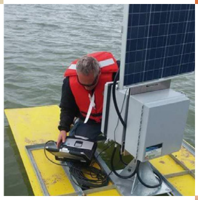
CAMP

Coordinated Aquatic Monitoring Program



Six Year Summary Report

Technical Document 1:
Introduction, Background, and Methods

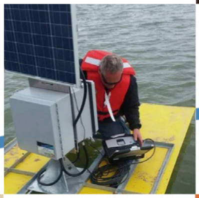
2008-2013

Submitted to:
Manitoba/Manitoba Hydro MOU Working Group

2017

Report Citation:

Coordinated Aquatic Monitoring Program (CAMP). 2017. Six Year Summary Report (2008-2013). Report prepared for Manitoba/Manitoba Hydro MOU Working Group by North/South Consultants Inc., Winnipeg, MB.



TECHNICAL DOCUMENT 1:
Introduction, Background, and Methods

- Introduction and background
- CAMP regional descriptions
- Sampling and laboratory methods
- Reporting approach and data analysis methods

TECHNICAL DOCUMENT 2:
Winnipeg River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

TECHNICAL DOCUMENT 3:
Saskatchewan River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic habitat

TECHNICAL DOCUMENT 4:
Lake Winnipeg Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

TECHNICAL DOCUMENT 5:
Upper Churchill River Region

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic Habitat

TECHNICAL DOCUMENT 6:
Lower Churchill River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

TECHNICAL DOCUMENT 7:
Churchill River Diversion Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

TECHNICAL DOCUMENT 8:
Upper Nelson River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic habitat

TECHNICAL DOCUMENT 9:
Lower Nelson River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

SIX YEAR SUMMARY REPORT (2008-2013)

Technical Document 1:
Introduction, Background, and Methods

by

North/South Consultants Inc.
83 Scurfield Blvd.
Winnipeg, MB R3Y 1G4
Tel: (204) 284-3366   Fax: (204) 477-4173
Email: info@nscons.ca

2017

TABLE OF CONTENTS

Page

Page

Page

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

ABBREVIATIONS AND ACRONYMNS

AIS	Aquatic invasive species
ANOVA	Analysis of variance
BCMOE	British Columbia Ministry of the Environment
BMI	Benthic macroinvertebrate(s)
CAMP	Coordinated Aquatic Monitoring Program
CALA	Canadian Association for Laboratory Accreditation Inc.
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CPUE	Catch-per-unit-effort
CRD	Churchill River Diversion
CRDR	Churchill River Diversion Region
CS	Control structure(s)
DELTs	Deformities, Erosion, Lesions, and Tumours
DFO	Fisheries and Oceans Canada
DL(s)	Detection limit(s)
DO	Dissolved oxygen
EC	Environment Canada
ECCC	Environment and Climate Change Canada
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)
EPT:C	Ratio of the combined abundances of Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) to the abundance of Chironomidae (non-biting midges)
FEMP	Federal Ecological Monitoring Program
GIS	Geographic information systems
GPS	Global positioning system
GS	Generating Station
ISQG	Interim sediment quality guideline
ITIS	Integrated Taxonomic Information System
K_F	Condition Factor
KHLP	Keeyask Hydropower Limited Partnership
kWh	Kilowatt hours
LCRR	Lower Churchill River Region
LEL	Lowest effect level
LKWPGR	Lake Winnipeg Region
LNRR	Lower Nelson River Region
LWCNRSB	Lake Winnipeg, Churchill and Nelson Rivers Study Board
LWR	Lake Winnipeg Regulation
MEMP	Manitoba Ecological Monitoring Program
MGET	Manitoba Growth, Enterprise and Trade
MoU	Memorandum of Understanding
MW	Megawatt

MWQSOGs	Manitoba Water Quality Standards, Objectives, and Guidelines
MWS	Manitoba Water Stewardship
MSD	Manitoba Sustainable Development
NAS	North American Standard
NSC	North/South Consultants Inc.
OECD	Organization for Economic Cooperation and Development
OSM	Ontario Small Mesh
PAL	Protection of aquatic life
PEL	Probable effect level
ppm	Parts per million
QA/QC	Quality assurance/quality control
QTC	Quester Tangent Corporation
RA	Relative abundance
RCEA	Regional cumulative effects assessment
SAC	Sediment alert concentration
SEL	Severe effect level
SQG(s)	Sediment quality guideline(s)
SRR	Saskatchewan River Region
TSS	Total suspended solids
UCRR	Upper Churchill River Diversion
UNRR	Upper Nelson River Region
WRR	Winnipeg River Region

1.0 INTRODUCTION AND BACKGROUND

The Coordinated Aquatic Monitoring Program (CAMP) represents a coordinated effort between the Government of Manitoba (Manitoba) and Manitoba Hydro to implement a long-term, systematic and system-wide aquatic monitoring program across Manitoba Hydro's hydraulic operating system in Manitoba.

Over the last 35 years, numerous aquatic environmental studies and monitoring programs have been conducted by Manitoba, Manitoba Hydro, Fisheries and Oceans Canada (DFO), Environment and Climate Change Canada (ECCC; formerly Environment Canada [EC]), and several academic institutions on waterways affected by hydroelectric development in Manitoba. These studies have included:

- post-project environmental monitoring programs to determine the effects of existing facilities;
- environmental assessment studies to determine the potential effects of future hydroelectric developments;
- issue- and site-specific environmental studies to address community concerns and/or formal obligations;
- monitoring of intensively used fish stocks on the system, such as commercial fisheries;
- monitoring of water quality;
- the collection of hydrometric data;
- monitoring associated with debris management programs; and
- research in areas such as reservoir greenhouse gases, marine mammals, mercury, and Lake Sturgeon (*Acipenser fulvescens*).

Examples of large-scale and/or long-term aquatic study or monitoring programs that have been conducted along Manitoba Hydro's hydraulic system include the following:

- The Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) pre-Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR) studies conducted from 1971 to 1975;
- The Federal Ecological Monitoring Program (FEMP) conducted from 1986 to 1992;
- The Canada – Manitoba Agreement on the Study and Monitoring of Mercury in the CRD conducted from 1982 to 1985;

- The Manitoba Ecological Monitoring Program (MEMP), conducted from 1985 through 1989, which complimented FEMP and transitioned from the 1982-1985 mercury monitoring program;
- Long-term monitoring of water quality by Manitoba Sustainable Development (MSD; formerly Manitoba Conservation and Water Stewardship) and ECCC; and
- Long term mercury monitoring under various agreements from 1991-present.

The majority of Manitoba Hydro's study and research conducted to date has been focused on the northern part of Manitoba Hydro's hydraulic system. These studies have been effective at meeting regulatory requirements and assessing impacts caused by Manitoba Hydro's facilities. The studies, however, have been largely issue-driven and site-specific, which have reflected varying regulatory requirements at the time of approval of each of the facilities, and historically, greater emphasis has been placed on regions where communities are located. As a result, historical studies have not been conducted in a comprehensive or consistent manner across Manitoba Hydro's hydraulic system.

Concurrent with Manitoba Hydro's aquatic environment studies, MSD has conducted monitoring in selected waterbodies along Manitoba Hydro's hydraulic system for resource management and environmental monitoring purposes. As these programs spanned a relatively large spatial scale, they have generally been conducted with consistent methods of data collection. However, these provincial monitoring programs also contained spatial and/or temporal gaps or variations in sampling intensity or collection methods.

With the need for a long-term coordinated aquatic monitoring program between Manitoba and Manitoba Hydro recognized, Manitoba determined that a Memorandum of Understanding (MoU) should be developed to identify and coordinate existing aquatic monitoring programs and to develop or expand monitoring programs as required to ensure that a consistent system-wide approach to aquatic environmental monitoring was implemented.

Accordingly, the MoU was drafted by Manitoba and signed in 2006, and resulted in the development of CAMP. CAMP integrates components of existing MSD and Manitoba Hydro long-term monitoring programs and addresses gaps that were identified in these existing programs. This integrated approach provides the basis for the largest coordinated monitoring program undertaken in Manitoba to date.

CAMP was designed to document the environmental condition of waterways affected by Manitoba Hydro's hydraulic operating system and facilitate a better understanding over time, of the environmental effects of hydroelectric operations. The primary objectives of CAMP, as identified in the MoU, are:

- To monitor and document the physical, chemical, and biological conditions of Manitoba Hydro's existing hydraulic system, in accordance with established scientific protocols;
- To provide long-term information on key physical, chemical, and biological parameters that can be used to assess environmental conditions and track aquatic ecosystem health over time; and
- To provide information that can assist with: a) the licensing of future developments; b) the renewal of licenses at existing developments; and c) the assessment of the potential impacts of new hydroelectric developments on the existing hydraulic system[1].

CAMP was designed to collect a range of environmental information with emphasis on components that are potentially affected by hydroelectric regulation. CAMP draft objectives and protocols were developed with representatives of federal and provincial agencies (e.g., DFO, ECCC, MSD); Manitoba Hydro, and consultants, and have been presented to Resource Management Boards, First Nations, and local communities for input and feedback to help guide their development.

Data collection under CAMP was initiated in spring 2008 and began with a three year Pilot Program, referred to as the Coordinated Aquatic Monitoring Pilot Program to test methodologies and logistics for the long-term implementation of CAMP. A detailed review and analysis of results of the Pilot Program were presented in CAMP (2014). This report presents the results of the first six years of CAMP (2008/2009-2013/2014), including data collected under the Pilot Program.

This report includes a brief overview of the program, including a description of the program history, scope, components, and sampling methods, a description of the reporting approach and methods, and detailed discussion of results for selected metrics.

The six-year report includes a summary report and nine technical documents as follows:

- Technical Document 1: Introduction, Background, and Methods
- Technical Document 2: Winnipeg River Region Results
- Technical Document 3: Saskatchewan River Region Results

---

[1] Given the broad geographic scale of the program, information collected will by necessity lack the intensive sampling rigor required to prepare comprehensive Environmental Impact Statements for new facilities.

- Technical Document 4: Lake Winnipeg Region Results
- Technical Document 5: Upper Churchill River Region Results
- Technical Document 6: Lower Churchill River Region Results
- Technical Document 7: Churchill River Diversion Region Results
- Technical Document 8: Upper Nelson River Region Results
- Technical Document 9: Lower Nelson River Region Results

Technical Document 1 provides a description of:

- CAMP (background and objectives), including monitoring components and spatial and temporal scope;
- monitoring regions;
- monitoring waterbodies;
- sampling and analytical methods; and
- reporting approach and data analysis methods.

1.1 LINKAGES BETWEEN HYDROELECTRIC DEVLOPMENT AND AQUATIC ECOSYSTEMS

Hydroelectric development modifies the aquatic ecosystem through various pathways or linkages of effect. The primary physical change related to the construction and operation of a hydroelectric generating station (GS) or control structure (CS) in relation to aquatic ecosystems is an increase in upstream water levels, resulting in the flooding of existing aquatic and terrestrial habitat, and downstream changes in water levels and flows. The extent of upstream flooding depends on the design of the GS (i.e., mode of operation), as well as the topography/morphology of the upstream terrestrial habitat. Generally, the upstream waterbody is expanded and deepened and water velocities are reduced as a result of impoundment. Aquatic habitat may also be directly lost due to the footprint of physical structures and in dewatered riverbeds immediately downstream of the structures.

Systems regulated for hydroelectric generation generally experience changes in water level/flow and ice regimes in accordance with the operating regime of the hydraulic operating system. The overall range of water level/flow variation may be reduced, but the frequency of water level/flow changes can occur more frequently, than in an un-regulated condition.

Water quality may be affected both upstream and downstream of GSs due to alterations in hydrology (water levels, depths, velocities), ice regimes, and flooding of terrestrial habitat. In addition, water diversion may affect water quality in cases where the water quality of the diverted flows differs from that of the aquatic system receiving the diverted flows.

Hydraulic effects (e.g., the creation of new habitat and alteration of existing habitat) and water quality effects may create cascading effects throughout the food web. The base of the food web is often affected (e.g., altering growing conditions for primary producers, including vascular plants and algae), causing subsequent changes at successive consumer levels (e.g. lower trophic organisms, fish). Consumers are also affected directly through habitat alterations. Examples of this include the loss of fish spawning habitat due to flooding and the blockage of upstream fish movements.

Humans are linked to the aquatic ecosystem in many ways, including the harvest and consumption of fish. Important hydroelectric-related effects may include adverse effects to the abundance and quality of species that are targeted in fisheries due to the provision of increased access to fish harvesting areas, as well as effects to the quality of fish that would affect their suitability for consumption.

CAMP has been designed to monitor the condition of the aquatic ecosystems along Manitoba Hydro’s hydraulic system in consideration of these potential linkages of effect and includes monitoring of physical, chemical, and biological components of the aquatic environment.

1.2 OVERVIEW OF CAMP

CAMP was established to monitor aquatic ecosystems throughout Manitoba Hydro’s hydraulic operating system. The program was designed by Manitoba and Manitoba Hydro, with input from federal agencies (i.e., DFO, ECCC and external academic participants, to monitor key physical, chemical, and biological attributes of waterways affected by Manitoba Hydro’s hydraulic generation system, including the CRD/LWR, and hydroelectric development on the Winnipeg, Nelson, and Saskatchewan rivers in Manitoba. Sampling design and frequency were selected by Manitoba and Manitoba Hydro, with input from DFO and ECCC, to provide scientifically defensible monitoring information to meet scientific expectations and regulatory requirements within the limitations of what is technically feasible. As part of the MoU, a working group was established to oversee the development and delivery of CAMP and is responsible for submitting annual reports required under the MoU to the Minister of Manitoba Conservation and Water Stewardship and the Chief Executive Officer of Manitoba Hydro. The program is intended to be adaptive and is reviewed regularly, including through an annual workshop attended by representatives of Manitoba, Manitoba Hydro, academic institutions, ECCC, DFO, and consultants and is modified as warranted, in response to findings of the program and feedback received from workshop attendees.

CAMP was designed to provide a series of snapshots of the condition of the various aquatic ecosystems. Monitoring results will be compared to existing environmental health criteria (e.g., water quality guidelines) and to previous years' data, and over time the information gathered will be used to identify changes in the environment and assess whether these changes are as a result of hydroelectric operations, other management activities (e.g., commercial fishing), or natural variation. For the foreseeable future, interpretation of changes identified during CAMP will use a weight of evidence approach. This approach integrates results of all components of CAMP to assess whether there is evidence of change occurring and, if so, in the long-term assess whether this change can be attributed to hydroelectric operations.

1.2.1 CAMP Components

CAMP was designed based on experience from existing monitoring programs in Manitoba, Canada, and globally. CAMP incorporates an ecosystem-based approach to monitoring that includes sampling of key physical, chemical, and biological components of the aquatic environment. An ecosystem consists of the living and non-living components of the environment. Energy in the form of nutrients flows through a trophic structure/biological assemblage and transfers nutrients among living and non-living parts. An ecosystem-based approach recognizes that a stressor (e.g., hydroelectric development) may affect the larger aquatic ecosystem as well as its component parts; effects on the aquatic environment may be positive or negative.

The major components monitored under CAMP are:

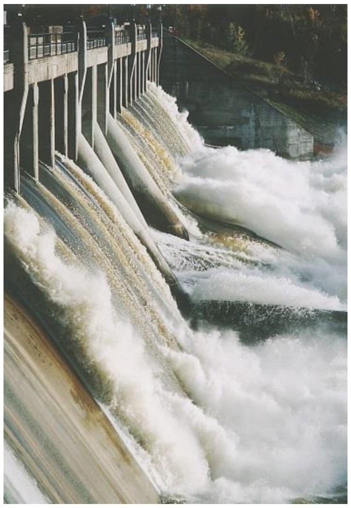
- hydrometrics;
- water quality;
- sediment quality;
- phytoplankton;
- benthic macroinvertebrates (BMI);
- fish communities;
- fish mercury; and
- aquatic habitat.

CAMP has evolved and expanded since it was first initiated in 2007, including the addition of a pilot program examining sediment transport. The CAMP working group determined that sedimentation monitoring should be incorporated into the CAMP in an effort to better understand the physical environment influences on other key parameters (fisheries, benthic, water quality, etc.) already included in the program. Monitoring began in 2013 with a sedimentation monitoring program on Playgreen Lake. This program included the collection of sedimentation data in Playgreen Lake during the open water and winter (ice covered) seasons. It was anticipated that subsequent CAMP sedimentation monitoring may be modified based on the findings of this work, other studies and stakeholder input. The report from this pilot program is included in Appendix 1. A brief description of these components is provided below.

1.2.1.1 Hydrometrics

Water levels and flows within a given system are a primary driver of aquatic ecosystem health and are a major consideration in water management decision making. Therefore a good understanding of past, present and forecasted water levels and flows within a given system are a necessity. Consequently, the collection of detailed hydrometric information is fundamental to making better water management and aquatic ecosystem health decisions.

Water Survey of Canada, Manitoba Sustainable Development, and Manitoba Hydro are the operating agencies for the Canada-Manitoba Hydrometric Program, the provincial component of the National Program. Hydrometric data used by Manitoba Hydro is collected, analyzed and published using processes and procedures referenced under these programs. A number of monitoring sites have been added to Manitoba Hydro's network of hydrometric stations to provide data for CAMP.



Generating Station Spillway

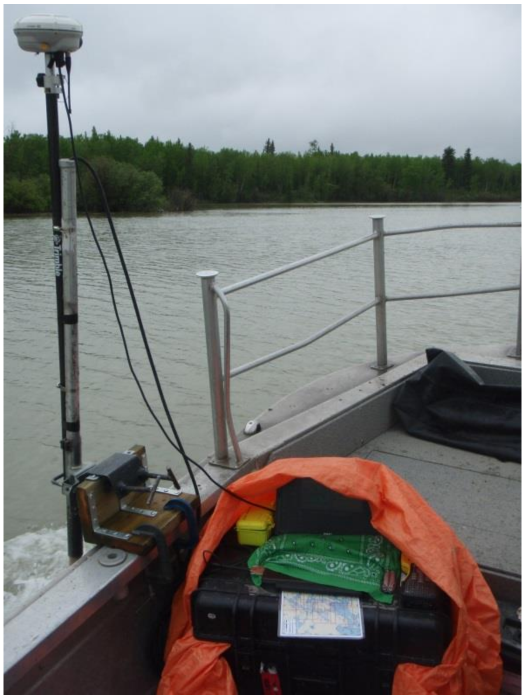
Nelson River and the Limestone GS

1.2.1.2 Aquatic Habitat

Aquatic habitat refers to the environment in which fish and other aquatic organisms live, and includes the physical, chemical, and biological constituents of the water, sediments, and terrestrial interface. However, as a component in CAMP, aquatic habitat refers only to physical attributes of the aquatic environment including water depth, velocity, substratum and cover (e.g., aquatic vegetation, terrestrial debris, and riparian vegetation). Changes in the quantity or quality of aquatic habitat can affect fish or other aquatic biota either directly (e.g., impediment of fish movements) or indirectly (e.g., altering food supply).

Inventorying and cataloguing aquatic habitats within Manitoba Hydro’s hydraulic operating system is being conducted under CAMP to provide information to support the interpretation of results of aquatic ecosystem monitoring and to establish a baseline against which the effects of future water flow manipulations on aquatic ecosystems can be assessed.

Results of aquatic habitat surveys are presented in the form of substrate and bathymetric maps. Substrate class area as well as depth, slope and volume statistics are calculated and tabulated for each waterbody surveyed. These and other physical habitat variables (e.g., velocity, aquatic and riparian vegetation) are ultimately expected to become key pieces of a broader habitat classification scheme that will be applied to all CAMP waterbodies as the program evolves.



Hydroacoustic sampling on Cross Lake.

Ponar substrate grab on Cross Lake

1.2.1.3 Water Quality

Water quality is of fundamental importance to all aquatic biota in an ecosystem and is also important from a human perspective (e.g., use as drinking water, irrigation, recreation, aesthetics). Water quality may be defined as the chemical (e.g., nutrients), physical (e.g., water temperature), and biological (e.g., microbiological organisms) characteristics of water, typically in relation to its suitability for a particular purpose (e.g., support of aquatic life, recreational use). Some water quality variables are essential to aquatic life, such as nutrients or dissolved oxygen (DO), while others are non-essential (e.g., some metals such as cadmium). Water quality conditions suitable for the protection of aquatic biota depend on the species present in an ecosystem, the life stages present (e.g., fish eggs or embryos versus mature fish), and other factors that modify effects of a particular variable on aquatic life (e.g., hardness). Some water quality variables may be harmful to aquatic biota when above certain levels – these levels are often functionally defined as water quality objectives or guidelines for the protection of aquatic life (PAL). Manitoba Water Stewardship (MWS 2011) developed Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs), last revised in November 2011, which include objectives and guidelines for various water uses including aquatic life, recreation, drinking water, aesthetics, and irrigation.

Water quality parameters monitored under CAMP include key variables that may be affected by hydroelectric development and that are important from the perspective of PAL. Water quality parameters include ‘routine’ variables such as DO, pH, total suspended solids (TSS), turbidity, alkalinity, conductivity, hardness, nutrients (nitrogen and phosphorus), carbon, chloride, sulphate, and temperature, as well as metals (e.g., cadmium) and a bacterium (Escherichia coli). Additionally, chlorophyll a (a green pigment found in aquatic macrophytes and algae) is monitored at all locations as a general indicator of phytoplankton biomass, productivity, and trophic status.

Water quality sampling is conducted three times in the open-water season and once in the ice-cover season at each site during each year of monitoring.

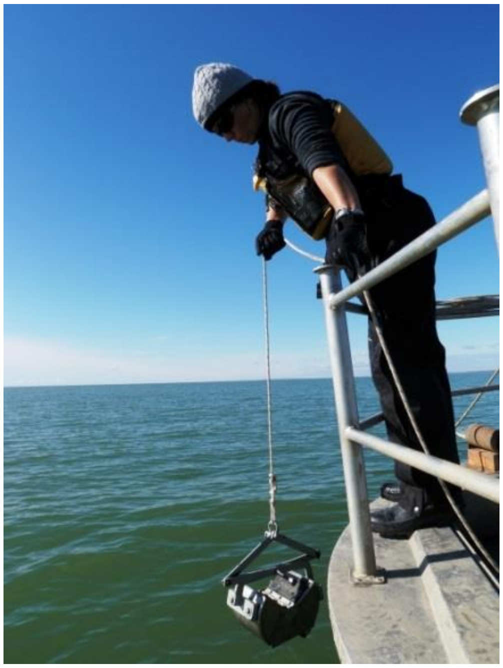
Sampling water quality at Lac du Bonnet.

Sampling water quality in the Burntwood River.

1.2.1.4 Sediment Quality

Sediment quality is of significance to the health of aquatic biota that live in or on sediments, or that directly or indirectly associate with the sediments and/or benthic communities. Sediment quality monitoring was initiated under CAMP in 2011, following completion of the Pilot Program, and includes monitoring of metals, nutrients, and supporting variables in surficial sediments. Monitoring of sediment quality under CAMP is conducted on a six year rotational basis at all annual waterbodies.

Sampling sediment quality in Assean Lake



Sampling sediment quality in Lake Winnipegosis

1.2.1.5 Phytoplankton

Phytoplankton are small, aquatic plants (i.e., algae) that are most often found suspended in the water column and form the main base of the aquatic food web. As such, they are the foundation for higher trophic levels in an aquatic ecosystem. Phytoplankton biomass and production are key indicators of the productivity of an ecosystem and are commonly monitored in aquatic ecosystems to assess the degree of eutrophication.

Phytoplankton may be affected by changes in water quality and hydrology; changes in phytoplankton abundance or composition can in turn affect invertebrate and fish populations. Although phytoplankton are a fundamental component of the aquatic ecosystem and food web, algal blooms can be problematic to aquatic biota and users of aquatic ecosystems (i.e., “nuisance blooms”), since blooms may cause oxygen depletion (i.e., due to respiration at night and/or during die-off of algal blooms), fouling of commercial fishing nets, and can also be an aesthetic nuisance. The presence of blue-green algae (or cyanobacteria) can create additional issues since certain types of cyanobacteria may produce toxins, such as microcystin, that may adversely affect aquatic biota, wildlife, livestock, and humans.

Phytoplankton taxonomic composition and biomass (i.e., taxonomic biomass) are monitored under CAMP as part of a bloom monitoring component (i.e., where chlorophyll *a* exceeds a benchmark of 10 µg/L), whereas chlorophyll *a* (an indicator of algal biomass) is measured annually at all sites. In addition, CAMP includes monitoring for a common algal toxin (microcystin) under the bloom monitoring component. Monitoring of phytoplankton community composition on an annual basis was also initiated at four waterbodies beginning in Year 2 of the Pilot Program.

Algal bloom at the inlet to Two-Mile Channel.

Species of blue-green algae (*Anabaena* sp.).

1.2.1.6 Benthic Macroinvertebrates

BMIs are small animals (can be seen with unaided eye that are 500 microns (μm) or greater) without a backbone such as worms, snails, clams, crayfish, and aquatic stages of some insects (e.g., mayflies and caddisflies). BMI live on or in the sediments in the bottom of aquatic ecosystems (lakes and rivers) and provide an important link between primary producers (e.g., phytoplankton) and fish. BMI are an ecologically important part of the food web, important food source for most fish species (at some point in their life cycle), and are well established biological indicators of aquatic ecosystem health.

BMI possess several features that make them useful as biological indicators. They are mainly sedentary (for that reason reflect site-specific impacts), ubiquitous, abundant, and are relatively easy to collect. In addition, BMI are relatively long-lived (months to years) and thereby integrate adverse effects over time, and are diverse and so respond to a wide variety of stressors.

Monitoring of BMI is one of the fundamental components of CAMP. Macroinvertebrates collected in the benthic sediments of lakes and rivers are collected from nearshore and offshore habitats. Supporting environmental data (sediment composition, water depth, etc.) at sampling locations are recorded to link the biological data to the natural habitat features. Invertebrate samples are sorted and identified to the lowest practical level (family-level, where possible); and Ephemeroptera (mayflies) are identified to the genus-level. Results are expressed in terms of metrics that describe the BMI community in each habitat type of the lakes and rivers. These metrics include measures of abundance (total numbers of BMI), composition (proportions of major BMI groups), richness (number of BMI taxa present), and a measure diversity (Simpson's Diversity Index, measure of relative abundance and distribution of BMI taxa).

BMI monitoring is conducted every year in late summer/early fall at annual waterbodies, and during the same sampling period every three years at rotational waterbodies.

BMI nearshore habitat of Cedar Lake

BMI sampling in the offshore habitat of Assean Lake

1.2.1.7 Fish Community

Fish represent most of the middle and upper trophic levels in aquatic ecosystems and many species are of direct interest to humans (i.e., harvested in subsistence, commercial, and/or recreational fisheries). The fish community is an effective integrator of effects to the aquatic ecosystem as a whole, since various fish species require different habitat types, are dependent on production from lower trophic levels, and are affected by changes to hydrology and/or water quality.

Monitoring of the fish community is a key component of CAMP. Monitoring targets both small-bodied fish species (i.e., forage fish) and large-bodied fish species (e.g., fish targeted in subsistence, commercial, and/or recreational fisheries) and includes measurements of parameters such as fish species diversity, abundance, growth, and condition. These data are used to generate key metrics - Hill’s Index, catch-per-unit-effort (CPUE), length-at-age, and Fulton’s condition factor (K_F).

Monitoring is conducted every year at annual waterbodies and every three years at rotational waterbodies.

Walleye

Northern Pike

1.2.1.8 Mercury Levels in Fish

Mercury is a naturally occurring metal that is present in abiotic media, including soils, rocks, and water, as well as biota. Mercury is introduced to aquatic ecosystems through natural and anthropogenic pathways including discharge of industrial effluents, atmospheric deposition, weathering of rock, and flooding. Inorganic mercury can be converted to the more toxic methylmercury (an organic form of mercury) through biotic (microbial) and abiotic processes. Typically, the majority of mercury found in surface waters is in inorganic form; generally, <10% of total mercury (which includes inorganic and organic forms) is present in the form of methylmercury (Canadian Council of Ministers of the Environment [CCME] 1999; updated to 2017). Methylmercury bioaccumulates and biomagnifies across food webs.

The concentration of mercury (a potent neurotoxin in vertebrates) in fish is of interest as it affects the suitability of fish for consumption by humans. Creation of reservoirs, for hydroelectric development or other purposes, commonly causes increases in mercury concentrations in fish as a result of the flooding of carbon-rich terrestrial soil and the subsequent methylation of mercury. Methylmercury enters the base of the food web and is biomagnified at each level, such that large piscivorous fish (e.g., Walleye [*Sander vitreus*]) at the top of the aquatic food web typically contain the highest concentrations.

Monitoring of fish mercury concentrations under CAMP was fully initiated in 2010 (limited monitoring occurred in 2009) and represents the continuation of a long-term mercury monitoring program conducted by Manitoba Hydro and DFO. Mercury concentrations are measured in muscle tissue of commercially important fish species (i.e., Northern Pike [*Esox lucius*], Walleye, and Lake Whitefish [*Coregonus clupeaformis*]). Monitoring of 1-year-old Yellow Perch

(*Perca flavescens*) is also conducted to provide a means for monitoring more short-term changes. Samples of fish muscle are collected during the conduct of the fish community monitoring.

Monitoring is conducted every year at two waterbodies (Threepoint Lake and Leftrook Lake) and every three years at additional sites.

Lake Whitefish

1.2.2 Spatial Scope

CAMP is conducted in eight regions (Figure 1-1) that encompass Manitoba Hydro’s hydraulic operating system as follows:

- Winnipeg River Region;
- Saskatchewan River Region;
- Lake Winnipeg Region;
- Upper Churchill River Region;
- Lower Churchill River Region;
- Churchill River Diversion Region;
- Upper Nelson River Region; and
- Lower Nelson River Region.

These regions span the province from southeastern Manitoba to the lower Churchill River in northern Manitoba, a range in latitude of 7.5 degrees. The regions encompass five of the six ecozones in Manitoba and the majority of Manitoba's ecoregions (Figure 1-2). Descriptions of the CAMP regions are provided in Section 2.0.

1.2.2.1 On-System and Off-System Waterbodies

Waterbodies or areas of waterbodies monitored under CAMP include on-system and off-system locations (Figure 1-3; Table 1-1). On-system waterbodies are those located on, and that are notably influenced by, Manitoba Hydro's hydraulic operating system (e.g., forebays and areas downstream of hydroelectric GSs and CSs). Off-system waterbodies include lakes and river reaches where water levels and flows are either entirely or largely unaffected by Manitoba Hydro's hydraulic operating system. However, some waterbodies considered as off-system may still be subject to regulation of flows by other organizations outside of Manitoba (i.e., upper reaches of the Churchill, Saskatchewan and Winnipeg rivers). Descriptions of waterbodies currently included in CAMP are provided in Section 2.0.

Reference sites are typically used in monitoring programs to account for effects or changes in a given parameter or indicator that are not related to the impact/stressor under study. Therefore, choosing a reference area that is as similar as possible to the exposure area is essential in order to interpret differences between the areas (EC 2012a). Ideal reference waterbodies are similar in all attributes except for the development/activity/stressor of interest; however, in practice, these conditions seldom, if ever, occur. Reference sites are ideally characterized by similar physical/chemical (e.g., drainage basin size, land use, soils/topography, hydrology, geology, lake morphometry, climate, aquatic habitat, etc.) and biological characteristics (community composition, population dynamics, food web structure, life history stages, etc.) as on-system sites.

Ideally, the off-system CAMP waterbodies would serve the role of reference waterbodies. However, since Manitoba Hydro's hydraulic operating system encompasses large rivers and lakes (including Lake Winnipeg), and large geographic areas and drainage basins, ideal reference waterbodies for comparison to most of these on-system waterbodies are not available. Off-system waterbodies are therefore not considered to be reference sites as used for an environmental impact assessment. Rather data collected from off-system waterbodies are intended to provide additional regional information for examining trends over time to assist in delineating the potential effects of Manitoba Hydro's hydraulic operating system from those of other stressors (e.g., climate change, presence of introduced species, management activities, etc.). Differences between on- and off-system sites, where noted, are not intended to indicate relative status of ecosystem health among waterbodies as it is recognized that these waterbodies may fundamentally differ and would not be expected to exhibit similar chemical or biological characteristics.

Sampling of on-system waterbodies addresses the primary objective of CAMP – to monitor aquatic ecosystem health along Manitoba Hydro’s hydraulic operating system. The off-system waterbodies were included in CAMP to provide regional information collected in a manner consistent with monitoring of on-system waterbodies that will assist in interpreting any observed environmental changes over time. Such comparisons are intended to help distinguish between hydroelectric-related effects and other external factors (e.g., climate change) in each CAMP region.

Table 1-1. Summary of waterbodies monitored under CAMP: 2008/2009 – 2013/2014.

Region	**Waterbody/Area**	**On-system**	**Off-system**	**Annual**	**Rotational**	**Sampling Years[1]**					
						2008/09	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**
Winnipeg River	Eaglenest Lake		X		X			X			X
	Pointe du Bois Forebay	X		X		X	X	X	X	X	X
	Lac du Bonnet	X		X		X	X	X	X	X	X
	Pine Falls Forebay	X			X				X		
	Manigotagan Lake		X	X		X	X	X	X	X	X
Saskatchewan River	Saskatchewan River	X			X			X			X
	South Moose Lake	X			X		X			X	
	Cedar Lake - southeast	X		X			X	X	X	X	X
	Cedar Lake - west	X			X				X		
	Cormorant Lake		X	X		X	X	X	X	X	X
Lake Winnipeg	Lake Winnipeg - Mossy Bay	X		X[2]		X	X	X	X	X	X
	Lake Winnipeg - Grand Rapids	X		X[2]		X	X	X	X	X	X
	Lake Winnipeg - Sturgeon Bay	X		X[2]		X	X	X	X	X	X
	Lake Winnipegosis		X	X		X	X	X	X	X	X
Upper Churchill River	Granville Lake		X	X		X	X	X	X	X	X
	Opachuanau Lake	X			X				X		
	Southern Indian Lake (Area 1)	X			X		X			X	
	Southern Indian Lake (Area 6)	X			X			X			X
	Southern Indian Lake (Area 4)	X		X		X	X	X	X	X	X

Table 1-1. continued.

Region	Waterbody/Area	On-system	Off-system	Annual	Rotational	Sampling Years [1]					
						2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Lower Churchill River	Partridge Breast Lake	X			X		X			X	
	Northern Indian Lake	X		X		X	X	X	X	X	X
	Fidler Lake	X			X				X		
	Billard Lake	X			X			X			X
	Lower Churchill River at Little Churchill River	X		X		X	X	X	X	X	X
	Lower Churchill River at Redhead Rapids [3]	X			X				X		
	Gauer Lake		X	X		X	X	X	X	X	X
Churchill River Diversion	Rat Lake	X			X			X			X
	Mynarski Lake Central	X			X				X		
	Notigi Lake	X			X		X			X	
	Threepoint Lake	X		X			X	X	X	X	X
	Footprint Lake	X			X			X			X
	Apussigamasi Lake	X			X		X			X	
	Leftrook Lake		X	X			X	X	X	X	X
Upper Nelson River	Two-Mile Channel	X		X [4]							X
	Upper Nelson River near Warren Landing	X		X [4]						X	X
	Playgreen Lake	X			X		X			X	
	Little Playgreen	X			X			X			X
	Cross Lake - West basin	X		X		X	X	X	X	X	X
	Sipiwesk Lake	X			X				X		
	Upper Nelson River upstream of the Kelsey GS	X			X				X		
	Walker Lake		X		X			X			X
	Setting Lake		X	X		X	X	X	X	X	X

Table 1-1. continued.

Region	Waterbody/Area	On-system	Off-system	Annual	Rotational	Sampling Years [1]					
						2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Lower Nelson River	Burntwood River downstream of First Rapids	X			X [5]		X [5]	X [5]	X [5]	X [5]	X [5]
	Split Lake	X		X			X	X	X	X	X
	Stephens Lake - south	X			X		X			X	
	Stephens Lake - north arm	X			X		X			X	
	Limestone Forebay	X			X			X			X
	Lower Nelson River downstream of the Limestone GS	X		X		X	X	X	X	X	X
	Hayes River		X	X		X	X	X	X	X	X
	Assean Lake		X	X		X	X	X	X	X	X

[1] Note that not all components were sampled at the frequency indicated for all waterbodies/areas. See descriptions provided for each monitoring component for details.

[2] Not all components monitored in this area.

[3] Site was subsequently moved to the lower Churchill River at the Churchill Weir where sampling was initiated in 2014.

[4] Only water quality monitored.

[5] Site sampled annually for water quality and rotationally for other components (BMI and fish sampling completed in 2011).

1.2.2.2 Selection of Waterbodies

CAMP incorporates monitoring of up to 42 waterbodies or reaches of river, spanning eight regions of Manitoba. Selection of on-system and off-system waterbodies monitored under CAMP was done through a collaborative approach between MSD and Manitoba Hydro for each of the eight CAMP regions. In general, selection of on-system waterbodies considered a number of factors including: the waterbody is affected by Manitoba Hydro's operations; that the waterbody was representative of conditions in the region; pre-existing data (i.e., past data that could be compared with data collected under CAMP); importance of waterbodies from a stakeholder perspective; and locations of First Nation communities and resource management areas.

Off-system waterbodies were identified based on general proximity/location in relation to on-system waterbodies, size/morphology (e.g., surface area/depth of lakes and discharge of rivers), anthropogenic activities/land use in the drainage basin, accessibility, importance to local stakeholders (e.g., harvesting), and knowledge of the aquatic ecosystems (i.e., presence of existing data that could be compared with data collected under CAMP) in these waterbodies. As previously noted, off-system waterbodies are not considered true reference sites due to inherent differences with on-system waterbodies, including but not limited to differences in drainage basin size, land use/topography/geology, and hydrology.

