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Physical, Chemical, and Biological Effects of the Churchill River Diversion and Lake Winnipeg Regulation on Aquatic Ecosystems

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PHYSICAL, CHEMICAL, AND BIOLOGICAL EFFECTS OF THE CHURCHILL RIVER DIVERSION AND LAKE WINNIPEG REGULATION ON AQUATIC ECOSYSTEMS

by

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ABSTRACT

Baker, R.F., and S. Davies. 1991. Physical, chemical, and biological effects of the Churchill River diversion and Lake Winnipeg regulation on aquatic ecosystems. Can. Tech. Rep. Fish. Aquat. Sci. 1806: v + 53 p.

This report constitutes Phase II of a two-part project designed to provide disclosure of the physical, chemical, and biological effects of the Churchill River diversion and Lake Winnipeg regulation on the aquatic environment. Specific geographical reference is made to the five communities signatory to the Northern Flood Agreement (NFA): Norway House, Nelson House, Cross Lake, Split Lake, and York Landing.

Phase I of this study provided an initial compilation and synthesis of available information relating to: water levels and flows; lake and river shorelines; erosion, sediment transport, and deposition; debris; ice; water chemistry; fisheries (including primary and secondary productivity); and mercury. Literature was reviewed hierarchically: first by community; second by physical, chemical, and biological effects; and third on a chronological basis. Socioeconomic effects were not included; neither was information from Southern Indian Lake (SIL) because the community was not signatory to the NFA.

The Phase I report was to be combined with information acquired through an Adaptive Environmental Management workshop that was intended to include all interested parties. Due to the refusal of the Northern Flood Committee to attend the workshop, or to provide community representation, it was cancelled. This report, therefore, is limited to information collected during the Phase I study, additional information provided by individuals and organizations active in the study area, and information published since release of the Phase I document. This report provides a comprehensive review of available literature but may not necessarily reflect the types and degree of impacts felt by residents of the affected communities.

Key words: Churchill River diversion; Lake Winnipeg regulation; hydrology; erosion; ice; water quality; fisheries; mercury; Northern Flood Agreement.

RÉSUMÉ

Baker, R.F., and S. Davies. 1991. Physical, chemical, and biological effects of the Churchill River diversion and Lake Winnipeg regulation on aquatic ecosystems. Can. Tech. Rep. Fish. Aquat. Sci. 1806: v + 53 p.

Le présent rapport constitue la phase II d'un projet en deux volets visant à divulguer les effets physiques, chimiques, et biologiques de la dérivation de la rivière Churchill et de la régularisation du lac Winnipeg sur le milieu marin. Il comporte des renvois géographiques directs aux cinq collectivités signataires de la Convention sur l'inondation des terres du Nord (CITN): Norway House, Nelson House, Cross Lake, Split Lake, et York Landing.

La phase II de cette étude a consisté en une compilation et une synthèse initiales de l'information disponible sur: les niveaux et débits d'eau; les lignes de rivage des lacs et rivières; l'érosion, le transport, et le dépôt des sédiments; les débris; les glaces; la composition chimique de l'eau; les pêches (productivités primaire et secondaire comprises); et le mercure. On a examiné la documentation hierarchiquement: (1) par collectivité; (2) par effets physique, chimiques, et biologiques; et (3) dans l'ordre chronologique. Les effets socioéconomiques n'ont pas été traités, pas plus que l'information de Southern Indian Lake (SIL) parce que la collectivité n'a pas signé la CITN.

Le rapport de la phase I devait être combiné à l'information acquise lors d'un atelier sur la gestion adaptative de l'environnement qui visait à réunir toutes les parties intéressées. Le Comité sur l'inondation des terres du Nord ayant refusé de participer à l'atelier, ce dernier a été annulé. Le présent rapport est donc limité à l'information recueillie durant l'étude de la phase I, à l'information additionnelle fournie par des particuliers et des organismes oeuvrant dans le domaine d'étude, et à l'information publiée depuis la parution du document de la phase I. Le présent rapport revoit en profondeur la documentation disponible, mais n'indique pas nécessairement les types et le degré des effets ressentis par les résidents des collectivités touchées.

Mots-clés: Dérivation de la rivière Churchill; régularisation du lac Winnipeg; hydrologie; érosion; glace; qualité de l'eau; pêches; mercure; Convention sur l'inondation des terres du Nord.

INTRODUCTION

This document represents the final phase of a contract to summarize the impacts of Lake Winnipeg Regulation (LWR) and Churchill River Diversion (CRD) on physical, chemical, and biological resources of the affected aquatic environment. The geographical area considered was restricted to water bodies utilized by native communities signatory to the Northern Flood Agreement (NFA)(1977): Norway House, Cross Lake, Nelson House, Split Lake, and York Landing. Usher and Weinstein (1991) were similarly contracted to review and assess existing data on renewable resource harvesting by the NFA communities and suggest a design for a socioeconomic impact assessment.

Phase I of the study consisted of the compilation and synthesis of all available literature pertinent to the subjects investigated. Prior to LWR and CRD, the Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) (1975) was established to study the physical, chemical, biological, socioeconomic, and cultural impacts of these developments.

Much of the recent literature published by the Department of Fisheries and Oceans (DFO) and Environment Canada has been funded under auspices of the Federal Ecological Monitoring Program (FEMP). This 5-yr program was undertaken jointly by Environment Canada and Fisheries and Oceans to fund post-project ecological research on the impact of hydroelectric development on the NFA communities and Southern Indian Lake. Annual summary reports have been published by FEMP since 1987 (Environment Canada, Fisheries and Oceans 1987, 1988, 1989), which summarize research conducted since 1986. Here, reference is made to specific studies within FEMP, rather than citing the annual reports.

Based on the data reviewed, summary tables were produced for each community. These tables assessed the extent of documentation provided by pre- and post-development conditions, the effects of LWR and CRD (negative, neutral, or positive) on physical, chemical, and biological parameters, summarized effects and identified significant data gaps. The Phase I report was completed in March, 1989.

Originally, the Phase II document was intended to include results from an Adaptive Environmental Management (AEM) workshop that was to be conducted between DFO, Manitoba Hydro, the Manitoba Department of Natural Resources (DNR), Environment Canada, the Northern Flood Committee (NFC), representatives from each of the NFA communities, individuals currently conducting research in the area, and the authors. Unfortunately, the AEM was not held because of the refusal of the NFC to attend or send community representatives. Community representation was required to assess how impacts of LWR and CRD were viewed by the communities. It was also felt that without attendance of the NFC, and members of the affected communities, insufficient new information would be elucidated to justify proceeding with the AEM.

In the absence of an AEM, a draft of the Phase I report was distributed for review to a wide variety of organizations, including federal and provincial government agencies, private consultants, native bands, and the NFC. Consequently, the Phase II document adds only new data and information provided by respondents to the Phase I document.

SCOPE

Prior to initiation of the Phase I report, a scoping meeting was held among the authors, DFO, Manitoba Hydro, Inland Waters Directorate (Environment Canada), and DNR. At this meeting, terms of reference for the contract, including geographical, scientific, and procedural guidelines were established.

Geographically, only the water bodies within the trapline boundaries of the five communities signatory to the NFA were considered. Therefore, the large data base for Southern Indian Lake was excluded from the analysis. Impacts of CRD on the village of South Indian Lake likewise were excluded.

Despite the proximity of the communities of Split Lake and York Landing, it was agreed during the scoping meeting that each community should be addressed separately, thereby giving them equal consideration.

Documentation and interpretation of information was limited to physical, chemical, and biological effects on aquatic ecosystems. Scoping meeting participants agreed that the parameters to be investigated would fall under the following categories: physical and chemical parameters, specifically water levels and flows; lake and river shorelines; erosion; sediment transport and deposition; debris; ice conditions; water chemistry and quality; and biological parameters (including primary and secondary productivity and mercury). Each of these parameters are described under "ORGANIZATIONAL STRUCTURE" below.

It was decided that dealing with the effects of LWR and CRD on factors such as transportation, personal health, loss of life, recreation, damage to boats and fishing gear, net fouling, access to shore etc., was beyond the scope of this report. Similarly, changes to the economics and value of commercial, sport, and domestic fisheries were not addressed here (see Usher and Weinstein 1991).

The intent of this report was to document all available information pertaining to each of the above categories, community by community, in an hierarchical fashion. No attempt was made to assess the methods used, the quality of research, or the accuracy and validity of conclusions made by the original authors. All conclusions regarding documentation of physical, chemical, and biological effects on aquatic ecosystems, which are presented in summary tables at the end of this document, reflect the sole opinion of the authors. It is important to note that our conclusions represent the cumulative impressions formed following careful review of all data examined, and consultation with, and input from, respondents following the Phase I report. Conclusions made by the authors reflect value judgments based on the data base reviewed. Opinions of the sponsoring agency or other groups may differ.

CONSTRAINTS

Cancellation of the AEM workshop eliminated the views and opinions of individuals living in communities affected by the projects. The NFC also denied the authors access to its library, to reports conducted specifically for the NFC, and to historical correspondence from members of the affected communities which could have provided valuable insight into the impacts of LWR and CRD on the aquatic ecosystem. No review of the content of the Phase I report was received by North/South Consultants from native bands or the NFC. This report is inherently biased, therefore, toward published and unpublished information provided by DFO, Manitoba Hydro, private consultants, DNR, Manitoba Environment, Water Resources Branch, and other government agencies. Thus, the authors recognize that the lack of local knowledge, which can only be supplied by the members of the affected communities, is a major shortcoming.

Exclusion of the literature base from Southern Indian Lake constrains the report to the extent that the considerable research that identifies adverse effects of impoundment and diversion, is not completely covered. However, an abbreviated bibliography, containing key scientific documents relevant to Southern Indian Lake, is provided in Appendix II for individuals wishing access to this information.

The utility of this Phase II report lies in its broad coverage of the impacts on physical, chemical, and biological parameters as a result of LWR and CRD, and a complete listing of the published historical data base.

ORGANIZATIONAL STRUCTURE

The report is organized hierarchically: impacts are discussed (1) generically, as they affect all communities, (2) specifically, as they affect individual communities, and (3) according to physical, chemical, and biological effects on a chronological basis.

HIERARCHY

Community

Under terms of the NFA, each of the five signatory communities has been granted land-use privileges over designated parcels of land, generally referred to as "trapline boundaries". For purposes of this report, only waterbodies that have been affected by CRD and LWR, and that fall within the trapline boundaries of each community as set out by the NFA (with minor exceptions), were assessed (Fig. 1). Following is a brief description of the waterbodies included for each community:

Norway House: Norway House has been affected by LWR. Within the Norway House trapline boundary, the following waterbodies were considered: Playgreen Lake, Little Playgreen Lake, Kiskittogisu Lake, the Lake Winnipeg north basin, and the Nelson River East Channel. The trapline boundary passes through the middle of Kiskitto Lake, indicating that resources are shared between Norway House and Cross Lake. Because Kiskitto Lake is nearer to the Cross Lake community than to Norway House, Kiskitto Lake was considered part of the Cross Lake area.

Cross Lake: Cross Lake also has been affected by LWR. Within the Cross Lake trapline boundary, the East and West Cross Lake basins, Sipiwesk, Kiskitto, Drunken, Walker, and Pipestone lakes were considered.

Nelson House: Nelson House has been affected by CRD. The following water bodies downstream of the Notigi dam were considered: Threepoint, Footprint, Wapisu, and Wuskwatim lakes; and the Burntwood River and its connecting arteries. Although the Burntwood River east of Wuskwatim Lake and lakes on the Burntwood such as Apussigamasi, Opegano, and Birchtree were affected by CRD and are within the trapline boundary, they were not considered due to their remoteness from the community.

Split Lake: Split Lake has been affected by both LWR and CRD. The waterbodies considered include Split Lake, the Burntwood River upstream to First Rapids, and the Nelson River between the Kelsey and Kettle generating stations, including Stephens Lake.

York Landing: York Landing has also been affected by LWR and CRD; however, the effects are difficult to separate from those of Split Lake because the final area and boundaries of the York Landing community have yet to be agreed upon by the NFA signatories. Therefore, with the exception of a limited number of references specific to York Landing, the information synthesis for the two communities is virtually identical. The decision to address the two communities separately was made for ease of reference, but has resulted in a repetition of facts.

Physical, chemical, and biological parameters

General reports that cover several physical or biological parameters are discussed in detail under "Physical and chemical parameters: Water levels and flows" and/or in the "Biological parameters" section, depending on the emphasis of the material. Only pertinent results from these reports are presented in subsequent sections to avoid unnecessary repetition. Studies that were done prior to LWR and CRD are summarized only briefly; they may serve as data sources for future comparisons.

Physical and chemical effects were combined to reduce repetition of data because of the overlap between the two categories. Parameters evaluated were sub-divided according to the following specific effects.

1. Physical and chemical parameters
   a) Water levels and flows: hydrographic and hydraulic information, elevation, volume, surface area, etc.;
   b) Lake and river shorelines: changes that have occurred as a result of erosion, slumping, ice, diversion, etc.;
   c) Erosion, sediment transport, and deposition: describes the location, volume, transport and destination of eroded river and lake bed and bank materials;
   d) Debris: describes the presence and impact of submerged and dislodged vegetation, trees, etc.;
   e) Ice: describes changes to and effects of ice formation, dams, break-up, slush ice, etc.;
   f) Water chemistry/quality: includes changes to "chemical" parameters such as ions, nutrients, salts turbidity, pH, minerals, etc. and "water quality" parameters such as colour, taste, and coliform bacteria.

2. Biological parameters: The assessment of CRD and LWR on aquatic resources includes effects on phytoplankton, zooplankton, zoobenthos, and fish. Due to the multidisciplinary nature of most fisheries biology studies, it was decided not to subdivide this section according to primary, secondary, and tertiary productivity in order to avoid unnecessary duplication of effort.

3. Mercury: presents historical mercury data for fish from the Churchill and Nelson River systems, and documents changes in mercury concentrations in fish populations. The issue of mercury is discussed under the "biological" parameters section rather than the "physical/chemical" parameters section because of the greater importance or impact of mercury on biological systems than on the physical/chemical environment. Due to the volume of material and importance of the mercury issue to the NFA communities, it was decided to devote a separate section of the study to mercury.

Chronology

Within each community and for each biophysical parameter, reports are summarized on a chronological basis, beginning with the earliest reports which document physical, chemical, and biological features of water bodies affected by LWR and/or CRD, and which are of importance to the NFA communities.

