Limestone Generating Station:

Aquatic Environment Monitoring Programs

A SYNTHESIS OF RESULTS FROM 1985 TO 2003

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Manitoba Hydro

LIMESTONE GENERATING STATION: AQUATIC ENVIRONMENT MONITORING PROGRAMS

A SYNTHESIS OF RESULTS FROM 1985 TO 2003

Prepared for Manitoba Hydro

by

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Foreword/Preface

The Limestone Generating Station is a 1,340-MW hydroelectric generating station situated on the Nelson River in northern Manitoba. Construction of the station commenced in the late 1970s during a period when the environmental assessment process was in its infancy in both Manitoba and Canada. During the initial stages of the project, there was no formal process in place and construction of the access road and cofferdam occurred without an assessment of the potential environmental effects. When the project was subsequently delayed and recommitted to in the mid 1980s, a joint provincial/federal environmental review process had been established and was triggered. However, because the project was already committed to and construction had commenced, the Environmental Impact Study, which was completed in 1986, focused on impact management rather than on determining impacts. Implementation of an aquatic effects monitoring program was a key recommendation of the study.

The Limestone Generating Station Environmental Management Program was approved by the provincial government in 1986 and required that fish populations be monitored in the construction and post-construction phases of the project to: 1) identify impacts; 2) develop mitigation options; 3) assess the effectiveness of mitigation initiatives; and 4) provide data and information to assist in the assessment of impacts of future hydroelectric development in the region. In undertaking this program, Manitoba Hydro conducted numerous studies to describe and understand impacts related to the construction of the generating station. As environmental assessment and monitoring approaches evolved, and information was gathered and results were analyzed, program objectives were modified to take a broader ecosystem-based approach to monitoring changes in the environment. More than 80 individual reports were produced documenting results of studies conducted from 1985 to 2003.

This report describes the evolution of the Limestone Generating Station aquatic environment monitoring programs and provides a technical record of the studies that were undertaken. Study results are synthesized to describe the aquatic environment within and downstream of the Limestone Forebay and to demonstrate changes to those environments to completion of the programs in 2003. To the extent possible, observed changes are interpreted in the context of potential changes caused to the physical, chemical, and biological environments by the construction and operation of the Limestone Generating Station.

Acknowledgments

This synthesis report was funded by the Environmental Licensing and Protection Division of Manitoba Hydro. Dennis Windsor oversaw commencement and conduct of the Limestone Environmental Monitoring Program for Manitoba Hydro and is thanked for his input and support. Roy Bukowsky, Pat McGarry, and Nick Barnes also provided input and support for documenting results of the Program. Glen Cook of Manitoba Hydro is thanked for his contribution in describing the physical environment and the effect of the project on that environment. Bill Brown, Warren Coughlin and Gary Swanson and the Environmental Licensing and Protection staff at Manitoba Hydro provided valuable input to the report. Staff of the Manitoba Department of Natural Resources, and particularly Gary Swanson, are acknowledged for collection and analysis of field data from 1985-1989. North/South Consultants Inc. staff are acknowledged for data collection and analysis for the period of 1989 to 2003.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Photos

1.0

INTRODUCTION

Manitoba Hydro is a provincial Crown Corporation with the mandate to generate, transmit, distribute, and market energy within and outside the province. As of January 2012, the Manitoba Hydro interconnected system had a generation capacity of approximately 5,400 **megawatts** (MW); 98% of which was from hydroelectric sources. Approximately 70% of Manitoba Hydro's hydroelectric generation capacity is provided by three generating stations located on the lower Nelson River in northern Manitoba (Figure 1-1).

The Limestone Generating Station (G.S.) is the fifth and largest **hydroelectric generating station** to be developed by Manitoba Hydro on the Nelson River (Photo 1-1). Located approximately 750 km northeast of Winnipeg and 80 km from Hudson Bay, the facility is capable of producing 1,340 MW of electricity and accounts for approximately 25% of the province's total generation capacity (Manitoba Hydro 2007).

Manitoba Hydro's decision to begin construction of the Limestone G.S. in 1974 was based on load forecast studies conducted in the early 1970s that indicated new generation facilities would be required by the early 1980s to meet growing energy demands (Hiley 1990). After completion of an access road to the Limestone site and the Stage 1 **cofferdam** in 1978, construction was suspended due to lower than projected load growth (Manitoba Hydro 2009). Construction was recommenced in 1985 when domestic load requirements increased and a twelve-year, 500-MW power sale to Northern States Power Company of Minneapolis was completed (Manitoba Hydro 2009).

In 1984, the Limestone G.S. Environmental Impact Study (EIS) was initiated to document and respond to anticipated environmental and socio-economic **impacts** associated with the continued development of the project. The EIS Final Report, issued in 1986, was reviewed by federal and provincial agencies in a joint process coordinated by the Manitoba Environmental Assessment Review Agency (MEARA). Due to the advanced stage of the project design and ongoing construction, the environmental programs stressed impact management rather than impact assessment. Impact management was to include both monitoring programs and mitigation works. In early 1986, the Provincial Land Use Committee of Cabinet (PLUC) approved the environmental impact management programs to be conducted during and after construction of the Limestone G.S.

PHOTO 1-1
The Limestone Generating Station on the lower Nelson River.

A primary concern identified in the Limestone study was the lack of comprehensive pre-project biological data and information, particularly fisheries data, from the lower Nelson River area. The PLUC subsequently approved a Limestone G.S aquatic environment program to monitor fish **populations** in

NOTE: **bolded** words within text are defined in the Glossary in Section 11.0.

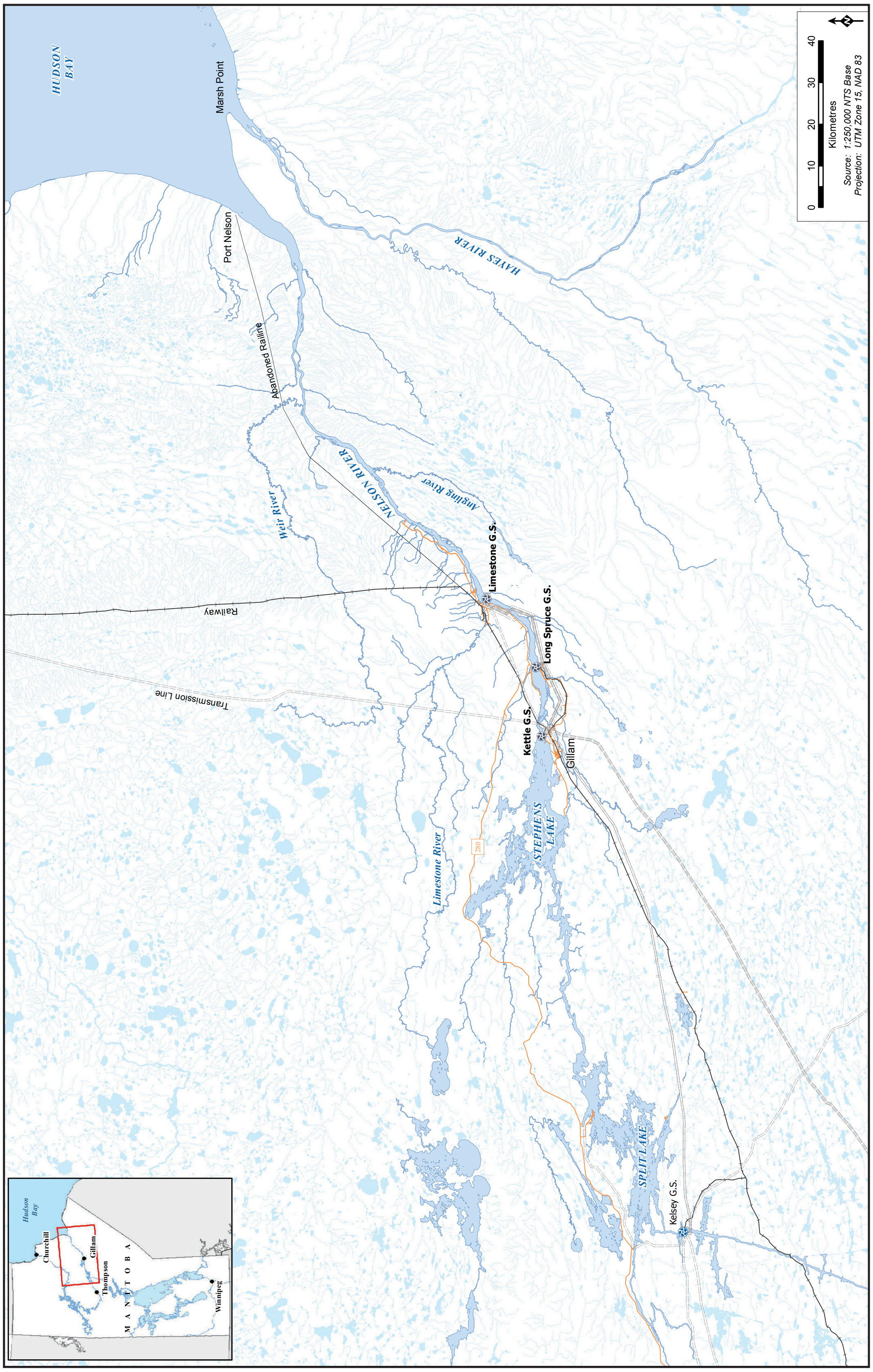


FIGURE 1-1 Locations of the Kettle, Long Spruce, and Limestone generating stations on the lower Nelson River in northern Manitoba.

the construction and post-construction phases to:

i) identify impacts;

ii) develop mitigation options;

iii) assess the effectiveness of mitigation initiatives; and

iv) provide data and information to assist in the assessment of impacts of future hydroelectric development in the region.

The work was to be funded by Manitoba Hydro.

Studies to address the PLUC recommendations commenced in 1985 and were primarily focused on the **fish community** and, in particular, the brook trout and lake sturgeon populations. The studies were expected to continue for a ten-year period. As approaches to environmental assessment and monitoring evolved during the program, and as information was gathered and mitigation opportunities evaluated, it was determined that a more holistic, longer-term approach to monitoring was required. In 1993, the Limestone G.S. aquatic environment monitoring program was refocused and expanded to examine a broader range of aquatic **ecosystem** components in order to determine linkages between physical changes and the biotic community. Studies were expanded to encompass the entire fish community, lower **trophic levels**, habitat, and **water quality**. The geographic scope of the studies also was extended from the Kettle G.S. **reservoir** downstream into the Nelson River Estuary. The studies continued through 2003.

The Limestone G.S. aquatic environment monitoring programs generated a significant quantity of environmental data and information. While more than 80 reports (see Chapter 13.0) have documented monitoring activities and results for individual aquatic components over time, this information and data had not been integrated to provide an overall understanding of how the **aquatic environment** evolved upstream and downstream of the Limestone G.S. during the period of monitoring. The objective of this report is to synthesize data collected during the Limestone G.S. aquatic environment monitoring programs and provide an understanding of the effects of the Limestone G.S. on the lower Nelson River aquatic ecosystem more than a decade after its completion. It is expected that this synthesis will be valuable for assessing potential impacts of future hydroelectric development.

2.0

ENVIRONMENTAL SETTING

2.1 Physical Environment of the Lower Nelson River

The Nelson River **watershed** extends from the Continental Divide in the Rocky Mountains to the Great Lakes, encompassing an area of over one million square kilometres (Rosenberg et al. 2005). It includes portions of four Canadian provinces (Alberta, Saskatchewan, Manitoba, and Ontario) and four American states (North Dakota, Minnesota, South Dakota, and Montana) (Figure 2-1). The river flows in a northeasterly direction for a distance of approximately 660 km from the north end of Lake Winnipeg to Hudson Bay, descending approximately 217 m in elevation.

The Nelson River was formed approximately 8,400 years ago (Pielou 1991). Before its formation, glacial Lake Agassiz discharged only small amounts of water because its natural discharge towards the north was held back by the Laurentide Ice Sheet. Once the ice began to recede, the Nelson River acted as a channel, draining the basin into Hudson Bay. Melting ice deposited **glacial till** throughout the river basin, forming a thin mantle often composed of loamy sand and **Precambrian** rock (Rosenberg et al. 2005). Loamy clay from calcareous till also was deposited in some locations as a result of a re-advancement of the glaciers over **lacustrine** sediments.

The majority of the Nelson River is located within the boreal forest zone of the Precambrian Shield of northern Manitoba. The lowest reaches of the river are contained within the Hudson Bay Lowlands, a vast plain of emerged marine clays, silts, and sands blanketed in most places by poorly drained bogs and swamps that support sparsely populated black spruce (*Picea mariana*). The river lies within the sub-arctic/boreal eco-climatic regions, which are characterized as having short, cool summers and long, cold winters with mean annual temperatures ranging from slightly above 0ºC at the outflow from Lake Winnipeg to slightly below 0ºC at the mouth of the river (Environment Canada 1993). Mean daily air temperatures are highest in July (up to 17.5ºC) and lowest in January (down to -27.5ºC) (Rosenberg et al. 2005).

Lake Winnipeg, the source of the Nelson River (Figure 2-2), is the tenth largest freshwater lake in the world by area and receives inflow from more than 900,000 km^2 of upstream drainage basins in the Canadian and American plains and the boreal shield of northwestern Ontario (Lake Winnipeg Research Consortium 2008). Many of its tributaries have been used for more than a century for purposes such as flood control, irrigation, community water supply, and hydroelectric **power** production. Use of Nelson River flows for hydroelectric power production commenced in 1960 with completion of the first unit at the Kelsey G.S. near the City of Thompson.

FIGURE 2-1
Drainage basin of the Nelson River.

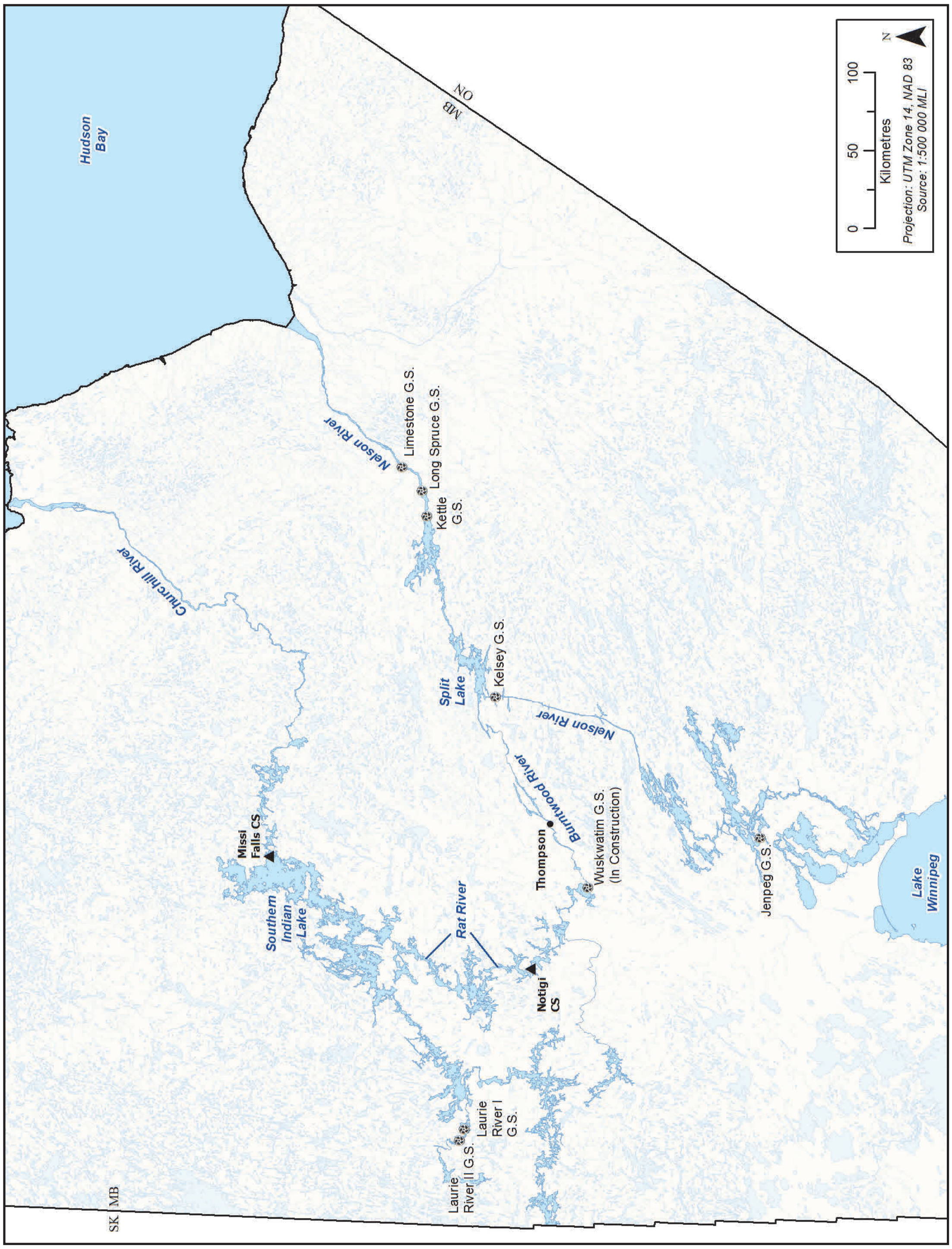


FIGURE 2-2 The Nelson River, including the Churchill River Diversion, from Lake Winnipeg to Hudson Bay.

In the early 1970s, Manitoba Hydro began development of the Lake Winnipeg Regulation project (LWR) to control outflows from Lake Winnipeg for the purposes of power generation and flood control. Regulation was achieved by constructing:

i) channels to improve outflows from Lake Winnipeg into the Nelson River; and

ii) a generating station (i.e., Jenpeg) in the upper reach of the river to regulate flows (Figure 2-2).

At the same time as the Lake Winnipeg Regulation project, Manitoba Hydro also began development of the Churchill River Diversion project (CRD) to augment flows through hydroelectric generating stations constructed on the lower Nelson River downstream of Split Lake. Construction of a control structure at Missi Falls and a channel from Southern Indian Lake to the Rat River system allowed diversion of up to 35,000 cfs (or 991 m^3/s) of water into the Rat and then the Burntwood rivers, and subsequently into the Nelson River at Split Lake (Figure 2-2). Churchill River Diversion flows, which are controlled by the Notigi Control Structure on the Rat River, now constitute approximately one third of the flows in the lower Nelson River below the Kelsey G.S. (Split Lake Cree and Manitoba Hydro 1996a).

Since 1976/77, the LWR and CRD water management projects have combined to influence water levels and flows in the lower Nelson River and have significantly increased hydroelectric generation. Seasonal average water level and flow patterns have generally been reversed to meet power generation demands; water levels and flows are increased during winter and reduced during the open-water periods. The Limestone G.S. is operated as a run-of-river plant due to the limited storage capacity of the forebay. The outflow from the generating station is governed by the releases from Stephens Lake at the Kettle G.S.. The operation of the Kettle G.S. is controlled for optimum energy production within the lower Nelson River system and the Manitoba Hydro system as a whole. At full loading of all the 10 units at 27.6 m of head, the units will pass approximately 5,000 m^3/s. Outflows in excess of this discharge rate must be released through the spillway.

PHOTO 2-1
The lower Nelson River downstream of Lower Limestone Rapids.

Prior to Limestone G.S., daily average flows generally varied from 1,000 m^3/s during drier periods to over 6,000 m^3/s during wetter periods. Within this range of daily average flows, the outflow pattern from the upstream generating stations varied between 1,000 m^3/s to 3,500 m^3/s during the day.

The section of the lower Nelson River that is the focus of this synthesis report is approximately 160 km long and extends from just upstream of the Kettle G.S. downstream to Port Nelson at the Nelson River Estuary (Figure 2-3). This portion of the river has a steep gradient, dropping approximately 141 m from Stephens Lake to the Nelson River Estuary (Figure 2-4). Prior to hydroelectric development, there were five sets of rapids: at the Kettle G.S. site; at the Long Spruce G.S. site; immediately upstream of the mouth of the Limestone River at the Limestone G.S. site; immediately downstream of the mouth of the Limestone River (i.e., Sundance Rapids); and 10 km farther downstream (i.e., Lower Limestone Rapids). Development of the Kettle, Long Spruce, and Limestone hydroelectric facilities has eliminated the upper three sets of rapids. Downstream of Lower Limestone Rapids, the river is not as steep and flattens, but remains swift-flowing, before draining into Hudson Bay at Port Nelson (Photo 2-1).

The geology of the area between the Kettle and Long Spruce generating stations is characterized by granitic and gneissic rock overlain with fine-grained and granular glacio-lacustrine deposits (Lake Winnipeg, Churchill and Nelson Rivers Study Board

FIGURE 2-3 The lower Nelson River from Stephens Lake to Hudson Bay.

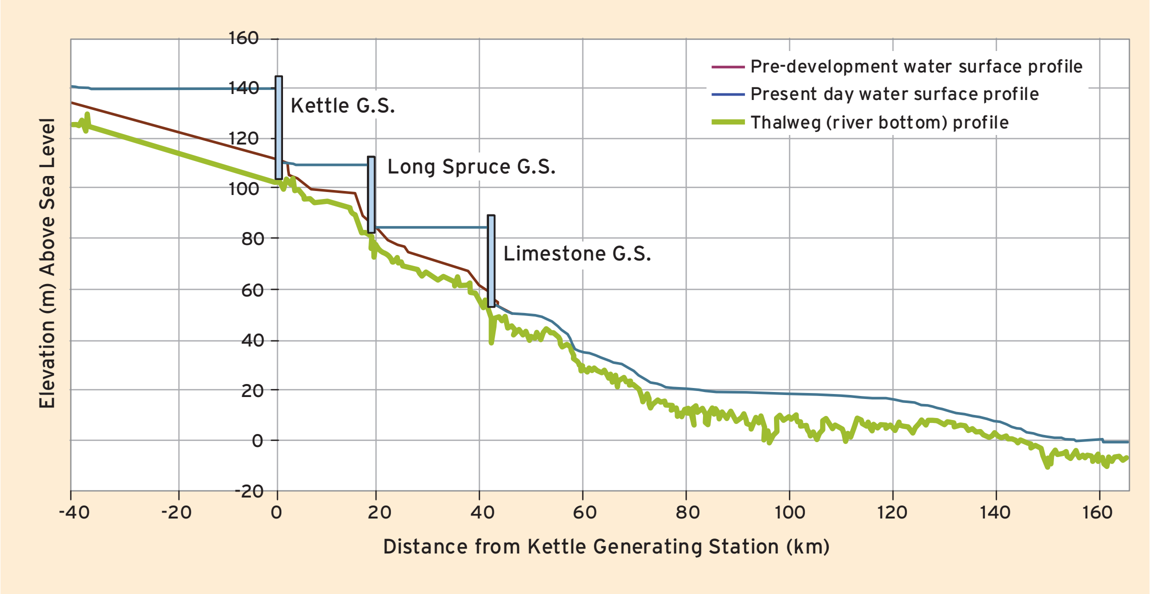


FIGURE 2-4
Surface water profile of the lower Nelson River from Kettle Rapids downstream to the Nelson River Estuary.

1975a; Didiuk 1975; Bodaly et al. 1984). Bedrock along this river reach is exposed in isolated outcrops and in shelves in the riverbed (Lake Winnipeg, Churchill and Nelson Rivers Study Board 1975b). A short distance downstream of the Long Spruce G.S., the local bedrock transitions to a horizontally layered sequence of sedimentary carbonate Ordovian rocks overlying the Precambrian rock. The depth to Precambrian rock varies along the river reach and is shallowest near the Limestone G.S. and deepest at the Nelson River Estuary. The sedimentary bedrock is overlain by a mixture of clays, silts, and gravels that were deposited by the advancing and retreating glaciers. Within the riverbed, much of the postglacial and till deposits have been eroded and replaced with river **alluvium**. The sedimentary bedrock is exposed only locally along the river banks and in the riverbed.

The banks of the lower Nelson River rise up to more than 30 m above the river near the Limestone G.S. and to much less near the estuary. The natural river channel is deeply incised through the mineral soils with many sections of steep eroding banks. Terrace sections established along the edges of these banks are regularly flooded and scoured by severe ice processes. The riverbed is composed of mostly a coarse river alluvium.

PHOTO 2-2
Ice remnants on shorelines of the Nelson River following break-up.

PHOTO 2-3
The west shore of the Nelson River just upstream of Port Nelson (middle top of photo) looking toward the estuary and Hudson Bay.

The existing steep gradient enables very fast flows below the Limestone G.S. The fast flows enable the river to produce and carry large volumes of **frazil ice**. The large masses of frazil ice grow into **floating ice pans** and are swept downstream and ultimately accumulate in the lower **velocity** areas near the Nelson River Estuary. The ice pans compress and consolidate resulting in an ice front that grows steadily in an upstream direction which by mid-February can create ice jams that may be up to 15 m thick at some locations like the area near Horseshoe Bay, a distance of nearly 30 km downstream from the Limestone G.S. During spring break-up, moving ice scours the riverbed and vegetation on the lower banks and leaves ice remnants stranded high on the shorelines due to the rapid drop in water levels (Photo 2-2). The ice remnants often persist on shorelines in mid-summer and result in 'glacial' drift deposits along the shore areas. Upstream of the generating stations, ice formation is generally more uniform and stable and breakup is considerable less violent.

PHOTO 2-4
Upstream aerial view of the Kettle G.S. (top of photo) and Long Spruce G.S. (middle of photo).

Black spruce forest dominates throughout the lower Nelson River region, with highest densities and growth along the banks of the Nelson River and other streams (Lake Winnipeg, Churchill and Nelson Rivers Study Board 1975b; Didiuk 1975). Uplands in the region are generally poorly drained, with sparse black spruce forest and scattered tamarack (*Larix laricina*) stands on peat bogs and fens. Lacustrine deposits of sand and gravel overlain by jack pine (*Pinus banksiana*) and lichen are present in isolated locations. Permafrost is intermittent throughout the region.

The large, sub-arctic estuary of the Nelson River is situated approximately 100 km downstream of the Limestone G.S. where the river enters Hudson Bay (Photo 2-3). The estuary is generally shallow

PHOTO 2-5
Long Spruce G.S. powerhouse tailrace.

(primarily less than 5 m in depth), with a narrow and deep (8-30 m) central channel that extends from just upstream of Port Nelson through the outer estuary into Hudson Bay. The coastal terrain at the estuary has little relief; wide mud flats dominate the nearshore area of the estuary, extending as far as 10 km offshore. Most of the mud flats are alternately exposed and flooded during the large twice-daily tides (up to 5.5 m). The bottom of the estuary is composed primarily of hard compacted fine silt, clay and sand, with numerous boulders and gravel shoals, and is subject to scouring by tide-generated currents and ice.

2.2 Hydroelectric Development on the Lower Nelson River

Initial hydroelectric development of the lower Nelson River (below the Kelsey G.S.) began with construction of the Kettle G.S., which started producing power in December of 1970. The reservoir created by Kettle G.S. resulted in a new body of water called Stephens Lake (over 220 km^2 of land was flooded) and increased average water levels at the generating station by approximately 31.5 m (Split Lake Cree and Manitoba Hydro 1996b).

Construction of the Long Spruce G.S., 16 km downstream of the Kettle G.S., began in 1973 and the station became fully operational in 1979 (Photos 2.4 and 2-5). Water levels were raised approximately 26 m at the station but only 14 km^2 of Nelson River shoreland and tributaries were flooded (Split Lake Cree and Manitoba Hydro 1996b).

Limestone G.S., the third phase of development on the lower Nelson River, is located 22 km downstream of the Long Spruce G.S. It has a net generating capability of 1,340 MW, making it the largest hydroelectric generating station in Manitoba. Prior to dam construction the river channel at the Limestone site was nearly 1 km wide with shallow rapids, flat sedimentary rock and boulder/cobble bottom, and vertical banks of gravel and clay till material in excess of 30 m high on both sides of the river.

3.0

REVIEW OF PHYSICAL EFFECTS OF THE LIMESTONE GENERATING STATION

3.1 Construction and Operation of Limestone Generating Station

Construction of the Limestone G.S. began in 1976 with development of an access road and establishment of a temporary construction camp and worksite on the north side of the Limestone River near the Hudson Bay railway crossing. A 20-m high cofferdam was constructed at the Limestone site (Hiley 1990), which constricted the Nelson River to one-third of its original width at Limestone Rapids (Photo 3-1). It was designed to protect the worksite from flooding during winter ice jamming, which annually raised water levels as much as 15 m above normal summer water levels at the Limestone site. In 1978, construction of the Limestone G.S. was suspended when generation requirements were decreased due to termination of an electricity exchange agreement with Northern States Power of Minneapolis, Minnesota. Load demand studies showed that power from Limestone would not be required until the early 1990s rather than the previously projected date of 1983. Construction resumed on the Limestone G.S. project in 1985 after a twelve-year, 500-MW, sales agreement was negotiated with Northern States Power Co. (Hiley 1990) (photos 3-2 to 3-3). The first of Limestone's ten turbine generators began producing power in September 1990 and all were in service by September 1992.

The Limestone G.S. was designed to make use of natural aspects of the Nelson River. The forebay created by the project was contained entirely within the natural riverbanks and largely within the ice-scoured zone, thus reducing impacts to the surrounding **environment** and eliminating the need for containment dykes (Hiley 1990).

PHOTO 3-1
Downstream aerial view of the Limestone G.S. cofferdam, November 1981.

PHOTO 3-2
Aerial view of the Limestone G.S. cofferdam showing construction of the powerhouse and spillway.

PHOTO 3-3
Construction of the Limestone G.S., 1989.

PHOTO 3-4
Aerial view of the Limestone G. S.

The Limestone G.S. (Photo 3-4) is configured similarly to the Kettle and Long Spruce generating stations, with earthfill dams connecting the principal structures to both banks of the river, an intake structure integral with the powerhouse, intakes, and service bay, and a concrete overflow spillway. The principal structures extend approximately 1.2 km across the river and rise 40 m above the natural riverbed. The ten generating units operate with an average head of 30.7 m and in a run-of-river mode that generally passes flows as received from upstream generating stations with some minor daily variation. Its turbines are vertical-shaft units with fixed-blade propellers rated at 133 MW (Hiley 1990), producing a total capacity of 1,340 MW.

The earthfill dams were constructed with impervious cores and granular and rockfill shells. The central cores extend to bedrock and are tied-in with grout curtains. To the extent possible, its permanent earthfill structures incorporated portions of the cofferdams. Construction of the earthfill structures required placement of approximately 2.9 million m^3 of material (Hiley 1990). The principal structures were constructed "in the dry" inside the cofferdam. Approximately 3.2 million m^3 of weathered bedrock in the riverbed were excavated to provide stable footings for the concrete structures and for intake and tailrace channels. Once the spillway was completed, river flows were passed through this structure, allowing the main earthfill dams to be constructed "in the wet". In total, nearly 700,000 m^3 of concrete was placed in the structures. Sand and aggregate for the concrete were procured from nearby borrow pits. The Limestone powerhouse was designed for a full gate outflow of just under 5,300 m^3/s (post-Conawapa development) with most of the powerhouse outflows occurring at the best gate outflow of about 4,800 m^3/s. Each generating unit has three 5.5 x 14-m intake gates. The spillway has seven bays with a total discharge capacity of 9,500 m^3/s (Photos 3-5 and 3-6); together, the powerhouse and spillway can pass a 1:10,000-year flood. The spillway has a stilling basin with constructed baffle blocks for energy dissipation (Hiley 1990).

Electricity generated at the Limestone G.S. is delivered to the Henday Converter Station

(C.S.), located approximately 1 km west of the generating station, where it is converted from alternating current (AC) to direct current (DC) for transmission to the Dorsey C.S. in southern Manitoba. Construction of the Henday C.S. started in 1975 and it began transmitting power from the Long Spruce G.S. to the Dorsey C.S. in 1979. Henday was designed to be expanded to receive the Limestone power output. Power from Henday is delivered by two high-voltage DC transmission lines called Bipole 1 and Bipole 2 that run south-westerly from the Limestone G.S. site to the Grand Rapids area and south to the Dorsey C.S. located northwest of Winnipeg.

A new fully serviced townsite, Sundance, was developed to accommodate the long-term construction employees and their families for the Limestone and Henday projects. In addition, a 1,500-person construction camp was developed to house temporary construction staff. Personnel were able to access the Limestone G.S. project by commercial aircraft via the Gillam airport and by all-weather roads. Construction equipment and materials were delivered to the site by rail and truck. The townsite, construction camp and worksite were decommissioned in the early 1990s following completion of the project.

3.2 Physical Impacts to the Aquatic Environment

3.2.1 Upstream

Impoundment of the Nelson River by the Limestone G.S. in 1989 physically altered a 22-km reach of the river from the dam site upstream to the Long Spruce Generating Station.

Prior to impoundment, the reach was wide, shallow, and swiftly flowing river environment, with flow and water elevation determined by discharge of the Long Spruce G.S. Upon completion of the Limestone G.S., water levels at the dam rose more than 25 m, thereby ponding water upstream to the Long Spruce G.S., and creating a deep, relatively narrow reservoir with slower flow (Figure 3-1; Photo 3-7). Average water residency time in the Limestone Forebay is approximately 30 hours.

PHOTO 3-5
The Limestone G.S. spillway.

PHOTO 3-6
Close-up of one of the spillway gates.

The Limestone G.S. impoundment resulted in a 6.8 km^2 increase in water surface area between the Long Spruce G.S. and the Limestone G.S., flooding only 3.1 km^2 of previously undisturbed land (i.e., land that had not previously experienced flooding during ice jams, extreme high-water events or ice scour; figures 3-2 and 3-3) (Manitoba Hydro 1996). Flooding was largely contained within the existing banks of the

FIGURE 3-1
Lower Nelson River water surface elevation (above sea level) upstream of the Limestone G.S. from 1985 to 1991 that shows the water level staging resultant from construction. Of note, the two spikes in the winters of 1985 and 1989 are the result of the ice processes.

