size distribution of sediments in Southern Indian Lake.

FEMP reports (Environment Canada and DFO 1987, 1988, 1989a, b, c, 1990) documented the sedimentation studies, observations, and assessments initiated under this program. The related activities included sediment budget analysis, morphological assessment, and sediment coring for quantitative assessment of sedimentation along the diversion route, including Southern Indian Lake. Some TSS and Secchi disk readings were also noted. (Environment Canada and DFO 1992a, b, c). 

North/South Consultants Inc. (2013) published the results of sedimentation investigations conducted in Southern Indian Lake during 2011-2012. Sediment traps were placed on the lake bottom in the fall of 2011 before the lake froze and were left there over the winter. The equipment was removed in March before the ice melted. Monitoring equipment was placed in four areas: Loon Narrows, Sandhill Bay, a bay near the Community Channel, and an area north of the Missi Falls CS. The authors made an estimate of the material accumulated in winter 2011-2012 on the bottom of the lake. These results could not be directly compared with the 1978-1981 studies (Fudge and Bodaly 1984) because of the precise location of the traps and some aspects of the design of the traps. The composition of the collected sediment in traps was dominated by clay and silt with low organic content.

Since 2008, suspended sediment and turbidity have been sampled in Southern Indian Lake and Opachuanau Lake under CAMP (CAMP 2014b, CAMP unpubl. data).
4.3.6 **ZONE 5 – LOWER CHURCHILL RIVER**

4.3.6.1 **AREA OVERVIEW**

As shown in Map 4-19, this zone covers the lower Churchill River from the Missi Falls CS to the Churchill Weir just upstream from the Churchill River estuary. Major lakes in this zone include Partridge Breast Lake, Thorsteinson Lake, Northern Indian Lake, and Fidler Lake.

4.3.6.2 **Erosion**

The LWCNRSB divided the lower Churchill River into ten reaches (Water Resources Branch 1974; LWCNRSB 1975). This study provided an overview of the physical setting of the lower Churchill River followed by detailed descriptions of each reach. The substantially reduced flows associated with the CRD were expected to decrease the width of the river channel and result in the subaerial exposure of many previously subaqueous surfaces.

Kellerhals Engineering Services Ltd. (1988) conducted a cursory examination of the morphological changes that took place along the lower Churchill River. Changes in morphology were evaluated visually by comparing pre- and post-CRD air photos. In certain locations, it was possible to make quantitative measurements of changes from the air photos using a digitizing tablet. Four sites along the lower Churchill River were examined in detail. The results indicated that the depleted flows have resulted in an approximate 30% decrease in average channel width. A large percentage of side and back channels were no longer occupied by the river, nor were many low-lying wetland areas. The size of most tributary fans had enlarged considerably. This appeared to be caused by both the exposure of previously submerged areas and, in a few locations, by the deposition of coarse textured materials transported by tributary streams. Channel incision and increased bank erosion were evident near the apex of two tributary streams. These processes resulted in locally substantial sediment production. In general, the observed morphological changes were relatively minor and were progressing at very slow rates. This was primarily due to the many bedrock controls along the lower Churchill River and to the incised nature of some channel reaches.

4.3.6.3 **Sedimentation**


Sedimentation processes in the lower Churchill River, Partridge Breast, Northern Indian, Fidler and Billard lakes, and the Churchill River estuary were investigated and presented in the LWCNRSB report (1975). This report did not suggest significant changes in the sediment regime in these waterbodies after the diversion.

Cleugh (1974), in a study prepared for LWCNRSB, reported physical parameters of water (including suspended sediment) at Missi Falls, Wood Lake, and the lower Churchill River and lakes (Partridge
Breast, Northern Indian, and Fidler lakes) collected between February and September of 1973. Also, suspended sediment data collected on the lower Churchill River for the water intake at the Town of Churchill was reported by Manitoba Hydro (1977c). Turbidity and suspended sediment concentration were measured between 1972 and 1974 on the lower Churchill River at Missi Falls and Fidler Lake, Oldman River at Northern Indian Lake, Gauer River at Thorsteinson Lake, Little Churchill River at Rescluse Lake, Beaver River near mouth, and water intake for the Town of Churchill (Morelli 1975).

Guilbault et al. (1979) compare pre-CRD (1961-1976) and post-CRD (1976-1977) water quality parameters including turbidity on the lower Churchill River below Fidler Lake. The effect of the CRD on water quality of the Churchill River was also investigated by comparing water chemistry data for pre-development (from 1972 to 1976) and post-development (1976-1984) by Playle and Williamson (1986). Environment Canada (1982) published chemical, physical and biological surface water quality data collected during 1980 and 1981 for Manitoba. In this report, turbidity values were reported for the Churchill River upstream of Red Head Rapids. Water sampling for suspended sediment and chemical analysis were collected on the Churchill River at Missi Falls from July to October, 1981, by Manitoba Hydro (Manitoba Hydro 1982).

Since 2008, Northern Indian Lake and the Churchill River above the confluence with the Little Churchill River have been monitored for water quality parameters (including suspended sediment) four times annually under CAMP, and Partridge Breast, Fidler, and Billard lakes and the lower Churchill River at Red Head Rapids have been monitored every three years; the Churchill reservoir will be monitored in 2014/15 as part of CAMP (CAMP 2014b, CAMP unpublished data).
Missi Falls C.S.
Churchill River
Southern Indian Lake
Winnipeg Lake
Winnipeg

Erosion and Sedimentation Zone 5

DATA SOURCE: Manitoba Hydro
DATE CREATED: 27-MAY-14
CREATED BY: MRK
VERSION NO: 1.0
REVISION DATE: 27-MAY-14
QA/QC: 3RD/1ST
COORDINATE SYSTEM: UTM NAD 1983 Z15N

Legend
Control Structures (C.S.)

Map 4-19

RCEA
Erosion and Sedimentation Zone 5

Map 4-19
4.3.7 **ZONE 6 – SOUTH BAY CHANNEL TO NOTIGI CONTROL STRUCTURE**

4.3.7.1 **AREA OVERVIEW**

This zone covers the Rat River system from the excavated outlet at the South Bay of Southern Indian Lake to the Notigi CS as shown in Map 4-20. Major lakes in this area include Issett, Rat, and Notigi. Notigi CS is the third main component of the CRD. It is a control structure on the Rat River that regulates the diversion flow into the Burntwood-Nelson River system.

4.3.7.2 **EROSION**

The LWCNRSB referred to the portion of the Rat River drainage system encompassing the river itself from Issett Lake to the Notigi CS and the adjoining lakes and major inflowing rivers as the Notigi reservoir (Water Resources Branch 1974). The terrain around the Notigi reservoir is generally bedrock-controlled with local areas of thicker overburden. LWCNRSB (1975) suggested that the effect of the diversion of the Churchill River into the diversion route would be greatest along the Rat River from Issett Lake to Karsakuwigamak Lake, where the river would be changed into a lake characterized by bedrock shorelines and actively eroding clay banks.

As part of the erosion monitoring program conducted by Manitoba Hydro along the CRD (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), only one erosion monitoring site has been monitored within Zone 6. The site is located on Notigi Lake, just upstream of the Notigi CS. Surveys were completed in 1981 and then at least once each year from 1983 to 2001. At this location, the profile consists of silt-clay rhythmites with a blocky structure.

As described for Zone 5, McCullough (1990) discussed sedimentation and erosion within Southern Indian Lake and within the Notigi reservoir. The Notigi reservoir has almost 2,000 km of shoreline, mostly along irregular, narrow bays or protected by a complex array of islands. In the first years after impoundment, the Notigi reservoir produced little sediment. However, the limited available sediment concentration data showed that data from the summers of 1986 and 1987 were higher than in 1984. It was suggested that substantial erosion of the more protected shorelines common on Notigi reservoir would begin only after the protective vegetation matte was destroyed, and that it would peak later in the life of the reservoir.

As part of the Keeyask Generation Project assessment, ECO STEM Ltd. (2012a) studied peatland disintegration in portions of the Notigi reservoir. Peatland breakdown and land area losses over a 22 year period were documented, and potential physical and biological factors contributing to different rates of peatland breakdown and land area loss were evaluated.