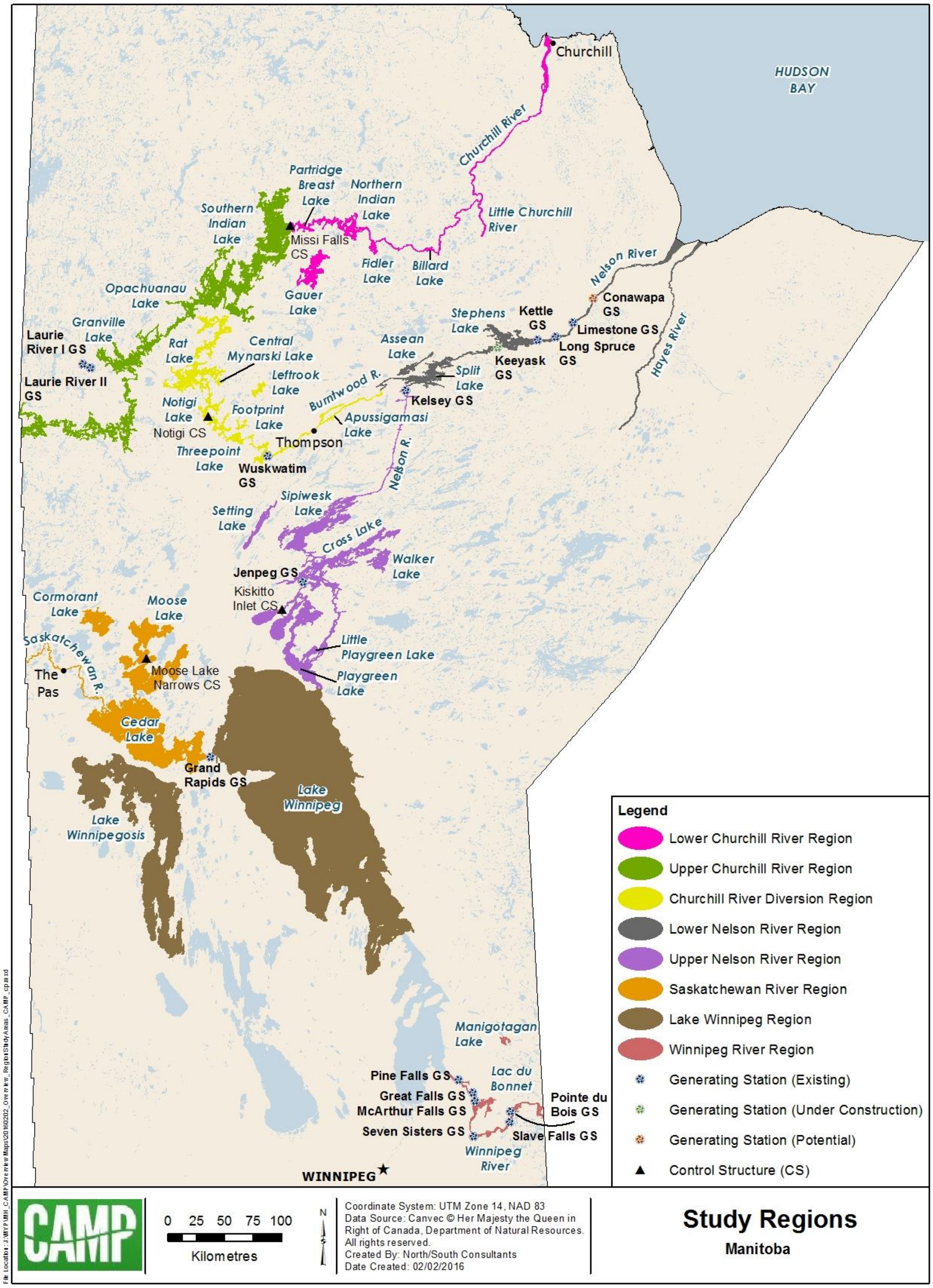
1.2.3 Temporal Scope

CAMP includes monitoring conducted on an annual and triennial basis. Annual monitoring is conducted at selected on- and off-system waterbodies in each CAMP region (annual waterbodies). Less frequent monitoring is conducted at additional waterbodies or areas of waterbodies on a three-year rotational basis to provide additional spatial coverage within the CAMP regions. These waterbodies are referred to as rotational waterbodies.

As a broad (geographically and ecologically) monitoring program, CAMP is intended to identify long-term trends or changes in aquatic ecosystems. CAMP includes sampling of some waterbodies/areas annually and others sampled on a three-year (or other) rotational basis. In addition, CAMP includes the collection of physical aquatic habitat information on a one time basis only. The major components monitored under CAMP, which vary in terms of timing, frequency, and intensity of monitoring are presented in Table 1-2.

Table 1-2. Timing and frequency of sampling of key CAMP components within a sampling year.

Key Component	**Frequency**	**Timing**
Hydrology	Continuous	Year-round
Water Quality	Four times per year	Three times in the open-water season (spring, summer, and fall) and once in winter
Sediment Quality	Once per sampling year	Late summer/fall in conjunction with BMI program
Phytoplankton	Three times per year	Open-water season concurrent with water quality monitoring
Benthic Macroinvertebrates	Once per sampling year	Similar time of year in a given waterbody over time (late summer/fall)
Fish Community	Once per sampling year	Similar time of year in a given waterbody over time (summer/fall)
Fish Mercury	Once per sampling year	Sampled in conjunction with fish community monitoring
Aquatic Habitat	One-time survey	Spring/early summer



Coordinate System: UTM Zone 14, NAD 83
Data Source: Canvec © Her Majesty the Queen in Right of Canada, Department of Natural Resources. All rights reserved.
Created By: North/South Consultants
Date Created: 02/02/2016

Figure 1-1. Study regions and waterbodies sampled under CAMP.

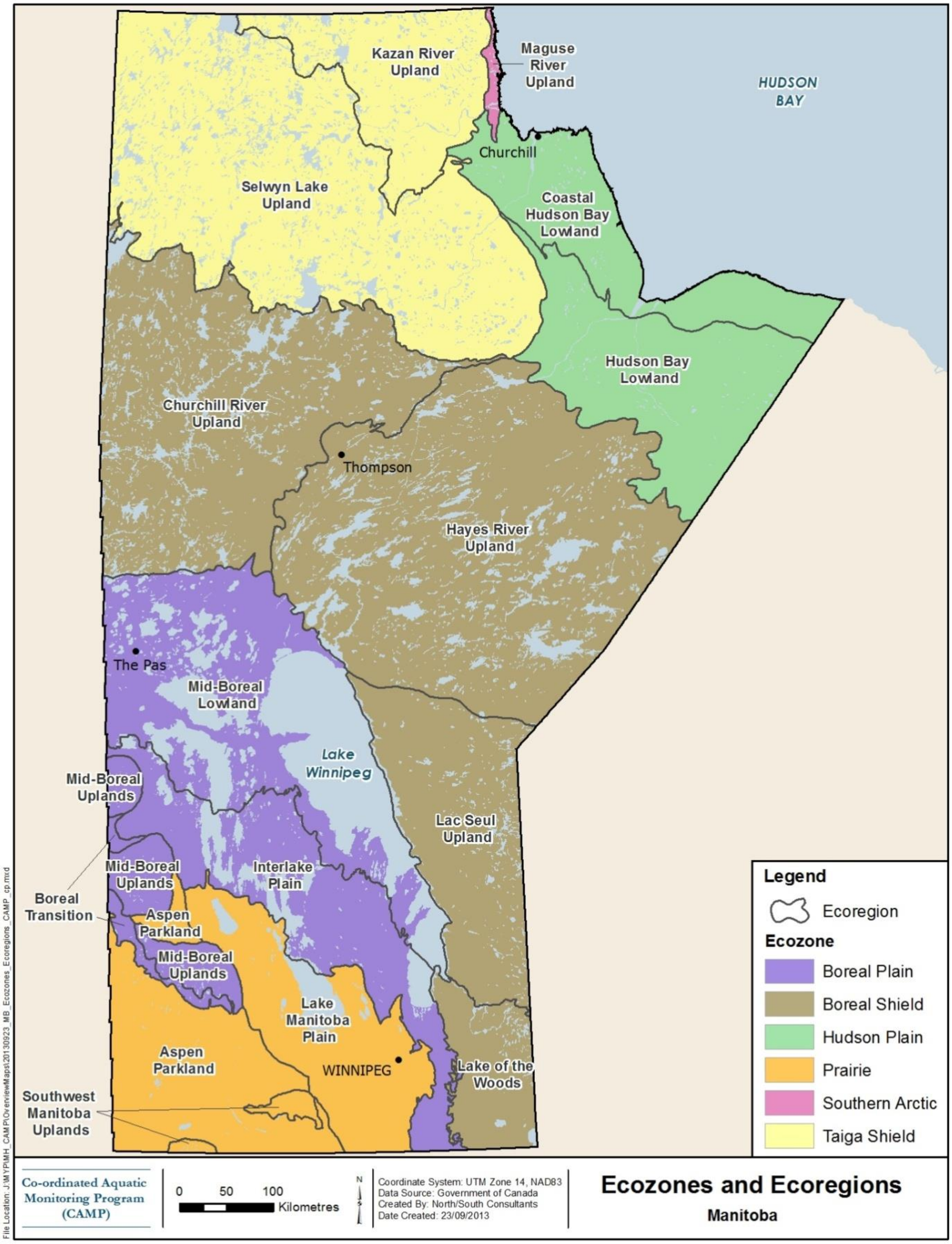


Figure 1-2. Manitoba ecozones and ecoregions.

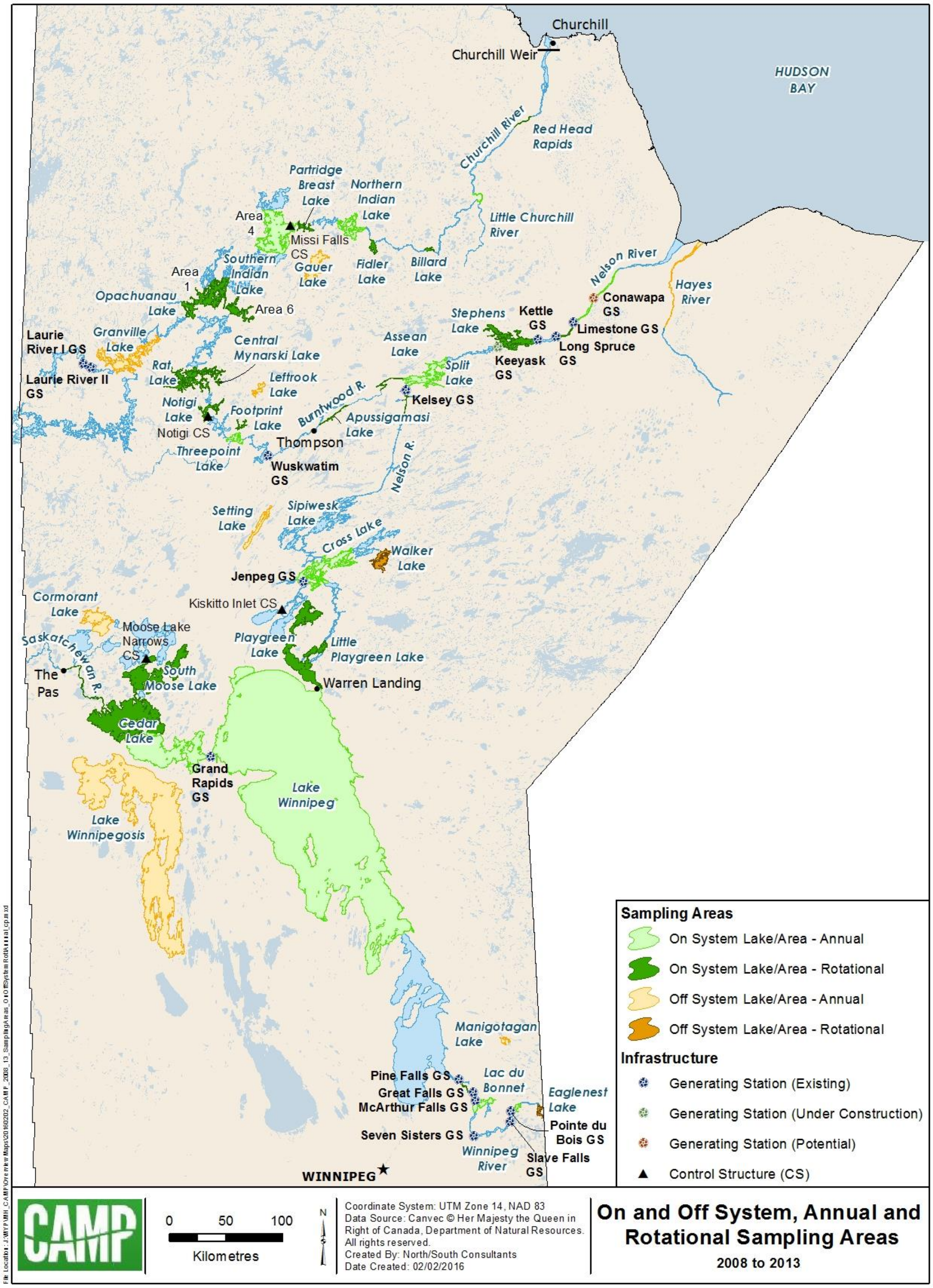


Figure 1-3. On-system and off-system waterbodies sampled under CAMP: 2008/2009-2013/2014.

1.3 DEVELOPMENT OF SCIENTIFIC PROTOCOLS

Sampling protocols were developed by MSD and Manitoba Hydro, with input from ECCC, DFO, academics, and consultants for the chemical and biological components of CAMP to provide a standardized approach to monitoring. Field sampling protocols were developed which included detailed descriptions of sampling methods and quality assurance/quality control (QA/QC) measures for each CAMP component.

An initial workshop was held in 2007 to scope the overall approach and design, components, and methods for CAMP. Workshop participants included representatives from MSD, DFO, ECCC, University of Manitoba, Manitoba Hydro and North/South Consultants Inc. (NSC)., as well as other external experts. Subsequent workshops were held annually (following completion of each year's open-water monitoring season) to discuss implementation of the previous year's field program and any changes required to the scientific protocols and the program overall.

1.4 DATABASE AND DATA MANAGEMENT

A significant amount of information has been, and will continue to be, collected as a result of CAMP. A data management system for CAMP was identified and utilized from the initiation of the Pilot Program, to ensure data are stored in a manner that will facilitate long-term accessibility and use, and to ensure associated metadata are documented (e.g., site Universal Transverse Mercator Units). The data management system was designed to:

- simplify and improve access to large volumes of environmental data;
- facilitate the analysis of large data sets for monitoring and assessment purposes;
- facilitate the interpretation and synthesis of data;
- facilitate the preparation of technical reports and summary documents;
- assist in review of, and modifications to, CAMP; and
- organize and archive the environmental information in digital format for future use.

The information system was designed to be flexible and scalable. The database includes data collected for all CAMP components outlined in Section 1.2.1, with the exception of water level and flow data which are currently managed within a separate Manitoba Hydro database. To ensure the integrity and similarity of the data and written information, procedures have been developed for data handling, including QA/QC measures.

1.5 REPORTING

To meet Manitoba's and Manitoba Hydro's needs under the terms of the MoU, as well as to meet the needs of the public and the scientific community, the following three levels of reporting were defined in the reporting strategy for CAMP:

- Annual Activity Report – an electronic report prepared annually and submitted to the Minister of MSD and the President/Chief Executive Officer of Manitoba Hydro. The Annual Activity Report summarizes the previous year's sampling program and meets the requirements outlined in the MoU;
- Website Annual Reporting – the CAMP web-site was launched in 2012 (CAMP 2012) which provides a detailed description of the program and presents a subset of data collected under CAMP. Annual reporting is published on the CAMP website (http://campmb.com/) which is updated as new information and/or data becomes available; and
- Three-Year Synthesis Reports – a hard copy, technical report prepared every three years. The Three-Year Technical Report includes analysis and interpretation of standard metrics in an integrated fashion. These reports will be posted on the CAMP website once they are completed.

This report represents the second Three-Year Synthesis Report produced for CAMP. It is intended to provide a documentation of monitoring and results of that monitoring conducted for the first six years of CAMP from 2008/2009 through 2013/2014.

1.6 CHANGES TO CAMP OVER TIME

While CAMP has generally maintained consistency in the design and implementation of the program since field sampling was first initiated in 2008, some changes to the program have been implemented over the first six years of the field program to:

- expand the areas/waterbodies incorporated in the monitoring program;
- focus the program to ensure sufficient data are collected but considering efficiencies and logistical issues;
- ensure the sampling design meets the objectives of CAMP;
- address logistical challenges associated with sampling methods; and
- to address emerging and/or new concerns, issues, or changes in standard scientific methods.

The following provides an overview of the key changes that have occurred over the period of 2008/2009 through 2013/2014.

1.6.1 Changes to Sampling Sites

Since completion of the Pilot Program sampling in 2010/2011 (CAMP 2014), a number of sites were added to CAMP as indicated below:

- Winnipeg River Region: the Pine Falls Forebay;
- Saskatchewan River Region: Cedar Lake – west basin;
- Lake Winnipeg Region: Lake Winnipeg at Mossy Bay (BMI sampling initiated in 2013); and Lake Winnipeg at Grand Rapids (BMI sampling initiated in 2013);
- Upper Churchill River Region: Opachuanau Lake;
- Lower Churchill River Region: the lower Churchill River at Red Head Rapids (sampled in 2011) - subsequently relocated to the lower Churchill River upstream of the Churchill Weir (first sampled in 2014); and Fidler Lake;
- Churchill River Diversion Region: Central Mynarski Lake;
- Upper Nelson River Region: Two-Mile Channel (water quality sampling only; initiated in 2013); upper Nelson River at Warren Landing (water quality sampling only; initiated in 2012); Sipiwesk Lake; and the upper Nelson River upstream of the Kelsey GS; and
- Lower Nelson River Region: no additions or changes.

With the exception of the BMI sampling added in the north basin of Lake Winnipeg and water quality sampling added to the Lake Winnipeg outflows - both of which are conducted annually - all other waterbodies added to CAMP following the completion of the Pilot Program are monitored on a rotational basis.

In addition to the new sampling sites added to CAMP, as noted above one site first sampled in 2011/2012 under CAMP – the lower Churchill River at Red Head Rapids – was subsequently dropped and relocated to a site further downstream on the lower Churchill River - the lower Churchill River upstream of the Churchill Weir. The primary reason for the site relocation was logistical challenges in relation to the fish community sampling program in the Red Head Rapids area. When sampled in 2011, the length of gill net was reduced from 22.9 m to 9.1 m long panels for this site due to shallow conditions and the expected scarcity of available habitat. However, even with a reduced net length (45.5 m long net) there was considerable difficulty locating sites where gill nets could be fished effectively at the time of the sampling program in 2011 due to relatively low water levels. In addition, low water level prevented site access with a fixed wing aircraft during the spring water quality sampling event. Ultimately, the site was relocated due to the combination of site access issues, poor/limited fish community sampling locations, and the requirement for a different sampling gear for the fish community monitoring. The new site (upstream of the Churchill Weir) was first sampled under CAMP in 2014/2015 and results of this sampling will be presented in the next summary report.

Lastly, CAMP initially included monitoring of multiple sites for water quality in Lake Winnipegosis – the off-system waterbody in the Lake Winnipeg Region. Five sites were monitored during the Pilot Program (2008/2009-2010/2011) and the number of sites was then dropped to three in 2011/2012, and ultimately to a single site in 2013/2014.

1.6.2 Changes to CAMP Components

Key components of CAMP including hydrometrics, water quality, BMI, fish, and mercury in fish have been included in the program since inception. However, other components were added to CAMP since the three year Pilot Program (i.e., sediment quality and sedimentation monitoring) and one component was reduced in scope (i.e., phytoplankton taxonomy and biomass).

As noted in Section 1.2.1.4, sediment quality sampling was added to CAMP beginning in 2011 and is to be conducted on a six year rotational basis at annual water quality sampling sites.

The CAMP working group determined that sedimentation monitoring should be incorporated into the CAMP in an effort to better understand the physical environment influences on other key parameters (fisheries, benthic, water quality, etc.) already included in the program. This monitoring began in 2013 with a sedimentation monitoring program on Playgreen Lake. This program included the collection of sedimentation data in Playgreen Lake during the open water and winter (ice covered) seasons. It was anticipated that subsequent CAMP sedimentation monitoring may be modified based on the findings of this work, other studies and stakeholder input. The phytoplankton taxonomy and biomass monitoring component conducted under CAMP was reduced from its original scope of monitoring at all waterbodies/sites on a three year rotational basis to annual monitoring at four waterbodies. The bloom monitoring component continues to be conducted, where phytoplankton taxonomy and biomass and microcystin are analysed in any sample where chlorophyll *a* exceeds the benchmark of 10 µg/L.

1.6.3 Changes to Sampling Methods

1.6.3.1 Benthic Macroinvertebrates

The BMI component was refined during the pilot program prior to Year 3 in an attempt to minimize the inherent variability noted for data collected in Years 1 and 2. Beginning in Year 3, sampling areas at all sites were stratified by water depth and constrained by habitat attributes (water velocity and substrate composition) to represent the predominant type of nearshore and offshore habitat within each waterbody (see Section 3.5 for details).

Nearshore habitat sampling methods were revised in Year 3 to target a ≤ 1 m water depth (i.e., wadeable depth) using a kicknet; sampling in Years 1 and 2 targeted a 3-5 m water depth range and was conducted with an Ekman or petite Ponar sampler.

The offshore habitat of the northern river sites (lower Nelson, Churchill, and Hayes rivers) is a difficult environment to sample reliably due to predominantly hard substrate and high water velocity. Rockbasket samplers were deployed under the initial study design implemented under the pilot program in 2008 and 2009. These samplers were occasionally lost, usually because of variable water levels/ flows and entanglement with floating large woody debris; also, floating organic debris would often impede proper retrieval. This sampling method made it difficult to produce the desired replication and repeatability for making temporal comparisons.

Offshore habitat sampling methods were revised in Year 3 to target 5 to 10 m water depth and consistent substrate composition with an Ekman or petite Ponar sampler. Water depths in Years 1 and 2 were greater than 5 m and varied as sampling polygons and locations were pre-determined and selected using a Random Point Generator extension for ArcGIS®.

1.6.3.2 Fish Community

Beginning in 2012/2013, gear orientation within a given waterbody was standardized such that approximately 50% of the gangs were set with the 5” panel near shore and the remainder with the 2” panel near shore (or the 16 mm small mesh panel if a small mesh gang was attached) and beginning in 2013/2014, efforts were made to ensure that this orientation (large mesh or small mesh near shore) remained constant over time at each site.

Although gillnet set durations were intended to be approximately 24 hours, poor weather or logistic complications occasionally resulted in longer gillnet sets. Beginning in 2012/2013, an effort was made to restrict the number of net sets that exceeded 36 hours in duration. If more than two sets on a waterbody were set for more than 36 hours then the sets were to be repeated.

Beginning in 2012/2013, individual metrics were taken from all specimens of target species captured in small mesh gangs, in addition to those captured in standard gangs to provide information on smaller fish from those species.

Beginning in 2011/2012, set times at the lower Churchill River at the Little Churchill River were reduced from approximately 24 hours to approximately 16 hours to minimize Lake Sturgeon mortality.

Following the pilot phase of the program, the two agencies conducting the fish ageing (MSD – Fisheries Branch and NSC) participated in a workshop held in January 2012 to compare ageing methods. Although the general methods for ageing otoliths and cleithra among the two agencies were similar, there were minor differences noted. Following the workshop some changes were made to the ageing methods to ensure consistency among the two agencies.

1.6.3.3 Fish Mercury

Prior to 2013, 1-year-old Yellow Perch for mercury analysis were obtained from regular CAMP fish community sampling. This approach often resulted in low sample sizes of this Yellow Perch age class, and targeted sampling was introduced starting with the 2013 field season. Targeted sampling is triggered when the number of 1-year-old Yellow Perch captured in regular CAMP fish community sampling within a given waterbody is less than 12 fish. The sole purpose of targeted sampling is to increase the number of Yellow Perch available for mercury analysis to meet the target size of 25 fish. Targeted sampling typically consists of short-term (1-3 hours) sets of small mesh gill nets deployed opportunistically at locations that may be distant from regular sampling sites, but that potentially provide suitable 1-year-old Yellow Perch habitat (i.e., littoral zone and/or within macrophytes). In addition, or alternatively, to using a small mesh gill net and dependent upon shoreline conditions, field crews may also use a small seine or a trap net for targeted sampling of 1-year-old Yellow Perch.

1.6.4 Aquatic Invasive Species

The introduction, and subsequent effects, of aquatic invasive species (AIS) on aquatic ecosystems and infrastructure are a widespread global concern. There are currently 15 AIS in Manitoba - three of which are of particular concern: zebra mussel (*Dreissena polymorpha*); spiny waterflea (*Bythotrephes cederstroemi*); and black algae (*Lyngbya wollei*). Zebra mussels were first confirmed in Lake Winnipeg in 2013 and are now known to be present in the north and south basins of Lake Winnipeg, Cedar Lake (west of Grand Rapids), and the Red River.

Manitoba recently issued an *Aquatic Invasive Species Regulation* intended to reduce, prevent, or minimize expansion of AIS throughout Manitoba's waterways. Various measures are prescribed under the Regulation to remove and kill AIS from water-related equipment or gear and watercraft.

CAMP has addressed AIS through two main activities:

- Targeted sampling for zebra mussel veligers was first initiated under CAMP in 2015 and has since expanded in spatial scope; and

- CAMP has adopted measures to minimize risk of spread of AIS associated with the implementation of the monitoring program beginning in earnest in 2015. This objective has resulted in some changes to the logistics of the program, including changing sequence and/or timing of sampling, implementation of decontamination of gear and watercraft, and use of dedicated or multiple sets of gear for certain waterbodies.

The first confirmed report of zebra mussels in Cedar Lake was as a result of sampling conducted under CAMP and it is expected that ongoing AIS sampling under the program will be a valuable tool for monitoring range extensions of zebra mussels and spiny waterflea moving forward.

1.6.5 Potential Future Changes

CAMP is intended to be adaptive in order to accommodate changing needs of the program, to respond to monitoring results as the program progresses, and in anticipation that external factors may require modification to the program (e.g., changes to water quality guidelines, changes in standard methods or gear). However, a cornerstone of CAMP is to utilize consistent methodologies over time to maximize the utility of the data over the long-term and consistencies will be maintained to the extent feasible into the future.

As described above, CAMP has undergone a number of modifications to date and it is anticipated that modifications will be required moving forward. One such expectation is that the types of gill nets used for the fish community monitoring component of CAMP may change in the future, due in part to a potential lack of availability of mesh sizes and/or composition of gill nets currently used for CAMP. A study was conducted under CAMP in 2014/2015 at two waterbodies to provide a comparison of results for the fish community monitoring using CAMP gill nets to North American Standard (NAS) and Ontario Small Mesh (OSM) gill nets. The study found that setting an equivalent length of similar, but not identical, mesh sizes of CAMP and NAS/OSM nets in the water yields comparable results, suggesting that a transition to NAS/OSM gill nets would be possible. It is unknown whether it would be possible to set shorter lengths of each of the panels (as is done in other jurisdictions) and yield comparable results.

2.0 CAMP REGIONAL DESCRIPTIONS

The following provides background descriptions of the eight CAMP monitoring regions, including descriptions of Manitoba Hydro’s hydroelectric facilities and CAMP waterbodies. Information on drainage basins, ecozones, locations, and waterbody characteristics are presented in Table 2-1.

Table 2-1. CAMP waterbody and watershed characteristics.

Waterbody	**Location**	**Sampling Frequency**	**Ecozone**	**Ecoregion**	**Drainage Basin (Total; km^2)** [1]	**Dominant Land Cover (within total watershed)** [2]	**Coordinates**		**Altitude (mASL)** [3]	**Surface Area (km^2)** [4]	**Shoreline Length (km)** [4]	**Shoreline Develop. Ratio**[5]	**Max Depth (m)**	**Mean Depth (m)**	**Mean Depth : Max Depth Ratio**	**Lake Volume (million m^3)**	**Drainage Basin Area: Lake Surface Area**
							Lat. (DD)	**Long. (DD)**									
Winnipeg River Region					136,871	Mixed Forest											
Eaglenest Lake	Off-system	Rotational	Boreal Shield	Lake of the Woods, Lac Seul Upland	125,883	Mixed Forest	50.31	-95.21	299	31.3	130	6.6	32 [6]	-	-	-	4,028
Pointe du Bois Forebay	On-system	Annual	Boreal Shield	Lake of the Woods, Lac Seul Upland	126,179	Mixed Forest	50.35	-95.48	300	37.5	217	10	36.5 [7]	9.44 [7]	0.259	268 [7]	3,367
Lac du Bonnet	On-system	Annual	Boreal Shield	Lake of the Woods, Lac Seul Upland	135,350	Mixed Forest	50.37	-95.91	252	81.7	162	5.1	69 [6]	-	-	-	1,656
Pine Falls Forebay	On-system	Rotational	Boreal Shield	Lake of the Woods	136,827	Mixed Forest	50.53	-96.13	228	6.8	32	3.4	42.5 [8]	12 [8]	0.282	8 [8]	18,743
Manigotagan Lake	Off-system	Annual	Boreal Shield	Lac Seul Upland	1,478	Coniferous Forest	50.86	-95.62	280	24.3	81.7	4.7	24.5 [9]	-	-	-	61
Saskatchewan River Region					411,709	Cultivated Crops											
Saskatchewan River – The Pas to Cedar Lake	On-system	Rotational	Boreal Plain	Mid-Boreal Lowland	405,601	Cultivated Crops	53.79	-101.06	254	-	-	-	-	-	-	-	-
South Moose Lake	On-system	Rotational	Boreal Plain	Mid-Boreal Lowland	9,179	Coniferous Forest	53.77	-100.03	254	735	682	7.1	12.0 [10]	4.8 [10]	0.4	1,460 [10]	12.5
Cedar Lake - West	On-system	Rotational	Boreal Plain	Mid-Boreal Lowland	408,303	Cultivated Crops	53.43	-100.33	253	1,216	1,098	8.9	-	-	-	-	336
Cedar Lake - South	On-system	Annual	Boreal Plain	Mid-Boreal Lowland	411,455	Cultivated Crops	53.14	-99.92	253	1,246	851	6.8	-	-	-	-	330
Cormorant Lake	Off-system	Annual	Boreal Plain	Mid-Boreal Lowland	3,162	Coniferous Forest	54.24	-100.82	254	333	269	4.2	27.5 [11]	-	-	-	9.5
Lake Winnipeg Region					1,026,845	Cultivated Crops											
Lake Winnipeg – North Basin	On-system	Annual	Boreal Plain Boreal Shield	Mid-Boreal Lowland, Lac Seul Upland	1,026,845	Cultivated Crops	52.82	-97.91	216	19,784 [20]	2,424 [20]	4.9	19 [20]	13.3 [20]	0.7	232400	51.9
Lake Winnipegosis	Off-system	Annual	Boreal Plain	Mid-Boreal Lowland, Interlake Plain	55,061	Deciduous Forest	52.71	-99.86	251	5,198	2,482	9.7	-	-	-	-	10.6
Upper Churchill River Region					261,443	Coniferous Forest											
Granville Lake	Off-system	Annual	Boreal Shield	Churchill River Upland	245,069	Coniferous Forest	56.28	-100.48	259	412	1,239	17.2	-	-	-	-	594
Southern Indian Lake - Area 1	On-system	Rotational	Boreal Shield	Churchill River Upland	252,895	Coniferous Forest	56.86	-99.26	258	354	817	12.3	-	-	-	-	715
Southern Indian Lake - Area 4	On-system	Annual	Taiga Shield	Selwyn Lake Upland	261,394	Coniferous Forest	57.31	-98.38	258	681	758	8.2	35.0 [10]	13.5 [10]	0.38	9,522 [10]	384
Southern Indian Lake - Area 6	On-system	Rotational	Boreal Shield	Churchill River Upland	261,394	Coniferous Forest	56.69	-98.93	257	132	361	8.9	-	-	-	-	1,988
Opachuanau Lake	On-system	Rotational	Boreal Shield	Churchill River Upland	248,663	Coniferous Forest	56.71	-99.59	258	84	228	7	-	-	-	-	2960
Lower Churchill River Region					299,817	Coniferous Forest											
Partridge Breast Lake	On-system	Rotational	Taiga Shield	Selwyn Lake Upland	261,870	Coniferous Forest	57.35	-97.93	242	22.3	98.2	5.9	-	-	-	-	11,738
Northern Indian Lake	On-system	Annual	Taiga Shield	Selwyn Lake Upland	271,193	Coniferous Forest	57.35	-97.26	234	61.3	388	10.9	39.8 [10]	5.77 [10]	0.14	351 [10]	2,704
Fidler Lake	On-system	Rotational	Taiga Shield	Selwyn Lake Upland	271,909	Coniferous Forest	57.19	-96.95	229	39.7	106	4.7	-	-	-	-	6,849
Billard Lake	On-system	Rotational	Taiga Shield	Selwyn Lake Upland	273,377	Coniferous Forest	57.15	-96.14	187	13.0	34.2	2.7	12.8 [10]	3.58 [10]	0.279	24 [10]	21,078
Lower Churchill River at Little Churchill River	On-system	Annual	Taiga Shield	Selwyn Lake Upland	284,222	Coniferous Forest	57.53	-95.33	132	-	-	-	-	-	-	-	-
Lower Churchill River at Red Head Rapids	On-system	Rotational	Hudson Plain	Coastal Hudson Bay Lowland	293,213	Coniferous Forest	58.12	-94.63	80	-	-	-	-	-	-	-	-
Lower Churchill River at Churchill Weir	On-system	Rotational	Hudson Plain	Coastal Hudson Bay Lowland	299,653	Coniferous Forest	58.68	-94.19	128	-	-	-	-	-	-	-	-
Gauer Lake	Off-system	Annual	Boreal Shield	Churchill River Upland	4,897	Coniferous Forest	57.01	-97.81	245	263	471	8.2	20.0 [12]	-	-	-	18.6

Table 2-1. continued.

Waterbody	Location	Sampling Frequency	Ecozone	Ecoregion	Drainage Basin (Total; km^2)[1]	Dominant Land Cover (within total watershed)[2]	Coordinates		Altitude (mASL)[3]	Surface Area (km^2)[4]	Shoreline Length (km)[4]	Shoreline Develop. Ratio[5]	Max Depth (m)	Mean Depth (m)	Mean Depth : Max Depth Ratio	Lake Volume (million m^3)	Drainage Basin Area: Lake Surface Area
Churchill River Diversion Region					280,754	Coniferous Forest											
Rat Lake	On-system	Rotational	Boreal Shield	Churchill River Upland	266,363	Coniferous Forest	56.14	-99.66	257	168	646	14.1	20.0[13]	-	-	-	1589
Central Mynarski Lake	On-system	Rotational	Boreal Shield	Churchill River Upland	276	Coniferous Forest	56.13	-99.20	257	15.8	72.9	5.2	-	-	-	-	17
Notigi Lake	On-system	Rotational	Boreal Shield	Churchill River Upland	267,581	Coniferous Forest	55.94	-99.32	254	75	308	10	29.7[21]	9.33[21]	0.314	756[21]	3,568
Threepoint Lake	On-system	Annual	Boreal Shield	Churchill River Upland	276,853	Coniferous Forest	55.69	-98.95	242	62.2	159	5.7	13.5[10]	4.5[10]	0.333	285[10]	4,450
Footprint Lake	On-system	Rotational	Boreal Shield	Churchill River Upland	1,441	Coniferous Forest	55.80	-98.88	242	27.6	124	6.7	15.72[21]	5.32[21]	0.338	203[21]	52.3
Apussigamasi Lake	On-system	Rotational	Boreal Shield	Hayes River Upland	280,393	Coniferous Forest	55.85	-97.61	187	17.8	80.8	5.4	16.72[10]	4.88[10]	0.292	112[10]	15,744
Leftrook Lake	Off-system	Annual	Boreal Shield	Churchill River Upland	389	Coniferous Forest	56.07	-98.62	252	46.3	141	5.8	12.67[21]	3.24[21]	0.256	150[21]	8.39
Upper Nelson River Region					1,056,135	Cultivated Crops											
Playgreen Lake	On-system	Rotational	Boreal Shield	Hayes River Upland, Mid Boreal Lowland	1,028,625	Cultivated Crops	53.99	-98.26	215	675	888	9.6	22.9[10]	2.6[10]	0.113	1441[10]	1,525
Little Playgreen Lake	On-system	Rotational	Boreal Shield, Boreal Plain	Hayes River Upland	1,032,615	Cultivated Crops	54.01	-97.87	215	84.8	238	7.3	14.6[15]	-	-	-	12,176
Cross Lake - West	On-system	Annual	Boreal Shield	Hayes River Upland	1,045,983	Cultivated Crops	54.68	-97.78	207	365	1,665	24.6	29.0[10]	4.0[10]	0.137	668[10]	2,867
Sipiwesk Lake	On-system	Rotational	Boreal Shield	Hayes River Upland	1,051,604	Cultivated Crops	55.05	-97.71	185	487	2,014	25.8	-	-	-	-	2,159
Walker Lake	Off-system	Rotational	Boreal Shield	Hayes River Upland	1,183	Shrub	54.71	-96.97	205	133	636	15.5	-	-	-	-	8.87
Setting Lake	Off-system	Annual	Boreal Shield	Hayes River Upland	10,952	Coniferous Forest	54.98	-98.65	222	126	269	6.8	24.5[16]	-	-	-	87
Upper Nelson River u/s of Kelsey GS	On-system	Rotational	Boreal Shield	Hayes River Upland	1,056,135	Cultivated Crops	55.87	-96.57	184	-	-	-	-	-	-	-	-
Lower Nelson River Region					1,392,453	Cultivated Crops											
Burntwood River d/s of First Rapids	On-system	Rotational	Boreal Shield	Churchill River Upland	290,233	Coniferous Forest	56.13	-96.83	167	-	-	-	-	-	-	-	-
Split Lake	On-system	Annual	Boreal Shield	Hayes River Upland	1,374,157	Cultivated Crops	56.14	-96.20	168	269	764	13.1	32[10]	5.55[10]	0.173	1,509[10]	5,109
Stephens Lake	On-system	Rotational	Boreal Shield	Hayes River Upland	1,380,009	Cultivated Crops	56.39	-95.05	138	307	658	10.6	35[18]	7.63[18]	0.218	-	4,494
Limestone Forebay	On-system	Rotational	Hudson Plain	Hudson Bay Lowland	1,380,984	Cultivated Crops	56.44	-94.18	82	26.8	53.6	2.9	29[19]	-	-	-	51,587
Lower Nelson River d/s of the Limestone GS	On-system	Annual	Hudson Plain	Hudson Bay Lowland, Coastal Hudson Bay Lowland	1,392,453	Cultivated Crops	56.80	-93.54	20	-	-	-	20.8[19]	-	-	-	-
Assean Lake	Off-system	Annual	Boreal Shield	Hayes River Upland, Churchill River Upland	542	Shrub	56.22	-96.47	176	76.3	196	6.3	19.8[10]	2.97[10]	0.15	224[10]	7.11
Hayes River	Off-system	Annual	Hudson Plain	Hudson Bay Lowland, Coastal Hudson Bay Lowland	108,960	Coniferous Forest	56.60	-92.67	13	-	-	-	-	-	-	-	-

[1] Prairie Farm Rehabilitation Administration (2008)
[2] Natural Resources Land Cover (2000)
[3] United States Geological Survey (2000)
[4] Natural Resources Canada (2011)
[5] Shoreline Development Ratio (Wetzel 1983)
[6] DFO (2008)
[7] Larter et al. (2010)
[8] Murray and Gillespie (2011)
[9] Manitoba Conservation (2007a)
[10] Data collected by NSC between 2010 to 2015 as part of CAMP
[11] Manitoba Conservation (2006)
[12] Manitoba Natural Resources (1990)
[13] Manitoba Conservation (2007b)
[14] Manitoba Conservation (2003a)
[15] DFO (2009)
[16] Manitoba Conservation (2007c)
[17] Manitoba Conservation (2003b)
[18] Cherepak (1990)
[19] Manitoba Hydro (Unpublished Data)
[20] Brunskill et al. (1980)
[21] North/South Consultants Survey (1999)

2.1 WINNIPEG RIVER REGION

2.1.1 Regional Description

The Winnipeg River Region includes the portion of the Winnipeg River watershed from the Ontario/Manitoba border downstream to the mouth of the river at Traverse Bay on Lake Winnipeg (Figure 2-1). This region also includes Manigotagan Lake, an off-system waterbody on the Manigotagan River.