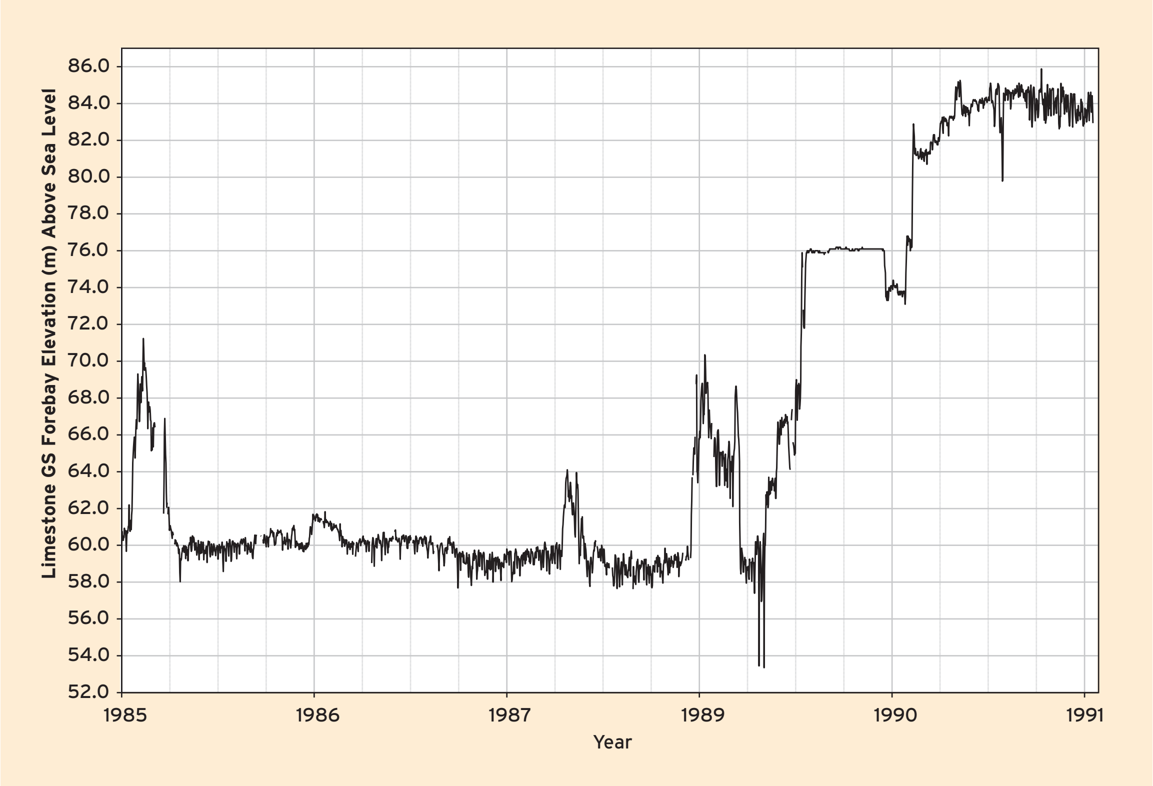


PHOTO 3-7
Downstream view of the Limestone Forebay from the base of the Long Spruce G.S.

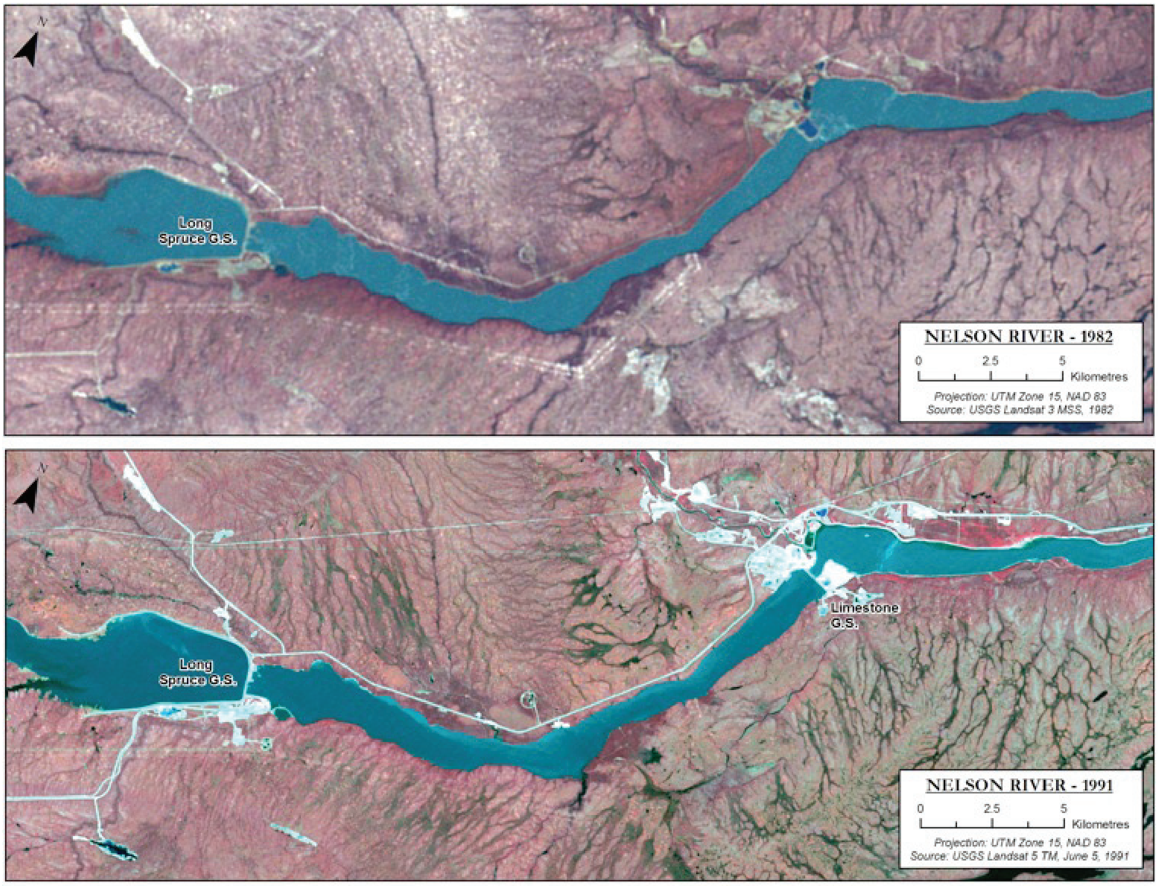


FIGURE 3-2
The Nelson River downstream of the Long Spruce G.S. prior to impoundment in 1982 (note presence of coffer dam at Limestone site) and following impoundment in 1991.

river, although the lower reaches of a few tributaries were affected. The gullies at the mouths of Brooks and Leslie creeks, which enter the midpoint of the forebay, were most affected, while Sky Pilot and Wilson creeks at the upstream end of the forebay were minimally affected (photos 3-8 to 3-11). Flooded areas were primarily mineral till soils and riverbed materials in stream valleys, riverbed terraces, and the steep Nelson River valley walls (Manitoba Hydro 1998).

Although the Limestone G.S. discharge pattern regularly varies more than 3,000 m^3/s during the day, it follows the operating pattern established by the Kettle G.S. This limits the fluctuations on the forebay as inflow and outflow on the forebay are generally balanced (Figure 3-4). Due to the relatively balanced forebay inflow/outflows, the forebay has operated within 1 m of its licensed full supply level of 85.3 m above sea level almost 99% of the time (Figure 3-5), although the license allows a 3-m operating range.

Extensive shoreline erosion has occurred along the perimeter of the Limestone Forebay with greater erosion rates on shorelines that are exposed to wind-induced wave action, resulting in **sediment** (primarily the fine material from the glacial till) and **organic** material introductions (i.e., trees, shrubs, moss) into the forebay (photos 3-12 and 3-13). These introductions are most likely deposited in the nearshore areas. Ice on the forebay forms earlier and is more uniform and consistent with lake ice than prior to river impoundment. It also stays longer, resulting in a later break-up. With more stable ice cover, forebay shorelines are not exposed to the severe ice scouring that occurred prior to impoundment.

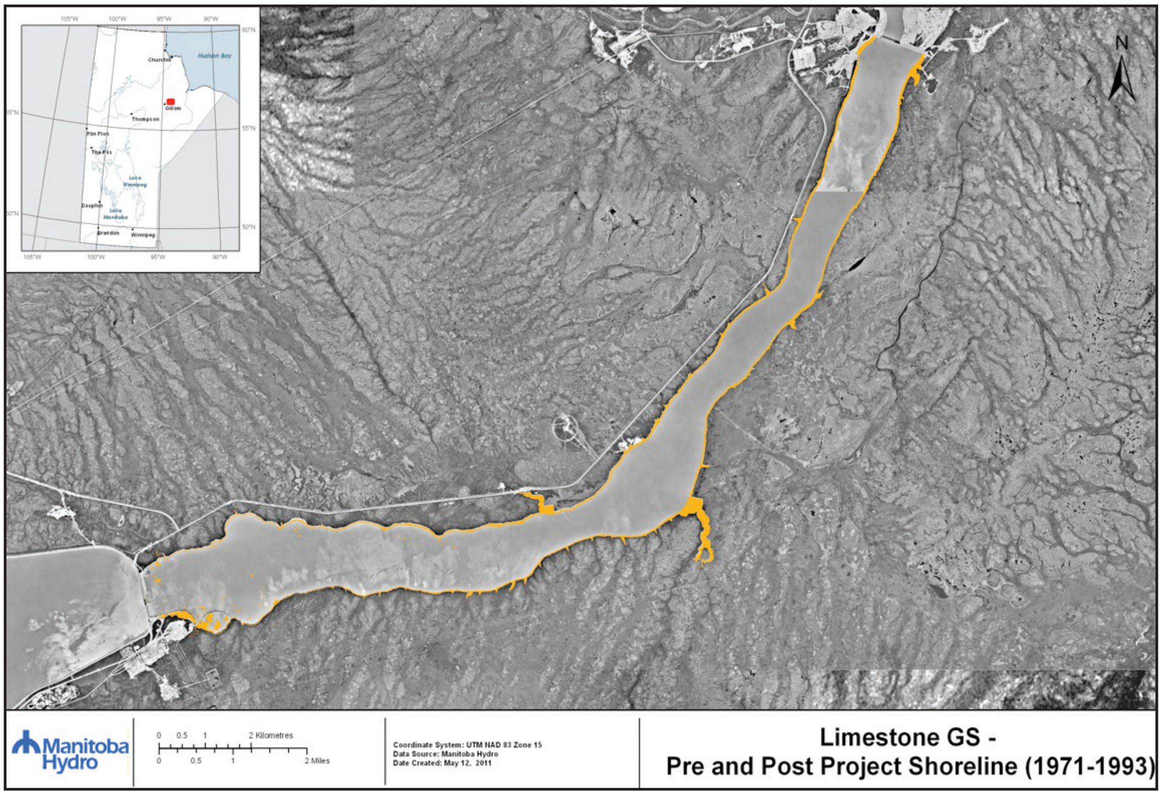


FIGURE 3-3 Pre- and post-project shoreline contours of the Limestone Forebay, 1971-1993.

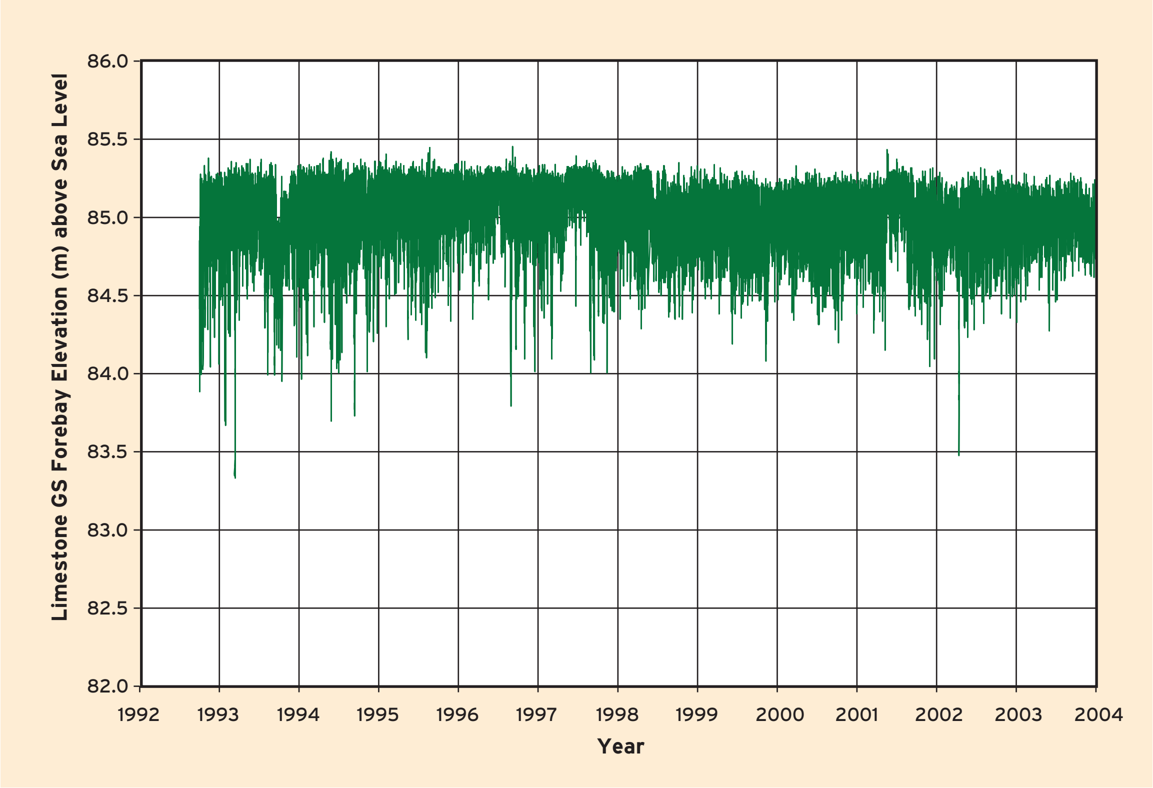
PHOTO 3-8 Brooks Creek as it enters the Limestone Forebay.

PHOTO 3-9
Leslie Creek as it enters the Limestone Forebay.

PHOTO 3-10
Sky Pilot Creek as it enters the Limestone Forebay.

PHOTO 3-11
Wilson Creek as it enters the Limestone Forebay.

FIGURE 3-4
Hydrograph of the Limestone Forebay water surface elevation above sea level (based on hourly spot measurements) from October 1992, when the last unit was commissioned, to December 2003.



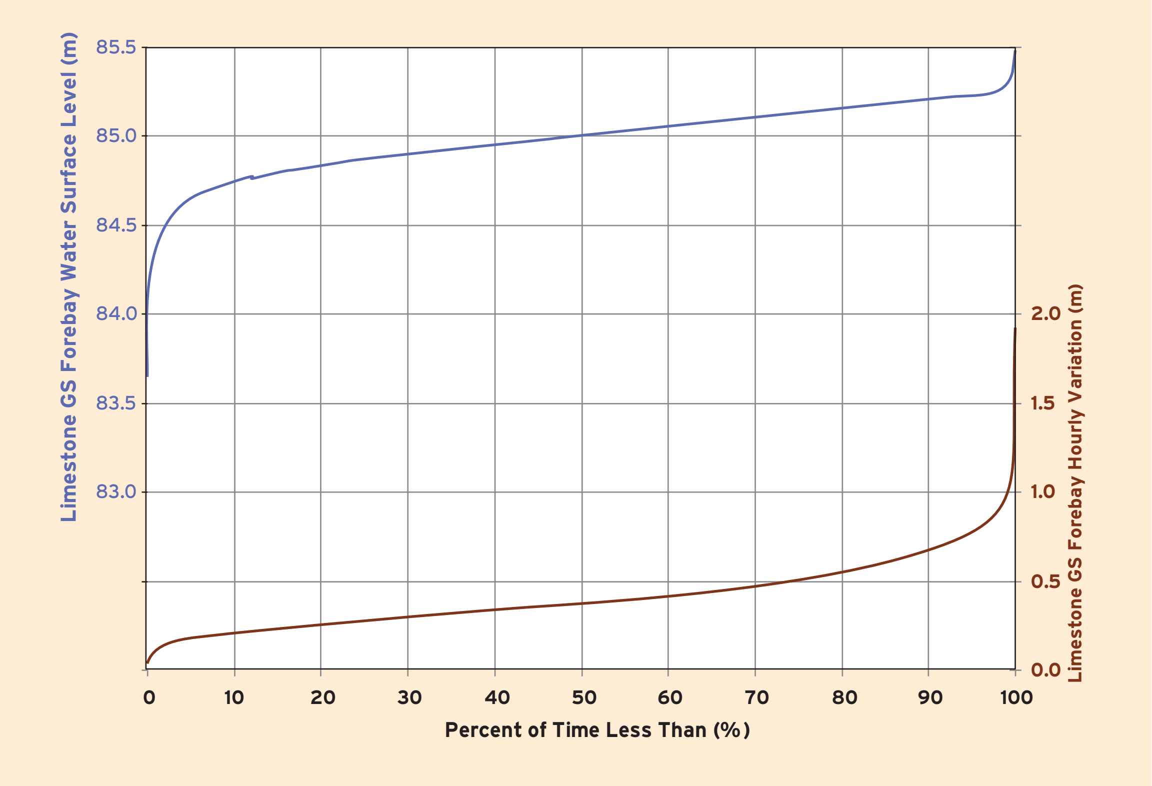


FIGURE 3-5
Limestone Forebay water surface level and variation duration curve from October 1992 to December 2003.

3.2.2 Downstream

Following completion of the Limestone G.S., the lower Nelson River flow regime downstream of the station remained dynamic, fluctuating on an hourly and daily basis (Figure 3-6). Outflows closely resemble outflows from the Long Spruce G.S. with patterns of flow continuing to vary depending on domestic power demand, water supply (drought/flood), forebay replenishment requirements, system outages, and export requirements.

Construction of the Limestone G.S. did not change the amount of water flowing down the Nelson River, but it did cause a shift in water level variation in a downstream direction. The most downstream point of discharge control on the river was moved a further 22 km downstream. Consequently, flow changes and the associated water level changes, which were once most noticeable below the Long Spruce G.S. and dampened in a downstream direction, were now most noticeable below the Limestone G.S. (Photo 3-14). For example, under average inflow conditions (50th percentile), daily water level fluctuations in the Horseshoe Bay area downstream near Conawapa Axis B, generally increased about 0.4 m, from 1.6 m to 2.0 m.

PHOTO 3-12
Shoreline erosion along the banks of the Limestone Forebay.

Prior to construction, high water velocities in the project area resulted in the formation of frazil ice which when swept downstream would grow into extensive ice pans. The pans would eventually jam

PHOTO 3-13
Bank slumping along the shorelines of the Limestone Forebay.

in constricted locations and then cause a thick ice cover to progress upstream past Lower Limestone Rapids. Construction of the Limestone G.S. has created lower velocities in the forebay which allows a smooth stable ice cover to form between the Long Spruce and Limestone generating stations. This has effectively eliminated the frazil ice generated in this reach and reduced the total ice supply to the downstream reaches of the lower Nelson River which also reduces the amount of ice available in the river to cause ice jamming and ice cover progression. This reduced the rate of upstream progression of the ice cover as well as reduced the upstream extent of the ice cover. After construction of the Limestone G.S., the progression of the ice cover past Lower Limestone Rapids occurs infrequently and typically only during low flow years. Consequently, extensive ice jamming, which was once common in the area downstream of the Limestone River mouth, no longer occurs in the reach downstream of the Limestone G.S. to Sundance Rapids. This has resulted in less ice scouring of the riverbed and banks in that area. Without the presence of the ice cover, anchor ice and aufeis processes that previously only occurred prior to ice cover development at Sundance Rapids are now allowed to continue throughout the entire winter after construction of the Limestone G.S.

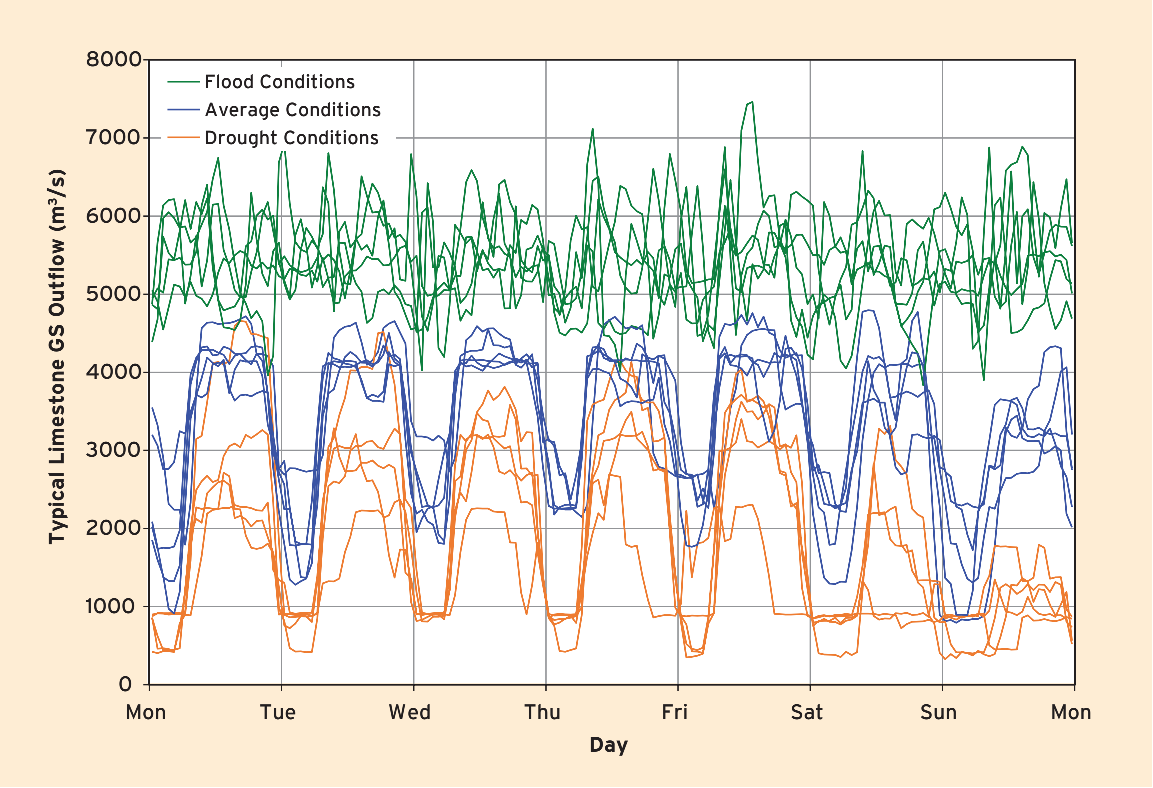


FIGURE 3-6
Typical hourly outflow patterns for the Limestone G.S. under different hydrologic conditions.

PHOTO 3-14
Typical river bottom substrates that are "wetted" and exposed on a daily basis in the lower Nelson River.

4.0

LIMESTONE GENERATING STATION AQUATIC ENVIRONMENT MONITORING PROGRAMS

4.1 Background

In the early 1980s, when the Provincial Land Use Committee of Cabinet (PLUC) was considering the potential effects of the Limestone G.S., there was only a small body of existing information on which they could rely to make their determinations. The first documented aquatic study in the lower Nelson River area was conducted in 1914 when the Burleigh expedition investigated the fisheries resources of Hudson and James bays (Comeau 1915). With the exception of two brook trout studies conducted by the provincial government (Doan 1948; Kooyman 1951), there was little further scientific interest in the aquatic resources of the lower Nelson River until hydroelectric development was initiated in the area. Construction of the Kettle and Long Spruce generating stations in the 1970s raised concern over impacts to the natural environment in the lower Nelson River region. This concern prompted water quality studies to be undertaken on Stephens Lake by the provincial government (Environmental Management Division) in 1972 (Crowe 1973), the Lake Winnipeg Churchill Nelson River Study Board in 1972 and 1973 (Cleugh 1974), and the Manitoba Ecological Monitoring Program from 1985 to 1989 (Ramsey et al. 1989; Green 1990). Additionally, the Long Spruce Forebay was sampled in 1972 and 1973, as reported in Cleugh (1974). Studies on fish populations inhabiting the lower Nelson River and tributaries were undertaken by the provincial fisheries branch (Doan et al. 1975; Gaboury 1978, 1980a, 1980b; Gaboury and Spence 1981). Wildlife resource impact assessments (Didiuk 1975) and studies of the geomorphology of the river, specifically the effects of the developments on bank erosion, sediment transport, permafrost, and ice regime (Penner et al. 1975) were also carried out. Although these studies were intended to assess the impacts of existing and proposed hydroelectric developments and to develop a planning framework for maintenance of resources in the area, it was clear to the PLUC during the environmental assessment process for the Limestone G.S. that the existing information was insufficient to understand all of the potential impacts of the project or to develop effective mitigation. Consequently, it was recommended by the PLUC that additional studies be conducted to identify impacts and to develop and assess mitigation. The studies were to evaluate the following:

- ecological changes in the shift from a **riverine** to more lacustrine environment;
- potential for stocking;
- immediate need and prospects for habitat enhancement in selected tributaries;
- potential for stage and/or flow constraints to upstream migration of fish into tributaries;
- incremental impacts of future developments; and
- limiting factors for brook trout and lake sturgeon populations.

It also was recognized that the studies would assist in the assessment of impacts of future hydroelectric development in the region. Limestone G.S. **aquatic monitoring** studies were implemented to address the PLUC recommendations.

When Limestone G.S. aquatic monitoring studies commenced in 1985, Manitoba Hydro, in consultation with provincial and federal authorities, determined that the Manitoba Department of Natural Resources (now Manitoba Conservation and Water Stewardship) Fisheries Branch was the agency most capable of collecting and interpreting baseline fisheries data. Several studies were undertaken as recommended in the Limestone G.S. Environmental Impact Study. Many of the studies were directed at assessing potential mitigation measures such as egg stocking and transfer of adult fish. Preliminary reports (Swanson 1986; Swanson and Kansas 1987; Swanson et al. 1988, 1990, 1991) documented the work conducted by the Manitoba Fisheries Branch during the period of 1985 to 1989 and assessed the degree of impact of ongoing hydroelectric development on the fisheries resources of the lower Nelson River watershed.

The scope of the aquatic resources studies in the lower Nelson River area was expanded during the late 1980s and early 1990s in anticipation of construction of the Conawapa G.S. downstream of the Limestone site. North/South Consultants Inc. was contracted by Manitoba Hydro in 1988 to implement fisheries assessment studies for the planned Conawapa hydroelectric project. Many of these studies were complementary to the Limestone G.S. aquatic monitoring studies and expanded the focus of the studies on the lower Nelson River to include water quality, lower trophic levels, and Nelson River Estuary components. In 1990, Manitoba Fisheries Branch ceased participation in the Limestone G.S. aquatic monitoring studies and Manitoba Hydro assumed full responsibility for the program. Planning and exploration studies for the Conawapa G.S. project were suspended in 1992. Information from all studies focusing on the aquatic environment conducted on the lower Nelson River prior to 1992 was summarized in a synthesis report produced by North/South Consultants Inc. (MacDonell and Bernhardt 1992).

4.2 Program Objectives

By 1993, approaches to environmental assessment in Canada had changed dramatically compared to the early 1980s and requirements for monitoring in this process were becoming more stringent. It was recognized that the nature of impacts resulting from construction of large-scale hydroelectric developments were complex, could be far reaching, and could occur over extended time frames. Understanding the nature of the impacts required an understanding of linkages between physical effects, lower trophic levels, and the organisms higher in the food web.

In 1993, the lower Nelson River aquatic studies were refocused to specifically address the ongoing effects of the Limestone G.S. The Limestone G.S. Aquatic Environment Monitoring Program (Limestone Monitoring Program) was formally developed to document long-term changes to the aquatic environment in the Nelson River and its tributaries both upstream and downstream of the Limestone G.S. Specific objectives of the multi-year monitoring program were:

- to provide baseline data to describe the existing aquatic environment in the Nelson River;
- to document changes occurring in the lower Nelson River aquatic environment subsequent to construction of the Limestone G.S.;
- to the extent possible given the lack of pre-project data, determine the nature, extent, and temporal scope of impacts to the aquatic environment resulting from construction and operation of the Limestone G.S. on the Nelson River;
- to provide information to evaluate the feasibility of mitigating and managing impacts resulting from construction and operation of the Limestone G.S.;
- to provide data and information to increase the capability to predict the effects of the Limestone G.S. and future generating stations on aquatic resources;

- to provide baseline data for the Nelson River Estuary in support of Manitoba Hydro's commitment to participate in the assessment of cumulative impacts of hydroelectric development in northern Canada; and
- to fulfill Manitoba Hydro's commitment to conducting post-development environmental monitoring programs for the Limestone G.S.

Some of the program studies were focused on collecting information on key physical or biological factors for which little information was previously available (e.g., water quality and lower trophic level studies), while other studies were designed to utilize existing baseline data to allow for pre- and post-impact comparisons (e.g., brook trout studies).

Construction of three generating stations (i.e., Kettle, Long Spruce, and Limestone) in close spatial and temporal proximity created a unique opportunity to monitor the long-term effects of reservoir creation on the lower Nelson River. The impoundments (designated as Stephens Lake/Kettle Forebay, Long Spruce Forebay, and Limestone Forebay within this report) created a "natural laboratory" of reservoirs of differing ages and stages of biological evolution. Monitoring in all three reservoirs not only provides an ongoing measure of change associated with the Limestone G.S., but also provides a glimpse of what the Limestone Forebay may look like in the future. Data collected from downstream of the Limestone G.S. provided a measure of change associated with altered water level fluctuations and acted as a surrogate for pre-project conditions.

Results of the Limestone G.S. aquatic monitoring studies have been delineated into four chapters within this report. The water quality, lower trophic level, and fish community results are presented in the first three chapters (chapters 5.0, 6.0, and 7.0, respectively). Because of the unique physical and biological environment in which they were conducted, studies focusing on the Nelson River Estuary are discussed separately in the fourth chapter (Chapter 8.0). Each chapter summarizes results of the aquatic monitoring studies in terms of the following:

- the scientific methods utilized to collect monitoring data;
- the existing environment as understood from pre-existing data and data collected during the monitoring studies; and
- ecological changes that have occurred following construction of the Limestone G.S. and those that are expected to occur in the future based on results of the studies.

The chapter following the result summarizations (Chapter 9.0) provides an integrated summary of the overall ecological changes that occurred both upstream and downstream of the generating station. A final chapter (Chapter 10.0) provides a discussion of the effectiveness of the program and recommendations for future effects monitoring programs. If detailed information is required regarding particular aspects of the monitoring programs or the results of specific investigations, the original documents referenced within the bibliography of this report should be accessed (see Chapter 13.0).

5.0

WATER QUALITY

5.1 Introduction

Water forms one facet of the habitat in which aquatic biota reside and is directly significant from a human perspective (e.g., as a source of drinking water, its use in recreational activities). The physical-chemical properties of surface water are a reflection of the local geology, soils, and vegetation in the watershed, climate and precipitation patterns, hydrological characteristics, and lake and river morphometries. Characteristics of water quality also may be affected by anthropogenic influences such as the release of municipal and industrial effluents, atmospheric releases and subsequent deposition, agriculture, land development, hydroelectric development, and forestry.

Hydroelectric developments can affect water quality in reservoirs and in the downstream riverine environment through a number of pathways. The extent of alterations to water quality caused by impoundments generally varies according to the size of the dam, its location along a river system, geography (latitude and altitude), water retention times, and the source of the water (Bergkamp et al. 2000). The general paradigm for the effects of temperate reservoir creation is the occurrence of a "trophic upsurge" – an increase in **nutrients** that subsequently leads to increased primary and secondary productivity. Nutrient enrichment and subsequent biological stimulation in reservoirs have generally been attributed to flooding, which releases nutrients to surface waters through decomposition of flooded organic matter (Henriques 1987). However, the occurrence and magnitude of the trophic upsurge effect is site-specific and depends upon a variety of other factors that directly or indirectly affect water quality (i.e., nutrients) and/or the primary producers (e.g., generally the smaller the amount of flooding, the smaller the nutrient enrichment). In addition, the trophic upsurge effect may not manifest in systems with low water residence times (i.e., that are rapidly flushed) or those where **primary production** is more limited by factors other than nutrients (e.g., light or temperature limitation). Nutrient enrichment due to flooding is temporary and water quality of temperate reservoirs generally resembles that of natural lakes within ten years (Hayeur 2001).

Impoundment also may alter water quality in reservoirs through:

i) increased shoreline erosion [with subsequent increases in **total suspended solids** (TSS)];

ii) reduced velocities and/or increased water residence times, leading to increased sedimentation ("sediment trapping" effect; Bergkamp et al. 2000);

iii) alterations to lake/river morphometries that may alter biogeochemical cycling and/or vertical **stratification**;

iv) changes to thermal and ice regimes [which may affect **dissolved oxygen** (DO) and temperature]; and

v) flooding, which can subsequently lead to nutrient enrichment, changes in **pH**, and/or effects on dissolved oxygen.

Hydroelectric developments can measurably change water quality in the downstream environment. Increased reservoir sedimentation may lead to enhanced shoreline erosion downstream of the generating station due to the reduced velocity of water (Photo 5-1). Increased water level fluctuations may also increase downstream erosion. Both of these effects may lead to increased TSS and reduced water clarity. Conversely, upstream impoundment may lead to enhanced sedimentation in the reservoir and subsequent reductions in TSS concentrations downstream. Other parameters, such as DO (due to

PHOTO 5-1
Shoreline erosion along the lower Nelson River downstream of the Limestone G.S.

changes in ice and/or thermal regimes and flooding upstream) and nutrients (due to changes in upstream water quality and downstream water level fluctuations), also may be affected. As for reservoirs, the precise effect of a dam and hydroelectric generating station on downstream water quality is determined by a variety of site-specific factors such as:

i) the design and operating regime of the generating station;

ii) basin morphometry and surface area;

iii) geology and topography;

iv) climate and geography; and

v) characteristics of the upstream reservoir (i.e., changes to water quality upstream affects downstream water quality).

Water quality was examined upstream and downstream of the Limestone G.S. to evaluate the existing environment and, to the extent practicable, to understand the potential effects of the project on the physical and chemical environment. The following is a synthesis of the results of those studies, which began in 1989, with a particular emphasis on key water quality parameters.

5.2 Methods

Between two and five water quality sites were sampled in the lower Nelson River from 1989 to 2001; a total of eight sites were sampled in 2002 and 2003 (Figure 5-1). Surface water samples were collected from Stephens Lake (i.e., the Kettle Forebay), the Long Spruce and Limestone forebays, and from the lower Nelson River **mainstem** 2-33 km downstream of the Limestone G.S. The sampling station on the lower Nelson River mainstem was re-located on several occasions over the course of the survey years in response to varying environmental conditions (i.e., due to **tributary** influences in 1992 and erosion of the riverbank in 1999). This station was initially located within the Limestone River plume (in 1990 and 1991), approximately 2 km downstream of the Limestone G.S., and was subsequently relocated farther downstream (approximately 20 km downstream of the Limestone G.S.) beginning in 1992. The mainstem sampling station was again re-located even farther downstream (approximately 33 km downstream of the Limestone G.S.) in 1999 due to the occurrence of natural bank slumping.