4.3.7.3 **SEDIMENTATION**

Vitkin and Penner (1979) assessed the impact of the CRD projects on sedimentation along the waterway between South Bay and Notigi structures based on the suspended sediment data collected by Manitoba Department of Natural Resources. The effect of the CRD on water quality parameters including turbidity

As part of the Wuskwatim GS aquatic environment studies, composition of bed materials in Notigi Lake was reported by Zrum and Neufeld (2003a) based on the sediment sampling conducted at four transects in 1999 and three transects in 2000.

Since 2008, Mynarski (Central basin), Rat, and Notigi (East and West basins) lakes have been sampled rotationally every three years for water quality parameters (including suspended sediment and turbidity) under CAMP (CAMP 2014b, CAMP unpubl. data).
4.3.8  ZONE 7 – NOTIGI CONTROL STRUCTURE TO EARLY MORNING RAPIDS

4.3.8.1  AREA OVERVIEW

This zone, shown in Map 4-21, covers the Rat/ Burntwood River system from the Notigi CS to Early Morning Rapids. Major lakes in this zone include Wapisu Lake, just downstream from Notigi, and Threepoint Lake. Footprint Lake and Osik Lake are also in this zone along the Footprint River, which is a tributary to the Burntwood River.

4.3.8.2  EROSION

The LWCNRSB divided Zone 7 into lake areas and river reaches between lakes (Water Resources Branch 1974). Approximately 90% of the Wapisu Lake shoreline is bedrock-controlled. Most of these shorelines are low bedrock shorelines with shallow backshore overburden, with a smaller amount characterized as bedrock shorelines with an overburden beach. Clay shorelines and willow shorelines can be found in embayments. Low bedrock shorelines are common on Threepoint Lake, with most areas between bedrock shoreline segments characterized by clay shorelines of low height. Beaches are common on Threepoint Lake.

LWCNRSB (1975) predicted the erosional response of Zone 8 to the CRD and regulation at the Notigi CS. The impact on lakeshores underlain by bedrock was anticipated to involve erosion until bedrock was reached. Dead trees were expected to clutter these shorelines indefinitely, and embayments and other protected shorelines would remain congested with standing dead trees. Steep clay banks would continue to erode, but at an accelerated rate.

As part of the erosion monitoring program conducted by Manitoba Hydro along the CRD (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), several sites within Zone 7 were monitored in 1981. However, the number of sites monitored in this area gradually decreased to one by 2001. This site is located on Threepoint Lake, and it has been surveyed in 1981 and then at least once each year from 1983 to 2001. In 1981, there were three sites near Nelson House, one just downstream of the Notigi CS and one near Gate Falls on the Burntwood River.

In May 1980, Manitoba Hydro retained MacLaren Engineers Inc. and Intergroup Consulting Engineers Ltd. to conduct an environmental overview of options for the development of power potential along the Rat-Burntwood diversion route. Most of the environmental work was conducted in 1980 and 1981, and the final report was released in 1984 (MacLaren/Intergroup 1984a). MacLaren/Intergroup (1984d) reported on the Wuskwatim reach, between the Notigi CS and Taskinigup Falls as it appeared in 1980, after three years of diversion flows. Some evidence was observed of locally significant erosion along river channels. The main areas of erosion identified were on Threepoint Lake within the Nelson House Reserve area, on the Rat River upstream and downstream of Wapisu Lake, and at Gods Rapids. Extensive erosion of lake shorelines had not taken place in this zone, although localized slumping was noted in coarse-grained and clay shorelines oriented towards the prevailing winds and exposed to long open water fetches.
Manitoba Hydro (1987) repeated the lake and river shoreline classification of the diversion route first presented in the Physical Impact Study (Water Resources Branch 1974). The classified reach extends from Notigi to Split Lake. The reclassification was based on 1:20,000 scale air photos flown in the summer of 1986.

Kellerhals Engineering Services Ltd. (1988) compared pre- and post-diversion lake surface areas and shoreline lengths in parts of Threepoint and Footprint lakes and along a river section between the two lakes. The evaluated lake areas increased by 36 to 53% post-diversion, while the river section between the lakes increased by 158%.

Kellerhals Engineering Services Ltd. (1988) also carried out feasibility studies to use historical air photos to map the distribution of three types of features that increased in abundance along the Rat-Burntwood system following the CRD: 1) inundated standing dead trees or accumulations of large floating debris, 2) unstable eroding materials, and 3) shallow water depths. The data from Footprint Lake indicated that prior to diversion, areas of shallow water depths or showing the presence of floating or submerged vegetation were limited to low gradient deltas near tributary streams. Cleared or eroding shorelines were similarly restricted to disturbed areas near Nelson House. Following diversion, extensive areas of former shoreline were flooded and this resulted in the generation of large amounts of dead standing trees, floating or submerged vegetation, and extensive areas with shallow water depths. The lengths of eroding shoreline increased from 4 km to 40 km, indicating the potential for widespread sediment production.

In addition to the feasibility studies described above, Kellerhals Engineering Services Ltd. (1988) also made estimates of the volume of material eroded at two sites within Zone 7. At Footprint Lake, a comparison of 1954 (1:61,000) and 1972 (1:24,000) air photos indicated no detectable change in shoreline position. Photography taken in 1985 (1:20,000) indicated generally much more turbid water conditions with localized sediment plumes extending off many of the west-facing shorelines and an average of 30 m of recession over a stretch of shoreline 300 m in length. The other site where volume estimates were made was in the reach that includes Gods, Caribou and Early Morning rapids. Five segments of river channel near the major rapids were selected for detailed study. The analysis indicated that approximately 50% of the total shoreline in the five segments were actively retreating.

Baracos and Galay (1973a) investigated shoreline stability, wave erosion and slope stability for the settlement of Nelson House. Flooding of the land, wave erosion and destabilization of marginally stable slopes were the main problems expected to arise from the CRD. Fourteen cross sections were surveyed with boreholes drilled at locations where bedrock outcrop was not evident.

Penner (1974) developed setback lines for the settlement of Nelson House based on the assumption that no protective works would be constructed. The setback line was developed based on a consideration of flooding, erosion and bank stability.

Manitoba Hydro (1982b) predicted short-term and long-term erosion at Nelson House in the areas not protected by riprap, and they defined areas to be protected in the future to prevent serious erosion. Work was carried out in 1977 and 1978 to protect six major road crossings and three cemeteries. Riprap work on three major reaches of shoreline and one cemetery was carried out in the winter of 1981-82. Erosion...
rates at Nelson House were established based on transects surveyed at twenty sites in 1980 and 1981, with rates of 0.3 to 2.7 m per year and an average of 1 m per year.

4.3.8.3 Sedimentation

Water samples for determination of suspended sediment concentration and chemical analysis were collected on the Rat River downstream of Notigi and upstream of Threepoint Lake in summer-fall of 1969 to 1972 (Manitoba Hydro 1970, 1971, 1973).

Sedimentation processes in the area between the Notigi CS and Early Morning Rapids were discussed in the LWCNRSB report (1975a). In this study, sediment and water quality data collected by federal and provincial agencies prior to 1972 were analyzed along with the 1972-1974 sediment data reported by Morreli (1975) for the Footprint River at Threepoint Lake, and the Rat River at Threepoint Lake.

The effect of the CRD on sediment transport along the Rat-Burntwood rivers from Notigi downstream was assessed by Underwood McLellan & Associates (1973a). The pre-CRD assessment was based on limited suspended sediment data collected by Manitoba Hydro, Water Survey of Canada, or private consultants at various locations from Threepoint Lake to upstream of Spilt Lake between 1968 and 1972. Post-CRD sediment load was estimated with sediment contributions coming from the Churchill River, natural erosion processes (existing shoreline slumping, sheet erosion), eroding shorelines, and channel erosion.

Underwood McLellan & Associates (1973b) proposed a suspended sediment monitoring program in the pre-diversion period and several years following diversion. The proposed monitoring included suspended sediment and bed material sampling.

Vitkin and Penner (1979) assessed the impact of the CRD projects on sedimentation upstream of Threepoint Lake based on the suspended sediment data collected by the Manitoba Department of Natural Resources. Suspended sediment concentrations collected in Footprint Lake for the open water season of 1981 were reported by Bodaly et al. (1987). In 1981, Manitoba Hydro collected water samples for suspended sediment concentration and chemical analysis in Footprint River, Footprint Lake, Threepoint Lake, and Mystery Lake (Manitoba Hydro 1982).