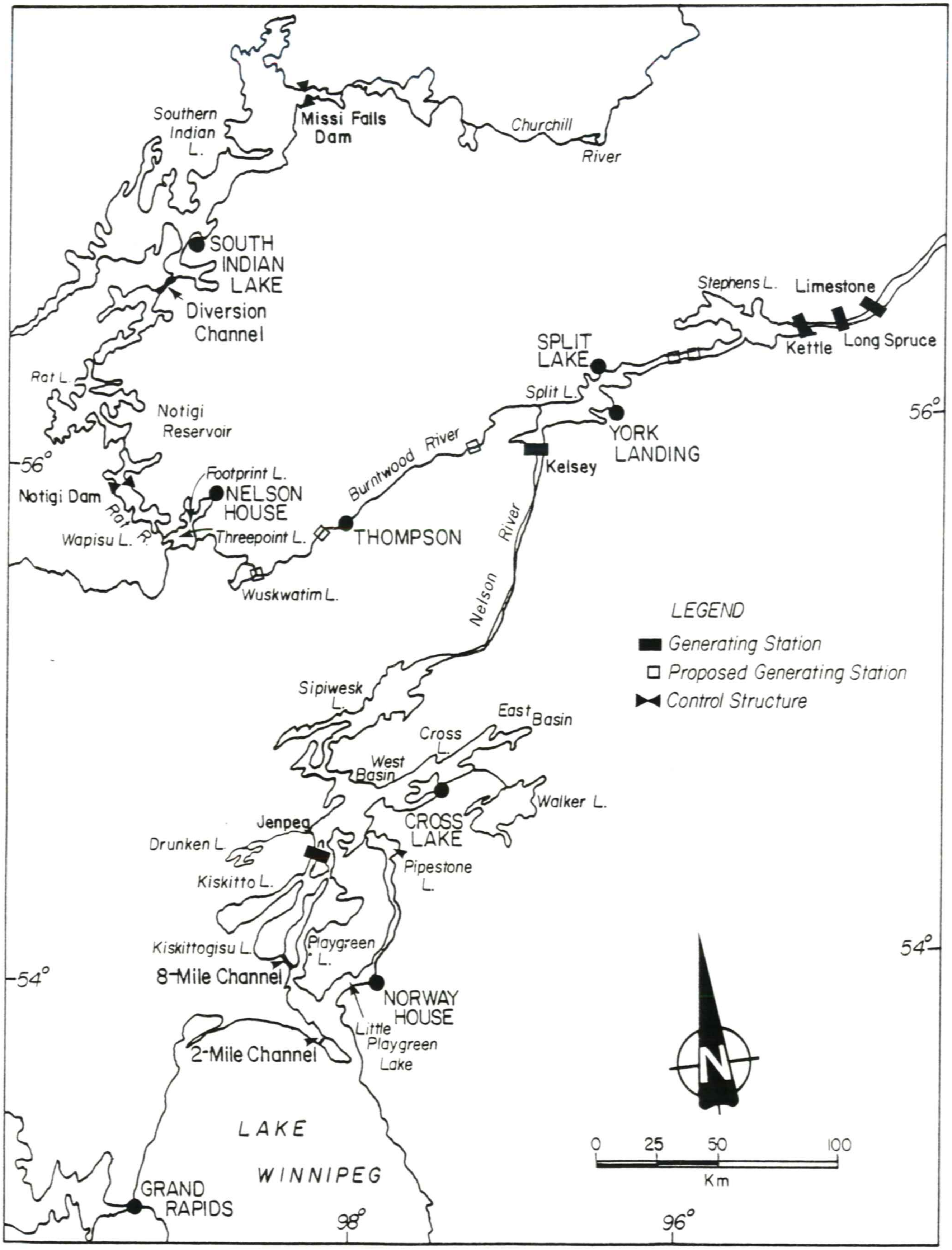

Fig. 1. Study area showing locations of the five Northern Flood Agreement communities, generating stations, and control structures.

LITERATURE REVIEW

GENERIC INFORMATION

The following information is pertinent to the communities of Norway House, Cross Lake, Split Lake, and York Landing, and should be reviewed in conjunction with the assessment of impacts to individual communities. Where a reference is followed by an asterisk, i.e. Lapointe et al. (1989)*, the information is also relevant to the Nelson House community. This information has not been repeated within each community section, in order to reduce unnecessary repetition.

Physical and chemical parameters

Water levels and flows: In 1953, the Canada Department of Mines and Technical Services collected water level and water chemistry data between Lake Winnipeg and Hudson Bay, as part of a larger water survey report of the Nelson River drainage basin (Thomas 1959).

Beginning in 1974, Manitoba Hydro collected detailed and extensive, annual hydraulic and hydrometric information from the Nelson River during both summer and winter from a number of sites on the Nelson River downstream of Playgreen Lake. The accumulated summer field reports and surveys, published annually, contain water level and discharge measurements from field surveys and automatic recorders situated throughout the system. This information is included in two separate series of documents. The first is a set of annual reports from 1974 to the present entitled "Lake Winnipeg Regulation Hydrometric Programs" (Manitoba Hydro 1987a, b). These reports contain information from upper Nelson River lakes (Playgreen, Kiskitto, Cross). The second series is a number of reports dating back to 1974 that contain summer (Manitoba Hydro 1987c) and winter (Manitoba Hydro 1987d) hydrometric data from the upper and lower reaches of the Nelson River, including the Cross Lake to Sipiwesk Lake reach, Split and Stephens lakes.

Environment Canada (1988)* provided a summary of historical water-level data for the period 1911 to 1987. Monthly and annual mean water levels for selected years and communities, between 1951 and 1987, as well as annual extreme water levels between 1968 and 1987, are given for Footprint Lake at Nelson House, Playgreen Lake, Kiskittogisu Lake and the Nelson River at Norway House, Cross Lake, and Split Lake.

Lake and river shorelines: R.W. Newbury and F. Penner of the Water Resources Branch (1974) did an extensive hydrologic and hydraulic evaluation of the Nelson River from Lake Winnipeg to Hudson Bay. The document provides detailed pre-diversion data on elevations, shoreline characteristics, and river and lake profiles.

Electromagnetic Sensing and Interpretation (1987)* has compiled an extensive catalogue of aerial photography (1945-1987) and satellite imagery (1972-1987) for the CRD and LWR region. This information can be used to document changes in lake and river shoreline characteristics for the years in which data are available.

Erosion, sediment transport, and deposition: Lapointe et al. (1989)* conducted a controlled field study on the Nelson River near Thompson to determine whether data collected by the four government agencies conducting sediment sampling in the NFA area were comparable. This study was prompted by the fact that each agency (Water Resources Branch, Environment Canada; Freshwater Institute, Fisheries and Oceans Canada; Water Quality Branch, Environment Canada; and Manitoba Environment) collect sediment data using different samplers and sampling methodologies, and analyze the data using different laboratory procedures. Results showed that, although the data were statistically different, in absolute terms these differences were very small. The most significant errors resulted from: (1) dip sampling as compared to depth-integrated sampling, and (2) sample splitting which is commonly conducted by both federal and provincial agencies. The report concluded that a negative bias of 10 to 20% resulting from dip sampling was acceptable for most requirements, but that the practice of sample splitting be discontinued.

Debris: There was poor documentation of the occurrence of debris in the system prior to LWR and CRD. After LWR and CRD, documentation was sporadic and inconsistent because no single study was implemented that systematically evaluated the problem of debris in water. Consequently, there were no references common to all communities.

Ice: Newbury (1968) detailed pre-impoundment and pre-diversion ice conditions for the Nelson River from the Lake Winnipeg outlet to Hudson Bay. The report includes information on ice formation, heat budgets, ice barriers, ice destruction, and the effects of stationary and moving ice on water movement, bank material, river channel patterns, and vegetation.

A technical engineering report on hydrologic and hydraulic studies prior to diversion, prepared by Water Resources Branch (1974), documents detailed pre-diversion data on elevations, shoreline characteristics, and river profiles of the Nelson River from Lake Winnipeg to Sipiwesk Lake. Based on this information, the report predicted impacts to ice regimes with LWR.

Manitoba Hydro has collected detailed and extensive winter ice and hydraulic information from a large number of sites in the LWR area since 1974/75. Data from Playgreen, Kiskitto, Kiskittogisu, the East and West channels of the Nelson River, Cross, Sipiwesk, Split and Stephens lakes are provided in two separate volumes of documents. These documents contain hydraulic information such as water surface elevations, velocities, and temperatures. Photographic and visual observations on ice formation, ice dams and break-up, and ice and snow survey data also are provided.

The first series contains accumulated winter field survey reports, and is entitled "Lake Winnipeg Regulation Report on Ice Survey and Hydrometric Programs"; these reports have been published annually since 1974 (Manitoba Hydro 1987a). The second series of reports contains annual ice and hydrometric data from the Nelson River between Cross and Sipiwesk lakes. The latest of these reports is entitled "Nelson River Investigations, Cross Lake to Sipiwesk Lake/Split Lake to Stephens Lake and Limestone G.S. to Port Nelson ice monitoring program and hydrometric surveys (Conawapa G.S. axis studies) for winter-spring 1986/87" (Manitoba Hydro 1987d).

Electromagnetic Sensing and Interpretation (1987) has compiled an extensive catalogue of aerial photography (1945-1987) and satellite imagery (1972-1987) for the CRD and LWR region. This information can be used to document changes in ice regime, formation, and break-up for the years in which data are available.

Gerard (1989)* summarized aspects of the natural ice regime and effects of hydroelectric development and operation on this regime. The report focused on impacts relevant to northern communities and discussed the effects of replacing the relatively predictable natural regime with that of an unpredictable, unnatural regime. Specific impacts on travel due to slush ice and thin ice conditions were noted. The report stressed that residents of affected communities should be made aware of possible changes to the natural ice regime.

Water chemistry/quality: In 1953, the Canada Department of Mines and Technical Services collected water level and water chemistry data between Lake Winnipeg, near Norway House, and Hudson Bay as part of a larger water survey report on the Nelson River drainage basin (Thomas 1959). Parameters measured included spot data on temperature, pH, colour, turbidity, suspended sediments, conductance, anions, cations, silica, and carbonate.

Environment Canada (1978, 1980) provided pre-development water chemistry/quality data from Manitoba waters for the 1961 to 1976 period as part of the National Water Quality Data Bank (NAQUADAT). Water chemistry data for the following locations are available: the Nelson River at Norway House (1972 to 1974); Cross Lake below the West Channel of the Nelson River (1973, 1974); Nelson River at Cross Lake; Nelson River below Sipiwesk Lake (1973, 1974); Kelsey Generating Station (1965 to 1976); Kettle Generating Station (1972 to 1976); and Split Lake community (1974 to 1976). Data from 1977 and 1978 are contained in Environment Canada (1982).

Environment Canada discontinued publishing NAQUADAT in report form in 1984. Water quality data from 1984 to the present are stored in a computerized format and are available to the general public by request from: Mr. Peter Brooksbank, Water Quality Branch, Environment Canada, Ottawa, Ontario K1A 0E4.

Electromagnetic Sensing and Interpretation (1987)* has compiled a catalogue of aerial photography (1945-1987) and satellite imagery (1972-1987) for the CRD and LWR region. This information can be used to trace changes in certain water chemistry (turbidity, temperature) and physical (debris, shoreline characteristics) parameters to determine the effects of LWR.

Playle (1986)* and Playle and Williamson (1986)* compared pre- and post-regulation water quality data from Norway House, the Burntwood and Nelson rivers, and Split Lake, for 20 parameters, including conductivity, alkalinity, pH, major ions, nutrients, total organic and inorganic carbon, colour, turbidity, and coliform bacteria. The results were later summarized by Playle et al. (1988)*. Results varied according to community. At Norway House, statistically significant increases in total organic and inorganic carbon, phosphorus, and turbidity were directly attributable to LWR and construction of Two- and Eight-Mile channels. Similar results were observed downstream at Cross Lake. In Cross and Sipiwesk lakes, increases in total organic and inorganic carbon, potassium, chloride, and turbidity and a decrease in total nitrogen were also directly attributable to LWR. Changes observed near the Cross Lake community were similar to those observed upstream at the Norway House community. At the Split Lake community, significant decreases in major ions, alkalinity, and conductivity occurred as a result of the introduction of softer, Churchill River water. Statistically significant increases in total organic carbon and turbidity were also observed, and were attributed to the combined effects of CRD and LWR. Playle (1986), Playle and Williamson (1986), and Playle et al. (1988) stated that a general problem with all water quality studies is the difficulty of separating natural environmental variability from anthropogenic effects on water chemistry parameters. Even after accounting for this variability, and errors associated with (1) differences in procedures and analytical methodology, and (2) the lack of replication, randomization, and control stations, determining ecological effects of changes to water chemistry/quality parameters has not been attempted.

Grapentine et al. (1988)* provided a comprehensive listing of existing water quality data bases for waters in the NFA area. Data collections from over 200 stations and 100 different parameters, for the period extending back to 1953, were summarized. Only data bases of federal government agencies and Inco Ltd. in Thompson were included. This report listed the dates sampled, parameters measured and number of replicate samples taken for Playgreen Lake, the Nelson River (East Channel), Sipiwesk Lake, Cross Lake, the Nelson River below Sipiwesk and Cross lakes, Split Lake, and the Burntwood River at the inflow to Split Lake.

Biological parameters

Livingston (1987*, 1988*, 1989*) provided a checklist of genera and relative biomass of phytoplankton taxa for Threepoint, Rat, Cross, Sipiwesk, Split, and Stephens lakes collected in 1980, 1981, 1986, 1987, and 1988. Changes in the relative importance of taxa (by order) are traced by lake and by year. No discussion of results is given.

Mercury: Derksen (1978a, 1979) reported mercury levels in fish for lakes along the Nelson River from Lake Winnipeg to Hudson Bay for the years 1969-1970 and 1969-1971, respectively. Data for sturgeon, goldeye, lake whitefish, cisco, northern pike, walleye, and perch were included. Mercury levels exceeded the 0.5 ppm Canadian export limit for only some species (generally walleye and pike), lakes, and years. In a summary of mercury levels in Manitoba fish prior to 1971, Derksen (1978b) noted that pike from Cross Lake and walleye and pike from Sipiwesk Lake had elevated (>0.5 ppm) mercury levels; Sipiwesk Lake fish exhibited the highest levels. Elevated mercury levels (0.25 - 0.50 ppm) in pike and walleye were also common at Playgreen Lake. Pike and walleye from Kiskitto and Kiskittogisu lakes had elevated levels (>0.5 ppm) of mercury despite the fact that neither lake receives water from Lake Winnipeg. The author could not explain why natural, background mercury levels were so high for fish from this area, but he speculated that high levels of mercury in fish prior to LWR could be attributed to the presence of naturally high levels of mercury existing in the soil surrounding certain lakes.

Reports published by the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (1983*, 1984*, 1985*, 1987*) discussed the issue of mercury. Although Norway House was not affected by CRD, soil and water samples were collected for analysis in the vicinity of this community; mercury could not be detected in the water, but was slightly above the detection level in soil.

D. Ramsey (Agassiz North Associates, Winnipeg, personal communication) has demonstrated a positive correlation between mercury concentration in fish and degree of flooding. He also stated that it was the amount of organic matter flooded that is important and "any relationship between mercury in fish and mercury in soil is an artifact of the colinearity between concentrations of mercury and organic matter in soils."

NORWAY HOUSE

Physical and chemical parameters

Water levels and flows: Detailed hydrometric and hydrographic data on the Nelson River from the Lake Winnipeg outlet to Cross Lake are provided in two internal Manitoba Hydro reports (Manitoba Hydro 1965a, b).

Crippen and Associates (1964) carried out the initial studies that considered three alternatives for LWR. During the course of this work, they examined the hydraulics of the upper Nelson River system.

Kuiper and Booy (1968) provided an overview on the feasibility of regulating Lake Winnipeg and recommended the most practical range for water-level regulation. Historical long-term levels of Lake Winnipeg were provided. Subsequent to this report, Booy (1969) recorded detailed 1969 water-level and outflow information for Lake Winnipeg at Warren Landing, and the East Channel of the Nelson River near Norway House.

Manitoba Hydro (1972a) was an internal report relating LWR to hydroelectric power development on the Nelson River. The possible effects of LWR on erosion, water chemistry, and fisheries were provided, including a documentation of historical water-level conditions on Lake Winnipeg since 1913.

Stockner (1972) and Ayles (1973) provided pre-regulation limnology and lake morphology data for Playgreen and Kiskittogisu lakes. Manitoba Hydro (1972b) conducted similar studies of Playgreen and Kiskittogisu lakes during 1970 and 1971, which included limnological and water chemistry data from a number of locations.