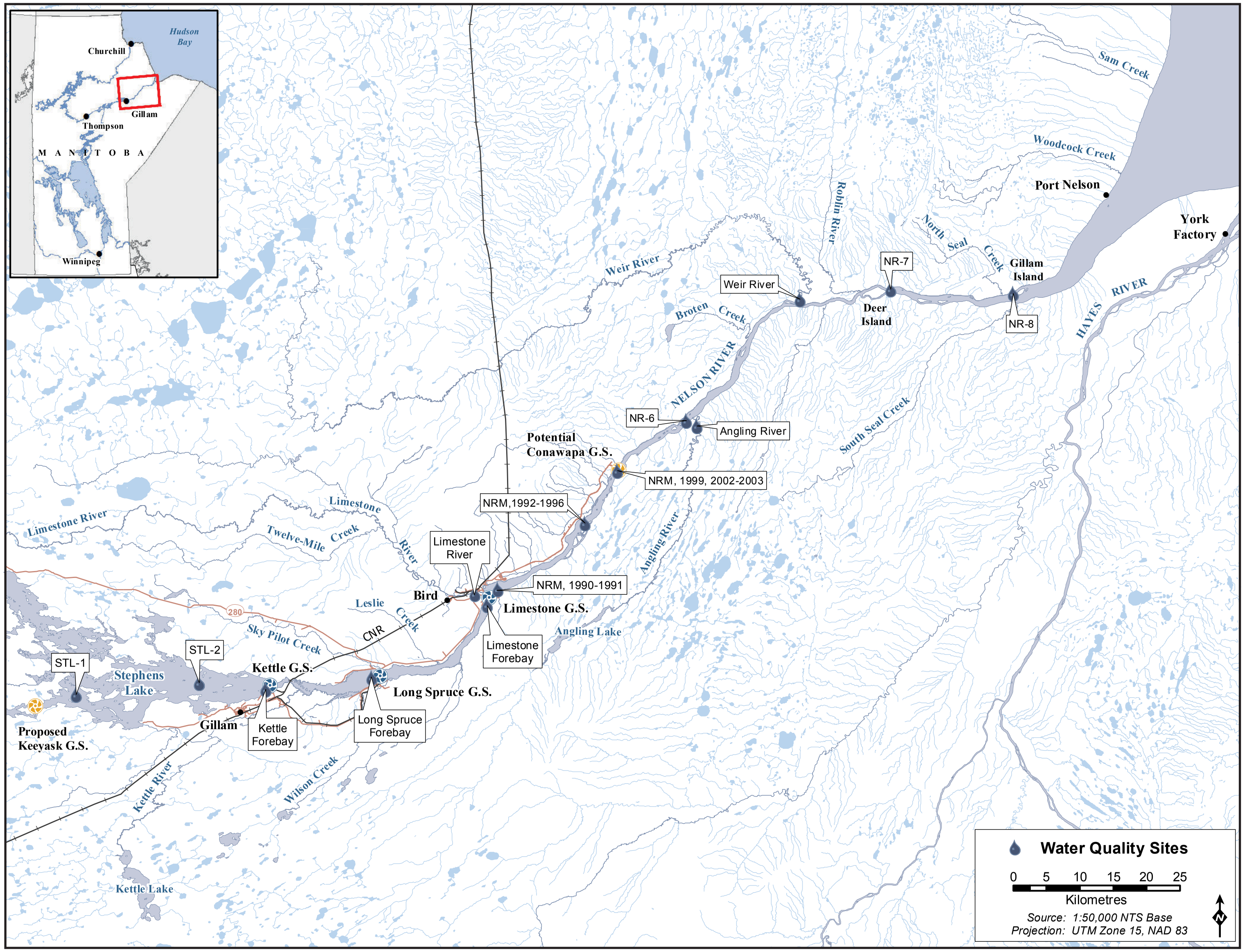


FIGURE 5-1 Water quality sites sampled in the lower Nelson River during the Limestone G.S. aquatic monitoring studies, 1989-2003.

Water quality was also sampled along the lower Nelson River between 2001 and 2003 as part of the Conawapa G.S. and Keeyask G.S. environmental baseline studies. Sites included two sites in Stephens Lake (south), the Long Spruce and Limestone forebays, and four sites downstream of the Limestone G.S. on the lower Nelson River (Figure 5-1).

Water samples were collected during the open-water season at frequencies ranging from every two to three weeks (1990-1993) to monthly or more (1989, 1994, 1996, 1999, 2001-2003). Although the frequency and number of samples collected varied among years, samples from all sites were typically collected on the same day within each sampling period. Consequently, data collected within a given year can be directly compared across all sites. Inter-annual comparisons are more tenuous due to inconsistencies in the timing and frequency of water quality sampling, as well as seasonal variation in water quality conditions. That is, direct comparisons of annual means for the various water quality parameters should be made with caution due to variations in timing and frequency of data collection.

Samples were submitted to analytical laboratories (Department of Fisheries and Oceans from 1990 to 1993; Norwest Laboratories in 1994, 1996, and 1999; and Enviro-Test Laboratories from 2001 to 2003) and analyzed for a multitude of water quality parameters (Table 5-1). Several of these parameters were measured in each study year, while others were measured in select years. The variation in the list of parameters was the result of ongoing changes in scope made to the monitoring programs. In addition, due to the use of three different analytical laboratories over the course of the study, different forms of nutrients were measured in earlier years (e.g., total dissolved nitrogen and total suspended nitrogen) than in latter years [e.g., total Kjeldahl nitrogen (TKN)]. In these instances, data were manipulated to the extent possible in order to derive data that were comparable among years. Where TKN was not measured, it was estimated by subtracting **nitrate/nitrite** nitrogen from total nitrogen.

All water quality data were evaluated qualitatively for potential outliers and transcription or analytical errors. On dates where more than one replicate sample was collected for analysis, the results for each sample were averaged for inclusion in descriptive statistical analyses (i.e., to derive annual averages). In instances where water quality results were reported as being below detection, a value equivalent to half the detection limit was used when calculating the statistical variables. Water quality results from certain parameters (i.e., DO, pH, and **total phosphorus**) were compared to Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOG).

5.3 Results

Of the water quality parameters measured at each sampling site over the course of the Limestone G.S. aquatic monitoring programs, the following were chosen for inclusion in this discussion due to their relatively large sample sizes and their relevance to environmental effects of hydroelectric development: **conductivity**; DO; pH; TSS; TKN; total phosphorus; total **dissolved phosphorus; dissolved organic carbon**; and **chlorophyll *a***. Descriptive statistics (i.e., mean, standard error, minimum, maximum, and the total number of samples collected) for these parameters are presented in Table 5-2 and figures 5-2 to 5-10.

Water quality at all sampling sites can be generally described as moderately nutrient-rich and alkaline, with moderate levels of TSS and low sensitivities to acidification (on the basis of pH; Palmer and Trew 1987). The sites can be classified as meso-eutrophic to eutrophic on the basis of total phosphorus concentrations (CCME 1999, updated to 2008; Table 5-3). There are a number of trophic categorization schemes for lakes based on chlorophyll *a*, one of which is presented in Table 5-3. Applying these lake trophic categories to sites on the lower Nelson River indicates all sites would be considered mesotrophic. Conversely, there are relatively few trophic categorization schemes that have been developed for rivers and streams. Applying the categories developed by Dodds et al. (1998) for rivers based on

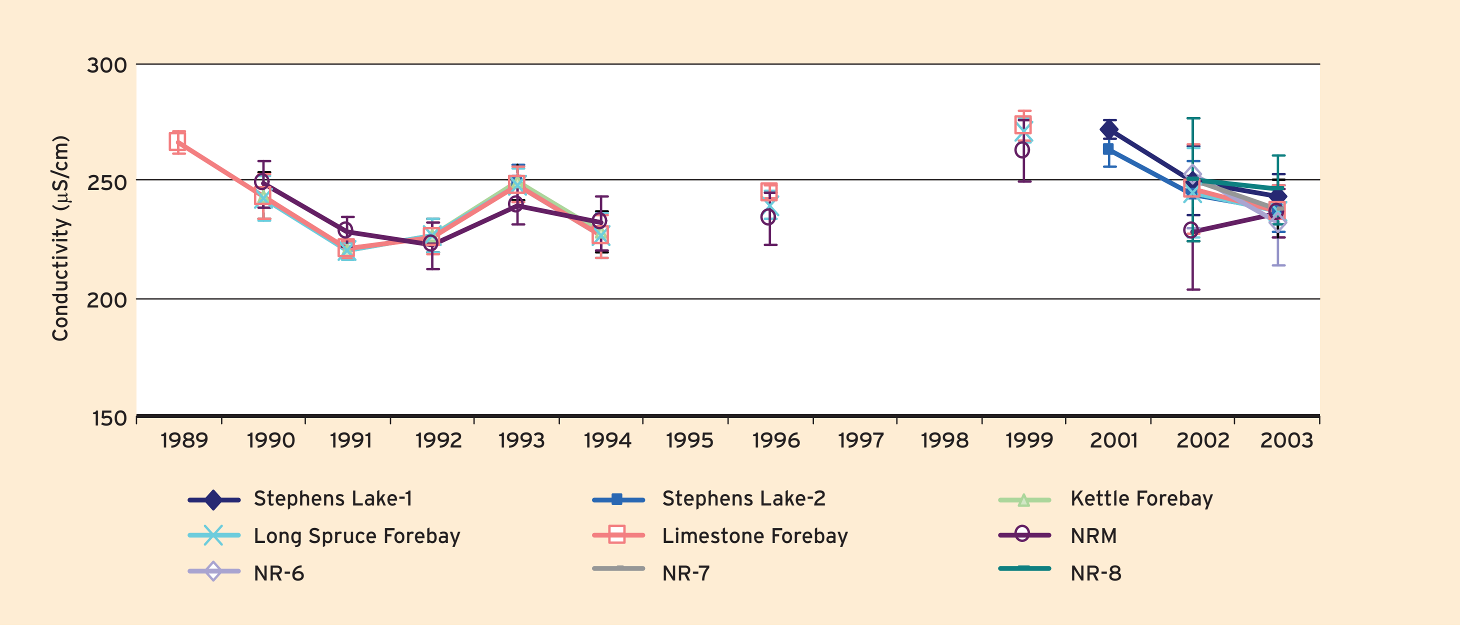


FIGURE 5-2
Mean (± 1 SE) conductivity in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

chlorophyll *a* indicate the sites on the lower Nelson River would be considered oligotrophic (Table 5-4). Given that the Limestone and Long Spruce forebays and the southern mainstem area of Stephens Lake are relatively riverine environments, the trophic categories developed for rivers may be most applicable. Trigger values that have been developed for lakes and rivers in the global environment indicate that chlorophyll ***a*** concentrations measured in the lower Nelson River would be indicative of good-fair conditions if lake criteria were applied (Table 5-5), but levels would be well below threshold criteria that have been developed for rivers (Table 5-6).

Conductivity is generally somewhat higher than "typical" levels for rivers in north-central Canada (Kalff 2002), but not unusual for northern Manitoba [e.g., Burntwood River (Cooley and Badiou 2004); Churchill River (Bezte and Bernhardt 2002; Bezte 2006)]. Some parameters (e.g., chlorophyll ***a***, conductivity, temperature) exhibit seasonal variations (Zrum and Kennedy 2000; Badiou and Cooley 2004, 2005; Badiou et al. 2005), as is typical of north temperate ecosystems where light and temperature vary considerably over the year. Available data also indicate that DO concentrations in the Limestone and Long Spruce forebays may decrease with depth during July or August of some years.

The following provides additional detail with regard to evaluation of potential water quality effects of the Limestone G.S. As described in the preceding section, water quality data were not collected prior to construction of the Limestone G.S. Therefore, there are no pre-project data against which post-project monitoring data can be compared to assess project-related changes. The assessment of effects of the Limestone G.S. on water quality is therefore limited to providing a description of water quality conditions across the study area, including a comparison of water quality variables to guidelines, a description of spatial differences observed across sites within years, and general descriptions of changes at a given site over the years. Due to changes in analytical methodologies over the course of the studies, evaluations of temporal changes should be considered with caution.

5.3.1 Conductivity

Conductivity is a measure of the amount of minerals and organic matter dissolved in water, reflecting both natural conditions such as local geology and anthropogenic activities that increase the amount of these substances in water (e.g., mining effluents). Conductivity may be affected by hydroelectric development through various pathways and may result in either an increased introduction of minerals and organic matter into the water column (e.g., through flooding and decomposition) and/or through changes to seasonal water level and flow patterns (i.e., changing dilution).

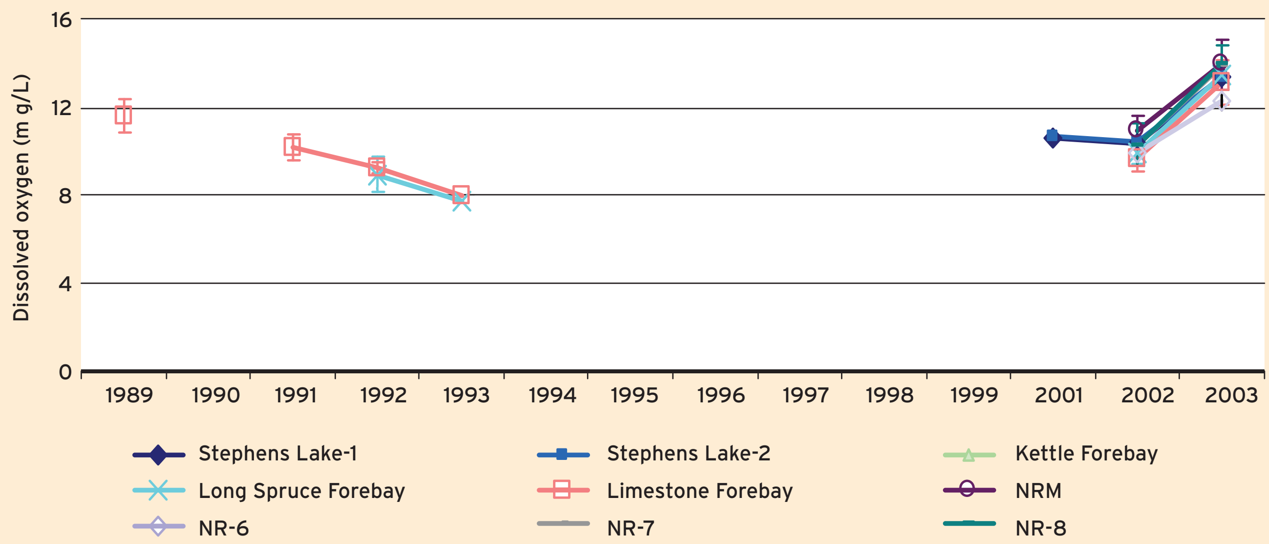
Within a given year, specific conductance was generally similar across sites (Figure 5-2), although the values were somewhat variable among years. This variability may be owing to natural environmental influences (e.g., discharge, precipitation) or to variation in sampling frequencies or type of measurement (data from 2001 to 2003 were measured *in situ* rather than in the laboratory). Specific conductance generally increased over the course of the open-water seasons, but the annual means for the open-water season were similar across all sites ranging from 220 to 273 µS/cm (Table 5-2).

5.3.2 Dissolved Oxygen and Stratification

Dissolved oxygen is required by virtually all aquatic **organisms** and the toxicity of many chemicals increases when DO levels are low (CCME 1999, updated to 2008). Sources of DO to aquatic systems are aeration (i.e., input of oxygen from the atmosphere), and **photosynthesis** by plants and **algae**, and oxygen carried by inflowing waters.

Some waterbodies, notably lakes and reservoirs, may regularly or periodically stratify and also may develop low DO concentrations at depth. Stratification is a function of changes in the 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. Stratification is usually defined as a temperature change of 1ºC or more in one metre of water. Two distinct layers may form a well-oxygenated upper layer (i.e., **epilimnion**) and a less-oxygenated (and sometimes **hypoxic)** lower layer (i.e., **hypolimnion**). Stratification may develop in summer when the epilimnion is warmed due to surface heating and the water circulation is not strong enough to mix the less dense water at the surface with the cooler, denser hypolimnetic waters. In fall, as the surface waters cool, mixing may occur between the epilimnion and hypolimnion as the temperature (and therefore density difference) between the layers is reduced. This process is known as **turnover**. In late fall/winter, the epilimnion may continue to cool and remain unmixed from the warmer and denser (water is most dense at 4ºC) hypolimnion thus forming stratification. If winter stratification occurs, turnover may occur again in the spring as the epilimnion warms. Numerous physical conditions affect the ability of stratification to develop in a lake

FIGURE 5-3
Mean (± 1 SE) dissolved oxygen *(in situ)* in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.



or reservoir including: morphometry (**fetch**); depth; 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, especially oxygen.

Dissolved oxygen concentrations of the surface waters in the lower Nelson River were measured infrequently prior to 1993, but were measured at all sites in 2002 and 2003. Depth profiles for both DO and temperature were also collected in 1992 and 1993 from the Limestone and Long Spruce forebays and between 2001 and 2003 from Stephens Lake.

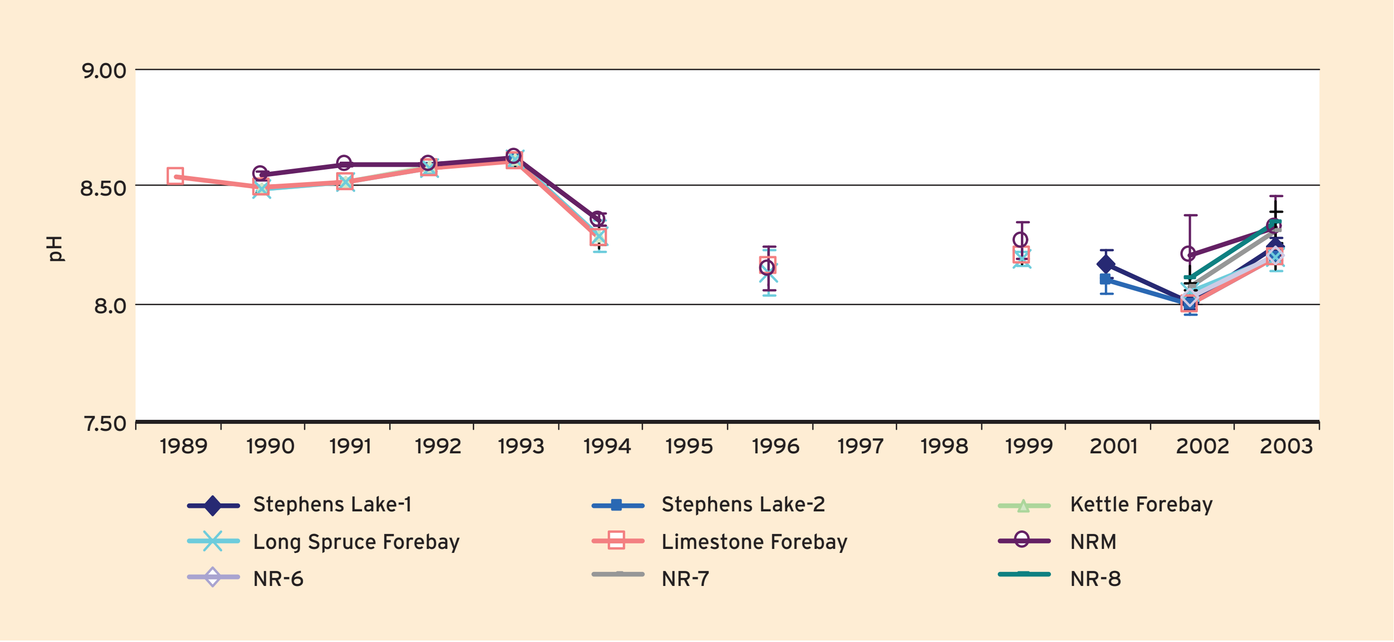
Surface DO measurements indicate that the lower Nelson River was well-oxygenated over the period of study (Table 5-2, Figure 5-3). Stephens Lake and the Limestone and Long Spruce forebays were not stratified during any period when depth profiles were recorded (Horne and Baker 1993; Kroeker and Horne 1993; MacDonell and Horne 1994; Badiou and Cooley 2004, 2005; Badiou et al. 2005). However, DO was 2.0 mg/L lower at depth in the Limestone Forebay in August 1992 and approximately 4.0 mg/L lower at depth in the Long Spruce Forebay in July 1992 (1.5 km upstream of the generating station). Another site sampled in the Long Spruce Forebay in August 1992 exhibited a much smaller change in DO at depth, suggesting a heterogenous occurrence. Depth gradients in DO concentrations are not unusual in aquatic ecosystems, particularly at deep locations such as in the Long Spruce and Limestone forebays.

Surface water DO concentrations measured during the open-water season were consistently above the most stringent MWQSOG for the protection of aquatic life (6.0 or 6.5 mg/L depending on presence of cool-water or cold-water **species**; Williamson 2002). Concentrations observed at depth were generally above 6.5 mg/L and always above 6.0 mg/L. Should the Limestone G.S. have affected DO, there is no indication that the project resulted in depletion to the extent that would be harmful to aquatic life.

5.3.3 pH

pH is a measure of water acidity, with a value of 7.00 indicating neutral conditions. A fairly wide range of pH is suitable for aquatic life and wildlife. However, extremely low (acidic) or high (alkaline) values of pH can be lethal to aquatic biota. More moderate changes in pH can indirectly affect biota by affecting the toxicity of substances (e.g., **ammonia**)

FIGURE 5-4
Mean (± 1 SE) pH in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem, 1989-2003. Note that pH was measured in the lab between 1989 and 1999, and measured *in situ* between 2001 and 2003.



by contributing to the mobilization of metals bound in sediments (e.g., increase bioavailability of metals) or by altering the physico-chemical form of metals in aquatic systems. pH may be altered by flooding of soils, decomposition of organic matter, and photosynthesis.

Mean pH was relatively consistent between sites, ranging from 8.48 to 8.62 between 1989-1993 and from 7.99 to 8.35 between 1994-2003 (Table 5-2, Figure 5-4). The apparent drop in mean pH between 1993 and 1994 may be attributable to two factors:

i) differences in instrumentation between analytical laboratories; and
ii) reduced sampling effort (i.e., the Limestone Monitoring Program changed from bi-weekly sampling to monthly sampling). pH did not exhibit any seasonal trends.

In all instances, pH was within the MWQSOG for the protection of aquatic life (6.50-9.00; Williamson 2002), indicating that the Limestone G.S. did not alter pH to the extent that it affected the suitability of the environment for aquatic life.

5.3.4 Total Suspended Solids

This water quality parameter is a measure of the concentration of suspended materials in the water column that generally affects light penetration and availability in aquatic ecosystems. At high concentrations, TSS can:

i) reduce fish growth rates;
ii) modify fish movements;
iii) affect fish egg and larval development;
iv) impair foraging and predation behaviour of fish;
v) reduce abundance of fish diet items;
vi) affect reproduction of aquatic biota;
vii) reduce immunocompetency of aquatic biota; and
viii) harm benthic habitats.

Even at lower concentrations, suspended solids can influence aquatic ecosystems by affecting the behaviour of aquatic life (e.g., predation success of fish) and by reducing light penetration into the water column, thereby limiting the growth of macrophytes and algae. In addition, TSS can make water unsuitable for drinking or recreation, and can affect the aesthetic quality of aquatic ecosystems. In riverine systems, suspended solid concentrations generally vary with river discharge as settling of suspended solids out of the water column increases when water velocity decreases.

Hydroelectric development may increase TSS through erosion of shorelines and/or through changes in water levels, flows or velocities, which may then increase sediment resuspension or increase sedimentation. However, TSS may be reduced in areas where water velocities are lowered, such as in reservoirs.

In general, the range of TSS concentrations observed across the study area was similar, with annual site means typically below 20 mg/L (Figure 5-5). However, spatial differences were observed between sites in certain years. Water quality data collected from aquatic monitoring studies between 1989 and 1999 indicated notably higher TSS concentrations at the Nelson River mainstem site below the Limestone G.S., relative to upstream, in 1992, 1993, and 1996. However, these differences were attributed to one or two high measurements of TSS in each year, which inflated the mean for that given year. For example, one measurement of TSS in 1992 was 156 mg/L at the Nelson River mainstem site. Without these high TSS values, mean concentrations ranged from 6 to 25 mg/L across the sites.

The higher levels of TSS measured at the Nelson River mainstem site coincided with the period of time that this site was located in an area of natural bank slumping, an observation that led to its relocation farther downstream after 1996. It is also worth noting that the highest TSS concentrations measured during this study occurred at the Nelson River mainstem site in 1996, a year of atypically high river discharge. Data collected at a greater number of sites in 2002 and 2003 indicate that TSS generally declined from the west side of Stephens Lake through the Long Spruce and Limestone forebays, increasing again at the lower end of the Nelson River (Figure 5-5).

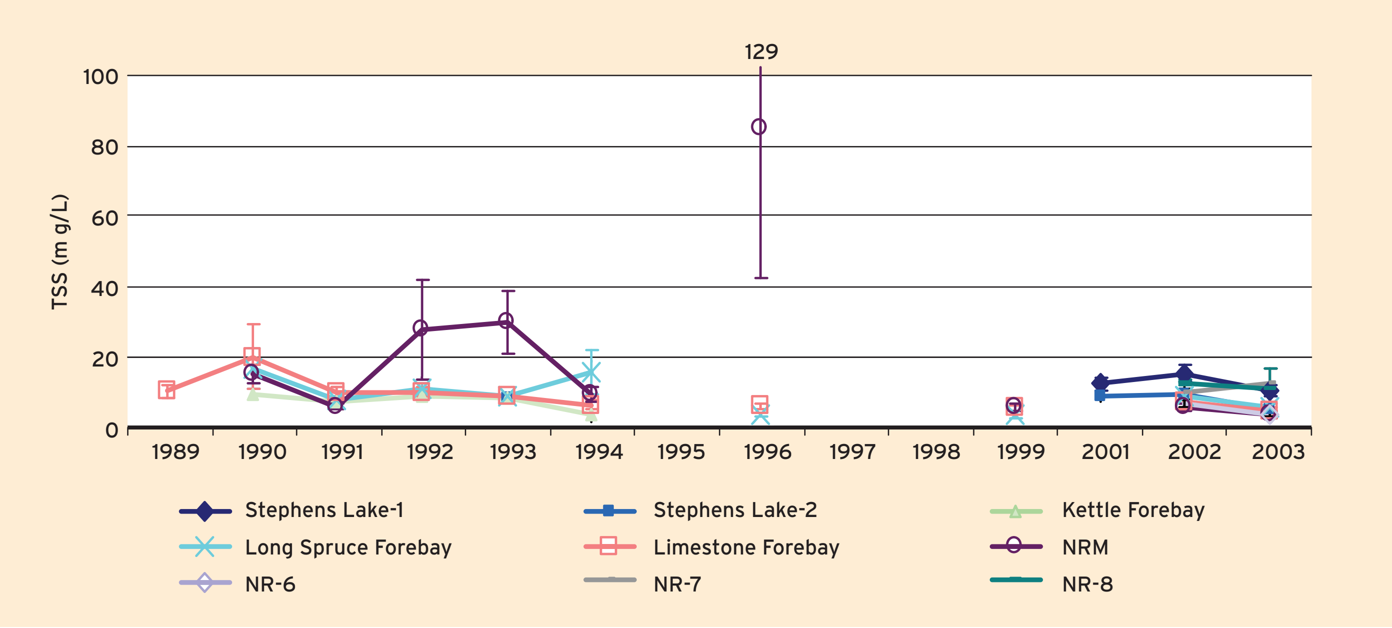


FIGURE 5-5
Mean (± 1 SE) total suspended solids (TSS) in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

Sediment transport patterns and processes can be highly complex and are strongly affected by hydrology. Therefore, in the absence of pre-Limestone data, it is not possible to determine if the Limestone G.S. caused a change in TSS concentrations upstream or downstream of the generating station. For example, it is not known if TSS concentrations in the Nelson River were similar to those observed at sites NR-7 or NR-8 (near Deer Island and Gillam Island, respectively; see Figure 5-1), or more similar to those measured in the Long Spruce Forebay. Manitoba water quality standards, objectives, and guidelines for TSS for the protection of aquatic life are defined on the basis of a relative change from "background" conditions. Therefore, it is not possible to compare measured TSS concentrations following construction of the Limestone G.S. to these objectives. However, the available information appears to indicate that TSS concentrations remained relatively similar between the upstream Long Spruce Forebay and the Limestone Forebay over the years of study.

5.3.5 Nutrients

Nitrogen, phosphorus, and carbon are the major nutrients that support the growth of aquatic plants, benthic algae (i.e., periphyton), and algae in the water column (i.e., **phytoplankton**). Sources of nutrients in surface waters include:

i) the breakdown of organic matter;

ii) excretion by organisms;

iii) wastewater discharges;

iv) erosion and run-off from nutrient-rich soils; and

v) 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 lead to the degradation of aquatic habitat through physical changes (e.g., excessive plant or algal growth) or through changes to water quality (reduced dissolved oxygen concentrations, reduced water clarity due to enhanced phytoplankton growth or 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 limiting factors such as water clarity, temperature, flushing rates, and turbulence.

Nutrient concentrations may increase in reservoirs and downstream environments following impoundment for hydroelectric (and other)

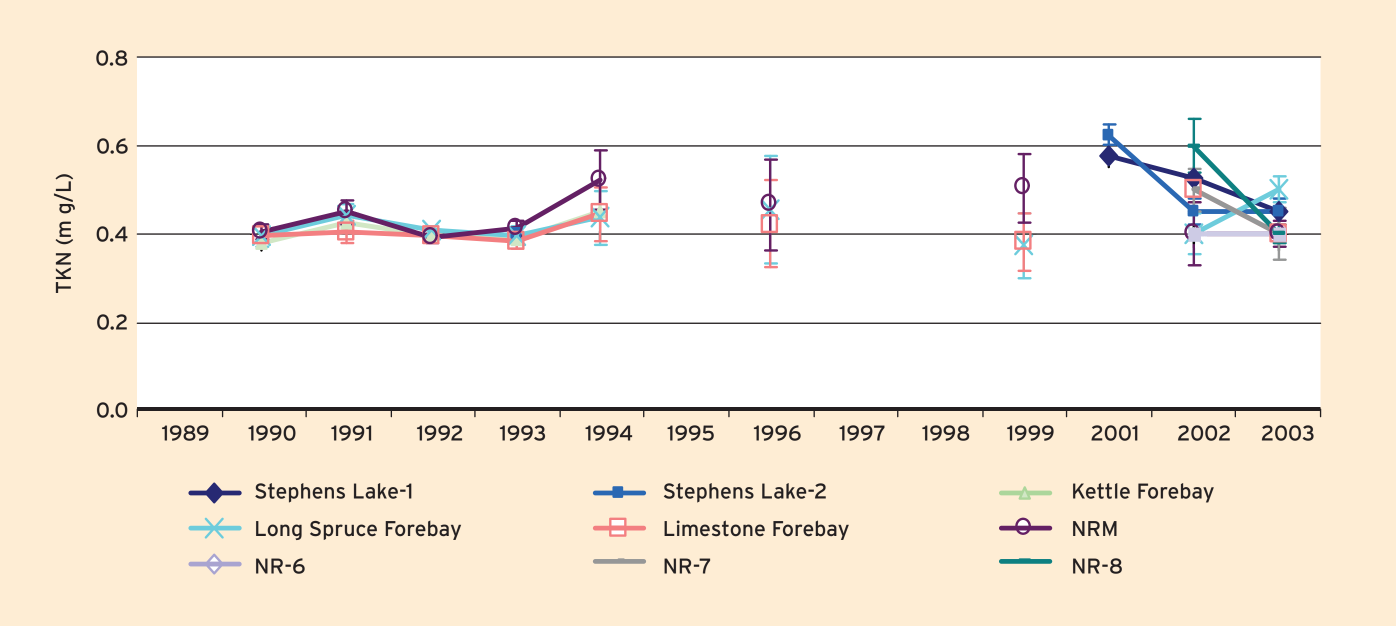


FIGURE 5-6 Mean (± 1 SE) total Kjeldahl nitrogen (TKN) in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1990-2003.

development through several pathways:

i) decomposition of flooded organic matter;

ii) increased shoreline erosion;

iii) alterations to the seasonal water level and flow patterns; and

iv) increased water level fluctuations.

Conversely, nutrient concentrations may decrease where impoundments lead to increased sedimentation, particularly in environments where nutrients are largely associated with particulate materials in the water column.

5.3.5.1 Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen is named for an analytical procedure that collectively measures organic and ammonia nitrogen. Over the course of the aquatic monitoring studies, three analytical laboratories were used and different forms of nitrogen were measured during different years. As such, there was no single nitrogenous parameter that was consistently measured that could be compared across sites and sampling periods. However, TKN was measured relatively frequently across years and/or could be calculated using other measured nitrogen parameters.

Mean TKN was relatively similar across sites in a given sampling year, ranging from 0.37 to 0.63 mg/L (Table 5-2, Figure 5-6), and there is no indication of a spatial trend or pattern for this parameter.

5.3.5.2 Phosphorus

Phosphorus is the most common nutrient limiting the growth of phytoplankton in fresh water, and concentrations are often related to the productivity of aquatic ecosystems (Wetzel 1983). Two types of phosphorus [total phosphorus (TP) and total dissolved phosphorus (TDP)] were quantified over the course of the aquatic monitoring studies. Dissolved forms of phosphorus are the most readily used by phytoplankton for growth. Therefore, the amount of dissolved phosphorus in the water column may fluctuate throughout the growing season as phosphorus is bound up in algae and plants in the spring and summer, and is released in the fall and winter with the death and decomposition of **plankton** and plant matter. Total phosphorus includes dissolved phosphorus as well as the phosphorus contained in suspended matter such as plankton (i.e., small plants and animals that exist in the water column) or bound to sediments.

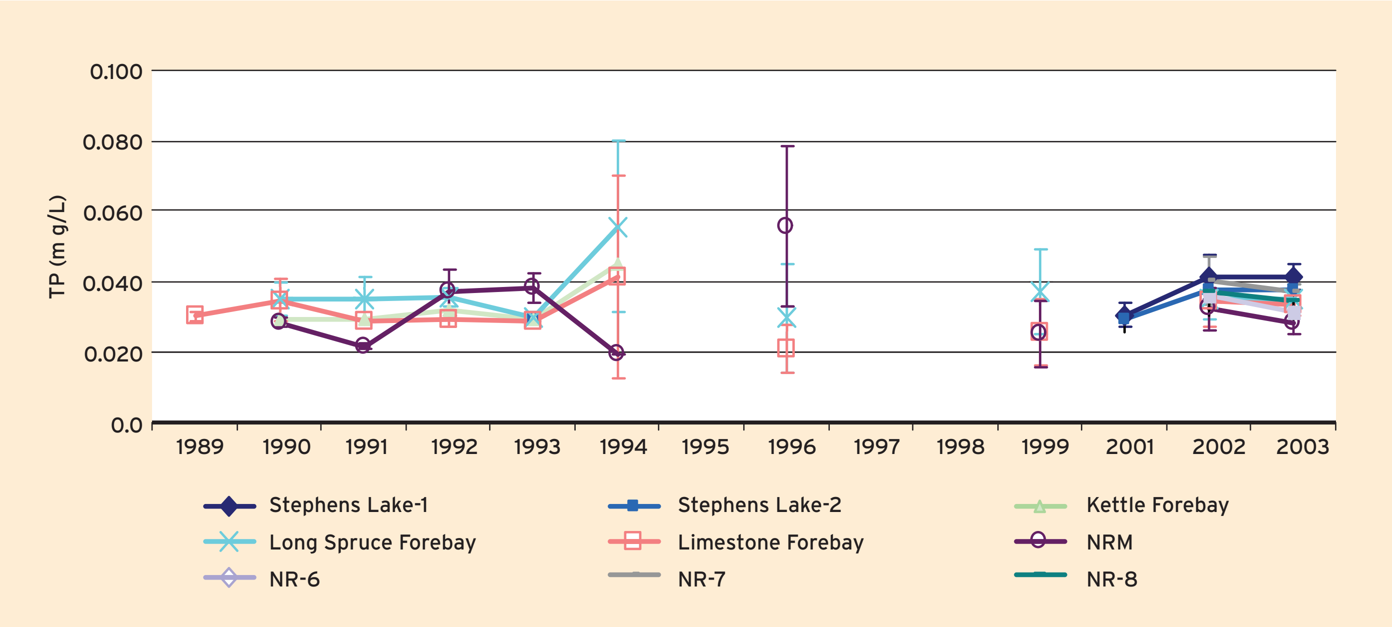


FIGURE 5-7
Mean (± 1 SE) total phosphorus (TP) in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

The majority of TP measurements collected in Stephens Lake and in the Long Spruce and Limestone forebays exceeded the Manitoba water quality guideline of 0.025 mg/L for lakes and reservoirs, which is intended to prevent the development of nuisance plant and algal growth (Williamson 2002). Conversely, most measurements collected in the Nelson River mainstem did not exceed the applicable guideline for streams (0.050 mg/L), although most measurements were above the guideline for reservoirs (i.e., >0.025 mg/L). Exceedences of the Manitoba water quality guideline for phosphorus are not an unusual occurrence in northern Manitoba, but do illustrate the relatively nutrient-rich conditions in the lower Nelson River system. On the basis of TP, the study area would be classified as meso-eutrophic to eutrophic using the CCME trophic categorizations for freshwater ecosystems (Table 5-3; CCME 1999, updated to 2008).