As part of the Wuskwatim GS EIS studies, suspended sediment data was collected during summer of 1999, 2000, and 2001 in Kinosaskaw Lake located upstream of Early Morning Rapid (Wuskwatim EIS Vol. 5, 2003c).

As part of the Wuskwatim GS aquatic environment studies, bottom substrate samples were collected and analyzed for particle size composition from Threepoint Lake in 1998-2000 (Zrum and Neufeld 2003b; Zrum and Kroeker 1999a), Wapisu Lake in 1999-2000 (Zrum et al. 2003), and Footprint Lake in 1999-2001 (Zrum and Neufeld 2003c).

Some sediment data has also been collected from Threepoint Lake, Rat River and backwater inlets upstream of Threepoint Lake and Leftrook Lake since 2007 as part of the Wuskwatim GS Aquatic Effects Monitoring Plan (AEMP). Collected data includes TSS, turbidity, substrate type, and sediment depositional rate (Wuskwatim GS AEMP 2007b). A summary of each year’s AEMP monitoring activities are presented in the AEMP annual reports. Blanchard and Schneider-Vieira (2009) summarized the 2007
aquatic habitat baseline monitoring in the Wuskwatim GS area. As part of this program, six sediment traps were deployed in Threepoint Lake in May 2007 and removed in September 2007. Grain size distribution and total dry weight of sediment deposited in each of the traps were analyzed and presented.

As part of CAMP, Threepoint Lake has been monitored for water quality four times annually since 2009, and Footprint and Apussigamasi lakes and the Burntwood River below First Rapids have been monitored rotationally every three years (CAMP 2014b, CAMP unpubl. data).
Legend
- Existing Generating Stations (G.S.)
- Control Structures (C.S.)

RCEA
Erosion and Sedimentation Zone 7

DATA SOURCE: Manitoba Hydro
DATE CREATED: 27-MAR-14
CREATED BY: 1.0
VERSION NO: 27-MAR-14
QA/QC: 380 / MRK
COORDINATE SYSTEM: UTM NAD 1983 Z15N

Thompson
Winnipeg
Hudson Bay
Lake
Winnipeg

036 Miles
03.57 Kilometres

Map 4-21

Threepoint Lake
Burntwood River
Early Morning Rapids

RCEA
Erosion and Sedimentation Zone 7

DATA SOURCE: Manitoba Hydro
DATE CREATED: 27-MAR-14
CREATED BY: 1.0
VERSION NO: 27-MAR-14
QA/QC: 380 / MRK
COORDINATE SYSTEM: UTM NAD 1983 Z15N

Thompson
Winnipeg
Hudson Bay
Lake
Winnipeg

036 Miles
03.57 Kilometres

Map 4-21
4.3.9  ZONE 8 – EARLY MORNING RAPIDS TO WUSKWATIM GS

4.3.9.1  AREA OVERVIEW

This zone covers the portion of the Burntwood River between Early Morning Rapids and the Wuskwatim GS, which includes Wuskwatim Lake as shown in Map 4-22. The Wuskwatim GS was completed in 2012 and is owned by the Wuskwatim Power Limited Partnership (WPLP), a legal entity involving Nisichawayasihk Cree Nation and Manitoba Hydro.

4.3.9.2  EROSION

The LWCNRSB classified about one-half of the Wuskwatim Lake shoreline as bedrock-controlled, with the rest classified as low alluvial and marsh types (Water Resources Branch 1974). LWCNRSB (1975) predicted the erosional response of Zone 8 to the CRD and regulation at the Notigi CS. The impact on lakeshores underlain by bedrock was anticipated to involve erosion until bedrock was reached. Dead trees were expected to clutter these shorelines indefinitely, and embayments and other protected shorelines would remain congested with standing dead trees. Steep clay banks would continue to erode, but at an accelerated rate.

As part of the CRD erosion studies (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), a few sites within Wuskwatim Lake had been monitored since 1981. However, the CRD monitoring program did not provide site-specific data to assess erosion impacts in the Wuskwatim development area. As a result, in order to assess shoreline erosion for the pre-Wuskwatim development condition, several new sites were established in 1989 with more added in 1993. The new monitoring program was referred to as the Physical Environment Monitoring Program (PEMP), and the three following paragraphs describe the results from three annual reports (Manitoba Hydro 2001a, 2008, 2012).

Manitoba Hydro (2001a) summarized the available CRD erosion monitoring data from 1989 through 2000. Data for each site includes a site plan, erosion transect survey profiles, photographs, field notes, and a textual description of the geology, erosional activity and a qualitative prediction of future erosion. Bank heights ranged from 2 to 10 m with erosion scarp heights of 0.5 to 5 m. Horizontal bank loss measurements were based on sequential measurements of the horizontal distance from a survey control point above the top of bank to the leading edge of the erosional scarp. This method was the same as that used by the Freshwater Institute on their erosion studies on Southern Indian Lake. Horizontal bank loss was as much as 11.6 m over the monitoring period.

Manitoba Hydro (2008) summarized erosion transect data collected in 2006 and 2007 at 27 lakeshore sites on Wuskwatim, Opegano and Birch Tree lakes and at eight sites on the Burntwood River downstream of the Wuskwatim GS. Top of bluff recession and cross sectional erosion were measured from erosion transects. Top of bluff recession measured from 2006 and 2007 transects was 52% higher than the historical average rates. The 52% increase was interpreted to be caused by high water levels during and preceding the 2006 and 2007 surveys.

the Wuskwatim GS. Average top of bluff recession rates for lakeshore sites surveyed between 2006 and 2011 was 1.0 m/yr while historical rates measured between 1989 and 2000 were 0.59 m/yr.

As part of ongoing studies to characterize the physical environment associated with the Wuskwatim Development Project, JDMA (2002) classified riverbanks and lake shorelines upstream and downstream of Wuskwatim Lake, and mapped changes in riverbank and lake shoreline position from 1985 to 1998 air photos. The upstream section extends from Early Morning Rapids to Cranberry Lake.

MacLaren/Intergroup (1984c) conducted an erosion study within the Wuskwatim reach, between the Notigi CS and Taskinigup Falls, after three years of diversion flows. Some evidence was observed of locally significant erosion along river channels. The main riverine areas of erosion identified in Zone 8 were downstream of Early Morning Rapids where the river makes a sharp ‘S’ bend. These eroding areas were generally characterized by steeply-banked overburden deposits of varying thickness. These materials were suggested to be extremely sensitive to changes in water level. Extensive erosion of the lake shorelines had not taken place in the lakes of the Wuskwatim reach, although a site along the south shore of Wuskwatim Lake was identified as an erosion hot spot.

Kellerhals Engineering Services Ltd. (1988) estimated erosion volumes at the southern shore of Wuskwatim Lake in order to test the feasibility of using air photos and topographic data to estimate sediment volumes produced by erosion. Comparative air photo studies were undertaken along an 8 km section of the southwest shore of Wuskwatim Lake. No detectable change was observed in shoreline position when comparing 1955 and 1972 photos. Photography taken in 1985 indicated extensive areas undergoing active erosion, with eroded trees littering the nearshore and highly turbid water conditions along the foreshore. Given the small scale of the 1972 photos (1:50,000), bank recession rates in the period up to 1985 were frequently smaller than what could be readily detected with the available equipment. Total bank retreat in the order of 10 to 15 m was indicated at some sites, indicating average recession rates of 2 m/yr.

JD MA has conducted several erosion studies on Wuskwatim Lake (JD MA 1991, 1992a,b,c, 1993). JD MA (1992c) used air photos to measure shore recession at points on clay segments of shoreline around Wuskwatim Lake. Pre- and post-CRD shore erosion was estimated from comparison of 1950 and 1972, and 1978 and 1985 air photos, respectively. Several measurement accuracy problems were identified and solutions were discussed. Average annual shore erosion estimates were about 0.7 m/yr in the 1950-1972 pre-diversion period and 1.9 m/yr in the 1978-1985 post-diversion period. JD MA (1992a) presented the results of an office and field study to predict shore erosion around the proposed Wuskwatim reservoir. The primary objectives of the study involved gaining a better understanding of erosion processes and, based on this, developing a numerical shore erosion predictive model for permafrost-affected reservoirs. The model was then used to predict shore bank positions 25, 50, 100, and 300 years after reservoir impoundment. Terrain maps of the Wuskwatim study area were developed and correlated with ecological land classification maps. The terrain maps were used in the erosion prediction. JD MA (1998) conducted a comparative evaluation of anticipated shore erosion impacts for two possible scenarios of forebay development. The primary output parameter on which the assessment was based was the predicted sediment volume likely to be eroded from the shore zone under the two forebay elevations considered.
Volume 4 of the Wuskwatim EIS (Manitoba Hydro and Nisichawayasihk Cree Nation 2003a) provides information on the physical environment. Section 6 presents information on erosion around Wuskwatim Lake, including the classification of the shoreline into four main types and the prediction of future erosion.