The Winnipeg River catchment drains 137,000 km2 of northwestern Ontario, southeastern Manitoba, and northern Minnesota, flowing 260 km in a generally northwesterly direction before entering Lake Winnipeg at Traverse Bay (Rosenberg et al. 2005). Most of the drainage area is in northwestern Ontario (70%), while approximately 21% is in Minnesota, and 9% is in Manitoba (Jones and Armstrong 2001).

In Manitoba, the Winnipeg River runs through the Boreal Shield Ecozone which is in turn composed of the Lake of the Woods Ecoregion to the south and the Lac Seul Upland Ecoregion to the north (Figure 1-2). Most of the catchment area is underlain by igneous and metamorphic bedrock, over which lies a variety of surface features including lakes and wetlands, bare rock outcrops, tills, forest and peatland soil types, and clay plains.

Much of the basin is forested, with jack pine, white pine, red pine, white spruce, black spruce, balsam fir, northern white cedar, tamarack, white birch, and trembling aspen among the more common tree species. Peatlands with black spruce-sphagnum bogs and swamps are common in the basin. The contemporary boreal forest in northwestern Ontario is composed of 71 species of trees and shrubs, 11 grass species, 40 herbs, 18 mosses and lichens, and 16 ferns (Royal Ontario Museum 2005). The dominant land cover of the drainage basin is classified as mixed forest (Table 2-1).

Temperatures vary little across the basin, with mean annual values from 0.5ºC to 2.0ºC, mean summer values from 14.0ºC to 15.5ºC, and mean winter values from –12.5º to –14.5°C (Rosenberg et al. 2005). Annual precipitation is moderate, ranging from 50 cm to 70 cm, with most (80%) falling as rain (Rosenberg et al. 2005).

The Winnipeg River catchment area has an economy largely based on renewable energy, forestry, mining, and recreation. Forestry, trapping, hunting, and tourism are the dominant land uses, though a significant portion of the Rainy River system is used in mixed farming or grazing. Overall the area remains relatively undeveloped: 30% of the catchment is devoted to forestry activities, <5% is in agriculture, and <1% is urban; the remainder of the basin is natural. Twelve percent of the catchment has park designation or protected status.

The catchment area population is concentrated in a few small towns (Kenora, Dryden, Red Lake, Sioux Lookout, Atikokan, International Falls, Pinawa, Lac du Bonnet, and Pine Falls) devoted largely to forestry processing and tourism. In Manitoba, there is one First Nation community (Sagkeeng First Nation) in the region near the Winnipeg River's confluence with Lake Winnipeg (Figure 2-1). The Winnipeg River basin has a low population density (0.6 people/km^2); however, the significant cottage development found on Lake of the Woods and along the Winnipeg River increases the population to >1 person/km^2 seasonally (Rosenberg et al. 2005).

The Winnipeg River has been regulated by several large dams to control water levels and provide storage to generate hydroelectric power. International and interprovincial regulatory boards oversee water-level and flow regulation, using 34 CSs that provide water for 11 power-generating facilities with a combined capacity of >900 megawatt (MW; Rosenberg et al. 2005). Alterations of stream water quantity, quality, and habitat have occurred with the intensification of logging and forestry, particularly in northwestern Ontario (Rosenberg et al. 2005). Three pulp mills (including the former Tembec at Pine Falls, Manitoba), nine lumber mills, and two panel-production facilities are currently operating or have recently ceased production in the Winnipeg River drainage basin. The Tantalum Mining Corporation of Canada Limited operates a tantalum, cesium, and spodumene mine at Bernic Lake, 60 km east of Lac du Bonnet, Manitoba (Manitoba Growth, Enterprise and Trade [MGET] 2017a).

Manigotagan Lake, an off-system waterbody, is located on the Manigotagan River system which flows directly into Lake Winnipeg near the community of Manigotagan (Figure 2-1). Manigotagan Lake receives inflows from both the upper Manigotagan and Moose rivers. The catchment area for the lake (1,500 km2), part of which is located in Ontario, is two orders of magnitude smaller than the catchments for CAMP waterbodies located on the Winnipeg River. Like the Winnipeg River catchment, the Manigotagan Lake catchment lies entirely within the Boreal Shield Ecozone. Conversely, while the Winnipeg River lies on the border of the Lake of the Woods and Lac Seul Upland ecoregions, the Manigotagan Lake drainage resides entirely in the latter. The dominant land cover is coniferous forest and there is presently little development (some cottages and a few outfitters) in the drainage basin. The drainage basin upstream of Manigotagan Lake is relatively undeveloped with a dominant land cover of coniferous forest. Historically, the Manigotagan Lake basin supported mines at Gem Lake (1932, 1934-1936), Long Lake (1927-1937, 1942, 1948-1951), and Beresford Lake (1933-1934, 1938-1940; MGET 2017b). Construction of a dam in the Manigotagan River at the outlet of Quesnel Lake in the late 1930s raised water levels in Manigotagan Lake by about 3.0 to 3.5 m (McTavish 1953). The dam was built to facilitate boat and barge traffic associated with the mining industry, which was then able to easily pass between Manigotagan and Quesnel lakes (Fitzjohn 1985).

Eaglenest Lake shoreline

Pointe du Bois shoreline

2.1.2 Hydroelectric Facilities

Prior to entering Manitoba, the Winnipeg River flows (comprising inflows from the English and Rainy River systems) are regulated by the Lake of the Woods Control Board at Lake of the Woods and Lac Seul.

Within Manitoba, Manitoba Hydro operates six GSs on the Winnipeg River which together produce approximately 583 MW of hydroelectric power. The GSs on the Winnipeg River include (beginning with the furthest upstream station) Pointe du Bois, Slave Falls, Seven Sisters, McArthur, Great Falls, and Pine Falls (Figure 2-1).

These hydroelectric GSs are designed and operated as run-of-the-river plants (i.e., water flowing to them from upstream is used immediately and not stored in a reservoir for later use). When river flows are greater than those needed to drive the turbines, water is spilled through the spillway and sluice gates.

2.1.2.1 Pointe du Bois GS

The Pointe du Bois GS is located approximately 170 km northeast of Winnipeg and approximately 45 km downstream of the Ontario/Manitoba border. The first of the station's 16 turbine generators was placed in service in 1911, making it the oldest power plant still operating on the Winnipeg River. With an operating head of 14 m, the Pointe du Bois GS has a licensed capacity of 78 MW and can generate an average of 580 million kilowatt hours (kWh) of electricity per year (Manitoba Hydro 2011). The Pointe du Bois GS has a normal operating maximum forebay elevation of 299.1 m (Manitoba Hydro 2011). To meet current dam safety requirements, Manitoba Hydro refurbished the main and south dam and constructed a new spillway at the Pointe du Bois facility. The existing powerhouse remains in service.

Pointe du Bois GS and spillway.

2.1.2.2 Slave Falls GS

The Slave Falls GS is located approximately 10 km downstream of the Pointe du Bois GS. The first of the station’s eight turbine generators came into service in 1931. The Slave Falls GS has a licensed capacity of 67 MW at an operating head of 9.75 m and can generate an average of 499 million kWh of electricity per year (Manitoba Hydro 2016).

Slave Falls GS and spillway.

2.1.2.3 Seven Sisters GS

The Seven Sisters GS, located approximately 43 km downstream of the Slave Falls GS, has been in operation since 1931, when the first of six turbine generators was brought on line. The Seven Sisters GS has an operating head of 18.6 m, a licensed capacity of 165 MW and can generate an average of 990 million kWh of electricity per year (Manitoba Hydro 2016). The Seven Sisters Forebay (Natalie Lake) has a surface area of 21 km^2 and a normal operating forebay elevation of 274.2 m (Manitoba Hydro 2016).

Seven Sisters GS.

2.1.2.4 McArthur GS

The McArthur GS is located approximately 30 km downstream of the Seven Sisters GS and approximately 40 km upstream of Lake Winnipeg. The McArthur GS has eight turbine units and it first produced power in 1954. The McArthur GS has an operating head of 7 m, a capacity of 55 MW, and can generate an average of 380 million kWh of electricity per year (Manitoba Hydro 2016). The McArthur GS Forebay area (Lac du Bonnet) has a surface area of 115 km^2 and a normal water level of 254.8 m (Manitoba Hydro 2016).

McArthur GS.

2.1.2.5 Great Falls GS

The Great Falls GS is located approximately 8 km downstream of the McArthur GS. The first of the station’s six turbine generators was brought into service in 1923. With an operating head of 17.7 m, the Great Falls GS has a capacity of 129 MW and can generate an average of 750 million kWh of electricity per year (Manitoba Hydro 2016). The Great Falls Forebay (the Winnipeg River) has a surface area of 10 km^2 and a normal operating forebay elevation of 247.5 m (Manitoba Hydro 2016).

Great Falls GS.

2.1.2.6 Pine Falls GS

The Pine Falls GS, the farthest downstream station on the Winnipeg River, is located approximately 13 km upstream of Lake Winnipeg, and 40 km north of the Town of Lac du Bonnet, and came into service in 1952. With an operating head of 11.3 m, the Pine Falls GS's six turbine generators have a capacity of 88 MW and can generate an average of 620 million kWh of electricity per year (Manitoba Hydro 2016). The Pine Falls Forebay (the Winnipeg River) has a normal operating forebay elevation of 229.2 m (Manitoba Hydro 2016).

Pine Falls GS.

2.1.3 Waterbody Descriptions

The Winnipeg River Region includes the Winnipeg River from the Manitoba/Ontario border to Lake Winnipeg, a distance of approximately 120 km. This region also includes Manigotagan Lake, an off-system waterbody on the Manigotagan River. There are three waterbodies sampled annually in the Winnipeg River Region: the Pointe du Bois Forebay (on-system); Lac du Bonnet (on-system), and Manigotagan Lake (off-system). Two additional waterbodies are sampled on a three year rotational basis under CAMP: Eaglenest Lake (off-system), which was first sampled under the Pilot Program (2010/2011); and the Pine Falls Forebay (on-system), which was first sampled in 2011/2012.

2.1.3.1 Eaglenest Lake

Eaglenest Lake, an off-system waterbody, is located upstream of the Pointe du Bois GS on the Winnipeg River, and spans across the Manitoba/Ontario border. Water levels on Eaglenest Lake are not affected by the Pointe du Bois GS but are affected by regulation of the Winnipeg River in Ontario. Eaglenest Lake is home to a fishing/hunting lodge and is fished recreationally. Sampling is conducted every three years and was initiated in 2010/2011 (Year 3 of CAMP).

Eaglenest Lake.

2.1.3.2 Pointe du Bois Forebay

The forebay of the Pointe du Bois GS is one of two on-system waterbodies sampled annually in the Winnipeg River Region. Sampling was initiated in 2008/2009 (Year 1 of the Pilot Program). The operation of the Pointe du Bois GS and regulation of the Winnipeg River in Ontario affect water levels on the Pointe du Bois Forebay. The Pointe du Bois Forebay supports a cottage development and is fished recreationally. Aquatic environment studies have been conducted by Manitoba Hydro in the Pointe du Bois Forebay and downstream since 2006 in support of the Pointe du Bois Spillway Replacement Project. Water quality has been monitored at the Pointe du Bois GS by ECCC since 1972.

Winnipeg River upstream of the Pointe du Bois GS.

2.1.3.3 Lac du Bonnet

Lac du Bonnet, the reservoir for the McArthur GS, is one of two on-system waterbodies that is monitored annually (beginning in 2008/2009) under CAMP. The operation of the McArthur GS and regulation of the Winnipeg River in Ontario affect water levels on Lac du Bonnet. The Town of Lac du Bonnet is situated on Lac du Bonnet, and there are numerous cottage developments on the lake. Lac du Bonnet is fished recreationally. MSD Fisheries Branch has conducted fish stock assessments on Lac du Bonnet since 1991.

Lac du Bonnet.

2.1.3.4 Pine Falls Forebay

The forebay of the Pine Falls GS is located on the Winnipeg River, just upstream of its confluence with Lake Winnipeg, and downstream of the Great Falls GS. Operation of the Pine Falls GS and the Great Falls GS affect water levels on the Pine Falls Forebay. Like the upstream waterbodies on the Winnipeg River, the Pine Falls Forebay is also affected by water regulation in Ontario. The forebay is located immediately upstream of the Town of Powerview - Pine Falls, and is fished recreationally. Water quality has been monitored in the Pine Falls Forebay by MSD since 2001. The Pine Falls Forebay is sampled every three years beginning in 2011/2012 under CAMP.

Pine Falls Forebay.

2.1.3.5 Manigotagan Lake

Manigotagan Lake, located on the Manigotagan River system approximately 60 km northeast of Lac du Bonnet, is an off-system waterbody monitored annually (beginning in 2008/2009) under CAMP. The lake was flooded (water levels were increased by 3-3.5 m) approximately 80 years ago through construction of a dam in the Manigotagan River (McTavish 1953). Manigotagan Lake is fished recreationally by anglers, including guests of the nearby Quesnel Lake Lodge.

Manigotagan Lake.

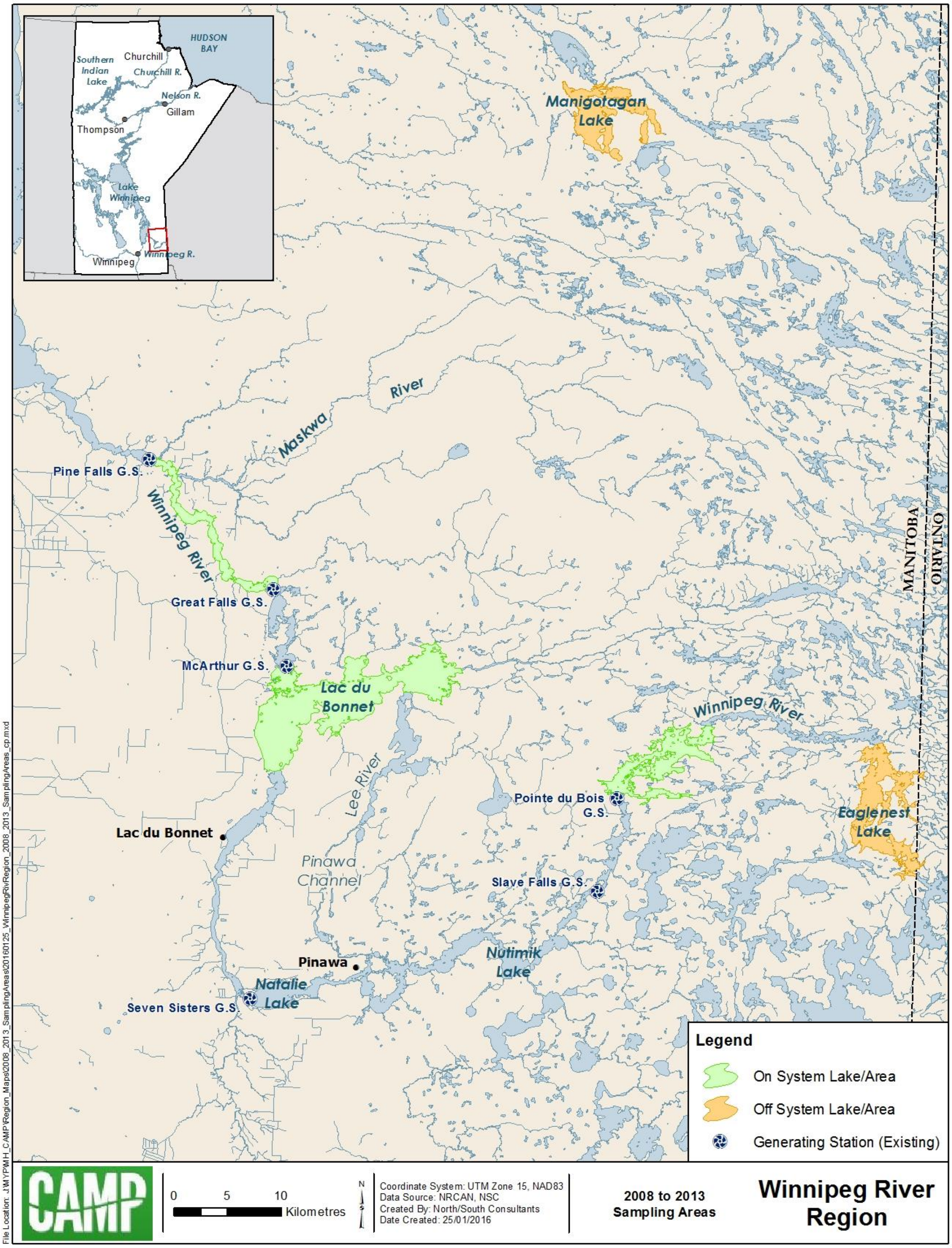


Figure 2-1. Winnipeg River Region.

2.2 SASKATCHEWAN RIVER REGION

2.2.1 Regional Description

The Saskatchewan River Region includes the portion of the Saskatchewan River watershed from the Saskatchewan/Manitoba border to Lake Winnipeg and Cormorant Lake (Figure 2-2).

The Saskatchewan River system drains a large area of western Canada from the Rocky Mountains in Alberta eastward to Lake Winnipeg in Manitoba. The river drains a total area of approximately 416,000 km^2, most of which is in Alberta (220,000 km^2) and Saskatchewan (174,000 km^2) with approximately 5% of the basin lying in Manitoba (22,000 km^2; Jones and Armstrong 2001). The basin covers much of the Boreal Plains Ecozone and the western portion of the Prairies Ecozone of western Canada (Smith et al. 1998 *In* Jones and Armstrong 2001). Within Manitoba, the Saskatchewan River is located in the Boreal Plain Ecozone and the Mid-Boreal Lowlands Ecoregion (Figure 1-2). Soils are generally rich and natural vegetation communities are diverse and include marsh/wetland, grassland, aspen parkland, and boreal forest (Jones and Armstrong 2001). The dominant land cover of the watershed is classified as cultivated crops (Table 2-1).

The climate of the drainage basin is classified as continental, although mean annual air temperature varies considerably within the watershed (Rosenberg et al. 2005). In the southern portion of the drainage basin (e.g., Calgary, Medicine Hat) mean daily temperatures range from -10°C in January to 16°C in July, with mean annual temperatures ranging from 3°C to 5°C (Rosenberg et al. 2005). In the northern portion of the basin (e.g., Edmonton, Saskatoon, Prince Albert) mean annual temperatures are 0.5°C to 2°C and monthly means range from -20°C to 19°C (Rosenberg et al. 2005). Precipitation is low across the basin, ranging from 30 cm to 50 cm. Peak precipitation occurs during summer, although snowmelt accounts for a significant proportion of the runoff, particularly in the mountain headwaters (Rosenberg et al 2005).

Land use within the drainage basin is largely agricultural, although forestry is common within the boreal forest portion of the drainage basin (Jones and Armstrong 2001). Agriculture varies from cultivation of specialty, cereal and forage crops, to range, pasture lands and livestock feedlots (Jones and Armstrong 2001). There are also several wastewater treatment lagoons and sewage treatment plants that discharge effluent directly to the Saskatchewan River mainstem or its tributaries (Jones and Armstrong 2001). One pulp and paper mill located at The Pas, Manitoba (Tolko Manitoba Kraft Papers) discharges effluent to the river.

The Saskatchewan River is a multi-use waterway, used extensively for agricultural irrigation and livestock watering, recreation, domestic and industrial consumption, and hydroelectric power generation (Jones and Armstrong 2001). Regulation of the Saskatchewan River basin began in the 1890s with the construction of irrigation projects and works to divert and deliver water to land in southern Alberta (Rosenberg et al. 2005). Diversion of water for irrigation projects was followed by regulation for hydroelectric power generation, first in the upper reaches of the Bow River (1911 to 1955) and then in the upper North Saskatchewan River (1965 to 1972) and Saskatchewan River (1963 to 1985; Rosenberg et al. 2005). Presently there are eleven hydroelectric GSs, six storage reservoirs (one on the mainstem and five on tributaries), and one regulating reservoir on the river (Rosenberg et al. 2005). Urban centres within the drainage basin include Banff, Calgary, Red Deer, Lethbridge, Medicine Hat, Edmonton, Saskatoon, Prince Albert, and The Pas.

The Cormorant Lake watershed (South Moose Lake watershed) is appreciably smaller (approximately 3,162 km^2; Table 2-1) than the Saskatchewan River watershed. The lake receives inflow from Clearwater Lake and several small tributaries and contains one outflow which drains via Frog Creek to North Moose Lake (Figure 2-2). Like the Saskatchewan River catchment, Cormorant Lake lies entirely within the Boreal Plain Ecozone and the Mid-Boreal Lowlands Ecoregion (Figure 1-2). The dominant land cover within the watershed is coniferous forest. The community of Cormorant is located on the east shore of the lake and there is one active fishing lodge nearby. Commercial fishing, trapping, forestry, and tourism are the primary industries in the area.

Cedar Lake.

Saskatchewan River.

2.2.2 Hydroelectric Facilities

The Saskatchewan River is formed by the confluence of the North and South Saskatchewan rivers in east-central Saskatchewan. In total, it drains an area of approximately 335,900 km^2 including parts of Montana, Alberta, Saskatchewan and Manitoba. The Saskatchewan River is a multi-use waterway, being used extensively for agricultural irrigation and livestock watering, recreational purposes, domestic and industrial consumption, and hydroelectric power generation (Jones and Armstrong 2001). Regulation of the Saskatchewan River basin began in the 1890s with the construction of irrigation projects and works to divert and deliver water to land in southern Alberta (Rosenberg et al. 2005). Diversion of water for irrigation projects was followed by regulation for hydroelectric power generation, first in the upper reaches of the Bow River (1911 to 1955) and then in the upper North Saskatchewan River (1965 to 1972) and Saskatchewan River (1963 to 1985; Rosenberg et al. 2005). Presently, there are eleven hydroelectric GSs, six storage reservoirs (one on the mainstem and five on tributaries), and one regulating reservoir within the Saskatchewan River drainage basin (Rosenberg et al. 2005). The Grand Rapids GS is the only station on the Saskatchewan River in Manitoba (Figure 2-2). Manitoba Hydro also maintains the Moose Lake Narrows Control Structure, a concrete spillway with a rock and earth fill dam, to isolate North Moose Lake from South Moose Lake, and the Red Earth Lake and One Man Lake CSs to enable management of the area north of Summerberry River separate from effects of the Grand Rapids GS (Figure 2-2).

2.2.2.1 Grand Rapids GS

The Grand Rapids GS is located approximately 200 km downstream of The Pas, Manitoba, and 4.4 km upstream of the outflow of the Saskatchewan River into Lake Winnipeg. Construction of the Grand Rapids GS was initiated in 1960 and the plant was fully operational by 1968. The Grand Rapids GS has an operating head of 36.6 m and an approximate capacity of 480 MW. The Grand Rapids GS is a peaking plant, meaning one which operates based on changes in the demand for electricity.

The Grand Rapids GS.

2.2.3 Waterbody Descriptions

The Saskatchewan River Region includes the Saskatchewan River from the Manitoba/Saskatchewan Border to the Grand Rapids GS at the outlet to Lake Winnipeg. It also includes waterbodies situated in the Moose Lake watershed. Two waterbodies are sampled annually under CAMP: Cedar Lake southeast basin (on-system), first sampled in 2009/2010; and Cormorant Lake (off-system), first sampled in 2008/2009. Two rotational waterbodies are also monitored in this region: the Saskatchewan River from the Town of The Pas to Cedar Lake (on-system), which was first sampled in 2010/2011; and South Moose Lake (on-system), which was first sampled in 2009/2010. Monitoring is also conducted in the west basin of Cedar Lake (on-system) on a three-year rotational basis, beginning in 2011/2012.

2.2.3.1 Saskatchewan River

The reach of the Saskatchewan River that is monitored under CAMP runs from the Town of The Pas downstream to its confluence at Cedar Lake. This reach of the Saskatchewan River is affected by Manitoba Hydro’s operations under some flow/water level conditions and is affected by upstream water regulation in Saskatchewan. The river supports subsistence, commercial and recreational fisheries. ECCC maintains a long-term water quality monitoring site upstream of The Pas. CAMP monitoring is conducted on a three year rotational basis and was first sampled in Year 3 of the Pilot Program (2010/2011).

The Saskatchewan River.

2.2.3.2 South Moose Lake

Water levels on South Moose Lake are affected by the Grand Rapids GS and water level regulation in Saskatchewan. South Moose Lake is home to Mosakahiken First Nation and the Community of Moose Lake. The lake is fished for subsistence, and also supports commercial and recreational fisheries. Monitoring of the fish community and the commercial fishery has occurred periodically since the 1960s. CAMP monitoring is conducted on a three year rotational basis and was initiated in Year 2 of the Pilot Program (2009/2010). An aquatic habitat survey of South Moose Lake was completed under CAMP in 2011.

South Moose Lake.

2.2.3.3 Cedar Lake – West and Southeast Basins

Cedar Lake, the reservoir for the Grand Rapids GS, is an on-system waterbody sampled under CAMP. The operation of the Grand Rapids GS and water regulation in Saskatchewan both affect water levels on Cedar Lake. Cedar Lake is home to Chemawawin First Nation and the community of Easterville. The lake supports important subsistence, commercial, and recreational fisheries and has an extensive history of aquatic monitoring. Long term fish stock monitoring to support the management of the commercial fishery has been conducted by MSD. Fish stocks have also been monitored since 1999 under an agreement between Manitoba Hydro and Chemawawin First Nation. Water quality has been monitored by MSD at the Grand Rapids GS since 2001. Zebra mussels have been recently introduced into Cedar Lake, with the first confirmed occurrence in 2015.

Two areas of Cedar Lake (west and southeast basins) are monitored under CAMP. The southeast basin is monitored annually and was first sampled in Year 2 of the Pilot Program (2009/2010). The west basin is monitored on a three year rotational basis and was first sampled in 2011/12.

Cedar Lake - west.

Cedar Lake - southeast

2.2.3.4 Cormorant Lake

Cormorant Lake is an off-system waterbody that is monitored annually under CAMP in the Saskatchewan River Region. Cormorant Lake, located in the South Moose Lake watershed approximately 60 km northeast of The Pas, receives inflows from Clearwater Lake, and drains into North Moose Lake via Frog Creek. The Community of Cormorant is situated on the east shore of Cormorant Lake and there is one active fishing lodge situated on the lake. The lake supports subsistence, commercial and recreational fisheries. There is little history of aquatic environment monitoring in this waterbody. CAMP monitoring was initiated in Year 1 of the Pilot Program (2008/2009).

Cormorant Lake.

Figure 2-2. Saskatchewan River Region.

2.3 LAKE WINNIPEG REGION

2.3.1 Regional Description

The Lake Winnipeg Region is composed of the north basin of Lake Winnipeg and Lake Winnipegosis (Figure 2-3). Lake Winnipeg, with a total surface area of approximately 23,750 km^2, is the largest lake in Manitoba and the tenth largest freshwater lake in the world (Brunskill et al. 1980; EC and MWS 2011). The lake's drainage basin, at nearly 1,000,000 km^2 in size, is the second largest watershed in Canada, encompassing parts of four Canadian provinces and four American states (EC and MWS 2011). The drainage basin includes parts of Alberta, Saskatchewan, Manitoba, Ontario, Montana, North Dakota, South Dakota, and Minnesota (Figure 2-3). The main tributaries to Lake Winnipeg, the Winnipeg and Saskatchewan rivers, account for 75% of Lake Winnipeg’s inflow, while the waters of the Red/Assiniboine, Dauphin, Pigeon, and Berens rivers, plus other smaller tributaries, comprise the remaining 25% (EC and MWS 2011).

Lake Winnipeg lies within the Boreal Plain Ecozone, although its entire eastern shoreline forms the boundary of the Boreal Shield Ecozone (Figure 1-2). The majority of the lake falls within the Mid-Boreal Lowland Ecoregion, with the southern portion of the South Basin falling within the Interlake Plain Ecoregion. The southern portion of the eastern shore is situated in the Lake of the Woods Ecoregion while the northern portion is situated in the Lac Seul Upland Ecoregion.

The majority of the Lake Winnipeg watershed (primarily areas to the west and south of Lake Winnipeg) flows through sedimentary landscapes, with semi-arid and temperate prairies throughout (EC and MWS 2011). These sedimentary landscapes are characterized by croplands and grasslands. In the eastern portion of the watershed, sedimentary soils are replaced by shallow, bedrock-underlain soils of the Precambrian Shield (EC and MWS 2011). Bogs and other wetlands cover an extensive portion of these landscapes. Rivers flowing through these resistant shield landscapes to the east of Lake Winnipeg are clearer-flowing than those in sedimentary prairie landscapes, where the soils are more erodible (EC and MWS 2011). The dominant land cover in the basin is classified as cultivated crops (Table 2-1).

The climate of Lake Winnipeg varies from north to south, with cooler, drier conditions to the north and warmer, wetter conditions to the south (EC and MWS 2011). Mean annual air temperature from 1999 to 2007 was 0.8°C at The Pas in the north and 2.5°C at Gimli in the south. Over the same time period, total annual precipitation ranged from approximately 20 cm to 43 cm over the north basin.

Human alteration of portions of the Lake Winnipeg watershed began in the late 1800s. Since then, water control projects in Ontario, Manitoba, Saskatchewan, Alberta, Minnesota, and North Dakota have all affected natural inflows to the lake (Baird and Stantec 2000). Hydroelectric GSs were first constructed along the Winnipeg River in Manitoba over 100 years ago. Drainage from Lake Manitoba into the Dauphin River has been regulated by the Fairford Dam since the early 1960s. Construction of the Grand Rapids GS, which impounded a short section of the Saskatchewan River below Cedar Lake, was completed in 1968. Since the construction of the Jenpeg GS and CS in 1976, Lake Winnipeg has become an important part of Manitoba Hydro's hydroelectric system.

Lake Winnipeg water levels undergo both short- and long-term changes (i.e., daily, monthly, seasonally, and annually) that result from variations in the amount of precipitation, evaporation, inflow to, and outflow from the lake, including the effects of regulation. Over the scale of centuries, isostatic rebound has been raising the outlet of the lake such that levels in the south basin are gradually increasing at an estimated rate of 20 cm/century (Baird and Stantec 2000; Nielsen 1998).

While there are few population centres on the north basin of Lake Winnipeg (e.g., Grand Rapids, Berens River), municipal and industrial wastewater discharges from large cities throughout the Lake Winnipeg basin contribute significant nutrient inputs to Lake Winnipeg as a whole and ultimately to the north basin. In Manitoba alone, Lake Winnipeg receives effluent from nearly 200 wastewater treatment facilities, as well as effluent from 10 large facilities, including municipal and industrial plants (Bourne et al. 2002).

Lake Winnipeg supports large commercial, subsistence, and recreational fisheries, various recreational activities, cottage developments, and lakeshore communities (e.g., Gimli, First Nation communities). The basin is home to approximately six million people and 17 million livestock, and includes 55 million hectares of agricultural land (Lake Winnipeg Implementation Committee 2005). The contamination of Lake Winnipeg has been the subject of intermittent study over the past four decades. Although there have been issues related to other contaminants (e.g., the commercial fishery was closed in the early 1970s due to mercury levels), the primary focus has been related to eutrophication, as a result of organic loading in the 1960s and more recently, enrichment by nitrogen and phosphorus (NSC 2006).

Like Lake Winnipeg, Lake Winnipegosis lies within the Boreal Plain Ecozone. The south portion (i.e., south of Birch Island) of Lake Winnipegosis is situated in the Interlake Plain Ecoregion, while the north portion is situated in the Mid-boreal Lowland Ecoregion (Figure 1-2). Although the Lake Winnipegosis watershed is considered large, Lake Winnipeg drains an area approximately 20 times larger, and the surface area of Lake Winnipeg is approximately four times larger, than that of Lake Winnipegosis (Table 2-1). The Lake Winnipegosis watershed extends west to include the moderately high relief of the Manitoba Escarpment and the valleys and plains of eastern Saskatchewan. Major tributaries include the Mossy, Red Deer, and Shoal rivers, and the lake discharges into Lake Manitoba via the Waterhen River.

The shoreline of Lake Winnipegosis is scarcely populated, with the Village of Winnipegosis, communities of Dawson Bay, Duck Bay, and Camperville, and First Nation lands held by the Chemawawin FN, Sapotaweyak FN, and the Pine Creek FN being the only population centres along the shores of the lake. However, the drainage basin includes larger centres such as the Town of Dauphin and the Town of Swan River. The region’s dominant land cover is deciduous forest (Table 2-1) and forestry is one of the primary industries of the region. A small portion of the land base, situated mainly in the southern portion of the region, is used for agriculture due to suitable soil composition, drainage, growing season length, and precipitation. This land base supports cereal and oil seed farming, as well as livestock production. The lake supports important subsistence, commercial, and recreational fisheries.

North basin of Lake Winnipeg. The Namao research vessel is shown on the upper left.

2.3.2 Hydroelectric Facilities

With a surface area of approximately 23,750 km^2, Lake Winnipeg is the seventh largest lake in North America (Brunskill et al. 1980). Although there are no structures related to hydroelectric generation in Lake Winnipeg proper (Figure 2-3), the outflow of the lake is regulated under the LWR project. LWR, which consists of a series of channels and CSs that control the outflow from Lake Winnipeg, serves a flood mitigation role, as well as serving as a key component of Manitoba Hydro's hydraulic system. Although on average, Lake Winnipeg outflows have been similar to pre-LWR conditions since LWR became operational, LWR allows for higher outflow from the lake (approximately 50% higher) during flood conditions. Some seasonal effects are also evident with higher average outflow in winter and lower average outflow in summer (Manitoba Hydro 2014).

2.3.3 Waterbody Descriptions

Two waterbodies are monitored annually under CAMP in the Lake Winnipeg Region. The on-system waterbody is the north basin of Lake Winnipeg and the off-system waterbody is Lake Winnipegosis.

2.3.3.1 Lake Winnipeg North Basin

Lake Winnipeg, the tenth largest freshwater lake in the world (EC and MWS 2011), is composed of a shallow, smaller, southern basin, and a deeper, larger, northern basin separated by a channel referred to as the narrows. The lake is affected by Manitoba Hydro's hydraulic operating system as well as by water regulation in Alberta, Saskatchewan, and Ontario, and regulation for purposes other than hydroelectric power production in Manitoba. The lake supports important subsistence, commercial, and recreational fisheries and has an extensive history of aquatic monitoring. Numerous communities are located on the shores of Lake Winnipeg and it supports extensive cabin developments and recreational activities. Concerns over eutrophication of Lake Winnipeg have recently been raised which have spurned intensive and extensive scientific study, monitoring, and management initiatives. Zebra mussels have been recently introduced into Lake Winnipeg, with the first confirmed occurrence in 2013 (http://www.gov.mb.ca/waterstewardship/stopais/index.html).

Annual monitoring of the fish community was initiated in 2008/2009 (i.e., Year 1 of CAMP), while monitoring of BMI was initiated in 2013/2014 under CAMP. Water quality monitoring of the north basin of Lake Winnipeg is conducted by MSD under a separate initiative, though results for a site near the Grand Rapids GS are incorporated into CAMP reporting.

North basin of Lake Winnipeg at Sturgeon Bay.

North basin of Lake Winnipeg at Mossy Bay.

North basin of Lake Winnipeg near Grand Rapids.

2.3.3.3 Lake Winnipegosis

Lake Winnipegosis is a large off-system waterbody west of the north basin of Lake Winnipeg. It is not affected by water regulation for hydroelectric power production but is affected by regulation in some tributaries for other purposes, such as flood protection. The lake supports important subsistence, commercial, and recreational fisheries and monitoring of the fish community has occurred annually since 1990 by MSD. CAMP monitoring of this waterbody was initiated in Year 1 of the Pilot Program (2008/2009).

Lake Winnipegosis near the water quality sampling site (left) and near the BMI sampling site (right).

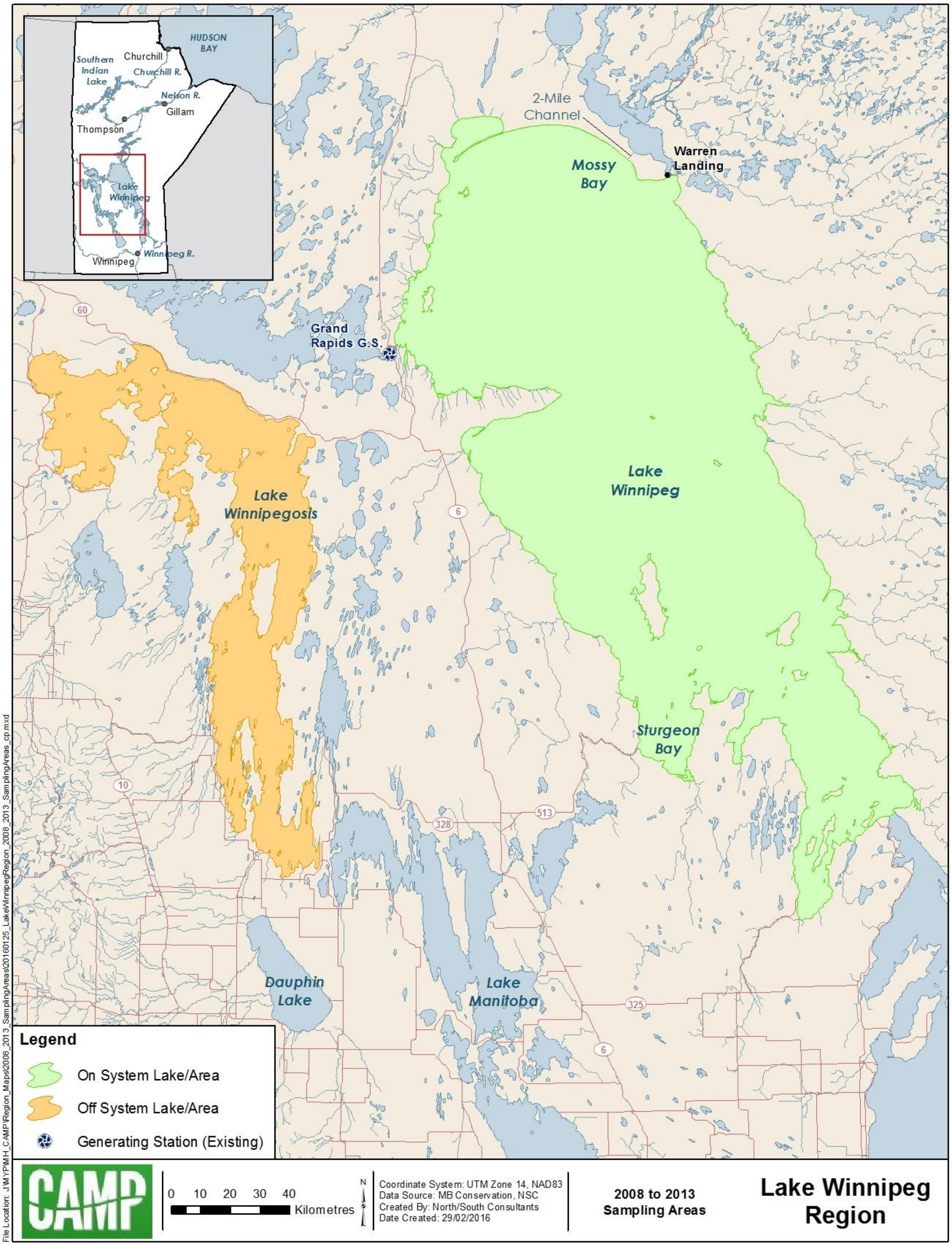


Figure 2-3. Lake Winnipeg Region.