The annual mean TP concentrations ranged from 0.019 to 0.056 mg/L across the six sites (Table 5-2, Figure 5-7). A single anomalous result (0.380 mg/L measured at the Nelson River mainstem site on June 30, 1994) was removed from the analysis because it did not correspond with elevated concentrations of other compounds and was assumed to be an analytical error.

Large variabilities were observed in TP concentrations in some years, notably 1994 and 1996. The reason for these observations is not clear, but may reflect episodic nutrient inputs and/or sampling or analytical error. In at least some instances, high mean TP co-occurred with high TSS concentrations.

In the 1990s, TP concentrations were relatively similar between Stephens Lake, the Long Spruce Forebay, and the Limestone Forebay. Data collected at additional sites in Stephens Lake in 2002 and 2003 indicate that TP generally declined from the western end of Stephens Lake through the Limestone Forebay (Figure 5-7). However, concentrations remained relatively similar between the Long Spruce and Limestone forebays in those years, as was observed in the earlier survey period.

Mean TDP ranged from 0.007 to 0.042 mg/L and high variability was observed at some sites in some years (Table 5-2, Figure 5-8). There was no strong spatial pattern evident for this parameter and, in general, concentrations were relatively similar across the study area in a given year.

Due to the lack of pre-project data for the Limestone G.S., it is not known what the effect of this project may have been on TP or TDP. However, conditions in the Limestone Forebay are relatively similar to

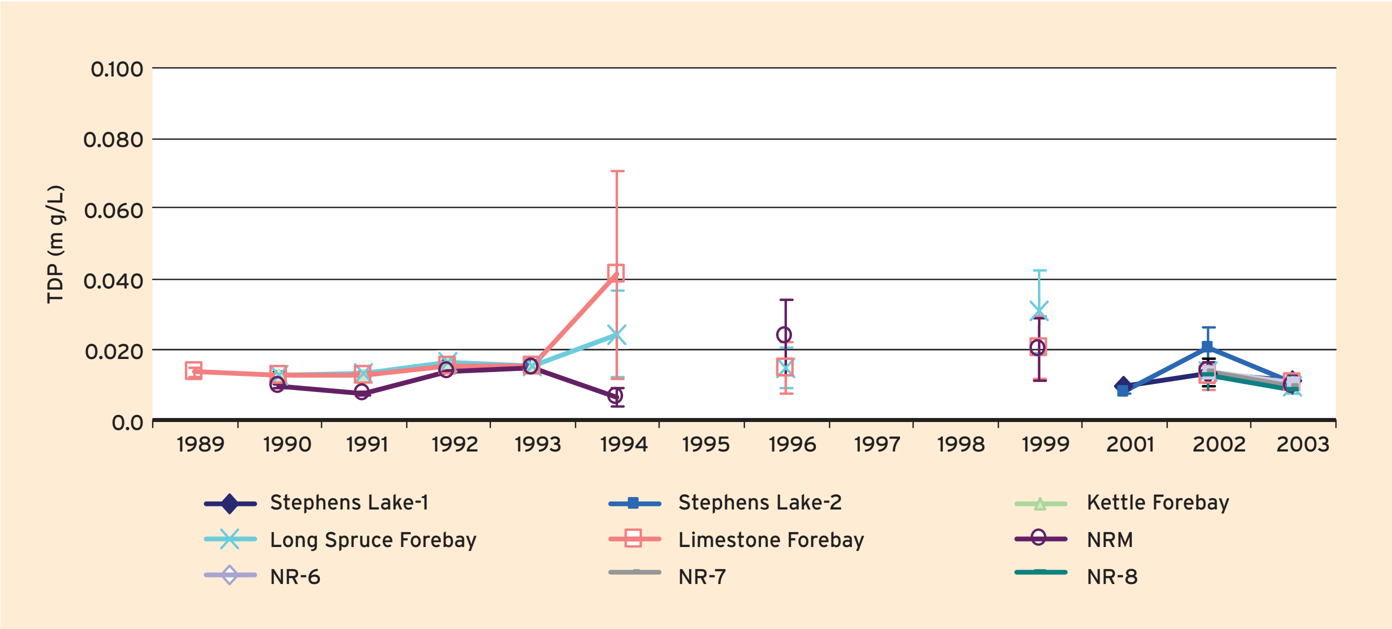


FIGURE 5-8
Mean (± 1 SE) total dissolved phosphorus (TDP) in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

sites upstream; therefore, the forebays have similar trophic status. Additionally, the available information indicates that neither TP nor TDP showed a notable increase in the Limestone Forebay, suggesting that flooding did not result in large increases in nutrients.

5.3.5.3 Dissolved Organic Carbon

Aquatic ecosystems derive energy from two main sources:

i) the growth of plants and algae within the waterbody using solar energy (i.e., autochthonous sources); and

ii) organic carbon derived from terrestrial areas within the watershed (i.e., allochthonous sources) (Wetzel 1983).

In riverine systems, the latter is more important for driving total ecosystem production.

In the aquatic environment, carbon exists in two primary forms: organic (such as the carbon contained in humic acids, sugars, and carbohydrates) and inorganic (such as the carbon contained in carbon dioxide, carbonate, and bicarbonate). Carbon is found in many different substances, some of which may be dissolved in water and others may be bound to (or contained within) particles suspended within the water column. Algae and rooted plants can use inorganic carbon, in the form of carbon dioxide, and convert it to organic carbon. **Bacteria** and other **microorganisms** may consume dissolved and particulate organic carbon, and, in turn, provide food for larger organisms such as invertebrates and fish. These organisms use organic carbon and release organic and inorganic carbon. The amounts and types of carbon present in aquatic ecosystems are dependent on a number of variables, including the geology, climate, topography, vegetative cover, and size of the watershed (Horne and Goldman 1994).

Concentrations of dissolved organic carbon (DOC) were very similar between the Kettle, Long Spruce, and Limestone forebays over the period of study (Figure 5-9). The highest overall concentrations occurred in 1996, which was a high-water year.

In most years of the Limestone G.S. aquatic monitoring programs (i.e., from 1989 to 1999), mean and maximum DOC were somewhat higher at the Nelson River mainstem site than at the upstream sites. As previously noted, higher concentrations observed between 1992-1996 could in part reflect the occurrence of erosion. In addition, higher levels observed at the mainstem site in 1990 and 1991 may reflect the influence of the Limestone River, which contains higher concentrations of DOC than

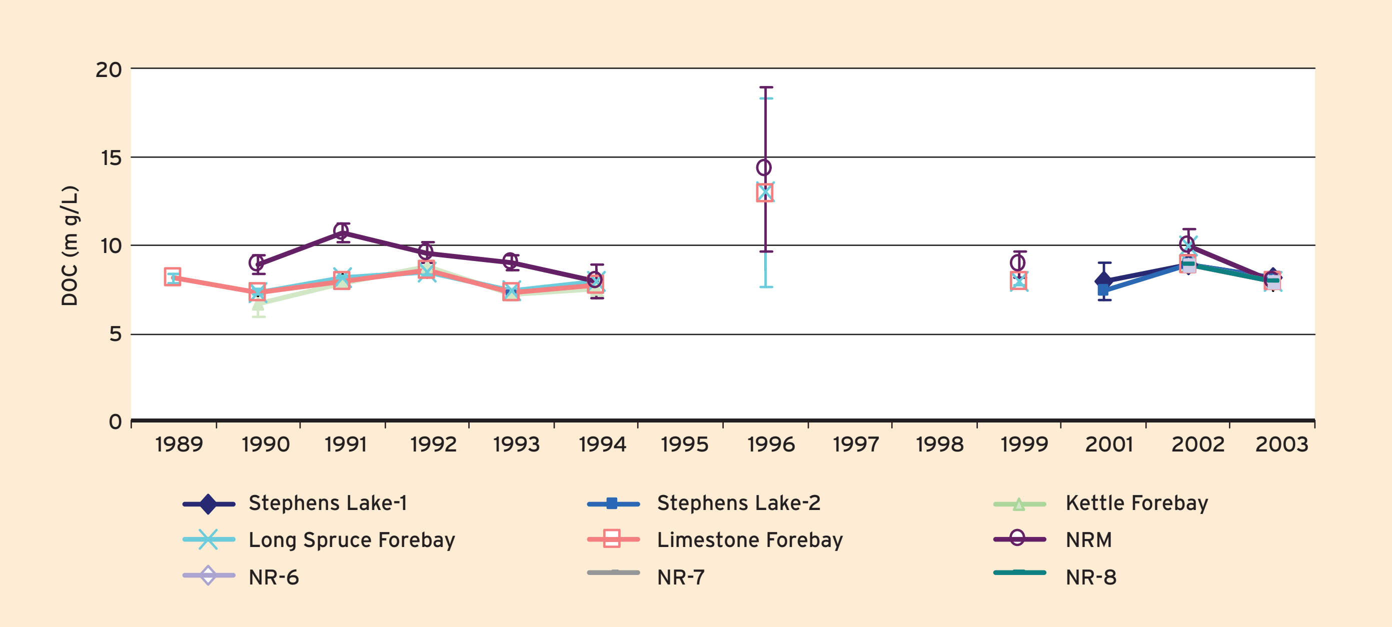


FIGURE 5-9
Mean (± 1 SE) dissolved organic carbon (DOC) in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

the mainstem of the Nelson River. (The mainstem monitoring site was located within the Limestone River plume in these years and was subsequently relocated downstream.) Alternatively, these spatial differences may reflect an effect of the Limestone G.S. on the downstream environment. Due to the lack of pre-impact data, the precise explanation cannot be discerned.

5.3.6 Chlorophyll *a*

Chlorophyll *a*, the primary photosynthetic pigment found in all algae, is often measured in studies of water quality as an indicator of the biomass of algae (or phytoplankton), and in turn, as an indicator of the productivity of an aquatic ecosystem. Although phytoplankton populations are discussed in Chapter 6.0 (Lower Trophic Levels), phytoplankton (and therefore chlorophyll *a* concentrations) in large rivers are generally influenced by:

i) concentrations of nutrients required for growth (i.e., nitrogen and phosphorus);

ii) water temperature;

iii) light availability; and

iv) physical conditions in the river such as turbulence and velocity.

Because hydroelectric development may affect various factors that influence phytoplankton growth and survival (i.e., thermal regimes, nutrient concentrations, water clarity, and hydrological cycles), chlorophyll *a* concentrations may be altered in regulated systems.

Chlorophyll *a* was relatively similar at all sites in all years, with annual means for the open-water season of approximately 3 to 9 µg/L (Table 5-2, Figure 5-10). As observed for other water quality parameters, there was no consistent spatial pattern evident for chlorophyll *a* across the study area.

5.4 Summary of Effects

Hydroelectric development may cause:

i) changes in water clarity and TSS (increases or decreases depending on the site-specific effects);

ii) increases in nutrients and decreases in pH due to flooding; and

iii) reductions in DO due to flooding, hydrological alterations, and/or changes in thermal or ice regimes.

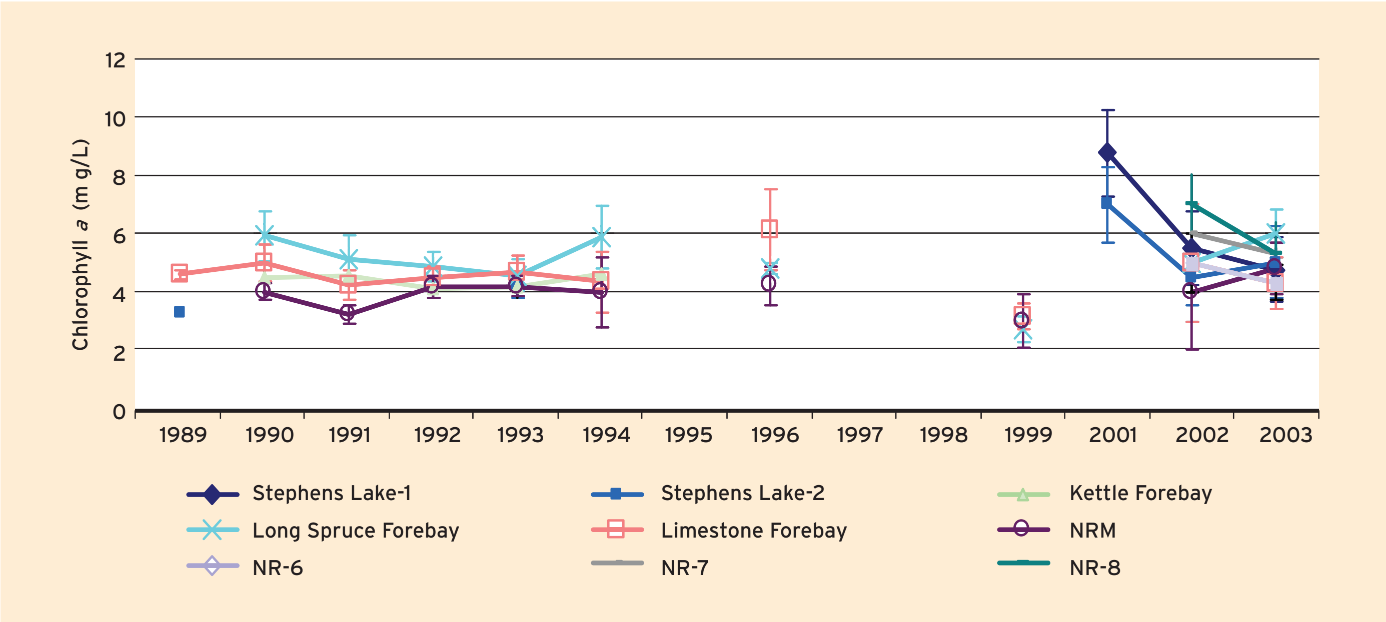


FIGURE 5-10 Mean (± 1 SE) chlorophyll *a* in Stephens Lake, the Kettle, Long Spruce, and Limestone forebays, and the Nelson River mainstem (including sites NR-6, NR-7, and NR-8), 1989-2003.

In general, the potential impacts of flooding on nutrients and pH are proportional to the amount of terrestrial habitat that is flooded (relative to the overall size of the reservoir), in conjunction with changes in water residence times and other hydrological conditions. Similarly, impacts to DO are generally higher where there is a large amount of flooding relative to the overall size of the reservoir, particularly in combination with large increases in water residence times. Given that the impoundment of the Limestone Forebay involved a relatively small area of flooding and that the water residence times are low (approximately 30 hours), effects of the project on nutrients, pH, and DO would conceptually be anticipated to be relatively small.

Due to the lack of pre-project data for the area, it is difficult to draw conclusions about the effects of the Limestone G.S. on water quality. However, the data collected post-construction indicate that, in general, water quality conditions were relatively similar between the Long Spruce and Limestone forebays in a given year. Most parameters were also similar in the Nelson River downstream of the generating station, but issues associated with relocation of the downstream monitoring site over the course of the monitoring programs complicate assessment of downstream changes. Data collected in more recent years (2002 and 2003) indicate that TP and TSS decrease from the western side of Stephens Lake to the first sampling site downstream of the Limestone G.S., then increase again in the downstream end of the Nelson River. Despite these spatial trends, TP concentrations remained relatively similar in the forebays and were consistently above the Manitoba water quality guideline over the course of the studies. Similarly, TKN and DOC were relatively similar across the forebays indicating that impoundment did not cause a large increase in nutrients in the reservoir. Dissolved oxygen concentrations were generally quite high in the Limestone Forebay and consistently above the most stringent MWQSOG for the protection of aquatic life across depth. In one sampling period (August 1992), DO was somewhat lower with depth in the Limestone Forebay, but the concentration remained above the Manitoba water quality objective. Therefore, the available information indicates that the Limestone G.S. did not create unfavourable DO conditions for aquatic life.

TABLE 5-1 Years in which each water quality parameter was measured during the Limestone G.S. aquatic monitoring studies.

Water quality variable	Years measured									
	1989[1]	1990[2]	1991[3]	1992[4]	1993[5]	1994[6]	1996[7]	1999[8]	2002[9]	2003[10]
Alkalinity		•	•	•	•				•	•
Acids		•	•	•	•					
Ammonia	•	•	•	•	•	•	•	•		
Dissolved ammonia-nitrogen									•	•
Nitrate	•	•	•	•	•					
Nitrite	•	•	•	•	•					
Nitrate/nitrite nitrogen						•	•	•	•	•
Dissolved Kjeldahl nitrogen						•	•	•		
Total Kjeldahl nitrogen						•	•	•	•	•
Total dissolved nitrogen	•	•	•	•	•					
Suspended nitrogen		•	•	•	•					
Total dissolved phosphorus	•	•	•	•	•	•	•	•	•	•
Suspended phosphorus	•	•	•	•	•					
Total phosphorus						•	•	•	•	•
Dissolved organic carbon	•	•	•	•	•	•	•	•	•	•
Total organic carbon						•	•	•	•	•
Dissolved inorganic carbon	•	•	•	•	•				•	•
Total inorganic carbon									•	•
Suspended carbon		•	•	•	•					
Total dissolved solids	•								•	•
Total suspended solids		•	•	•	•	•	•	•	•	•
Turbidity							•		•	•
True colour									•	•
Chlorophyll *a*	•	•	•	•	•	•	•	•	•	•
pH	•	•	•	•	•	•	•	•	•	•
Specific conductance*	•	•	•	•	•	•	•	•	•	•

Table 5-1 continued

Water chemistry variable	Years measured									
	1989[1]	1990[2]	1991[3]	1992[4]	1993[5]	1994[6]	1996[7]	1999[8]	2002[9]	2003[10]
Hardness									•	•
Calcium		•	•	•	•				•	•
Chloride		•	•	•	•				•	•
Fluoride									•	•
Iron		•	•	•	•				•	•
Magnesium		•	•	•	•				•	•
Manganese		•	•	•	•				•	•
Mercury									•	•
Potassium		•	•	•	•				•	•
Sodium		•	•	•	•				•	•
Soluble reactive silica		•	•	•	•					
Silica						•				
Sulphate		•	•	•	•				•	•
Trace elements									•	•
Gross α and β radioactivity									•	•
Polynuclear aromatic hydrocarbons									•	•
Total extractable hydrocarbons									•	•
Benzene, toluene, ethylbenzene, & xylenes									•	•
Total volatile hydrocarbons									•	•
Fecal coliform bacteria									•	•
Cryptosporidium sp.									•	•
Giardia sp.									•	•

* Specific conductance was measured in the lab in 1990-1999 and *in situ* in 1989, 2002, and 2003.

[1] - Baker 1990b
[2] - Baker 1991
[3] - Baker 1992
[4] - Kroeker and Horne 1993; Horne and Baker 1993
[5] - Schneider-Vieira 1994
[6] - Schneider-Vieira 1996
[7] - Horne 1997
[8] - Zrum and Kennedy 2000
[9] - Badiou and Cooley 2005
[10] - Badiou et al. 2005

TABLE 5-2 Summary of water quality parameters measured in the lower Nelson River (from Stephens Lake to Gillam Island) during the Limestone G.S. aquatic monitoring studies, 1986-2003.

Site	Specific conductance[1] (μS/cm)					Dissolved oxygen[2] (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Stephens Lake-1										
2001	271	4	262	281	4	10.57	0.17	10.19	11.00	4
2002	250	15	207	274	4	10.33	0.81	8.77	12.01	4
2003	243	9	216	258	4	13.36	0.90	12.37	16.05	4
Stephens Lake-2										
1986	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-
1993	249	7	226	284	9	-	-	-	-	-
2001	263	7	242	275	4	10.71	0.35	10.00	11.64	4
2002	244	14	204	271	4	10.46	0.88	8.71	12.13	4
2003	238	10	210	253	4	13.40	0.77	11.91	15.52	4
Kettle Forebay										
1990	244	10	204	293	10	-	-	-	-	-
1991	220	3	204	237	10	-	-	-	-	-
1992	227	7	203	269	10	-	-	-	-	-
1993	249	7	226	284	9	-	-	-	-	-
1994	228	9	210	255	5	-	-	-	-	-
Long Spruce Forebay										
1990*	243	10	205	287	10	-	-	-	-	-
1991*	220	3	203	237	10	-	-	-	-	-
1992	227	7	205	269	10	8.95	0.79	7.70	11.00	4
1993	248	7	226	284	9	7.75	-	-	-	1
1994	227	10	204	255	5	-	-	-	-	-
1996	240	6	220	253	5	-	-	-	-	-
1999	271	5	252	284	6	-	-	-	-	-
2002 (site: NR-3)	245	19	201	291	4	9.93	0.53	8.96	11.40	4
2003 (site: NR-3)	237	11	207	255	4	13.47	0.70	11.76	14.95	4
2003 (site: NR-4)	237	11	207	257	4	13.16	1.02	10.38	14.98	4

Table 5-2 continued

Site	Specific conductance[1] (µS/cm)					Dissolved oxygen[2] (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Limestone Forebay										
1989	266	5	251	273	4	11.66	0.76	9.70	12.90	5
1990	243	10	205	287	10	-	-	-	-	-
1991	221	4	203	237	10	10.20	0.58	8.90	11.40	4
1992	226	7	206	267	10	9.25	0.25	9.00	9.50	2
1993	248	7	228	284	9	8.00	-	-	-	1
1994	226	9	207	252	5	-	-	-	-	-
1996	245	3	239	253	5	-	-	-	-	-
1999	273	6	250	286	6	-	-	-	-	-
2002 (site: NR-4)	246	19	204	295	4	9.68	0.55	8.33	10.91	4
2003 (site: NR-4)	237	11	207	257	4	13.16	1.02	10.38	14.98	4
NRM										
1990*	248	10	195	287	10	-	-	-	-	-
1991*	228	6	184	246	10	-	-	-	-	-
1992*	222	10	152	261	10	-	-	-	-	-
1993	240	8	204	270	9	-	-	-	-	-
1994	232	11	209	255	4	-	-	-	-	-
1996	234	11	193	254	5	-	-	-	-	-
1999	262	13	234	298	5	-	-	-	-	-
2002 (site: NR-5)	228	24	181	259	3	10.94	0.72	9.50	11.76	3
2003 (site: NR-5)	236	10	208	253	4	13.97	1.14	10.80	16.18	4
NRM (NR-6)										
2002	253	23	213	291	3	9.96	0.38	9.31	10.82	4
2003	232	18	200	261	3	12.26	0.39	11.27	13.11	4
NRM (NR-7)										
2002	250	26	203	293	3	10.25	0.88	8.92	12.82	4
2003	238	12	207	259	4	13.93	0.56	12.97	15.40	4
NRM (NR-8)										
2002	250	26	202	2	3	10.31	0.99	9.15	12.27	3
2003	246	15	210	272	4	13.97	0.82	12.33	16.23	4

Table 5-2 continued

Site	Lab pH					Total suspended solids (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Stephens Lake-1										
2001	8.16	0.06	8.02	8.31	4	15	2	10	18	4
2002	8.00	0.03	7.95	8.10	4	18	2	11	23	4
2003	8.23	0.04	8.13	8.30	4	13	1	9	16	4
Stephens Lake-2										
1986	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-
1993	8.61	0.02	8.51	8.73	9	10	1	8	14	9
2001	8.09	0.06	7.99	8.26	4	11	2	7	15	4
2002	7.99	0.05	7.88	8.10	4	12	2	10	<20	4
2003	8.19	0.02	8.15	8.24	4	7	2	3	11	4
Kettle Forebay										
1990	8.48	0.01	8.43	8.55	10	12	1	8	18	10
1991	8.51	0.01	8.45	8.56	10	9	1	7	12	9
1992	8.58	0.02	8.46	8.66	10	11	1	7	15	10
1993	8.61	0.02	8.51	8.73	9	10	1	8	14	9
1994	8.28	0.04	8.20	8.40	5	6	2	<1	14	5
Long Spruce Forebay										
1990*	8.49	0.01	8.43	8.55	10	19	6	8	66	10
1991*	8.52	0.01	8.46	8.55	10	10	1	8	14	9
1992	8.57	0.02	8.45	8.65	10	13	2	7	24	10
1993	8.61	0.02	8.51	8.73	9	11	1	9	15	9
1994	8.28	0.07	8.10	8.50	5	18	6	6	39	5
1996	8.12	0.10	7.80	8.30	5	6	1	4	8	5
1999	8.18	0.03	8.10	8.30	6	6	1	2	10	6
2002 (site: NR-3)	8.04	0.04	7.94	8.14	4	11	2	6	13	4
2003 (site: NR-3)	8.19	0.06	8.01	8.30	4	8	1	5	9	4

Table 5-2 continued

Site	Lab pH					Total suspended solids (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Limestone Forebay										
1989	8.53	0.01	8.51	8.55	4	13	2	9	17	4
1990	8.49	0.01	8.44	8.55	10	22	9	10	105	10
1991	8.51	0.01	8.45	8.56	10	12	2	8	20	9
1992	8.57	0.02	8.45	8.66	10	12	1	6	18	10
1993	8.61	0.02	8.50	8.73	9	11	0	9	13	9
1994	8.27	0.05	8.13	8.40	5	9	1	6	13	5
1996	8.15	0.06	8.00	8.30	5	8	1	6	11	5
1999	8.20	0.04	8.10	8.30	6	8	1	5	11	6
2002 (site: NR-4)	7.99	0.02	7.95	8.05	4	10	2	6	13	4
2003 (site: NR-4)	8.19	0.05	8.04	8.29	4	7	1	4	9	4
NRM										
1990*	8.54	0.02	8.45	8.59	10	17	3	5	34	10
1991*	8.59	0.01	8.53	8.62	10	8	1	4	10	9
1992*	8.59	0.02	8.42	8.68	10	30	14	9	156	10
1993	8.62	0.02	8.52	8.75	9	32	9	10	90	9
1994	8.35	0.02	8.30	8.40	4	12	2	7	17	4
1996	8.14	0.09	7.90	8.40	5	87	42	15	206	5
1999	8.26	0.08	8.10	8.50	5	8	1	5	11	5
2002 (site: NR-5)	8.20	0.17	7.87	8.39	3	8	1	6	10	4
2003 (site: NR-5)	8.32	0.14	8.09	8.69	4	6	1	4	7	4
NRM (NR-6)										
2002	8.02	0.02	7.95	8.06	4	9	1	8	12	4
2003	8.20	0.05	8.10	8.31	4	6	0	5	7	4
NRM (NR-7)										
2002	8.06	0.02	8.01	8.11	4	12	1	9	16	4
2003	8.30	0.08	8.09	8.45	4	15	4	9	27	4
NRM (NR-8)										
2002	8.10	0.05	7.99	8.20	4	15	1	13	18	4
2003	8.34	0.09	8.14	8.55	4	13	6	5	30	4

Table 5-2 continued

Site	Total Kjeldahl nitrogen[3] (mg/L)					Dissolved Kjeldahl nitrogen[4] (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Stephens Lake-1										
2001	0.6	0.03	0.5	0.6	4	0.5	0.03	0.4	0.5	4
2002	0.5	0.02	0.5	0.6	4	0.5	0.03	0.4	0.5	4
2003	0.5	0.03	0.4	0.5	4	0.5	0.03	0.3	0.4	4
Stephens Lake-2										
1986	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-
1993	0.4	0.02	0.4	0.4	4	0.3	0.0	0.3	0.4	4
2001	0.6	0.02	0.6	0.7	4	0.6	0.03	0.5	0.6	4
2002	0.5	0.03	0.4	0.5	4	0.4	0.03	0.3	0.4	4
2003	0.5	0.03	0.4	0.5	4	0.4	0.03	0.3	0.4	4
Kettle Forebay										
1990	0.4	0.01	0.3	0.4	7	0.4	0.0	0.3	0.4	7
1991	0.4	0.02	0.4	0.5	6	0.4	0.0	0.4	0.5	6
1992	0.4	0.01	0.4	0.4	10	0.4	0.0	0.3	0.4	10
1993	0.4	0.01	0.3	0.4	9	0.4	0.0	0.3	0.5	9
1994	0.5	0.07	0.3	0.7	5	0.4	0.1	0.2	0.6	5
Long Spruce Forebay										
1990*	0.4	0.02	0.3	0.5	7	0.3	0.0	0.2	0.4	10
1991*	0.4	0.02	0.4	0.5	6	0.3	0.0	0.3	0.4	10
1992	0.4	0.01	0.4	0.5	10	0.3	0.0	0.3	0.4	10
1993	0.4	0.02	0.3	0.5	9	0.3	0.0	0.3	0.4	9
1994	0.4	0.06	0.4	0.7	5	0.4	0.0	0.3	0.6	5
1996	0.5	0.12	0.1	0.8	5	0.4	0.1	0.1	0.7	5
1999	0.4	0.07	0.1	0.7	6	0.4	0.1	0.1	0.6	6
2002 (site: NR-3)	0.4	0.05	0.3	0.5	4	0.4	0.0	0.3	0.5	4
2003 (site: NR-3)	0.5	0.03	0.4	0.5	4	0.5	0.0	0.4	0.5	4

Table 5-2 continued

Site	Total Kjeldahl nitrogen[3] (mg/L)					Dissolved Kjeldahl nitrogen[4] (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Limestone Forebay										
1989	-	-	-	-	-	-	-	-	-	-
1990	0.4	0.02	0.4	0.5	7	0.3	0.0	0.2	0.4	10
1991	0.4	0.03	0.3	0.5	6	0.3	0.0	0.2	0.4	10
1992	0.4	0.01	0.4	0.4	10	0.3	0.0	0.3	0.4	10
1993	0.4	0.01	0.3	0.4	9	0.3	0.0	0.2	0.4	9
1994	0.4	0.06	0.3	0.7	5	0.5	-	0.3	0.8	5
1996	0.4	0.10	0.1	0.8	5	0.4	-	0.1	0.8	5
1999	0.4	0.06	0.2	0.6	6	0.4	-	0.2	0.6	6
2002 (site: NR-4)	0.5	0.03	0.4	0.5	4	0.5	0.0	0.4	0.5	4
2003 (site: NR-4)	0.4	0.02	0.4	0.5	4	0.4	0.0	0.4	0.5	4
NRM										
1990*	0.4	0.02	0.3	0.5	7	0.3	0.0	0.2	0.4	10
1991*	0.4	0.03	0.3	0.5	7	0.4	0.0	0.3	0.4	10
1992*	0.4	0.01	0.3	0.5	10	0.3	0.0	0.3	0.4	10
1993	0.4	0.02	0.3	0.5	9	0.3	0.0	0.3	0.4	9
1994	0.5	0.07	0.4	0.7	4	0.7	0.3	0.3	1.9	4
1996	0.5	0.10	0.2	0.8	5	0.4	0.1	0.1	0.7	5
1999	0.5	0.08	0.3	0.7	5	0.5	0.1	0.3	0.7	5
2002 (site: NR-5)	0.4	0.07	0.3	0.5	3	0.4	0.1	0.2	0.4	3
2003 (site: NR-5)	0.4	0.03	0.3	0.4	4	0.3	0.0	0.2	0.3	4
NRM (NR-6)										
2002	0.4	0.02	0.4	0.5	4	0.4	0.0	0.3	0.4	4
2003	0.4	0.04	0.3	0.5	4	0.3	0.0	0.2	0.4	4
NRM (NR-7)										
2002	0.5	0.05	0.4	<1.0	4	0.4	0.1	0.3	0.5	4
2003	0.4	0.06	0.3	0.6	4	0.4	0.1	0.2	0.5	4
NRM (NR-8)										
2002	0.6	0.06	0.4	<2.0	4	0.5	0.1	0.3	1.0	4
2003	0.4	0.02	0.4	0.5	4	0.4	0.0	0.3	0.4	4

Table 5-2 continued

Site	Total phosphorus (mg/L)					Total dissolved phosphorus (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Stephens Lake-1										
2001	0.030	0.004	0.024	0.038	4	0.010	0.001	0.008	0.011	4
2002	0.041	0.006	0.026	0.057	4	0.014	0.004	0.007	0.022	4
2003	0.041	0.004	0.035	0.051	4	0.012	0.001	0.010	0.014	4
Stephens Lake-2										
1986	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-
1993	0.029	0.001	0.024	0.035	9	0.016	0.001	0.012	0.021	9
2001	0.029	0.004	0.023	0.039	4	0.009	0.001	0.008	0.010	4
2002	0.037	0.006	0.022	0.050	4	0.021	0.006	0.006	0.035	4
2003	0.038	0.004	0.025	0.044	4	0.011	0.002	0.008	0.016	4
Kettle Forebay										
1990	0.029	0.001	0.023	0.033	10	0.013	0.001	0.010	0.016	10
1991	0.029	0.001	0.024	0.034	10	0.013	0.001	0.010	0.017	10
1992	0.032	0.001	0.026	0.038	10	0.017	0.001	0.012	0.020	10
1993	0.029	0.001	0.024	0.035	9	0.016	0.001	0.012	0.021	9
1994	0.045	0.026	0.019	0.070	2	-	-	-	-	-
Long Spruce Forebay										
1990*	0.035	0.005	0.022	0.065	10	0.013	0.001	0.011	0.016	10
1991*	0.035	0.006	0.018	0.089	10	0.013	0.001	0.010	0.018	10
1992	0.035	0.003	0.027	0.057	10	0.017	0.001	0.012	0.021	10
1993	0.030	0.002	0.022	0.035	9	0.016	0.001	0.011	0.020	9
1994	0.056	0.025	0.031	0.080	2	0.025	0.012	<0.005	0.070	5
1996	0.029	0.016	<0.005	0.089	5	0.015	0.006	<0.005	0.035	5
1999	0.037	0.012	<0.005	0.079	6	0.031	0.012	<0.005	0.077	6
2002 (site: NR-3)	0.035	0.006	0.019	0.048	4	0.014	0.004	0.006	0.022	4
2003 (site: NR-3)	0.035	0.004	0.023	0.040	4	0.010	0.002	0.006	0.017	4