Manitoba Hydro (2008) summarized erosion transect data collected in 2006 and 2007 at 27 lakeshore sites on Wuskwatim, Opegano, and Birch Tree lakes and at eight sites on the Burntwood River downstream of the Wuskwatim G.S. Bioremediation measures were implemented at several test sites in Wuskwatim Lake sometime after 2009 to test the effectiveness of these techniques for reducing shoreline erosion. However, no reports from this project have been made available at this time.

ECOSTEM Ltd. conducted several peatland disintegration and shoreline studies in the Wuskwatim Lake area, as a component of the Wuskwatim Generation Project environmental assessment (Manitoba Hydro and Nisichawayasihk Cree Nation 2003b) and post-project monitoring. For the environmental assessment studies, historical air photos were used to document historical peatland breakdown rates and land area losses over a 24 year period following implementation of the CRD. Different rates of peatland breakdown were related to physical factors. Factors controlling peatland disintegration processes in the Wuskwatim Lake area were further evaluated in ECOSTEM Ltd. (2012a) through comparisons with other locations on the Rat/Burntwood and Nelson rivers that have been affected by hydroelectric flooding and water regulation.

4.3.9.3 Sedimentation

Water samples for determination of suspended sediment concentration and chemical analysis were collected from Wuskwatim Lake in summer-fall of 1969 to 1972 (Manitoba Hydro 1970, 1971, 1973). The effect of the CRD on sediment transport along the Rat-Burntwood rivers downstream of Notigi was assessed by Underwood McLellan & Associates (1973a). The pre-CRD assessment was based on limited suspended sediment data collected by Manitoba Hydro, Water Survey of Canada, or private consultants at various locations from Threepoint Lake to upstream of Spilt Lake between 1968 and 1972. Post-CRD sediment load was estimated with sediment contributions coming from the Churchill River, natural erosion processes (existing shoreline slumping, sheet erosion), eroding shoreline, and channel erosion.

A suspended sediment monitoring program was proposed in the pre-diversion period and several years following diversion (Underwood McLellan & Associates 1973b). The proposed monitoring included suspended sediment and bed material sampling.

Manitoba Hydro (1982) collected water samples for suspended sediment concentrations and chemical analysis in Wuskwatim Lake from July to October 1981.

As part of the Wuskwatim G.S aquatic environment studies, bottom sediment and water transparency samples were collected and analyzed for particle size composition in Wuskwatim Lake in 1998 (Zrum and Kroeker 1999b).

Sediment deposition rate in Wuskwatim Lake was investigated between 1999 and 2001 using sediment traps and coring (Bezte and Richardson 2004). Sediment traps were set up in summer of 1999 and 2000 at 10 locations. The collected sediment in the traps comprised of clay and silt. Sediment cores were taken...
from a 10 m deep area in Wuskwatim Lake in 2001. Radiochemical analyses were carried out on these samples.

The Wuskwatim GS EIS presented the pre-construction sediment load and sedimentation processes in the Wuskwatim GS Project area and evaluated the potential effects of the lake erosion changes associated with construction and operating of the Project on sedimentation in Wuskwatim Lake (Wuskwatim EIS Vol. 1, 2003a). A sediment budget model was created for Wuskwatim Lake using limited sediment data available at the time of the study (Wuskwatim EIS Vol. 4, 2003b). As part of the EIS studies, suspended sediment data was collected during summer of 1999, 2000, and 2001 on the Burntwood River downstream of Early Morning Rapids, downstream of Cranberry Lake, and downstream of Taskinigup Falls, on the Wuskwatim Brook, and in Sesep and Wuskwatim lakes (Wuskwatim EIS Vol. 5, 2003c).

KG S Acres (2009g) analyzed sediment data (including turbidity and TSS concentration) collected in 2003 in an area from Wuskwatim Lake to Spilt Lake. The report discussed the nature of TSS distribution in Wuskwatim Lake and its dependency on climate factors such as wind. It also presented a relationship between Tu and TSS.

The Wuskwatim Generation Project PEMP was initiated by Manitoba Hydro on behalf of the Wuskwatim Power Limited Partnership to document various physical environment parameters during the construction and operational phases of the Project (Wuskwatim Generation Project PEMP 2007a). As part of this monitoring program, sediment parameters including suspended sediment, bedload, bed material and turbidity data have been collected on the Burntwood River from Early Morning Rapids to Split Lake since 2005. The water quality and sedimentation data collected under this program are presented in several reports prepared by KG S Acres (2008a, 2010a, b, c, d, e, 2011) and HATCH (2011a, b, c, 2012a, b, c). A summary of each year’s PEMP monitoring activities and collected sediment data are presented in the PEMP annual reports. The latest PEMP report presents sediment data collected in 2012 along with a summary of the sediment data collected since 2005 under this program (Wuskwatim Generation Project PEMP 2012/2013 Annual Report, 2013).

Some sediment data has also been collected in Wuskwatim Lake since 2007 as part of the Wuskwatim GS AEMP. Collected data includes TSS, Tu, substrate type, and sediment depositional rate (Wuskwatim GS AEMP 2007b). A summary of each year’s AEMP monitoring activities are presented in the AEMP annual reports. Blanchard and Schneider-Vieira (2009) summarized the 2007 aquatic habitat baseline monitoring in Wuskwatim Lake. Some of the specific objectives of this program were to provide information on pre-impoundment conditions in the Wuskwatim GS study area for the substratum along transects off of eroding and non-eroding shorelines, and rates of sediment deposition as measured in sediment traps in the same area. Three transects were sampled in 2007 to determine the lake bed material type. Nine sediment traps were deployed in Wuskwatim Lake in May, 2007 and removed in September 2007. Grain size distribution and total dry weight of sediment deposited in each of the traps were analyzed and presented.
Legend

- Existing Generating Stations (G.S.)
4.3.10  ZONE 9 – WUSKWATIM GS TO SPLIT LAKE INLET

4.3.10.1  AREA OVERVIEW

This zone covers the portion of the Burntwood River downstream of the Wuskwatim GS to the inlet of Split Lake as shown in Map 4-23. Major lakes in this zone include Opegano, Ospwagan, Birch Tree, Mystery, and Apussigamasi.

4.3.10.2  EROSION

The LWCNRSB divided Zone 9 into several reaches (Water Resources Branch 1974). The Burntwood River flows through glacial Lake Agassiz deposits in this area. The majority of the shorelines and backshore areas are represented by silts and clays overlying bedrock. In general, irregular and narrow channel sections contain bedrock shorelines while widenings in the channel and embayments contain clay banks. Opegano and Birch Tree lakes are situated in deep deposits of lacustrine material where shoreline instability is common. The Burntwood River between these lakes is generally bedrock-controlled.

Apussigamasi Lake is largely bedrock-controlled, with heavy overburden in embayments. The river channel to Split Lake rests on bedrock, with thick lacustrine deposits present locally.

LWCNRSB (1975) predicted the erosional response of Zone 9 to the CRD and regulation at the Notigi CS. Lakeshores underlain by bedrock and those characterized by steep clay banks were predicted to respond similar to those described in Zone 7 and 8. Along river channel reaches, an increase in channel size was anticipated, both vertically and laterally, with little change occurring where the channel was bedrock-controlled but perhaps up to 20 m of retreat on either side of the channel where the channel width was controlled by clay shores. The main difference anticipated between rivers and lakeshores was the removal of flooded and fallen trees, with riverbanks not expected to contain the amount of dead standing trees expected along protected lakeshores.

As part of the CRD erosion studies (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), nine sites within Zone 9 were monitored in 1981. Manitoba Hydro (2001b) compiled the available survey data since 1981 at nine erosion monitoring sites within Zone 9. Each site was also described in terms of the extent and types of erosion observed, and field photographs were provided for most sites. The monitoring locations in this zone include sites on Opegano and Birch Tree lakes, at the Thompson pumphouse, sewage plant and cemetery, and at First Rapids and Manasan Falls. Two of the three sites downstream of the Manasan Falls CS displayed considerable erosion, as they were located on the south shore of the Burntwood River in the direct path of flows that passed through the control structure.