Koshinsky (1973) provided pre-regulation water levels and flow rates for Playgreen, Kiskitto, and Kiskittogisu lakes.

Water Resources Branch (1974, 1975) documented pre-regulation (from 1927) water levels for Playgreen, Kiskitto, and Kiskittogisu lakes and historical flow rates and duration curves for the East and West channels of the Nelson River at Lake Winnipeg. Water levels and flows of the upper Nelson River from Lake Winnipeg to Sipiwesk Lake were also provided.

Manitoba Hydro (1975a) documented field hydrometric data for open-water discharge and gauge relationships for Lake Winnipeg prior to 1974. The Final Regulation Manual for LWR (Manitoba Hydro 1977a) provided hydraulic data and relationships at the time of completion of LWR at Jenpeg. It also described the progress made during construction of Two- and Eight-Mile channels and summarized the licensing requirements for regulation.

A series of internal Manitoba Hydro reports provided detailed hydrometric relationships and performance of the LWR system during winter periods commencing in 1973/74 through 1986/87 (Manitoba Hydro 1987a).

The Kiskitto Lake Regulation Committee (1977) investigated operational aspects of Kiskitto Lake regulation in order to optimize the natural resource potential of the area. The report recommended minimum and maximum water levels and flows that should be maintained to ensure reasonable depths for fish production and to prevent eutrophication.

Teillet et al. (1978), in a resource allocation and assessment of the Norway House community, provided a summary of water level and flow information prior to LWR. Projected water levels and flow data with CRD and LWR were also presented for the Lake Winnipeg outflow, East and West Nelson River channels, and Playgreen Lake.

Unies Ltd. (1980) analyzed the effects of LWR on Lake Winnipeg water levels, water flows, and potential energy generating capability in downstream stations.

Underwood McLellan Ltd. (1983a, 1984a) stated that water level fluctuations resulting from LWR restricted access to Playgreen Lake and the Nelson River. It was noted that, although water levels did not exceed historic minimum and maximum levels, the rate of fluctuation was significantly higher.

MacLaren Plansearch Inc. (1985) conducted an extensive examination of Playgreen Lake in an attempt to determine: (1) effects of regulation on Playgreen Lake and Lake Winnipeg and; (2) impacts of Two-Mile and Eight- Mile channels on fisheries, shorelines, hydrology, sedimentation, limnology, water quality, and aquatic vegetation. As a result of LWR, water levels within Playgreen Lake rose 0.23 m above mean, long-term (1914-1969) levels. However, mean water levels during the seven years (1977-1983) after regulation, were 0.27 m lower than the mean level for the six years prior to regulation. Water levels at Norway House were approximately 0.1 m lower than Playgreen Lake levels; therefore, levels at Norway House had been only slightly affected. Completion of Two-Mile and Eight-Mile channels in 1976 facilitated the flow of Lake Winnipeg water into Playgreen and Kiskittogisu lakes, respectively. This flow is affected by seasonal and episodic events related to weather, hydrology, and water levels. Due to recent low water levels, however, measured flow rates and lake levels did not differ from pre-LWR data (MacLaren Plansearch Inc. 1985). The control of the 1979 flood waters by LWR was considered a positive effect felt by Norway House. Natural flows, however, were believed to have been lower than "normal" during this period (R. Halliday, Inland Waters Directorate, Regina, personal communication).

Data provided by P. Boothroyd (Canadian Wildlife Service, Winnipeg, personal communication) indicated that mean monthly water levels were 0.16 m higher at Norway House after regulation (1977-1987) than prior to regulation (1915-1974), despite below normal rainfall. Results of the MacLaren Plansearch Inc. (1985) study and Inland Waters and CWS data appear to be contradictory.

Since 1974, Manitoba Hydro has collected detailed and extensive hydraulic and hydrometric information during the summer and winter periods from a large number of sites in the LWR area. Data from Playgreen, Kiskitto, Kiskittogisu, and Cross lakes and the East and West channels of the Nelson River are provided. Summer field reports are entitled "Lake Winnipeg Regulation Hydrometric Programs" and have been published annually since 1975 (Manitoba Hydro 1987b).

<u>Lake and river shorelines</u>: Koshinsky (1973) described shoreline characteristics of Playgreen, Kiskitto and Kiskittogisu lakes prior to regulation.

A detailed technical report on hydrologic and hydraulic studies prior to diversion, was prepared by R.W. Newbury and F. Penner as part of a Water Resources Branch (1974) study. Prediversion data on shoreline profiles and classification of the Nelson River from Lake Winnipeg to Sipiwesk Lake were provided. The report also predicted impacts to shorelines with LWR.

Teillet (1978) and Teillet et al. (1978) published resource allocation and assessment reports for Norway House prior to LWR. Physical geography (including biophysical, morphometric and limnological parameters), natural resource allocation, and socioeconomic information was presented. Shoreline types for Playgreen, Little Playgreen, Kiskittogisu, and Kiskitto lakes, and the East and West channels of the Nelson River were documented. The importance of shoreline type to fish species of economic importance was also described.

According to MacLaren Plansearch Inc. (1985), post-LWR Playgreen Lake shorelines differed little from pre-LWR conditions, with a dynamic equilibrium having been reestablished since regulation. The shape and nature of shorelines between Peat Point and Weasel Point on the southwest shore of Playgreen Lake were unaffected by LWR. No erosion of the eastern shorelines of the south basin of Playgreen Lake were observed after LWR.

Erosion, sediment transport, and deposition: In an internal Manitoba Hydro (1972a) report relating LWR to power generation on the Nelson River, rough approximations of shoreline erosion on Lake Winnipeg were calculated based on anticipated water regimes with regulation, compared to those under natural conditions. Erosion was not expected to be a major concern as a result of LWR, because regulated lake volumes were expected to fall well within historical high and low water levels.

Prior to LWR, Manitoba Hydro (1974a, 1975b, 1977c) documented sedimentation data collected from Playgreen Lake during 1971-1973, 1974-1975, and 1972-1977, respectively. Data included suspended sediment measurements, light penetration, wave action, wind velocity, wind direction, and discharge.

Brunskill and Graham (1979) provided data on offshore sediments (particle size, composition, mineralogy, chemistry, etc.) of northern Lake Winnipeg. The attenuation of light due to suspended sediments in Lake Winnipeg was described by Brunskill et al. (1979).

MacLaren Plansearch Inc. (1985) stated that erosion of Playgreen Lake shorelines was a natural, historic phenomenon. Pre-and post-regulation data on the most vulnerable shoreline within Playgreen Lake near Peat Point showed no relationship to LWR (MacLaren Plansearch Inc. 1985). The report also stated that erosion on the north shore of Lake Winnipeg contributed substantial amounts of organic and inorganic material to Playgreen Lake via Warren Landing and Two-Mile Channel. Heavier fractions settled out, although internal shoreline erosion maintained relatively turbid plumes of water parallel to the southwestern shore of Playgreen Lake. These suspended solids did not appear to flow north to Little Playgreen Lake. Sediment plumes affected 20-54% of the south basin, both before and after LWR.

Manitoba Hydro (1985a) published an analysis of 1984 sedimentation data which completed the documentation of sediment data collected from Playgreen Lake (see above). Suspended sediment, light penetration and wind and wave conditions were documented.

As discussed under "GENERIC INFORMATION: Physical and chemical parameters: Water levels and flows" above, Manitoba Hydro has collected extensive hydraulic information from the Norway House area between 1974 and the present (Manitoba Hydro 1987a). Included in a number of the earlier annual reports is an assessment of sediment transport from Lake Winnipeg into Playgreen and Kiskittogisu lakes. Sediment concentration and light penetration data from a variety of depths at each site were collected during the summer. These reports contain unanalyzed data only.

Debris: MacLaren Plansearch Inc. (1985) noted that increases in autochthonous (indigenous or naturally occurring) and allochthonous (introduced as a result of flooding) debris within Playgreen Lake occurred throughout the spring and summer, attenuating with increasing distance downstream from Two-Mile Channel. It was felt that slightly higher than normal amounts of debris were being introduced during the spring via Two-Mile Channel but the increase, if any, could not be quantified due to the lack of pre-regulation data on debris. The degree of net fouling, used as an indicator of debris, was inconclusive and could not prove that either an increase or decrease had occurred. Based on bottom core samples, no apparent differences were found in the introduction and deposition of organic debris on lake bottoms before and after LWR.

A review of the MacLaren Plansearch Inc. (1985) report by DFO (D. Bodaly, G. McCullough, DFO, Winnipeg, personal communication), stated that the subject of debris was inadequately addressed. DFO analyses indicated that a positive correlation between the proximity to Two-Mile Channel and net fouling could be established. Conclusions in the MacLaren report also were based on post-LWR water levels, which were below predicted levels due to recent drought conditions. In fact, Norway House fishermen were compensated annually by Manitoba Hydro for problems with net fouling by debris in Playgreen Lake.

Ice: Kuiper and Booy (1968) reported that Playgreen Lake was completely covered by ice during winter, inhibiting flow rates.

Manitoba Hydro (1973a) predicted possible effects of LWR on winter transportation, including effects of ice, from Warren Landing to Cross Lake. Existing and alternate transportation systems were considered, and remedial measures were proposed. The effects of Jenpeg, Two- and Eight-Mile channels, and other regulation measures on ice formation and conditions, water levels, water velocity, and open-water areas were considered.

Manitoba Hydro (1974b) provided a preliminary assessment of how ice conditions at Warren Landing and Little Playgreen Lake may be affected by construction of Two-Mile Channel. Initial conclusions were that the Warren Landing area may "be subject to poor and unpredictable ice conditions".

Manitoba Hydro (1975c) outlined possible problem areas and possible solutions to lessen the impact of adverse ice covers which could develop with the operation of Two- and Eight-Mile Channels.

Manitoba Hydro (1977b) documented the timing of freeze-up, ice thickness in outlet lakes, ice jams, and performance of Two- and Eight-Mile Channels and Ominawin Bypass during the first winter of LWR (1976/1977).

A series of Manitoba Hydro reports, starting in 1974 and published annually to 1987, documented the timing of freeze-up and ice formation and thickness on Lake Winnipeg and the upper Nelson River and channels (Manitoba Hydro 1987b). Two-Mile Channel was mostly ice-free all winter whereas Eight-Mile Channel was largely ice-covered with variable open-water stretches from year to year. The impact of open-water, or thin- or slush-ice conditions created in the channels or in Playgreen Lake is not assessed.

Water chemistry/quality: Stockner (1972) and Ayles (1973) provided pre-regulation water chemistry data including nutrients, salts, pH, turbidity, alkalinity, conductivity, oxygen, and temperature for Playgreen and Kiskittogisu lakes for 1970 and 1971. Stockner (1972) gave a more detailed summary of water chemistry parameters than did Ayles (1973), especially for Kiskittogisu Lake. He concluded that Kiskittogisu Lake was unproductive due to low nutrient levels and low water exchange rates. Stockner (1972) also concluded that Kiskittogisu Lake was much less productive than Playgreen Lake.

Manitoba Hydro (1972a) stated that LWR was expected to have only minimal impact on water chemistry parameters of Lake Winnipeg.

Sparling (1973) examined the domestic water supply of the Norway House settlement in 1972. He concluded that water quality was unsatisfactory prior to regulation, and although the effects of LWR were not expected to have significant detrimental effects, conditions would not improve.

Koshinsky (1973) described the limnology of Playgreen, Kiskitto, and Kiskittogisu lakes and provided water chemistry parameters such as ions, nutrients, total solids, pH, conductivity, carbon, nitrogen, phosphorus, gases, and heavy metals. Morelli (1975) also examined water chemistry from Playgreen, Kiskitto, and Kiskittogisu lakes and presented pre-LWR data.

Kristofferson et al. (1975) conducted a limnological survey of the north basin of Lake Winnipeg. Several sites examined were located in the immediate vicinity of the Nelson River outlet. Temperature, oxygen, pH, conductivity, alkalinity, ions, nutrients, and gasses were measured during 1974.

Teillet et al. (1978) provided a summary of monthly water chemistry parameters including major ions, nutrients, alkalinity, conductivity, and coliforms between August 1972 and September 1974 near the Norway House community.

Brunskill et al. (1980) presented limnological data on the morphometry, hydrology, and watershed of Lake Winnipeg, including the north basin.

Underwood McLellan Ltd. (1983a, 1984a) evaluated the domestic water supply of the Norway House community. Water was analyzed for major ions, metals, pH, total organic carbon, dissolved solids and "water quality" parameters such as nitrate-nitrite, colour, odour, and coliform bacteria. Iron and total organic carbon had increased significantly after LWR. The community also felt that incidences of high turbidity in the drinking water were a direct result of Two-Mile Channel. The report concluded that water quality did not meet Canadian Drinking Water Guidelines either before or after LWR.

MacLaren Plansearch Inc. (1985) noted an increase in nutrients and primary productivity in the south basin of Playgreen Lake after LWR, which may have had a positive effect on fish production. Cooler thermal plumes in summer and warmer plumes in fall observed downstream of Two-Mile Channel, were not believed to have had detrimental effects on the whitefish fishery.

However, D. Bodaly (DFO, Winnipeg, personal communication) stated that unpublished DFO documents showed no evidence for increased nutrient levels and productivity. The statement made by MacLaren Plansearch Inc. (1985), that productivity has increased based on elevated DIC and pH values, was considered extremely tenuous.

Duncan and Williamson (1988) found that nine water quality parameters tested were either positively or negatively linearly related to discharge at Norway House. These relationships varied with location and time.

Biological parameters

Kuiper and Booy (1968) stated that 90% of fish production in Playgreen Lake depended on movement of fish between Lake Winnipeg and Playgreen Lake. Due to insufficient data on the fish stocks, these authors did not attempt to predict the potential impacts of LWR.

Manitoba Hydro (1972a) related LWR to hydroelectric power development on the Nelson River, including an evaluation of the potential impacts of LWR on Lake Winnipeg fisheries resources. The report stated that drawdown may inhibit migration of fish into spawning streams and have a negative impact on egg survival. It concluded that minimal effects on primary productivity and invertebrates were expected, with no net detrimental effect on fish stocks.

Schlick (1972) described the Playgreen Lake fish community from an experimental gillnetting survey which was conducted for the purpose of determining the commercial quota for the lake. Rudimentary lake morphometry and water chemistry data are also provided.

Stockner (1972) and Ayles (1973) provided information on pre-regulation fish populations from Playgreen and Kiskittogisu lakes. Ayles (1973) described species composition and standing crop of the bottom fauna in addition to fish population statistics. Species composition, catch-per-unit-effort (CPUE) and age-size relationships were provided for pike, walleye, sauger, lake whitefish, lake cisco, sucker, and burbot. Stockner (1972) provided rudimentary data for lake whitefish and walleye stocks.

Manitoba Hydro (1972b) conducted a similar fisheries survey of Playgreen and Kiskittogisu lakes. Fisheries data included species composition from gillnets and beach seines, age and size information, and a study of whitefish spawning. Water chemistry and limnological data were also collected coincidentally.

Pollard (1973) concluded that lake whitefish move back and forth between Playgreen Lake and Lake Winnipeg, primarily during autumn spawning runs. Age, growth, and maturity data of Playgreen Lake whitefish were provided. Koshinsky's (1973) survey of the outlet lakes of Lake Winnipeg during 1970 and 1971 placed emphasis on Playgreen, Kiskitto, and Kiskittogisu lakes. Species composition and relative abundance of invertebrates and fish populations were determined. Abundance, growth, size, and condition factor were compared between lakes and appeared to indicate, that for the major species, each lake contained discrete populations. Tagging studies also revealed movement of whitefish from Lake Winnipeg into Playgreen Lake during fall. A description of the volume, utilization, and value of the domestic and commercial gillnet fishery was provided. The report described the major anticipated impacts (positive and negative) to aquatic resources following hydroelectric development.