Table 5-2 continued

Site	Total phosphorus (mg/L)					Total dissolved phosphorus (mg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Limestone Forebay										
1989	0.030	0.001	0.028	0.032	4	0.014	0.001	0.012	0.018	4
1990	0.034	0.006	0.025	0.088	10	0.013	0.000	0.011	0.015	10
1991	0.028	0.001	0.024	0.033	10	0.013	0.001	0.009	0.019	10
1992	0.029	0.002	0.012	0.038	10	0.016	0.001	0.010	0.020	10
1993	0.029	0.001	0.023	0.034	9	0.016	0.001	0.011	0.019	9
1994	0.041	0.029	0.012	0.070	2	0.042	0.030	0.008	0.160	5
1996	0.021	0.007	<0.005	0.035	5	0.015	0.007	<0.005	0.035	5
1999	0.025	0.010	<0.005	0.053	6	0.021	0.009	<0.005	0.049	6
2002 (site: NR-4)	0.034	0.007	0.016	0.047	4	0.013	0.004	0.006	0.022	4
2003 (site: NR-4)	0.033	0.003	0.023	0.039	4	0.011	0.002	0.008	0.017	4
NRM										
1990*	0.028	0.001	0.021	0.034	10	0.010	0.001	0.007	0.013	10
1991*	0.021	0.001	0.018	0.025	10	0.008	0.001	0.005	0.011	10
1992*	0.037	0.006	0.027	0.094	10	0.014	0.001	0.009	0.018	10
1993	0.038	0.004	0.023	0.064	9	0.015	0.001	0.011	0.019	9
1994	0.019	-	0.019	0.019	1	0.007	0.003	<0.005	0.013	4
1996	0.056	0.023	<0.005	0.123	5	0.024	0.011	<0.005	0.064	5
1999	0.025	0.009	<0.005	0.049	5	0.020	0.009	<0.005	0.049	5
2002 (site: NR-5)	0.032	0.006	0.025	0.044	3	0.014	0.003	0.010	0.020	3
2003 (site: NR-5)	0.028	0.003	0.021	0.032	4	0.010	0.001	0.007	0.014	4
NRM (NR-6)										
2002	0.036	0.006	0.024	0.047	4	0.014	0.004	0.006	0.022	4
2003	0.031	0.002	0.025	0.036	4	0.011	0.001	0.008	0.013	4
NRM (NR-7)										
2002	0.040	0.007	0.024	0.054	4	0.014	0.004	0.006	0.021	4
2003	0.037	0.002	0.034	0.041	4	0.010	0.001	0.007	0.013	4
NRM (NR-8)										
2002	0.037	0.005	0.025	0.048	4	0.013	0.004	0.005	0.023	4
2003	0.034	0.003	0.028	0.040	4	0.009	0.001	0.006	0.012	4

Table 5-2 continued

Site	Dissolved organic carbon (mg/L)					Chlorophyll *a* (µg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Stephens Lake-1										
2001	8	1	6	11	4	9	1	5	12	4
2002	9	0.4	8	10	4	6	1	2	8	4
2003	8	0.3	8	9	4	5	1	3	8	4
Stephens Lake-2										
1986	-	-	-	-	-	3	-	3	4	-
1987	-	-	-	-	-	8	-	3	12	-
1988	-	-	-	-	-	6	-	5	7	-
1989	-	-	-	-	-	3	-	2	5	-
1993	7	0	6	8	9	4	0	3	6	9
2001	8	0.3	7	8	4	7	1	4	10	4
2002	9	0.4	8	10	4	5	1	2	6	4
2003	8	0.3	8	9	4	5	1	2	7	4
Kettle Forebay										
1990	7	1	1	8	10	5	0	3	6	10
1991	8	0	6	9	10	5	0	1	6	10
1992	9	0	7	11	10	4	0	2	5	10
1993	7	0	6	8	9	4	0	3	6	9
1994	8	0	6	8	5	5	1	3	7	5
Long Spruce Forebay										
1990*	7	0	7	8	10	6	1	3	11	10
1991*	8	0	7	9	10	5	1	1	11	10
1992	9	0	7	10	10	5	1	3	8	10
1993	7	0	7	8	9	5	1	3	8	9
1994	8	1	6	9	5	6	1	3	8	5
1996	13	4	8	30	5	5	0	4	5	5
1999	8	0	8	9	6	3	0	2	5	6
2002 (site: NR-3)	10	1	8	10	4	5	2	<1	8	4
2003 (site: NR-3)	8	0	7	9	4	6	1	4	8	4

Table 5-2 continued

Site	Dissolved organic carbon (mg/L)					Chlorophyll *a* (μg/L)				
Year	Mean	SE	Min	Max	n	Mean	SE	Min	Max	n
Limestone Forebay										
1989	8	0	8	9	3	5	0	4	5	4
1990	7	0	7	8	10	5	1	3	10	10
1991	8	0	7	9	10	4	1	1	6	10
1992	9	0	7	11	10	5	0	2	6	10
1993	7	0	7	8	9	5	1	3	8	9
1994	8	0	6	9	5	4	1	2	8	5
1996	13	5	6	29	4	6	1	3	11	5
1999	8	0	8	9	6	3	0	2	5	6
2002 (site: NR-4)	9	0	8	10	4	5	2	<1	8	4
2003 (site: NR-4)	8	0	8	8	4	4	1	2	6	4
NRM										
1990*	9	1	7	12	10	4	0	3	6	10
1991*	11	1	9	15	10	3	0	2	5	10
1992*	10	1	8	13	10	4	0	2	5	10
1993	9	0	7	11	9	4	0	3	6	9
1994	8	1	6	10	4	4	1	2	7	4
1996	14	5	8	33	5	4	1	2	6	5
1999	9	1	8	12	5	3	1	1	6	5
2002 (site: NR-5)	10	1	9	12	3	4	2	1	7	3
2003 (site: NR-5)	8	0	8	9	4	5	1	3	7	4
NRM (NR-6)										
2002	9	0	9	9	4	5	1	2	9	4
2003	8	0	7	8	4	4	1	3	6	4
NRM (NR-7)										
2002	9	0	8	10	4	6	2	1	10	4
2003	8	0	7	9	4	5	1	4	7	4
NRM (NR-8)										
2002	9	0	9	9	4	7	1	4	10	4
2003	8	0	7	9	4	5	1	2	7	4

SE = Standard error Min = Minimum Max = Maximum
n = total number of samples collected NRM = Nelson River mainstem

[1] Measured in the lab 1990-1999; measured *in situ* in 1989, 2002, and 2003

[2] Surface water measurements

[3] Measured directly in 1994, 1996, 1999, 2002, and 2003; values for other years calculated as: TKN = TN - nitrate/nitrite

[4] Measured directly in 1994, 1996, and 1999; values for 1990-1993 calculated as: DKN = TDN - nitrate and nitrite; values for 2001-2003 calculated based on regression between TDN and TKN (from 1994-1999 data)

* Unpublished data

TABLE 5-3 Summary of selected trophic status classification schemes and open-water means for water quality data collected from the lower Nelson River, 1990-2003.

Water quality parameter	Lake trophic status							
Waterbody	Ultra-oligotrophic	Oligotrophic	Oligo-mesotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	Reference
Total phosphorus (mg/L)	<4	4 - 10	-	10 - 20	20 - 35	35 - 100	>100	CCME (1999)
Stephens Lake-1						38		This study
Stephens Lake-2					33			This study
Kettle Forebay					33			This study
Long Spruce Forebay						36		This study
Limestone Forebay					30			This study
NRM					31			This study
NRM (NR-6)					34			This study
NRM (NR-7)						39		This study
NRM (NR-8)						36		This study
Chlorophyll *a* (µg/L)	0.01 - 0.50	0.3 - 3.0	-	2.0 - 15.0	-	10 - 500	-	Wetzel (1983)
Stephens Lake-1				6.3				This study
Stephens Lake-2				4.8				This study
Kettle Forebay				4.4				This study
Long Spruce Forebay				5.0				This study
Limestone Forebay				4.6				This study
NRM				4.0				This study
NRM (NR-6)				4.7				This study
NRM (NR-7)				5.7				This study
NRM (NR-8)				6.2				This study

Table 5-3 continued

Water quality parameter	Lake trophic status							
Waterbody	Ultra-oligotrophic	Oligotrophic	Oligo-mesotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	Reference
Dissolved organic carbon (mg/L)	-	2	-	3	-	10	-	Kalff (2002)
Stephens Lake-1						8		This study
Stephens Lake-2						8		This study
Kettle Forebay						8		This study
Long Spruce Forebay						9		This study
Limestone Forebay						9		This study
NRM						10		This study
NRM (NR-6)						9		This study
NRM (NR-7)						9		This study
NRM (NR-8)						9		This study

TABLE 5-4 A trophic status classification for rivers and streams based on chlorophyll *a* and open-water means for water quality data collected from the lower Nelson River, 1990-2003.

Water quality parameter	Lake trophic status							
Waterbody	Ultra-oligotrophic	Oligotrophic	Oligo-mesotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	Reference
Chlorophyll *a* (μg/L)	-	<10.0	-	10-30	-	>30	-	Dodds et al. (1998)
Stephens Lake-1		6.3						This study
Stephens Lake-2		4.8						This study
Kettle Forebay		4.4						This study
Long Spruce Forebay		5.0						This study
Limestone Forebay		4.6						This study
NRM		4.0						This study
NRM (NR-6)		4.7						This study
NRM (NR-7)		5.7						This study
NRM (NR-8)		6.2						This study

TABLE 5-5 A common classification scheme for European lakes (Cardoso 2001, in Carvalho et al. 2002).

Parameter	Units	Condition				
		Excellent	Good	Fair	Poor	Bad
TP (mean)	(μg/L)	Natural levels	<125% of excellent	125-150% of excellent	150-200% of excellent	>200% of excellent
Chlorophyll *a* (mean)	(μg/L)	<2	<5	<10	<25	>25
Chlorophyll *a* (maximum)	(μg/L)	<5	<10	<20	<50	>50
Secchi depth (mean)	(m)	>5	2-5	1.5-2	1-1.5	<1
Secchi depth (minimum)	(m)	>3	1-3	0.7-1	<0.7	<0.7

TABLE 5-6 Threshold criteria used in European member states to designate rivers subject to eutrophication (Cardoso et al. 2001, in Carvalho et al. 2002).

Parameter	Units	United Kingdom	Ireland	France	Joint Research Centre Ispra (Italy)
TP (mean)	(μg/L)	>100	>50	<100	75-200
Chlorophyll *a* (mean)	(μg/L)	>25	>60	>60	-
Chlorophyll *a* (maximum)	(μg/L)	>100	-	-	-

6.0

LOWER TROPHIC LEVELS

6.1 Introduction

Trophic levels are the feeding levels in food chains or webs. Primary producers, which consist of plants and algae, comprise the bottom trophic level, followed by primary consumers (i.e., herbivores, those organisms that consume plants or algae), then secondary consumers (i.e., carnivores feeding on herbivores), and so on. Decomposers are another highly important component at the base of the food chain, providing food to many of the same **aquatic invertebrate** groups that consume algae. Lower trophic level studies conducted over the course of the Limestone G.S. aquatic environment monitoring programs focused on primary producers and secondary invertebrate consumers. Within the aquatic ecosystem, these groups are important in determining the amount of energy (i.e., food) available for higher trophic levels, in particular fish.

Lower trophic community structure is a function of the environment in which it exists. Historically, the lower trophic community in the lower Nelson River was a river community with the most abundant species being those adapted to large riverine environments.

Construction of hydroelectric generating facilities has changed the aquatic habitat available for lower trophic levels. Changes that have occurred include the following:

- increased water levels, decreased water velocities, and a change from **lotic** to more **lentic** conditions in the Nelson River mainstem upstream of generating stations;
- alterations in other components of the physical environment such as ice, erosion, and sediment deposition resulting from the modified water regime have affected the habitat available for lower trophic level organisms; and
- increased frequency and range of water level fluctuations and changes in ice conditions downstream of the farthest downstream generating station.

The ultimate effect of each of these changes is different for each lower trophic group. A change that may be positive for one group may be negative for another. In addition, direct effects on one group may lead to indirect effects on other groups.

Lower trophic level studies were initiated in 1990 and continued through 2003. The objectives were to:

i) provide an understanding of the existing environment;

ii) determine how lower trophic levels within the aquatic ecosystem were changing in response to operation of the Limestone G.S.; and

iii) determine how this affected food availability for the fish community.

Effort was focussed on general surveys over a broad area rather than intensive sampling designed to provide quantitative estimates of changes in parameters such as biomass and abundance.

The studies compared components of the lower trophic community in the Long Spruce and Limestone forebays and the Nelson River mainstem downstream of the Limestone G.S. Limestone Forebay data provided an ongoing understanding of the changes occurring within the forebay following impoundment. Data from the Long Spruce Forebay provided an understanding of the potential condition of the Limestone Forebay in the future. Data from the Nelson River mainstem acted as a surrogate for pre-impact data, and provided the closest approximation to conditions within the river downstream of the Long Spruce G.S. prior to construction of the Limestone G.S.

6.2 Methods

Prior to initiation of the Limestone G.S. monitoring studies, there was minimal site-specific information on lower trophic levels within the lower Nelson River. The benthic invertebrate fauna in the Limestone Forebay was monitored throughout the study years, from 1990 to 2003. Initial sampling identified important limitations of sampling techniques (i.e., not all habitat types were sampled), and sampling methodology was modified during the course of the studies to ensure that data were representative of habitats in the forebay. Consequently, information can be used to document the presence and relative abundance of invertebrates in various areas of the forebay in comparison to results obtained by similar methods in the Long Spruce Forebay and Nelson River mainstem, but does not provide a quantitative account of changes in invertebrate productivity following impoundment. Other components of the lower trophic community (e.g., algae, rooted plants, zooplankton) were described by surveys conducted in 1992. Zooplankton surveys were repeated in 2002. Methods used to sample each trophic level are discussed below. A summary of locations and years that each method was used is provided in Table 6-1.

6.2.1 Primary Productivity

6.2.1.1 Phytoplankton

Phytoplankton biomass was estimated using two techniques:

i) measurement of chlorophyll *a* concentrations of water samples (1990-1999); and

ii) direct enumeration of phytoplankton (1992).

Although chlorophyll *a* provides an indication of phytoplankton biomass, it may not be directly related to biomass because the proportion of pigment varies from 0.3-3.0% of dry weight among algal species (Lee 1980). Results of chlorophyll *a* analysis are provided in Chapter 5.0. Phytoplankton biomass was directly enumerated in water samples collected from the Long Spruce and Limestone forebays and from the Nelson River mainstem near Lower Limestone Rapids and Gillam Island during fall 1992. Cell densities were enumerated in a 10-ml aliquot of a water sample preserved with Lugol's solution. Cell density for each species was converted to wet-weight biomass by measuring individual cells of each species, applying the geometric formula best fitted to the cell shape (Vollenweider 1968), and assuming a specific gravity of one for the cellular mass.

6.2.1.2 Aquatic Macrophytes and Attached Algae

A survey for aquatic macrophytes was conducted in the Long Spruce and Limestone forebays and in the Nelson River downstream to Gillam Island during August 1992. Macrophyte presence was noted, specimens were collected for identification, and the amount of area covered by plants was estimated visually. Although not directly studied over the course of the Limestone monitoring programs, detailed studies of the abundance and distribution of attached algae in the lower Nelson River mainstem were conducted after 2003.

6.2.2 Zooplankton

Zooplankton were first collected in the Long Spruce and Limestone forebays at the end of August 1992, at two points in the central and nearshore areas of each forebay. Samples were collected using a 77-µm mesh Nitex plankton net with a mouth diameter of 0.25 m and a total length of one metre. Each tow covered a surface distance of approximately 300 m, during which time the net was constantly moved from surface to bottom. Zooplankton were also collected at Gillam Island in 1992 using the same gear, but hauling the net 0.25 to 0.50 m below the surface for a variable distance. In 2002, zooplankton were collected at one site in each of the Long Spruce and Limestone forebays during June, July, August, and October. Zooplankton were collected in vertical, bottom-to-surface tows with a 63-µm mesh, 0.22-m mouth diameter, 1.3-m long conical net. The net was lowered to the bottom then slowly retrieved to the surface by hand.

6.2.3 Benthic Invertebrates

A variety of sampling techniques were employed to sample benthic invertebrates. This was due to the range of habitat types and the technical difficulties associated with certain habitats, such as areas of hard substrate in deep, fast-flowing water.

Pan traps

Adult insects along the forebays (representing insects that had emerged locally) were sampled with pan traps set at several locations in the lower Limestone Forebay and at one site each in the Long Spruce Forebay and the Nelson River mainstem (Figure 6-1). Pan traps consisted of 30 x 50-cm dish pans filled with antifreeze (Photo 6-1). Liquid soap was added to the antifreeze to reduce surface tension such that insects landing in the pan would sink. The pans, which were placed near the shoreline, captured adult insects returning to the water to deposit their eggs. Two pan traps were set 2 to 10 m apart at each sampling location. Pan traps were employed in 1990, 1992, 1994, 1996, and 1999. Pan trap locations in the Limestone Forebay were moved in 1990 following full impoundment due to flooding of the initial sampling site. Additional sites were added in the middle and lower portions of the Limestone Forebay in 1992 as catches at the site nearest to the Limestone G.S. appeared to be influenced by insects arising downstream of the generating station from riverine environments. These traps provided a record of relative insect abundance at various locations, but, as discussed in the following section, pan trap catches reflected insect abundance in the general vicinity, not within the specific section of the forebay where they were set. In addition, they provided information only on the insect component of the benthic fauna.

Emergence Traps

Shoreline areas were sampled in 1992 for emerging adult aquatic insects with emergence traps. Traps were set approximately 10 m offshore at all sites sampled with pan traps except for the mainstem site, where high-water velocity precluded their use. Emergence traps were identical to those used by Rosenberg et al. (1980) and consisted of an inverted funnel with a sampling area of 0.1 m^2 leading to an air-filled collecting vial containing a sponge soaked with formalin. Each trap was suspended approximately 1 m below the water surface by Styrofoam® floats and anchored to the bottom. Insect larvae swimming to the water surface, to emerge within the area covered by the funnel, entered and were trapped within the collection bottle. These traps provided a direct measure of the insects emerging at specific sites (unlike the pan traps which integrated a larger area), but sampled a very small portion of the overall forebay and were restricted in the areas where they could be set.

PHOTO 6-1
Sampling adult insects from a pan trap set along the shoreline of the lower Nelson River.

PHOTO 6-2
A Ponar grab used to sample benthic invertebrates from areas with soft substrate in the lower Nelson River.

Ponar grabs

Soft substrata were sampled with Ponar grabs (Photo 6-2) at sites in the upper, middle, and lower sections of both the Long Spruce and Limestone forebays in 1990, 1992, 1993, and 2003 (Figure 6-2). These grabs provide quantitative measures of the entire invertebrate fauna (not just the insect component), but samples could not be collected from substantial areas of the forebays due to the rocky substratum. Consequently, between 1993 and 2003, rock traps were used instead (see below). Soft substrata were also sampled with Ponar grabs at various locations in the lower Nelson River mainstem below the Limestone G.S. in 2002 and 2003 (figures 6-3 and 6-4). In areas where the substrate was relatively hard, other sampling devices were used (see below).

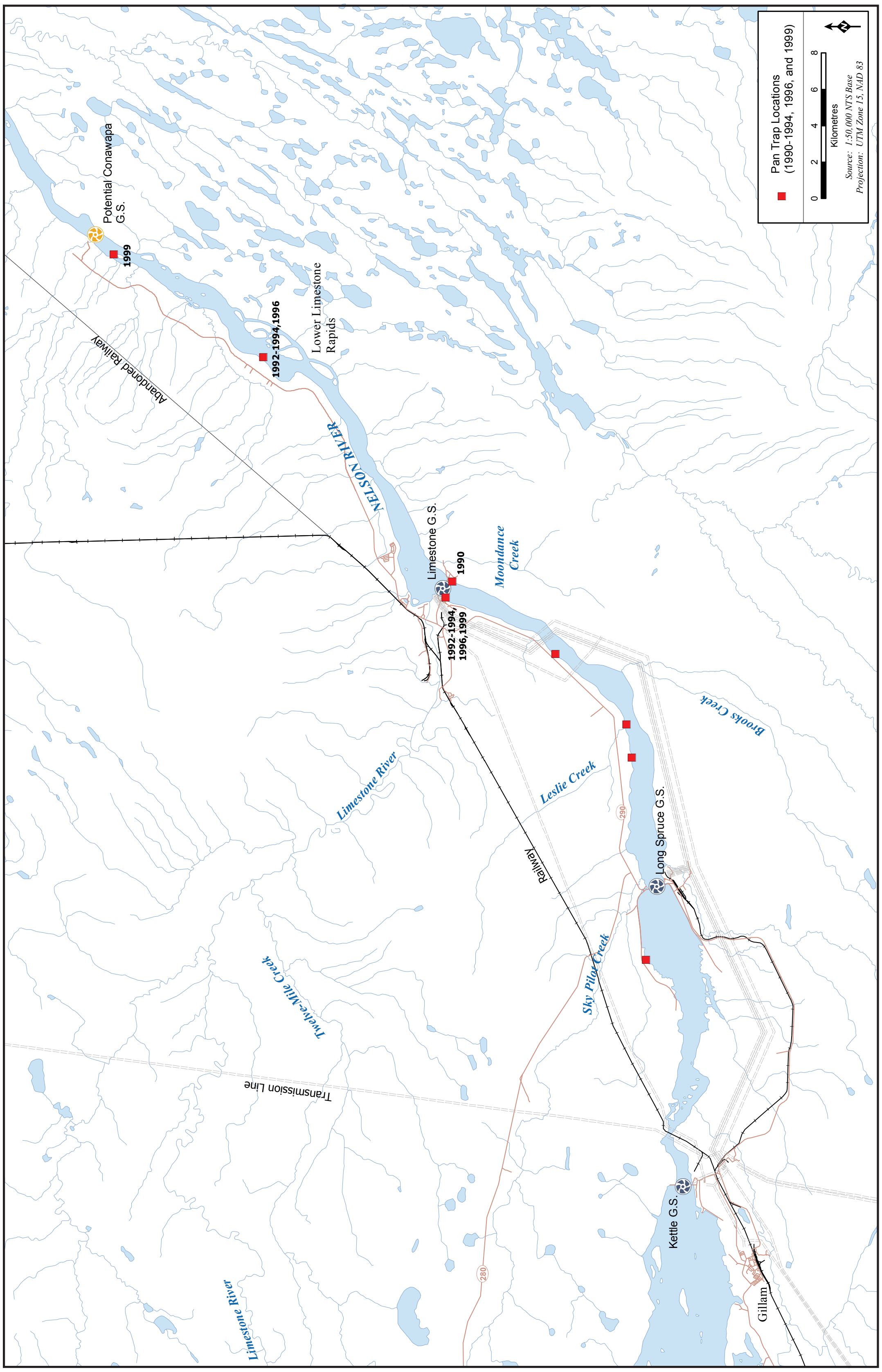


FIGURE 6-1 Pan trap locations in the Long Spruce and Limestone forebays and at locations in the Nelson River mainstem downstream of the Limestone G.S., 1990-1994, 1996, and 1999.

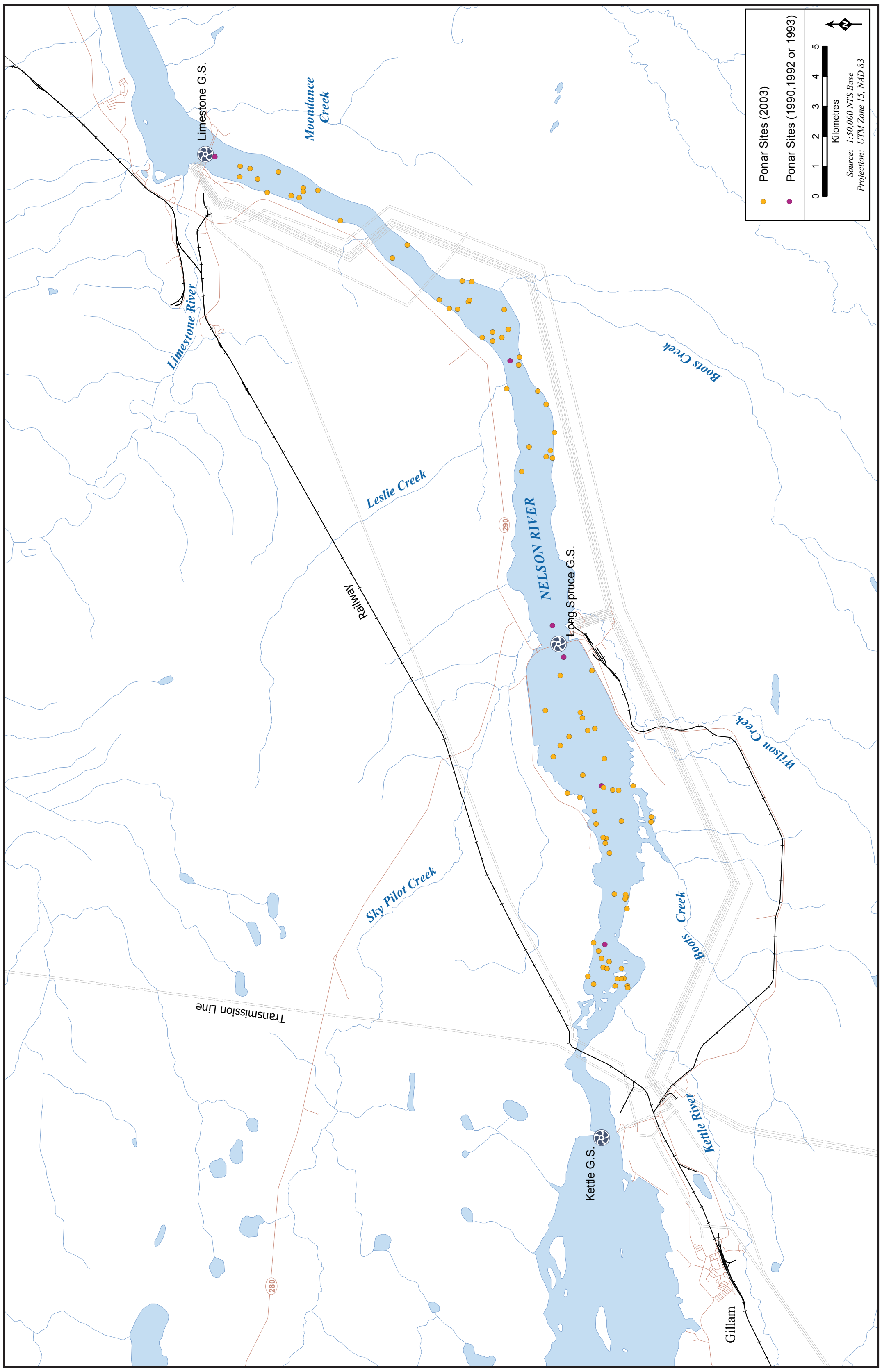


FIGURE 6-2 Ponar grab sites in the Long Spruce and Limestone forebays in 1990, 1992, 1993, and 2003.

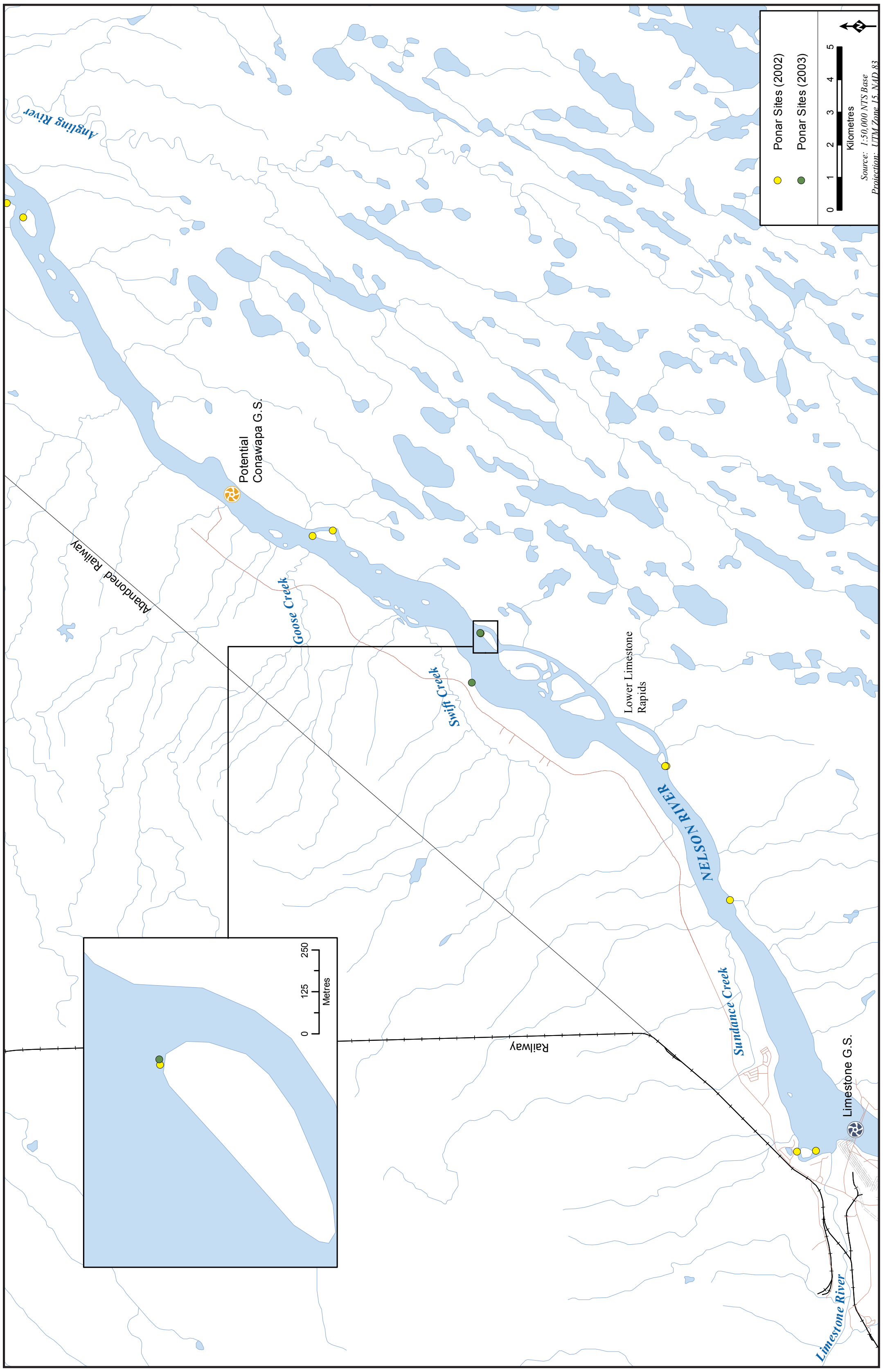


FIGURE 6-3 Ponar grab sampling sites in the lower Nelson River from the Limestone G.S. downstream to Frank's Island, 2002 and 2003.

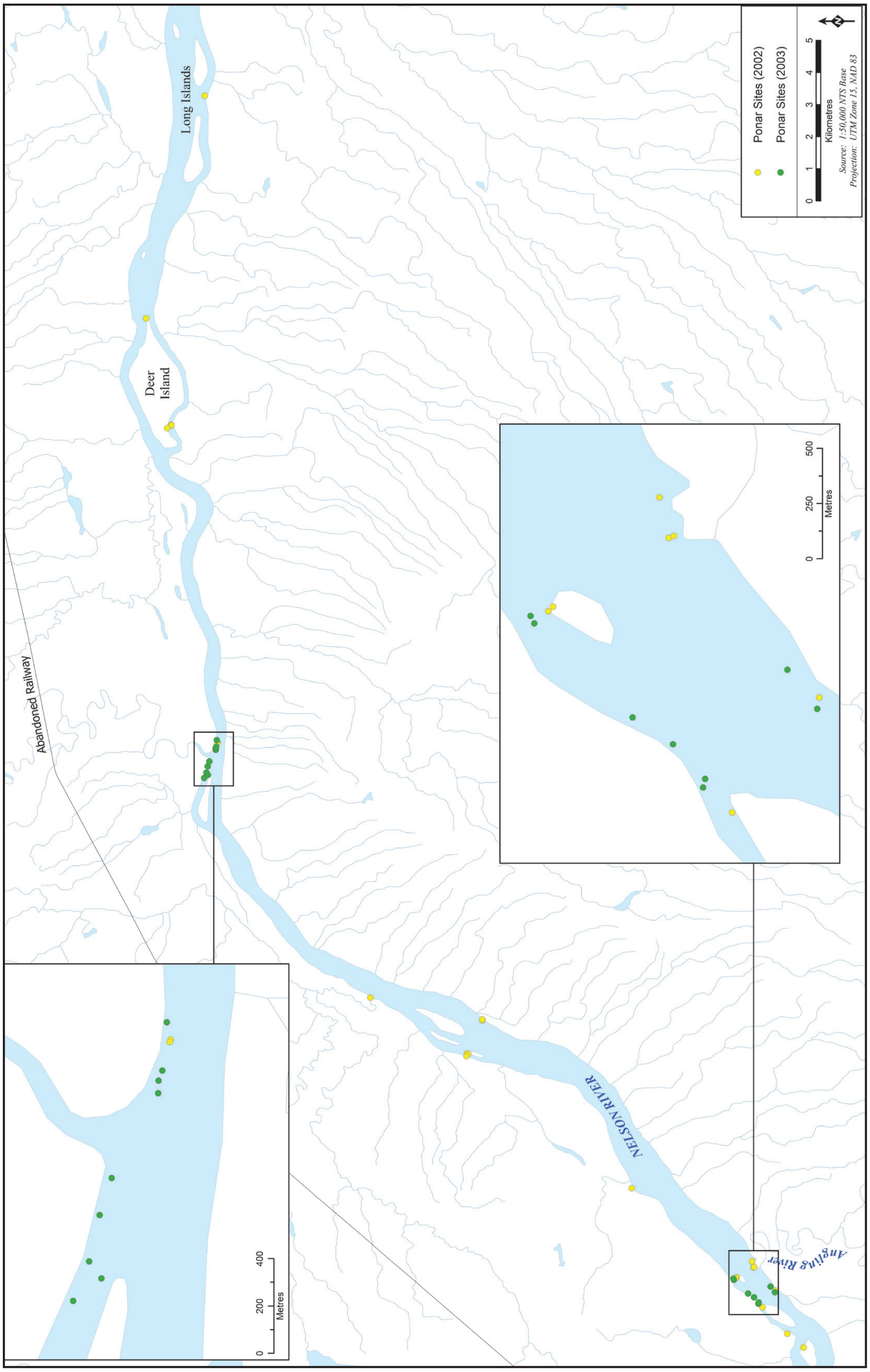


FIGURE 6-4 Ponar grab sampling sites in the lower Nelson River from the mouth of the Angling River downstream to Long Islands, 2002 and 2003.