Manitoba Hydro (2008) summarized erosion transect data collected in 2006 and 2007 at sites along the Burntwood River between the foot of Early Morning Rapids and Birch Tree Lake. Manitoba Hydro (2012) summarized erosion monitoring results obtained from profiles surveyed in 2006, 2007, 2008, 2009, and 2011 in this area. Erosion was observed on the south shore of the Burntwood River just downstream of the Wuskwatim GS due to a deviation in the construction sequence, which resulted in flow being directed at an unprotected bank.
As part of ongoing studies to characterize the physical environment associated with the Wuskwatim Development Project, JDMA (2002) classified riverbanks and lake shorelines upstream and downstream of Wuskwatim Lake, and mapped changes in riverbank and lake shoreline position from 1985 to 1998 air photos. The downstream section extends from Taskinigup Falls to First Rapids.

Volume 4 of the Wuskwatim EIS (Manitoba Hydro and Nisichawayasihk Cree Nation 2003a) provides information on the physical environment. Section 7 presents a prediction of downstream riverbank erosion.

Kellerhals Engineering Services Ltd. (1988) estimated erosion volumes at First Rapids in order to test the feasibility of using air photos and topographic data to estimate sediment volumes produced by erosion. Prior to the CRD, First Rapids consisted of three bedrock-controlled sills. Bedrock was exposed on both channel banks, and the valley walls confined the river channel continuously. Following diversion, the width of the channel near First Rapids widened substantially and additional bedrock became exposed. An estimated 60,000 to 270,000 m³ of sediment was removed from this area between 1970 and 1981.

MacLaren/Intergroup (1984c) provided some information on erosion within the Manasan Falls reach, extending between Taskinigup Falls and Manasan Falls. MacLaren/Intergroup (1984b) conducted an erosion study along the First Rapids reach, between Manasan Falls and Split Lake. Significant erosion was observed mainly at the major rapids and at a few exposed lakeshore sites.

Baracos and Galay (1973c) evaluated the regime of the Burntwood River near Thompson, the state of the riverbanks, and the extent of low-lying facilities, and then predicted the effect of the CRD. The report included a discussion of the stability of the banks of the Burntwood River near Thompson. Severe local instabilities of the bank have been caused by gullying where flows from drains have been routed to the top of the bank. Some evidence of localized shoreline erosion due to waves caused by either wind or boat traffic had been observed.

4.3.10.3 Sedimentation

Pre-development water samples for determination of suspended sediment concentration and chemical analysis were collected on the Burntwood River (downstream of Birch Tree Lake and upstream of Thompson), Manasan, and Odei rivers in the summer-fall of 1969 to 1972 (Manitoba Hydro 1970, 1971, 1973). Also, turbidity, as a surrogate for suspended sediment, was collected as part of the water quality program in the Burntwood River at the Thompson and Birch Tree mine pumphouses from 1974 to 1976 (Manitoba Hydro 1976, 1977c).

Sedimentation processes in this zone were discussed in the LWCNRSB report (1975a). In this study, sediment and water quality data collected by federal and provincial agencies prior to 1972 were analyzed along with the 1972-1974 sediment data reported by Morreli (1975) for the Burntwood River at Thompson and Taylor River at Thompson (Pipe Lake).

The effect of the CRD on sediment transport in this zone was assessed by Underwood McLellan & Associates (1973a). The pre-CRD assessment was based on limited suspended sediment data collected by Manitoba Hydro, Water Survey of Canada, or private consultants at various locations from Threepoint Lake to upstream of Spilt Lake between 1968 and 1972.
A suspended sediment monitoring program was proposed in the pre-diversion period and several years following diversion (Underwood McLellan & Associates 1973b). The proposed monitoring included suspended sediment and bed material sampling.

Vitkin and Penner (1979) assessed the impact of the CRD projects on sediment regime in the Burntwood River (downstream of Wuskwatim Lake, downstream of First Rapids, and upstream of Split Lake) and at Manasan Falls based on the suspended sediment data collected by the Manitoba Department of Natural Resources. Guilbault et al. (1979) compared pre-CRD (1961-1976) and post-CRD (1976-1977) water quality parameters including turbidity in Burntwood River near Thompson.

Post-CRD water samples were collected for suspended sediment concentration and chemical analysis on the Burntwood River, Thompson pumphouse, Birch Tree Lake, Ospwagan Lake, Mystery Lake, and O dei River from July to October 1981 by Manitoba Hydro (Manitoba Hydro 1982). The effects of LWR and the CRD on water quality of the Burntwood at Thompson was also investigated by comparing water chemistry data for pre-development (from 1972 to 1976) and post-development (1976-1984) by Playle and Williamson (1986).

As part of the Wuskwatim GS aquatic studies, bottom substrate samples were collected and analyzed for particle size composition in Birch Tree Lake in 2000 and 2001 (Zurm and Neufeld 2003d) and in Opegano Lake and the Burntwood River (between Wuskwatim and Opeganao lakes) from 1998 to 2001 (Zrum and Juliano 2004).

KGS Acres (2009g) analyzed sediment data (including turbidity and TSS concentration) collected in 2003 along the Burntwood River from Wuskwatim Lake to Spilt Lake, and in Opegano and Birch Tree lakes. The report discussed the nature of TSS distribution and its dependency on climate factors such as wind in the Burntwood River, and Opegano and Birch Tree lakes. It also presented a relationship between Tu and TSS.

The Wuskwatim GS EIS presented the pre-construction sediment load and sedimentation processes in the Wuskwatim GS project area and evaluated the potential effects of the lake erosion changes associated with construction and operating of the project on sedimentation in the Burntwood River (Wuskwatim EIS Vol. 1, 2003a).

Wuskwatim Generation PEMP was initiated by Manitoba Hydro on behalf of the Wuskwatim Power Limited Partnership to document various physical environment parameters during the construction and operational phases of the Project (Wuskwatim Generation Project PEMP 2007a). As part of this monitoring program, sediment parameters including suspended sediment, bedload, bed material and turbidity data have been collected on the Burntwood River from Early Morning Rapids to Split Lake since 2005. The water quality and sedimentation data collected under this program are presented in several reports prepared by KGS Acres (2008a, 2010a, b, c, d, e, 2011) and HATCH (2011a, b, c, 2012, 2013a, b, c). A summary of each year’s PEMP monitoring activities and collected sediment data is presented in the PEMP annual reports. The latest PEMP report presents sediment data collected in 2012 along with a summary of the sediment data collected since 2005 under this program (Wuskwatim Generation Project PEMP 2012/2013 Annual Report, 2013).
Some sediment data has also been collected on the Burntwood River between the Wuskwatim GS and Split Lake since 2007 as part of the Wuskwatim GS AEMP. Collected data includes TSS, turbidity, substrate type, and sediment depositional rate (Wuskwatim GS AEMP 2007b). A summary of each year's AEMP monitoring activities is presented in the AEMP annual reports. The turbidity data collected under this program are presented in several reports prepared by KGS Acres (2010b, 2011) and HATCH (2012, 2011c).
Legend

- Existing Generating Stations (G.S.)
- Control Structures (C.S.)
4.3.11  **ZONE 10 - SPLIT LAKE TO GULL RAPIPS**

4.3.11.1  **AREA OVERVIEW**

This zone covers the lower Nelson River including Split Lake to just upstream of Stephens Lake as shown in Map 4-24. Major lakes in this zone include Split, Clark, and Gull lakes. There are currently no structures related to hydroelectric development in this zone although the proposed Keeyask GS would be located at the downstream end of this zone at Gull Rapids.

4.3.11.2  **Erosion**

The LWCNRSB divided Zone 10 into two main reaches (Water Resources Branch 1974). Split Lake formed the upper reach. About 98% of the Split Lake shoreline is bedrock-controlled, with a mix of shoreline types consisting of low bedrock-controlled shorelines (type 15), bedrock-controlled shorelines with an overburden beach (type 14), steep bedrock shorelines (type 11), and low bedrock shorelines with shallow backshore overburden (type 13). Low alluvial and low willow shorelines comprised the final 2% of the Split Lake shoreline. The lower reach extends from the outlet of Split Lake to the upper end of the Kettle forebay. About 80% of the lower reach consisted of low bedrock shorelines with shallow backshore overburden. About 10% consisted of bedrock-controlled shorelines with an overburden beach. The final 10% consisted of low willow shoreline.