Ayles (1974) conducted a brief fishing program to investigate fish resources of the East Channel of the Nelson River. CPUE statistics, size, and condition of major species were determined. She concluded that the East Channel fish fauna differed from that of Playgreen and Cross lakes, being more typical of a riverine fish fauna.

The Kiskitto Lake Regulation Committee (1977) briefly described and presented historical statistics for the Kiskitto Lake commercial fishery; it discussed the impact of LWR on Kiskitto Lake fish populations. The report stated that short-term detrimental effects were expected as a result of the elimination of fish movement between Kiskitto Lake and the West Channel of the Nelson River.

Teillet (1978) and Teillet et al. (1978) described commercial and domestic fishing statistics for the Norway House community between 1969 and 1976. The vast majority of fishing effort by Norway House residents was carried out on Playgreen Lake, with a lower level of effort on Lawford and Molson lakes, which were unaffected by LWR.

In 1974, Derksen and Hangasjarvi (1979) sampled plankton at 20 stations in the Lake Winnipeg north basin. Relative biomass and species composition for phytoplankton and zooplankton were given.

Howard (1980) provided age, growth, maturity, and diet information for lake whitefish and sauger from an experimental seining and gillnetting study conducted in the Lake Winnipeg north basin between 1963 and 1967.

Lysack (1980, 1981) presented a stock assessment of the commercial fish species in the north basin of Lake Winnipeg. In a comparative study, Lysack (1982) found marked differences in yield, maturity, and age-size relationships for whitefish captured in experimental nets from Playgreen Lake and Lake Winnipeg. Insufficient data prevented an assessment of how LWR would affect either whitefish stock.

Commercial catch statistics for Playgreen Lake whitefish between 1975 and 1977 were examined by Sopuck (1978). O'Connor (1982) examined 1975 to 1981 data to determine if changes in population characteristics (growth, mortality, maturity, yield) had occurred. He determined that, despite a decline in mean weight and in growth rate of whitefish in Playgreen Lake, changes in the population could not be related to LWR and were more likely due to gear selectivity. Sopuck (1978) and O'Connor (1982) also concluded that Two-Mile Channel had no demonstrable positive or negative effects on the catch and quality of whitefish in Playgreen Lake.

Hilderman Witty Crosby Hanna and Assoc. (1983) examined the impacts of LWR on the Playgreen Lake commercial fishery. This was a non-technical report utilizing data from other fisheries, such as Southern Indian Lake, to describe biological changes that may have occurred in Playgreen Lake.

An economic evaluation of the Playgreen Lake commercial fishery was conducted by the Manitoba Department of Natural Resources (DNR) (1983). Effects of LWR were related to changes that have occurred in the fishery.

An extensive study of the Playgreen Lake fishery was conducted in 1984 by MacLaren Plansearch Inc. (1985). This report concluded that LWR did not adversely affect lake whitefish in Playgreen Lake. CPUE, yield, and total market value of whitefish increased at Two-Mile Channel and Warren Landing, despite net fouling. The report stated that Playgreen Lake and Lake Winnipeg whitefish maintained high flesh quality. The yield and value of the walleye fishery also increased. An increase in primary productivity in the south basin of Playgreen Lake, as a result of Two-Mile Channel construction, may have contributed to increased fish production. However, DFO's review of this document stated that there was insufficient data to make these claims (D. Bodaly, DFO, Winnipeg, personal communication). Pre- and post-project estimates of primary productivity in Playgreen Lake have never been made; therefore, the argument that primary production has increased in Playgreen Lake since construction of Two-Mile Channel cannot be supported.

The Norway House Indian Band sought compensation for the loss of commercial fishing opportunities at Playgreen Lake due to the effects of LWR (Canada Department of Indian and Northern Affairs 1987; Claim Number 16). A final settlement was negotiated for 2.282 million dollars in exchange for absolution of further claims until 1990. Claims for loss of domestic fishing are outstanding and are in the process of being negotiated (D. Depape, Manitoba Hydro, Winnipeg, personal communication).

Mercury: Canada Department of Fisheries and Oceans Inspection Branch (unpublished data, 1970-1982) have revealed no significant trend or increase in mercury content of fish from Playgreen Lake since LWR.

CROSS LAKE

Physical and chemical parameters

Water levels and flows: In 1953, the Canada Department of Mines and Technical Services collected water level and chemistry data below Sipiwesk Lake as part of a larger survey of the Nelson River drainage basin (Thomas 1959).

Hydrometric and hydrographic data from Sipiwesk and Cross lakes, including cross-section profiles at selected locations, were collected in the summer of 1961 by Manitoba Hydro (1961).

Detailed hydrometric and hydrographic data on the proposed Bladder Rapids hydroelectric development between Cross and Sipiwesk lakes were collected by Manitoba Hydro in 1964 and 1965 and published as an internal document (Manitoba Hydro 1966). Additional hydrographic and hydrometric data on the Nelson River, between Kiskittogisu and Sipiwesk lakes, are contained in two additional reports (Manitoba Hydro 1965a, b).

Cleugh (1974) conducted a comprehensive hydrographic survey of Nelson River lakes, including Cross Lake, between 1972 and 1973. Velocity and discharge at the inlet and outlet channels of the Nelson River at Cross Lake were determined.

Existing and predicted water levels and flow regime under LWR for Cross Lake are contained in Manitoba Department of Mines, Resources and Environmental Management (1974); it profiles the community of Cross Lake.

Manitoba Hydro (1979) used open-water hydrometric and hydraulic data between 1961 and 1964 to analyze backwater flow conditions between Sipiwesk and Cross lakes under natural and regulated flows.

Water Resources Branch (1975) provided detailed pre-diversion data on water levels and flows and duration curves for sites along the CRD route from the Notigi control structure to Split Lake. It also included predictions on the effects of changes in levels and flows with diversion.

Studies into maintaining acceptable water levels on Cross Lake through the construction of weirs at the Cross Lake outlet, were undertaken by Goulter et al. (1980) and Manitoba Hydro (1981a). These reports presented information on the hydraulics of the Cross Lake outlet channels, including water level, discharge and flow distribution data.

Detailed water levels for Cross Lake from January 1912 to 1981, with the exception of several small intervals, are contained in Manitoba Hydro (1982a). Pre-and post-LWR stage duration curves and monthly water-level fluctuations for Cross Lake also were documented.

Gaboury and Patalas (1981, 1982) concluded that significant and largely detrimental effects on the biophysical environment had occurred at Cross Lake as a result of LWR. The reports stated that LWR had resulted in dramatic fluctuations in water levels between spring and fall. LWR had decreased the volume of Cross Lake by 53%, decreased lake area by 26%, and decreased mean water depth from 2.4 m prior to LWR, to 1.5 m after LWR. Winter drawdown also has increased since regulation, and this has detrimentally affected survival and recruitment of fish, reduced access to spawning grounds, stranded fish, and caused oxygen depletion (see "Biological parameters", below). Data presented in the 1981 and 1982 reports have been summarized by Gaboury and Patalas (1984) and by Bodaly et al. (1984a).

The Nelson River Group (1984, 1986) published an extensive assessment of the effects of LWR on Cross Lake. The pre-LWR condition of the Cross Lake community and the traditional lands contained within the trapping boundaries were documented. The impact of LWR and its associated structures were assessed, tracing the changes which have occurred since the start of regulation in 1976. Historical water regimes of Lake Winnipeg and Cross Lake between 1912 and 1981, including monthly mean water levels, were also presented. In addition, a detailed description of seasonal and monthly fluctuations in water levels of Cross Lake since regulation also were provided. LWR has reversed the natural flow regime, with highest water levels occurring in winter and lowest levels during the open-water season. Under regulation, low summer water levels consistently exceeded lowest minimum levels recorded, and fluctuated much more rapidly than natural levels. Substantial reductions in water level and reversal of the natural, seasonal flow regime have resulted in significant negative impacts on aquatic resources.

Historical, pre-regulation, and post-regulation water level and flow data for Sipiwesk Lake were also documented. However, impacts are not as extreme, given the ameliorating effect of the Kelsey Generating Station. Impacts of LWR on water levels of Drunken, Pipestone, Walker, Kiskitto, and Kiskittogisu lakes were also discussed.

Playle and Williamson (1986) stated that the mean level of Cross Lake has been reduced by 1.7 m since LWR. This has resulted in an increase in suspended sediment and turbidity due to resuspension of fine sediment by wind action.

Lake and river shorelines: University of Manitoba (1973) described shoreline characteristics of the Nelson River, and provided a prediction of the impacts of impoundment and diversion on Cross Lake shorelines.

Cole (1974) described existing shoreline conditions in the vicinity of the Cross Lake community and attempted to predict impacts on the shoreline as a result of LWR. Impacts resulting from water-level regulation are discussed relative to shorelines, vegetation, and effects on the community.

Teillet et al. (1977) and Teillet (1978) published resource allocation and assessment reports for the Cross Lake settlement prior to regulation. Physical geography (including biophysical, morphometric, and limnological data), resource allocation, and socioeconomic information are presented. These reports provided morphometric data and shoreline characteristics for lakes in the Cross Lake area, including Cross, Playgreen, Kiskittogisu, Pipestone, Kiskitto, Drunken, and Walker lakes, prior to LWR.

Gaboury and Patalas (1981, 1982) reported that fluctuations in water levels on Cross Lake had resulted in alternate flooding and exposure of littoral zones. Exposure of the littoral zone during drawdown periods caused reduced access to the lake. The reports stated that Walker Lake morphometry and shorelines have not been affected by regulation.

Changes in the shoreline and morphometry of Cross Lake were documented by the Nelson River Group (1986). LWR reduced the total pre-regulation surface area of Cross Lake by an average of 16%, with a maximum reduction of 27% in June, 1980. A significant loss of reproductive and feeding habitat for fish has occurred because of this reduction.

Erosion, sediment transport, and deposition: The Nelson River Group (1986) stated that erosion had not been identified as a major adverse environmental consequence of LWR due to the net reduction in lake volume. More rapid fluctuations in lake levels than would have occurred under natural conditions, and the effects of wind and wave action resuspending sediments had, however, contributed to a higher sediment concentration in the water than existed prior to LWR.

Debris: The Nelson River Group (1984, 1986) stated that concerns about the presence of increased amounts of debris had been expressed by Cross Lake residents. However, the amount of debris was not quantified either before or after LWR. The report also stated that Manitoba Hydro has compensated claims filed as a result of damage to equipment and nets by debris.

Ice: Manitoba Hydro (1973a) outlined the effects of LWR on winter transportation in the Cross Lake area near the Jenpeg site. The report contained current and predicted effects of LWR on ice formation, ice conditions, the extent of open water, and water levels. Pre-regulation ice conditions at 13 stations on Cross Lake were documented in Manitoba Hydro (1974b). This report concluded that LWR may cause reduced ice thickness and delayed freeze-over at several of the stations in the narrows between Cross Island and the mainland.

Manitoba Hydro (1983a) concluded that increased flow in the West Channel with LWR had a positive effect, resulting generally in increased ice thickness. Increased slush ice and transportation problems encountered during 1982/83 were said to be due to a heavy snowfall, and were unrelated to LWR.

The Nelson River Group (1984, 1986), in response to claims by Cross Lake residents that there was an increase in slush-ice due to LWR, examined the possible causes. They concluded that regulation of the natural outflow pattern during the winter may have contributed to increased slush ice conditions, but that it was impossible to predict or quantify the degree of impact.

Review of the above reports revealed that residents and Manitoba Hydro had inconsistent or contradictory impressions as to the effect of LWR on ice conditions.

Manitoba Hydro (1986) stated that ice conditions and problems in the Nelson River upstream of Jenpeg occurred primarily as a result of downstream hanging ice dam formation. A technical evaluation of the utilization of ice booms to facilitate winter flow rates was presented.

Manitoba Hydro collected detailed annual winter hydraulic and hydrometric information for a number of sites between Playgreen Lake and the Lower Nelson River. The information, which is continuous from the winter/spring of 1974/75 to the present, is available in a series of internally published Manitoba Hydro reports. Visual documentation (including photographs) of ice formation, ice jams, and ice break-up is also provided.

Water chemistry/quality: In 1953, the Canada Department of Mines and Technical Services collected water level, water chemistry, and physical data below Sipiwesk Lake, as part of a larger water survey report of the Nelson River drainage basin (Thomas 1959). Parameters measured included temperature, pH, colour, turbidity, suspended sediments, conductance, anions, cations, silica, and carbonate.

Sparling (1973) examined the domestic water supply of the Cross Lake community prior to LWR and attempted to predict possible impacts of LWR on water quality. He concluded that the domestic water supply was already classified as contaminated, and stated that the quantity and quality of water was expected to deteriorate further after regulation.

Cleugh (1974) conducted a comprehensive hydrographic survey of Nelson River lakes, including Cross Lake, between 1972 and 1973. Major ions, nutrients, solids, conductivity, carbon, nitrogen, phosphorus, and iron concentrations were determined. Limnological parameters and estimates of phosphorus loading rates were also calculated.

Koshinsky (1973) surveyed the limnology, water chemistry, and aquatic resources of Lake Winnipeg outlet lakes, including Cross Lake, during the summers of 1970 and 1971. Water chemistry parameters examined included major ions, nutrients, total solids, pH, conductivity, heavy metals, carbon, nitrogen, nutrients, and gases.

Morelli (1975) collected water chemistry data for northern Manitoba Lakes, including Cross Lake, during 1973 and 1974. Most major water chemistry parameters were determined.

Teillet et al. (1977) provided pre-LWR monthly water chemistry data including ions, nutrients, alkalinity, conductivity, pH, coliforms, etc., from August 1972 to October 1974 for Cross Lake.

Gaboury and Patalas (1981, 1982) stated that changes in water chemistry parameters before and after regulation could not be quantified due to inadequate pre-regulation data. A comparison of water chemistry parameters collected from the outlet of Cross Lake in 1973 (Cleugh 1974) with data from 1980 and 1981 from several stations within Cross Lake (Gaboury and Patalas 1981, 1982) revealed no significant differences in water chemistry. Certain limnological parameters have been significantly altered, however. Proliferation of submergent vegetation in Cross Lake since LWR has resulted in severely reduced winter oxygen concentrations as a result of decomposition. Summer water temperatures and the amount of suspended sediment in the water have also increased substantially because of lake volume (Gaboury and Patalas 1981).

Underwood McLellan (1983b, 1984b) compared the domestic water supply at Cross Lake before and after LWR. Major ions, metals, carbons, suspended solids, alkalinity, pH, and "water quality" parameters such as nitrate-nitrite, colour, odour and coliform bacteria were evaluated. Water supplies did not meet Canadian Drinking Water Guidelines before, or after regulation. Although levels of most parameters were not significantly different after regulation, severe reductions in lake volume have had substantial adverse effects on availability and quality of water.

The Nelson River Group (1986) also concluded that water quality monitoring of Cross Lake before and after LWR was inadequate and infrequent. Although it was known that drinking water did not meet Canadian Drinking Water Standards, the lack of baseline information negated the possibility of quantifying the changes brought about by LWR.

Duncan and Williamson (1988) found that nine water quality parameters in Cross Lake were linearly related to discharge as affected by LWR. They concluded that water chemistry/water discharge relationships had been considerably altered since LWR. They also concluded that these relationships were too simplistic to permit the establishment of direct, predictive relationships between discharge and water chemistry parameters.