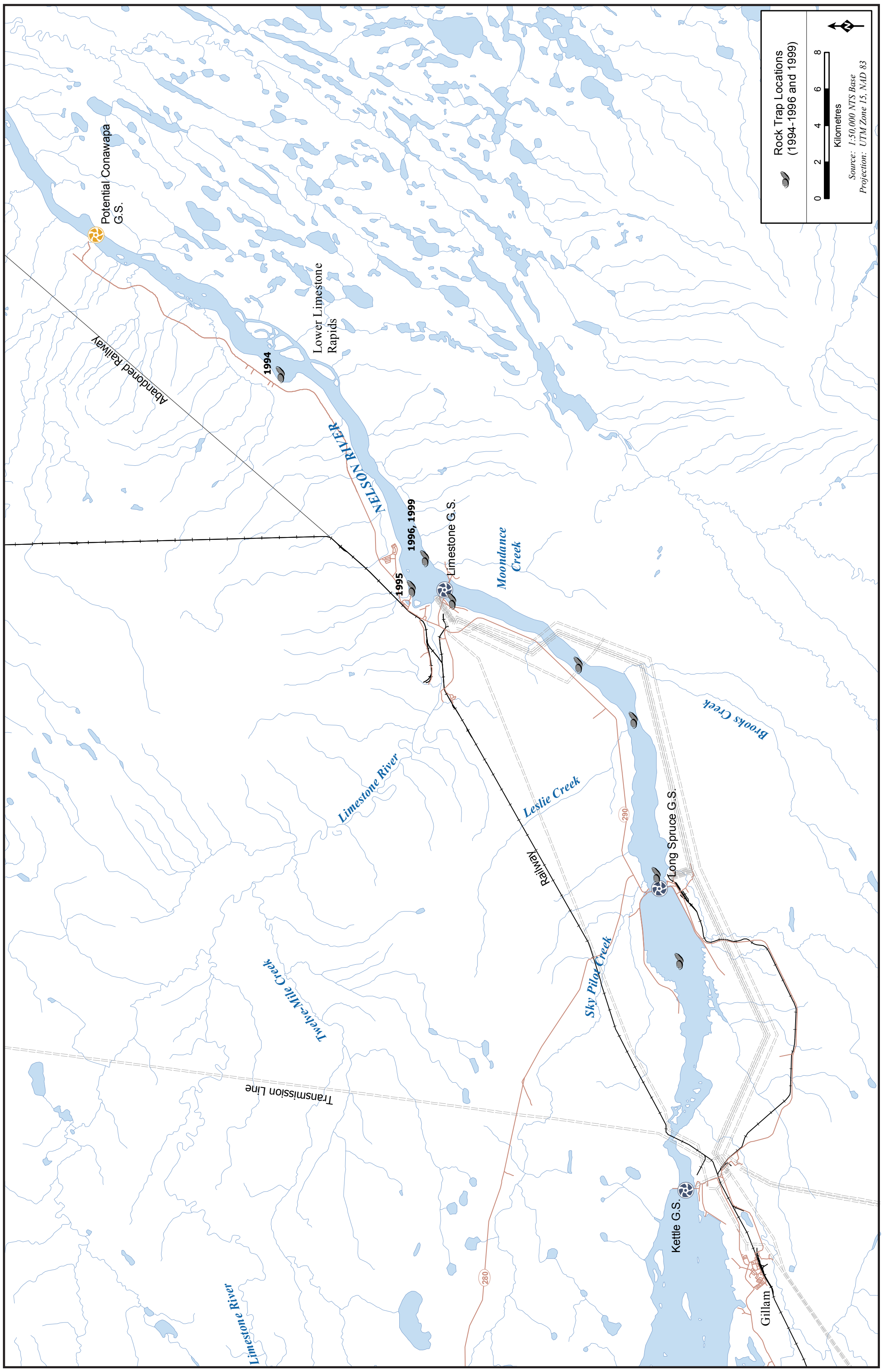


FIGURE 6-5 Rock trap locations in the Long Spruce and Limestone forebays and at locations in the lower Nelson River mainstem downstream of the Limestone G.S., 1994-1996 and 1999.

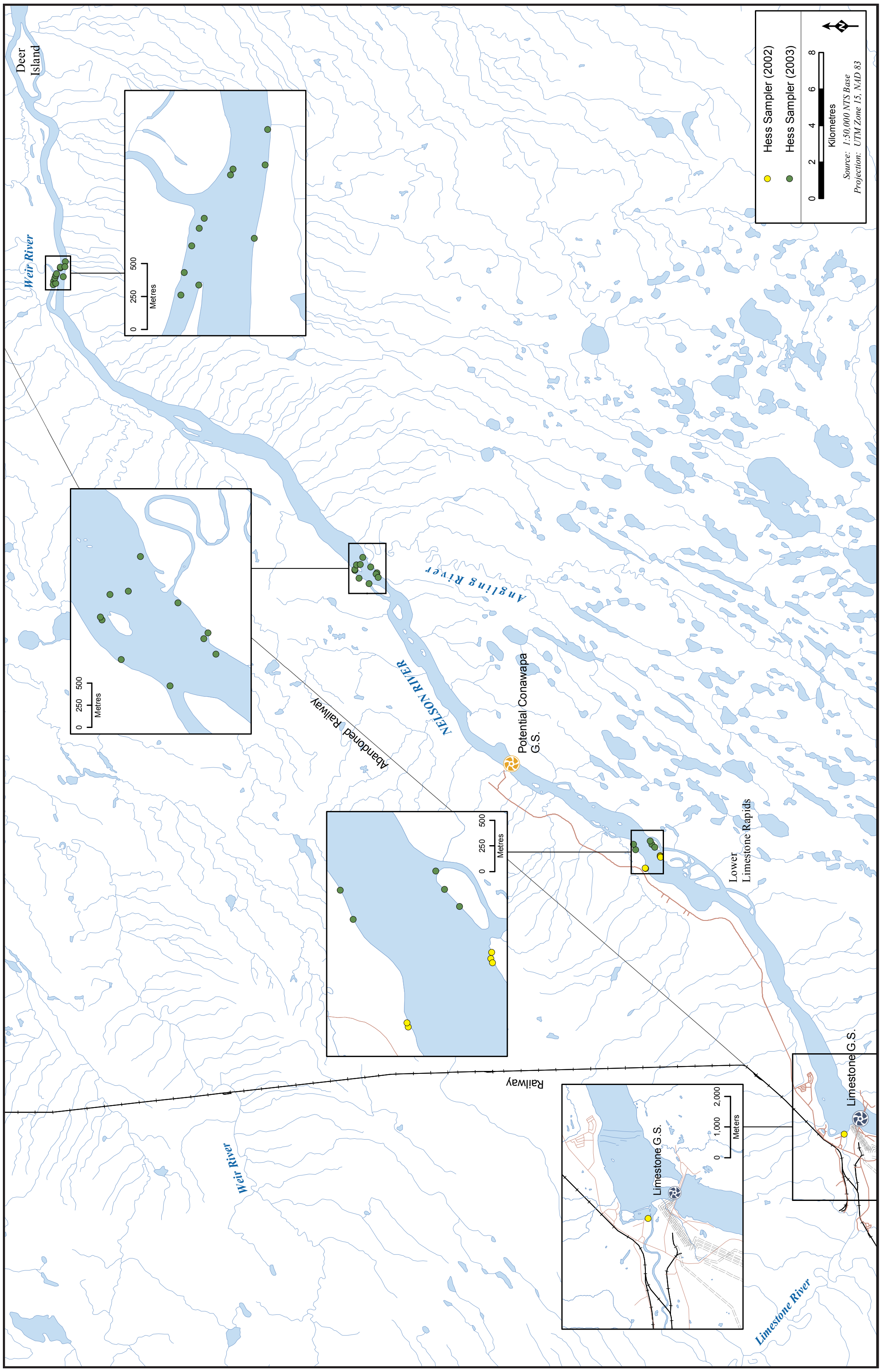


FIGURE 6-6 Hess sampler locations in the lower Nelson River downstream of the Limestone G.S., 2002 and 2003.

Rock traps

Benthic invertebrate communities in rocky or hard substrata were sampled using artificial substrate samplers (i.e., rock traps) in the forebays and at one site in the Nelson River mainstem below the Limestone G.S. (Figure 6-5). Rock traps consisted of a 38-cm high cone (constructed from 0.5-cm steel rods) with a basal diameter of 28 cm. Gaps in the cone decreased from the base to the top, but on average were 5.0 x 2.5 cm^2 in area. A solid aluminium sheet (pizza plate) was fixed to the base of the cone by a removable central bar. Each trap was filled with approximately 15 rocks (angular limestone) collected on site. The rock traps were generally set for the entire open-water season, with retrieval just prior to freeze-up. Rock traps were deployed in 1994, 1995, 1996, and 1999.

Hess samplers

Wadable areas with gravel and cobble substrate in the lower Nelson River below the Limestone G.S. were sampled using a Hess sampler in 2002 and 2003 (Figure 6-6). The Hess sampler is a cylinder-shaped device that is pushed into the river bottom (Photo 6-3). The bottom substrate is scrubbed, stirred, and washed and the upstream mesh windows (500-μm) facilitate the water current to carry the sample into an attached collection bag and finally into a 500-μm mesh cod-end. As with Ponar grabs, these samplers provide quantitative measures of the benthic invertebrate community, though in limited areas of the lower Nelson River.

Airlift samplers

Deep-water areas with coarse and rocky substrate were sampled with an airlift sampler in the lower Nelson River below the Limestone G.S. in 2002 and 2003 (Figure 6-7). The airlift sampler is a long, vertical tube that is placed onto the substrate and secured (Photo 6-4). A 10-second air blast then disturbs and suctions the sample up through the sampler and into a 500-μm mesh cod-end. These samplers provide quantitative data on benthic invertebrate communities; however, during sample collection, the airlift sampler was restricted in use to areas of low current.

PHOTO 6-3
A Hess sampler used to sample aquatic invertebrates from wadable river habitats with gravel and cobble substrata.

PHOTO 6-4
An airlift sampler used to sample aquatic invertebrates from deep-water river habitats with coarse and rocky substrata.

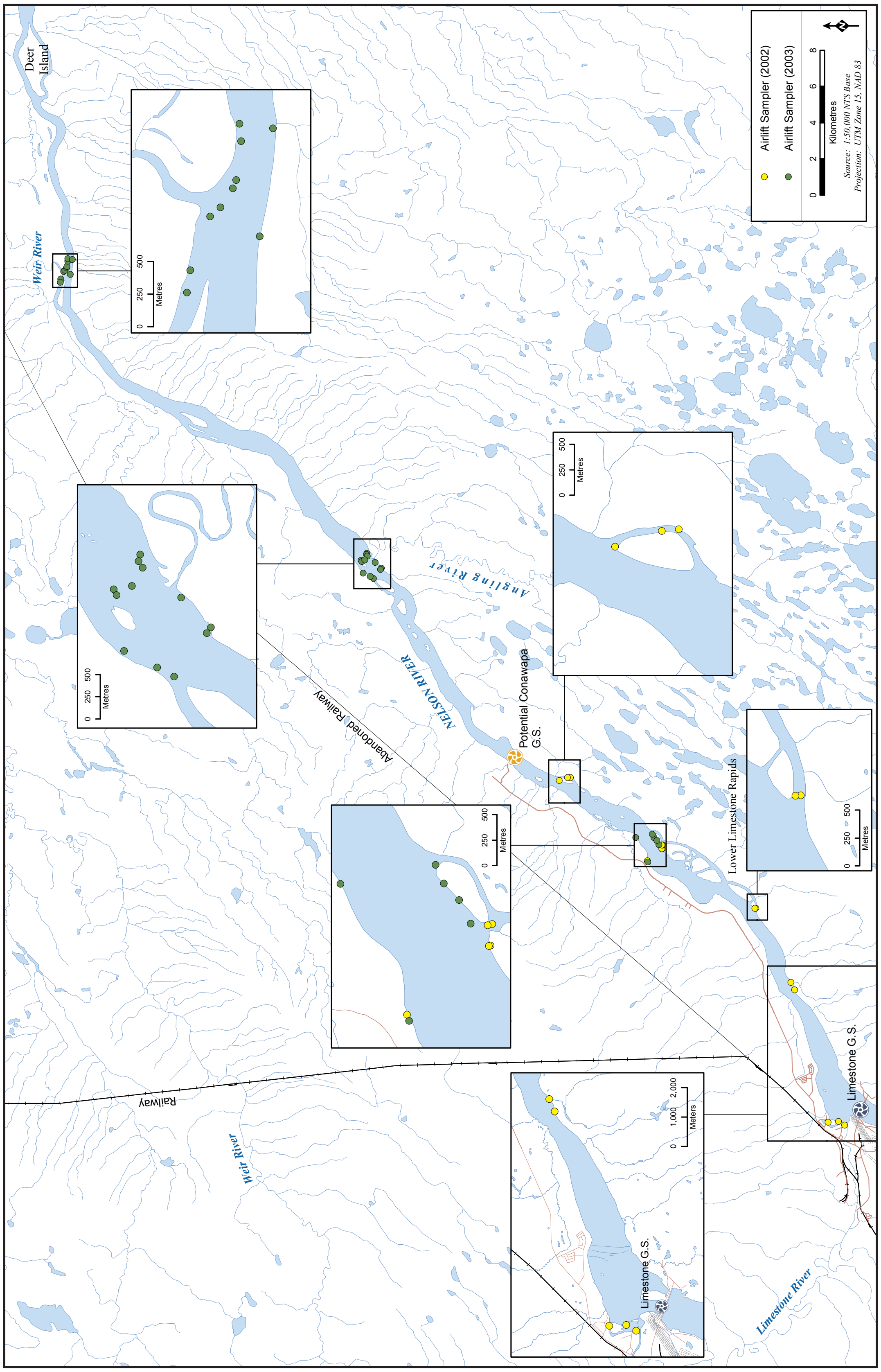


FIGURE 6-7 Airlift sampling locations in the lower Nelson River downstream of the Limestone G.S., 2002 and 2003.

6.3 Results

6.3.1 Primary Productivity

6.3.1.1 Phytoplankton

As discussed in Chapter 5.0, chlorophyll *a* measured in water quality samples is an indicator of phytoplankton biomass. Chlorophyll *a* was measured in the Long Spruce and Limestone forebays and in the lower Nelson River mainstem from 1990 to 2003. Chlorophyll *a* was relatively similar at all sites in all years, with annual means for the open-water season of approximately 3 to 9 µg/L. Based on the trophic categorization scheme developed for rivers, the forebays are considered oligotrophic (see Chapter 5.0 for more details).

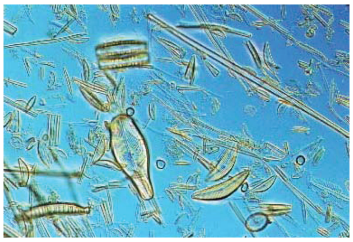


PHOTO 6-5
Magnified image of some typical phytoplankton.

A total of 49 species of phytoplankton were identified from the lower Nelson River in August 1992 (Table 6-2, Photo 6-5). Approximately half of the species were uncommon, occurring at only one site. Only five species were common to all sites. The phytoplankton communities in the Long Spruce and Limestone forebays and downstream in the Nelson River mainstem were similar, with no large differences in the proportions of algal groups. Diatoms (principally *Melosira italica*) and cryptophytes (primarily *Rhodomonas minuta*) dominated assemblages. At Gillam Island, diatoms (largely *M. italica* and *Melosira binderama*) were virtually the only phytoplankton present. The phytoplankton assemblage from the forebays had a much smaller proportion of green and chrysophyte algae compared to assemblages sampled from Stephens Lake in 1988 (Livingston 1989) and 1989 (Janusz 1990a). Higher water velocities downstream of Stephens Lake may be unsuitable for these species.

Phytoplankton biomass estimates for August 1992 from the Long Spruce and Limestone forebays, and from the lower Nelson River mainstem near the Conawapa site, were similar and somewhat higher than farther downstream at Gillam Island. Values from the forebays were approximately 60% of those reported by Livingston (1989) and Janusz (1990a) during late summer at a mainstem location on Stephens Lake. The differences may be related to water residence time, which is approximately 28 days in Stephens Lake compared to 1-2 days in the forebays.

Measurements of phytoplankton biomass conducted in the lower Nelson River in 1992 were insufficient to determine whether significant production was occurring *in situ* or whether most phytoplankton were a product of upstream lakes. Phytoplankton samples included both lacustrine and benthic species. Many chain-forming species were present as long chains, suggesting that cell division was occurring. However, the absence of consistent differences in chlorophyll *a* concentrations among sites on the lower Nelson River over a considerable period of study suggests that the presence of the forebays does not result in an overall increase in phytoplankton as water moves through the system.

6.3.1.2 Aquatic Macrophytes

Surveys for aquatic macrophytes were conducted in the Long Spruce and Limestone forebays, the lower Nelson River mainstem below the Limestone G.S., and Beaver and Goose creeks in 1992. Survey data were supplemented by collections made by Stepaniuk (1991). A complete taxonomic list and distribution are presented in Table 6-3.

Few aquatic macrophytes were found in the lower Nelson River mainstem during the 1992 surveys. The majority identified were located along a shallow 3-km reach of the north shore of the Long Spruce Forebay, an area that was flooded in 1979. Within this area, a vegetative community, including two sedge species (*Carex aquatilis* and *Eleocharis palustris*) and water parsnip (*Sium sauve*), covered approximately 90% of the shoreline. In the same area, approximately 10-20% of the littoral zone supported beds of submerged vegetation dominated by Richardson's pondweed (*Potamogeton richardsonii*). Over the remainder of the Long Spruce Forebay, vegetation was patchy and limited to bays or flooded islands. Only 5-10% of the shoreline supported emergent vegetation and less than 1% of the littoral zone contained submergent vegetation. Limited growth of submerged rooted vegetation is typical of reservoirs with fluctuating water levels, where little permanently wetted habitat receives sufficient light to support photosynthesis during the growing season.

In contrast to the Long Spruce Forebay, no aquatic macrophytes were observed in 1992 along the entire shoreline of the Limestone Forebay, including the creek mouths. Studies conducted subsequent to the completion of the Limestone Monitoring Program in 2003 have found that aquatic plants have colonized limited areas in sheltered habitats such as flooded creek mouths.

North-shore tributary streams downstream of the Limestone G.S. and upstream of the proposed Conawapa G.S. site can be divided into lower "wooded" and upstream "bog" portions. Upstream portions of tributaries are characterized by reduced gradients and an open canopy. This habitat supports a minimal growth of macrophytes, with cover estimated at less than 5%. The narrow-leaf bur-reed (*Sparganium angustifolium*) is the most common macrophyte within this habitat.

In the lower, wooded sections of the tributary streams, habitat is characterized by steep gradients, large-diameter substrate, and a closed canopy. Some emergent sedges (*Carex* spp.) are present, but few true aquatic macrophytes have established themselves in these habitats. Pip (1979) hypothesized that few macrophytes grow in small creeks because of severely fluctuating water levels and periodic scouring. Narrow-leaf bur-reed and water arum (*Calla palustris*) are two species found within these habitats. Overall macrophyte cover within the downstream portion of tributary streams was estimated at less than 1%.

Sago pondweed (*Potamogeton pectinatus*) was collected from the lower Nelson River below the Limestone G.S. in 1992, which grew in an isolated clump near Gillam Island. Stepaniuk (1991) recorded one species of water milfoil (*Myriophyllum* sp.) immediately below the Limestone G.S. Fluctuating water levels, high-water velocity, ice scouring, and lack of suitable substrate combine to make the Nelson River mainstem an unfavourable habitat for aquatic macrophytes.

6.3.1.3 Attached Algae

Attached algae that grow on macrophytes, stones or mud are often a major food source for invertebrates, but their contribution to total algal production is seldom considered. Growth of these algae is limited to substrates of relatively constant water cover where sufficient light can penetrate to the substrate. Anecdotal reports of filamentous green algae growing in the tailrace area of the Long Spruce G.S. suggest that such areas provide potential habitat. Although benthic algal biomass was not estimated during the aquatic monitoring studies, gill nets frequently become clogged with drifting filamentous algae, apparently from benthic sources. Because the calculated area of permanently submerged substrate receiving sufficient light for photosynthesis in the Long Spruce and Limestone forebays is extremely small, it is likely that the majority of drifting algae is produced in upstream reservoirs such as Stephens, Sipiwesk, and Split lakes. Conditions of these lakes are more suitable for the production of benthic algae.

Growths of attached algae have also been observed in open areas (mainly at creek mouths) of a few north-shore tributary streams downstream of the proposed Conawapa site. Tributary streams have not been surveyed for algae, but benthic algae probably provide significant primary production where sufficient light passes through the overhead canopy, as has been demonstrated in other areas (Hynes 1970). Extensive bands of attached algae were observed along shallow rocky shoals in the lower Nelson River below the proposed Conawapa site during detailed fish habitat work conducted post-2003.

6.3.2 Zooplankton

A total of 38 species of zooplankton were reported from the Long Spruce and Limestone forebays during the 1992 summer survey, and species composition was similar between the forebays (Table 6-4). Rotifers were the most numerically dominant, comprising 90% of the total zooplankton numbers. Copepods and cladocerans were much less abundant comprising 12-13% of the total zooplankton numbers in each forebay (Photo 6-6). Numbers of rotifers

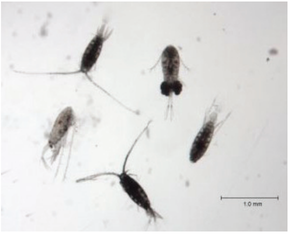


PHOTO 6-6 Magnified image of some typical copepod zooplankton.

and copepods were approximately one-half to one-third of those reported from a mainstem station of Stephens Lake (Janusz 1990b). Zooplankton numbers at the Stephens Lake site were low compared to other lakes in the same study. This was attributed to the short water retention time, preventing the accumulation of zooplankton biomass (Ramsey et al. 1989). The comparatively lower total zooplankton numbers observed in the lower Nelson River forebays in 1992 are attributable to even higher water flushing rates. Mortality of zooplankton in swift rivers is also very high (Hynes 1970); therefore, many zooplankters washed out of upstream lakes would likely die. Numbers of Cladocera, (primarily large numbers of *Eubosmina*), were the same or higher in the Long Spruce and Limestone forebays than in the mainstem of Stephens Lake. *Eubosmina* is often abundant in rivers and appears well-adapted to high-water velocities (Hynes 1970).

Twenty-three cladoceran and copepod taxa were identified from the Long Spruce and Limestone forebays in 2002 (Table 6-4). (It should be noted that rotifers were excluded from data analysis due to a change in sampling protocol after the zooplankton survey in 1992.) Copepoda comprised the majority of the zooplankton catch in both forebays during spring and again in the Limestone Forebay during fall. Conversely, Cladocera dominated the zooplankton catch during the summer sampling periods and also in the Long Spruce Forebay during fall. *Eubosmina longispina* was identified as the dominant cladoceran species in both forebays during August, which was consistent with results from the 1992 summer survey.

Zooplankton samples were collected in the open river near Gillam Island from July to September in 1988 and again in August of 1992. This area, where the water is swift but not very deep (1 to 2 m with an 8-m deep channel at one site), is more riverine than upstream impoundments, and may be representative of zooplankton at sites downstream of the Limestone G.S. as well as in larger tributary streams.

As expected, the proportion of typical zooplankton (rotifers, cladocerans, and copepods) was low. More than 40% of the fauna collected in zooplankton nets were drifting insect larvae.

6.3.3 Benthic Invertebrates

The benthic invertebrate fauna of the lower Nelson River is a diverse group, including oligochaetes (aquatic earthworms), gastropods (snails), bivalves (clams), crustaceans (ostracods, amphipods), and insects [primarily the larval stage(s) of terrestrial adult species]. As discussed earlier, the diversity of habitats in this environment required sampling using a suite of methods. Results for each sampling method are discussed below and overall conclusions are presented at the end of this chapter.

Pan traps and emergent traps

Although pan traps are an effective method of capture for emerging adult insects, the precise source of the insects captured cannot be determined. Some species fly upstream before laying eggs, while the flight patterns of others are random or vary with environmental changes (Bird and Hynes 1981; Gullefors 1987). For example, many species of Diptera (true flies) lay their eggs in wetlands and small streams rather than open rivers (Merritt and Cummins 1996). Therefore, pan trap data may not always be indicative of the insects emerging from waters adjacent to the traps. While species that obviously originated from outside large river environments (e.g., dipterans) were excluded from the pan trap data, individuals may have originated in adjacent rivers or from the tailrace downstream of the sampling site. Conversely, pan trap catches provide a useful integrated measure of insects with aquatic larval forms within the study area and provide information from surveys conducted throughout the 1990s.

Chironomids (non-biting midges) were the most abundant group captured in pan traps in the forebay and mainstem sites. Trichopterans (caddisflies) were the next most abundant group, while plecopterans (stoneflies) and ephemeropterans (mayflies) were captured in relatively low proportions. Chironomid emergence produced three separate peaks:

i) late June to early July;

ii) late July; and

iii) late August

Trichopteran emergence generally peaked in late July.

Species-specific analysis of Trichoptera within the pan traps indicated that species composition of sites in the Limestone Forebay was intermediate between that of the Long Spruce Forebay and the Nelson River mainstem, with species more typical of lake environments predominant in the former and more riverine species predominant in the latter. The trap set adjacent to the lower Limestone Forebay generally had the greatest number of species in common with the mainstem site, suggesting that some of the individuals captured may have originated in the tailrace below the generating station. For example, the predominant trichopteran species at the lower Limestone Forebay and Nelson River mainstem sites were characteristic of fauna inhabiting fast-flowing water and included *Hydropsyche* spp. and *Cheumatopsyche* spp. (family Hydropsychidae). In contrast, the predominant trichopteran species captured in the Long Spruce Forebay were more typical of slow-flowing, more lacustrine environments and included *Hydroptila* spp. (family Hydroptilidae) and *Polycentropus* spp. (family Polycentropodidae). However, data from emergence traps set in 1992 indicated that some species typical of riverine environments (e.g., hydropsychids) emerged directly from the lower Limestone Forebay.

Emergence traps in this study sampled a very small area. Insects captured in any given trap were subject to chance emergence events and, as a result, estimates of total abundance may be less than accurate. For this reason, among-site comparisons were not valid and this sampling technique was discontinued after 1992.

The total number and relative abundance of insect groups caught in pan traps varied considerably among sites and years (figures 6-8 and 6-9). However, insects were collected at all sites for all years in the Limestone Forebay. Apart from the extremely low catch in the lower forebay immediately after impoundment, catches were within the range observed upstream in the Long Spruce Forebay and downstream in the unimpounded Nelson River mainstem, indicating that insect production continued despite the large changes in water levels and flows post-impoundment. No conclusions can be reached regarding trends in abundance at specific locations in the forebay, given that insects may travel a considerable distance prior to being trapped in the pans. In addition, interannual differences of catches at the Long Spruce Forebay, where conditions have stabilized in relation to impoundment, indicate the inherent variability in this sampling technique.

Ponar grabs

Sediments too hard to be sampled using Ponar grabs were relatively common: in 1993, samples were only obtained in 64 and 42% of the attempts in the Long Spruce and Limestone forebays, respectively. During a more intensive survey in 2003, Ponar grab samples were obtained from 77 and 68% of the

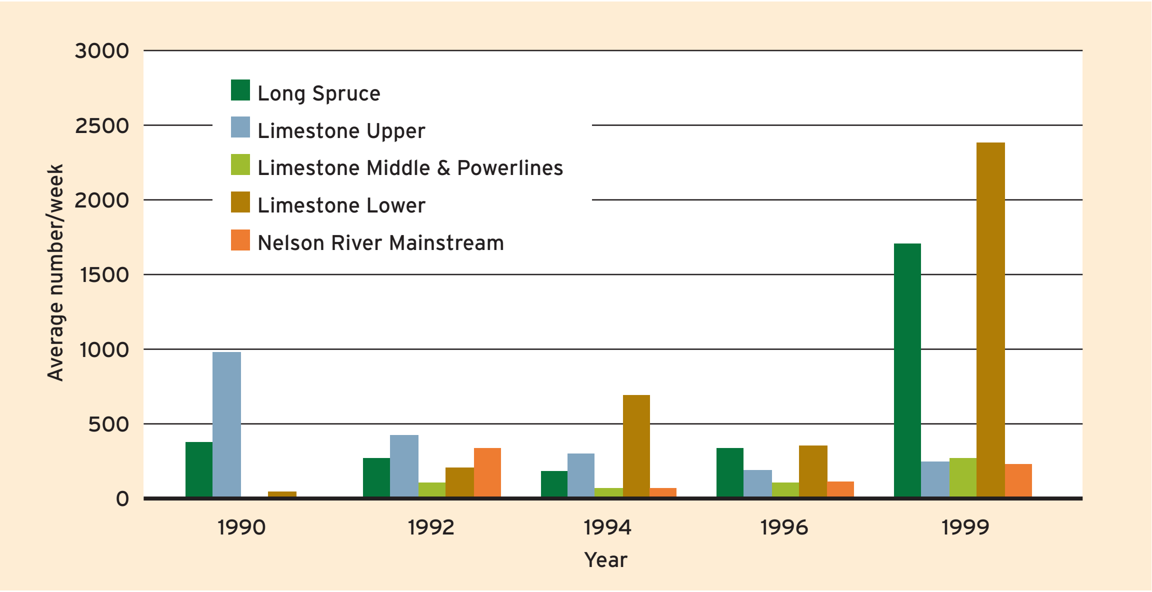


FIGURE 6-8
Average number of adult insects captured per week in pan traps set in the Long Spruce Forebay, the Limestone Forebay (upper, middle, and lower regions), and in the Nelson River mainstem downstream of the Limestone G.S. in 1990, 1992, 1994, 1996, and 1999.

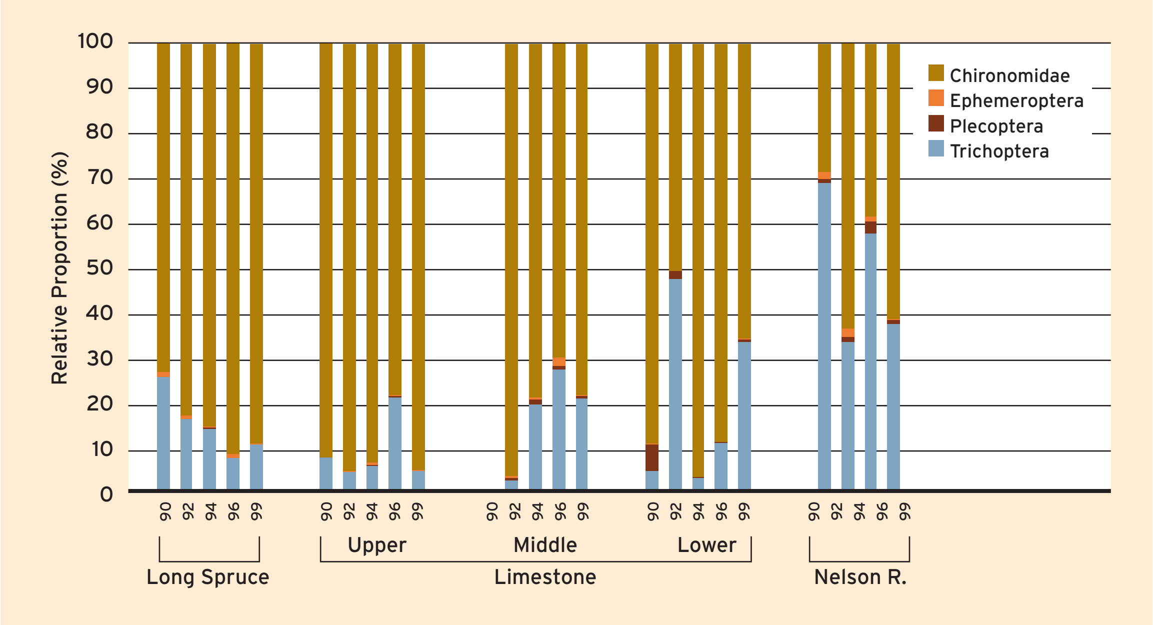


FIGURE 6-9 Taxonomic composition of adult insects captured per week in pan traps set in the Long Spruce Forebay, the Limestone Forebay (upper, middle, and lower regions), and in the Nelson River mainstem downstream of the Limestone G.S. in 1990, 1992, 1994, 1996, and 1999.

attempted sites in the Long Spruce and Limestone forebays, respectively. The higher retrieval rate in 2003 is attributed to a change in sampling protocol, in which the Ponar grab was gently lowered to the forebay bottom and shifted slightly if a boulder was encountered adjacent to a soft sediment area.

Chironomids, oligochaetes, and amphipods (scuds) were the most abundant invertebrates and, in conjunction with ephemeropterans, bivalves, and gastropods, comprised the majority of organisms collected in all years (Table 6-5, photos 6-7 and 6-8).

PHOTO 6-7 Magnified image of a typical chironomid larva.

PHOTO 6-8 Magnified image of a typical amphipod.

The abundance and relative composition of invertebrates in Ponar grab samples varied considerably among locations and years (figures 6-10 and 6-11). The abundance of benthic invertebrates in the Limestone Forebay appeared to increase over the course of the study, reaching levels (3100, 3000, and 5500 individuals/m^2 in the upper, middle, and lower sections) comparable to those observed in the Long Spruce Forebay (2300, 3200, and 4200 individuals/ m^2 in the upper, middle, and lower sections) by 2003. Although few sites in the Nelson River mainstem could be sampled with Ponar grabs, average invertebrate abundance was comparable to the forebays (Figure 6-10). However, given the interannual variability observed in the Long Spruce Forebay, where the invertebrate fauna would no longer be undergoing substantial changes in response to impoundment, it is possible that observed trends reflect interannual variability due to other causes and not an evolution of the forebay fauna.

The forebays tended to have relatively greater numbers of amphipods and ephemeropterans than the Nelson River mainstem site, where oligochaetes and dipterans tended to be relatively more abundant. Amphipods generally occur in greater numbers within slower moving water; therefore, an increase in their abundance following impoundment could be expected. Greater abundance of ephemeropterans [primarily Ephemeridae (burrowing mayflies)] may be due to the establishment of silt or clay bottoms (the preferred habitat of burrowing mayflies; Merritt and Cummins 1996) in the lower region of each forebay following impoundment.

Rock traps

Rock traps were first deployed in 1994 to provide more site-specific information than could be gained from the pan traps, while providing a measure of relative invertebrate abundance on rocky substrates, which could not be sampled with Ponar grabs.