LWCNRSB (1975) predicted the erosional response of Zone 10 to the CRD. Around Split Lake, the type 15 and 14 shorelines were anticipated to recede by about 3 to 6 m following the CRD. The steep bedrock shorelines were not expected to respond to impoundment. The low alluvial and low willow shorelines were anticipated to see the severest flooding due to their low relief. Minimal erosion was anticipated between the outlet of Split Lake and the upper end of the Kettle forebay.

As part of the CRD erosion studies (Manitoba Hydro 1982a, 1983a, 1984, 1985a, 2001b), one site within Zone 9 was monitored in 1981. However, it appears that this site has not been monitored since 1981. Four erosion monitoring transects are presently being monitored near the settlement of York Landing, but no results have been reported to date.

JDMA (2007) presents the results of an air photo, map and literature study describing the physical environment and shoreline classification around the community of Split Lake for defining suitable shore monitoring and repair guidelines. Shoreline recession was mapped from multiple sets of air photos. The south shore of the peninsula where the Split Lake community is located has been eroding at an average rate of 0.2 to 0.4 m/y between 1947 and 2003. In contrast, the north shore appeared relatively stable over this period. However, shoreline erosion has been observed recently along the north shore, where riprap has been placed for shore protection (J. Tutkaluk, pers comm 2014).

JDMA (2012a) discussed shore zone processes that result in erosion of mineral soil in the existing environment of the proposed Keeyask Generation Project. The report summarized data from stereoscopic air photos, published literature and reports, multi-season field observations and photographs, shore zone classification data, air photo terrain mapping, shore zone video, erosion transect data, nearshore cores, and Manitoba Hydro’s ice reconnaissance reports and videos. Historical average
May 2014

post-CRD annual bank recession rates were below 0.25 m/y over the majority of the mineral shoreline length. Maximum bank recession rates rarely exceeded 1-2 m/y. These high rates were restricted to relatively localized shoreline areas where river flow was channelized against shore banks by ice dams that typically formed below Birthday and Gull rapids on an annual basis.

JDMA (2012b) presented results of analyses done to project future bank recession and sediment loads due to erosion of mineral soil shores without the Keeyask Project in place. Future bank recession rates were projected based on rates measured using air photos dated 1986 to 2006 and from erosion transects surveyed in the summers of 2006 and 2007.

ECOSTEM Ltd. conducted several peatland disintegration, shoreline characterization and land area loss studies for the Keeyask Generation Project physical and terrestrial environment assessments. Existing shoreline and peatland conditions in the reach from Clark Lake to the Long Spruce GS are described in Keeyask Hydropower Limited Partnership (2012a, b) and ECOSTEM Ltd. (2011; 2012a, b, c). Historical air photos, field transects and laboratory studies were used to document flooded land area, historical peatland breakdown, peat resurfacing rates and land area losses over a variety of periods at several locations on the Rat/ Burntwood and lower Nelson rivers. Physical and biological factors controlling peatland disintegration processes and land area losses were evaluated through comparisons within and between multiple locations on the Rat/ Burntwood and Nelson rivers affected by past hydroelectric flooding and water regulation. These studies also included predictions of future shoreline composition, resurfacing of flooded peat and the amount of organic material (peat) released into the aquatic system with and without the Keeyask GS. ECOSTEM Ltd. (2011a, b) report on physical properties of peat relevant for peatland disintegration processes and organic sedimentation.

4.3.11.3 **Sedimentation**

Most of the studies conducted before and after the CRD were focused on Split Lake, with limited mention of Clark and Gull lakes. However, in the past decade sediment monitoring plans were initiated in this zone to facilitate the EIS of the proposed Keeyask GS. A brief account of the studies conducted in this region is given below.

Schlick (1968) reported turbidity in Split Lake measured in 1966, while comparing the productivity of the Nelson and Burntwood rivers. Manitoba Hydro (1970, 1971, 1973) presents results of water sampling for suspended sediment concentration conducted from 1969 to 1972, and published the results under the scope of CRD surveys. Hecky and Harper (1974) had also recorded TSS values in Split Lake while studying the primary productivity of the lower Churchill lakes. Cleugh (1974) surveyed the hydrography of lower Churchill lakes and reported TSS values in Split Lake. Both of these studies were commissioned by the LWCNR Study Board. The final LWCNRBS reports (1975a, b, c, d) contain turbidity values measured at different locations along the diversion route, including Split Lake. Penner et al. (1975) undertook a physical impact study to examine the effects of hydro developments on the lower Nelson River. This study focused towards assessing the sediment load and provided a prediction for post-development. Average TSS concentrations in Zone 10 were provided in this report.

Manitoba Hydro (1982) published turbidity and TSS concentrations for Split Lake obtained from water sampling that was conducted in the open water season of 1981. Manitoba Environment and Workplace
Safety & Health investigated the effects of LWR and the CRD on water quality by comparing pre-development (1972-1976) water chemistry data with the post-development (1976-1984) data. Split Lake was included in this study area. The findings of this comparison were published in Playle and Williamson (1986).

FEMP reports (Environment Canada and DFO 1987, 1988, 1989a, b, c, 1990) documented the sedimentation studies, observations, and assessments initiated under this program. The related activities included sediment budget analysis, morphological assessment, and sediment coring for quantitative assessment of sedimentation along the diversion route, including Split Lake. Some TSS and Secchi disk readings were also noted. Summaries of these reports were published in two technical documents and one summary report (Environment Canada and DFO 1992a, b, c).

The effects of hydroelectric generating stations on Split Lake were evaluated by Split Lake Cree – Manitoba Hydro joint studies. During this process, Lawrence (1996) reviewed previous studies and available data to identify the gaps. An environmental monitoring program was recommended and sediment monitoring was initiated in 1996. Turbidity and TSS concentrations in a reach from Split Lake to Stephens Lake have been recorded since 1996.


Sedimentation monitoring has been performed at Split Lake as part of a program conducted by Manitoba Hydro to address concerns raised by Tataskweyak Cree Nation regarding the potential impact of Wuskwatim GS on suspended sediment in Split Lake. Sedimentation data collected includes bed material, TSS, and turbidity. Data has been collected since 2007 at selected sites located in this zone (Schneider-Vieira and Hnatiuk 2009, 2010, 2011, 2013).

As part of the Keeyask Generating Station EIS studies, Manitoba Hydro initiated an extensive sediment data collection program to perform sedimentation studies in the reach spanning from Clark Lake to the location of proposed Keeyask GS. Given below is an account of the major sedimentation studies conducted by Manitoba Hydro and the consultants in the study area since 2004.

KG S Acres (2009g) analyzed sediment data (including turbidity, and TSS concentration) collected in 2003 in an area from Wuskwatim Lake to Split Lake. The report discussed the nature of TSS distribution in Wuskwatim Lake, its dependency on climate factors such as wind and its effect on TSS concentration in the downstream lakes including Split Lake. Acres Manitoba Ltd. (2004) performed a preliminary sediment budget analysis for the proposed Keeyask GS. In this study TSS, turbidity, and bed material samples collected by North South Consultants (in 2001-2003) and by Acres Manitoba (in 2004) from the river reach from Split Lake to Stephens Lake were used. Manitoba Hydro (2006) collected TSS and turbidity
data at variable depths over several sections across the Nelson River from Clark Lake to the proposed location of Keeyask G.S. Bed loads were measured at all TSS measurement locations.

Acres Manitoba (2009) provides an assessment of suspended and total sediment loads carried by the Nelson River using data collected since 2001. The study area spans from Clark Lake to Kettle G.S. KGS Acres (2010e) provided Split Lake turbidity data collected in 2009. KGS Acres (2011) compiled the Split Lake turbidity data from 2007 to 2010, collected as a component of the Wuskwatim G S PEMP.

KGS Acres (2012a) provided an assessment of transport and deposition of mineral sediment for the during operation phase of the Keeyask G S in Stephens Lake. KGS Acres (2012b) also established a relationship between TSS and turbidity in the proposed Keeyask G S project area using data collected from 2006 to 2010.