2.4 UPPER CHURCHILL RIVER REGION

2.4.1 Regional Description

The Upper Churchill River Region is composed of the Churchill River watershed extending from the Saskatchewan/Manitoba border downstream to the natural outlet of Southern Indian Lake at Missi Falls and the man-made outlet at South Bay (Figure 2-4).

The upper Churchill River watershed drains approximately 260,000 km^2 of northern Alberta, Saskatchewan, and Manitoba, eventually emptying into Southern Indian Lake, Manitoba. In 1976, the Churchill River was impounded at the outlet of Southern Indian Lake, and most of its flow was diverted by means of CRD into the Rat/Burntwood river system and eventually to hydroelectric GSs on the Nelson River.

The majority of the Upper Churchill River Region lies within the Churchill River Upland Ecoregion of the Boreal Shield Ecozone, although the northern portion of Southern Indian Lake falls within the Selwyn Lake Upland Ecoregion of the Taiga Shield Ecozone (Figure 1-2).

The climate of the upper Churchill River drainage basin is variable due to the large size of the watershed. The coldest month of the year is typically January, with mean daily air temperatures generally ranging from –10ºC in the south to –27.5ºC in the north (Rosenberg et al. 2005). The warmest month of the year is typically July, with mean daily air temperatures generally ranging from 17.5°C in the south to 15ºC in the northern part of the basin (Rosenberg et al. 2005). The number of frost-free days range from approximately 120 in the south to 60 to 70 in the northern and western fringes of the portion of the watershed suitable for widespread agricultural activity (Rosenberg et al. 2005). The mean annual precipitation for the basin is approximately 40 cm (Rosenberg et al. 2005).

The dominant land cover within the upper Churchill River drainage basin is coniferous forest (Table 2-1) and these forests have supported a number of commercial forestry operations in central Saskatchewan (Rosenberg et al. 2005). Large portions of western central Saskatchewan lying within the upper Churchill River drainage basin are composed of grasslands underlain by brown, dark brown and black soils that support cultivated land or uncultivated land used for grazing (Rosenberg et al. 2005). There is also some non-renewable resource activity within the basin, including metal mining concentrated in northern Saskatchewan and Manitoba. Within Manitoba there are three mine properties in the Churchill River watershed (i.e., Keystone gold mine near Lynn Lake, Ruttan copper-zinc mine near Leaf Rapids, and the Farley Lake mine), all of which shut down their mining and/or milling operations in the early 2000s (MGET 2017b). Hydroelectric development has altered the Southern Indian Lake portion of the upper Churchill River through the construction of CRD. Additionally, there are two hydroelectric GSs on the upper Churchill River system in Saskatchewan (the Island Falls Dam on the Churchill River and the Whitesand Dam on the Reindeer River), as well as two small hydroelectric GSs (Laurie River I and II) and several small CSs on the Laurie River, which is a tributary to the Churchill River in Manitoba.

The upper Churchill River watershed supports extensive commercial and domestic fishing hunting and trapping, as well as commercial sport fishing and hunting operations. Additionally, recreational use of the Churchill River (particularly in Saskatchewan) is common.

The upper Churchill River basin is sparsely populated and all communities within the watershed in Saskatchewan and Manitoba are smaller than 5,000 people. Communities or First Nations found within the upper Churchill River basin in Manitoba include Pukatawagan, Granville Lake, Lynn Lake, Leaf Rapids, and South Indian Lake.

Granville Lake.

Southern Indian Lake (Area 4).

2.4.2 Hydroelectric Facilities

The upper Churchill River flows entering Manitoba have been regulated to some extent since 1928. MacKay (1992) reported that the Island Falls GS on the upper Churchill River in Saskatchewan (constructed in 1928-1930) has had major impacts on water levels and flows along the Churchill River in Manitoba. As well, the Whitesand Dam (completed in 1942) on the Reindeer River in Saskatchewan continues to regulate the outflows from Reindeer Lake. Heilman-Ternier and Harms (1975) reported that the operating policy of the two dams is to minimize water level fluctuations at the Island Falls reservoir (Sokatisewin Lake) by increasing the flow from Reindeer Lake when the Churchill River flows are low, and by decreasing the flow from Reindeer Lake when the Churchill River flows are high. The authors reported that this policy had resulted in relatively constant levels on the Island Falls reservoir and a moderation of natural seasonal variation in flows to downstream areas. In 1981, a change in operating regime at Island Falls GS resulted in a shift from base load operations to those that maximized power generation. Following the change, EMA (1993) *In* Cooley and MacDonald (2008) reported that post-1980 winter monthly flows were 25-38% higher than natural conditions and summer flows were 15-25% lower than natural conditions.

The Churchill River flows northeast to Manitoba and, in its natural state, continued through Southern Indian Lake and a series of other smaller lakes before eventually emptying into Hudson Bay near the Town of Churchill. In 1976, a CS was constructed at Missi Falls (Missi Falls CS) at the outlet of Southern Indian Lake which raised the level of the lake and diverted the majority of the flow of the Churchill River flow southward into the Rat/Burntwood River system, eventually draining to the lower Nelson River at Split Lake.

The primary water regulation structure within the Upper Churchill River Region in Manitoba is the Missi Falls CS (Figure 2-4). Manitoba Hydro GSs located within the region consist of the Laurie River I and Laurie II GSs located on the Laurie River, a tributary to the Churchill River upstream of Granville Lake. Both Laurie I and Laurie II GSs were purchased by Manitoba Hydro in 1970 from Sherritt Gordon Mines Limited. Manitoba Hydro also maintains a number of CSs that were constructed by Sherritt Gordon Mines as part of the Laurie River project. These include the Loon River Diversion CS, the Eager Lake CS, the Russell Lake CS, and the Kamuchawie CS (Figure 2-4).

2.4.2.1 Laurie River I GS

The Laurie River I GS is located approximately 200 km northwest of Thompson and approximately 27 km west of the community of Granville Lake. The station was built to supply Sherritt Gordon’s mining operations in the area and went into operation in 1952. With an operating head of approximately 16.6 m, Laurie River I has two turbine units and a capacity of 5 MW of electricity (Manitoba Hydro 2016).

2.4.2.2 Laurie River II GS

The Laurie River II GS is located approximately 10 km upstream of the Laurie River I GS. Like the Laurie I GS, the Laurie II GS was built by Sherritt Gordon Mines and began operation in 1958 to supply local mining operations. With an operating head of approximately 18.1 m, Laurie River II also has a capacity of 5 MW of electricity, but only one turbine unit (Manitoba Hydro 2016).

2.4.2.3 *Missi Falls Control Structure*

The Missi Falls CS was constructed between 1973 and 1976 at the natural outlet of Southern Indian Lake. It raised the water level of Southern Indian Lake by approximately 2.7 m and regulates both the water level in Southern Indian Lake and the amount of water allowed to pass downstream to the lower Churchill River (Manitoba Hydro and the Province of Manitoba 2015). The Missi Falls CS consists of six spillway bays as well as earth dams and dykes. The minimum licensed outflow is 14.2 m^3/s during open-water conditions and 42.5 m^3/s under ice cover. The CS is capable of discharging 3,200 m^3/s at a forebay level of 258.3 m (Manitoba Hydro and the Province of Manitoba 2015).

Missi Falls Control Structure at Southern Indian Lake.

2.4.3 Waterbody Description

The Upper Churchill River Region is composed of the Churchill River extending from the Saskatchewan/Manitoba border downstream to the natural outlet of Southern Indian Lake at Missi Falls and the man-made outlet at South Bay. Annual monitoring is conducted at Granville Lake (off-system) and Southern Indian Lake Area 4 (on-system) and was initiated in Year 1 of the Pilot Program in these waterbodies. Three additional areas (all on-system) are monitored under CAMP on a three-year rotational basis in this region: Opachuanau Lake, first monitored in 2011/2012; Southern Indian Lake Area 1, first monitored in Year 2 of the Pilot Program; and Southern Indian Lake Area 6, first monitored in Year 3 of the Pilot Program.

2.4.3.2 Granville Lake

Granville Lake, an off-system, annual waterbody, is located upstream of Southern Indian Lake along the upper Churchill River. Granville Lake water levels are not affected by CRD the majority of the time; a measureable backwater effect occurs less than 10 percent of the time when low flows on the upper Churchill River (and consequently low Granville Lake levels) are combined with Southern Indian Lake being near its maximum operating limit. The water levels of Granville Lake are also affected by flow regulation upstream in the Saskatchewan portion of the watershed. Granville Lake is home to the Community of Granville Lake and the lake is fished for subsistence and commercially. MSD has maintained a long-term water quality sampling site on the lake since the 1970s. Monitoring of Granville Lake under CAMP has been conducted annually since Year 1 of the Pilot Program.

Granville Lake.

2.4.3.3 Opachuanau Lake (Southern Indian Lake – Area 0)

Opachuanau Lake (also referred to as Southern Indian Lake – Area 0), is located upstream of Southern Indian Lake. The lake is affected by Manitoba Hydro’s hydraulic system and water regulation in Saskatchewan. Opachuanau Lake supports subsistence and commercial fishing and has been the subject of extensive historical aquatic monitoring. Opachuanau Lake is monitored under CAMP on a three-year rotational basis and was first sampled in 2011/12.

Opachuanau Lake.

2.4.3.4 Southern Indian Lake – Areas 1, 4, and 6

Southern Indian Lake, an on-system lake, functions as a storage reservoir for CRD due to the operation of the Missi Falls and Notigi CSs. Like lakes upstream, Southern Indian Lake is also affected by water regulation in the Province of Saskatchewan. Southern Indian Lake is home to O-Pipon-Na-Piwin First Nation and the Community of South Indian Lake. There is a long history of aquatic monitoring in Southern Indian Lake, dating back to the pre-CRD period. It was investigated as part of the LWCNRSB studies in the 1970s, it was home to a DFO research station that operated in the 1970s and 1980s, was monitored under the 1986-1990 FEMP, and is currently (2003-present) being studied by the South Indian Lake Environmental Steering Committee. Additionally, fish stocks have been monitored by Manitoba Fisheries Branch since the 1990s and water quality has been monitored at a site near the Community of South Indian Lake since the 1970s by MSD.

Historical studies of Southern Indian Lake divided the lake into seven areas (Areas 1-7) and three of these areas (1, 4, and 6) are monitored under CAMP. Areas 1, 4, and 6 support important subsistence fisheries and Areas 1 and 4 either presently support (Area 1) or have supported (Area 4) important commercial fisheries. The commercial fishery of Southern Indian Lake – Area 4 is currently closed.

Monitoring has been conducted annually since Year 1 of the Pilot Program in one area of the lake (Area 4, west of Missi Falls) under CAMP. Areas 1 (southwestern basin) and 6 (basin south of the Community of South Indian Lake) are sampled on a three year rotation and were first monitored under CAMP in 2009/2010 and 2010/2011, respectively. An aquatic habitat survey was completed at Southern Indian Lake Area 4 under CAMP in 2013.

Southern Indian Lake – Area 1.

Southern Indian Lake – Area 4.

Southern Indian Lake – Area 6.

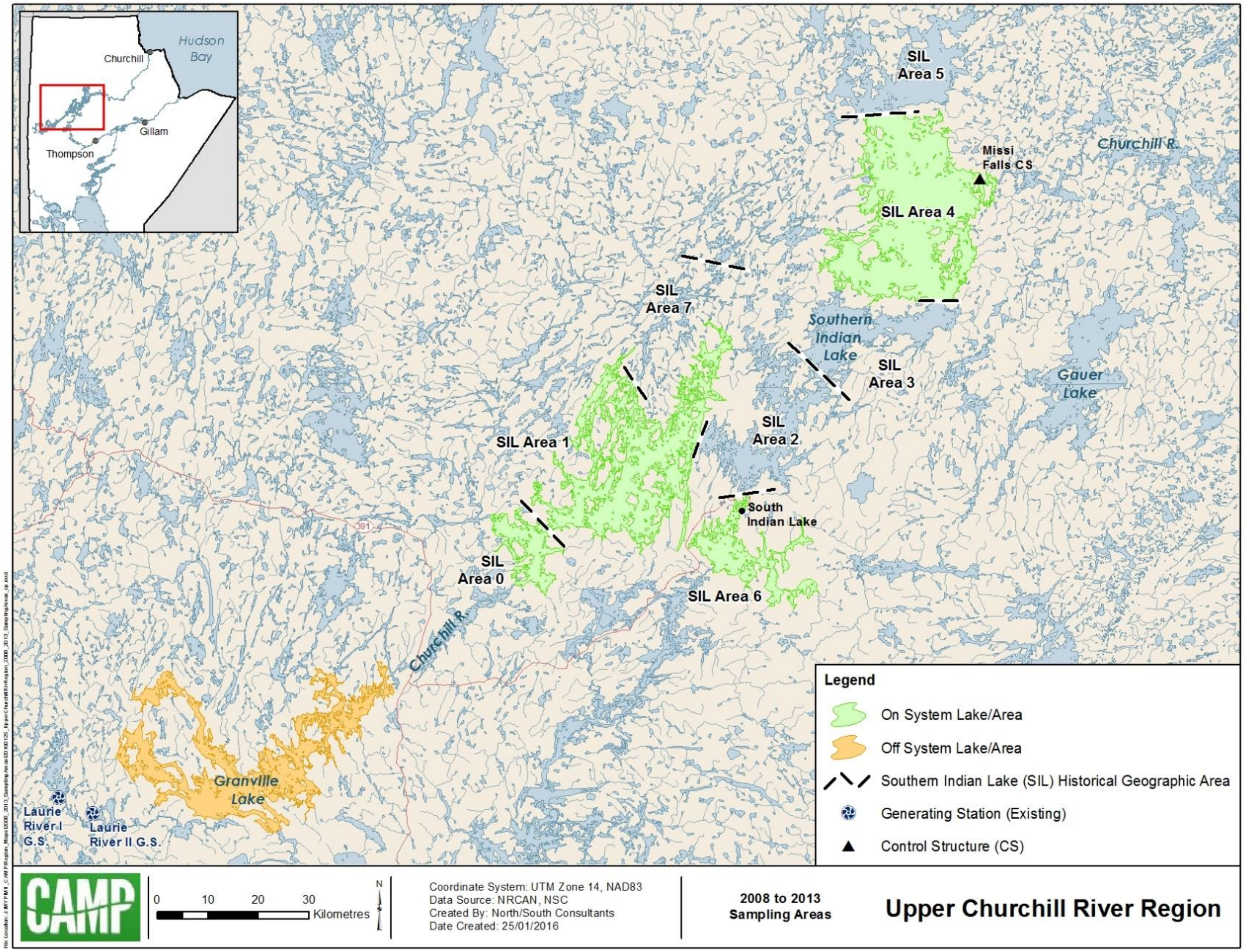


Figure 2-4. Upper Churchill River Region.

2.5 LOWER CHURCHILL RIVER REGION

2.5.1 Regional Description

The Lower Churchill River Region is composed of the portion of the Churchill River extending from the Missi Falls CS at the natural outlet of Southern Indian Lake to the mouth of the river at the Town of Churchill on Hudson Bay (Figure 2-5). The region also includes Gauer Lake, an off-system waterbody located south of the Churchill River.

Historically, the Churchill River at Southern Indian Lake drained approximately 260,000 km^2 of northern Alberta, Saskatchewan, and Manitoba. However, since the Churchill River was impounded at the outlet of Southern Indian Lake by the Missi Falls CS in 1976, a large portion of its flow was diverted by means of CRD to hydroelectric GSs on the lower Nelson River. Consequently, post-CRD discharge along the lower Churchill River has been considerably lower than historic rates (Manitoba Hydro and the Province of Manitoba 2015).

The Lower Churchill River Region spans three ecozones (Boreal Shield, Taiga Shield, and Hudson Plain) and four ecoregions (Churchill River Upland, Selwyn Lake Upland, Hudson Bay Lowland, and Coastal Hudson Bay Lowland; Figure 1-2). The shield ecozones are characterized by numerous lakes and wetlands and have a poorly organized drainage system (Rosenberg et al. 2005). The lower portion of the lower Churchill River flows through the Hudson Plain Ecozone, an area characterized by flat muskeg plains, extensive permafrost, shallow lakes, and raised gravel beaches (Lane and Sykes 1982 *In* Rosenberg et al. 2005). The dominant land cover of the Lower Churchill River Region is classified as coniferous forest (Table 2-1).

The climate of the Lower Churchill River Region is characterized by long cold winters and short cool summers. The coldest month of the year is generally January with a mean daily air temperature near –27.5ºC recorded at Churchill (Rosenberg et al. 2005). The warmest month of the year is typically July, with mean daily air temperatures of around 11.5°C recorded at Churchill (Manitoba Hydro and the Town of Churchill 1997). The mean annual precipitation for the entire Churchill River basin (including both the upper and lower Churchill River regions) is approximately 40 cm (Rosenberg et al. 2005), which is similar to levels recorded at Churchill (Manitoba Hydro and the Town of Churchill 1997).

The Lower Churchill River Region is sparsely populated with only one community (i.e., Town of Churchill located along the shore of Hudson Bay) located within the region. Individuals from Churchill and several First Nation communities participate in domestic and commercial harvesting of fish and wildlife along the lower Churchill River. Additionally, recreational fishing and other recreational uses of the lower Churchill River near Churchill are common. There are no forestry activities within the region and there are no historic or active mines in the Lower Churchill River Region.

Gauer Lake is located in the Boreal Shield Ecozone and the Churchill River Upland Ecoregion (Figure 1-2), approximately 125 km north of the City of Thompson (Figure 2-5). The surface area of the lake is 263 km^2, with a drainage basin of 4,897 km^2 (Table 2-1). Gauer Lake receives inflows from the upper portion of the Gauer River and a few smaller tributaries. The lower portion of the Gauer River forms the outflow from Gauer Lake and discharges into the lower Churchill River below Missi Falls. The dominant land cover of the watershed is shrub (Table 2-1). Gauer Lake supports a commercial fishery and likely supports some subsistence fishing, hunting, and trapping. There are no permanent residences in the watershed, although there are a couple of seasonal fishing camps on the shore of Gauer Lake. There is no forestry activity and no active mines in the watershed.

Lower Churchill River.

Lower Churchill River at the confluence of the Little Churchill River.

2.5.2 Hydroelectric Facilities

As discussed in Section 2.4.2, the Missi Falls CS has minimum licensed open-water and winter outflows and therefore controls the amount of water being released into the lower Churchill River. Approximately 203.7 km^2 of the lower Churchill River was dewatered as a result of CRD (Manitoba Hydro and the Province of Manitoba 2015). There are no hydroelectric GSs on the lower Churchill River. The Lower Churchill River Water Level Enhancement Weir Project was constructed in 1998-1999 to increase water levels along a 10 km long reach of the lower Churchill River, to enhance recreational opportunities in the area, and to increase the amount of aquatic habitat. The rock-fill weir and ancillary features were built 10 km south of the Town of Churchill, just upstream of Mosquito Point (Figure 2-5).

The Churchill Weir.

2.5.3 Waterbody Descriptions

The Lower Churchill River Region includes the Churchill River from the Missi Falls CS at the natural outlet of Southern Indian Lake to the mouth of the river at the Town of Churchill on Hudson Bay (Figure 2-5). The region also includes Gauer Lake, which is located south of the lower Churchill River. Three areas have been monitored annually under CAMP beginning in Year 1 of the Pilot Program: Northern Indian Lake (on-system), the lower Churchill River at the Little Churchill River (on-system), and Gauer Lake (off-system). Three additional lakes, all of which are on-system, are monitored on a three-year rotational basis in this region: Partridge Breast Lake, which was first sampled in Year 2 of the Pilot Program; Fidler Lake, which was first sampled in 2011/2012 under CAMP; and Billard Lake, which was first sampled in Year 3 of the Pilot Program. In addition, monitoring was conducted in 2011/2012 in the lower Churchill River at Red Head Rapids.

2.5.3.1 *Partridge Breast Lake*

Partridge Breast Lake, an on-system waterbody, is located on the lower Churchill River, immediately downstream of the Missi Falls CS and upstream of Northern Indian Lake. Its water levels are affected by CRD. The lake supports a subsistence fishery and periodically supports a commercial fishery. There has been limited historical monitoring of the fish community and water quality in this waterbody. BMI sampling was conducted bi-annually on the lake from 1977 to 1983, and in 1973 and 1987. CAMP monitoring is conducted on a three-year rotational basis in Partridge Breast Lake and was first sampled in Year 2 of the Pilot Program.

Partridge Breast Lake.

2.5.3.2 *Northern Indian Lake*

Northern Indian Lake is an on-system waterbody located downstream of the Missi Falls CS and Partridge Breast Lake, and is affected by CRD. Although the lake supports subsistence and commercial fisheries, with the exception of limited data collected prior to CRD as part of the LWCNRSB studies, the fish community has received little study. There has been limited historical monitoring of water quality in this waterbody. There is comparatively more historical monitoring data for the BMI community for Northern Indian Lake; BMI sampling was conducted bi-annually on the lake from 1977 to 1983, and in 1973 and 1987. Northern Indian Lake has been monitored annually under CAMP beginning in Year 1 of the Pilot Program. An aquatic habitat survey was completed in a portion of Northern Indian Lake under CAMP in 2010.

Northern Indian Lake.

2.5.3.3 Fidler Lake

Fidler Lake, an on-system lake located on the lower Churchill River between Northern Indian Lake and Billard Lake, is also affected by CRD. Fidler Lake supported a commercial fishery in the past; currently the lake is not commercially fished and is believed to support little subsistence or recreational fishing. In general, there is relatively limited historical monitoring information for Fidler Lake. Limited information on the fish community, commercial fishery, and water quality was collected prior to CRD as part of the LWCNRSB studies. In addition, BMI sampling was conducted bi-annually on the lake from 1977 to 1983 and in 1973 and 1987. Fidler Lake is monitored on a three-year rotational basis under CAMP and was first sampled in 2011/2012.

Fidler Lake.

2.5.3.4 Billard Lake

Billard Lake is an on-system lake located on the lower Churchill River, downstream of Northern Indian Lake and upstream of the Churchill River at the Little Churchill River. Like lakes located upstream, it is affected by CRD. A fly-in hunting/fishing camp is located on the lake, suggesting that some recreational fishing occurs. Billard Lake supported a commercial fishery in the past; however, at present there is no commercial fishery and likely little subsistence fishing. With the exception of limited study of the commercial fishery done as part of the LWCNRSB studies prior to CRD, there has been limited aquatic monitoring in this lake. Billard Lake is monitored on a three-year rotational basis under CAMP and was first sampled in Year 3 of the Pilot Program. An aquatic habitat survey of Billard Lake was completed under CAMP in 2010.

2013/ 8/ 5

Billard Lake.

2.5.3.5 Churchill River at the Little Churchill River

The second on-system waterbody sampled annually under CAMP is a reach of the lower Churchill River at its confluence with the Little Churchill River. Like upstream sites on this river, water levels and flows in this area are affected by CRD. The site is fished for subsistence. Prior to the initiation of CAMP, there had been very little aquatic environmental information collected at this location. Sampling has been conducted annually under CAMP beginning in Year 1 of the Pilot Program.

Lower Churchill River at the Little Churchill River confluence.

2.5.3.6 Churchill River at Red Head Rapids

This riverine sampling area is located on the lower Churchill River downstream of the Little Churchill River confluence and upstream of the Town of Churchill. Water levels and flows in this area are affected by CRD. The area supports a minimal amount of recreational fishing. No BMI or fish community information had been collected from this site prior to the initiation of CAMP. However, water quality was monitored by ECCC from 1972 through 1996 at this location. This reach of the lower Churchill River, a rotational site, was first sampled in 2011/2012 under CAMP, at which time it was identified to pose significant safety/access and logistical challenges with respect to implementation of CAMP monitoring. An alternative site located downstream near the Town of Churchill (i.e., upstream of the Churchill Weir) was subsequently selected and was first sampled in 2014/2015.

Lower Churchill River at Red Head Rapids.

2.5.3.7 Churchill River at the Weir

This riverine sampling area is located on the lower Churchill River immediately upstream of the Churchill Weir near the Town of Churchill. Water levels and flows in this area are affected by CRD and the Weir itself. The Weir was constructed in 1998 and 1999 to increase the amount of fish habitat and recreational fishing opportunities in the area. The area supports a moderate level of recreational fishing, most of it concentrated in Goose Creek which flows into the lower Churchill River just upstream of the Weir. This reach of the lower Churchill River, a rotational site, was first sampled in 2014/2015 under CAMP as an alternative to sampling at Red Head Rapids which had proved to be logistically challenging.

Lower Churchill River at the Churchill Weir.

2.5.3.9 Gauer Lake

Gauer Lake is the off-system lacustrine site monitored annually under CAMP in the Lower Churchill River Region. Gauer Lake is situated on the Gauer River, which flows into the Churchill River downstream of the Missi Falls CS, and is not affected by water regulation. The lake is fished commercially and for subsistence. There is little history of aquatic monitoring on Gauer Lake. It was first sampled under CAMP in Year 1 of the Pilot Program.

Gauer Lake.

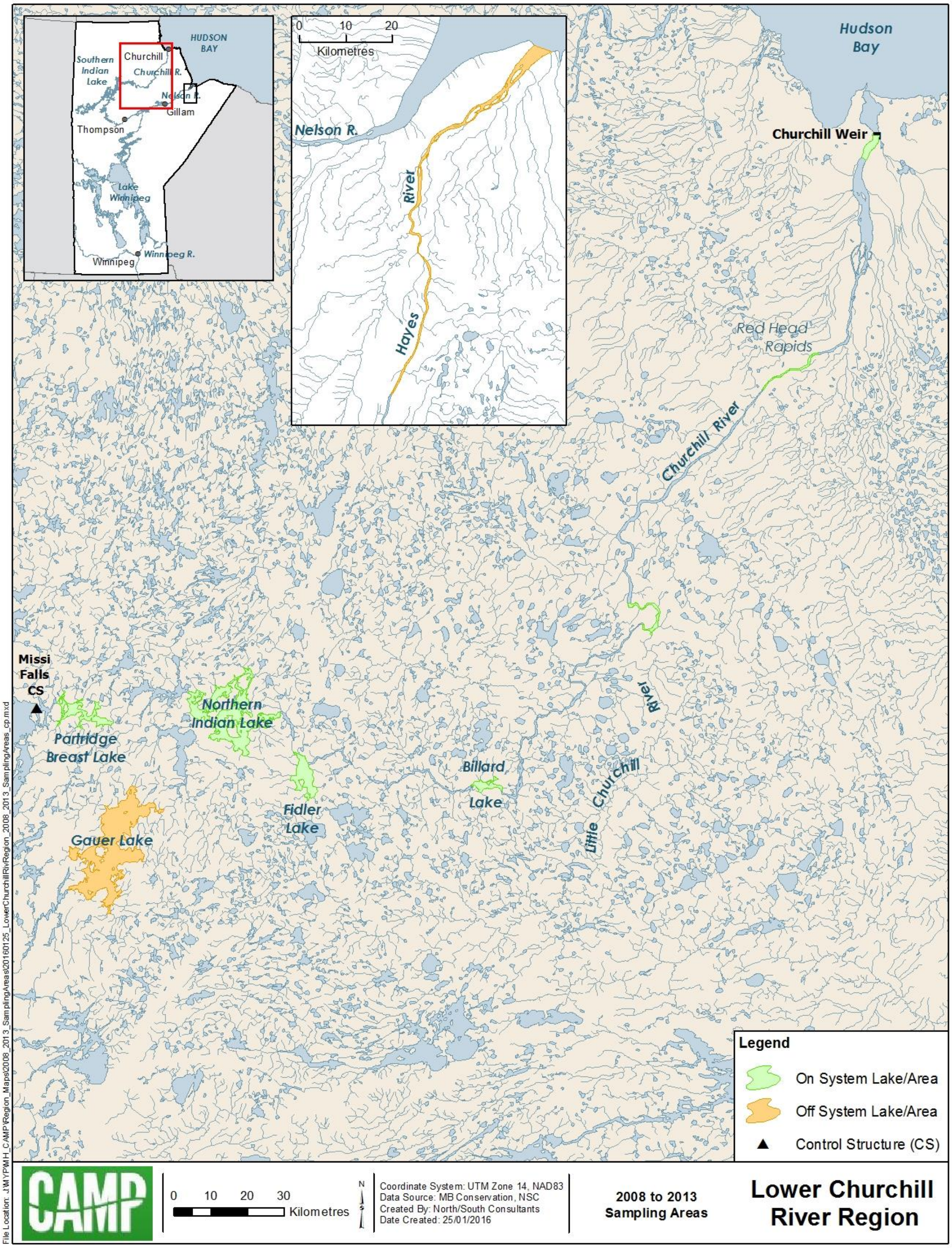


Figure 2-5. Lower Churchill River Region.

2.6 CHURCHILL RIVER DIVERSION REGION

2.6.1 Regional Description

The Churchill River Diversion Region is composed of the portion of the CRD that extends from the man-made outlet of Southern Indian Lake at South Bay, through the Rat/Burntwood river system to First Rapids on the Burntwood River, approximately 20 km upstream of Split Lake (Figure 2-6). The region also includes Leftrook Lake, an off-system lake, located on the Footprint River system.

In 1976, the Churchill River was impounded at Southern Indian Lake and most of its flow was diverted by means of the CRD to hydroelectric GSs on the Nelson River. The CRD involved the construction of an artificial outlet at South Bay on Southern Indian Lake, construction of a channel linking Southern Indian Lake and the headwaters of the Rat River, impoundment of Southern Indian Lake by the Missi Falls CS, and impoundment of the upper Rat River by the Notigi CS. When commissioned, the CRD re-directed most of the natural flow of the Churchill River through the Rat River to its confluence with the Burntwood River at Threepoint Lake (Figure 2-6). The size of the effective drainage basin at Apussigamasi Lake (downstream of Threepoint Lake) after diversion is approximately 280,000 km^2 (Table 2-1).

The majority of the Churchill River Diversion Region lies within the Churchill River Uplands Ecoregion of the Boreal Shield Ecozone with a small proportion of the region falling within the Hayes River Upland Ecoregion of the same ecozone (Figure 1-2). Precambrian Shield bedrock underlies the majority of this region (Smith et al. 1998 *In* Jones and Armstrong 2001). Outcroppings of granitic Precambrian bedrock are common throughout the region and, when not exposed at the surface, the bedrock is overlain by a variety of soil types including brunisols (derived from sand deposits), luvisols (derived from lacustrine clay deposits), and deep organic soils (derived from peat deposits; Jones and Armstrong 2001). Some streams and lakes in the Rat/Burntwood River system are underlain by lacustrine clay deposits and are naturally turbid, a feature that is uncharacteristic of most waterbodies in the Boreal Shield Ecozone (Jones and Armstrong 2001). The dominant land cover of the region is coniferous forest (Table 2-1). Black spruce and jackpine are the dominant tree species within forest cover; sphagnum moss, black spruce, and ericaceous shrubs and sedges and brown mosses dominate the bogs and fens, respectively (Jones and Armstrong 2001).

The climate of the Churchill River Diversion Region, based on data from Thompson for the period of record between 1971 and 2000, is characterized by mean monthly temperatures ranging from 15.8ºC in July to –24.9ºC in January (Manitoba Hydro and Nisichawasihk Cree Nation 2003). Rainfall accounts for about 67% of the approximately 50 cm of annual precipitation, with the majority occurring between June and September (Manitoba Hydro and Nisichawayasihk Cree Nation 2003).

Land use and industry within the Churchill River Diversion Region include forestry, mining, commercial fishing and trapping, subsistence fishing, hunting, and trapping, and recreation (including recreational fishing and sport hunting; Jones and Armstrong 2001). The region is sparsely populated, with the only major urban centre being the City of Thompson. The only other population centre within the region is at Nelson House located on Footprint Lake. The region is home to two nickel mines: the Vale Canada (Vale) INCO mining and smelting complex just south of Thompson; and the Birchtree Mine located at Birchtree Lake, approximately 10 km southwest of Thompson, both of which are currently active (MGET 2017c). Both the City of Thompson and Vale discharge treated domestic and industrial effluent to the Burntwood River (Jones and Armstrong 2001).

Leftrook Lake is located in the Boreal Shield Ecozone and the Churchill River Upland Ecoregion (Figure 1-2) approximately 60 km northwest of the City of Thompson and 30 km north northeast of Nelson House near the head of the Footprint River system (Figure 2-6). The surface area of Leftrook Lake is 46 km^2, with a drainage basin of 389 km^2 (Table 2-1). The lake receives inflow from a few small tributaries and is drained by the Footprint River. The shorelines consist of exposed bedrock and bedrock overlain with lacustrine deposits of stratified silts and clays (Beke et al. 1973). The bedrock is primarily granitic with wide belts of gneissic and volcanic rock. The area surrounding the lake is characterized as one of moderate topographic relief with intermittent depressions and peat accumulations (LWCNRSB 1975). The dominant land cover of the watershed is coniferous forest (Table 2-1). Vegetation is dominated by black spruce forest with patches of mixed forest. Leftrook Lake supports subsistence fishing, hunting, and trapping. There are no permanent residences in the watershed although there are a few seasonal campsites on the shoreline of Leftrook Lake. There are no forestry activities or active mines in the watershed.

The community of Nelson House on Footprint Lake (left). Rat Lake (right).

2.6.2 Hydroelectric Facilities

Churchill River Diversion directs much of the flow from the Churchill River into the Rat/Burntwood and Nelson rivers, to be used for added power generation at both existing and potential future GSs on the Rat/Burntwood and lower Nelson rivers. In addition to the Missi Falls CS, CRD consists of two major components and one ancillary component (Figure 2-6), as follows:

- an excavated channel (South Bay Diversion Channel) from South Bay in Southern Indian Lake to Issett Lake directs Churchill River water to the Rat River (tributary to the Burntwood River) and ultimately into the Nelson River;
- a CS at Notigi Lake (Notigi CS) on the Rat River regulates the amount of water being diverted into the Burntwood/Nelson River system; and
- an ice CS at Manasan Falls reduces the risk of inundation to the City of Thompson as a result of ice jams in the Burntwood River. The project consists of an ice boom across the Burntwood River upstream of a groin/gap structure, a bypass channel with a concrete overflow weir, and a flood channel protected by a dyke.

The region also contains the newly constructed Wuskwatim GS.

2.6.2.1 South Bay Diversion Channel

The South Bay Diversion Channel is a 9.3 km long, approximately 61 m wide excavated channel constructed from South Bay in Southern Indian Lake to Issett Lake at the headwaters of the Rat River system (a tributary to the Burntwood River; Manitoba Hydro and the Province of Manitoba 2015). The channel diverts water from the Churchill River system to the Rat/Burntwood and Nelson rivers.

2.6.2.2 Notigi Control Structure

The Notigi CS was constructed between 1974 and 1975 and is located on the Rat River between Notigi and Wapisu lakes (Manitoba Hydro and the Province of Manitoba 2015). The structure consists of three spillway bays, a main dam, and a saddle dam located on the Rat River at the outlet of Notigi Lake designed to regulate the amount of water released through the diversion route into the Burntwood and Nelson rivers. The CS is capable of discharging 1,869 m^3/s at a forebay elevation of 259.32 m (Manitoba Hydro and the Province of Manitoba 2015).

Notigi Control Structure.

2.6.2.3 Wuskwatim GS

The Wuskwatim Power Limited Partnership, a partnership of Manitoba Hydro and Nisichawayasihk Cree Nation, recently completed construction of the Wuskwatim GS on the Burntwood River approximately 45 km southwest of Thompson. The 200 MW station was commissioned in 2012 and consists of three turbine generator units. The Wuskwatim GS is a low head, modified run-of-the river design that resulted in approximately 0.4 km^2 of flooding (Manitoba Hydro and the Province of Manitoba 2015).

Wuskwatim GS.

2.6.3 Waterbody Descriptions

The CRDR is composed of the portion of the CRD route that extends from the man-made outlet of Southern Indian Lake at South Bay, through the Rat/Burntwood river system (including the Notigi CS) to First Rapids on the Burntwood River, approximately 20 km upstream of Split Lake (Figure 2-6). The region also includes Leftrook Lake, which is located on the Footprint River system. Two lakes have been monitored annually under CAMP, beginning in Year 2 of the Pilot Program: Threepoint Lake (on-system), and Leftrook Lake (off-system). Five additional lakes, all of which are on-system, are monitored on a three-year rotational basis in this region: Rat and Footprint lakes, which were first sampled in Year 3 of the Pilot Program; Notigi and Apussigamasi lakes, which were first sampled in Year 2 of the Pilot Program; and Central Mynarski Lake, which was first sampled in 2011/2012.

2.6.3.1 Rat Lake

Rat Lake is located on the Rat/Burntwood River system, upstream of Notigi Lake. Water levels on Rat Lake are regulated by CRD and it supports a commercial fishery. Information on Rat Lake was collected as part of the LWCNRSB studies conducted prior to CRD, and in a number of post-CRD studies conducted by the DFO, and under MEMP, FEMP, and the Wuskwatim Generation Project Environmental Impact Statement baseline studies. Rat Lake is monitored on a three-year rotational basis under CAMP, beginning in Year 3 of the Pilot Program.

Rat Lake.

2.6.3.3 Central Mynarski Lake

Although Central Mynarski Lake is located off the Rat/Burntwood River system upstream of Rat Lake and Notigi Lake, its water levels are affected by CRD and it is considered an on-system waterbody. Central Mynarski Lake supports a commercial fishery. Aquatic environment information was collected from Central Mynarski Lake as part of the LWCNRSB studies conducted prior to CRD and in post-CRD studies by DFO. However, historical monitoring information for this lake is limited. Central Mynarski Lake is monitored under CAMP on a three-year rotational basis and was first sampled in 2011/2012.

2011/ 9/ 8

Central Mynarski Lake (left photo of shoreline and nearshore algal bloom).

2.6.3.4 Notigi Lake

Notigi Lake is located on the Rat/Burntwood River system, downstream of Rat Lake and upstream of Threepoint Lake. It includes the forebay of the Notigi CS, a primary component of CRD. The lake supports subsistence and commercial fisheries. Aquatic environment information was collected from Notigi Lake as part of the LWCNRSB studies conducted prior to CRD, and in post-CRD studies conducted by DFO, and under MEMP, and the Wuskwatim Generation Project EIS baseline studies. Notigi Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 2 of the Pilot Program.

Notigi Lake – west.

Notigi Lake – east.

Notigi Lake – west shoreline.

2.6.3.6 *Threepoint Lake*

Threepoint Lake is located on the mainstem of the CRD route (Rat/Burntwood River system), upstream of Wuskwatim Lake and downstream of Notigi Lake. The lake is affected by Manitoba Hydro's hydraulic operating system. Threepoint Lake supports subsistence and commercial fisheries. Past aquatic studies include the LWCNRSB studies conducted prior to CRD, and post-CRD studies conducted under MEMP, FEMP, and the Wuskwatim GS aquatic baseline and monitoring programs. Threepoint Lake has been monitored annually under CAMP, beginning in Year 2 of the Pilot Program.