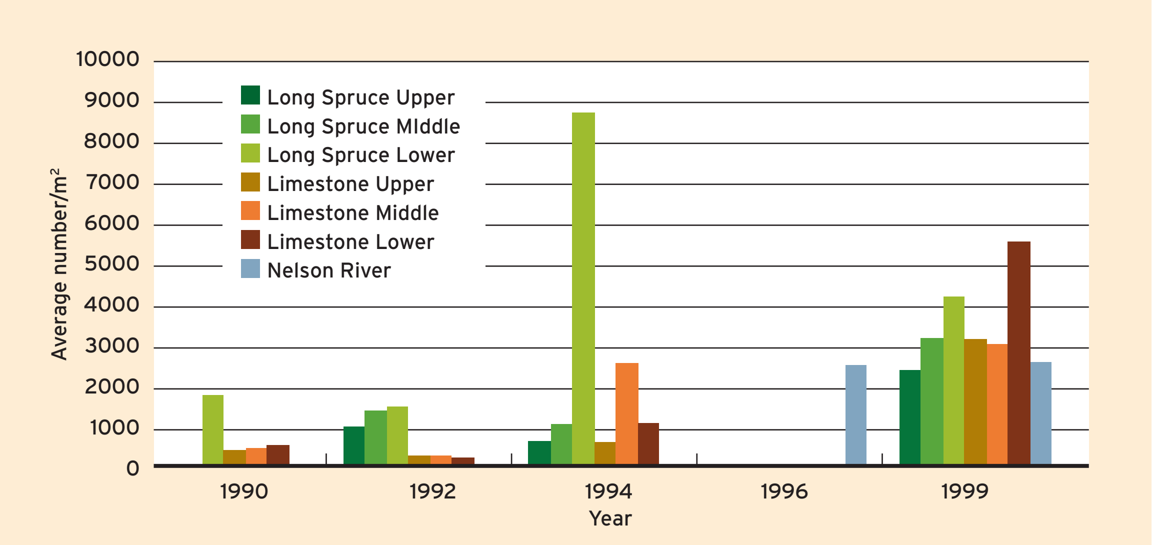


FIGURE 6-10
Average number of benthic invertebrates per m² from Ponar grab samples in the upper, middle, and lower regions of the Long Spruce and Limestone forebays and in the Nelson River mainstem downstream of the Limestone G.S., 1990, 1992, 1993, 2002, and 2003.

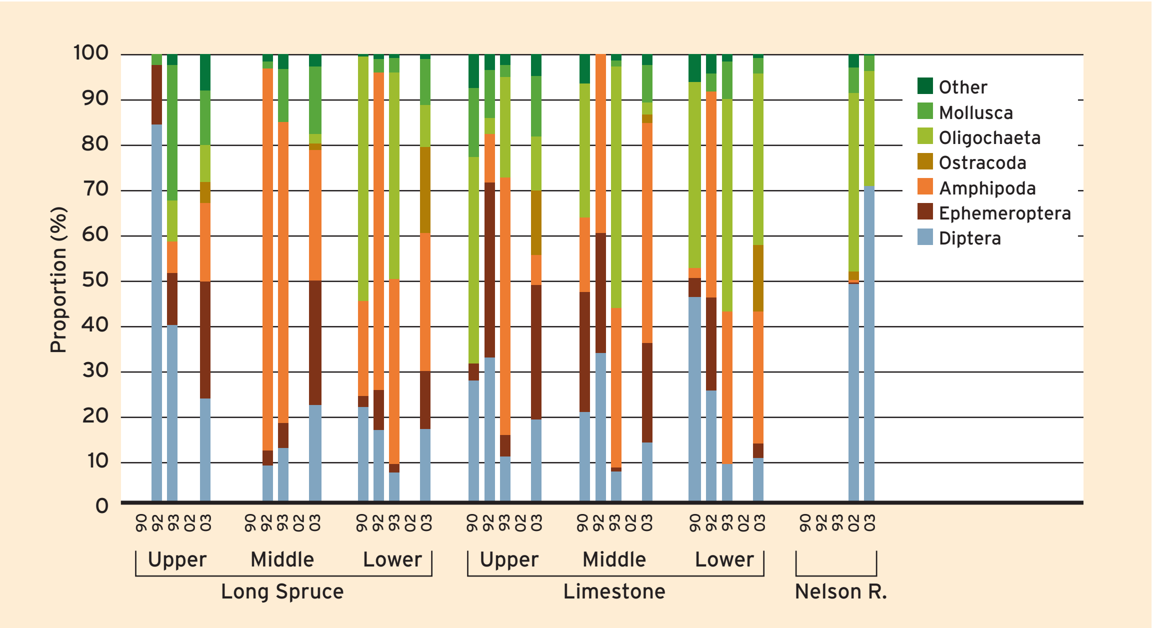


FIGURE 6-11
Taxonomic composition of benthic invertebrates collected from Ponar grab samples in the upper, middle, and lower regions of the Long Spruce and Limestone forebays and in the Nelson River mainstem downstream of the Limestone G.S., 1990, 1992, 1993, 2002, and 2003.

As with the other sampling techniques, there is considerable variability among sites and years (figures 6-12 and 6-13). During the first three years of the study (1994-1996), catches were lower in the middle and lower sections of the Limestone Forebay than in the Long Spruce Forebay, the upper Limestone Forebay (where impoundment had the least effect on water levels), and in the Nelson River mainstem; in 1999, catches in all locations were comparable. However, as discussed for the other sampling methods, the high interannual variability observed in the Long Spruce Forebay indicates that observed changes may reflect natural background variability rather than an evolution with the forebay.

Chironomids comprised a substantial part of the catch at all locations in most years. However, in the forebays, ephemeropterans and amphipods were also abundant, while in the Nelson River mainstem, trichopterans formed a substantial portion of the catch.

FIGURE 6-12
Average number of aquatic invertebrates captured in rock traps set in the Long Spruce Forebay, the Limestone Forebay (upper, middle, and lower regions), and in the Nelson River mainstem downstream of the Limestone G.S., 1994-1996 and 1999.

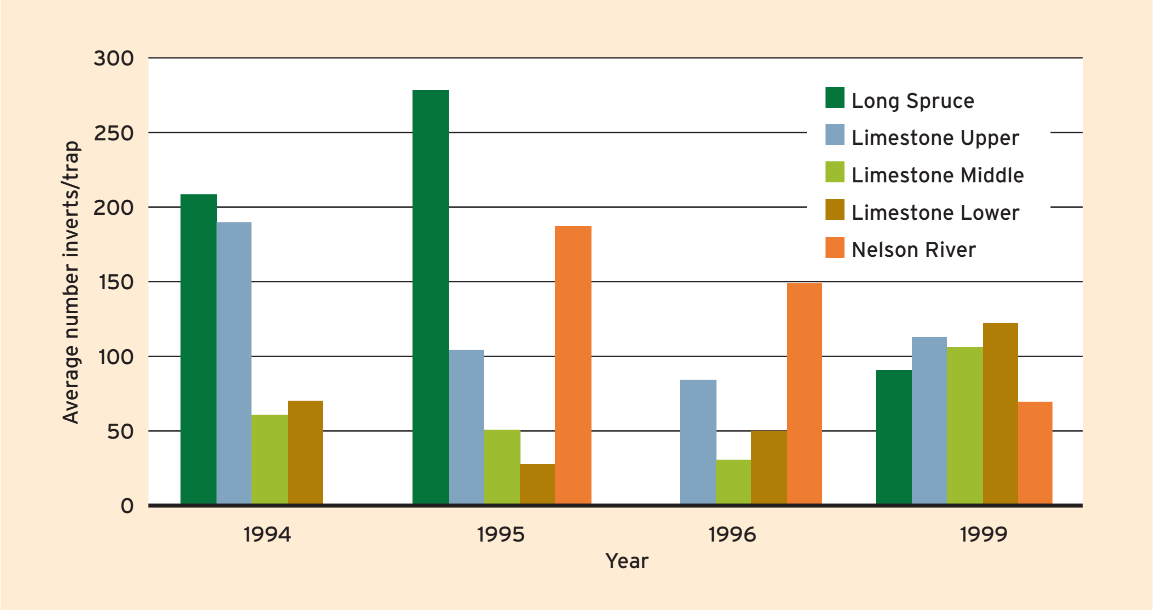
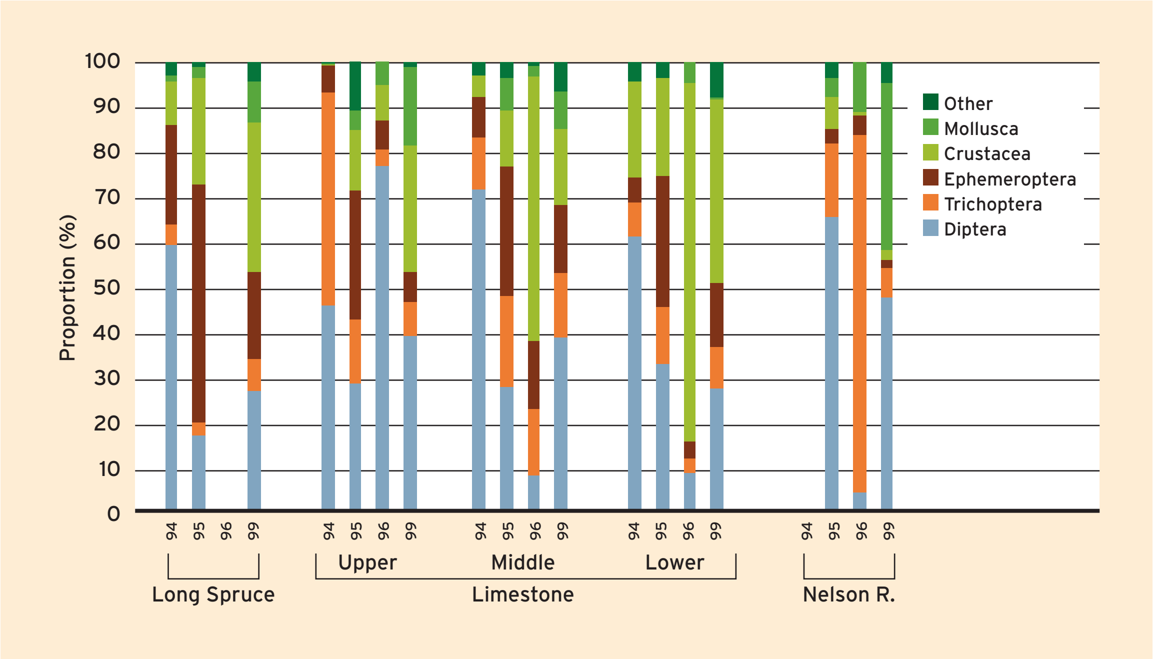


FIGURE 6-13
Taxonomic composition of invertebrates captured in rock traps set in the Long Spruce Forebay, the Limestone Forebay (upper, middle, and lower regions), and in the Nelson River mainstem downstream of the Limestone G.S., 1994-1996 and 1999.



Hess samples and airlift samples

In 2002 and 2003, in anticipation of future downstream development, the Nelson River mainstem was targeted with sampling techniques designed to better sample the large, fast-flowing river. Shallow locations were sampled with Hess samplers, while deep locations (where velocity was sufficiently low) were sampled with airlift samplers. These methods were not suitable for the reservoir environment, so directly comparable data could not be obtained from the Limestone Forebay.

Mean invertebrate densities of 186 to 1,633 individuals/m^2 were collected in Hess samples at various locations in the mainstem. Of the 29 invertebrate taxa identified, the most abundant were oligochaetes and chironomids, comparable to results from Ponar grab and rock trap samples. Other common taxa included bivalves, ephemeropterans, gastropods, hemipterans (true water bugs), plecopterans, and trichopterans.

A total of 24 taxa were collected with an airlift sampler from the lower Nelson River at various locations downstream of the Limestone G.S. in 2002 and 2003. Mean invertebrate densities varied between 194 and 514 individuals/m^2, with oligochaetes and chironomids being the most abundant groups. Ephemeropterans, gastropods, hirudineans (leeches), hydrozoans, ostracods (seed shrimps), and plecopterans also were identified.

6.4 Summary of Effects

Impoundment by the Limestone G.S. resulted in only moderate changes in lower trophic level groups within the Limestone Forebay, generally reflecting a change from a riverine to a slightly more lacustrine environment. Impoundment of rivers to form reservoirs can result in more dramatic changes in production and species composition where impoundment is associated with extensive flooding and the creation of a large reservoir with truly lacustrine characteristics. However, as construction of the Limestone G.S. resulted in minimal flooding with no detectable organic enrichment (see Chapter 5.0), there was no associated stimulation of production among the lower trophic levels.

6.4.1 Primary Productivity

Results of chlorophyll *a* analyses indicate no consistent temporal or spatial differences among the forebays or the Nelson River mainstem, suggesting that impoundment had little, if any, effect on phytoplankton biomass. Chlorophyll *a* data suggest that the area can be classified as oligotrophic based on trophic classification information presented in Chapter 5.0. The absence of a marked increase in phytoplankton biomass is likely due to the short water residence time within the forebay which, although longer than the unimpounded river, is still too short to allow substantial growth of phytoplankton.

Aquatic macrophyte growth was scarce in the Limestone Forebay three years after impoundment. A survey conducted in 2002 found limited macrophyte growth in some of the sheltered bays created in flooded tributary mouths. Rooted vegetation is slightly more abundant in the Long Spruce Forebay. Macrophyte growth is often minimal in reservoirs due to frequent water level fluctuations; in addition, the limited area of fine-textured substratum along the shoreline and ice-scour on the lower Nelson River limit potential habitat for macrophytes.

Extensive areas of attached algae were observed in the lower Nelson River mainstem in studies conducted after 2003 (completion of the Limestone Monitoring Program); given the absence of suitable growing conditions for attached algae in much of the forebay, impoundment may have reduced growth of these algae.

6.4.2 Zooplankton

Typical zooplankters such as cladocerans and copepods were present in the forebays in surveys conducted in 1992 and 2002. Comparison to samples collected in the Nelson River mainstem at Gillam Island in 1992 indicated that zooplankton abundance was higher in the forebays, and that the composition was different, with drifting invertebrates, rather than typical zooplankton, dominating the catch at the river site.

The abundance of these zooplankters in the river prior to impoundment by the Limestone G.S. is not known; however impoundment appears to create a more suitable environment. This is likely due to decreased water velocity rather than increased nutrient supply, as levels of organic matter within the forebays were not markedly higher than at downstream sites (see Chapter 5.0).

6.4.3 Benthic Invertebrates

Both the forebay and unimpounded river environments of the lower Nelson River provide a diverse array of habitats for benthic invertebrates. The variability in total invertebrate abundance and relative composition in all the sampling methods employed (i.e., pan traps, Ponar grabs, Hess sampler, airlift sampler, and rock traps) indicates the heterogeneous nature of the environment, both on a site-specific scale (among replicates) as well as among sections of the forebays and the Nelson River mainstem downstream of the Limestone G.S.

Following impoundment, the prevalence of soft substrates in the forebays appeared to increase relative to hard, rocky areas. The mainstem and forebays exhibit differences in the relative abundance of certain major groups (e.g., the relatively greater abundance of amphipods and ephemeropterans within the forebays vs. relatively more trichopterans in the mainstem). These differences may be indicative of relatively greater areas of lower velocity, soft substrate habitat in the forebays in comparison to the mainstem. However, the upper sections of both forebays provide habitat for riverine species.

Although definitive conclusions regarding changes in the total abundance of invertebrates in the Limestone Forebay cannot be reached due to the variability observed among locations and years, it is noteworthy that abundance recorded within the Limestone Forebay was generally within the range of samples collected in the Long Spruce Forebay and the Nelson River mainstem.

Invertebrate abundance in the Long Spruce Forebay is generally comparable to, or greater than, that in the Nelson River mainstem downstream of the Limestone G.S. when samples collected by the same method are compared. However, this result cannot be readily transferred to overall abundance within the forebay vs. unimpounded river habitat without an understanding of the relative abundance of invertebrates in various habitat types or the relative abundance of the habitats in the forebays vs. river locations.

TABLE 6-1 A summary of the methods used to sample lower trophic levels in the Long Spruce and Limestone forebays and in the lower Nelson River mainstem, 1990-2003. The symbol "+" denotes that samples were collected.

Waterbody	Organisms	Method	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2002	2003
Long Spruce Forebay	Benthic inverts	Ponar grab	+		+	+								+
		Rock trap					+	+	+			+		
	Emergent insects	Pan trap	+		+	+	+		+			+		
		Emergence trap			+									
	Phytoplankton													
	- direct enumeration	Water sampling			+									
	- estimated from Chl *a* analysis	Water sampling	+	+	+	+	+		+			+		
	Zooplankton	Plankton net			+								+	
	Macrophytes	Presence/absence			+									
Limestone Forebay	Benthic inverts	Ponar grab	+		+	+								+
		Rock trap					+	+	+			+		
	Emergent insects	Pan trap	+		+	+	+		+			+		
		Emergence trap			+									
	Phytoplankton													
	- direct enumeration	Water sampling			+									
	- estimated from Chl *a* analysis	Water sampling	+	+	+	+	+		+			+		
	Zooplankton	Plankton net			+								+	
	Macrophytes	Presence/absence			+									
Nelson River mainstem	Benthic inverts	Ponar grab			+								+	+
		Rock trap						+	+			+		
		Airlift sampler											+	+
		Hess sampler											+	+
	Emergent insects	Pan trap	+		+	+	+		+			+		
	Phytoplankton													
	- direct enumeration	Water sampling			+									
	- estimated from Chl *a* analysis	Water sampling			+	+	+		+			+		
	Macrophytes	Presence/absence			+									

TABLE 6-2 Species of phytoplankton identified from the lower Nelson River[1] system in 1992. The symbol "+" denotes presence.

Class	Species	Kettle Forebay	Long Spruce Forebay	Limestone Forebay	Nelson River Mainstem	Gillam Island
Cyanophyceae						
	Anabaena sp.			+		
	Aphanizomenon flos-aquae	+	+	+	+	
	Chroococcus limneticus		+			
	Gomphosphaeria lacustris	+				
	Merismopedia glauca	+	+			
Dinophyceae						
	Gymnodinium sp.	+				
	Peridinium inconspicum					
	Peridinium pusilla			+		
Cryptophyceae						
	Cryptomonas erosa	+	+	+	+	
	Cryptomonas ovata	+			+	
	Cryptomonas rostratiform	+	+	+		
	Katablepharis ovalis	+	+	+		
	Rhodomonas minuta	+	+	+	+	
Chrysophyceae						
	Chrysidiastrum catenatum					
	Dinobryon sertularia		+			
	Dinobryon sociale	+				
	Ochromonas sp.	+				+
	Ophiocytium cochleare					
	Salpinogoeca sp.		+			
	Stelexomonas dichotoms				+	
	Stichlogloea spp.					+
Bacillariophyceae						
	Amphora sp.					
	Asterionella formosa		+	+	+	+
	Chaetoceros sp.					
	Cyclotella bodanica					
	Cyclotella comta		+	+		
	Cyclotella stelligera	+		+	+	+
	Cyclotella sp.				+	
	Cymbella gracilis				+	
	Diatoma vulgare				+	
	Eunotia sp.					
	Fragilaria construens				+	
	Fragilaria spp.		+			
	Gomphonema sp.					
	Melosira binderana	+	+	+	+	+
	Melosira italica	+	+	+	+	+
	Navicula sp.					

Table 6-2 continued

Class	Species	Kettle Forebay	Long Spruce Forebay	Limestone Forebay	Nelson River Mainstem	Gillam Island
Bacillariophyceae (cont.)						
	Nitzschia filiformis				+	+
	Nitzschia fonticola					
	Rhoicosphenia curvata					
	Stephanodiscus astreae	+	+	+	+	+
	Surirella delicatissima					
	Surirella ovata					
	Synedra acus	+	+	+	+	
	Synedra ulna	+	+	+	+	+
	Tabellaria fenestrata	+			+	
	Tabellaria flocculsa					+
Chlorophyceae						
	Ankistrodesmus braunii					
	Ankrya judai	+		+		+
	Botryococcus braunii					
	Chlamydomonas spp.	+	+		+	+
	Chodatella sp.			+		
	Closterium sp.	+	+	+	+	
	Closterium kutzingii					
	Coelastrum cambricum		+			
	Crucigeniella quadrata					+
	Gloeococcus schroeteri			+		
	Monoraphidium sp.					
	Monoraphidium contortum		+			+
	Monoraphidium setiforme	+	+	+	+	+
	Mougeotia sp.					+
	Oocystis borgei		+			+
	Pediastrum duplex	+			+	+
	Scenedesmus denticulatus	+			+	
	Scenedesmus quadricauda					+
	Staurastrum sp.					+
	Staurastrum paradoxum					

[1] Phytoplankton also were collected in the Nelson River Estuary in 1992 (see Chapter 8.0).

TABLE 6-3 Species of macrophytes identified in the lower Nelson River in 1992. The symbol "+" denotes presence.

Family	Genus/Species	Common name[1]	Long Spruce Forebay	Limestone Forebay	Nelson River mainstem
Alismataceae					
	Sagittaria cuneata	Arum-leaved arrowhead	+		+
Araceae					
	Calla palustris	Water arum	+	+	+
Callitrichaceae					
	Callitriche palustris	Vernal water-starwort	+	+	+
Cyperaceae					
	Carex aquatilis	Water sedge	+*		+
	Carex vesicaria	Blister sedge[2]		+	+
	Cyperaceae sp.	n/a			+
	Eleocharis palustris	Creeping spike-rush[2]	+*		
	Scirpus microcarpus	Small-fruited bulrush			+
Equisetaceae					
	Equisetum fluviatile	Swamp horsetail	+	+	+
	Equisetum palustre	Marsh horsetail			+
	Equisetum pratense	Meadow horsetail[2]			+
	Equisetum variegatum	Variegated horsetail			+
Gentianaceae					
	Menyanthes trifoliata	Bogbean			+
Graminae					
	Glyceria borealis	Northern manna grass	+		
Haloragaceae					
	Hippuris vulgaris	Mare's-tail	+*	+	+
	Myriophyllum exalbescens	Northern water-milfoil	+*	+	
	Myriophyllum verticillatum	Bracted water-milfoil			+*

Table 6-3 continued

Family	Genus/Species	Common name[1]	Long Spruce Forebay	Limestone Forebay	Nelson River mainstem
Lentibulariaceae					
	Utricularia intermedia	Flat-leaved bladderwort	+		
	Utricularia vulgaris	Common bladderwort	+		
Nymphaeaceae					
	Nuphar variegata	Yellow pond-lily	+		
Ranunculaceae					
	Ranunculus aquatilis	White water-crowfoot	+*		+
	Ranunculus gmelinii	Gmelin's crowfoot	+		+
Sparganiaceae					
	Sparganium angustifolium	Narrow-leafed bur-reed	+	+	+
Typhaceae					
	Typha latifolia	Common cattail		+	
Umbelliferae					
	Sium suave	Water parsnip	+*		
Zosteraceae					
	Potamogeton alpinus	Red pondweed		+	+
	Potamogeton friesii	Fries pondweed		+	
	Potamogeton gramineus	Variable pondweed	+	+	+
	Potamogeton pectinatus	Sago pondweed	+	+	+*
	Potamogeton richardsonii	Richardson's pondweed	+*	+	+
	Potamogeton vaginatus	Large-sheath pondweed			+
	Stuckenia filiformis	Thread-leaved pondweed	+	+	+

[1] Lahring (2003)
[2] Integrated Taxonomic Information System (2008)
* Species that were collected in the lower Nelson River proper. All other species were collected in tributaries to the lower Nelson River.

TABLE 6-4 Species of zooplankton identified in the lower Nelson River during surveys conducted in 1992 and 2002. The symbol "+" denotes presence.

PHYLUM / Subphylum / Class / Subclass / Order / Family	Species	Limestone Forebay		Long Spruce Forebay		Nelson River Mainstem
		1992	2002	1992	2002	1992
CNIDARIA						
Hydrozoa	Unknown	+		+		+
ROTIFERA[1]						
Eurotatoria						
Monogonota						
Ploima						
Asplanchnidae	*Asplanchna* sp.	+		+		
Brachionidae	*Kellicottia* sp.	+		+		
	Keratella cochlearis	+		+		
	Keratella quadrata	+		+		
Notommatidae	Unknown	+		+		
Synchaetidae	*Polyarthra* sp.	+		+		
Flosculariaceae						
Filiniidae	*Filinia* sp.	+		+		
ARTHROPODA						
Chelicerata						
Arachnida						
Acari[2]	Unknown	+		+		+
Crustacea						
Branchiopoda						
Phyllopoda						
Diplostraca[3]	Unknown					+
Bosminidae	*Bosmina longirostris*		+		+	
	Eubosmina coregoni		+		+	
	Eubosmina longispina	+		+		
Chydoridae	Unknown	+		+		
	Acroperus harpae	+		+		
	Alona costata	+		+		
	Alona guttata				+	
	Camptocercus rectirostris		+		+	
Daphniidae	*Ceriodaphnia quadrangula*		+		+	
	Ceriodaphnia reticulata	+		+		
	Daphnia dubia	+		+		
	Daphnia galeata mendotae		+		+	
	Daphnia longiremis		+		+	
	Daphnia pulex	+		+		
	Daphnia retrocurva	+	+	+	+	

Table 6-4 continued

PHYLUM / Subphylum / Class / Subclass / Order	Family	Species	Limestone Forebay 1992	Limestone Forebay 2002	Long Spruce Forebay 1992	Long Spruce Forebay 2002	Nelson River Mainstem 1992
ARTHROPODA	Daphniidae	*Daphnia schodleri*[4]	+		+	+	
		Simocephalus sp.	+		+		
	Leptodoridae	*Leptodora kindtii*	+	+	+	+	
	Sididae	*Diaphanosoma brachyurum*	+		+		
		Diaphanosoma leuchtenbergianum				+	
		Sida crystallina	+		+		
Maxillopoda							
Copepoda							
Calanoida							
	Centropagidae	*Limnocalanus macrurus*	+	+	+	+	
	Diaptomidae	*Diaptomus minutus*				+	
		Diaptomus siciloides		+		+	
		Leptodiaptomus ashlandi		+		+	
		Skistodiaptomus oregonensis		+			
	Temoridae	*Epischura* spp.	+	+	+		
		Epischura lacustris	+	+	+	+	
		Epischura nevadensis	+	+	+		
Cyclopoida							
	Cyclopidae	*Cyclops bicuspidatus thomasi*	+	+	+	+	
		Cyclops vernalis		+		+	
		Eucyclops agilis		+		+	
		Macrocyclops albidus		+		+	
		Mesocyclops edax	+		+		
		Microcyclops varicans	+		+		
Malacostraca							
Eumalacostraca							
Amphipoda		Unknown	+		+		+
Lophogastrida		Unknown					+
Ostracoda		Unknown	+		+		+
Podocopa		Unknown	+		+		
Hexapoda							
Insecta							
Pterygota							
Diptera			+		+		+
Ephemeroptera			+		+		+
Trichoptera			+		+		+

Table 6-4 continued

PHYLUM / Subphylum / Class / Subclass / Order / Family	Species	Limestone Forebay 1992	Limestone Forebay 2002	Long Spruce Forebay 1992	Long Spruce Forebay 2002	Nelson River Mainstem 1992
ANNELIDA						
Clitellata						
Oligochaeta		+		+		+

[1] Excluded from 2002 sampling protocol

Previous reports may have used taxa that are no longer recognized as valid according to the Integrated Taxonomic Information System (2008), including the following:

[2] Subclass Acari was formerly Subclass Acarina

[3] Order Diplostraca was formerly Order Conchostraca

[4] *Daphnia schodleri* has an invalid synonym spelled *D. shoedleri*

TABLE 6-5 Benthic invertebrate groups identified in the lower Nelson River in 1990, 1992, 1993, 2002, and 2003. The symbol "+" denotes presence.

PHYLUM / Subphylum / Class / Subclass / Order / Family	Limestone Forebay		Long Spruce Forebay		Nelson River Mainstem
	1990-1993[1]	2003	1990-1993[1]	2003	2002, 2003
ANNELIDA					
Clitellata					
Hirudinea	+	+	+	+	+
Oligochaeta	+	+	+	+	+
PLATYHELMINTHES		+		+	+
ARTHROPODA					
Chelicerata					
Arachnida					
Acari[2]		+		+	+
Crustacea					
Branchiopoda					
Phyllopoda					
Diplostraca[3]	+	+	+		+
Malacostraca					
Eumalacostraca					
Amphipoda	+	+	+	+	+
Ostracoda		+		+	+
Hexapoda					
Insecta					
Pterygota					
Coleoptera	+				+
Diptera (unidentified)	+		+		
Ceratopogonidae		+		+	+
Chironomidae		+		+	+
Empididae					+
Tabanidae					+
Tipulidae					+
Ephemeroptera (unidentified)	+		+	+	+
Ephemerellidae				+	
Ephemeridae		+		+	
Heptageniidae		+		+	+
Leptophlebiidae				+	
Siphlonuridae		+			
Hemiptera (unidentified)					+
Corixidae				+	
Megaloptera					
Sialidae		+		+	
Plecoptera (unidentified)	+				+

Table 6-5 continued

PHYLUM / Subphylum / Class / Subclass / Order / Family	Limestone Forebay		Long Spruce Forebay		Nelson River Mainstem
	1990-1993[1]	2003	1990-1993[1]	2003	2002, 2003
ARTHROPODA					
Plecoptera					
Chloroperlidae					+
Nemouridae					+
Perlidae					+
Perlodidae					+
Trichoptera (unidentified)	+		+		+
Hydropsychidae				+	+
Lepidostomatidae					+
Leptoceridae		+		+	
Molannidae				+	
Polycentropodidae		+		+	
MOLLUSCA					
Bivalvia (unidentified)	+		+		
Heterodonta					
Veneroida					
Pisidiidae		+		+	+
Palaeoheterodonta					
Unionida					
Unionidae		+		+	
Gastropoda	+	+	+	+	+

1 Insecta identifications from 1993 data were taken to the Order level and Mollusca identifications were taken to the Class level

Previous reports may have used taxa that are no longer recognized as valid according to the Integrated Taxonomic Information System (2008), including the following:

2 Subclass Acari was formerly Subclass Acarina

3 Order Diplostraca was formerly Order Conchostraca

7.0

FISH COMMUNITY

7.1 Introduction

Fish community investigations conducted as part of the Limestone G.S. aquatic environment monitoring programs were intended to build on and provide supplementary information to studies conducted previously by Manitoba Fisheries Branch and to studies conducted in anticipation of the planned Conawapa G.S. (see Chapter 4.0). Some studies were designed to collect information on key physical or biological factors for which little information was previously available (e.g., tributary studies), while other studies were designed to utilize existing baseline data to allow for pre- and post-impact comparisons (e.g., brook trout studies). The results presented herein are from studies conducted from 1989 to 2003. Where the existing baseline pre-dated 1989, the complete dataset has been included. For results of studies conducted by Manitoba Fisheries Branch from 1985 to 1989, refer to the following reports: Swanson 1986, Swanson and Kansas 1987, Swanson et al. 1988, 1990, and 1991.

Construction of the Limestone G.S. has had a substantial effect on the aquatic environment that has produced and supports the lower Nelson River fish community. Changes relevant to the fish community include the following:

- increased water levels, decreased water velocities, and a change from lotic to more lentic conditions in the Nelson River mainstem upstream of the generating station;
- **inundation** and loss of stream habitat in the lower reaches of Leslie and Brooks creeks;
- blockage of fish movement from downstream of the generating station to upstream of the station; and
- increased water level fluctuations and changes in ice conditions at river mouths and in the Nelson River downstream of the generating station.

Similar to invertebrate taxa, the nature and importance of each of these changes is different for each fish species. A change that may be positive for one species may be negative for another. In addition, direct effects on one species may lead to indirect effects on other species.

The objectives of the fish community studies were to gain an understanding of **life history** characteristics and requirements of the local fish community and to monitor changes that occurred following completion of the Limestone G.S.

7.2 Methods

Fish community studies were delineated into five broad categories:

- brook trout studies;
- lake sturgeon studies;
- forebay studies;
- tributary studies; and
- lower Nelson River mainstem studies.

While each study was designed to address key issues with regard to hydroelectric development on the Nelson River, there was significant overlap in the collection of information between studies during the monitoring programs. For example, investigations that focused on brook trout or lake sturgeon also provided information relevant to other fish community studies. Similarly, studies focused on the fish community as a whole also provided information on brook trout and lake sturgeon.

The following provides a brief description of the rationale and methods used for each study.

7.2.1 Brook Trout Studies

Brook trout have been designated as a Manitoba Heritage Species due to its limited natural distribution, socio-economic importance, and unique life history characteristics. Because of its special status and sensitivities to the activities and effects associated with hydroelectric development, brook trout were the focus of additional effort to delineate life history characteristics and requirements, and to monitor its response to impacts. Monitoring studies focused on:

i) establishing a long-term database for brook trout populations both upstream and downstream of the Limestone G.S.; and

ii) understanding key life history requirements and how those requirements may be affected by large-scale hydroelectric development.

Brook trout are known to utilize habitat in the Nelson River mainstem, but primarily inhabit tributaries. Consequently, monitoring studies focused on tributaries to the Limestone Forebay and tributaries to the lower Nelson River downstream of the Limestone G.S. Information on brook trout abundance in the Nelson River mainstem was gathered during the forebay and mainstem monitoring studies (sections 7.2.3 and 7.2.5, respectively).

Brook trout monitoring studies focused on three life stages: larvae; **juvenile**; and adult. Larval drift was monitored from 1990 to 1999 with the purpose of providing a relative indication of hatch strength on a yearly basis in selected streams. Larvae were captured during spring in drift nets [designed after Burton and Flannagan (1976)] that consisted of a tapered aluminium box attached to a tapered 500-μm Nitex bag with a cod-end collecting bottle. The drift nets were oriented into the current, placed approximately 10 cm below the water surface, and fixed between two t-bars embedded into the stream substrate (Photo 7-1). Net contents were collected on a daily basis and sorted for larval brook trout.

Juvenile brook trout abundance was monitored by electrofishing standardized reaches in selected streams during the month of August from 1990 to 1994 and again in 1997, 1999, 2002, and 2003 (Photo 7-2). Two to four 100-m electrofishing reaches were established on each stream. Each sampling period consisted of three electrofishing forays in a downstream direction through each reach. A fine-mesh seine was placed at the lower end of each stream reach prior to commencement of electrofishing to prevent fish from escaping. Fish immobilized within the electrical field of the backpack electrofishing unit were collected with a dip net and measured. Catches provided a relative comparison of juvenile brook trout abundance on a yearly basis. Information on forage fish species was also collected during the electrofishing surveys.

PHOTO 7-1
Drift trap used to capture larval fish as they drift downstream during spring.

PHOTO 7-2
Conducting juvenile brook trout abundance and distribution surveys using a backpack electrofisher.

PHOTO 7-3
Two-direction fish weir set in 9-Mile Creek to capture upstream and downstream brook trout fall migrants.