HATCH (2011c, 2012) presented the continuous turbidity data measured during 2010 and 2011 in Split Lake. HATCH (2013d) summarized field data (TSS, turbidity, sediment composition) collected by Manitoba Hydro in 2009 and 2011 within the Trapline 13 area and on Split Lake at York Landing to establish baseline sedimentation data prior to the development of the proposed Keeyask Generation Project. Historic sedimentation data was included in this report in tabular form as a reference.
4.3.12  ZONE 11 – STEPHENS LAKE TO LIMESTONE GS

4.3.12.1  AREA OVERVIEW

Shown in Map 4-25, this zone covers Stephens Lake and the lower Nelson River downstream to the Limestone GS and includes Manitoba Hydro’s three biggest generating stations. The Kettle GS is located at the downstream end 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.

4.3.12.2  EROSION

The LWCNRSB divided Zone 11 into two main reaches (Water Resources Branch 1974). The upper reach consists of Stephens Lake (i.e., the Kettle GS forebay), which was flooded in two stages in the falls of 1970 and 1971, with the increase in water level varying from about 30 m at the dam to about 13 m at the base of Gull Rapids. The lower reach extends from the Kettle GS to the present location of the Limestone GS. The highest banks along the Nelson River were found in this reach. Ice-scoured till banks (type 21) formed about 80% of the reach. Portions of these banks were very steep with the winter trim line extending as much as about 15 m above the open water level. The vegetation below the trim line was limited to grasses and small stunted willows. Above the trim line, a closed forest of white and black spruce was found. Bedrock was frequently found at the open water shoreline. The remaining 20% of the banks were characterized as slumping overburden shorelines (type 25). The lower half of these banks was frequently steep and bare.

LWCNRSB (1975) predicted the erosional response of Zone 11 to the CRD. However, the subsequent flooding associated with the construction of the Long Spruce and Limestone generating stations was not considered in that study. The physical impact of these hydroelectric developments was forecasted by Penner et al. (1975) using a refined shoreline classification system tailored for the lower Nelson River.

As part of the Physical Impact Study (Water Resources Branch 1974), the impact of hydroelectric development was assessed at the Kettle forebay. The Kettle forebay was formed over two stages in the falls of 1970 and 1971. The increase in level varies from a maximum of 30 m at the dam to a minimum of 13 m at the base of Gull Rapids. The readjustment process involved undercutting due to wave action on high till banks, extensive thawing of permafrost throughout the reservoir resulting in widespread areas of instability and slumping, large areas of flooded vegetation with some floating peat islands, severe erosion of overburden banks and midstream islands. No impact was observed over about 5% of the shoreline where bedrock formed the shoreline. Severe impact was observed over the remaining 95% of the shoreline, with impacts consisting of flooded vegetation, erosion and permafrost thawing.

Manitoba Hydro (1992) presented erosion monitoring results from a fall 1991 survey at 12 sites along the Limestone forebay. Surveyed profiles from as early as 1986 were plotted with surveys from all subsequent years up to 1990 to provide a record of pre-development erosion. A second set of plots were presented with the fall 1991 surveys included, showing post-development erosion. Photographs were presented to illustrate post-development conditions.
Penner et al. (1975) evaluated the geomorphology and river processes present along the lower Nelson River, downstream of the Kettle GS. The present shoreline state was mapped and data on stratigraphy, permafrost characteristics, ice processes, sedimentation, and vegetation were collected and analyzed. Overall, the study dealt with three aspects of the river environment: the banks and shoreline, the vegetation, and the delta. The physical impact of the reservoirs planned for the lower Nelson River at four sites between the Kettle GS and Gillam Island was assessed. The effects of the reservoirs on the current delta forming processes were estimated. Timber clearing guidelines for the flooding banks along the lower Nelson River were proposed.

JDMA (2011) calculated historical bank recession rates on Long Spruce and Limestone forebays by mapping and measuring the top-of-bank position on 1993 and 2006 air photos. This document provides a brief summary of the methods used and deliverables generated. This study utilized georeferenced air photos for the Limestone and Long Spruce forebays (JDMA 2011g, h).

JDMA (2011m) reports on sediment cores extracted from Long Spruce and Limestone forebays, which are regarded as proxy sites for the Conawapa project. The 2007 coring operations indicate that the deposition of finer-grained cohesive sediment was very limited and discontinuous within the Long Spruce and Limestone forebays during the post-flooding period. However, no offshore cores or cores taken from immediately upstream of the dams have been acquired. Subsequently, nearshore sediment cores were collected at the mouths of two creeks in the Long Spruce forebay and two creeks in the Limestone forebay to assess potential impacts on sedimentation in flooded creek mouths (JDMA 2011a). Twenty-four sediment cores were collected to determine whether the flooded mouths of tributary streams have served as sediment traps.

Erosion monitoring transects were established on Stephens Lake and on the Long Spruce forebay in 2006. However, no documents describing the results of these surveys have been found.

### 4.3.12.3 Sedimentation

Sediment related studies in this zone before and after the CRD are rare. Most of the sedimentation related work has been done to support the of the proposed Keeyask GS and planned Conawapa GS EIIs. Also, a few water quality studies contain discreet accounts of TSS and turbidity at selected locations. A brief account of the studies conducted in this region is given below.


Acres Manitoba (2004) performed a preliminary sediment budget analysis for the proposed Keeyask G.S. In this study TSS, turbidity, and bed material samples collected by North South Consultants Inc. (in 2001-2003) and by Acres Manitoba (in 2004) from the river reach from Split Lake to Stephens Lake were used. Acres Manitoba (2009) contains an assessment of suspended and total sediment load flowing through the study area using data collected since 2001. The study area spans from Clark Lake to Kettle G.S.

Savard and Cooley (2011) conducted a sediment sampling program and produced sediment sampling size distributions of the suspended particles in the Limestone forebay.

K.G.S Acres (2012a) provided an assessment of transport and deposition of mineral sediment for the during operation phase of the Keeyask G.S. The assessments included quantification and spatial distribution of post-project TSS concentrations, and nearshore and offshore deposition. The study area spans from Clark Lake to the proposed location of the Keeyask G.S. K.G.S Acres (2012b) also established a relationship between TSS and turbidity in the proposed Keeyask G.S project area using data collected from 2006 to 2010.

North/South Consultants (2012) documented the AEMP of Limestone G.S. As part of this program, water quality sampling, including TSS and turbidity, was performed along the Nelson River from Stephens Lake to Port Nelson during 1989-2003.

K.G.S Acres (2012c) discussed sediment regimes in the Lower Nelson River from Kettle G.S at the exit of Stephens Lake to Gillam Island near the start of the Nelson River estuary. Temporal and spatial analysis of sedimentation data and contributing factors such as wind, precipitation and discharge on sediment load were presented in this report.

Water quality parameters including suspended sediment and turbidity in the north and south basins of Stephens Lake are monitored every three years as part of CAMP (CAMP 2014b, CAMP unpubl. data). Also, the Limestone forebay is sampled every winter (i.e., when the riverine site is unsafe); the forebay is sampled during the open-water season every three years as part of CAMP (CAMP 2014b, CAMP unpubl. data).
RCEA
Erosion and Sedimentation Zone 11
4.3.13 ZONE 12 – LIMESTONE GS TO GILLAM ISLAND

4.3.13.1 AREA OVERVIEW

This zone covers the lower Nelson River from the Limestone GS to Gillam Island as shown in Map 4-26. Gillam Island is the upstream extent of tidal influence from the Nelson River estuary. There are currently no hydroelectric structures located in this zone although the planned Conawapa GS would be located 18 mi (29 km) downstream from the Limestone GS.

4.3.13.2 EROSION

The LWCNRSB divided Zone 12 into two main reaches (Water Resources Branch 1974). The upper reach extends from the Limestone GS to Goose Creek. Here, the river has eroded itself into the Paleozoic bedrock so that 80% of the bed and bank material is limestone (type 12 shorelines). The height of the winter trim line exceeds that of the bedrock shorelines in this area by up to 10 m, which results in either slumping in the banks above or an ice-modified terrace above the bedrock shoreline. The remaining 20% of the upper reach consists of ice-scoured till banks (type 21) or shorelines in slumping overburden (type 25). The lower reach consists of roughly equal portions of ice-scoured till bank and shorelines in slumping overburden. These banks are similar to those in the upper reach, except that thaw-induced slumping is more widespread and the height of the winter trim line decreases with proximity to Hudson Bay.