Threepoint Lake

2.6.3.7 *Footprint Lake*

Footprint Lake is located downstream on the Footprint River system and is affected by backwater effects of CRD. Footprint Lake is home to Nisichawayasihk First Nation and the community of Nelson House. The lake supports a recreational fishery. Aquatic environment information was collected under the LWCNRSB studies conducted prior to CRD, and in post-CRD studies including the Wuskwatim Generation Project EIS baseline and monitoring studies. MSD has maintained a long-term water quality monitoring site on the lake since the 1970s (site is currently monitored under CAMP). Footprint Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 3 of the Pilot Program.

Footprint Lake shoreline.

2.6.3.8 Apussigamasi Lake

Apussigamasi Lake is located on the Burntwood River, just downstream of the City of Thompson. The lake is affected by CRD and is fished recreationally. Fish population monitoring was conducted on the lake by Manitoba Fisheries Branch in 1984. Other historical monitoring has included the Wuskwatim Generation Project EIS baseline and monitoring studies and water quality monitoring conducted by MSD. Apussigamasi Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 2 of the Pilot Program. An aquatic habitat survey of Apussigamasi Lake was completed under CAMP in 2010.

Apussigamasi Lake

2.6.3.10 Leftrook Lake

Leftrook Lake, an off-system waterbody, is a headwater lake on the Footprint River, located upstream of the effects of CRD. The lake supports subsistence and recreational fisheries. Aquatic environment data was collected from Leftrook Lake as part of the Wuskwatim Generation Project EIS studies and there is a long-term record of mercury in fish from Leftrook Lake. Leftrook Lake has been monitored annually under CAMP, beginning in Year 2 of the Pilot Program.

Leftrook Lake.

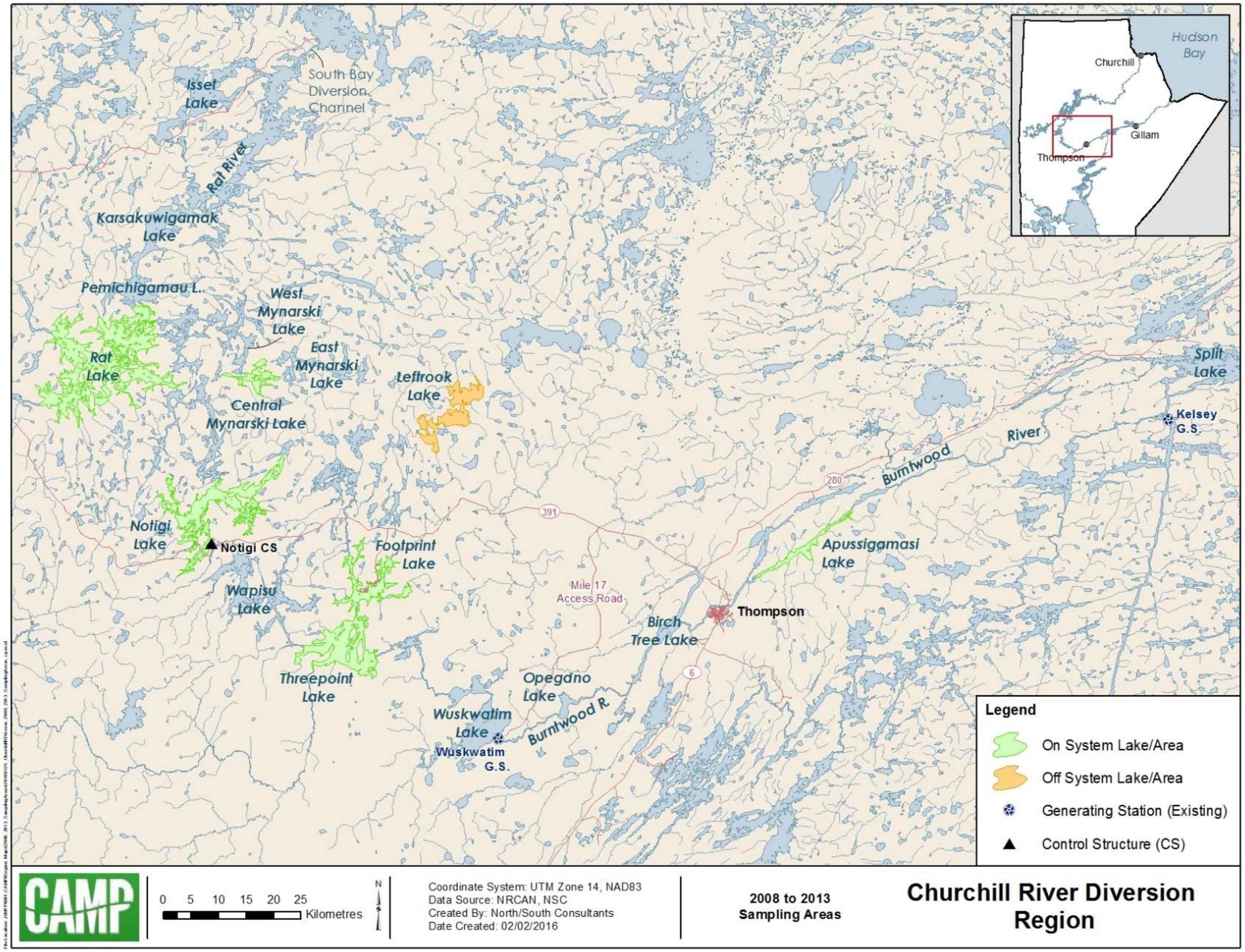


Figure 2-6. Churchill River Diversion Region.

2.7 UPPER NELSON RIVER REGION

2.7.1 Regional Description

The Upper Nelson River Region is composed of the Nelson River extending from the outlet of Lake Winnipeg to the Kelsey GS near Split Lake (Figure 2-7). The region also includes two off-system lakes: Setting Lake located on the Grass River system, and Walker Lake which flows into the east basin of Cross Lake via the Walker River.

In its headwaters near Lake Winnipeg, the upper Nelson River divides into two channels; the east channel conveys water past the community of Norway House and into Cross Lake, while the west channel directs water through a series of smaller lakes, past the Jenpeg GS and into Cross Lake. At the outlet of Cross Lake, the Nelson River again forms one channel as it continues northward (Rosenberg et al. 2005).

The Nelson River is the only outflow from Lake Winnipeg and the watershed drains a total area of approximately 1,050,000 km^2, including the Saskatchewan, Winnipeg, and Red river basins. Cultivated crops are the dominant land cover within the entire Nelson River drainage basin (Table 2-1). Although the Nelson River watershed drains an area comprising several ecozones and ecoregions, the Upper Nelson River Region lies exclusively within the Boreal Shield Ecozone and primarily within the Hayes River Upland Ecoregion (Figure 1-2). However, because lacustrine clay materials underlie much of the drainage basin upstream of Lake Winnipeg, the Nelson River carries more dissolved solids and a higher sediment load than most other Canadian Shield rivers (Jones and Armstrong 2001). One hydroelectric GS is located near each of the upstream (Jenpeg GS) and downstream (Kelsey GS) boundaries of the Upper Nelson River Region.

In this region, the Nelson River generally flows as a series of short cascades through a complex series of bedrock-controlled lake basins (Rosenberg et al. 2005). The region was heavily glaciated and is covered by thin (< 2 m deep) glacial till overburden and poorly drained peat-based wetlands (Rosenberg et al. 2005). The vegetative community of the region is characterized by stunted black spruce, jack pine, aspen, and willows (Rosenberg et al. 2005).

The climate of the basin is continental and characterized by short, cool summers and long, cold winters. Mean daily air temperatures are highest in July and lowest in January, generally ranging from 17.5 to –22.5°C, respectively (Rosenberg et al. 2005). Annual precipitation is approximately 50 cm, with 67% of this total falling between May and October (Rosenberg et al. 2005).

The Upper Nelson River Region has a very low population density, with the Cree Nation communities of Norway House and Cross Lake being the only concentrated population centres along the river. Individuals from these communities, as well as individuals from the communities of Wabowden, Thicket Portage, and Pikwitonei, participate in domestic and commercial harvesting of fish and wildlife in the area (Rosenberg et al. 2005). The region also supports a limited number of sport fishing and hunting lodges. There are no active mines or pulp and paper mills in the Upper Nelson River Region.

Community of Cross Lake.

Little Playgreen Lake.

Setting Lake, adjacent to the Town of Wabowden, is located in the same ecoregion (Hayes River Upland) and ecozone (Boreal Shield) as the other upper Nelson River waterbodies (Figures 1-2 and 2-7). The lake has a surface area of 126 km^2 and a drainage basin of approximately 11,000 km^2 (Table 2-1). Setting Lake receives inflows from the upper portion of the Grass River and a few small creeks, and discharges via the lower portion of the Grass River to the Nelson River. Surficial deposits are composed of lacustrine materials (silt and clay) and the soil is a grey-wooded podzol (Schlick 1968). The dominant land cover of the watershed is coniferous forest (Table 2-1) and the area around the lake is dominated by black spruce (Schlick 1968). With the exception of the Town of Snow Lake, the Setting Lake watershed has a low population density. In addition, although Wabowden is proximal to Setting Lake, the community lies within the drainage basin of a tributary that flows into the Grass River downstream of the outlet of Setting Lake. There are many historic mines and a few operating mines in the upper Grass River watershed (MGET 2017b,c). Setting Lake supports a commercial fishery, a recreational fishery, and a cottage development.

Walker Lake is located in the Boreal Shield Ecozone and the Hayes River Upland Ecoregion (Figure 1-2). The lake has a surface area of 133 km^2 and a drainage basin of approximately

1,200 km^2 (Table 2-1). Walker Lake, located approximately 50 km east of the community of Cross Lake, flows into the east basin of Cross Lake via the Walker River. Walker Lake receives inflow from the Walker River and several smaller tributaries. The dominant land cover of the watershed is shrub (Table 2-1) and the area adjacent to the lake is poorly drained with black spruce forest in upland areas and spruce bogs, peatlands, and fens in low lying areas. There are no permanent residences in the Walker River watershed, although there are a couple of seasonal camps on Walker Lake.

2.7.2 Hydroelectric Facilities

Manitoba Hydro's development of the hydroelectric potential of the Nelson River includes regulation of the outflow of Lake Winnipeg through the LWR project. Prior to LWR, the flow of the Nelson River at Warren Landing (Lake Winnipeg's only outflow prior to LWR) depended upon the water level of the lake and the seasonal conveyance capacity which was impeded by vegetated shallows, rock outcrops, and smaller islands in the open-water season and on the degree of obstruction of the river's channels by ice during the winter (Manitoba Hydro and the Province of Manitoba 2015). The LWR project included a number of components built to substantially increase the outflow potential of Lake Winnipeg into the upper Nelson River. Operational components include Two-Mile Channel (constructed between Lake Winnipeg and Playgreen Lake), Eight-Mile Channel (constructed between Playgreen Lake and the southern end of Kiskittogisu Lake), Ominawin Bypass Channel (constructed between the most northerly outlet of Kiskittogisu Lake and the west channel of the Nelson River), a rock excavation in the Kisipachewuk Channel (the most southerly outlet of Kiskittogisu Lake), and the Jenpeg GS and CS. Additional components include the Kiskitto Inlet CS, main dam, and dykes (designed to maintain water levels within their natural range), the Black Duck CS and Diversion Channel, and the Stan Creek Diversion Channel (Manitoba Hydro 2014; Manitoba Hydro and the Province of Manitoba 2015).

LWR has increased the outflow capacity of Lake Winnipeg by approximately 50% and has reduced the magnitude and frequency of flooding on Lake Winnipeg (Environment Canada and Manitoba Water Stewardship 2011; Manitoba Hydro 2014). In an effort to mitigate effects of the LWR on Cross Lake, the Cross Lake Weir was constructed in 1991 to raise the mean, and reduce the range of, water levels of the lake. Manitoba Hydro operates two hydroelectric GSs on the upper Nelson River (the Jenpeg and Kelsey GSs).

2.7.2.1 Two-Mile Channel

Two-Mile Channel was constructed to augment the natural outlet of Lake Winnipeg, by cutting a channel across the narrowest point of land between the north end of Lake Winnipeg and

Playgreen Lake, about 10 km northwest of Warren Landing (Figure 2-7). The channel is approximately 3.1 km long, 9 m deep, and 183-213 m in width (Manitoba Hydro 2014; Manitoba Hydro and the Province of Manitoba 2015).

2.7.2.2 Eight-Mile Channel

Eight-Mile Channel was constructed to connect Playgreen Lake with the southernmost end of Kiskittogisu Lake to increase the outflow of water from Playgreen Lake (Figure 2-7). The channel is approximately 12.9 km in length, 6 m deep, and approximately 213-366 m wide (Manitoba Hydro 2014; Manitoba Hydro and the Province of Manitoba 2015).

2.7.2.3 Ominawin Bypass Channel

The Ominawin Bypass Channel was constructed to improve the outflow from Kiskittogisu Lake at its most northerly outlet into the west channel of the Nelson River (Figure 2-7). The channel, which contains a center rockfill groin, is approximately 6 m deep, and 3.4 km long, and 427 m wide (Manitoba Hydro; 2014 Manitoba Hydro and the Province of Manitoba 2015).

2.7.2.4 Kisipachewuk Channel Improvement

The Kisipachewuk Channel Improvement was undertaken to increase flow through the outflow of Kiskittogisu Lake to the Nelson River. It involved excavation of the existing riverbed over a length of approximately 80 m and a width of 60 m (Manitoba Hydro and the Province of Manitoba 2015).

2.7.2.5 Jenpeg GS

The Jenpeg GS is located 525 km north of Winnipeg and 100 km north of Lake Winnipeg at the point where the west channel of the upper Nelson River flows into Cross Lake (Figure 2-7). The primary function of the Jenpeg GS is to regulate the outflow from Lake Winnipeg into the Nelson River. The secondary function is to utilize the hydraulic head at the site to produce electricity. Construction of the Jenpeg GS began in 1972 and all six generating units were operating by 1979. The Jenpeg GS has an operating head of 7.3 m and a capacity of 125 MW (Manitoba Hydro and the Province of Manitoba 2015). Although approximately 45.6 km^2 of land was flooded by the project, the immediate forebay extends from the Kisipachewuk Channel north to the GS and has a surface area of 0.47 km^2, a mean water level of 216.1 m, and an operating range of 213.97 to 217.54 m (Manitoba Hydro and the Province of Manitoba 2015).

Jenpeg Generating Station.

2.7.2.6 Cross Lake Weir

Lake Winnipeg Regulation reversed the historic pattern of water levels and fluctuations at Cross Lake. In an effort to increase average water levels and reduce the range of water levels on Cross Lake, the Cross Lake Weir Project was constructed in 1991 (Figure 2-7; Manitoba Hydro and the Province of Manitoba 2015). This included the construction of a rock weir and channel excavation at the outlet of Cross Lake. The average monthly water level was approximately 0.5 m higher after construction of the weir compared to prior to construction of LWR; this was attributed to effects of the weir, as well as the relatively high recent outflows from Lake Winnipeg. Water level fluctuations also decreased post-weir; average monthly water level variation dropped from 0.3 m (post-LWR) to 0.2 m (post-weir) which is similar to pre-LWR conditions (0.2 m; Manitoba Hydro and the Province of Manitoba 2015).

The Cross Lake Weir.

2.7.2.7 Kelsey GS

The Kelsey GS is located approximately 680 km north of Winnipeg on the upper Nelson River where it enters Split Lake (Figure 2-7). The Kelsey GS was the first plant constructed on the Nelson River. The station, which came into service in 1961, has an operating head of 17.1 m and a capacity of 292 MW. Creation of the Kelsey GS reservoir flooded approximately 165.8 km^2; the reservoir includes the forebay, the Nelson River, and Sipiwesk Lake upstream of the station. The immediate forebay has a surface area of 708 km^2 and a maximum operating forebay elevation of 184.4 m (Manitoba Hydro and the Province of Manitoba 2015). The GS is generally operated as a base load station, which means all seven units operate at the maximum output all of the time.

Kelsey GS.

2.7.3 Waterbody Descriptions

The upper Nelson River area extends from the outlet of Lake Winnipeg near Warren Landing to the Kelsey GS (Figure 2-7). The region also includes Setting Lake, which is located on the Grass River system. Two lakes have been monitored annually under CAMP, beginning in Year 1 of the Pilot Program: Cross Lake (west basin; on-system), and Setting Lake (off-system). Four additional lakes and a reach of the upper Nelson River are monitored on a three-year rotational basis in this region: Playgreen Lake (on-system), which was first sampled in Year 2 of the Pilot Program; Little Playgreen (on-system) and Walker (off-system) lakes, which were first sampled in Year 3 of the Pilot Program; and Sipiwesk Lake and the upper Nelson River downstream of Sipiwesk Lake (both on-system), which were first sampled in 2011/2012. In addition, water quality monitoring in the two outflows of Lake Winnipeg (Nelson River near Warren Landing and Two-Mile Channel) was initiated in 2012/2013 and 2013/2014 as part of CAMP, respectively.

2.7.3.1 Nelson River near Warren Landing

The natural outlet of Lake Winnipeg is the Nelson River at Warren Landing. Water quality sampling was initiated under CAMP in this area in 2012/2013 and is conducted annually.

Lake Winnipeg looking into the Nelson River outlet.

Shoreline of the upper Nelson River near Warren Landing.

2.7.3.2 Two-Mile Channel

Two-Mile Channel is located west of the Nelson River outflow and provides a second outflow into Playgreen Lake. Water quality sampling at two sites (near the inflow and near the outflow) in Two-Mile Channel was initiated in 2013/2014 under CAMP and is conducted annually.

Inlet to Two-Mile Channel (spring 2016).

Two-Mile Channel Outlet (summer 2013).

2.7.3.3 Playgreen Lake

Playgreen Lake, one of the Lake Winnipeg outlet lakes, is the first lake downstream of Lake Winnipeg on the upper Nelson River. The majority of flow from Lake Winnipeg enters Playgreen Lake at Two-Mile Channel, flowing out through Eight-Mile Channel and the Ominiwan Bypass Channel (Figure 2-7); it is affected by LWR and backwater effects from the Jenpeg GS. The lake supports an important commercial fishery and there is a long history of monitoring fish stocks, though using different methods than those used for CAMP, as well as historical short-term studies conducted on the fish community. Water quality has also been monitored historically, though no long-term monitoring site exists for the lake. Playgreen Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 2 (2009/2010) of the Pilot Program. An aquatic habitat survey was completed under CAMP in 2012.

Playgreen Lake.

2.7.3.4 Little Playgreen Lake

Little Playgreen Lake is home to Norway House Cree Nation and the Community of Norway House. The lake is affected by LWR and backwater effects from the Jenpeg GS and it supports an important subsistence fishery. There is a long history of monitoring water quality in the area but minimal monitoring of other components of the aquatic environment. Little Playgreen Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 3 (2010/2011) of the Pilot Program.

Little Playgreen Lake.

2.7.3.5 Cross Lake - West Basin

Cross Lake (west basin) is downstream of the Jenpeg GS. The operation of the Jenpeg GS and LWR impact water levels on Cross Lake and, until the construction of the Cross Lake outlet weir in 1991, which was constructed to partially mitigate the effects of LWR, these operations resulted in significant draw-downs during low flow conditions. Cross Lake is home to Cross Lake First Nation and the Community of Cross Lake and the west basin supports an important subsistence fishery. The adjoining east basin and Pipestone Lake also support important commercial fisheries. Cross Lake has a long history of aquatic environment monitoring and study. Historical studies have included a number of pre-LWR (e.g., LWCNRSB studies) and post-LWR studies, such as MEMP and Manitoba Hydro’s Post Weir Monitoring Program, and routine fish stock monitoring since 1992. Water quality has also been monitored by MSD in the lake since the 1970s (site is currently monitoring under CAMP). Historical monitoring programs have largely used methods that are similar to the CAMP protocol.

Cross Lake (west basin) has been monitored annually under CAMP, beginning in Year 1 (2008/2009) of the Pilot Program. An aquatic habitat survey of the west basin was completed under CAMP in 2011.

Cross Lake.

2.7.3.6 Sipiwesk Lake

Sipiwesk Lake is the most downstream lake on the upper Nelson River. Lake water levels are affected by the Kelsey GS and LWR (Manitoba Hydro and the Province of Manitoba 2015). It supports an important commercial fishery operating out of Wabowden and is an important subsistence harvest area for both Wabowden and Cross Lake First Nation. Historical monitoring has included pre-LWR studies (e.g., LWCNRSB studies) and post-LWR studies (e.g., MEMP). MSD has maintained a long-term water quality monitoring site on the lake since the 1970s. Sipiwesk Lake is monitored under CAMP on a three-year rotational basis and was first sampled in 2011/2012.

Sipiwesk Lake.

2.7.3.7 Upper Nelson River Upstream of the Kelsey GS

The upper Nelson River water levels were first affected by the Kelsey GS in 1960, and further altered by the operation of the Jenpeg GS and LWR in 1976. It supports an important commercial fishery, with an additional large scale fishery on the connected tributary, Cauchon Lake. There has been minimal aquatic monitoring in this area. This reach of the upper Nelson River is monitored under CAMP on a three-year rotational basis and was first sampled in 2011/2012.

Upper Nelson River upstream of the Kelsey GS.

2.7.3.8 Walker Lake

Walker Lake drains into the east basin of Cross Lake via the Walker River and is an off-system waterbody for the Upper Nelson River Region. The lake is affected by a backwater effect when water levels exceed 207.6 m in Cross Lake; while this effect has always occurred naturally, LWR and construction of the Cross Lake Weir can affect the frequency, timing, and magnitude of backwater effects in Walker Lake. Walker Lake supports an important commercial fishery and is an important subsistence harvest area for Cross Lake First Nation and the Community of Cross Lake. There is relatively little historical monitoring information for Walker Lake and only a few limited studies of fish stocks using methods similar to the CAMP protocol. Walker Lake is monitored under CAMP on a three-year rotational basis and was first sampled in Year 3 of the Pilot Program.

Walker Lake.

2.7.3.9 Setting Lake

Setting Lake, an off-system waterbody, is on the Grass River system and both it and its tributaries are unregulated. Setting Lake is near the Town of Wabowden and also is home to a major cottage subdivision. The lake is fished for subsistence, commercially and recreationally. There is a long but sporadic history of monitoring of fish stocks and water quality using methods that are similar to the CAMP protocol. However, there is no historical record of water level monitoring. Setting Lake has been monitored annually under CAMP since Year 1 (2008/2009) of the Pilot Program.

Setting Lake

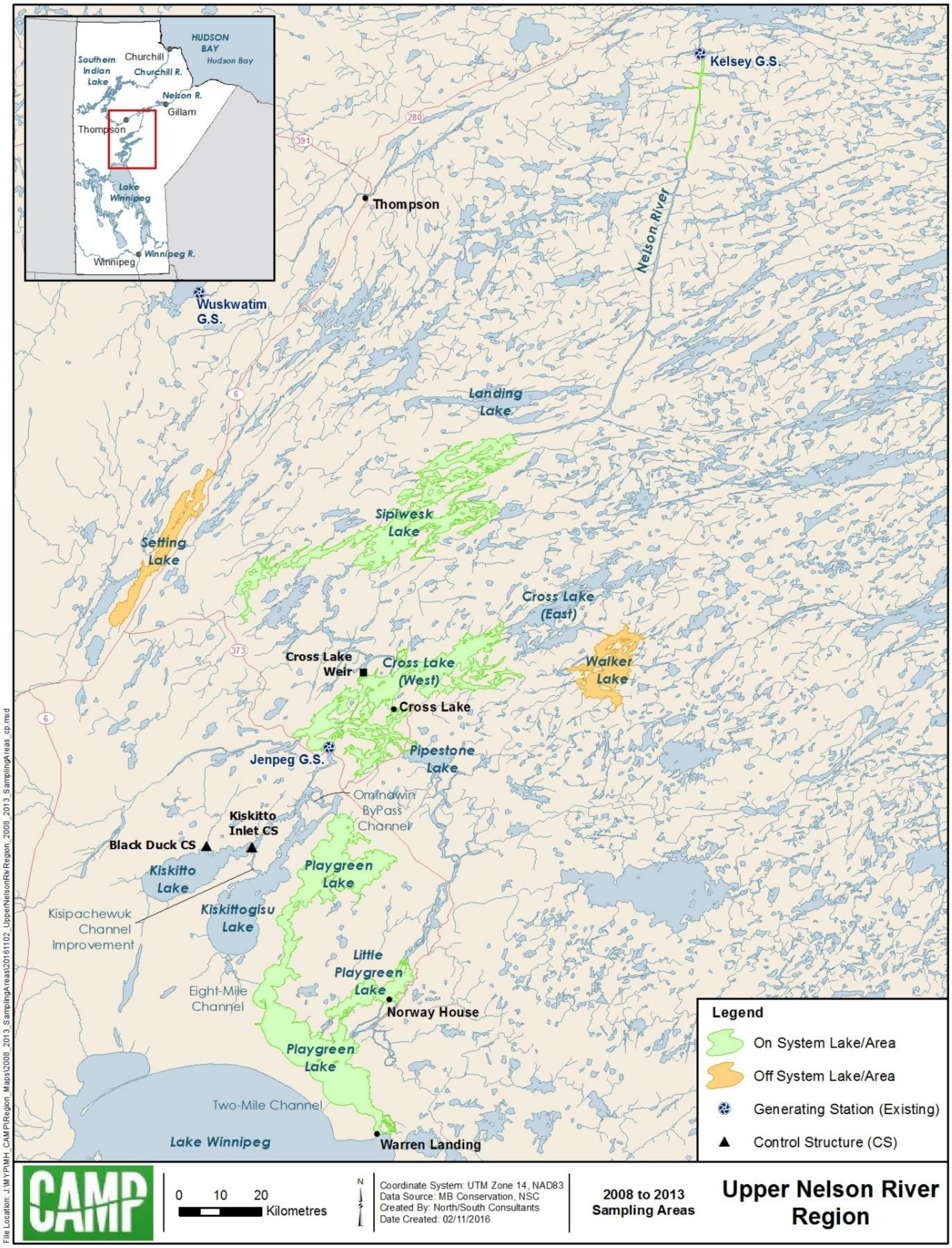


Figure 2-7. Upper Nelson River Region.

2.8 LOWER NELSON RIVER REGION

2.8.1 Regional Description

The Lower Nelson River Region is composed of the reach of the Nelson River (including lakes and reservoirs) extending from the Kelsey GS downstream to the river’s outlet at Hudson Bay, the Burntwood River from First Rapids to Split Lake, an off-system river (Hayes River) and an off-system lake (Assean Lake; Figure 2-8).

The lower Nelson River flows in a relatively straight single channel from Split Lake to its mouth on Hudson Bay, interrupted by several lakes and reservoirs. Portions of this reach of the river have steep banks that gradually decrease in slope as they approach the estuary at Hudson Bay (Rosenberg et al. 2005). The most downstream 150 km of river is part of the marine intrusion zone that has emerged above sea level since the last glaciation (7,000 to 9,000 years ago; Rosenberg et al. 2005). Waterbodies along the lower Nelson River include Split, Clark, Gull, and Stephens lakes, and the Long Spruce and Limestone GS forebays (Figure 2-8). Prior to dam construction and reservoir creation, Split Lake was the only substantial lacustrine waterbody along the lower Nelson River.

At its mouth, the Nelson River drains an area of approximately 1,400,000 km^2 (Table 2-1). The lower Nelson River cuts through the Boreal Shield and Hudson Plain ecozones, but the watershed encompasses almost all other ecozones in Manitoba, including the Taiga Shield, the Boreal Plain and the Prairie (Figure 1-2). Although much of the lower Nelson River itself is situated on the Canadian Shield, because lacustrine clay materials underlie much of the drainage basin upstream of Lake Winnipeg, the lower Nelson River (as is the case with the upper Nelson River) carries more dissolved solids and a higher sediment load than most other Canadian Shield rivers (Jones and Armstrong 2001). The Lower Nelson River Region flows through the Hayes River Upland Ecoregion of the Boreal Shield Ecozone and the Hudson Bay Lowland and the Coastal Hudson Bay Lowland ecoregions of the Hudson Plain Ecozone (Figure 1-2). The region was heavily glaciated and is covered by thin (<2 m) glacial till overburden and poorly drained peat-based wetlands (Rosenberg et al. 2005).

The dominant land cover within the watershed is cultivated crops (Table 2-1); however, the vegetative community of the region is characterized by stunted black spruce, aspen, and willows (Rosenberg et al. 2005). A major tributary of the lower Nelson River is the Grass River which flows into the Nelson River immediately downstream of the Kelsey GS. There are many historic mines and a few operating mines in the upper Grass River watershed (MGET 2017b,c). In addition to the mines in the upper Grass River watershed, there is also an operating mine (the Bucko Lake mine) near Wabowden (MGET 2017c) that falls within the drainage basin of the

Grass River downstream of Setting Lake (Figure 2-7). There are no operating or historic mines in the Lower Nelson River Region apart from those in the Grass River system. There is some forestry activity in the upper Grass River system, but none in the rest of the Lower Nelson River Region, and the region supports some tourism. The lower Nelson River is highly regulated for the purposes of hydroelectricity generation, with three existing, one under construction, and one potential hydroelectric GS located on this stretch of the river.

The climate of the basin is continental and characterized by short, cool summers and long, cold winters. Mean daily air temperatures are highest in July (≈17.5º) and lowest in January (≈ – 2.5°C; Rosenberg et al. 2005). Annual precipitation is approximately 50 cm, with 67% of this total falling as rain between May and October (Rosenberg et al. 2005).

The lower Nelson River watershed has a low population density, with the Cree Nation communities of Split Lake, York Landing, and Bird and the Town of Gillam being the only substantial population centres along the river. All have wastewater treatment facilities. Individuals from these communities, as well as individuals from the communities of Pikwitonei and Ilford, participate in domestic, commercial, and recreational harvesting of fish and wildlife.

The Hayes River, a Canadian Heritage River, originates just upstream of Molson Lake in the Hayes River Upland Ecoregion (Boreal Shield Ecozone) and flows northeast through the Hudson Bay Lowland and Coastal Hudson Bay Lowland ecoregions (Hudson Plain Ecozone) for a distance of approximately 650 km to Hudson Bay (Figures 1-2 and 2-8). The drainage basin of the Hayes River is approximately 109,000 km^2 and the dominant land cover in the entire drainage basin is coniferous forest (Table 2-1). The major tributary is the Gods River, which originates in Ontario, but the Hayes River also receives inflows from the Fox and Pennycutaway rivers and numerous smaller tributaries. Historically, the Hayes River was a very important route of the fur trade and York Factory was the central link between Europe and inland Canada (Beck 1977). The area is much less travelled now, with a dozen or so First Nation communities scattered throughout the watershed. Present resource use (i.e., subsistence, commercial, and recreational fishing, hunting, and trapping) is centered around a small number of First Nation communities scattered throughout the watershed in both Ontario and Manitoba. There are also several commercial fishing lodges in the drainage basin. There are no active mines in the drainage basin; two gold mines in the Gods River watershed operated in the 1930s and 1940s (MGET 2017b,c).

Assean Lake is located in the Boreal Shield Ecozone and straddles the border between the Hayes River Upland and Churchill River Upland ecoregions (Figure 1-2). The lake is located approximately 80 km northeast of the City of Thompson and 30 km west of the community of

Split Lake (Figure 2-8) with a surface area of 76 km^2 and a drainage basin of 542 km^2 (Table 2-1). Assean Lake receives inflow from the Clay River and several smaller tributaries and either receives inflow from, or is drained by, the Assean River (Holm et al. 2003). Surficial deposits (up to 20 m thick) are composed of lacustrine materials (clay, silt, sand, and basal till) while the underlying bedrock is gneiss and schist (Christoffersen 2005). The dominant land cover of the watershed is shrub (Table 2-1) and the area adjacent to the lake is poorly drained with black spruce forest in upland areas and spruce bogs, peatlands, and fens in low lying areas. Stands of sporadically distributed trembling aspen are also present (Holm et al. 2003). Assean Lake supports subsistence and commercial fishing, hunting, and trapping and a recreational fishery. There are no permanent residences in the watershed although there are a couple of seasonal camps on the shoreline of Assean Lake. Although there has been considerable mineral exploration in the Assean Lake area (particularly during the decade between 2000 and 2010; Christoffersen 2005), there are no currently operating or historic mines in the Assean Lake watershed (MGET 2017b,c).

Town of Gillam and Stephens Lake.

Lower Nelson River at Gillam Island.

2.8.2 Hydroelectric Facilities

At Split Lake, the upper Nelson River is joined by the Burntwood (includes diverted flows from the Churchill River) and Grass rivers from the northwest to form the lower Nelson River. The lower Nelson River then flows northeastward for approximately 330 km to its mouth at Hudson Bay. Manitoba Hydro operates three hydroelectric GSs along this section of the Nelson River: the Kettle, Long Spruce, and Limestone GSs (Figure 2-8). The Keeyask GS, currently under construction, and the potential Conawapa GS are also located on the lower Nelson River (Figure 2-8).

2.8.2.1 Kettle GS

The Kettle GS came into service in 1970 and was the first plant built on the lower Nelson River. It is located approximately 7 km west of the Town of Gillam, and approximately 740 km north of Winnipeg (by air). The Kettle GS has 12 turbine generators with a capacity of 1,220 MW, an operating head of 30.8 m, and a maximum operating forebay elevation of 141.122 m (Manitoba Hydro and the Province of Manitoba 2015). The Kettle GS reservoir (Stephens Lake), which flooded 220.6 km^2 (Manitoba Hydro and the Province of Manitoba 2015), has a surface area of 307 km^2 (Table 2-1).

Kettle GS and Stephens Lake.

2.8.2.2 Long Spruce GS

The Long Spruce GS was built between 1971 and 1979 and was Manitoba Hydro’s second GS constructed on the lower Nelson River. The station is located about 745 km northeast of Winnipeg, 21 km east of Gillam, and 16.5 km downstream from the Kettle GS. The first of the station’s 10 turbine generators came on line in 1977, while the final turbine was put into service in 1979. With an operating head of 24.4 m, the Long Spruce GS has a capacity of 980 MW and a maximum operating forebay elevation of 110.0 m under open-water conditions and 110.3 m under ice cover (Manitoba Hydro and the Province of Manitoba 2015). The Long Spruce reservoir (the Nelson River) has a surface area of 36 km^2, including approximately 13.7 km^2 of flooded area (Manitoba Hydro and the Province of Manitoba 2015). The Long Spruce GS is operated as a run-of-the-river system, with flows governed by releases from Stephens Lake at the Kettle GS.

Long Spruce GS.

2.8.2.3 Limestone GS

The Limestone GS is Manitoba Hydro’s newest and largest GS built on the Nelson River. It is located 750 km north of Winnipeg, 55 km northeast of Gillam, and 23 km downstream of the Long Spruce GS. The first of the station’s 10 turbine generators came into service in 1990 and the last in 1992. With an operating head of 31.2 m, the Limestone GS has a capacity of 1,350 MW (Manitoba Hydro and the Province of Manitoba 2015). The Limestone GS Forebay is almost entirely contained within the natural riverbanks of the Nelson River and has a surface area of 26.8 km^2 (Table 2-1) and a maximum operating forebay elevation of 85.313 m (Manitoba Hydro and the Province of Manitoba 2015). As with other GSs on the lower Nelson River, the Limestone GS is operated as a run-of-the-river operation.

Limestone GS and reservoir.

2.8.2.4 Keeyask GS

The Keeyask Generation Project is a 695 MW hydroelectric GS at Gull Rapids on the lower Nelson River in northern Manitoba. The Project is approximately 730 km northeast of Winnipeg, 35 km upstream of the existing Kettle GS, where Gull Lake flows into Stephens Lake, 60 km east of the community of Split Lake, 180 km east-northeast of Thompson and 30 km west of Gillam. Construction of the Project began in July 2014 and is expected to begin operating by 2019 (Manitoba Hydro and the Province of Manitoba 2015). The Keeyask reservoir will be approximately 93 km^2 after full initial impoundment (full supply level), consisting of approximately 48 km^2 of existing waterways and approximately 45 km^2 of newly inundated lands (Keeyask Hydropower Limited Partnership [KHLP] 2012). The reservoir is predicted to expand by approximately 7 to 8 km^2 during the first 30 years of operation due to the erosion of some mineral shorelines and peatland disintegration (KHLP 2012).

Gull Lake (left). Gull Rapids prior to construction of the Keeyask GS (right).

2.8.3 Waterbody Descriptions

The Lower Nelson River Region is composed of the reach of the Nelson River (including lakes and reservoirs) extending from the Kelsey GS downstream to the river’s outlet at Hudson Bay, the reach of the Burntwood River between First Rapids and Split Lake, and off-system lacustrine (Assean Lake) and riverine (Hayes River) waterbodies (Figure 2-8).

Four waterbodies/areas are monitored annually under CAMP: Split Lake (on-system), which was first sampled in 2009/2010; the lower Nelson River downstream of the Limestone GS (on-system), which was first sampled in 2008/2009; Assean Lake (off-system), which was first sampled in 2009/2010; and the Hayes River (off-system), which was first sampled in 2008/2009.

Four additional areas are monitored on a three-year rotational basis in this region: the Burntwood River below First Rapids (on-system), which was first sampled for all components in 2011/2012[2]; Stephens Lake north and south (both on-system), which were first sampled in Year 2 (2009/2010) of the Pilot Program; and the Limestone Forebay (on-system), which was first sampled in Year 3 (2010/2011) of the Pilot Program.

2.8.3.1 Burntwood River (Between First Rapids and Split Lake)

The reach of the Burntwood River between First Rapids and Split Lake is approximately 35 km long and is an on-system waterbody. It represents the second largest tributary to Split Lake and the lower Nelson River (the largest being the upper Nelson River). The hydrology of the Burntwood River, including this reach, has been affected by CRD. The area supports subsistence and recreational fishing and Split Lake, located downstream of the Burntwood River, also supports a commercial fishery. Past aquatic monitoring conducted in the area includes limited study prior to CRD (e.g., LWCNRSB studies) and more extensive recent studies conducted as part of the Keeyask Generation Project environmental studies program. This reach of the Burntwood River is monitored annually for water quality (beginning in Year 2 of the Pilot Program) and on a three-year rotational basis for other components (beginning in 2011/2012).

Burntwood River and First Rapids.

2.8.3.2 Split Lake

Split Lake, an on-system lake, receives inflows from the upper Nelson and Burntwood rivers, and is therefore affected by both LWR and CRD, as well as operation of the Kelsey GS. Split Lake is home to Tataskweyak Cree Nation, and the Community of Split Lake, and

---

[2] Water quality is monitored annually at this site and was first sampled under CAMP in 2009/2010.

York Factory First Nation and the Community of York Landing. Split Lake supports an important subsistence fishery and is also fished commercially and recreationally. Aquatic environment studies have included pre-LWR/CRD studies conducted by the LWCNRSB, and post-LWR/CRD studies including MEMP, FEMP, the Split Lake Monitoring Program (1997-1998), and as part of the Keeyask Generation Project environmental studies program. Water quality has been monitored in the lake by MSD since the 1970s (site currently sampled under CAMP). Split Lake has been monitored annually under CAMP since Year 2 (2009/2010) of the Pilot Program.

Split Lake and the Community of Split Lake.

2.8.3.3 Stephens Lake – North and South

Stephens Lake, which includes the forebay of the Kettle GS, is located on the lower Nelson River. The operation of the Kettle GS and other upstream Manitoba Hydro hydraulic operations impact water levels on Stephens Lake. The Town of Gillam is located along the shores of Stephens Lake. The lake can generally be described as consisting of a southern riverine portion through which the main flow of the Nelson River passes (i.e., Stephens Lake - South), and a northern arm, which is relatively isolated from the Nelson River flow (i.e., Stephens Lake - North). The North and South Moswakot rivers flow into the north arm of Stephens Lake, which was originally Moose Nose Lake.