Ramsey et al. (1989) summarized water chemistry data collected by the Manitoba Department of Natural Resources (DNR) between 1985 and 1988. The report documented existing conditions from three sites in Cross and Sipiwesk lakes and compared them to water chemistry prior to LWR. In Cross Lake, nutrient concentrations were similar to, or higher than levels recorded prior to LWR. Nitrate - nitrogen and total dissolved phosphorus concentrations increased, whereas total dissolved nitrogen, and dissolved organic and inorganic carbon did not change. Carbon, nitrogen, and phosphorus showed no consistent changes. Anions were uniformly lower, whereas cations were generally lower than in 1972-1973. No change in transparency, turbidity, or dissolved solids was observed. In 1987-1988 at Sipiwesk Lake, mainstem concentrations of nitrate, dissolved nitrogen, phosphorus, and organic and inorganic carbon were similar to 1972-1973 concentrations. Suspended phosphorus, nitrogen and carbon concentrations were lower, as were all anions and cations. Turbidity and transparency did not change, whereas the concentration of suspended solids was lower.

Biological parameters

Studies by Sunde (1959, 1961) and Kooyman (1955) examined life history characteristics (growth, reproduction, mortality, etc.) and commercial catch statistics of the Nelson River lake sturgeon fishery between 1953 and 1956. Management recommendations were also provided.

Sunde (1964) reported a relatively high rate of Triaenophorus infestation in whitefish from Walker Lake in 1963. Schlick (1966a) examined lake whitefish from Sipiwesk Lake for Triaenophorus cysts in muscle during 1966, and concluded that lake whitefish had low infestation rates and were of export quality.

Driver (1965) and Driver and Doan (1972) provided data collected during a biological survey of Cross Lake in 1965. Lake morphometry, rudimentary water chemistry, benthos, and experimental gillnetting data were provided. Commercial fishing and parasite infestation of lake whitefish were also discussed.

Koshinsky (1973) determined species composition and relative abundance of invertebrates and fish in Cross Lake and compared them with upper Nelson River lakes. Growth, size, age, and condition factors for important fish species were also determined. A description of the present and historical volume, utilization and value of the domestic and commercial gillnet fisheries were also provided. Major anticipated positive and negative impacts on fisheries resources following hydroelectric development were outlined.

Ayles (1973) examined fish resources of the East Channel of the Nelson River and Pipestone Lake. Species composition, CPUE statistics, and growth and condition factors were provided. The East Channel, unlike Playgreen and Cross lakes, contained no whitefish and only small quantities of northern pike and sauger. Productivity was estimated to be half that of Cross Lake and one third that of Playgreen lake. Fish fauna of the East Channel was found to be more typical of riverine than lacustrine habitats, which explained the reduced productivity.

Ayles et al. (1974), presented pre-regulation fisheries data from Cross and Sipiwesk Lakes. Information included species composition, population statistics, growth, production and diet of major species. Commercial fishing statistics prior to 1973 were also provided for these lakes.

Teillet et al. (1977), in a resource assessment inventory of the Cross Lake settlement area, provided fisheries data for Cross Lake and adjacent, domestically or commercially fished lakes such as Pipestone, Walker, Playgreen, Kiskittogisu, and Kiskitto lakes. Commercial harvest statistics between 1969 and 1976 for these and several lakes unaffected by regulation were presented. The majority of fishing effort by Cross Lake residents took place on Cross, Pipestone, and Walker lakes with Kiskitto and Kiskittogisu lakes being fished primarily by Wabowden residents.

Gaboury and Patalas (1981, 1982) conducted an extensive study of Cross, Pipestone, and Walker lakes. They examined lake morphometry, physical and chemical water parameters, benthos (species composition and biomass), and fisheries. Growth, mortality, size-age relationships, CPUE, species composition, and diet of pike, walleye, whitefish, and cisco were presented. Only limited comparisons could be made between preregulation data for Cross Lake fisheries collected by Driver and Doan (1972) and Ayles et al. (1974) and post-regulation data from Cross, Walker, and Pipestone lakes because of different gear types and levels of fishing effort.

Gaboury and Patalas (1982) compared invertebrate data collected in 1965 by Driver and Doan

(1972) with 1980-1981 data. They found no shift in major invertebrate groups; however, they stated it was possible that standing crops of plankton and benthos might be reduced because of a decrease in lake volume and exposure of the littoral zone, but did not present supporting data.

Gaboury and Patalas (1981, 1982) concluded that Cross Lake, and to a lesser extent Pipestone Lake, had been negatively impacted by LWR, whereas Walker Lake was relatively unaffected. These impacts included a reduction in available habitat for plankton, benthos, and fish; de-stabilization of the littoral zone; decreased reproductive success of commercial fish species due to decreased depth and high summer water temperatures; and a fish winterkill in 1981. Reduction in lake volume and area has resulted in reduced standing crops of plankton and benthos, and a decline in the size and abundance of whitefish and walleye of Cross and Pipestone lakes. The proliferation of submergent macrophytes due to reduced water levels also has resulted in reduced winter oxygen concentrations because of macrophyte decomposition. This is believed to have caused significant winter kills of fish. Reduced oxygen levels during summer because of higher temperatures have also placed additional stress on the fish populations in Cross Lake. Results also indicated that the East and West basins of Cross Lake contain discrete fish stocks and should be managed separately.

A positive correlation between winter drawdown and poor year class survival of coregonids from Cross Lake, and to a lesser extent Pipestone Lake, was also observed by Gaboury and Patalas (1982). They hypothesized that drawdown may de-water spawning and nursery areas, resulting in increased hatching mortality and decreased recruitment. De-watering also prevented walleye and pike from entering spawning streams in Cross and Pipestone lakes. Regulation of Cross Lake did not detrimentally affect coregonid reproductive success in Walker Lake.

The Nelson River Group (1984, 1986) concluded that LWR has had severe deleterious impacts on the fisheries of Cross, Pipestone, Drunken, and Kiskitto lakes. The reduction in area and volume of the lakes has resulted in impaired productivity at all levels of the food web. Prior to regulation, total annual harvest of whitefish and walleye ranged between 85,000 and 130,000 lbs. By 1980, this had declined to 5,000 lbs and, in 1981, the harvest was zero (Nelson River Group 1984). Between 1980 and 1985, there was an overall reduction of preferred fish of 72% in West Cross Lake and a 68% reduction in East Cross Lake. Whitefish and cisco were only 17% and 7%, respectively, as abundant in 1985 as in 1980. The reduction in commercial and domestic harvest of whitefish and walleye in Cross Lake was well documented by the Nelson River Group (1984, 1986), the Manitoba Fisheries Branch, and the Freshwater Fish Marketing Corporation.

Whitefish year-class survival had been more negatively affected by drawdown in East Cross than in West Cross Lake. With a virtual elimination of several year classes, the catch of whitefish was expected to be very low after 1985 (Nelson River Group 1986). A similar situation existed at Pipestone Lake, as whitefish stocks declined by 59% between 1977 and 1984. Walleye stocks, however, increased by 12% during the same period. Whitefish also declined by 82% and walleye by 12% in Kiskitto Lake. Overall production in Kiskittogisu Lake increased, however, as walleye stocks rose by 66% despite a 40% reduction in whitefish stocks. In conclusion, severe negative impacts on fish resources in lakes utilized by the Cross Lake Indian band were a direct result of LWR.

Mohr and Kirton (1986) presented 1985 fish population data (CPUE, growth, maturity, size relationships, mortality, and survival) for fish populations of Cross and Sipiwesk lakes. Mohr (1987) and Green (1987b) summarized 1986 and 1987 fish population data, respectively, from Sipiwesk and Cross lakes. Data from Cross Lake were divided into two data sets, one each for the East and West basins, following the hypothesis of Gaboury and Patalas (1982) that each basin contains discrete fish stocks. Neither report provided an interpretation of results or a discussion of the data.

The Cross Lake Indian Band has sought compensation for loss of fishing due to LWR (Canada Department of Indian and Northern Affairs 1987; Claim Number 100). Settlement of this claim is pending. Numerous claims have been settled between Manitoba Hydro and the Cross Lake Band for loss of life, equipment, and fishing gear.

Sopuck (1987a) examined fish populations and water chemistry of Pipestone Lake in 1986 and compared the data to 1980 and 1981 data collected by Gaboury and Patalas (1981, 1982). He concluded that fish species composition had been significantly altered. White sucker and northern pike populations increased, both in terms of number and biomass, whereas whitefish populations, and to a lesser extent lake cisco, decreased. Quota species, lake whitefish, walleye, and goldeye, made up 11.3% of the catch in 1981, and only 8.2% in 1986, a decline of 27%. The altered water regime had reduced spawning success of whitefish, while having positive effects on white sucker and northern pike populations. Year-class strength of walleye was also observed to be closely associated with water levels: high survival rates were correlated with high water levels.

Green (1988b) documented fish population data (length-frequency, growth, mortality) from Sipiwesk and Cross lakes during a 1987 study.

Patalas (1988) outlined the status of lake sturgeon populations in Sipiwesk Lake from 1987-1988 data. No reference to the past or present state of the sturgeon population was made, or with regard to LWR.

Derksen et al. (1988) provided preliminary fisheries data collected as part of data requirements stipulated under Claim #18 of the NFA. Pre- and post-project CPUE data for various waterbodies were compared, but are currently under revision by the author (A. Derksen, MFB, Winnipeg, personal communication). Species composition, age-frequency distributions, and CPUE for fish species in Sipiwesk Lake and Cross Lake (East and West basins) were provided.

Between 1985 and 1988, water chemistry, zooplankton, and zoobenthos samples were collected on Cross and Sipiwesk lakes by the DNR, under Claim #18 of the NFA (A. Derksen, MFB, Winnipeg, personal communication). These data have been published by Ramsey et al. (1989); they compared differences in water chemistry, and primary and secondary productivity from these lakes with the pre-CRD years of 1972 and 1973. Between 1985 and 1988, the standing crop of phytoplankton in Cross and Sipiwesk lakes was approximately three and two times higher, respectively, than in 1973. No single group accounted for the increase as community structure remained relatively similar between pre- and post-LWR. The increase in biomass was unexpected considering the absence of higher nutrient concentrations and transparency in 1985-1987. The relative biomass and community composition of the most abundant groups of zooplankton were also provided for these lakes; a comparison between pre- and post-LWR could not be made due to the absence of pre-development data.

Mercury: Environment Canada (1979a, b) provided mercury levels in Sipiwesk Lake water samples in 1977, 1978, and 1979.

Williamson (1980) surveyed northern Manitoba lakes in 1979 for the presence of heavy metals. Data are provided on zinc, nickel, cadmium, copper, lead, and mercury levels.

DFO (1982) summarized mercury levels in fish from commercial and/or survey samples in the Cross Lake area. The report is strictly a compilation of data. DFO Inspection Branch data (unpublished data 1970-1987) did not reveal significant increases in fish mercury from Cross Lake since LWR.

NELSON HOUSE

Physical/chemical parameters

Water levels and flows: Manitoba Hydro (1969) presented discharge data collected on the Burntwood River downstream of Wuskwatim Lake during the winter of 1968/69.

Underwood McLellan and Associates Ltd. (1970) evaluated several alternate routes for diversion of the Churchill River into the Nelson River watershed. This was a multi-disciplinary study which examined physical, biological, and socioeconomic aspects of the proposed development scheme. The report provided a largely theoretical discussion of perceived impacts on the various systems under consideration, based on an evaluation of impacts observed in other reservoirs and hydroelectric projects around the world. Given this information and the specific geological, limnological, biological, and socioeconomic conditions for each system, a more directed and specific assessment and prediction of impacts was presented. A prediction of water levels and flows along the Rat - Burntwood River system was developed based on an evaluation of aerial photographs and drill data to evaluate possible effects of increased flow between Notigi and Split Lake.

During the summer/fall periods of 1969 and 1970, Manitoba Hydro (1970 and 1971, respectively) surveyed five locations between Wapisu and Wuskwatim lakes. Water samples were collected and analyzed for sediment content, and discharges were determined in order to calculate sediment discharge rates. This project was continued in 1971 and 1972 by Manitoba Hydro (1973b).

As part of the planning for additional proposed hydroelectric sites along the Burntwood River, Manitoba Hydro (1973c) conducted an extensive engineering study of the winter hydraulics of the Rat - Burntwood River system between the Notigi control structure and Split Lake. Water and ice elevations were determined prior to CRD and projected for each additional development, beginning with CRD. Rating curves and surface water elevations were determined for the length of the Burntwood River. This study was repeated during the winter of 1985/86 (Manitoba Hydro 1987e) in order to provide open-water hydraulic information along the diversion route. Cross-sectional surveys revealed that significant changes in river hydraulics and elevation had occurred since initial surveys (Manitoba Hydro 1973c), because of erosion of the river bed and banks.

Underwood McLellan and Associates Ltd. (1973a) documented pre-diversion, open-water, stage-discharge relationships for Threepoint Lake and Footprint Lake outlets, including monthly historic water-level elevations for Footprint

Lake from 1957 to 1972, as part of the Rat - Burntwood Mitigation Study. The potential for water-level control for the Wapisu, Threepoint, and Footprint lakes area subsequent to diversion was also evaluated.

Crippen Acres Engineering (1974) examined pre-diversion water levels of Footprint Lake (and to a lesser extent, Threepoint Lake) with the aim of proposing alternative schemes to control water levels within the existing natural range of Footprint Lake, to negate effects of diversion on the lake. Pre-diversion water levels and flows were also described in a document profiling the Nelson House community by the Manitoba Department of Mines, Resources and Environmental Management (1974b).

Cleugh (1974) and Brown (1974) conducted extensive hydrographic and morphometric surveys of the Rat - Burntwood lakes. Cleugh (1974) calculated flow rates and volumes under pre-diversion conditions for Wapisu and Threepoint lakes. Morphometrics of Wapisu, Wuskwatim, and Threepoint lakes were determined by Brown (1974). Data include bathymetry, area, depth, volume, shoreline length, shoreline development, and outflow.

Hecky and Ayles (1974), provided a general description of pre-diversion limnological conditions and water chemistry for Burntwood River lakes. Effects of diversion on the limnology of the area were predicted.

Water Resources Branch (1974, 1975) provided detailed pre-diversion data on water levels and flows, and duration curves for sites along the CRD route from the Notigi control structure to Split Lake. Effects of changes in levels and flows as a result of diversion were predicted.

Interdisciplinary Systems Ltd. (1976) prepared an informal "question and answer" style report aimed at providing information to residents of Nelson House on how the CRD would affect water levels and flows at Footprint Lake and lakes in the vicinity of their community.

Crippen Acres (1976, 1978) provided information on expected changes in water levels and ice conditions in the Burntwood River under diversion conditions. They predicted that an alteration of the flow regime in the Burntwood River would occur as a result of ice damming. Predictions and recommendations were made concerning water elevations during winter, flows, and break-up conditions under best- and worst-case scenarios.

Hopper et al. (1978) described the methodology used to estimate changes in water regimes and flows caused by hanging ice dam formation during winter.

Manitoba Hydro (1980, 1981b) documented the effects on water levels and erosion in the Nelson House area of a winter flow rate augmented by 2000 cfs during the winters of 1979/80 and 1980/81. The relationship between increased flows and water levels at Nelson House was also documented. In 1981 and 1982, Manitoba Hydro (1982b and 1985b, respectively) examined the effects of a summer flow through the Burntwood River augmented by 5000 cfs. Relationships between predicted water levels, recorded water levels, and outflow were documented. Manitoba Hydro (1982c) reported that a flow during the summer of 1981 augmmented by 9000 cfs produced no negative impacts.