LWCNRSB (1975) predicted the erosional response of Zone 12 to the CRD. The vertical bedrock shorelines (type 12), which formed 80% of the upper reach, were not expected to be influenced by raised open water levels. Higher winter water levels, however, were anticipated to increase the slumping of overburden that mantles the bedrock cliffs. It was anticipated that the altered water regime would have minor effects on the ice-scoured till banks (type 21), with only localized erosion and bank slumping near the shoreline. The shorelines in slumping overburden were expected to experience an increase in the rate of erosion and consequent slumping in the locations where banks were already actively eroding. However, the slumping overburden shorelines in Zone 12 were generally viewed as protected from erosion at normal water levels by a boulder or cobble layer along the shoreline, and it was mainly at higher water levels that these shorelines were expected to be vulnerable.

Conawapa-related research is ongoing and none of the reports mentioned below are finalized reports. The references in the reference list indicate whether the report status is in draft stage or if it has reached REV-0 status, meaning that it is still not final but signoff sheets have been completed.

JD MA (2011b) made an assessment of historical changes in geomorphology of the lower Nelson River using 1:250,000 scale topographic maps. The topographic maps used were developed based on air photos and field surveys from the 1950s. Features identified in these maps were compared with features identified in a 2006 orthoimage. From these comparisons, it appeared that there has been very little change in the overall morphology of the Nelson River since the 1950s.

JD MA (2011c) characterized the geomorphology of the planned Conawapa forebay and the materials along the banks. Landforms were mapped from air photos. Materials and stratigraphy were described.
based on field observations and grain-size analyses. This document described the methods and deliverables. JDMA (2011d) digitized a bedrock subcrop map produced by D.S. Matheson during low flow explorations in September 1986. JDMA (2011e) digitized the shoreline classification applied to the lower Nelson River by Penner et al. (1975).

JDMA (2011f, k) made preliminary estimates of minimum, maximum and mean erosion rates using 1993 georeferenced air photos (JDMA 2011i) and 2006 orthoimagery. These rates were used to provide a preliminary estimate of sediment delivery from bank erosion. The mass of eroded sediment was also estimated using transect surveys conducted in 2006, 2007, and 2008.

JDMA (2013a) represents a draft report on the erosional response of the shores of the Nelson River to the construction of the Limestone GS. Air photos acquired in 1985 were compared with 2006 imagery to search for downstream changes since the construction of the Limestone GS. The study also compared 1954 air photos with 2003 imagery at selected locations between the Angling River and Gillam Island. Historical ice observations indicated that the ice front progressed to the Limestone Cofferdam or further upstream prior to construction of the Limestone GS, and after that time the ice front generally advanced only as far as Lower Limestone Rapids or rarely to Sundance Rapids. Thus, since construction the 8 to 10 m of staging associated with the advancement of the ice front did not occur as frequently between Sundance Rapids and Lower Limestone Rapids, and it is not known to have occurred upstream of Sundance Rapids. High winter water levels are essential for causing erosion over much of this reach, because bedrock generally prevents erosion at the open water shoreline. The trim line has become vegetated upstream of Sundance Rapids since 1985, and this increase in vegetation was observed to diminish with distance downstream of Sundance Rapids. In summary, a reduction in the amount of erosion since the construction of the Limestone GS has been inferred in most locations upstream of Lower Limestone Rapids that would previously see erosion during the winter when water levels were raised up above the bedrock open water shoreline.

JDMA (2013b) assessed historical rates of erosion at five sites containing heritage values along the lower Nelson River. Four air photos from 1954 and one from 1971 were compared with the 2003 orthoimagery and the 2004 LiDAR digital elevation model. Detectable bank erosion was observed only in six locations within four of the five sites considered. These locations represented the zones where the greatest amount of erosion would have occurred historically. The amounts of recession measured ranged from 1 to 30 m.

JDMA (2013c) described and quantified the existing erosional conditions on the banks of fourteen tributaries within the hydraulic zone of influence of the planned Conawapa project. Erosion along these tributaries was too slight to be detected using air photos and therefore had to be estimated qualitatively. The Angling and Weir rivers were also considered. JDMA (2013d) provided an estimate of future bank erosion in the tributaries dealt with above. The eroded sediment volumes estimated were based on the projection of estimated historical rates of erosion.

JDMA (2013e) documented the nature of and controls on mass wasting landforms and processes in the existing environment of the planned Conawapa forebay. The document integrated data from several sources, including field observations, previous work, erosion transect data, borehole logs, LiDAR data, climate data, tree-ring analysis, and vertical and oblique aerial photos. Erosional activity and landforms were investigated at several sites. Field observations were made at the three Conawapa sites where the
largest amount of erosion had been recorded in transect surveys. A distinct lack of erosion recorded on most transect sites was attributed in part to the presence of an erosion-resistant open water shoreline. A slope failure classification was developed for this part of the Nelson River consisting of four types: rotational slips, failures related to perched groundwater flow systems, earthflows, and surficial slides on burned forest slopes.

Van Zeyl et al. (2013) investigated a landslide that occurred in Horseshoe Bay in December 2008. The failure occurred between December 14 and 17, 2008, in the upper part of a 45 m-high, northwest facing bank of the Nelson River, within 1 km downstream of the planned Conawapa GS. The slope failure occurred at a spring site in a bay associated with a buried valley. The sediment input to the river from this event was roughly 20,000 to 25,000 m³. The source zone consisted of a 25 m-thick zone of water-bearing sand and gravel confined between ice-rich silty clay at the top of the bank and laminated to rhythmically bedded silt and clay at the base of the section. The collapse was confined to the material above the basal silts and clays and was associated with a perched groundwater flow system. A strong argument for drainage cutoff by the advancement of seasonal frost has been demonstrated through the correlation of the bank collapse with the timing of a significant cold snap recorded at two nearby weather stations. The failure illustrates the importance of stratigraphy in controlling bank erosion in this area. Previously, fluvial erosion was seen as an important control on mass wasting in Horseshoe Bay. However, surface information suggested that no toe erosion except to remove the slide deposit had occurred at this site since 2004.

4.3.13.3 Sedimentation

The earliest study on the lower Nelson River sediment regime was undertaken by Penner et al. (1975). This physical impact study was initiated to examine the effects of the proposed hydro development (including Long Spruce, Limestone, Gillam Island reservoirs) on bank erosion, sediment transport, permafrost, and on the ice regime along the lower Nelson River.


Capar and Gill (2008a, b) presented information on benthic invertebrate and sediment samples collected from the lower Nelson River mainstem (between Limestone GS and Long Island) during open water season in September/October 2002 and September 2003.

Savard and Cooley (2011) reported the 2010 sediment quality sampling program that was conducted at three sampling locations on the lower Nelson River from Limestone GS forebay to Deer Island. Results of this sampling program indicated that sediment particle size in suspension were coarser with increased distance from the Limestone GS. The turbidity data was also recorded and reported for this reach.

KGS Acres (2012b) discussed the sediment regime in the lower Nelson River from Kettle GS at the exit of Stephens Lake to Gillam Island near the start of the riverine portion of the Nelson River estuary. Temporal and spatial analysis of sedimentation data and contributing factors such as wind, precipitation and discharge on sediment load were presented in this report. Based on an extensive sedimentation data collection program in the open water seasons of 2005 to 2008 and the winters of 2007/2008 to
2009/2010, suspended load, bedload and total load carried by the Nelson River between Limestone G S forebay to upstream of Gillam Island were estimated (KGS Acres 2012c). Sediment parameters collected and analyzed in these studies included TSS measurements, particulate size, continuous turbidity, bed material samples, and bedload. A summary of field activities and sediment parameters collected each year are presented in several field reports (KGS Acres 2007, 2008b, c, 2009a, b, c, d, e, f, 2010f, g, h, i, j). A relationship was developed between TSS and turbidity using data collected in the period of 2006 to 2009 on the lower Nelson River (KGS Acres 2014).

Sediment transport under dynamic variation of ice condition (during ice formation, before break-up, and during the break-up period) was studied in an area downstream of planned Conawapa G S (Weiss et al. 2013; Zare et al. 2013; Moore et al. 2013).

Water quality parameters such as suspended sediment and turbidity in the lower Nelson River below the Limestone G S are sampled three times annually under CAMP (CAMP 2014b, CAMP unpub. data).
Legend

- Existing Generating Stations (G.S.)

Map 4-26

RCEA

Erosion and Sedimentation Zone 12
4.3.14 Scientific References

4.3.14.1 Erosion References

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