PHOTO 7-4
Hoop net set in the Limestone River to capture upstream brook trout fall migrants.

Adult brook trout abundance was monitored in selected streams by enumerating spring and/or summer movements (1990-1994, 1997-1999) and pre- and post-**spawning** fall movements (1990-1999, 2002, 2003) using two-direction fish **weirs** and/or hoop nets, gill nets, and angling (photos 7-3 and 7-4). Yearly catches provided a relative indication of abundance of adult fish in each stream. Brook trout were generally measured for length and weight, and tagged. An ageing structure (a pelvic fin ray) was also removed from each fish. Subsamples of ageing structures were periodically sampled for **strontium** (Sr) content. Strontium is an element that is several hundred times more concentrated in **marine** waters than in freshwater, which is reflected in the bony structures of fish feeding in these environments. Therefore, strontium concentrations can be used to determine whether an individual fish captured in fresh water has spent time in the marine environment. Virtually all brook trout captured during the monitoring studies were released unharmed (with the exception of larvae).

In total, brook trout were monitored in 16 streams during the Limestone G.S. monitoring studies, including: three impounded perennial tributaries to the Limestone Forebay (Wilson, Sky Pilot, and Leslie creeks); four major Nelson River tributaries (Moondance Creek and Limestone, Angling, and Weir rivers) and six north-shore nursery streams (Sundance, Beaver, Swift, Tiny, Goose, and Fifteen creeks) downstream of the Limestone G.S.; and three spawning tributaries to the Limestone River [CN (also called Gravel Pit), 9-Mile, and 12-Mile creeks]. The locations of all brook trout monitoring studies conducted in the aforementioned streams, both upstream and downstream of the Limestone G.S., are presented in tables 7-1 and 7-2.

7.2.2 Lake Sturgeon Studies

Lake sturgeon has been designated as a Heritage Species in Manitoba due to its limited natural distribution, socio-economic importance, and unique life history characteristics. More recently (in 2006), Nelson River lake sturgeon were classified as "Endangered" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and are currently under consideration for listing under the Species at Risk Act (SARA). Because of this status, lake sturgeon warranted special attention by the aquatic monitoring programs. Studies that focused on this species collected life history information to supplement that previously collected by Manitoba Fisheries Branch. Information on lake sturgeon abundance in the study area also was collected during the forebay, tributary, and lower Nelson River mainstem monitoring studies (sections 7.2.3, 7.2.4, and 7.2.5, respectively).

Lake sturgeon studies were generally focused in two areas: the mouth of the Weir River (1992, 1994, 1996-1998) and immediately below the Limestone G.S. (1992, 1995). Larval sturgeon were collected

PHOTO 7-5
Large drift trap used to capture larval lake sturgeon as they drift downstream during late spring and early summer.

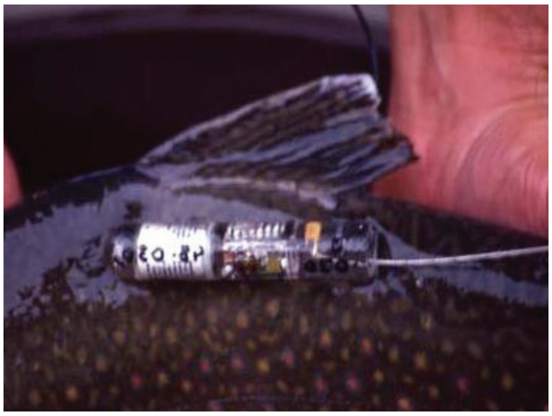


PHOTO 7-6
Typical external radio transmitter used to track the movements of several species of fish, including lake sturgeon.

with 950-µm Nitex drift traps (Photo 7-5) and both juvenile and adult sturgeon were captured with 140, 229, and 305-mm nylon stretched-mesh gill nets. Adult sturgeon were measured for length and weight, tagged, and, where possible, classified by sexual maturity. Radio transmitters were periodically applied to subsamples of lake sturgeon (Photo 7-6), which were then tracked on a regular basis for the duration of the transmitters. Virtually all lake sturgeon captured during the monitoring studies were released unharmed (with the exception of larvae).

7.2.3 Forebay Studies

Inundation and fragmentation of habitat were the two most noticeable impacts to the aquatic fauna of the Nelson River resulting from construction of the Limestone G.S. The objectives of the forebay studies were to monitor how these impacts affected the fish community upstream of the generating station and to determine how similar impacts have affected fish populations in older reservoirs for comparative and predictive purposes.

Gillnetting studies were conducted annually in the Limestone Forebay from 1989 (immediately following impoundment) to 1999 (with the exception of 1991), and again in 2003. Gillnetting studies also were

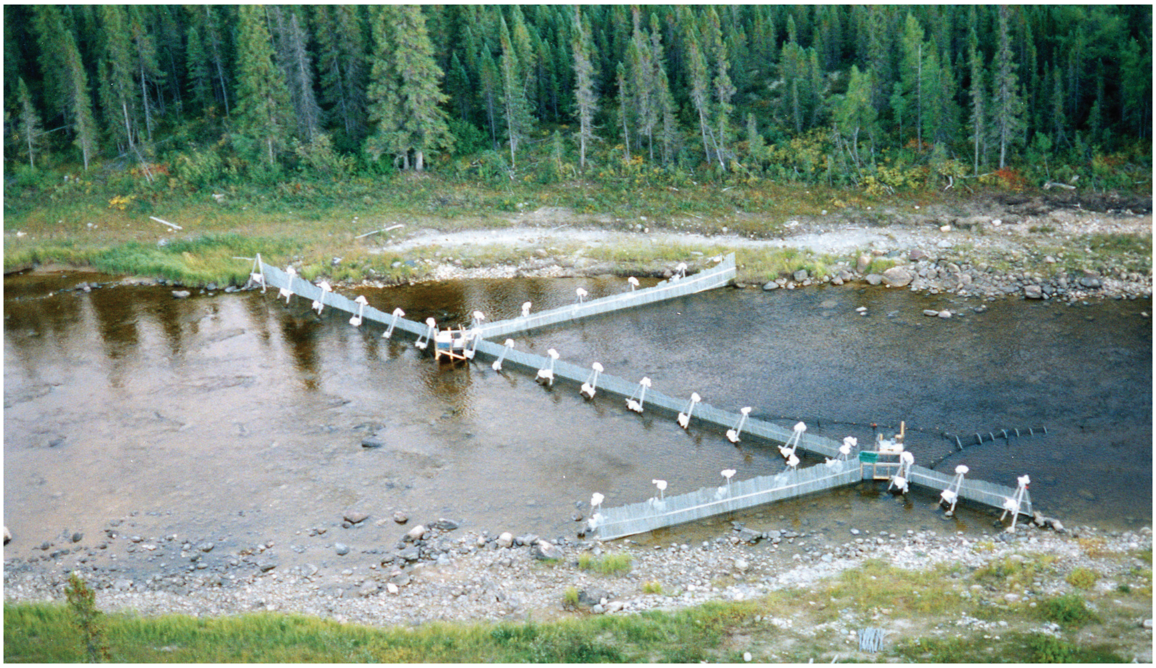


PHOTO 7-7
Two-direction fish weir set in the Angling River to monitor fish use of tributaries of the lower Nelson River.

conducted in the Long Spruce Forebay in 1989, 1992, 1993, 1996, 1999, and 2003 and in the Kettle G.S. forebay portion of Stephens Lake in 1993, 1996, 1999, 2002, and 2003, which supplemented previous index gillnetting conducted in Stephens Lake by Manitoba Fisheries Branch in 1983, 1984, and 1986-1989 (Patalas 1984; Kirton 1986; Hagenson 1987, 1988, 1989, 1990).

Gillnet gangs were comprised of six 25-m (1.8-m deep) panels of 38, 51, and 76-mm nylon mesh and 95, 108, and 127-mm twisted monofilament mesh. Gillnet gangs were set for approximately 48 hours in total at ten sampling sites in each forebay in each year. A large-mesh gillnet gang consisting of two 25-m panels of 229 and 305-mm nylon mesh was set concurrent with other experimental gangs to catch lake sturgeon. Gill nets were checked twice daily. Captured fish were measured for length, weighed, and classified by sexual maturity. Subsamples of fish were selected for stomach content, mercury, and/or strontium analyses or for tagging and release.

7.2.4 Tributary Studies

Studies were initiated in 1990 to monitor fish movements into and out of lower Nelson River tributaries downstream of the Limestone G.S. The objectives were to provide an understanding of fish use of these habitats, determine how water level fluctuations downstream of the Limestone G.S. were affecting fish movements into tributaries, and to gain an understanding of how habitat fragmentation was affecting the mainstem fish species utilizing downstream tributaries. Fish movements into and out of selected tributaries (i.e., Limestone, Angling, Weir, Roblin, and Kaiskwasotasine rivers and Broten and Moondance creeks) were periodically monitored throughout the open-water season using two-direction fish weirs and hoop nets (Photo 7-7). Fish captured were enumerated by species, measured for length and weight, and, where possible, classified by sexual maturity. Subsamples of fish were selected for tagging, age analysis, and for determination of mercury and strontium concentrations. In addition to fish movement studies, a backpack electrofishing survey was conducted in North and South Seal creeks in 2003 to inventory fish populations and fish habitat. Both tributaries flow into the lower Nelson River roughly 25 km upstream of the mouth of the Nelson River Estuary.

PHOTO 7-8
Sampling large-bodied fish using a boat electrofisher.

7.2.5 Lower Nelson River Mainstem Studies

A series of independent studies (1991, 1992, 1997, 2002, and 2003) were undertaken within the lower Nelson River, downstream of the Limestone G.S., to gain an understanding of the resident fish community and fish habitats present. Fish were sampled using standard index gill nets, large-mesh (229 and 305-mm) gill nets, and an electrofishing boat (Photo 7-8). Electrofishing catches were related to habitat types. Fish captured were enumerated by species, measured for length and weight, and, where possible, classified by sexual maturity. Subsamples of fish were selected for tagging, age analysis, and for determination of mercury and strontium concentrations. Data collected from the lower Nelson River fish community were used as a surrogate for pre-impact conditions in the Limestone Forebay and provided a baseline against which future changes downstream of the Limestone G.S. can be measured.

7.3 Results

The lower Nelson River is a large, shallow, fast flowing, turbid river that undergoes relatively large temperature fluctuations (i.e., <0 to 20ºC) on an annual basis. Substrata are primarily limestone sills, igneous cobble and gravel, and boulder with fines occurring in depositional areas lateral to the main channel. The fish habitat is composed of four basic types:

i) rapids;

ii) intermittently exposed shoal reaches where the width of the river is relatively shallow and has an undulating cobble bottom;

iii) relatively deep "U"-shaped channel lined with gravel; and

iv) combinations of the other types but mainly shallow cobble bottoms dissected by a relatively deep U-shaped channel.

Tributary streams are characterized by clear water flowing through beaver ponds and riffle-run-pool habitat sequences. Moderately-sized lake habitat is available in the headwaters of some of the larger rivers (e.g., Angling Lake on the Angling River and McMillan Lake in the Limestone River system).

A total of 37 fish species were identified in the lower Nelson River system during the Limestone G.S. aquatic environment monitoring programs (Table 7-3). The fish community is a product of the predominance of river and stream habitat in the system. The most abundant fish species are those best adapted to large riverine environments. Some species utilize the cool groundwater springs in Nelson River tributaries for incubating eggs. The smaller tributaries also provide protection from predatory fish and enhance feeding opportunities for juveniles. Several species are **diadromous/ amphidromous**, taking advantage of the productive marine waters of Hudson Bay for foraging during summer. Others utilize the headwater lakes as off-current refuges and for overwintering.

PHOTO 7-9
Optimal brook trout stream habitat in the lower reach of 12-Mile Creek.

The following sections describe the existing environment on a species-specific basis as understood from historical studies and the Limestone G.S. aquatic monitoring studies. Each section also provides a description of the changes that have been observed for that species over the course of the monitoring studies and changes that may be expected to occur in the future based on data gathered from the older Kettle and Long Spruce forebays. The final sections describe how the fish communities both upstream and downstream of the Limestone G.S. have adapted to the altered habitats.

7.3.1 Brook Trout

In Manitoba, brook trout (*Salvelinus fontinalis*) are endemic to tributaries on the west shore of Hudson Bay from the Ontario border to the North Knife River, and historically occurred in the lower Nelson River and its tributaries as far upstream as the Kettle River (Figure 7-1).

Optimal brook trout habitat is generally described as having the following characteristics:

i) clear and cold water;

ii) silt-free rocky substrate;

iii) riffle-run-pool sequences with an approximate 1:1 pool-riffle ratio with areas of slow, deep water;

iv) well-vegetated stream banks and abundant instream cover; and

v) relatively stable water flow, temperature regimes, and stream banks (Raleigh 1982) (Photo 7-9).

Turbid waters, characteristic of the lower Nelson River mainstem, are generally avoided by brook trout, although Lower Limestone Rapids and the mouths of creeks are thought to provide some important foraging habitat for larger trout. Of 4,831 fish captured during an extensive electrofishing survey of the Nelson River mainstem in 1992, only five were brook trout – four of which were captured

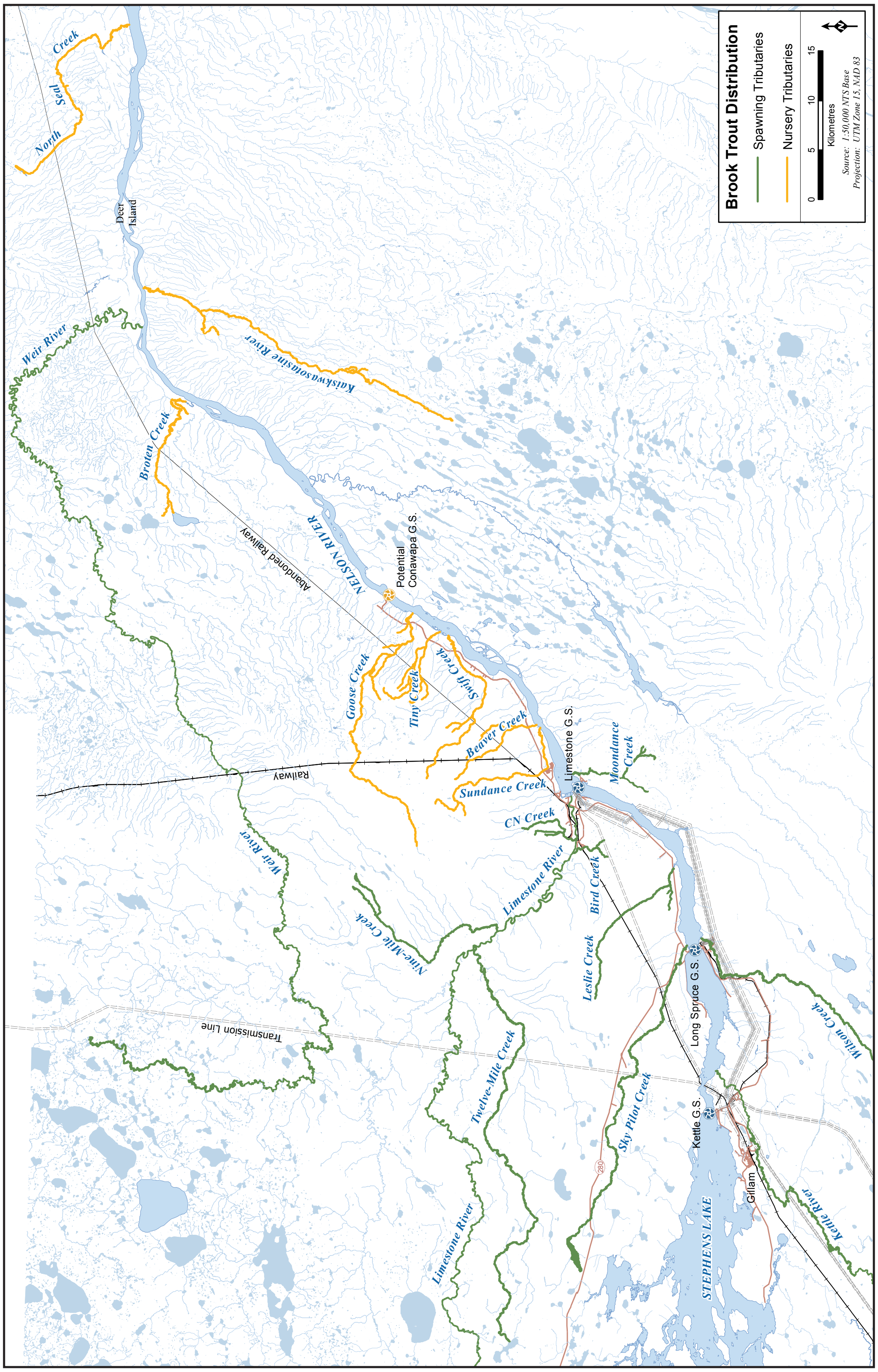


FIGURE 7-1 Distribution of brook trout tributary habitat in the lower Nelson River region.

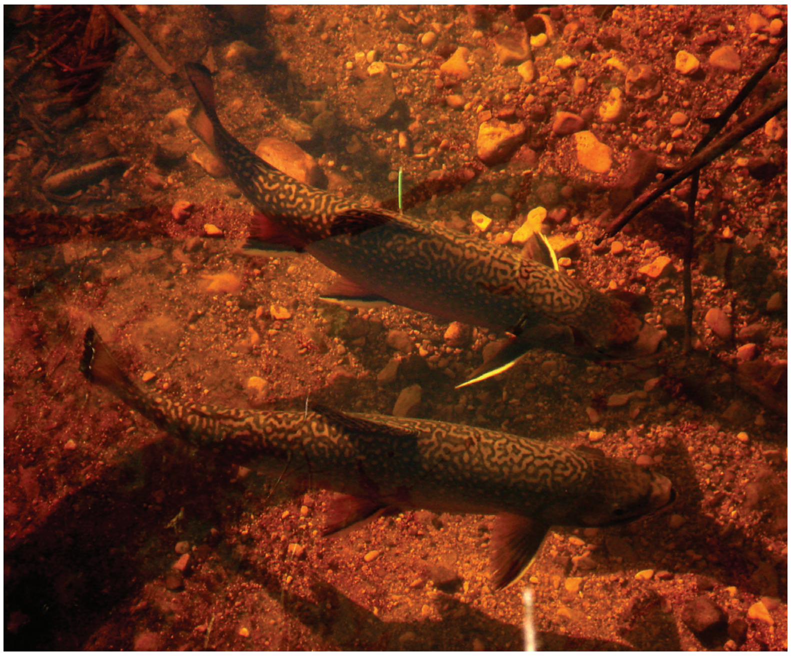


PHOTO 7-10
Adult brook trout preparing to spawn atop a gravel substrate.

PHOTO 7-11
A juvenile brook trout.

in tributary confluence habitat (Remnant and Baker 1993). The tributaries provide more optimal habitat and, consequently, that is where brook trout are most abundant and spend the majority of their life cycles in the Nelson River system. (The Nelson River mainstem, on the other hand, is used primary as a corridor between habitats important for different life history stages.) Although trout occur in some headwater lakes (e.g., McMillan Lake; Gaboury 1980a), they are not found in abundance in any lacustrine environments in the Nelson River system.

Brook trout spawning occurs in the fall over gravel/ rocky substrate with groundwater upwellings (localized depression of water temperature) (Swanson et al. 1988, 1991; Curry and Noakes 1995; Blanchfield and Ridgway 1996, 1997, 1998). Groundwater upwellings, which are critical in providing suitable conditions for brook trout egg incubation (Benson 1953; Webster and Eiriksdottier 1976), are most common in north-shore Nelson River tributaries, where most brook trout spawning locations have been identified (Figure 7-1).

One male and one female brook trout perform the actual spawning act, but each may **spawn** with different mates during the reproductive period (Scott and Crossman 1973). Occasionally, several smaller "satellite" male trout will attempt to spawn with a single female at the same time. Eggs are laid in a redd, covered with gravel by the female, and incubate over the winter (Photo 7-10). Groundwater upwellings act to regulate temperature and oxygen levels, and remove wastes (Webster and Eiriksdottier 1976; Durst 2000). The actual date of hatching depends on water temperatures and oxygen, but is thought to primarily occur in April and May in the lower Nelson River area. Larvae will remain in the gravel until the yolk sac is absorbed, but some will become entrained in the current and drift passively downstream. Larval brook trout between 20-30 mm long are generally captured in drift traps in lower Nelson River tributaries from the middle of May until the end of June. Brook trout become free swimming when they reach 30-38 mm long (Scott and Crossman 1973).

Juvenile brook trout inhabit shallow pools and riffles in either their natal streams or migrate into smaller, nursery streams (Photo 7-11). North-shore Nelson River tributaries downstream of the Limestone G.S. (e.g., Sundance, Beaver, Swift, Tiny, Goose, and Fifteen creeks) are known to provide rearing habitat for juvenile brook trout (Photo 7-12), which migrate upstream during spring and early summer. Decreasing discharges often cause fish to become isolated in nursery streams for periods of time during summer. This isolation serves to protect juvenile brook trout from other piscivorous fish such as northern pike and burbot, which inhabit the larger streams and rivers. Brook trout may spend up to three years in nursery streams prior to moving into larger streams or migrating back to suitable spawning locations. Juvenile brook trout densities are typically lower in nursery streams than in spawning streams such as Moondance and CN creeks.

Brook trout found in the larger tributaries (e.g., Limestone and Weir rivers) are generally larger and show faster growth rates than trout found in moderately-sized creeks (e.g., Sky Pilot and 9-Mile creeks). Similarly, trout in moderately-sized creeks tend to grow faster than trout in small creeks (e.g., CN and 3-Mile creeks). Due to space and food restrictions, it is surmised that as trout become older and larger, they utilize larger tributaries (Photo 7-13). Consequently, few trout older than four years of age are found in the smallest tributaries. Trout as old as nine years of age have been found in the Weir River (Gaboury 1980a). The smaller spawning tributaries such as CN Creek appear to be an important source of brook trout for the larger body-sized river populations.

Downstream movements of brook trout out of the Nelson River and into Hudson Bay were reported in the early 1900s by the Burleigh expedition (Comeau 1915). Although some brook trout remained in freshwater habitats throughout the year, it was thought that most individuals over two years of age in the Nelson River system made an annual trip to Hudson Bay for feeding (Doan 1948). Examination of strontium concentrations in brook trout during the Limestone Generating Station Environmental Monitoring Program revealed that only a small proportion of adults in the larger tributaries are amphidromous (<25% had strontium concentrations $\geq$215 µg Sr/g fish tissue). It has been hypothesized that brook trout amphidromy is a response to competition for space and food in larger tributaries and is more "facultative" rather than "obligatory" (Swanson et al. 1988). In other words, brook trout will migrate into salt water when habitat and population conditions dictate that it is advantageous to do so, but will remain in fresh water throughout their life cycles if there is no advantage to undertaking a seaward migration. Proximity to Hudson Bay also is an important factor in determining the level and benefits of amphidromy. Seventy-two percent of brook trout sampled from French Creek, near the mouth of the Hayes River, had strontium concentrations suggesting they were amphidromous (Swanson et al. 1991). In contrast, 53 and 12% of brook trout sampled moving into the Weir (~50 km upstream of Hudson Bay) and Limestone (~115 km upstream of Hudson Bay) rivers, respectively, had strontium concentrations that suggested amphidromy (Figure 7-2). Smaller creeks such as Moondance or CN creeks have an even lower proportion of adult trout (less than 5%) with strontium concentrations that suggest amphidromy. Tagged brook trout moving out of the Nelson River system have been recaptured as far north as the Churchill River Estuary, in French Creek, and in the Hayes River system to Shamattawa, a remote community located on the banks of the Gods River about 175 km upstream (Figure 7-3). At one time, it was thought that sea-run trout developed a silver colouration. Analysis of strontium concentrations has shown that it is not possible to discriminate between sea-run and non-migratory brook trout by colour (Gaboury 1980a).

PHOTO 7-12
A small brook trout nursery stream along the north shore of the lower Nelson River below the Limestone G.S.

Brook trout in the lower Nelson River system feed primarily on aquatic insects, but also on other invertebrates (e.g., hirudineans, crustaceans, gastropods), fish, and occasionally small mammals such as mice (Gaboury 1978).

Brook trout typically mature at 3-4 years of age, regardless of growth rate. While trout will mature at

PHOTO 7-13 Adult brook trout from a large tributary of the lower Nelson River.

lengths of 250 mm in smaller tributaries such as CN Creek, trout in the Limestone River may not mature until reaching 400 mm in length.

Brook trout spawning usually peaks in September, but is highly variable and may begin in August and extend into late October (Bretecher and MacDonell 1999a). Spawning tends to occur earlier in smaller tributaries than in larger tributaries (Gaboury 1980a). Low discharges and beaver dams can affect accessibility to smaller creeks such as CN, Moondance, and 9-Mile creeks, and can prevent upstream movements of brook trout to spawning areas in some years. Some trout show a relatively strong homing tendency, having been captured in the same spawning pool for three consecutive years (Gaboury 1980a). However, it is also common to capture the same trout in different spawning streams in successive years. This suggests that brook trout use habitat opportunistically, which provides potential for mixing of stocks between streams.

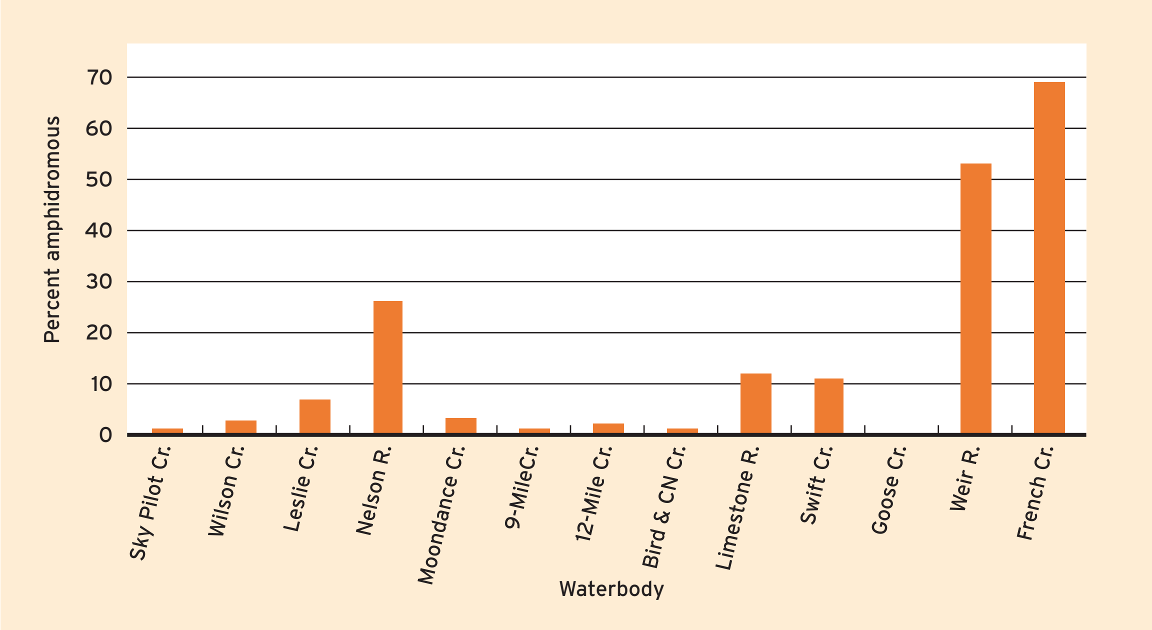


FIGURE 7-2 Percent of brook trout sampled from lower Nelson River tributaries and French Creek that are considered to be amphidromous (pelvic fin strontium levels in excess of 215 µg/g).

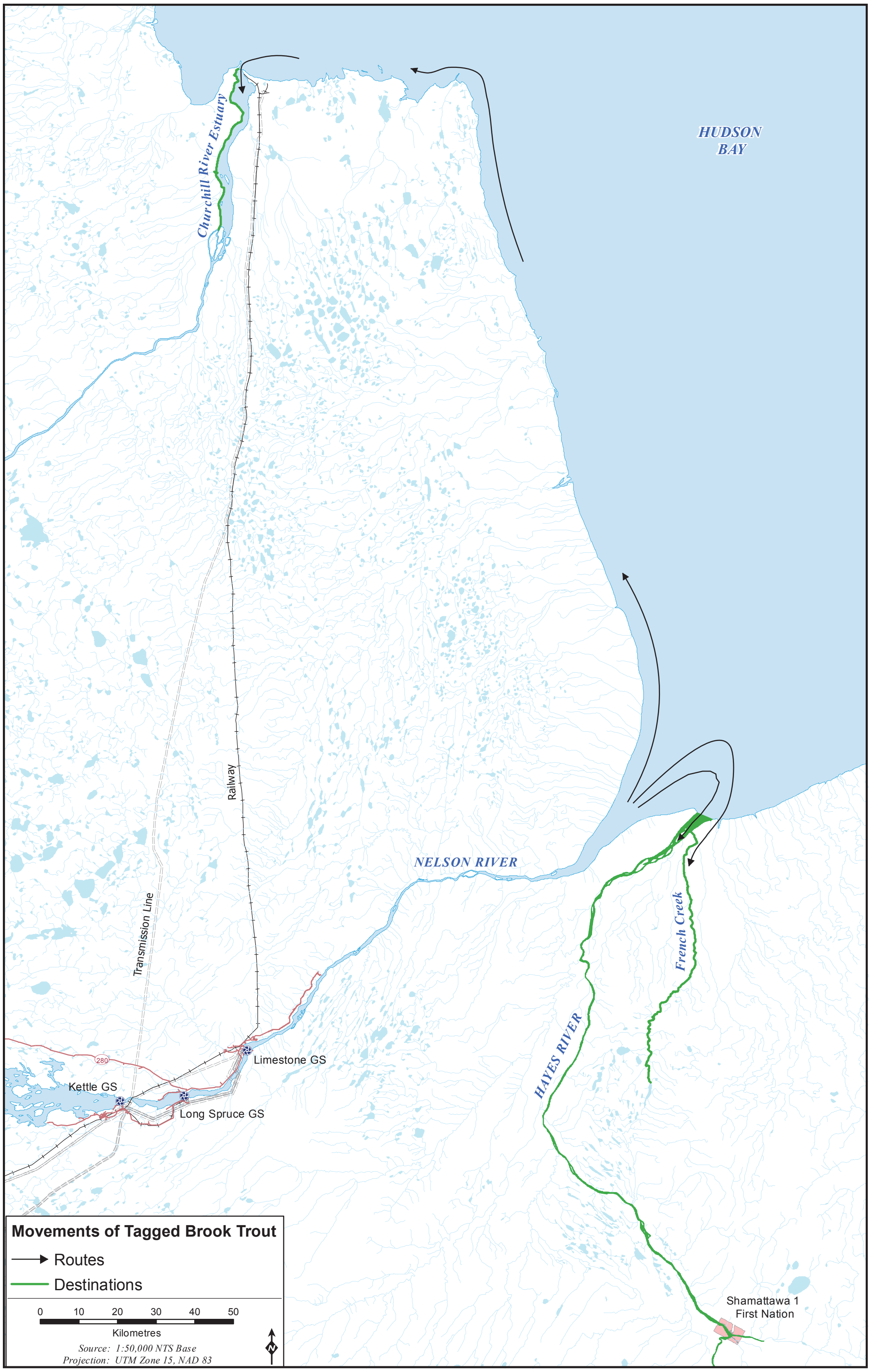


FIGURE 7-3
Movements of tagged brook trout out of the lower Nelson River and into other river systems.

Once spawning is complete, trout appear to passively move downstream before moving into overwintering locations. Overwintering primarily occurs in the larger tributaries, although trout are known to overwinter in smaller tributaries such as CN Creek and in the lower Nelson River as far downstream as the estuary (although this is thought to be uncommon).

Lower Nelson River brook trout were subject to a number of anthropogenic influences prior to construction of the Limestone G.S., and these influences have significantly affected local populations. Sport and domestic fisheries have simultaneously targeted brook trout since construction of the Hudson Bay railway in the early 1900s. Exploitation of the species increased further with an influx of construction workers during development of the Kettle G.S. in the 1960s and the Long Spruce G.S. in the 1970s. Kettle River habitat was impacted by construction of two water control structures in 1966 and diversion of the Butnau River in 1968 (Swanson 1986). By the time construction of the Limestone G.S. commenced in the mid 1980s, Kettle River brook trout populations were on the verge of extirpation and populations in Wilson Creek were severely depleted (Swanson 1986; Swanson et al. 1990). The extent to which previous activities affected other brook trout populations in the lower Nelson River area is uncertain.

Changes Following Construction of the Limestone Generating Station

Brook trout are primarily adapted for manoeuvring and feeding in shallow, fast flowing, and clear water. Consequently, the shift from a lotic to more lentic environment upstream of the Limestone G.S. further reduced the suitability of the Nelson River mainstem for brook trout. The poor suitability of the habitat is evidenced by the absence of brook trout in catches during ten years of annual post-project index gillnetting surveys in the Limestone Forebay. Increases in the abundance of piscivorous fish (i.e., walleye and northern pike) during this period have further reduced the suitability of forebay habitat for brook trout.

Tag returns one year following impoundment (in 1990) suggested that at least 4% of trout tagged in 1989 (8 of 231 tags) and possibly as many as 47% of trout tagged in 1990 (8 of 17 tags) from both Sky Pilot and Wilson creeks had emigrated downstream out of the forebay the following year. Some of the downstream movement may have been in response to intra-species competition as the number of brook trout enumerated during fall 1989 was the highest recorded during monitoring from 1987 through 2002. Although the magnitude of downstream emigration was greatest immediately following impoundment, such movements were still detected several years later. A brook trout tagged in Sky Pilot Creek in 1998 was recaptured in the Hayes River system in 1999. Downstream movement through turbines or over the spillway may increase injury/mortality rates, and those that survive are unable to return to their natal streams. Consequently, brook trout currently inhabiting Wilson, Sky Pilot, and Leslie creeks are essentially isolated within their streams with only limited potential for mixing of stocks between the three tributaries. Results from adult brook trout transfer studies to the Kettle River system in the 1980s (Swanson et al. 1988, 1990, 1991) proved to be inconclusive (not enough trout were radio-tagged to establish movement patterns post-release), but it was subsequently concluded that this mitigation strategy would be ineffective in re-establishing depleted populations upstream of the hydroelectric development.

Despite isolation, monitoring results suggest there was little change in brook trout abundance in Sky Pilot Creek ten years after impoundment (Figure 7-4). Catches during fall 1998 were comparable to catches prior to impoundment. As previously discussed, movement of brook trout out of tributaries is likely a function of competition. Consequently, populations could be expected to remain relatively stable despite emigration. Since very little habitat in Sky Pilot Creek was affected by impoundment, the ability of the creek to support brook trout did not change. The same assumption can be made for Wilson Creek. However, increases in piscivorous fish in the forebay and increased access to tributaries because of the backwater effect of impoundment may increase the susceptibility of brook trout to predation.