The lake supports subsistence, commercial, and recreational fisheries. Aquatic environment studies have included pre-LWR/CRD studies conducted by the LWCNRSB, and post-LWR/CRD studies including MEMP, the Limestone GS Aquatic Environment Monitoring Program, and the Keeyask Generation Project environmental studies program. Stephens Lake North and South are monitored on a three-year rotational basis under CAMP, and were first sampled in Year 2 (2009/2010) of the Pilot Program.

Stephens Lake – north

Stephens Lake - South

2.8.3.4 Limestone GS Forebay

The Limestone GS is located on the lower Nelson River downstream of Stephens Lake and is the furthest downstream GS on this river. The operation of the Limestone GS and upstream Manitoba Hydro hydraulic operations affect water levels on the Limestone GS Forebay. The forebay is fished for subsistence and recreation. There has been extensive pre-, during, and post-construction aquatic monitoring of the forebay area as part of Limestone GS Aquatic Environment Monitoring Program, and post-construction monitoring under the Keeyask and Conawapa Generation Project environmental studies programs. The Limestone Forebay is monitored on a three-year rotational basis under CAMP, and was first sampled in Year 3 (2010/2011) of the Pilot Program.

Limestone GS, forebay and lower Nelson River.

2.8.3.5 Lower Nelson River Downstream of the Limestone GS

The annual on-system riverine site in the region is the lower Nelson River mainstem near the location of the potential Conawapa GS. The lower Nelson River is affected by LWR, CRD, and local GSs, notably operation of the Limestone GS which impacts water levels on the Nelson River mainstem. The lower Nelson River supports some subsistence and recreational fishing. Aquatic environment information has been collected from this general area as part of the Limestone GS Aquatic Environment Monitoring Program, and the Keeyask and Conawapa Generation Projects environmental studies programs. Annual sampling under CAMP was initiated in Year 1 (2008/2009) of the Pilot Program.

Lower Nelson River.

2.8.3.6 Hayes River

The Hayes River, which flows to Hudson Bay, is a Canadian Heritage River and is one of the few large unregulated rivers in Canada; it serves as a riverine off-system waterbody for the Churchill and Nelson rivers under CAMP. The reach of the river monitored under CAMP is an approximately 20 km long stretch of the lower Hayes River, with the confluence of the Hayes and Pennycutaway rivers located near the mid-point of the reach. This portion of the river supports some subsistence fishing. Previous aquatic monitoring is relatively limited, though water quality was monitored by ECCC for approximately 20 years (1974 through 1996); water quality is currently monitored at this historical site under CAMP. Annual sampling under CAMP was initiated in Year 1 (2008/2009) of the Pilot Program.

2013/ 8/ 5

Hayes River.

2.8.3.7 Assean Lake

Assean Lake, an off-system lake, discharges into the Nelson River at Clark Lake via the Assean River, and is unaffected by Manitoba Hydro’s hydraulic operating system. The lake supports a few cabins and is fished for subsistence, commercially and recreationally. Aquatic environment information has been collected from Assean Lake as part of the Keeyask Generation Project environmental studies program.

Annual sampling under CAMP was initiated in Year 2 (2009/2010) of the Pilot Program. An aquatic habitat survey of Assean Lake was completed under CAMP in 2010.

2011/ 6/27

Assean Lake.

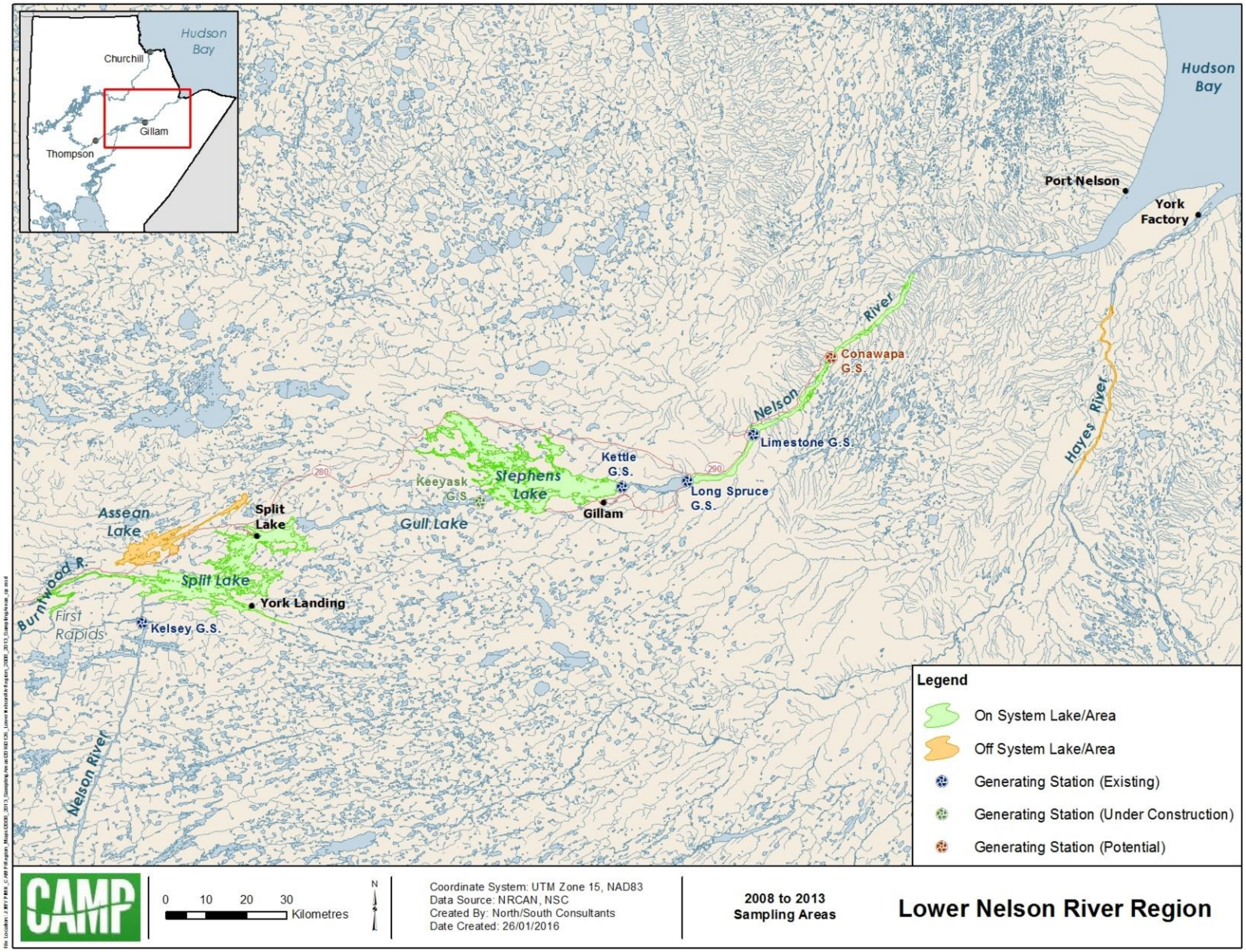


Figure 2-8. Lower Nelson River Region.

3.0 SAMPLING AND LABORATORY METHODS

3.1 HYDROLOGY

Within CAMP, hydrometric data refer to water levels and flows obtained from stations operated by either Water Survey of Canada or Manitoba Hydro. Both agencies are part of the National Hydrometric Program; a cooperative endeavor between the federal, provincial and territorial governments to provide accurate, timely and standardized data and information on the current and historic availability of surface water. Water Survey of Canada, MSD, and Manitoba Hydro make up the provincial component of this program. The parties recognize the value of cooperative water monitoring activities for reasons including operational and cost efficiencies.

Hydrometric data were considered in the interpretation of monitoring results for the various components of CAMP since water levels and flows may affect water quality conditions, the physical attributes of aquatic habitat, and aquatic biota.

3.1.1 Quality Assurance Management System

3.1.1.1 Vertical Control

Vertical control in the form of benchmarks has been established at all stations in order to effectively and accurately calibrate continuously recorded water levels. Water level information may or may not be based upon a Geodetic Survey of Canada, Canadian Government Vertical Datum[3]. This information is available from the operating agency.

3.1.1.2 Water Level Record

Water levels are recorded on a continuous basis at the hydrometric stations using pressure transducers and data loggers; generally every five minutes in order to adequately capture surface water fluctuations. Hourly and daily values are calculated based on the five minute readings.

Field staff visit stations on a regular basis to maintain a high level of station performance. Direct water level measurements are taken during these visits and are compared to the level indicated by the water level sensor. The sensor is calibrated based on the water level measurement taking into account field conditions at the time of the visit.

---

[3] All of Manitoba Hydro’s stations are referenced to a Geodetic Survey of Canada datum. The chosen datum depends on the location of the hydrometric station.

3.1.1.3 Water Level / Discharge (Flow) Relationship

Discharges are calculated on a continuous basis; generally every five minutes since they are derived from the water level record. Hourly and daily values are calculated based on the five minute readings.

The water level record at a flow station is maintained and calibrated as mentioned above. In addition, discharge measurements (usually using an Acoustic Doppler Current Profiler) are also taken in order to develop and maintain a well-defined relationship (curve) between water level and flow throughout the entire range of water levels. Using the curve, flows can be calculated based on recorded water levels.

3.1.1.4 Record Interpretation and Computation

Raw data are transmitted via satellite in near real-time, retrieved and converted using a suite of software then ingested into the appropriate databases.

Data are processed by qualified technicians using national processes and procedures developed under the National Hydrometric Program. Using hydrological data management software, corrections are applied to the data based on field measurements and noted conditions. The data are compared to all available relevant data in the area to verify its accuracy and account for environmental influences.

Several levels of review ensure compliance with applicable standards and ensure that associated station information is up-to-date. Data are generally not estimated where values are missing.

3.2 AQUATIC HABITAT INVENTORY

Components of CAMP, such as the BMI and fish community monitoring, are habitat-based and therefore require an understanding of habitat types and distribution within the lakes monitored under the program. Detailed and contemporary habitat information (i.e. depth and substrate types) is currently lacking for a number of CAMP lakes. As a result, CAMP introduced an aquatic habitat inventory program in 2010. The program differs from the other study components of CAMP in that habitat inventories are conducted on a one-time basis (per lake) without additional monitoring in subsequent years, though additional periodic monitoring may be undertaken in the future to evaluate changes over time. The objective is to obtain a contemporary snap-shot of the physical environment and overall aquatic habitats of the CAMP waterbodies.

Boat-based hydroacoustic remote sensing combined with physical bottom validation sampling is the preferred method of large-scale bathymetric and bottom type data collection for the aquatic habitat inventory program. The surveys are conducted early in the open-water season (late May through July) to avoid periods when aquatic plants are abundant in the shallow nearshore areas, as dense macrophyte beds limit the ability to survey in large shallow nearshore areas of the waterbodies.

Surveys conducted to date consisted of three main activities: 1) boat-based global positioning system (GPS)-linked hydroacoustic depth and bottom-type surveys; 2) benthic validation sampling (substrate material size and composition); and 3) shoreline documentation (description, photos, GPS coordinates).

The hydroacoustic surveys were boat-based employing a Quester Tangent Corporation (QTC) scientific grade single beam echosounder coupled to a sub-metre grade Trimble real-time differential GPS. The QTC system uses QTC VIEW hardware and software to log acoustic waveform data, along with National Marine Electronics Association positional data to an accompanying laptop. The QTC System contains an analogue-to-digital converter which obtains the amplitude envelope of the waveform echoed from the bottom of the waterbody. The signal shape of the echoed waveform is influenced by the physical properties of the surficial sediment and immediate subsurface. These physical properties include: sedimentary properties (grain size and condition of state); seabed roughness (sedimentary bedforms and bedrock outcropping features); and plant organisms found on the bottom. The signal shape is then described by 166 non-descriptive variables related to the grain size, hardness, and overall bottom roughness.

Secondary echosounders were employed for surveys in 2012 and 2013 (Playgreen Lake and Southern Indian Lake). Survey crews were equipped with consumer grade Lowrance HDS units complete with dual 83/200 kHz transducers and 455/800 kHz sidescan transducers. These secondary transducers were used for two purposes: 1) As a backup depth sounding source in the event of primary transducer failure; 2) As an additional method of validating bottom types using the sidescan images produced during operation.

Typically the survey vessel was operated at 5-10 km/hr with the QTC system set to record data at one second intervals. Surveys consisted of parallel shoreline transects, and depending on the shape of the waterbody in question, a series of latitudinal or longitudinal grid lines spaced anywhere from 50 to 400 metres apart. Spacing was condensed in areas of significance, such as in the vicinity of CAMP fish sampling areas.

Bottom validation of the water body was accomplished with a Ponar dredge sampler deployed at random locations along the hydroacoustic survey route in order to validate the acoustic data collection. At each selected validation site, GPS coordinates, substrate description (type and size according to a modified Wentworth (1922) scale, composition, and any additional comments), and digital photos of samples were recorded.

Beginning in 2010/2011, habitat maps (i.e., substratum and depth) have been developed, by means of acoustic bottom typing and substrate validation, for waterbodies where there is either no existing information and/or where existing information is deemed inadequate.

Surveying on Split Lake.

Substrate validation sample.

3.3 WATER QUALITY

3.3.1 Sampling Methods

The following provides an overview of the field sampling methods employed in Years 1 through 6 of CAMP. A detailed description of field sampling methods is provided in CAMP (2014), Appendix 1.

The water quality sampling program consisted of three sampling periods in the open-water season and one sampling period in late winter. Sampling included measurement of *in situ* parameters (temperature, DO, turbidity, pH, specific conductance) across the water column (where velocities were conducive), measurement of Secchi disk depths (where velocities were conducive), and collection of samples of surface water for submission to an analytical laboratory accredited under Canadian Association for Laboratory Accreditation Inc. (CALA) for analysis of a suite of water quality parameters.

Samples for laboratory analysis were collected as near-surface grab samples, euphotic zone samples, and bottom samples (where sites were stratified at the time of sampling). Surface grab samples were collected at each site near the water surface (approximately 30 cm below the surface) for analysis of the full suite of variables including turbidity, TSS, total dissolved solids, conductivity, alkalinity, pH, organic carbon, phosphorus (total, dissolved and particulate), nitrogen (ammonia, nitrate/nitrite and total Kjeldahl nitrogen, true colour, hardness, *Escherichia coli*, and total metals (Table 3-1).

Samples for analysis of chlorophyll *a* were collected across the euphotic zone (estimated as two times the Secchi disk depth) during the open-water season at sites where velocities were conducive. At riverine sites with high velocities and at all sites in the ice-cover season, samples for analysis of chlorophyll *a* were collected as surface grabs. In addition, for the first two years of CAMP, both surface grabs and euphotic zone samples for analysis of chlorophyll *a* were collected at lake sites to explore differences between these two sampling methods. Since 2011/2012, only euphotic zone samples are collected in the open-water season at lake sites.

At sites that were found to be thermally stratified at the time of sample collection, samples were also collected from approximately 1 m above the sediments (i.e., bottom sample) using a Kemmerer water sampler. These bottom samples were analysed for all water quality parameters excepting chlorophyll *a* and *E. coli*.

Standard QA/QC measures were integrated into the water quality component of CAMP, including the preparation of detailed field sampling protocols, standard measures to avoid sample contamination during and following sample collection, inclusion of field QA/QC samples (triplicates, field and trip blanks, and inter-laboratory comparison samples) and QA/QC of water quality data.

Sampling water off a float plane.

Sampling water with a Kemmerer sampler.

Water quality sampling at the lower Churchill River at the Little Churchill River.

3.3.2 Laboratory Methods

All water quality samples for laboratory analysis were submitted to a CALA accredited analytical laboratory (ALS Laboratories, Winnipeg, MB). Inter-laboratory comparison samples for water quality were submitted to a second CALA accredited laboratory (Maxxam Analytics, Winnipeg, MB).

Table 3-1. Water quality metrics measured under CAMP.

Variable	Unit	Variable	Unit
***In situ* Variables**		**Metals**	
Dissolved oxygen	(mg/L)	Aluminum	(mg/L)
Turbidity	(NTU)	Antimony	(mg/L)
Temperature	(°C)	Arsenic	(mg/L)
pH	-	Barium	(mg/L)
Specific conductance	(µS/cm)	Beryllium	(mg/L)
Secchi disk depth	(m)	Bismuth	(mg/L)
		Boron	(mg/L)
Laboratory Variables/ Routine Variables[1]		Cadmium	(mg/L)
		Calcium	(mg/L)
Total alkalinity (as $CaCO_3$)	(mg/L)	Cesium	(mg/L)
Bicarbonate alkalinity (as HCO_3)	(mg/L)	Chromium	(mg/L)
Carbonate alkalinity (as CO_3)	(mg/L)	Cobalt	(mg/L)
Hydroxide alkalinity (as OH)	(mg/L)	Copper	(mg/L)
Ammonia	(mg N/L)	Iron	(mg/L)
Nitrate/nitrite	(mg N/L)	Lead	(mg/L)
Total Kjeldahl nitrogen	(mg/L)	Magnesium	(mg/L)
Total dissolved phosphorus	(mg/L)	Manganese	(mg/L)
Total particulate phosphorus	(mg/L)	Mercury	(mg/L)
Total phosphorus	(mg/L)	Molybdenum	(mg/L)
Dissolved organic carbon	(mg/L)	Nickel	(mg/L)
Total organic carbon	(mg/L)	Potassium	(mg/L)
Total inorganic carbon	(mg/L)	Rubidium	(mg/L)
Total dissolved solids	(mg/L)	Selenium	(mg/L)
Specific conductance	(µmhos/cm)	Silver	(mg/L)
Total suspended solids	(mg/L)	Sodium	(mg/L)
Turbidity	(NTU)	Strontium	(mg/L)
True colour	(TCU)	Tellurium	(mg/L)
pH	-	Thallium	(mg/L)
Hardness (as $CaCO_3$)	(mg/L)	Tin	(mg/L)
Chloride	(mg/L)	Titanium	(mg/L)
Sulphate	(mg/L)	Tungsten	(mg/L)
		Uranium	(mg/L)
Biological Variables		Vanadium	(mg/L)
E. coli	(CFU/100 mL)	Zinc	(mg/L)
Chlorophyll *a*	(µg/L)	Zirconium	(mg/L)
Pheophytin *a*	(µg/L)		

[1] Dissolved Kjeldahl nitrogen was also analysed at three sites (lower Nelson River downstream of the Limestone GS, Hayes River, and the lower Churchill River at the Little Churchill River) beginning in 2014.

3.4 SEDIMENT QUALITY

3.4.1 Sampling Methods

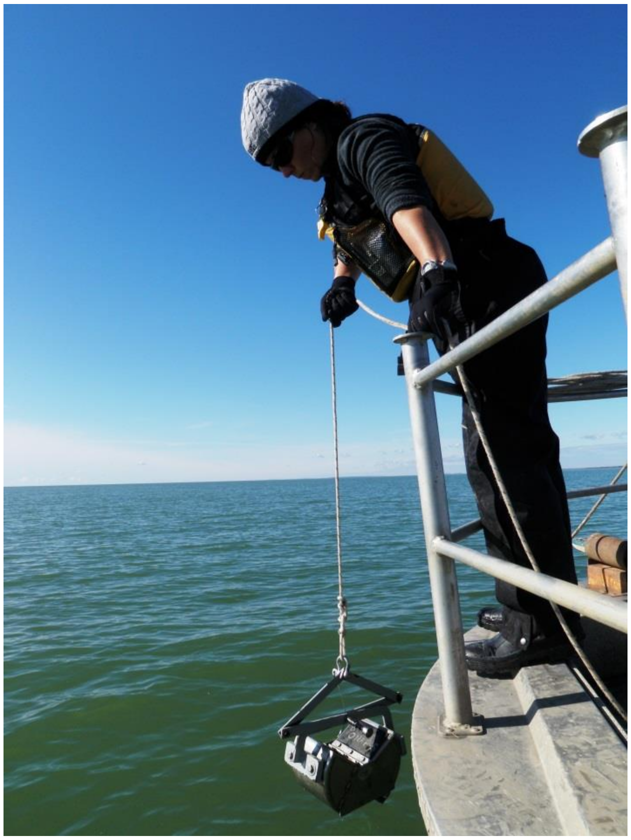
Sediment quality sampling was conducted in 2011 in conjunction with the BMI sampling program at or near the annual water quality sampling sites to the extent feasible (i.e., where adequate fine substrate was present). The exception was Lake Winnipegosis, where sediment quality was sampled at the offshore (i.e., deep) BMI sampling site due to logistics associated with sampling the water quality site on this lake. Sediment quality sampling in Lake Winnipeg was conducted by MSD in 2011 under the broader provincial monitoring program in the lake and methods differed from CAMP (see below).

Sampling methods were based on standard methodologies, including guidance for metal mining environmental effects monitoring (EC 2011), Environment Canada (1994) guidance for sediment quality sampling, and British Columbia Ministry of Water, Land, and Air Protection (2003) field sampling methods.

Three samples (i.e., triplicates) were collected within a 2 m radius at each site with either a petite Ponar dredge or an Ekman grab sampler. One grab sample was collected at each site, excepting Threepoint Lake where multiple grabs were collected and homogenized to obtain sufficient sample for analysis. The upper 5 cm of sediments were collected and submitted to an analytical laboratory accredited under CALA for analysis of the parameters indicated in Table 3-2.

Standard QA/QC measures were integrated into the sediment quality component of CAMP, including the preparation of detailed field sampling protocols, standard measures to avoid sample contamination during and following sample collection, inclusion of field QA/QC samples (interlaboratory comparison samples and a homogenate duplicate sample), and QA/QC of sediment quality data.

Sampling methods for the Lake Winnipeg site, which was sampled under the broader provincial Lake Winnipeg monitoring program, differed from the CAMP methods. While a triplicate sample was collected for metals and nutrients as it is for CAMP, the Lake Winnipeg sediment samples were collected from the upper 2 cm rather than the upper 5 cm. Supporting variables (particle size and loss on ignition) were analysed from a composite sample but data were not available for preparation of this report.



Deploying a sediment sampler: Lake Winnipegosis.

3.4.2 Laboratory Methods

All sediment quality samples for laboratory analysis were submitted to a CALA accredited analytical laboratory (ALS Laboratories, Winnipeg, MB). Inter-laboratory comparison samples for sediment quality were submitted to a second CALA accredited laboratory (Maxxam Analytics, Winnipeg, MB).

Table 3-2. Sediment quality metrics measured under CAMP.

Variable	Unit	Variable	Unit
Metals		**Nutrients**	
Aluminum	(µg/g)	Nitrate-N	(µg/g)
Antimony	(µg/g)	Nitrite-N	(µg/g)
Arsenic	(µg/g)	Nitrate/ Nitrite-N	(µg/g)
Barium	(µg/g)	Total Kjeldahl nitrogen	(%)
Beryllium	(µg/g)	Total Phosphorus	(µg/g)
Bismuth	(µg/g)	Inorganic Carbon	(%)
Boron	(µg/g)	Total Organic Carbon	(%)
Cadmium	(µg/g)	Total Carbon	(%)
Calcium	(µg/g)		
Cesium	(µg/g)	**Physical Properties**	
Chromium	(µg/g)	Sand (2.0 mm - 0.05 mm)	(%)
Cobalt	(µg/g)	Silt (0.05 mm - 2 µm)	(%)
Copper	(µg/g)	Clay (<2 µm)	(%)
Iron	(µg/g)	Moisture	(%)
Lead	(µg/g)		
Magnesium	(µg/g)		
Manganese	(µg/g)		
Mercury	(µg/g)		
Molybdenum	(µg/g)		
Nickel	(µg/g)		
Potassium	(µg/g)		
Rubidium	(µg/g)		
Selenium	(µg/g)		
Silver	(µg/g)		
Sodium	(µg/g)		
Strontium	(µg/g)		
Sulfur	(µg/g)		
Tellurium	(µg/g)		
Thallium	(µg/g)		
Tin	(µg/g)		
Titanium	(µg/g)		
Tungsten	(µg/g)		
Uranium	(µg/g)		
Vanadium	(µg/g)		
Zinc	(µg/g)		
Zirconium	(µg/g)		

3.5 BENTHIC MACROINVERTEBRATES

3.5.1 Sampling Methods

As described in Section 1.6.3, the BMI component of CAMP was refined prior to the Year 3 field program in an attempt to minimize the inherent variability noted for BMI data collected in Years 1 and 2. The following provides an overview of the BMI field sampling methods employed in Years 1 and 2 and in Years 3 through 6 of CAMP. A detailed description of field sampling methods employed in Years 1 through 3 is provided in CAMP (2014).

Benthic macroinvertebrate monitoring was conducted annually at a minimum of one off-system waterbody and one on-system waterbody within each monitoring region. Sampling areas (i.e., polygons) were stratified by water depth and constrained by other aquatic habitat attributes (e.g., substrate type, absence of aquatic plants, water velocity, etc.) such that sampling areas represented the predominant habitat type(s) within each waterbody and/or the habitat type(s) that may be most affected by water level fluctuation (natural and due to regulation).

The refined study design gave consideration to Environment Canada’s Canadian Aquatic Biomonitoring Network and Environment Canada’s Environmental Effects Monitoring program guidance for metal mining and pulp and paper industries programs (EC 2010, 2012a, 2012b). These changes were intended to increase the statistical power of the data without a substantial change to sampling effort and analytical costs. Methods are described below for Years 1 and 2, and Years 3 to 6 of CAMP.

3.5.1.1 Years 1 and 2

Fifteen BMI samples (i.e., replicates) were collected using an Ekman or petite Ponar grab sampler (0.023 m^2) in each nearshore and offshore polygon for a total of 30 samples per waterbody. The water depth criterion was between 3 and 5 m (predominantly-wetted) for the nearshore habitat and greater than 5 m for the offshore habitat (permanently-wetted).

In the northern rivers (the lower Nelson, lower Churchill, and Hayes rivers), 10 rock baskets were deployed in Year 1 of the pilot program at each river site and 20 rock baskets (sampling area of each rock basket 0.032 m^2) were deployed in Year 2 at each river site.

All BMI samples were retrieved to the surface, emptied into a 500 µm mesh rinsing bucket, and carefully sieved. Invertebrates retained by the mesh were washed into labelled plastic jars and fixed with 10% formalin. Fixed samples were shipped to the NSC laboratory (Winnipeg, MB) for processing and identification.

Sediments were also collected in association with the BMI sampling program for analysis of standard supporting variables. In Year 1, one sediment sample was collected in each habitat type; in Year 2, three sediment samples were collected in each habitat for a total of six sediment samples per waterbody. Sediments were collected using an Ekman or petite Ponar grab sampler, and contents were sub-sampled with a 5 cm diameter core tube (0.002 m^2 surface area) to provide a sample of approximately 100 mL of sediment. Sediment samples were kept cool in the field, and then frozen until delivered to an analytical laboratory accredited under CALA (ALS Laboratories, Winnipeg, MB) for particle size (percent sand, silt, and/or clay), and total organic carbon analyses.

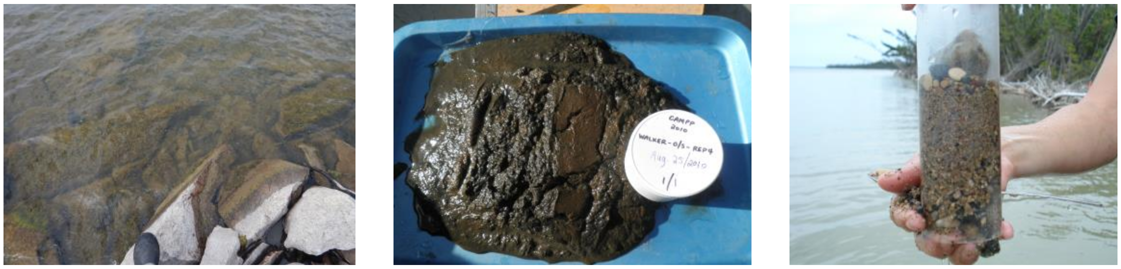
3.5.1.2 Years 3 to 6

The new study design implemented in 2010 utilized a travelling-kick-sweep approach in the nearshore habitat; offshore habitat was sampled using the same methods as applied in Years 1 and 2 (i.e., using an Ekman or petit Ponar grab sampler). Within both habitat polygons, each of the five replicate stations consisted of three randomly collected BMI sub-samples. The three sub-samples were combined to provide a single BMI composite sample for each replicate station for a total of ten samples per waterbody.

In the nearshore habitat (intermittently-exposed), water depths were ≤ 1 m (i.e., wadeable depth), with consistent water movement/velocity (low or medium velocity habitat); areas containing aquatic macrophyte beds were avoided to minimize variability. In the offshore habitat (permanently-wetted), water depths were 5 to 10 m with homogeneous substrate, and consistent water movement/velocity (low or medium velocity habitat).

All BMI samples were emptied into a 500 µm mesh bucket, and carefully sieved. Invertebrates retained by the mesh were washed into labelled plastic jars and fixed with 10% formalin. Fixed samples were shipped to the NSC laboratory (Winnipeg, MB) for processing and identification.

Five sediment grab samples were collected in each habitat polygon (one from each replicate station) for a total of 10 benthic sediment samples per waterbody. In the nearshore habitat, sediments were collected using a plastic soup ladle or by hand. Sampling methods for offshore sites were consistent with those employed in Years 1-2, as described in Section 3.5.1.1 above. Sediment samples were kept cool in the field, and moved into refrigeration until delivered to ALS Laboratories for particle size and total organic carbon analyses. In the nearshore habitat where sediment samples could not be collected because of predominantly hard substrate, (i.e., bedrock and/or cobble), a photographic and visual description was documented.



Benthic substrates at:
Granville Lake nearshore (left), Walker Lake offshore (centre), and Stephens Lake south nearshore (right)

Additional supporting variables measured during BMI sample collection included a description of the substrate and water depth. In 2010, relative benchmarks were established along the shore at each waterbody. The distance from the benchmark along the shore to the water level at time of sampling and the high water mark were recorded; a shorter distance indicates a relatively higher water level at the time of sampling.

3.5.2 Laboratory Analysis Methods

The following provides an overview of the BMI laboratory methods employed in Years 1 through 6 of CAMP. A detailed description of laboratory methods employed in Years 1 to 3 is also provided in CAMP (2014).

In the NSC laboratory, each BMI sample was rinsed through a 500 µm brass test sieve. The entire sample was examined visually to determine whether splitting (sub-sampling) was required as the target was 300 benthic invertebrates per sample. Samples containing fewer than 300 macroinvertebrates were sorted in their entirety. If splitting was required, the whole sample was scanned to remove any large and/or rare organisms. A Folsom Plankton Splitter (1.0 or 4.0 L, specific to sample volume) was used to divide the whole sample into aliquots that were sorted until at least 300 invertebrates were counted. When the 300 organism count was achieved part way through an aliquot, the remainder of that fraction was processed so that a known portion was sorted. The following taxa were not included in the 300 organism count: Ostracoda, Cladocera/Rotifera, Copepoda, Harpacticoida, Porifera, Nemata, Platyhelminthes, and non-aquatic taxa.

BMIs were sorted from the sample matrix under a desktop magnifying lamp (3X magnification) and transferred to 70% ethanol prior to being identified to the appropriate taxonomic level. The approximate proportion of the organic and inorganic component (vegetation, detritus, and/or substrate) of each sample was recorded on the laboratory benchsheets. Samples were processed following the NSC QA/QC sorting guidelines. All sorted samples were checked by a second laboratory technician; with the provision that a re-sort of the entire sample was required if sorting efficiency was less than 95%.

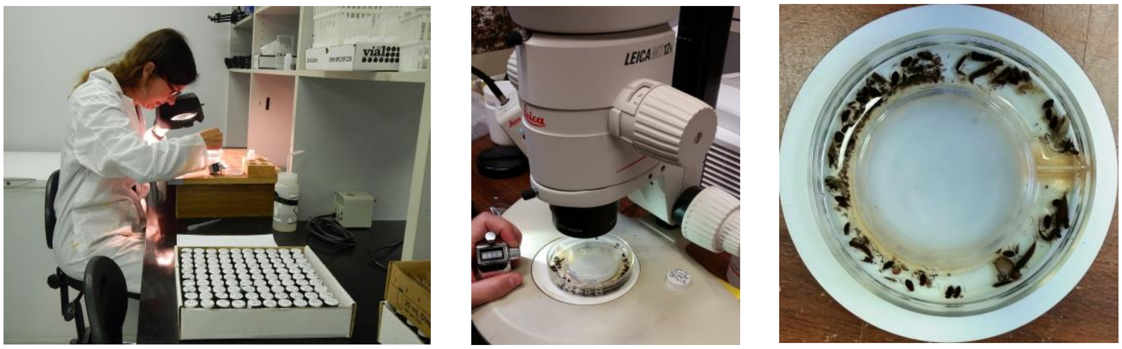
BMIs were enumerated and identified using a Leica MZ12.5 stereomicroscope with maximum 100x magnification. The BMIs in lake/reservoir and riverine environments were identified to:

- family, or lowest practical level for non-Insecta;
- family for Insecta and sub-family for Chironomidae; and,
- genus for Ephemeroptera.

Taxonomic analysis was performed using reference texts: Clifford (1991), Merritt and Cummins (1996), Peckarsky et al. (1990), Smith (2001), Stewart and Stark (2002) and Wiggins (2004). Scientific names used followed the Integrated Taxonomic Information System classification (ITIS 2013). Taxonomic identifications were verified (i.e., subject to QA/QC) by submitting 10% of randomly selected samples from each waterbody to an external taxonomic specialist. The target accuracy for in-house identifications is 90%; identifications and/or enumeration discrepancies were corrected on the taxonomic benchsheet.

All sorted BMI samples are retained should further identification be required. A taxonomic reference collection of benthic invertebrates was assembled to ensure taxonomic consistency throughout the duration of CAMP. An external taxonomic specialist was used to verify all of the identifications in the collection.

Sediment samples were submitted to a CALA accredited analytical laboratory (ALS Laboratories, Winnipeg, MB) for particle size and total organic carbon analyses.



Invertebrate sorting and identification in the laboratory.

3.6 FISH COMMUNITY

3.6.1 Sampling Methods

Gillnetting sites were selected to provide a broad spatial representation and to avoid bias towards certain habitat types or fish species. In lacustrine waterbodies, sampling sites were distributed between shallow and deep areas, while in riverine waterbodies, sampling sites were generally selected based on the practicality of setting a net in a given location and, to the degree possible, to encompass the full extent of sample area and habitat types. With some exceptions, gillnetting sites that were established for all annual and rotational waterbodies during the pilot program were used for the duration of the first six years of CAMP. In a few waterbodies, some sites established under the pilot program were discontinued and were replaced with new sites. Typically this was done to improve spatial coverage of the waterbody, to provide more equal representation of a variety of habitat types, or to eliminate a site where physical conditions did not allow the gill nets to be set properly.

Standard gang index gill nets consisted of 22.9 m (25 yds) long, 1.8 m (2 yds) deep panels of five mesh sizes (stretched): 51 mm (2”), 76 mm (3”), 95 mm (3.75”), 108 mm (4.25”), and 127 mm (5”). At one location first sampled in 2011/2012, the standard gang index gill nets consisted of panels of the same mesh size and depth but a panel length of 9.1 m (10 yds). All mesh was constructed of twisted nylon and coloured light green. A # 30 lead line and a 1.0 cm (3/8”) float line was seamed to each gillnet panel. At approximately every third site, the large mesh end of a small mesh index gillnet gang was attached to the smallest mesh end of the standard gang. Small mesh gangs consisted of three 10 m long by 1.8 m deep panels of 16 mm, 20 mm, and 25 mm clear monofilament mesh. The gangs were assembled by attaching the float line to float line and lead line to lead line with meshes in sequence of size. Originally, small mesh gangs had lead lines and float lines built into the net; over the period of 2012/2013 to 2013/2014, small mesh gangs used at all locations had float lines and lead lines seamed on to the mesh in the same method as for the standard gangs. Standard gang sites were labeled as GN# and small mesh sites were labeled as SN#.

Gill nets were set perpendicular to the nearest shore, except at riverine sites where the current dictated that the nets were set parallel to the flow. Beginning in 2012/2013, within a given waterbody, approximately 50% of the gangs were set with the 127 mm panel near shore and the remainder with the 51 mm panel near shore (or the 16 mm small mesh panel if a small mesh gang was attached). Beginning in 2013/2014, efforts were made to ensure that this orientation (large mesh or small mesh near shore) remained constant in subsequent years. Gillnet gangs were set for approximately 24 hours. Set times at the lower Churchill River at the Little Churchill River were reduced to approximately 16 hours to minimize Lake Sturgeon mortality.

All fish captured in standard gang and small mesh index gill nets were counted by mesh size and species at each site. Individual metrics were taken from all specimens of selected species (Walleye, Sauger [*Sander canadensis*], Northern Pike and Lake Whitefish); these species differed from waterbody to waterbody. The information collected from the selected species included:

- fork length (± 2 mm);
- weight (±10 g);
- sex and state of maturity;
- occurrence of Deformities, Erosion, Lesions, and Tumours (DELTs); and
- ageing structures (otoliths from Walleye, Sauger and Lake Whitefish, and cleithra from Northern Pike).

In addition to the species listed above, White Sucker (*Catostomus commersonii*) (beginning in 2010/2011) and Lake Sturgeon were weighed, measured for fork length and total length (Lake Sturgeon), and inspected for DELTs. Starting in 2013/2014, Lake Sturgeon caught at select locations (e.g., lower Churchill, lower Nelson, and Hayes rivers) were marked with PIT tags and Floy-tags. All other fish species were sampled as follows:

- any remaining fish from each mesh in the standard gangs were separated by species, counted and bulk weighed (±10 g); and
- any remaining fish from small mesh gangs were not separated by mesh but were counted and bulk weighed (±10 g for large-bodied species or ±1 g for small-bodied species).

Gill net being pulled at Leftrook Lake.

Walleye on measuring board.

3.6.2 Laboratory Methods

Fish ageing analyses were conducted on otoliths and cleithra by NSC and MSD – Fisheries Branch.

Otoliths were aged using the “crack and toast” method where an otolith is placed on a hard surface, seated on a piece of paper towel and scored cross wise across the focus with a scalpel until the otolith snaps in half. The cracked plane of one half of the otolith was then lightly polished utilizing a Foredom® BL-1A Bench Lathe (Foredom Electric Company, Bethel, CT) customized with a coarse stone wheel and a secondary fine grit sandpaper attachment. Toasting was achieved by slowly passing the cracked and polished plane of the otolith in and out of the tip of the flame of an alcohol-filled Bunsen Burner until it darkened. The cracked, polished, and toasted otolith was inserted into plasticine with the cracked edge facing up and a drop of clearing medium (i.e., oil of wintergreen or water) was applied to the cracked surface and viewed under a dissecting microscope with reflected light.

Cleithra were boiled to remove any tissue or oil residue remaining on the structure following removal from the fish. Cleithra were typically read “free hand” (i.e., without magnification) at NSC; however, a dissecting microscope or magnified ring light was used when required. MSD used a magnified ring light to read all cleithra.