The geology, soils, and hydraulics of the Burntwood River, in the vicinity of the proposed Wuskwatim Generating Station, and potential impact of the station on river hydraulics at Nelson House, were investigated by Manitoba Hydro (1983c).

MacLaren/InterGroup (1984) investigated the status (as of 1980) of water bodies affected by CRD. The objective of the study was to assess the potential impacts of projected hydroelectric facilities at Early Morning Rapids (between Threepoint and Wuskwatim lakes) and Wuskwatim Lake. Flow rates in lakes along the diversion route, such as Threepoint, Wapisu and Wuskwatim, increased up to 10 times average annual flows (31,200 cfs), and water level increased an average of 4.0 m on Threepoint, Footprint, and Wapisu lakes. Detailed pre- and post-diversion water-level and flow information for all water bodies on the Rat and Burntwood rivers was provided. Pre- and post-diversion morphometric information and basin retention time for Wapisu, Threepoint, Footprint, and Wuskwatim lakes were also given.

Total lake area increased by 37% for Wapisu Lake, 31% for Threepoint and Footprint lakes, and 13% for Wuskwatim Lake (Bodaly et al. 1984a). Water levels increased in Threepoint and Footprint lakes by an average of 4.0 m (Underwood McLellan Ltd. 1983c). According to P. Boothroyd (Canadian Wildlife Service, Winnipeg, personal communication), mean monthly water levels at Nelson House have increased between 3.8 m and 5.5 m, with an average increase of 4.7 m, which was higher than that reported by Underwood McLellan Ltd. (1983c).

Historical water levels at Nelson House between 1915 and 1983 have been documented by Environment Canada (1985) as part of a national summary of water level data.

Crippen Acres Engineering (1987) documented winter hydraulics of the Burntwood River between the Notigi control structure and Split Lake. Field observations and surveys of open-water levels and flow rates were provided. Results of the study were presented in the form of maximum winter stage discharge curves for each of the proposed hydroelectric stations on the Burntwood River (Manasan, Wuskwatim, and First Rapids).

Beginning in the summer of 1974, Manitoba Hydro collected detailed and extensive hydraulic and hydrometric information from the Burntwood River. The information was collected at a number of sites in the Nelson House area during both summer and winter periods. The accumulated summer field reports contain water-level and discharge measurements from surveys and automatic gauges situated along the diversion route. The summer reports are entitled "Churchill River Diversion and Lower Churchill River Hydrometric Program" and have been published annually between 1974 and 1987 (Manitoba Hydro 1987f).

Bathymetric maps after CRD were constructed for Rat and Threepoint lakes (Cherepak 1989). Surface area, mean depth, shoreline length, and shoreline development indices were calculated for both lakes.

Lake and river shorelines: Underwood McLellan and Associates Ltd. (1970) evaluated several possible diversion routes for the Churchill River, including the Rat - Burntwood. Predictions as to the effects of diversion on shoreline processes and formations along the diversion route were made. A description of soil types in the area was also provided.

Underwood McLellan and Associates Ltd. (1973a) described pre-diversion shoreline lengths and characteristics of the Burntwood River system as part of a study to predict erosion and sediment transport.

The University of Manitoba (1973) summarized shoreline characteristics of the Nelson River and diversion route. A pre-impact assessment of impoundment and diversion on Burntwood River shorelines was presented.

Baracos and Galay (1973) conducted an extensive survey and classification of pre-diversion shoreline conditions of Footprint Lake. Recommendations to minimize anticipated, extensive shoreline erosion in certain vulnerable areas due to increased water levels were made.

Brown (1974) conducted morphometric surveys of Wuskwatim, Wapisu, and Threepoint lakes. Morphometric data included bathymetry, area, depth, shoreline length, and shoreline development indices.

Lombard North Group (1975) prepared a pre-impact assessment of CRD on the Nelson House community. The report predicted severe deleterious impacts on river and lake shorelines due to flooding and erosion.

Interdisciplinary Systems Ltd. (1976) prepared a non-technical report describing the theoretical effects of CRD on lake and river shorelines (see "Water levels and flows", above). Possible effects of shoreline changes, erosion, and debris were discussed.

MacLaren/InterGroup (1984) stated that, except in certain river stretches linking Threepoint, Wuskwatim, and Wapisu lakes, limited change in shoreline characteristics had occurred. It was noted that bank erosion in Wuskwatim and Footprint lakes had also occurred at exposed sites.

Shoreline characteristics (geological composition, washout coefficient, type, etc.) were presented for Wuskwatim, Threepoint, Wapisu, and Footprint lakes by MacLaren/InterGroup (1984). Bodaly et al. (1984a) and Derksen and Green (1987) presented pre- and post-impoundment areas, lake levels, lake areas, and percentage area increases for each of the aforementioned lakes.

Manitoba Hydro (1987g) presented information on an open-water hydraulic survey of the Burntwood River between Notigi and Split Lake. It was noted that significant changes in river shoreline characteristics because of river bed and bank erosion had occurred since diversion. These changes resulted in corresponding changes in water levels and flow profiles at sites surveyed in 1972 and 1973, prior to diversion (Manitoba Hydro 1973c).

Kellerhals Engineering Services Ltd. (1987, 1988) and Northwest Hydraulic Consultants (1987, 1988) provided detailed information on erosion along channelized parts of the Burntwood River. The reports stated that large-scale morphological changes to shorelines have not occurred in channelized sections, yet they were a severe problem in many areas. This conclusion was based on interpretation of photo-mosaic and satellite imagery before and after diversion. Kellerhals Engineering Services Ltd. (1988) observed that shoreline stability had been dramatically affected and debris-clogged water was extensive along the Rat - Burntwood River system, yet little detailed work has been done by any group to quantify post-diversion changes in shoreline characteristics. Deleterious impacts to shorelines varied substantially according to location and type (i.e. bedrock vs clay/silt). On Footprint and Threepoint lakes, substantial increases in submerged vegetation occurred as a result of diversion: approximately 87% of the shoreline of Threepoint Lake had submerged standing debris, and 37% of the Footprint Lake shoreline consisted of submerged standing vegetation (47% of the shoreline was cleared of vegetation prior to CRD).

Erosion, sediment transport, and deposition: Underwood McLellan Ltd. (1970) provided a general discussion and prediction of the effects of diversion on erosion, transport, and deposition of sediment through the Rat - Burntwood system. The majority of information presented was based on studies conducted at other reservoirs.

Underwood McLellan and Associates Ltd. (1973b) provided general predictions on the sediment transport regime along the CRD route under diversion conditions. Existing river conditions, including hydraulics, suspension, and movement of sediments (concentration and volume), were discussed and related to changes in these parameters because of CRD. Sites on Threepoint, Wapisu, Footprint, and Wuskwatim lakes were examined for bank composition and stability.

The Lombard North Group (1975), in a pre-impact assessment of CRD at Nelson House, predicted extensive erosion and destruction of river and lake shorelines resulting in marked increases in turbidity, suspended sediments, transportation, and deposition of sediments downstream.

Manitoba Water Resources Branch (1979) provided a sediment budget analysis of the impact of CRD on erosion and sedimentation along the Rat-Burntwood River system, between the Notigi control structure and Split Lake. A review of the sediment sampling program, which was conducted by Manitoba Hydro from 1969 to 1977, and later by the Water Resources Branch in 1979, was also provided.

Manitoba Hydro (1980, 1981b) documented effects on water levels and erosion in the Nelson House area of a winter flow rate augmented by 2000 cfs. It was concluded that increased flow would not cause additional erosion at sites monitored along the diversion route. The 1980 report also documented areas of new and continued erosion downstream from Notigi, and stated that erosion on the diversion route is continuing and will require some time to come to equilibrium.

In 1981 and 1982, Manitoba Hydro (1982b and 1985b, respectively) examined effects of a summer flow through the Burntwood River augmented by 5000 cfs. During the three-week test period, no unexpected or unusual erosion events were noted.

In 1981 and 1982, Manitoba Hydro (1982d and 1983b, respectively) examined 23 sites along the CRD route for erosion. Erosion at Threepoint, Wuskwatim, and Footprint lakes was among the highest recorded, ranging from 1 to 53 ft^3 of erosion per foot of shoreline between June 1981 and October 1982. Erosion profiles (length and slope of bank and soil volume) were presented for each site examined. Large differences in stability and erosion were found among sites, each being differentially susceptible to waves, wind, and current. Manitoba Hydro (1982d) stated that erosion scenarios and site descriptions outlined in the LWCNRSB (1975) reports were fundamentally accurate, predictive accounts. The report also stated that erosion was not a continuous process, but rather was event-related, and that exposed shorelines "rapidly evolved from the effects of the initial inundation to an unstable but more "natural" appearance, i.e. these shores are not characterized by standing timber or floating debris".

MacLaren/InterGroup (1984) stated that shoreline erosion was difficult to assess subsequent to diversion; therefore, they did not attempt to evaluate this in a 1980 study. Limited data on horizontal and vertical erosion of lakes and rivers were presented. Active regression of side slopes at bends in the Rat and Burntwood rivers was noted as being particularly severe. Erosion was expected to continue for several decades until such time as dynamic equilibrium of lake and river shorelines became re-established. MacLaren/InterGroup (1984) also reported that the increase in sediment plumes at erosion sites and overall sediment load was not severe. Only limited statements regarding changes in other water quality parameters in the Rat - Burntwood River systems were made by the authors. Guilbault et al. (1979) and MacLaren/InterGroup (1984) both stated that no significant increase in sediment load or turbidity had occurred downstream of Notigi, because of deposition and settling of sediments in the Rat - Notigi reservoir. No increase in concentrations of total suspended solids from pre-diversion levels was recorded in Rat, Notigi and Split lakes.

Northwest Hydraulic Consultants Ltd. (1987, 1988) used satellite imagery data to interpret differences in turbidity and sediment load before and after diversion. The effects, sources, and sinks of sediment along the CRD route were discussed. The 1988 report focused on providing additional information on the effects of sediment on aquatic resources, and examined temporal and spatial variation in sediment content along the CRD. Northwest Hydraulic Consultants Ltd. (1988) concluded that erosion, turbidity, and deposition in the Rat - Burntwood River system were saltatory in nature, and not consistent over its route. Specific sites were found to be more susceptible to erosion than others, with lakes along the diversion route acting as sediment sinks. For example, most of the sediment transported downstream of Wuskwatim Lake originated along the Burntwood River downstream of the lake outlet. Notigi Lake also acted as a sediment sink, but Wapisu acted as a net contributor of sediment. Northwest Hydraulic Consultants Ltd. (1988) concluded that, except for water treatment problems, the effect of actual sediment had negligible impact at Nelson House.

Crippen Acres Engineering (1987) described winter hydraulics of the Burntwood River between Notigi and Split Lake. During the course of the measurement of ice dam length and slope, an evaluation of riverbank and bed erosion was made at sites where cross-sections of the river were taken. Adjustments to existing cross-section profiles were documented and included in the report.

Kellerhals Engineering Services Ltd. (1987, 1988) utilized air photo-mosaic maps to delineate changes in erosion sites and rates along the CRD route. Results indicated that existing photographic evidence was sufficient to estimate erosion rates at severely eroded sites. The group also concluded that erosion at Footprint, Threepoint, and Wuskwatim lakes had increased significantly following completion of CRD, with an average shoreline recession of 2-3 $m \cdot yr^{-1}$ at selected sites. Shoreline erosion on Footprint and Wuskwatim lakes exceeded erosion on river sections connecting the lakes. An assessment of the impact of erosion and sediment deposition on aquatic resources of the Nelson House region was not made.

Debris: Underwood McLellan and Associates Ltd. (1970) discussed the potential effects of flooding and submergence of vegetation and trees, including the distribution and ultimate fate of debris in water. Specific effects of debris on fisheries, access, transportation, recreation, and other socioeconomic factors for Nelson House were provided.

Underwood McLellan and Associates Ltd. (1973a) predicted that significant debris accumulation would occur along the diversion route, and outlined anticipated problem areas.

The Lombard North Group (1975) predicted considerable deleterious impacts on transportation, fishing, access, and recreation for Nelson House residents as a result of increased debris from CRD.

Clearing of shoreline vegetation to the 805 ft mark on Footprint Lake in the vicinity of Nelson House was conducted as a mitigative measure (MacLaren/InterGroup 1984). Due to this, Footprint Lake was generally clear of debris and the community did not have major debris-related transportation or recreation problems. Only limited information was provided on the effects of debris at Wapisu, Wuskwatim, or Threepoint lakes. It was stated, however, that debris negatively impacted these lakes. The report also predicted continued erosion of river and lake shorelines for several decades, which will continue to contribute debris to the system.

Studies by Kellerhals Engineering Services Ltd. (1987, 1988) of debris on Footprint and Threepoint lakes are summarized in "Lake and river shorelines", above. These authors concluded that significant negative impacts because of debris had occurred in the Nelson House area.

Ice: An extensive survey of winter hydraulics of the Burntwood River between the Notigi control structure and Split Lake was conducted by Manitoba Hydro (1973c). Cross-sectional surveys of the river were made noting flow rates, water levels, and ice elevations under normal ice and extreme ice jam conditions. This study was repeated during 1985/86 (Manitoba Hydro 1987e) to obtain open water level information along the Burntwood River.

LaSalle Hydraulic Laboratory Ltd. (1974) published a report predicting theoretical levels on Threepoint and Wapisu lakes under severe winter conditions, such as downstream ice jam formation, once CRD was implemented.

Manitoba Hydro (1975d) provided a photo documentation of ice breakup during April and May 1975 in the vicinity of Nelson House.

Crippen Acres Engineering (1976, 1978) predicted changes in water levels and ice conditions in the Burntwood River under diversion conditions. They concluded that fast, flowing water during winter would create slush ice. This in turn would cause formation of hanging ice dams and alter the flow regime in the Burntwood River and Split Lake. Predictions and recommendations were made concerning winter water elevations, flows, and breakup conditions given best and worst case scenarios.

Hopper et al. (1978) described the methodology used to estimate changes in water regimes due to hanging ice dam formation caused by a buildup of slush ice.

Crippen Acres Engineering (1987) conducted an extensive survey of the winter hydraulics of the Burntwood River between the Notigi control structure and Split Lake. A large number of river cross-sections were surveyed for ice dam length and slope, water levels, and erosion.

From the winter of 1974/75 to the present, Manitoba Hydro has collected detailed and extensive hydraulic and hydrometric information from the Burntwood River. The information has been collected during both the summer and winter from a large number of sites located throughout the Nelson House area. Accumulated winter field reports and observations contain photographic documentation and visual observations of ice formation, ice dams, and ice breakup, including water-level recordings from a number of sites situated along the diversion route. Winter reports are entitled "Churchill River Diversion and Lower Churchill River Ice Surveys and Hydrometric Program" and have been published annually between 1975 and 1987 (Manitoba Hydro

1987h). Data from 1988 to the present are not yet published. All published reports could not be reviewed because they were unavailable and because of constraints connected with preparation of this report.

Water chemistry/quality: Underwood McLellan and Associates Ltd. (1970) (see "Water levels and flows", above) provided a non-specific and non-technical qualitative evaluation of water quality of the Burntwood River. The report also provided impact predictions on how diversion would affect turbidity, oxygen content, temperature, and productivity.

During the summer/fall periods of 1969 and 1970, Manitoba Hydro (1970 and 1971, respectively) surveyed five locations between Wapisu and Wuskwatim lakes. River discharge information and water samples were collected to determine sediment content for the purpose of calculating sediment discharge rates. This program was continued in 1971 and 1972 (Manitoba Hydro 1973b).