At each agency, all structures were viewed once by an experienced ageing technician and assigned an age and confidence index rating based on qualitative and quantitative characteristics of the structure. Internal QA/QC measures included ageing of 10% of the structures from each waterbody by an alternate experienced ageing technician not involved in the initial age determination. After the internal QA/QC was completed, 10% of the ageing structures collected in that sampling year were exchanged between NSC and MSD and were aged to assess accuracy and consistency between agencies.

Walleye otolith showing annuli.

Northern Pike cleithra.

3.7 FISH MERCURY

3.7.1 Sampling Methods

Three species of large-bodied fish (i.e., Lake Whitefish, Northern Pike, and Walleye) were sampled for mercury under CAMP. These species were selected based on one or more of the following: (1) for historical reasons (i.e., species were commonly sampled in historical studies); (2) because of their economic importance; and/or, (3) in the case of Northern Pike and Walleye, because they are predators at the top of the aquatic food chain and therefore at the greatest risk for biomagnification of mercury. In addition to these large-bodied, long-lived fish, 1-year-old (1+) Yellow Perch were also sampled for mercury analysis. Yellow Perch are widespread and abundant prey fish for Pike and Walleye in the CAMP waterbodies and, because they do not undertake extensive movements, are considered suitable indicators of “local” production and bioaccumulation of (methyl)mercury. The young Perch may also provide insights regarding annual changes in the supply of mercury to the ecosystem which is one reason that makes them a preferred biological indicator for the monitoring and evaluation of trends in methylmercury accumulation in freshwater systems (Wiener et al. 2007; Depew et al. 2013). Finally, as opposed to other species, age 1+ Yellow Perch can often be readily identified in the field based on the length distribution of the catch.

Sampling for fish mercury during the first six years of CAMP was conducted concurrently with the sampling of the fish community in June-September. Consistency of sampling time was maintained within individual waterbodies, but because of logistical constraints due to the south/north phenology gradient, sampling times differed between waterbodies.

Because of sometimes low catches of 1-year-old Yellow Perch during fish community sampling, targeted sampling was introduced for this species starting in 2013 for the sole purpose to increase the number of fish available for mercury analysis to the target size of 25 fish. Targeted sampling may employ small mesh gill nets used in fish community sampling but also alternative gear such as seines and traps, and may be carried out at convenient locations distant from regular sampling sites that potentially provide suitable 1-year-old Yellow Perch habitat.

Initially, Lake Sturgeon was not a target species for the fish mercury monitoring component of CAMP. However, because little information exists on mercury concentrations in this species from Manitoba waters and due to its status as endangered under the Committee on the Status of Endangered Wildlife in Canada, muscle tissue for mercury analysis was collected from accidental mortalities of Sturgeon during the conduct of CAMP sampling starting in 2010.

Fish mercury sampling was conducted on a three-year rotation (2010 and 2013) for most waterbodies, and these lakes and rivers are referred to as “annual waterbodies”. A few waterbodies were also sampled every three years, but the first sampling year under CAMP was either one year prior to (e.g., Stephens Lake-South) or one year post (e.g., Sipiwesk Lake) the 2010 starting year for the annual waterbodies. The waterbodies with offset starting years are referred to as “rotational waterbodies”. Two waterbodies in the CRD region, Leftrook and Threepoint lakes, were sampled every year between 2010 and 2013. In addition to the regular sampling described so far, limited sampling was conducted in 2011 for waterbodies where sample sizes obtained in 2010 were substantially below target numbers or a species was not captured at all. This supplemental sampling particularly applied to Yellow Perch. Mercury concentrations in Lake Sturgeon were measured for accidental mortalities throughout the CAMP area, and sampling was not limited to a particular CAMP sampling location.

To be consistent with the methodology of previous fish mercury monitoring programs in Manitoba (e.g., Jansen and Strange 2007a; Strange and Bodaly 1999) an effort was made to collect 36 fish each of Lake Whitefish, Northern Pike, and Walleye for analysis of mercury in skeletal muscle. The individuals chosen for mercury analysis of these three species were to represent a broad size range and, as much as possible, an equal representation of size classes. In addition to the large-bodied species, up to 25 young Yellow Perch were collected. These fish were retained for analysis based on their length; aged Yellow Perch from previous collections in Manitoba indicate that 1-year-old Yellow Perch nearing the end of their second summer measure between 60-100 mm fork length. Yellow Perch available for mercury analysis sometimes exceeded the upper limit of the target length range and subsequent ageing indicated that some individuals analysed for mercury were older than 1 year. Unless the mercury concentrations were considered outliers, these data points were not removed prior to data analysis and are referred to as “1-year-old” Yellow Perch. A detailed description of field sampling methods is provided in CAMP (2014), Appendix 1.

3.7.2 Laboratory Analysis Methods

Muscle samples of large-bodied fish and whole bodies of Yellow Perch were collected at each site and frozen. Partially thawed Yellow Perch were processed for length, weight, and other biological data in the laboratory and a sample consisting of the body midsection from (but excluding) the pectoral girdle to the caudal peduncle was prepared for submission for mercury analysis. These perch “carcasses” were weighed and wrapped in cling-wrap prior to shipment to an analytical laboratory accredited under CALA (ALS Laboratories, Winnipeg, MB) for analysis of total mercury.

Quality assurance/quality control measures incorporated into the fish mercury program included development of a detailed field sampling protocol, which includes descriptions of measures to minimize sample contamination and maintenance of sample integrity, and the analysis of duplicate samples, and an inter-laboratory comparison (samples sent to Flett Research, Winnipeg, MB). For a detailed account of Laboratory methods and QA/QC measures see CAMP (2014), Appendix 1.

4.0 DATA ANALYSIS METHODS AND REPORTING APPROACH

The following sections provide a description of the objectives, approach, and methods applied for analysis and reporting. The terms of reference for the six year summary report specified that the reporting would include an exploratory analysis of available data for key indicators and metrics to:

- provide a preliminary evaluation of potential trends within the six year monitoring period; and
- provide an initial review of data to explore potential relationships between biological and chemical metrics and hydrological conditions.

It is recognized that although a large quantity of data was acquired over the initial six years of CAMP, these data are relatively limited in terms of monitoring for long-term trends and/or relationships with physical (and other) variables due to the short temporal period. Six years of data may be insufficient to detect trends over time, notably long-term trends. Additionally, any indications of potential trends over the six year period do not necessarily imply a long-term trend is occurring, as apparent trends over this interval may simply reflect the relatively limited time period assessed in conjunction with inter-annual variability in a metric. Consideration of a longer period of record is required to evaluate for true long-term trends.

In addition, many of the regions experienced high flows/water levels for most of the six year monitoring period and the lower range of the hydrographs was generally underrepresented or lacking altogether. This further limited the ability to explore broad-scale relationships between hydrological conditions and chemical and biological metrics. In addition, it is cautioned that identification of significant correlations between chemical or biological and hydrological metrics does not infer a causal relationship (i.e., correlations simply indicate that two metrics are related). Lastly, the scope of these initial analyses was limited to a relatively high-level exploratory approach. For these reasons, discussions of trends and relationships with hydrological conditions discussed in this report are considered exploratory/preliminary and are expected to be revised and updated as additional data are acquired.

4.1 HYDROLOGY

Hydrologic conditions are characterized under CAMP to provide context for the interpretation of monitoring data for the other CAMP components (i.e. fish community, lower trophic levels, and water quality). Hydrology provides the basis for the aquatic environment and differences in flows and water levels between and within years can affect the chemical and biological components of the environment.

4.1.1 Description of Key Indicators and Metrics

Unlike the other CAMP components, no formal key metrics have been identified for hydrology. No key metrics were calculated because at present there are no readily identifiable numeric criteria that provide a useful description of hydrology as it affects the chemical and biological components of the environment on an annual basis. The exploratory analyses described in each of the CAMP sections may in future identify metrics that may be useful to calculate and consider in the interpretation of monitoring data. For example, average water levels during the open-water season to the time of sampling were compared to the condition of Walleye; if, as more data are collected, a relationship is established, then this may become a CAMP metric.

Water levels and flows form the basis of the CAMP description of the hydrological conditions in the different regions.

4.1.2 Data Analysis Methods

To analyze hydrometric data for this report, gauging station and GS data (i.e. water levels and flows) were compiled and hydrographs were created that illustrate the progression of water levels and flows through time for each region. As well, key differences among years and a description of the causes of these differences (e.g., precipitation) were provided in the text. For each region, hydrographs were compared for all years to identify any patterns or consistencies. Raw water level and flow data were also provided to study team members to support the analyses exploring potential relationships between environmental components and water levels and flows.

4.1.3 Reporting

For each region, the hydrologic conditions over the period from 2008 to early 2014 were characterized using hydrographs and included descriptions of typical and anomalous conditions (e.g., high flows).

4.2 AQUATIC HABITAT

The key objectives for the analysis of CAMP aquatic habitat inventory data were to:

- process and analyze hydroacoustic tracking data to extract depth and acoustic bottom type classes matching physical benthic grab data; and
- produce contemporary aquatic habitat maps representing substrate and depth for waterbodies studied during the 2011-13 CAMP synthesis reporting period.

The first objective was addressed through two approaches: (1) hydroacoustic signal processing software (QTC View) was used to determine depth from acoustic returns in real-time in the field;

and (2) hydroacoustic post-processing software (QTC Impact) was used to acoustically classify bottom-types using a statistical unsupervised clustering approach.

The second objective was addressed in a geographic information systems (GIS) environment. Classified acoustic bottom depth and classified bottom type tracking data (objective 1) were imported into the GIS. Spatial interpolation tools within the GIS were used to produce a continuous depth surface for each waterbody being studied. Acoustically classified survey track data were labeled according to corresponding validation data.

The specific data processing, analysis, and mapping methods employed are described below.

4.2.1 Data Analysis Methods

4.2.1.1 Acoustic Data Processing, Analysis, and Classification

During the boat-based hydroacoustic surveys QTC View software recorded and ‘picked’ real-time depths from acoustic waveform signals according to pre-set parameters. The geo-located acoustic bottom signal data recorded by the QTC systems during the surveys were imported into QTC Impact software for post-processing. The software facilitates data processing, review, statistical analysis, and classification of the acoustic data. Where large data volumes were encountered, the data were merged, reviewed for errors, and imported to a third party statistical software package for statistical analysis and classification.

Within QTC Impact, principal component analysis was used to reduce the 166 acoustic elements or variables recorded in the field to three principal component variables (Q1, Q2, Q3) that contain greater than 90% of the acoustic variability found within the dataset. Using QTC Impact, an unsupervised cluster analysis was then used to group acoustic samples into classes with similar bottom type acoustic responses via the principal component analysis variables. This unsupervised classification approach requires user-supplied labelling of classes using validation data collected in the field after the clustering analysis.

Acoustic data with anomalous depths and irregular waveform were rejected within QTC Impact prior to analysis. Data were reviewed once more prior to export to ASCII text format. The acoustic data were then imported into Microsoft Excel® for further processing. Depths were corrected for transducer position below the surface of the water, which can range anywhere from 20 cm to 70 cm, depending on the waterbody and survey vessel used.

4.2.1.2 Shoreline Mapping

In order to produce contemporary aquatic habitat maps at a reasonable scale, CAMP waterbodies required relatively accurate (spatial and temporal) georeferenced shoreline geometry data. CAMP waterbody data were generally georeferenced to 1:50,000 federal topographic data (Centre for Topographic Information 2011-13), but when these vector data were not deemed sufficient, other data sources were sought. Examples of other shoreline data sources included but were not limited to: various resolutions of satellite imagery; digital orthometric aerial imagery; or, other vector data products. Where possible, shorelines extracted from other sources were referenced to date of acquisition and mean water level of the target waterbody during acquisition.

4.2.1.3 Bathymetric Mapping

To develop a bathymetric surface (or grid) across each surveyed waterbody, spatial interpolation software (Golden Software's Surfer or ArcGIS® Spatial Analyst) was used to model depths for unsurveyed areas using depths measured at surveyed geographic locations and a geostatistical Kriging interpolation method. These interpolated depth surfaces were imported into a GIS. Environmental Systems Research Institute`s ArcGIS® software was then used to symbolize the depth surfaces into a user-specified number of depth classes creating a continuous grid of depths. Vector contour lines were then produced and overlaid on the continuous depth surface interval map. Finally, background topographic data were used to provide additional context for the bathymetric depth data. ArcGIS® was then used to summarize the interpolated depth data, and estimate such variables as mean and maximum depth, and volume for each waterbody.

4.2.1.4 Substrate Mapping

Acoustically classified bottom-type data were imported into ArcGIS® software as a discrete point data layer. The acoustic classes were then labelled according to the corresponding substrate class based on field benthic validation data. The acoustically classified point data were used to interpret the boundaries of continuous substrate areas or polygons. Once boundary interpretation and polygon digitization was complete, the areas were reviewed for errors and inconsistencies. They were then assigned a representative symbol that best reflected the substrate class. Total area for each substrate class was calculated in the GIS and then exported into Microsoft Excel® for formatting.

4.3 WATER QUALITY

The key objectives of the analysis of the first six years of CAMP water quality data were to:

- evaluate whether water quality conditions are suitable for aquatic life;
- evaluate whether there are indications of temporal trends in water quality metrics; and
- provide an initial review of linkages between water quality metrics and key drivers, notably hydrological conditions, where feasible.

The first objective was addressed through comparisons to MWQSOGs for PAL to evaluate overall ecosystem health (MWS 2011). A description of the MWQSOGs is provided in Section 4.3.3. In addition, some water quality metrics were compared to published categorization schemes to describe trophic status (total phosphorus, total nitrogen, and chlorophyll *a*), scales of water hardness, and nutrient limitation. Section 4.3.4 provides a description of the categorization schemes applied.

The second objective (temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken to assess whether there were significant differences between years at annual sites; and (2) trends were examined visually through graphical plots for annual sites. Six years of data may be insufficient to detect trends over time, notably long-term trends, and the assessment was therefore restricted to qualitative assessment of the available data for sites monitored annually.

The third objective was addressed through statistical analysis of hydrological and water quality metrics to evaluate correlations between flow or water level and water quality metrics. Significant relationships between hydrological and water quality metrics were observed for some sites in the recent Manitoba Hydro and the Province of Manitoba’s (2015) Regional Cumulative Effects Assessment (RCEA), as well as earlier studies (e.g., Duncan and Williamson 1988).

This report focuses upon three key indicators: DO, nutrients/trophic status, and water clarity. Metrics for these indicators include DO concentrations and temperature, total nitrogen, total phosphorus, chlorophyll *a*, and TSS. A description of these key indicators and metrics is provided in Section 4.3.1. While not selected as key indicators at the CAMP workshop in 2014, additional water clarity metrics (Secchi disk depth and turbidity) were also described, as concentrations of TSS were relatively low in some regions (i.e., at or below analytical detection limits [DLs]) and these additional metrics are more sensitive descriptors of water clarity.

Manitoba Hydro and the Province of Manitoba’s (2015) RCEA identified several effects of hydroelectric development on water quality in the Churchill, Nelson, and Rat/Burntwood river systems. The RCEA also identified several water quality metrics that appear to be undergoing relatively recent increases or decreases (i.e., trends) in some waterbodies. Therefore, CAMP water quality monitoring results for parameters other than key metrics were also reviewed and summarized where of particular note (e.g., where there was evidence of temporal trends or where a metric did not meet MWQSOGS for PAL).

4.3.1 Description of Key Indicators and Metrics

Three key indicators, composed of seven metrics, of water quality were selected for reporting as indicated in Table 4-1. The following provides a brief description of these indicators and metrics and their relevance to aquatic ecosystem health.

4.3.1.1 Dissolved Oxygen

Dissolved oxygen is essential for the survival of most aquatic biota. It is consumed by aquatic organisms including, animals, plants, algae, and bacteria in the water column and sediments. Sources of DO to aquatic systems are aeration (i.e., input of oxygen from the atmosphere) and photosynthesis by plants and algae. The concentration of DO in surface waters is affected by water temperature; colder water can hold more DO than warmer water and saturation occurs at a higher concentration in winter. DO may decrease in north temperate ecosystems that experience long periods of ice cover due to the lack of an oxygen source from the atmosphere (i.e., no or minimal reaeration due to ice). In some cases, depletion of oxygen over the winter may lead to anoxic (i.e., no oxygen) conditions and cause fish kills (commonly referred to as winterkill). DO may also vary across the water column in lakes that stratify, typically being lowest at depth.

Some waterbodies, notably lakes, may regularly or periodically stratify. Stratification is a function of changes in water’s density with changes in temperature (e.g., through surface warming or cooling) and the ability of the lake to mix upper and lower layers of water. It is often defined as a temperature change of 1^{o}C or more over one meter of water. Two distinct layers may form: an upper layer (epilimnion); and a lower layer (hypolimnion). Stratification may develop in summer when the epilimnion is warmed due to surface heating and the lake circulation is not strong enough to mix the less dense water at the surface with the cooler, denser hypolimnetic waters. In fall/winter, the epilimnion may cool and remain unmixed from the warmer and denser hypolimnion thus forming stratification. Numerous physical conditions affect the ability of stratification to develop in a lake including: lake morphometry; distance across which the wind blows (fetch); lake depth; lake volume; water residence time; air temperatures; wind speed; and solar radiation. Stratification is significant from a biological perspective as it affects temperature profiles in waterbodies and because it results in isolation of upper and lower layers of water, thus affecting exchange and flow of chemical constituents. In particular, stratified waterbodies may develop significant DO depletion in bottom waters. For these reasons, temperature is monitored at the same time as DO and is used to interpret DO measurements.

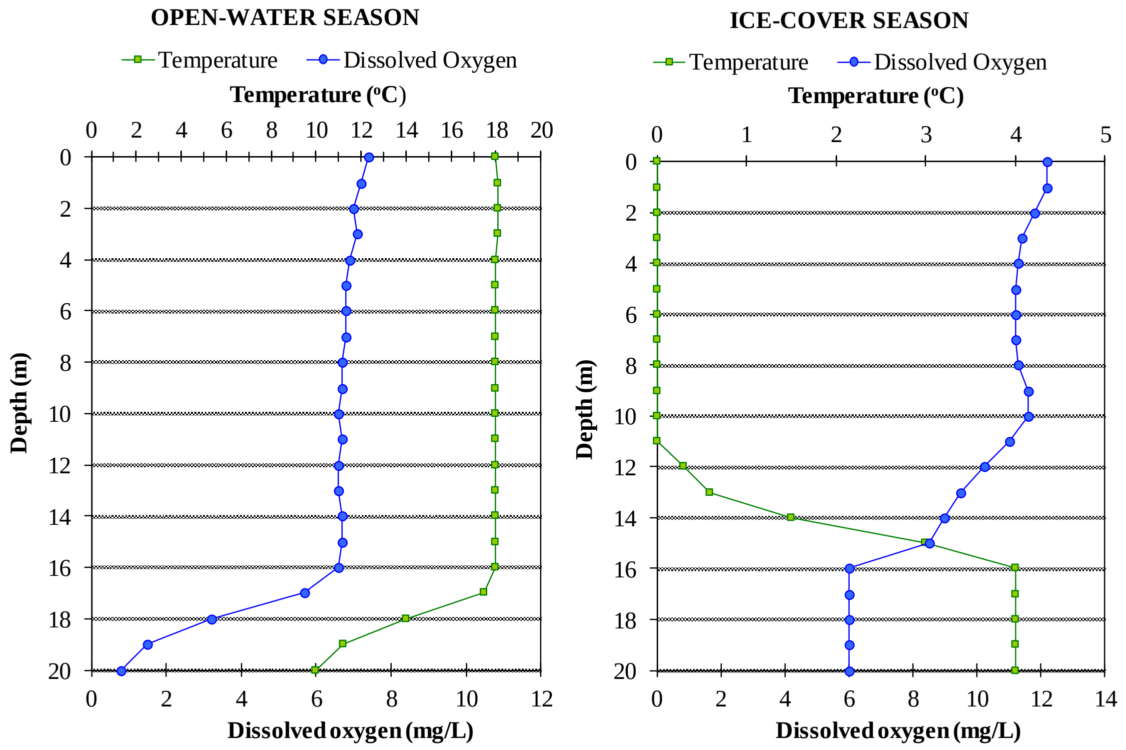


Figure 4-1. Conceptual dissolved oxygen and temperature depth profiles for the open-water and ice-cover season. Note thermal stratification and reductions in dissolved oxygen occur in the lower depths in both seasons.

4.3.1.2 Water Clarity

Water clarity is often described using measures of TSS or turbidity, which are generally interrelated (and typically correlated) but represent different measures. TSS is a measure of the amount (by weight) of suspended solids, which includes organic matter and inorganic matter such as sediment, in water. Turbidity is a measure of scattering of light by suspended particles in water and it reflects the transparency of water caused by dissolved and suspended substances (Caux et al. 1997). At very high concentrations, TSS can reduce fish growth rates, modify fish movements, affect fish egg and larval development, impair foraging and predation behaviour of fish, reduce abundance of fish diet items, affect reproduction of aquatic biota, reduce immunocompetency of aquatic biota, and harm benthic habitats. At lower concentrations, suspended sediment can influence aquatic ecosystems by reducing light penetration into the water column, thereby limiting the growth of plants and algae, and may affect behaviour of aquatic life (e.g., predation success of fish). Sources of TSS in surface waters include shoreline erosion, point sources (e.g., municipal or industrial wastewaters), surface water runoff/land use, and sediment resuspension.

Sediment plumes off eroding shorelines in Stephens Lake (left) and Rat Lake (right).

Secchi disk depth refers to the depth at which a black and white coloured disk lowered into the water is no longer visible. It is used as a general indicator of water clarity and can be used to estimate the depth of the euphotic zone (generally defined as the depth at which 1% surface radiation remains) in aquatic ecosystems. As Secchi disk depth is affected by all factors affecting visibility, including the presence of algae, it is often used as one of several indicators of trophic status in lakes.

Measuring Secchi disk depth in Cormorant Lake (left) and Stephens Lake (right).

4.3.1.3 Nutrients, Chlorophyll a, and Trophic Status

Nitrogen and phosphorus are the major nutrients in surface waters that support the growth of aquatic plants, benthic algae (i.e., periphyton), and algae in the water column (phytoplankton). Sources of nutrients in surface waters include the breakdown of organic matter, excretion by organisms, wastewater discharges, erosion and run-off from the watershed, sediment resuspension, and atmospheric deposition. Nutrients are not toxic at the concentrations normally found in surface waters. However, nutrient enrichment can stimulate excessive growth of plants and algae (i.e., eutrophication), which can subsequently lead to the degradation of aquatic habitat through physical changes (e.g., excessive plant or algal growth over gravel substrate), and through changes to water quality (reduced DO at night, reduced water clarity due to phytoplankton, and possible production of toxins by some forms of phytoplankton). Stimulation of plant or algal growth by nutrient enrichment in individual water bodies also depends on several other factors that potentially limit plant or algal growth, such as water clarity, temperature, flushing rates, and turbulence. Phosphorus is the most common nutrient limiting the growth of phytoplankton in lentic fresh water systems and concentrations are often related to the productivity of aquatic systems (Wetzel 1983).

Phytoplankton are small, aquatic plants (i.e., algae) that are most often found suspended in the water column and form the main base of the aquatic food web. As such, they are the foundation for higher trophic levels in an aquatic ecosystem. Phytoplankton biomass and production are key indicators of the productivity of an ecosystem and are commonly monitored in aquatic ecosystems to assess the degree of eutrophication. Chlorophyll *a* (a green pigment found in aquatic macrophytes and algae) is monitored at all locations under CAMP as a general indicator of phytoplankton biomass, productivity, and trophic status.

Phytoplankton may be affected by changes in water quality and hydrology. Changes in phytoplankton abundance or composition can in turn affect invertebrate and fish populations. While a critical component of aquatic ecosystems, excessive quantities of algae (i.e., algal blooms) can be problematic to aquatic biota and users of aquatic resources, since blooms may cause oxygen depletion (i.e., due to respiration at night and/or during die-off of algal blooms), fouling of commercial fishing nets, and can also be an aesthetic nuisance. The presence of a certain kind of phytoplankton - blue-green algae (or cyanobacteria) - can create additional issues since certain types of cyanobacteria may produce toxins, such as microcystin, that may adversely affect aquatic biota, wildlife, livestock, and humans.

Algae near the inlet to Two-Mile Channel.

4.3.2 Data Analysis Methods

All data analyses treated censured values (i.e., values reported as below the analytical DL) as equal to one half the DL. In cases where triplicate samples were collected, sample means were used for the determination of summary statistics and analyses.

Potential outliers were identified through data review and plotting. Few outliers were formally removed from the data analysis and reporting, with the exception of DO data. Issues were identified with the one of the DO meters used for CAMP, notably at temperatures below 10^{o}C, and a number of DO measurements were removed from the datasets for reporting purposes. Removal of other outliers from the datasets is documented within the presentation and discussion of results.

4.3.2.1 Temporal Comparisons and Trends

Statistical analyses were undertaken to evaluate inter-annual differences for sites samples annually over the first six years of CAMP; as the key water quality metrics may vary notably between the open-water and ice-cover seasons, statistical comparisons were restricted to data collected in the open-water season. All parameters detected in > 30% of samples for a given site were subjected to statistical analysis. Statistical methods varied in accordance with results of tests for normality of data. For parameters exhibiting a normal distribution, analyses were conducted using a t-test or analysis of variance (ANOVA) and a Tukey's test ($\alpha = 0.05$). For parameters not meeting the assumptions of a normal distribution (normality was tested on raw, untransformed data and log-transformed data), analyses were performed using the non-parametric Mann-Whitney test for two samples or with a Kruskal-Wallis test followed by the Dunn's multiple pairwise comparisons procedure (two-tailed; $\alpha = 0.05$).

4.3.2.2 Relationships With Hydrological Metrics

Linear regression analysis was undertaken to evaluate relationships between water quality and hydrological metrics (i.e., typically daily mean discharge and/or daily mean water level) for sites sampled annually under the first six years of CAMP, using data for the open-water season only. For some sites (i.e., lakes with longer residence times), hydrological metrics were derived for longer averaging periods. Raw and log-transformed data were analysed at a significance level of 0.05. Statistical analyses were conducted using XLStat. Regression analyses were also conducted between Julian date and water quality and/or hydrological metrics for some sites to explore the role of seasonality in the variability of water quality in the open-water season.

4.3.3 Comparison to Manitoba Water Quality Objectives and Guidelines

Manitoba water quality objectives and guidelines have been developed for a number of water quality parameters for the purpose of protecting aquatic biota and wildlife, and various human usages including recreation, drinking, irrigation, and livestock watering (MWS 2011). As a primary objective of CAMP is to document and monitor aquatic ecosystem health, CAMP water quality monitoring results were compared to MWQSOGs for PAL.

For many water quality variables there is a single water quality objective or guideline for PAL specified in the MWQSOGs, but for some variables there are multiple objectives or guidelines, and for still others, objectives and guidelines are calculated based on site-specific conditions. A summary of MWQSOGs for PAL applied in this report is provided in Table 4-2; brief explanations for variables for which there are either multiple PAL objectives/guidelines, or for which site-specific objectives or guidelines are derived, are provided below.

Objectives for ammonia vary according to the presence of cool-water (e.g., Walleye) or cold-water (e.g., Lake Whitefish) aquatic life, the presence of early (e.g., fish eggs) or mature (e.g., adult fish) life history stages of biota, averaging duration (i.e., 1 hour, 4-day, or 30-day average), pH, and water temperature. Site-specific water quality objectives were calculated for ammonia based on pH and water temperature measured at each site for both cool- and cold-water aquatic biota. In the interest of being conservative, the presence of early life history stages was assumed based on water temperatures (above or below 5^{o}C).

Site-specific PAL objectives were also calculated for cadmium, copper, chromium, lead, nickel, and zinc based on water hardness measured in the same water sample. To be conservative, monitoring results were compared to the long-term (4-day) objectives for PAL for these variables.

Like PAL objectives for ammonia, PAL objectives for DO vary according to the presence of cool- or cold-water aquatic life, the presence of mature or early life history stages of aquatic life, and exposure duration. As the presence of various life history stages at a particular water quality site sampled under CAMP cannot always be determined, to be conservative, DO data were compared to the most stringent objectives associated with water temperatures/time of year. In addition, since CAMP sampling frequency does not allow for determination of 7 day averages, minima, or 30-day averages of DO concentrations, the most stringent objectives in terms of exposure duration were applied.

In some instances, the laboratory analytical DLs were higher than the MWQSOGs for PAL and comparisons to MWQSOGs could not be undertaken. The Manitoba PAL guideline for mercury was modified (revised from 100 ng/L to 26 ng/L) in 2011 (MWS 2011) and analytical DLs employed for mercury under CAMP were not always sufficiently low to facilitate comparison to the revised guideline. In addition, analytical DLs for silver (0.0001 mg/L) and selenium (0.001 mg/L) are equal to the Manitoba PAL guidelines. Therefore, where either variable was detected, the guidelines were exceeded. However, measurements that are at or near analytical DLs are associated with relatively high uncertainty and there is low confidence that an actual exceedance of a PAL guideline has occurred when the guideline is at or near the DL.

In addition to the MWQSOGs, CAMP water quality data were compared to the Canadian CCME PAL guidelines for chloride (CCME 1999; updated to 2017) and the British Columbia Ministry of the Environment (BCMOE) PAL guidelines for sulphate (Meays and Nordin 2013) as there are currently no PAL guidelines for Manitoba for these substances.

4.3.4 Categorization and Description of Waterbodies

Lakes, reservoirs, and rivers sampled under CAMP were compared to various published categorization schemes to describe trophic status, nutrient limitation, and scales of water hardness.

Trophic status of CAMP waterbodies (rivers, lakes, and reservoirs) was classified utilizing the CCME Canadian phosphorus guidance framework for the management of freshwater systems (CCME 1999; updated to 2017) and the trophic state categorization scheme based on total phosphorus (Table 4-3). Lake and reservoir trophic states were also classified according to the Organization for Economic Cooperation and Development (OECD 1982) categorization scheme based on chlorophyll *a*, and the categorization scheme for total nitrogen presented by Nürnberg (1996).

There are few trophic classification schemes available for streams and rivers and no nationally or internationally accepted schemes for these waterbodies. As noted above, the CCME trophic classification scheme for total phosphorus is intended to be applied to all freshwater ecosystems including rivers and as such this scheme was applied for CAMP riverine sites. The trophic classification schemes based on total nitrogen and chlorophyll *a* for rivers presented in Dodds et al. (1998) were also applied to CAMP riverine sites (Table 4-4).

Nitrogen to phosphorus molar ratios were calculated to assist in estimating the limiting nutrient. Ratios less than 10 were considered indicative of nitrogen limitation and values greater than 20 were considered indicative of phosphorus limitation. Ratios between 10 and 20 were considered to indicate co-limitation. This approach is consistent with that applied by EC and MWS (2011) in the State of Lake Winnipeg Report.

Water hardness was compared to the Canadian Council of Resource and Environment Ministers (CCREM 1987) scale indicated in Table 4-5.

Table 4-1. Key water quality indicators and metrics identified at the CAMP workshop.

Key Indicator	**Key Metric**
Nutrients and Trophic Status	• Total phosphorus • Total nitrogen • Chlorophyll *a*
Dissolved Oxygen	• Dissolved oxygen • *Temperature/Stratification
Water Clarity	• Total suspended solids

*Supporting metric

Table 4-2. Summary of MWQSOGs for the protection of aquatic life (MWS 2011).

Parameter	**Unit**	**MWQSOG**	**Objective or Guideline**	**Comments**
pH	-	6.5-9.0	Guideline	
Dissolved oxygen	(mg/L)	Open-water: 6.0 and 6.5 Ice-cover: 5.5 and 9.5	Objective	Most stringent objectives for cool- and cold-water aquatic life
Ammonia	(mg N/L)	Site-specific	Objective	Values calculated based on pH and water temperature
Nitrate	(mg N/L)	2.93	Guideline	
Total phosphorus	(mg/L)	Lakes, ponds, reservoirs: 0.025 Streams/rivers: 0.050	Narrative guideline	For protection of various water uses.
Metals				
Aluminum	(mg/L)	0.1	Guideline	
Arsenic	(mg/L)	0.15	Objective	
Boron	(mg/L)	1.5	Guideline	
Cadmium	(mg/L)	Site-specific	Objective	Values calculated based on water hardness
Chromium	(mg/L)	Site-specific	Objective	Values calculated based on water hardness
Copper	(mg/L)	Site-specific	Objective	Values calculated based on water hardness
Iron	(mg/L)	0.3	Guideline	
Lead	(mg/L)	Site-specific	Objective	Values calculated based on water hardness
Mercury	(mg/L)	0.000026	Guideline	Guideline for "inorganic mercury"
Molybdenum	(mg/L)	0.073	Guideline	
Nickel	(mg/L)	Site-specific	Objective	Values calculated based on water hardness
Selenium	(mg/L)	0.001	Guideline	
Silver	(mg/L)	0.0001	Guideline	
Thallium	(mg/L)	0.0008	Guideline	
Uranium	(mg/L)	0.015	Guideline	
Zinc	(mg/L)	Site-specific	Objective	Values calculated based on water hardness

Table 4-3. Trophic categorization schemes applied for CAMP lakes and reservoirs.

Metric		Trophic categories						Reference
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hypereutrophic	
Total phosphorus	(mg/L)	<0.004	0.004-0.010	0.010-0.020	0.020-0.035	0.035-0.100	> 0.100	CCME (1999; updated to 2017)
Chlorophyll *a*	(µg/L)	-	<2.5	2.5-8	-	8-25	>25	OECD (1982)
Total nitrogen	(mg/L)	-	<0.350	0.350-0.650	-	0.651-1200	>1200	Nurnberg (1996)

Table 4-4. Trophic categorization schemes applied for CAMP river sites.

Metric		Trophic categories						Reference
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hypereutrophic	
Total phosphorus	(mg/L)	<0.004	0.004-0.010	0.010-0.020	0.020-0.035	0.035-0.100	> 0.100	CCME (1999; updated to 2017)
Chlorophyll *a*	(µg/L)	-	<10	10-30	-	>30	-	Dodds et al. (1998)
Total nitrogen	(mg/L)	-	<0.7	0.7-1.5	-	>1.5	-	Dodds et al. (1998)

Table 4-5. Hardness scale for aquatic ecosystems (CCREM 1987).

Hardness as Calcium Carbonate (mg/L)	Degree of Hardness
0-30	Very soft
31-60	Soft
61-120	Moderately soft (hard)
121-180	Hard
180+	Very Hard

4.4 SEDIMENT QUALITY

The key objective of the analysis of CAMP sediment quality data was to evaluate whether conditions are suitable for aquatic life. The key objective was addressed through comparisons to sediment quality guidelines (SQGs) for PAL.

There are Manitoba SQGs for a number of substances, including several metals/metalloids (MWS 2011), which were adopted from the CCME guidelines issued in 1999 (CCME 1999; updated to 2017). Two criteria are provided: (1) an SQG; and (2) a higher value referred to as the probable effect level (PEL). The SQG is a threshold below which adverse effects to biota are expected to occur rarely whereas the PEL defines the level above which adverse effects are expected to occur frequently. Concentrations lying between the SQG and the PEL reflect a condition of increased risk of adverse effects. These criteria are intended to be applied to the upper 5 cm of sediment (CCME 1999; updated to 2017).

The province of Ontario (Persaud et al. 1993; Fletcher et al. 2008) has also issued SQGs for a number of substances in addition to those represented in the Manitoba or CCME SQGs. Similar to Manitoba and CCME guidelines, Ontario specifies a lowest effect level (LEL) and a severe effect level (SEL). The interpretation of these two thresholds is consistent with the Manitoba SQG and PEL, respectively.

Manitoba SQGs (MWS 2011) were considered for metals for which there are guidelines; as noted above, these SQGs are identical to the CCME guidelines. For additional parameters, guidelines applied by other jurisdictions in Canada were considered. Briefly, benchmarks considered in the assessment were, in the following order (Table 4-6):

- Manitoba SQGs (arsenic, cadmium, chromium, copper, lead, mercury, and zinc; MWS 2011);
- Ontario SQGs (total phosphorus, total organic carbon, total Kjeldahl nitrogen, iron, manganese, and nickel; Persaud et al. 1993; Fletcher et al. 2008); and
- the British Columbia sediment alert concentration (SAC) for selenium (BCMOE 2014, 2017), recently adopted as an interim sediment quality guideline (ISQG) by Alberta Environment and Sustainable Resource Development (2014).

As only one year of data is available for sediment quality, inter-annual differences and temporal trends could not be examined for this component. Key indicators and metrics were not identified for reporting on sediment quality and reporting focused upon metrics for which there are SQGs as described above. All data analyses treated censured values (i.e., values reported as below the analytical DL) as equal to one half the DL.

Table 4-6. Sediment quality guidelines applied for CAMP reporting.

Metric	Manitoba/CCME Sediment quality guidelines (µg/g d.w.)		Ontario Sediment quality guidelines (µg/g d.w.)		British Columbia SAC/ AB ISQG (µg/g d.w.)
	SQG	**PEL**	**LEL**	**SEL**	
Metals					
Arsenic	5.9	17			
Cadmium	0.6	3.5			
Chromium	37.3	90			
Copper	35.7	197			
Iron			20,000	40,000	
Lead	35	91.3			
Manganese			460	1,100	
Mercury	0.17	0.486			
Nickel			16	75	
Selenium					2.0
Zinc	123	315			
Nutrients					
Total Organic Carbon			10,000	100,000	
Total Phosphorus			600	2,000	
Total Kjeldahl Nitrogen			550	4,800	

4.5 BENTHIC MACROINVERTEBRATES

The key objectives of the analysis of the Years 3 to 6 of CAMP BMI data were to:

- evaluate whether there are indications of temporal trends in BMI metrics; and
- provide an initial review of linkages between BMI metrics and key drivers, notably hydrological conditions, where feasible.

The first objective (temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken to assess whether there were significant differences between years at annual sites; and (2) trends were examined visually through graphical plots for annual sites. Four years of data may be insufficient to detect trends over time, notably long-term trends, and the assessment was therefore restricted to qualitative assessment of the available data for sites monitored annually.

The second objective (linkages with hydrological conditions) was addressed through preliminary analysis of linkages between selected BMI metrics from the nearshore habitat and hydrological metrics for annual CAMP waterbodies.

The following provides a brief description of the BMI metrics and their relevance to aquatic ecosystem health (Section 4.5.1). Also provided is an overview of the BMI data analysis methods used in Years 3 through 6 of CAMP (Section 4.5.2).

4.5.1 Description of Key Indicators and Metrics

Although it is feasible to derive a great variety of indicators to describe the BMI community, lake/reservoir and riverine environments were assessed using four key BMI indicators selected at CAMP workshops: abundance/density; composition; taxa richness; and diversity. The metrics for these indicators include: total number of invertebrates; ratio of Ephemeroptera, Plecoptera, and Trichoptera (EPT) to Chironomidae (EPT:C), total taxonomic richness (family-level); EPT richness (family-level); and Simpson's Diversity Index (Table 4-7). Though not identified at the CAMP workshop, one additional metric - Ephemeroptera richness (genus-level) – was incorporated into reporting. The following provides a brief description of these metrics and their relevance to aquatic ecosystem health.