Prior to diversion, extensive water chemistry data were collected between 1970 and 1973 at numerous sites along the Churchill, Rat - Burntwood, and Nelson River systems including Footprint and Threepoint lakes (Morelli 1973).

Extensive water chemistry data were collected by Underwood McLellan and Associates Ltd. (1973a) between 1972 and 1973 for the Burntwood River at the Rat, Footprint, and Threepoint Lake outlets.

Morelli (1975) collected water chemistry data (ions, nutrients, conductivity, and pH) from northern Manitoba lakes including Threepoint Lake and the Footprint River.

Environment Canada (1978) provided water quality data for Manitoba between 1961 and 1976 as part of the NAQUADAT. Water chemistry data from Threepoint and Footprint lakes are contained in this summary.

Guilbault et al. (1979) examined changes in water chemistry of the Burntwood River using pre- and post-diversion data collected by the Inland Waters Directorate. Despite limitations associated with the data, these authors concluded that phosphorus, potassium, and aluminum had increased and that calcium had decreased since CRD. Unexpectedly, no significant increases in total solids, turbidity, nitrogen, or carbon were observed.

Water quality data along the CRD were presented for Footprint, Wuskwatim, and Threepoint lakes in two Manitoba Hydro (1982d, 1983b) reports. Data were given for suspended solids, turbidity, filterable and non-filterable residue, and heavy metals content.

Underwood McLellan Ltd. (1983c, 1984c) documented pre- and post-diversion water chemistry and water quality parameters for the Nelson House domestic water supply. Major ions, metals, carbons, sediment, and "water quality" parameters such as nitrate-nitrite, colour, odour, taste, and coliform bacteria were examined. A comparison of water quality parameters before and after diversion showed that major water quality parameters did not vary significantly. However, residents of Nelson House have perceived a reduction in water quality and attribute the change to the CRD. It was also stated that surface waters in the vicinity of Nelson House did not meet the Canadian Drinking Water Guidelines either before or after diversion.

MacLaren/InterGroup (1984) reported that the increase in sediment plumes and the overall sediment load with CRD was not severe. However, only brief statements regarding water quality changes occurring in the Rat - Burntwood River system were made by the authors. Guilbault et al. (1979) and MacLaren/InterGroup (1984) stated that no significant increase in sediment load or turbidity occurred downstream of the Notigi control structure because of deposition and settling of sediments in the Rat - Notigi reservoir. No increase in total suspended solids from pre-diversion levels was recorded between Rat, Notigi, and Split lakes. However, a significant decrease in conductivity, alkalinity, and major ions occurred due to diversion of soft, Churchill River water into the system.

Playle (1986), Playle and Williamson (1986) and Playle et al. (1988) analyzed pre- and post-diversion water chemistry data from Footprint Lake in an attempt to detect changes in water chemistry resulting from the CRD. They concluded that water chemistry was relatively stable on Footprint Lake before and after diversion because of its distance from the main flow of diverted water. However, statistically significant increases in phosphorus, total organic carbon and turbidity, and a significant decrease in conductivity had occurred. These changes were attributed to the flooding of Footprint and upstream lakes caused by CRD.

Downstream from Nelson House in the Burntwood River, Duncan and Williamson (1988) calculated that 15 water quality parameters (including conductivity, total inorganic carbon, phosphorus, pH, and turbidity) were linearly correlated with discharge by the CRD. The model, however, was found to be too simplistic to have any predictive value.

Grapentine et al. (1988) (see details under "GENERIC INFORMATION: Water chemistry/quality") provided a list of dates sampled and water quality parameters measured at Threepoint, Wapisu, Wuskwatim and Footprint lakes and Rat and Footprint rivers (above Threepoint Lake).

Ramsey et al. (1989) compared existing (1985-1988) water chemistry and productivity conditions at three sites in Threepoint and Rat lakes with pre-CRD years (1971-1973). They concluded that major changes in water quality in Rat Lake have occurred since pre-development studies in 1973. Concentrations of all nutrients were significantly lower in 1986 and 1987. However, no significant changes in dissolved and suspended solids, anions and cations occurred. In Threepoint Lake, similar declines in nutrient concentrations appear to have occurred; however, these conclusions are limited by the lack of pre-impact data. There was no change in transparency and turbidity, suspended solids were lower, and dissolved solids were higher in 1986 and 1987 than before CRD. No consistent change in major ions was observed.

Biological parameters

Schlick (1966b) surveyed lake whitefish for Triaenophorus infestation in Wuskwatim Lake in 1966. Infestation rate was low, and the fish were classified as "A" grade whitefish.

Underwood McLellan and Associates Ltd. (1970) provided a general evaluation of the status of fisheries in the Churchill and Rat - Burntwood River systems prior to diversion. Production and value of commercial species (whitefish, pike, walleye) for Wapisu and Wuskwatim lakes for 1964-1965 and 1968-1969 were given. The effects of reservoir creation and river diversion on fish life history parameters (spawning, survival, growth, feeding, etc.) and species composition and relative abundance were also discussed, based on changes that have occurred in other systems.

A number of studies examining all levels of the aquatic food web were conducted in lakes of the Churchill and Rat - Burntwood river systems as part of the LWCNRSB (1975) reports. Species composition, biomass, and standing crop of phytoplankton (Hecky and Harper 1974), crustacean zooplankton (Patalas and Salki 1974), and zoobenthos (Hamilton and McRae 1974) were determined for Wapisu and Wuskwatim lakes. Ayles et al. (1974) presented pre-impoundment data for fish from Wapisu, Threepoint, and Wuskwatim lakes. Species composition, population statistics (age, length, weight), catch statistics, growth, condition, and diet information for whitefish, pike, and walleye were provided. Commercial fishing statistics were also included.

Weagle (1974) summarized Nelson House commercial fishing statistics, for the period 1948 to 1972. An examination of exploitation and reproduction of major species was also provided.

The Lombard North Group (1975) conducted a pre-impact assessment of potential CRD effects on aquatic resources in the Nelson House area. Substantial reductions in standing stocks of phytoplankton, zooplankton, zoobenthos, and fish were expected. They concluded that overall productivity would be reduced and that spawning, nursery, and feeding habitat of fish would be lost, resulting in a decline in fish stocks. General effects of flooding on specific fish species were also discussed.

Wiens and Rosenberg (1982; unpublished data) compared results of a survey of macrobenthic invertebrates from lakes along the Rat - Burntwood River system prior to and after diversion. Benthic macoinvertebrate abundance in Wuskwatim and Wapisu lakes averaged 3275 organisms/m^2 prior to diversion (1973), increased to 12609/m^2 in 1979, and declined to values similar to pre-diversion abundances by 1987. The changes were thought to reflect changes in nutrient supply. Taxonomic composition of the benthos remained unchanged.

MacLaren/InterGroup (1984) presented commercial and domestic harvest statistics for Nelson House fishermen. An economic assessment of the fishery was conducted and CPUE, volume, and value of the fishery were compared with unaffected lakes. The report described the fisheries as small, erratic, and confined to Wapisu, Footprint, and Wuskwatim lakes. It also stated that, with increased lake levels, short-term (5-10 years) deleterious impacts would be expected, but the report projected long-term (>10 years) benefits such as increased standing stocks of phytoplankton, zoobenthos, and fish.

Patalas (1984a) described fish population data from Notigi, Wapisu, Threepoint, and Footprint lakes during 1983. Species composition, relative abundance, growth, and age composition for whitefish, walleye, sauger, and northern pike were presented. The data were not analyzed.

Green (1987a) summarized 1985 fish population data from Threepoint, Wapisu, and Footprint lakes. Green (1987b, 1988a) summarized 1986 and 1987 fish population data, respectively, for Threepoint and Rat lakes. Kirton and Mohr (1987) provided summary data for fish populations (primarily pike, walleye, sauger, and whitefish) from Wuskwatim and Apussigamasi lakes from 1984. Kirton (1987) presented 1984 data for Footprint and Threepoint lakes. Species composition, relative abundance, age-size relationships, maturity, and growth data for whitefish, walleye, sauger, and northern pike were provided in all of the above reports. There was no interpretation of results within or between years or lakes.

The Nelson House Fisherman's Association negotiated an interim settlement in 1988 with Manitoba and Manitoba Hydro for project-induced adverse effects to the Nelson House commercial fishery (Claim #103). This interim settlement subsidized loss of fishing income and released

Manitoba and Manitoba Hydro from further compensation until October 31, 1988 (Canada Department of Indian and Northern Affairs 1987). Claims for loss of domestic fishing are pending (D. DePape, Manitoba Hydro, Winnipeg, personal communication).

Phytoplankton data (species composition and biomass) were collected for Threepoint Lake in 1986 and 1987 (Livingston 1987, 1988) and for Rat and Pipestone lakes in 1986 (Livingston 1987). No analysis or discussion of results were provided.

Ramsey et al.'s (1989) summary of 1985-1988 DNR data documented existing conditions in Threepoint and Rat lakes, and compared conditions of water chemistry, and primary and secondary productivity to pre-CRD years (1971- 1973). Changes in species distribution and biomass of the Rat Lake phytoplankton community occurred after CRD. Lower nutrient concentrations after CRD are believed to have resulted in a reduced standing crop of phytoplankton. Biomass and species composition data for zooplankton were provided for Rat and Threepoint lakes in 1987 and 1988; no comparisons could be made with pre-CRD conditions primarily because of differences in sampling methodology.

Mercury: Derksen (1978a, 1979) presented mercury data for fish from Wuskwatim Lake, Rat Lake, and sites along the Burntwood - Grass River system in the Nelson House region for 1969-1970 and 1969-1971, respectively. Muscle mercury content exceeded 0.5 ppm for selected species, lakes, and years.

Environment Canada (1979a, b) provided a summary of mercury data for the SIL - Rat/Burntwood system. Mercury levels in water samples from the Threepoint and Footprint rivers above Threepoint Lake, and Threepoint Lake were given for selected years. Northern pike and walleye were also tested for mercury levels in selected years but sample sizes were too small to be conclusive.

Environment Canada (1979a) documented increases in fish muscle mercury content in 1978 and 1979 for fish from Wuskwatim Lake. Prediversion mercury content of water samples from Footprint Lake and fish mercury content from Footprint, Threepoint, and Wuskwatim lakes are contained in an Environment Canada (1979b) report. The data were obtained by the Fish Inspection Laboratory, DFO.

McGregor (1980) summarized muscle mercury data from Wuskwatim Lake walleye (1970-1977), Rat Lake whitefish, walleye, and pike (1978) and Notigi Lake pike and walleye (1977 and 1978). Data were insufficient to reveal trends among years or locations.

A data report by the Canada Department of Fisheries and Oceans (1982) summarized mercury concentrations in fish from commercial and survey samples in the Nelson House area.

Increases in fish mercury content occurred coincidentally with increasing water levels subsequent to diversion and flooding (Bodaly et al. 1984b). Lakes along the diversion route (Wuskwatim and Footprint) had high mercury levels during years immediately following diversion and flooding. There was no evidence that a decline in mercury levels had occurred from 1978 to 1984. Pre- and post-diversion muscle mercury content data were given for walleye and whitefish from Wuskwatim Lake.

Rannie and Punter (1984) examined existing data on levels and sources of mercury in north-central Manitoba and the region covered by the Canada - Manitoba mercury agreement, including Nelson House. Potential sources of mercury, both natural (bedrock, soil) and anthropogenic (mine tailings, smelters, industrial processes, agriculture), and mobilization factors such as bank erosion, flooding, and forest fires were described.

MacLaren/InterGroup (1984) documented changes in fish mercury levels for the Burntwood River system prior to 1980. As pre-diversion data for mercury did not exist for any area other than Wuskwatim Lake, changes in mercury levels before and after diversion could not be assessed for most areas. However, between 1976 and 1984, mercury levels in pike and walleye in Threepoint and Footprint lakes doubled to 1.0 ppm and 1.5 ppm, respectively. During the same period, mercury levels in whitefish increased from 0.22 ppm to 0.39 ppm. The Wapisu Lake fishery was closed in 1978 due to elevated mercury levels.

Williamson (1986) determined extractable mercury concentrations from water (1977-1984) and sediments (1979-1983) in Footprint Lake. Most concentrations were below detection limits (0.02 $\mu g \cdot L^{-1}$) and were not different from sites examined in other areas affected by CRD and LWR.

A Canada Department of Fisheries and Oceans (1987) Inspection Branch report summarized mercury content information for commercial fish shipments from lakes along the CRD route. Muscle mercury increased significantly between 1976 and 1979, and stabilized at the higher levels which resulted in the closure of the Wapisu Lake commercial fishery. Data for Rat, Wapisu, and Wuskwatim Lake whitefish, walleye, and northern pike were also presented.

Bodaly et al. (1987b) attempted to determine possible relationships between mercury levels in soil, sediment, vegetation, plankton, and fish and selected limnological parameters in the Southern Indian Lake area, including Footprint Lake, from data collected between 1981 and 1982. Relationships between these parameters were loose, and were described briefly in the report. Bodaly et al. (1987a) also determined that there was no relationship between depletion of mercury in flooded soils and mercury levels in fish. A significant relationship between mercury methylation by bacteria on vegetation and mercury in small fish was established and attributed to CRD.

Two reports on mercury levels in fish collected from lakes on the Rat - Burntwood and Nelson River systems summarized information collected between 1983 and 1985. The first, Green (1986), compiled muscle mercury data from commercial species obtained from experimental gillnets along the CRD route. Data analysis was limited to determining the relationship between fish length and mercury levels. The second, Derksen and Green (1987), conducted an extensive analysis and interpretation of these and additional data, comparing mercury concentration with age and size of fish, and degree of flooding, for selected species and water bodies. The objective of the study was to determine those fish species in which mercury contamination presented the greatest concern to the health of Nelson House residents. Mercury concentrations were highest in lakes most affected by CRD, particularly in lakes of the Notigi Forebay. Mercury levels in fish from Footprint, Wapisu, Threepoint, and Wuskwatim lakes had increased significantly; highest concentrations were found among the piscivorous species (walleye, sauger, and pike). Positive correlations between fish size, age, and degree of flooding and muscle mercury concentration were found for some parameters, species, and lakes. Derksen and Green (1987) concluded that the level of mercury contamination in fish from flooded lakes apparently had not declined since diversion and impoundment in 1976.

SPLIT LAKE

Physical and chemical parameters

Water levels and flows: Mollard and Associates (1965) provided an early pre-impact assessment of the physiographic and hydraulic features of Split Lake.

Detailed, specific hydrographic and hydrometric survey data for stations on the Nelson River between Sipiwesk and Split lakes are contained in two Manitoba Hydro (1965a, b) reports. Observations on the 1964 spring breakup between Split Lake and Hudson Bay were also made by Manitoba Hydro (1965c).

In 1972 and 1973, Manitoba Hydro (1973c) examined water and ice elevations of the Burntwood River system between the Notigi control structure and Split Lake under normal and ice jam conditions. In 1985-1986, Manitoba Hydro (1987e) followed up this study by examining open-water hydraulics of the Burntwood River system. Crippen Acres Engineering (1987) examined winter hydraulics of the Burntwood River as part of the updated survey. These studies generated detailed information on summer and winter water levels and flow rates from cross-sectional surveys along the length of the river to Split Lake.

Cleugh (1974) conducted an extensive hydrographic survey of the Nelson River diversion route in 1971 and 1972. The report also documented inlet and outlet flow rates at Split Lake.

Water Resources Branch (1975) documented mean water levels of Split Lake and mean flow rates of the Nelson River at Split Lake since 1927. Water surface elevation levels and discharge information from Notigi to Split Lake, including the Nelson and Burntwood rivers, were included in a Water Resources Branch (1974) report.