4.5.1.1 Total Abundance

Differences in the numbers of organisms are influenced by a variety of physical (e.g., substrate type, flow conditions), biological (e.g., benthic algal biomass), and chemical (e.g., DO and nutrient concentrations) factors. As such, the total number of invertebrates measured in a waterbody is a reflection of numerous aquatic habitat variables that have been integrated by the community over time.

Cormorant Lake nearshore sampling polygon (left) and benthic substrate (right)

4.5.1.2 Community Composition

Ephemeroptera, Plecoptera, and Trichoptera are generally considered to be more sensitive and Chironomidae less sensitive to environmental stress (e.g., nutrient enrichment, low DO). A community considered to be in good biotic condition may display an even distribution (i.e., ratio of 1:1) among these groups, while communities with disproportionately high numbers of chironomids (i.e., ratio <<1) may indicate environmental stress, either natural or anthropogenic. Although chironomids are often described as being tolerant to adverse conditions, many taxa belong to this group and the perceived tolerance of the group as a whole may be attributable to only a few taxa. Typically, chironomids are able to tolerate the conditions of periodic exposure in the upper littoral zone as well as be able to rapidly take advantage of newly wetted habitat, capable of colonizing bare substrates within a month (Fisher and Lavoy 1972; Scheifhacken et al. 2007). Chironomidae are also relatively more abundant on fine textured sediments (e.g., silt/clay, sand) than Ephemeroptera, Plecoptera, and Trichoptera and so differences in the EPT:C may reflect differences in substrate, in particular as fine substrates are more common in deeper areas of waterbodies.


Ephemeroptera (mayfly)
Chironomidae (midge)

Representative BMI major groups: Ephemeroptera and Chironomidae.

4.5.1.3 Richness

Total Richness

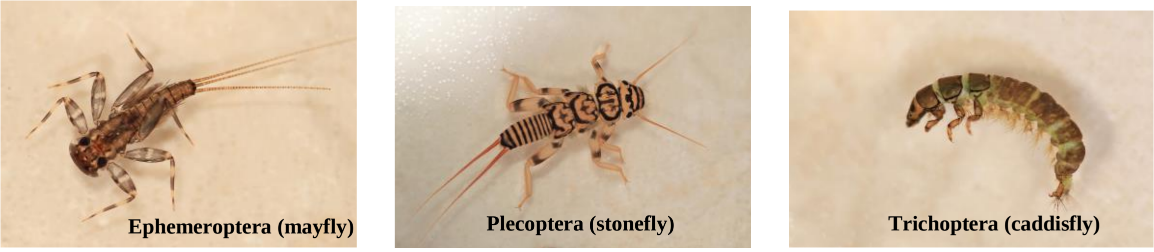
Total richness is the total number of distinct taxa or different types of aquatic macroinvertebrates at the family-level. The number of unique taxa (total taxonomic richness) reflects habitat diversity, with more diverse habitats typically supporting a richer fauna than less diverse habitats. Richness also provides information about the degree of perturbation (either natural [e.g., increased scouring during high flow events] or anthropogenic [e.g., increased suspended sediments in surface waters related to surface disturbance]) that has occurred at a site, with sampling events associated with more taxa often suggesting that fewer perturbations have recently occurred at that site.


Bivalvia (clam)
Amphipoda (scud/freshwater shrimp)

Representative BMI major groups: Bivalvia and Amphipoda.

Ephemeroptera, Plecoptera, and Trichoptera Richness

EPT richness is the total number of distinct taxa (family-level) within the groups, Trichoptera, Ephemeroptera, and Plecoptera. Similarly, Ephemeroptera richness is the total number of distinct taxa at the genus-level. EPT richness as an indicator of aquatic health is based on the premise that high-quality waterbodies usually have the greatest richness. In general, high diversity of EPT taxa can indicate a stable nearshore habitat.


Ephemeroptera (mayfly)
Plecoptera (stonefly)
Trichoptera (caddisfly)

Representative BMI major groups: EPT, Ephemeroptera, Plecoptera, and Trichoptera.

4.5.1.4 Diversity

Simpson’s Diversity index (1-D) provides an estimate of the probability that two individuals in a sample belong to the same taxa. The higher the index (0 to 1), the less likely it is that two individuals belong to the same taxa (i.e., likely the higher the diversity; Magurran 1988, 2004). However, it is important to keep in mind that this index is not itself ‘diversity’ and it is highly nonlinear. Diversity indices attempt to summarize the relative abundance of various taxa. An index may provide more succinct information about BMI communities than abundance or richness alone. Simpson’s Diversity index de-emphasizes rare taxa, while highlighting common taxa and evenness among taxa (i.e., similarity of population sizes of different species; Mandaville 2002). Generally, diverse communities are indicators of good water quality.

Lake Winnipeg (Grand Rapids) offshore sampling polygon (left) and Manigotagan Lake nearshore benthic substrate (right).

4.5.2 Data Analysis Methods

To prepare offshore data for analysis, the abundance of invertebrates in each dredge sample was converted to density (number of invertebrates per square meter [individuals/m^2]) by dividing the total number of invertebrates per sample by the bottom area of the sampling device (0.023 m^2) and the number of composited sub-samples (if applicable). For nearshore samples, the abundance of invertebrates was estimated as individuals per each timed kicknet.

The mean and standard error were calculated for each BMI metric to characterize the aquatic habitat types (nearshore, offshore) sampled for each waterbody. Supporting environmental variables (e.g., particle size composition and total organic content of sediments) were also described to aid in the understanding of BMI metrics. BMI metrics were reviewed through graphical methods, including box plots, to assist with the identification of potential outliers that would require special consideration during subsequent data analysis. Any visual outliers were not explored further and were retained for analysis due to the relatively limited quantity of data available to date.

Metrics were visually examined for within and between site differences using histograms showing the standard errors. Where the standard error overlapped, means were not considered different; however, the absence of an overlap does not necessarily indicate a statistically significant difference.

4.5.2.1 Temporal Comparisons and Trends

Statistical analyses were undertaken to evaluate temporal (among years) differences in both habitat types for each annual waterbody. Prior to statistical analyses, BMI metrics were tested for normality using the Shapiro-Wilk test ($\alpha = 0.05$) on raw, untransformed data. For metrics exhibiting a normal distribution, differences among years were assessed using ANOVA and a Tukey's test (α = 0.05). For metrics not meeting the assumptions of a normal distribution, the non-parametric Kruskal-Wallis test followed by the Dunn's multiple pairwise comparisons procedure (two-tailed; α = 0.05) was applied. All analyses were performed using a current version of XLStat.

4.5.2.2 Relationships With Hydrological Metrics

Mean discharge and water levels were calculated for the "growing season" each year that an annual waterbody was sampled, defined as the period between the approximate average annual date of ice-free conditions and sample collection date. Given that only four years of data from consistent sample collection were available (2010-2013), and that each year was considered a single sample, insufficient data were available for statistical analysis. Instead, the potential for relationships between mean discharge and water level and mean invertebrate abundance, richness and diversity was evaluated through inspection of tabular and graphical presentation of the data. The three selected metrics were those that most often differed among sample years in temporal comparisons described in Section 4.5.2.1 (i.e., abundance, richness and diversity).

Table 4-7. Key BMI indicators and metrics identified at the CAMP workshop.

Key Indicator	**Key Metric**
Total Abundance	• Total number of all organisms in a sample.
Composition of Major Groups	• EPT:C ratio
Taxa Richness*	• Total taxonomic richness • EPT Richness
Diversity	• Simpson's Diversity Index (1-D)

*Ephemeroptera Richness also included in reporting.

4.6 FISH COMMUNITY

The key objectives for the analysis of CAMP fish community data were to:

- evaluate whether there are indicators of temporal changes or trends in fish community metrics; and
- provide an initial review of linkages between fish metrics and key drivers, notably hydrological conditions, where feasible.

The first objective (analysis of temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken, where possible, to assess whether there were significant differences between years at annual locations; and (2) graphical plots for annual sites were examined visually for trends. The second objective was addressed by regression analysis of hydrological (discharge and/or water level) and fish community metrics. As discussed in Section 4.0, these analyses are considered to be exploratory in nature. It is cautioned that the identification of significant correlations between fish community metrics and hydrological variables does not infer a causal relationship (i.e., correlations simply indicate that two metrics are related).

This report focuses upon four key indicators: community diversity; fish abundance; species condition, and species growth. Metrics for these indicators include Hill's effective species richness, CPUE, Fulton's condition factor, and length-at-age (Table 4-8). A description of these key indicators and metrics is provided in Section 4.6.1. While not selected as key indicators at the CAMP workshop in 2014, an additional diversity metric (relative abundance [RA]) was also described as a shift in species composition have been observed in some waterbodies (Manitoba Hydro and the Province of Manitoba 2015).

4.6.1 Description of Key Indicators and Metrics

4.6.1.1 Diversity

The diversity of a fish community is commonly measured as the number of species (i.e., richness) and the relative abundance of these species. Numerous diversity indices have been developed for the assessment of ecosystem health; in principle, healthier ecosystems support a more diverse community. Hill's effective species richness is a measure of the number of species (i.e., richness) and the distribution of the different species (i.e., evenness) making up the community in an area.

While not identified at the CAMP workshop as a key metric, relative abundance was also included in reporting. Relative abundance is a measure of species diversity that is calculated as the proportion of the number of a particular species relative to the total catch. The relative abundance was calculated as the percentage of each species in the total catch in standard and small mesh gillnet gangs.

5.6.1.2 Abundance

The abundance of fish in a waterbody is influenced by a variety of physical (e.g., substrate type, flow conditions), biological (e.g., benthos production, predator/prey interactions), and chemical (e.g., DO) factors. CPUE is a common metric used to estimate the abundance of fish populations in a particular waterbody. It is generally considered a coarse estimate of abundance that can reflect trends in an ecosystem. Shifts in species abundance can reflect changes in species-specific responses to alterations in environmental conditions. CPUE is expressed as the number of fish captured in a standardized length of gill net over a fixed amount of time.

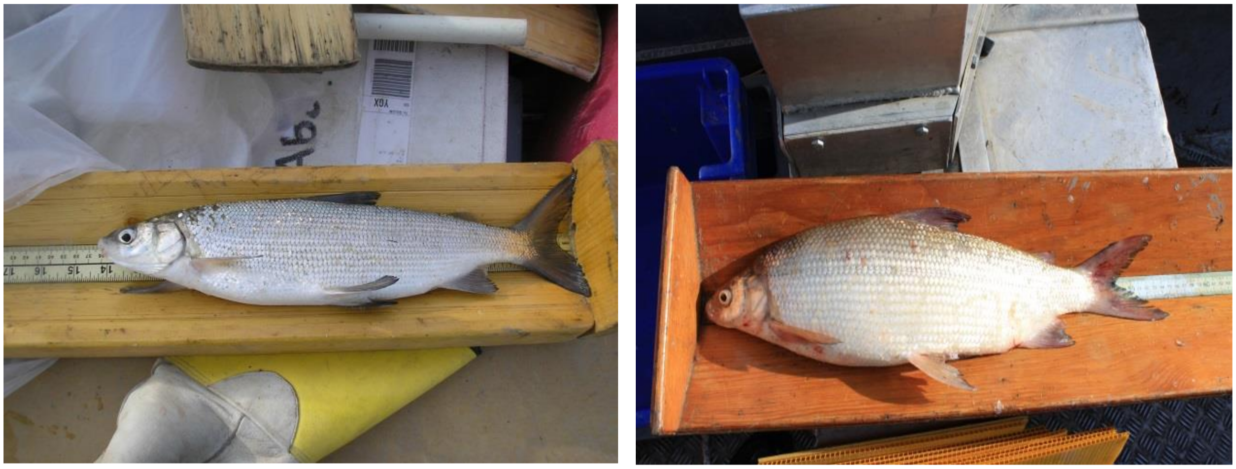
5.6.1.3 Condition

Information on fish condition (i.e., girth or fatness) reflects the nutritional status and health of fish. The condition of a fish is often influenced by age, sex, season, state of maturation (immature, pre-spawn, spawning), fullness of gut, type of food consumed, amount of fat reserves (stored in the mesenteric cavity, muscle tissue and liver), and amount of muscles. Because of these variables, it is important that populations be sampled at the same time of year to ensure fish are at the same stage of the reproductive cycle. Lack of food, poor water quality, or disease can cause stress that results in lower condition. Fulton's condition factor is a mathematical formula to quantify the condition of fish, and is based on the ratio of fish length and weight, in order to quantitatively compare the condition of individual fish within a population, compare the same population over time, or compare different populations.

Walleye showing a higher (left) and lower (right) condition factor.

5.6.1.4 Growth

Growth is a measure of body length as a function of age. Growth rates differ between and within species; successive cohorts may grow differently depending on environmental conditions. Growth was characterized from length-at-age and focused on the length distribution of fish of a given age selected for each species. The age selected to calculate the metric (i.e., length-at-age) ranged from 3 to 5 years, depending on the species. The age selected for each species was chosen to represent fish that are large enough to be recruited in the sampling gear, but are still young enough to be prior to, or at, the age of first maturity. Immature fish are allocating energy to growth rather than reproduction. Another factor for the selection of the age class was whether there were sufficient numbers of fish in the year-class for statistical analyses. The age selected was 3 years for Walleye and Sauger, 4 years for Northern Pike, and 4 and 5 years [considered separately] for Lake Whitefish.



Growth of Lake Whitefish, showing 350 mm (left) and 480 mm (right) long individuals.

4.6.2 Data Analysis Methods

4.6.2.1 Calculation of Metrics

The Hill’s index was calculated for the combined small mesh and standard gang index gillnet catches using the formula:

$$H = \exp\left(-\Sigma^{S}_{i}(pi \times \ln pi)\right)$$

where: pi = the proportion of each of i species.

A CPUE value was calculated for the total catch of fish in standard gang and small mesh gill nets and for select species. CPUE was standardized to a 30 m long net for small mesh gangs and to a 100 m long net for standard gangs. The CPUE was first calculated for each site and these values were then averaged to calculate a waterbody-specific value. The formula for the calculation of CPUE is:

$$\text{CPUE} = C_x \text{ or } C_t / E \times 24 \text{ h} / L \times 100 \text{ m or } 30 \text{ m}$$

where: C_x = the number of individuals of a species;

C_t = the total number of fish caught;

E = effort (set hours); and

L = the length of the gillnet gang.

The formula used to calculate Fulton's condition factor is:

$K_F = W \times 10^5 / L^3$

where: W = total weight; and

L = fork length.

Since condition typically increases with body size in fish (Blackwell et al. 2000), Fulton's condition factors were calculated for fish within a selected range of fork lengths in order to reduce variability associated with fork length. The size range for each species was selected to maximize the number of individuals in the sub-sample for all regions, while minimizing the size of the fork length range. The species-specific ranges were 200-349 mm for Sauger, 300-499 mm for Lake Whitefish, Walleye and White Sucker, and 400-699 mm for Northern Pike. Sub-samples of less than 20 individuals from a waterbody in a given year were excluded from the analysis.

Fork length-at-age was calculated for each target species by averaging the fork length of individuals of the selected age class (i.e., 3-year-old Walleye and Sauger, 4-year-old Northern Pike, and 4- and 5-year-old [considered separately] Lake Whitefish) captured in small and standard gang index gill nets for each waterbody in every sampling year. Samples of one or two individuals were excluded from the analysis. The fork length at each age was also calculated for waterbodies sampled annually by averaging the fork length of all individuals captured over the 6 year sampling period.

Relative abundance was calculated for the standard gangs only due to the large variation observed in the small mesh gangs. The formula for the calculation of RA:

$RA = C_x / C_t \times 100$

where: C_x = number of fish caught of species *x*; and

C_t = total number of fish caught.

4.6.2.2 Statistical Analyses

Box plots of annual mean values of the key metrics for each waterbody were plotted using XLStat. These graphs were used to compare the annual mean values for each sampling year within a given waterbody, as well as among waterbodies in a region.

For each waterbody that was sampled annually, statistical analysis testing for differences ($p < 0.05$) among sample years was conducted using XLStat. Treating each individual fish as the observational unit, ANOVA was used for Fulton's condition factor and length-at-age; whereas for CPUE, each gillnet site was treated as the observational unit, and as a result, mixed model ANOVA was used to analyze CPUE. Multiple comparisons among sample years was conducted using Tukey's test. Because the site values were pooled to produce a single Hill's index value for each year, statistical analysis could not be performed on this metric.

4.6.2.3 Relationships With Hydrological Metrics

Two of the fish community metrics that were considered to show the most direct linkages to annual changes in hydrological conditions were included in the hydrological metrics analysis: CPUE and Fulton's condition factor. Water level and flow conditions during the sampling season can affect CPUE either directly through effects on the abundance of fish in the area or indirectly due to reduced gear-effectiveness (e.g., high flows can reduce the efficacy of gill nets). The condition of a fish can vary in a given season depending on the availability of prey items, particularly benthic invertebrates. Water levels and flows can affect the abundance of fish diet items and the composition of lower trophic level communities and this in turn can affect fish condition.

Four hydrological metrics were selected to examine the potential effects of discharge and water level on the fish community metrics. The hydrological metrics were chosen following a review of metrics used in similar investigations on the effect of hydrologic fluctuations on biological communities (e.g., White et al. 2008). Mean discharge and water levels were calculated for the open-water season and the sampling period in each year. The duration of the open-water season was estimated for each waterbody as the period between the approximate average annual date of ice-off (based on a qualitative examination of multiple years of satellite photos at each waterbody) and the end of the fish community sampling period for each year. The sampling period included only the dates during which fish community sampling was undertaken. For lakes, discharge data from the gauging station located immediately upstream of the lake were used, where available. If no gauging station was located directly upstream of a lake, only water level metrics were used. For a riverine location, discharge data from the nearest gauging station was used. All hydrologic data was provided by Manitoba Hydro.

Simple linear regression was used to investigate the relationships between annual mean CPUE and Fulton's condition factor values for each waterbody and the hydrological metrics (i.e., annual mean open-water season discharge and water level and sampling period mean discharge and water level). To decrease the effect of large CPUE values, each CPUE metric was ln transformed prior to analysis. Discharge metrics were also ln transformed prior to analysis. Only results from regressions deemed statistically significant (i.e., $p < 0.05$) are presented in this report. All statistical analyses were performed using XLStat.

Table 4-8. Key fish community indicators and metrics identified at the CAMP workshop.

Key Indicator	Key Metric
Fish Abundance	• Catch-per-unit-effort
Community Diversity[1]	• Hill's effective species richness
Species Growth[2]	• Length-at-age • Weight-at-age[3]
Species Condition[2]	• Fulton's Condition factor

[1] Relative abundance was also included in reporting.
[2] Key indicators and metrics evaluated for target fish species.
[3] Key metric omitted from reporting due to the high variation observed with weight.

4.7 FISH MERCURY

The key objectives of the analysis of CAMP fish mercury data were to:

- evaluate the suitability of fish for domestic, recreational and commercial fisheries; and
- evaluate whether there are indications of temporal differences in fish mercury concentrations.

The first objective was addressed through comparisons to the Health Canada standard for commercial marketing of freshwater fish in Canada (Health Canada 2007a,b) and the Manitoba aquatic life tissue residue guideline for human consumers (MWS 2011) for the three target species (Lake Whitefish, Northern Pike, and Walleye).

The second objective (temporal changes or trends) was addressed through statistical comparisons between years for a given waterbody or riverine area where more than one year of data were available. Trends could generally not be assessed for fish mercury as only two years of monitoring data were available for all but two sites that were monitored annually.

Due to the limited amount of data for fish mercury (i.e., mainly two years of data), an analysis of potential relationships with hydrological metrics (an objective for most other CAMP components) was not undertaken. Relationships between fish mercury concentrations and hydrological metrics will be further investigated with acquisition of additional data in the future.

This report focuses upon one key indicator (fish muscle mercury concentration) and two key metrics: arithmetic mean mercury concentration; and length-standardized mean mercury concentration (hereafter referred to as “standard mean(s)”).

4.7.1 Description of Key Indicators and Metrics

The concentration of mercury in target fish species was the key indicator identified for this component. Both the absolute concentration of mercury (i.e., as measured) and a standardized concentration of mercury (i.e., standardized to a specified length of fish) were evaluated in this report. The former provides a direct measure of the suitability of fish, while the latter (i.e., standardized concentrations) provides a means for comparing fish mercury concentrations between waterbodies and/or years by standardizing the data to a common length of fish. This is done to reduce the effect of fish size on mean mercury concentrations because fish accumulate mercury over their life time such that older, larger individuals usually have higher concentrations than younger, smaller fish (Green 1986; Evans et al. 2005).

Length-standardized concentrations were derived for the target species (Lake Whitefish, Walleye, and Northern Pike). Data transformation was not undertaken for Yellow Perch as CAMP targets a specific age class of this species and fish captured for this component are inherently of a limited size range.

4.7.2 Data Analysis Methods

All data analyses treated censured values (i.e., values reported as below the analytical DL) as equal to two thirds of the DL. In cases where multiple analyses were available for the same tissue sample (i.e., replicates), mean concentrations were used for the determination of summary statistics and analyses.

Outlier data points were identified based on the absolute level and the distribution of K_F values within each species; lengths were flagged and removed from the data set prior to statistical analyses of summary parameters if no plausible explanation for an outlier value could be found (e.g., a switch of length and weight values, misplaced decimal point).

The standard lengths chosen for derivation of length-standardized mercury concentrations (Lake Whitefish - 350 mm fork length, Northern Pike - 550 mm, and Walleye - 400 mm) were consistent with those used in previous Manitoba fish monitoring programs (see summary in Jansen and Strange 2007a). A standard length of 100 mm was used for 1-year-old Yellow Perch, largely based on lengths used in previous Manitoba studies.

The average fork length of Lake Sturgeon captured in years 2011-2013 was substantially smaller than the standard length of 1,000 mm used in the previous CAMP report (CAMP 2014). This pattern is expected to continue for future CAMP monitoring because the standard length of 1,000 mm was established based on past data from commercial catches and domestic harvest by First Nations members, which both target larger fish. In contrast, CAMP does not target sampling of Lake Sturgeon and only includes analysis of incidental mortalities that occasionally occur during the fish community monitoring program. The size of Lake Sturgeon captured under CAMP reflects the average size of fish susceptible to gill net capture. For this reason, the standard length of Lake Sturgeon was reduced from 1,000 mm to 700 mm for reporting purposes.

Length-standardized mean mercury concentrations (also referred to as standard means) were calculated from unique regression equations generated by species and waterbody from the relationship between logarithmic transformations of the muscle mercury concentrations (µg/g or parts per million [ppm]) and fork lengths (mm) of each individual. On a few occasions (always associated with a small sample size), the relationship between fish length and mercury concentration was not significant and length standardization was not meaningful. To present data in more familiar units, all standardized means and their measure of variance were retransformed to arithmetic values. In addition to means, the percentage of individual fish of each species with concentrations of mercury exceeding the Health Canada standard for retail fish of 0.5 ppm (see Section 4.7.2.2) was calculated.

4.7.2.1 Statistical analyses including Temporal Comparisons

Differences in standard means between years (i.e., inter-annual comparisons) were established if the 95% confidence limits of two means did not overlap.

4.7.2.2 Comparison to Health Canada Guideline

To evaluate the suitability of fish for human consumption, mean and individual concentrations were compared to the 0.5 ppm total mercury Health Canada standard for commercial marketing of freshwater fish in Canada (Health Canada 2007a, b), which also represents the Manitoba guideline for mercury in fish for the protection of human consumers (MWS 2011).

5.0 LITERATURE CITED

Alberta Environment & Sustainable Resource Development. 2014. Environmental quality guidelines for Alberta surface waters. Water Policy Branch, Policy Division, Edmonton. 48 pp.

Baird and Stantec. 2000. Lake Winnipeg shoreline erosion study. A report prepared by W.F. Baird & Associates Coastal Engineers Ltd. and Stantec Consulting Ltd. 2000. W.F. Baird & Associates Coastal Engineers Ltd., Oakville, ON.

Beck, A.E. 1977. An inventory and assessment of the resources of the Hayes River. Manitoba Rep. No. 77-3. Dept. of Mines, Resources and Environmental Management. 118 pp.

Beke, G.J., H. Veldhuis, and J. Thie. 1973. Bio-physical land inventory of the Churchill-Nelson rivers study area north-central Manitoba. The Lake Winnipeg, Churchill and Nelson Rivers Study Board technical report, Appendix 3, Section A. 167 pp.

Blackwell, B.G., M.L. Brown, and D.W. Willis. 2000. Relative weight (Wr) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8: 1-44.

Bourne, A., N. Armstrong, and G. Jones. 2002. A preliminary estimate of total nitrogen and total phosphorus loading in streams in Manitoba, Canada. Manitoba Conservation Rep. # 2002-04. Manitoba Conservation, Winnipeg, MB.

British Columbia Ministry of Environment (BCMOE). 2014. Ambient Water Quality Guidelines for Selenium: Technical Report Update. Water Protection and Sustainability Branch, Environmental Sustainability and Strategic Policy Division, April 2014.

BCMOE. 2017. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture. Summary Report. Water Protection & Sustainability Branch, January 2017.

British Columbia Ministry of Water, Land, and Air Protection. 2003. British Columbia field sampling manual: For continuous monitoring and the collection of air, air-emission, water, wastewater, soil, sediment, and biological samples. January 2003.

Brunskill, G.J., S.E.M. Elliott, and P. Campbell. 1980. Morphometry, hydrology, and watershed data pertinent to the limnology of Lake Winnipeg. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1556. 32 pp.

CAMP. 2014. Three year summary report (2008–2010). Report prepared for the Manitoba/Manitoba Hydro MOU Working Group by North/South Consultants Inc., Winnipeg, MB.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB. Updated to 2017.

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

Caux, P.-Y., Moore, D. R. J., and MacDonald, D. 1997. Ambient water quality guidelines (criteria) for turbidity, suspended and benthic sediments. BC Environment.

Cherepak, B.C. 1990. The post-flood bathymetry of Split and Stephens Lakes, 1989. Manitoba Department of Natural Resources. Fisheries Branch MS Report No. 90-08. 78 pp.

Christoffersen, J.E. 2005. Geological report on the Assean Lake gold property, Manitoba, Canada. A report prepared for Canadian Gold Hunter Corp. 41 pp. Available: http://www.ngexresources.com/i/pdf/AsseanLakeTechnicalReport.pdf. (November 2012).

Clifford, H.F. 1991. Aquatic invertebrates of Alberta. The University of Alberta Press, Edmonton, AB. 538 pp.

Cooley, P. and J. Macdonald. 2008. Lake Sturgeon habitat on the Churchill River near Island Falls Hydroelectric Station. A report prepared for Saskatchewan Power Corporation by North/South Consultants Inc. 85 pp.

Coordinated Aquatic Monitoring Program (CAMP). 2012. Coordinated Aquatic Monitoring Program [online]. Available from http://www.campmb.com [Accessed November 2012]

Coordinated Aquatic Monitoring Program (CAMP). 2014. Three year summary report (2008–2010). Report prepared for the Manitoba/Manitoba Hydro MOU Working Group by North/South Consultants Inc., Winnipeg, MB.

Depew, D.C., N.M. Burgess, and L. Campbell 2013. Modelling mercury concentrations in prey fish: derivation of a national-scale common indicator of dietary mercury exposure for piscivorous fish and wildlife. Env. Poll. 176: 234-243.

Dodds, W.K., J.R. Jones, and E.B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Wat. Res. 32: 1455-1462.

Duncan, D.A., and Williamson, D.A. 1988. Water chemistry/water discharge relationships within the Churchill River Diversion and Lake Winnipeg Regulation region, Manitoba, Canada. Northern Flood Agreement Manitoba Ecological Report Series 88-5, Water Standards and Studies Section, Manitoba Department of Environment and Workplace Safety and Health, Winnipeg, MB. 57 pp.

Environment Canada (EC). 1994. Guidance document on collection and preparation of sediment for physicochemical characterization and biological testing. Environmental Protection Series, Report EPS 1/RM/29, December 1994. 122 pp.

EC. 2010. Pulp and paper environmental effects monitoring (EEM) technical guidance document. Government of Canada. 490 pp.

EC. 2011. Metal mining guidance for environmental effects monitoring. Government of Canada. Various pagination.

EC. 2012a. Metal mining technical guidance for environmental effects monitoring. Government of Canada. 550 pp.

EC. 2012b. Canadian Aquatic Biomonitoring Network: Wadeable streams field manual. Government of Canada. 52 pp.

Environment Canada and Manitoba Water Stewardship (EC and MWS). 2011. State of Lake Winnipeg: 1999 to 2007. June, 2011. 209 pp.

Evans, M. S., D. Muir, W. L. Lockhart, G. Stern, M. Ryan, and P. Roach. 2005. Persistent organic pollutants and metals in the freshwater biota of the Canadian Subarctic and Arctic: An overview. Science of the Total Environment 351‐352: 94‐147.

Fisher, S.G. and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. Journal Fisheries Research Board of Canada 29: 1472-1476.

Fisheries and Oceans Canada (DFO). 2008. Lake of the Woods. Canadian Hydrographic Service, digital charts. BSB V4. CEN12.

DFO. 2009. Lakes and Rivers in Manitoba and Saskatchewan. Canadian Hydrographic Service, digital charts. BSB V4. CEN13.

Fitzjohn, D. 1985. Caribou (Quesnel) – Manigotagan lakes creel census, 1984. Manitoba Department of Natural Resources, Fisheries Branch. 39 pp.

Fletcher, R., P. Welsh, and T. Fletcher. 2008. Guidelines for identifying, assessing and managing contaminated sediments in Ontario: An integrated approach. Ontario Ministry of the Environment, May 2008.107 pp.

Green, D.J. 1986. Summary of fish mercury data collected from lakes on the Rat Burntwood and Nelson River systems, 1983-1985. Manitoba Natural Resources, Fisheries Branch MS Report No. 86 06. 359 pp.

Health Canada. 2007a. Human health risk assessment of mercury in fish and health benefits of fish consumption. Health Canada: Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch, Ottawa, ON, 48 pp.

Health Canada. 2007b. Updating the existing risk management strategy for mercury in fish. Health Canada: Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch, Ottawa, ON, 30 pp.

Heilman-Ternier, J. and V.L. Harms. 1975. Plant ecology - taxonomy. Churchill River Study Final Report 5, Saskatoon, SK. 126 pp.

Holm, J., V.L. Richardson, and R.L. Bretecher. 2003. Results of index gillnetting studies conducted in Assean Lake, Manitoba, summer 2002. Report # 02-05. North/South Consultants Inc., Winnipeg, MB. 80 pp.

Integrated Taxonomic Information System (ITIS). 2013. Available: http://www.itis.gov. (September 2013).

Jansen, W. and N. Strange. 2007a. Mercury in fish from northern Manitoba reservoirs: results from 1999-2005 sampling and a summary of all monitoring data for 1970-2005. A report prepared for Manitoba Hydro by North/South Consultants Inc., 102 pp.

Jones, G. and N. Armstrong. 2001. Long-term trends in total nitrogen and total phosphorus concentrations in Manitoba streams. Manitoba Conservation Rep. No. 2001-07. Manitoba Conservation, Winnipeg, MB.

Keeyask Hydropower Limited Partnership (KHLP). 2012. Keeyask Generation Project Environmental Impact Statement: Response to guidelines. Keeyask Hydropower Limited Partnership, Winnipeg, MB.

Lake Winnipeg Implementation Committee. 2005. Restoring the health of Lake Winnipeg: Canada's sixth great lake. Lake Winnipeg Implementation Committee, Winnipeg, MB. 56 pp.

Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB). 1975. Lake Winnipeg, Churchill and Nelson Rivers Study Board: technical report. Lake Winnipeg, Churchill and Nelson Rivers Study Board, Winnipeg, MB. 425 pp.

Larter, J.L., P.M. Cooley and T. Sutton. 2010. Depth, substratum, and aquatic macrophyte distributions: Lamprey Rapids to Slave Falls GS tailrace. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 51 pp.

MacKay, G.H. 1992. An evaluation of the impacts on water levels and flows within the Pukatawagan Resource Area caused by Manitoba Hydro actions. G.H. MacKay and Associates, Winnipeg, MB.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey. 189 pp.

Magurran, A.E. 2004. Measuring biological diversity. Blackwell Science Ltd., Oxford, U.K. 215 pp.

Mandaville, S.M. 2002. Benthic macroinvertebrates in freshwaters – taxa tolerance values, metrics, and protocols. Project H-1. Soil and Water Conservation Society of Metro Halifax. 48 pp. + Appendices.

Manitoba Conservation. 2003a. Threepoint Lake angling map.

Manitoba Conservation. 2003b. Split Lake angling map.

Manitoba Conservation. 2006. Cormorant Lake angling map.

Manitoba Conservation. 2007a. Manigotagan Lake angling map.

Manitoba Conservation. 2007b. Rat Lake angling map.

Manitoba Conservation. 2007c. Setting Lake angling map.

Manitoba Growth, Enterprise and Trade (MGET). 2017a. http://www.manitoba.ca/iem/busdev/industrial/cesium.html (accessed February 2017).

MGET. 2017b. http://www.manitoba.ca/iem/min-ed/mbhistory/timeline.html (accessed February 2017).

MGET. 2017c. http://www.manitoba.ca/iem/busdev/sector/mines.html (accessed February 2017).

Manitoba Hydro. 2011. Pointe du Bois Spillway Replacement Project: Environmental Impact Statement. 550 pp.

Manitoba Hydro. 2014. Lake Winnipeg Regulation. A document in support of Manitoba Hydro's request for a final licence under the Manitoba Water Power Act. July 2014. Manitoba Hydro. Winnipeg, MB. 75 pp.

Manitoba Hydro. 2016. https://www.hydro.mb.ca/corporate/facilities/generating_stations.shtml (accessed October 2016).

Manitoba Hydro and Nisichawayasihk Cree Nation. 2003. Wuskwatim Generation Project: Environmental Impact Statement. Volumes 1-10. Manitoba Hydro, Winnipeg, MB.

Manitoba Hydro and the Province of Manitoba. 2015. Regional cumulative effects assessment for hydroelectric developments on the Churchill, Burntwood and Nelson river systems: Phase II Report. Winnipeg, MB. xxx + 4459 pp.

Manitoba Hydro and the Town of Churchill. 1997. Lower Churchill River water level enhancement weir project. Manitoba Hydro, Winnipeg, MB, and the Town of Churchill, Churchill, MB.

Manitoba Natural Resources. 1990. Gauer Lake angling map.

Manitoba Water Stewardship (MWS). 2011. Manitoba Water Quality Standards, Objectives, and Guidelines. Water Science and Management Branch, MWS. MWS Report 2011-01, November 28, 2011. 67 pp.

McTavish, W.B. 1953. A biological survey of Manigotagan Lake. Manitoba Department of Mines and Natural Resources, Game and Fisheries Branch. 19 pp.

Meays, C. and R. Nordin. 2013. Ambient water quality guidelines for sulphate. Technical Appendix: Update April 2013. Water Protection & Sustainability Branch Environmental Sustainability and Strategic Policy Division, British Columbia Ministry of Environment (BCMOE).

Merritt, R.W. and Cummins, K.W. 1996. An introduction to the aquatic insects of North America, 3rd Edition. Kendal/Hunt Publishing Co., Dubuque, IA. 862 pp.

Murray, L. and M.A. Gillespie. 2011. Lake Sturgeon inventory and habitat assessment of the Winnipeg River from McArthur to Pine Falls, 2010. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 52 pp. Report # 10-04.

Natural Resources Canada (NRC). 2011. Canvec Edition 8, 2011.04.18 (www.geogratis.ca)

Natural Resources Land Cover. 2000. Circa 2000 Vector (www.geobase.ca)

Nielsen, E. 1998. Lake Winnipeg coastal submergence over the last three centuries. Journal of Paleolimnology 19: 335-342.

North/South Consultants Inc. (NSC). 2006. Literature review related to setting nutrient objectives for Lake Winnipeg. North/South Consultants Inc., Winnipeg, MB. 186 pp.

Nürnberg, G.K. 1996. Trophic state in clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake Reservoir Management. 12: 432-447.

Organization for Economic Cooperation and Development (OECD). 1982. Eutrophication of waters: monitoring, assessment and control. Final Report. OECD cooperative programme on monitoring of inland waters (eutrophication control). Environment Directorate, OECD, Paris, France. 154 pp.

Peckarsky, B.L., P.R. Fraissinet, M.A. Penton, D.J. Conklin Jr. 1990. Freshwater macroinvertebrates of Northeastern North America. Cornell University Press, New York. 442 pp.

Persaud, D., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment, Water Resources Branch, ISBN 0-7729-9248-7.

Prairie Farm Rehabilitation Administration Watershed Project. 2008. Version 8, 2008.03.31.

Rosenberg, D.M., P.A. Chambers, J.M. Culp, W.G. Franzin, P.A. Nelson, A.G. Salki, M.P. Stainton, R.A. Bodaly, and R.W. Newbury. 2005. Nelson and Churchill River Basins. Pages 853-901 in A.C. Benke and C.E. Cushing, editors. Rivers of North America. Academic Press, San Diego, CA.

Royal Ontario Museum. 2005. Royal Ontario Museum website. Available: www.rom.on.ca. (November 2012).

Scheifhacken, N., C. Fiek, and K.-O. Rothhaupt. 2007. Complex spatial and temporal patterns of littoral benthic communities interacting with water level fluctuations and wind exposure in the littoral zone of a large lake. Fundamental and Applied Limnology 169: 115-129.

Schlick, R.O. 1968. A survey of Setting Lake in 1967. Manitoba Dep. Mines Nat. Res., Fish. Br. MS. Rep. No. 68-6. 17 pp.

Smith, D.G. 2001. Pennak’s freshwater invertebrates of the United States: Porifera to Crustacea, 4th edition. John Wiley & Sons Inc., New York. 638 pp.

Stewart, K.W. and B.P. Stark. 2002. Nymphs of North American stonefly genera (Plecoptera), 2nd edition. The Caddis Press, OH. 510 pp.

Strange, N.E. and R.A. Bodaly. 1999. Mercury in fish in northern Manitoba reservoirs and associated waterbodies: results from 1998 sampling. Prepared for the Program for Monitoring Mercury Concentrations in Fish in Northern Manitoba Reservoirs. 56 pp.

United States Geological Survey. 2000. Source SRTM 90 m.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. The Journal of Geology 30: 377-392.

Wetzel, R.G. 1983. Limnology, 2nd edition. Saunders College Publishing, New York. 767 pp.

White, M.S., M.A. Xenopoulos, K. Hogsden, R.A. Metcalfe, and P.J. Dillon. 2008. Natural lake level fluctuation and associated concordance with water quality and aquatic communities within small lakes of the Laurentian Great Lakes region. Hydrobiologica 613: 21-31.

Wiener, J.G., R. A. Bodaly, S.S. Brown, M. Lucotte, M.C. Newman, D.B. Porcella, R.J. Reash, and E.B. Swain. 2007. Monitoring and evaluating trends in methylmercury accumulation in aquatic biota. Pages 87-122 *In* R. Harris, D.P. Krabbenhoft, R. Mason, M.W. Murray, R. Reash, and T. Saltman, editors. Ecosystem responses to mercury contamination: indicators of change. CRC Press, New York.

Wiggins, G.B. 2004. Caddisflies the underwater architects. University of Toronto Press, Toronto. 292 pp.

CAMP

Coordinated Aquatic Monitoring Program

www.campmb.com