The Lower Nelson River Overview Study Team (1981) examined effects of regulation by the Kelsey Generating Station and the effects of CRD on Split Lake. The annual fluctuation in water levels and flow rates had increased and the average annual water level on the lake was 0.5 m higher. The report also stated that annual water levels and flows in Split, Sipiwesk, and Stephens lakes are variable, complicated, and subject to the combined influence from Kelsey inflow, CRD, and Kettle outflow. For example, water levels in Stephens Lake increased by 237% above pre-development levels as a result of diversion and regulation, whereas levels in Split Lake increased by less than 1%.

Underwood McLellan Ltd. (1983d, 1984d) evaluated water quality at Split Lake, stating that "with the exception of a two month period in 1979, the Split Lake mean monthly level has remained between the previous maximum and minimum since diversion". The report also stated that no outflow data were available for Split Lake because the nearest gauge was at the Kettle Generating Station.

MacLaren/InterGroup (1984) conducted an overview study of the Burntwood River and Split Lake area as part of an assessment of potential future hydroelectric generating sites. The report stated that as a result of CRD, water levels increased by 2.4 m and flows by nine times pre-CRD levels at First Rapids Reach (39 km upstream of Split Lake) on the Burntwood River.

A summary of historical Manitoba water level data for the period of 1911 to 1987 was provided by Environment Canada (1988). Monthly and annual mean water levels, as well as annual extreme water levels for the period of 1964 to

1987 for Split Lake, are contained in this summary.

Lake and river shorelines: Crowe (1973) conducted a limnological and biological survey of Stephens Lake and the Nelson River upstream of the Kelsey Generating Station during 1972. A brief, qualitative description of shoreline characteristics of these areas was presented.

The University of Manitoba (1973) conducted a study to describe pre-impact shoreline characteristics of the Nelson River, including Split Lake. Expected impacts on shoreline characteristics at Split Lake by LWR and CRD were described.

The geomorphology of Split Lake and Stephens Lake shoreline types were described by the Lower Nelson River Overview Study Team (1981). This study was conducted as part of the impact assessment of completed (Kelsey, Kettle) and proposed (Birthday, Gull, Limestone, Conawapa, Gillam Island) generating stations on the lower Nelson River.

MacLaren/InterGroup (1984) determined that shoreline morphometry at Split Lake had not been severely impacted due to the limited amount of flooding that had occurred. The most active areas of erosion and alteration of shoreline occurred upstream of Split Lake on the Burntwood River. The lower reaches of the Burntwood River were also classified.

An assessment of the open-water hydraulics of the Burntwood River was conducted by Manitoba Hydro (1987g), to document changes in river hydraulics which have occurred since diversion. Data from an extensive series of cross-sectional river profiles revealed that significant changes in hydraulics occurred as a result of erosion, which has modified banks and shorelines. Crippen Acres Engineering (1987) also examined winter hydraulics of the Burntwood River system to Split Lake. As a result of these two studies, a great deal of detailed information exists on the physical and hydraulic characteristics of the Burntwood system.

Kellerhals Engineering Services Ltd. (1987, 1988) utilized air photo mosaics to calculate erosion volumes and rates of sediment transport along the CRD route to Split Lake.

Erosion, sediment transport, and deposition: Underwood McLellan and Associates Ltd. (1973b) described pre-diversion hydraulic and sediment conditions of the Burntwood River to Split Lake. Only one site was within the Split Lake trapping boundary; therefore, pertinent information is limited. Suspended sediment concentrations and volumes in the Burntwood River after diversion were predicted based on data collected between 1969 and 1972. The report concluded that diversion would cause significant increases in sediment concentrations due to incoming Churchill River water and channel erosion. It was expected that conditions would vary significantly, both temporally and spatially.

In 1971 and 1972, Manitoba Hydro (1973b) collected discharge, water chemistry, and sediment concentration data at several sites on the Burntwood and Nelson rivers upstream from Split Lake. These data, and river profiles, were presented for each site surveyed.

Manitoba Water Resources Branch (1979) prepared a sediment budget and an analysis of the impact of CRD on erosion and sedimentation along the Rat - Burntwood River system, between the Notigi control structure and Split Lake. A review of the sediment sampling program conducted by Manitoba Hydro from 1969 to 1977, and by the Water Resources Branch in 1979, was also provided.

During 1981 and 1982, Manitoba Hydro (1982d) examined shoreline erosion at 19 sites between Southern Indian Lake and Split Lake. Only two sites (Split Lake and First Rapids) were relevant to the Split Lake study area. The Split Lake site was a stable bedrock shoreline, whereas the First Rapids site was highly eroded (160 ft^3 of erosion per foot of shoreline).

Shoreline erosion along the lower Burntwood River, Split Lake, and areas in the vicinity of Split Lake were evaluated as part of the MacLaren/InterGroup (1984) study. Due to limited erosion of the Burntwood River, little if any increase in suspended sediment or adverse effects on water quality, was observed at First Rapids Reach, Split Lake, and areas immediately downstream of Split Lake. Changes in the ice regime, because of increased flows associated with CRD and LWR, resulted in increased erosion during winter.

Manitoba Hydro (1973c, 1987g) and Crippen Acres Engineering (1987) conducted extensive summer and winter hydraulic monitoring programs on the Burntwood River. These studies revealed that significant erosion of the river bed and banks occurred as a result of diversion. These changes were quantified as changes in cross-sectional profiles of the river between pre- and post-CRD periods.

Kellerhals Engineering Services Ltd. (1987, 1988) provided data on erosion volumes and rates of sediment transport observed along the Rat - Burntwood River system. They concluded that erosion along the channelized part of the diversion route has not caused large-scale morphological changes. The report also stated that little work has been done to quantify changes in shoreline characteristics or the relationship between sediment transport and deposition in the Burntwood River or Split Lake. The 1988 study examined areas as far downstream as First Rapids, 39 km from Split Lake. This area suffered substantial erosion between 1977 and 1981 (2.2 to 9.7×10^4 $tonnes \cdot yr^{-1}$), but this rate was reduced by 50% from 1982 to 1986. Sediment production statistics downstream of First Rapids were also given. Detailed recommendations for future studies and monitoring of erosion and shoreline changes were outlined.

Northwest Hydraulic Consultants Ltd. (1987, 1988) used satellite imagery to interpret differences in turbidity and detect erosion patterns before and after CRD and LWR. Despite the fact that total suspended sediment concentration ($mg \cdot L^{-1}$) did not increase subsequent to CRD, total sediment load ($tonnes \cdot yr^{-1}$) to Split Lake increased 10x (due to increased flows). This rate was still five times less than predicted by pre-impact studies. Significant increases in turbidity and suspected substantial deposition of sediment in Split Lake occurred as a result of CRD. Major areas affected by increases in turbidity and sediment deposition were the west basin of the lake and mouth of the Burntwood River. Detailed studies on sediment loading and deposition had not been conducted in Split Lake, and specific effects on aquatic resources were subsequently unknown.

Debris: MacLaren/InterGroup (1984) stated that little or no increase in debris had been noticed by Split Lake residents either in the lake or along shorelines; transportation, net damage, and aesthetics were not affected by debris resulting from CRD or LWR.

However, Hilderman Witty Crosby Hanna and Associates and I.D. Engineering (1985) stated that the Split Lake community had perceived an increase in debris, and had related the increase to flooding. Neither the degree of flooding nor the amount of debris was assessed.

A. Derksen (MFB, Winnipeg, personal communication) observed Split Lake residents piling debris for use as firewood in 1985 and 1986; therefore, debris may have been a problem at that time.

No study has specifically focused on debris, so there are conflicting opinions as to the severity of the problem.

Ice: Manitoba Hydro (1973c) described 1973 water and ice elevations along the diversion route to Split Lake. Projected water and ice elevations as a result of CRD were also calculated.

MacLaren/InterGroup (1984) stated that ice formation in the vicinity of First Reach Rapids, 39 km upstream from Split Lake, had deleterious effects on shoreline stability and water chemistry in the lower Burntwood River and western Split Lake. Hanging ice walls that formed in turbulent sections of the river increased erosion of banks due to the formation of ice dams. This in turn caused additional diversion of water, resulting in scouring and erosion of adjacent shorelines. During breakup, ice adhering to large chunks of shoreline also increased shoreline erosion and sedimentation.

Manitoba Hydro compiled hydraulic and hydrometric data for the lower Nelson River at Split Lake during the winter periods beginning in 1978. The accumulated field reports have been published annually through the 1986/87 winter, and are entitled "Churchill River Diversion and Lower Churchill River Ice Surveys and Hydrometric Program" (Manitoba Hydro 1987h). Included are winter ice data from First Rapids and the mouth of the Burntwood River at Split Lake.

Crippen Acres Engineering (1987) examined winter hydraulics of the Burntwood River system between the Notigi control structure and Split Lake. This included open-water level observations and measurements of ice dam lengths and slopes along the river. Results were presented as maximum winter stage discharge curves for existing and planned hydro developments along the Burntwood River. These studies provided detailed and specific information on winter hydraulics of the Burntwood River system.

At Split Lake, higher water levels have damaged docks and other structures close to the shoreline due to the pile-up of wind-driven ice floes on shore. Higher ice levels have also caused a scouring of willows along the shoreline and the Split Lake Band has abandoned the use of canvas canoes.

Water chemistry/quality: Morelli (1973) presented extensive water chemistry information collected in 1970 and 1973 for Split and Sipiwesk lakes. The report is a data summary only, and has no methods, results, or discussion.

Crowe (1973) conducted a limnological and biological survey of Stephens Lake, and the Nelson River upstream of the Kelsey Generating Station in 1972. She presented a description of the limnology and water chemistry (temperature, Secchi depth, oxygen, nutrients, and major ions) at the sites.

Cleugh's (1974) hydrographic survey of the Nelson River diversion route in 1971 and 1972 presented detailed limnological and water chemistry data for Split Lake. Parameters measured included: ions, nutrients, conductivity, solids, carbon, nitrogen, phosphorus loading rates, and gases.

Underwood McLellan Ltd. (1983d, 1984d) provided a review and assessment of the potable water supply at the Split Lake community. Pre-diversion water chemistry data (1972-1974) are compared with post-diversion data (1976-1982) and Canadian Drinking Water Guidelines. Water chemistry parameters examined included: ions, turbidity, alkalinity, total dissolved organics, inorganic carbon and solids, heavy metals and "water quality" parameters such as nitrate-nitrite and coliform bacteria. Results indicated that most water quality parameters were not significantly different before and after diversion, with the exception of turbidity, total organic carbon and iron, which have all increased. Underwood McLellan Ltd. (1984d) concluded that, although surface waters of Split Lake did not meet Canadian Drinking Water quality standards either before or after CRD and LWR, water quality had declined due to CRD.

MacLaren/InterGroup (1984) stated that CRD and LWR had little effect on the water chemistry of Split Lake. Conductivity and alkalinity declined as a result of the introduction of at least 30,000 cfs of softer Churchill River water. Although total sediment load increased due to increased flows, the concentration of suspended sediments and turbidity of the water had not increased significantly.

Duncan and Williamson (1988) found that 10 water quality parameters were linearly correlated with discharge at Split Lake. They concluded that the relationships established, which varied both temporally and spatially, were too simple to have any predictive value.

Ramsey et al.'s (1989) summary of DNR data included Split and Stephens lakes. The report compared 1986-1987 water chemistry and primary and secondary productivity to the pre-CRD years of 1971-1973. Comparisons of spatial and annual variability for a wide range of water chemistry parameters were made among sites in Split Lake. Significant differences existed between sampling sites within the lake for several parameters. These varied according to the influence of river water from different sources, such as the Nelson, Burntwood and Aiken rivers. Lower concentrations of major ions, suspended carbon, nitrogen, phosphorus, and silica were attributed to CRD. Transparency was higher whereas suspended sediment concentration was lower in 1986-1987 than in 1972-1973. Since diversion, nutrients in the western basin of Stephens Lake declined significantly whereas turbidity and suspended solids increased; this reflected effects of backflooding rather than increased river flow. Similar changes in water chemistry did not occur in the main body of Stephens Lake. Here, many nutrients, anions, cations, suspended and dissolved solids, conductance, turbidity, and transparency were within the range of values observed during 1972-1973.

<u>Biological parameters</u>

Fisheries surveys of Sipiwesk and Split lakes were carried out in 1966 by Schlick (1968a and b, respectively). These included lake morphometry, rudimentary water chemistry, benthos collections, and experimental gillnetting. The data generated were used to calculate commercial catch quotas for Split and Sipiwesk lakes.

Crowe (1973) conducted a limnological and biological survey of Stephens Lake and the Nelson River upstream of the Kelsey Generating Station in 1972. Zoobenthos of these two regions was described, including species composition, distribution, and relative biomass of major taxa.

Ayles et al. (1974) provided fisheries data, collected in 1973, for Split Lake and the Kettle Reservoir. Information included species composition, population and catch statistics, growth, production, diet of major species, and commercial fishing statistics prior to 1973.

Patalas (1984b) provided fish population data on relative abundance, species composition, growth rates, and age composition for whitefish, walleye, sauger, and pike from Sipiwesk, Split, and Stephens lakes collected during 1983. However, these data were not compared with data from previous years, so changes to Split Lake fish populations were unknown.

Hilderman Witty Crosby Hanna and Associates and I.D. Engineering (1985) documented historical commercial fishing records for Split Lake between 1969 and 1983. Data were broken down by species, quota, value, and harvest, and showed that the commercial and domestic fishery was extremely variable from year to year. The report stated that the Split Lake community believed that hydro development caused a decline in the quantity and quality of fish harvested, an increase in fishing effort, and problems with flooding and debris, although no data were presented to substantiate these claims.

Kirton (1986) presented 1984 data and Hagenson (1987a and 1988) presented 1986 and 1987 data, respectively, on fish populations of Split and Stephens lakes. Hagenson (1987b) provided 1985 fish population data for Split Lake. These reports included information on species composition, relative abundance (CPUE), age-size frequency, growth, maturity, and mortality for whitefish, walleye, sauger, and northern pike. These are data reports and do not provide any interpretation.

Sopuck (1987b) examined age, growth, and mortality of lake sturgeon in Sipiwesk Lake from 1976-1978. The population structure was similar to that of the late 1950's based on 1953-1956 data. LWR and CRD apparently did not affect the Sipiwesk Lake sturgeon population.

Ramsey et al. (1989) summarized biological data collected by DNR during 1986 and 1987 from Split and Stephens lakes. Comparisons to before CRD and LWR revealed the following: (1) In Split Lake, mean phytoplankton biomass was 25-50% greater in 1987-1988 than in 1972-1973. Community differences occurred as a result of the reduced importance of cyanophytes and increased importance of diatoms since CRD and LWR. (2) In Stephens Lake, significant differences in the phytoplankton community existed between the eastern, central, and western basins, prior to diversion. After diversion, the western basin became more similar to the central and eastern basins along the main body of Stephens Lake, which did not differ significantly from the pre-diversion phytoplankton community. However, considerable annual variation in mean biomass existed during both periods. (3) Zooplankton community composition, biomass, and periodicity were discussed for Split and Stephens lakes for the 1987-1988 data; however, no comparison could be made between 1972-1973 and 1987-1988 data.

Hagenson (1989) provided 1988 fisheries data for Split and Stephens lakes. Data on relative species abundance, CPUE, gillnet selectivity, growth, age, maturity, survival, and mortality were presented. These data were collected to provide documentation for Claim #18 of the NFA and to provide additional background information to assist in management of the fish stocks. A discussion of results is not provided.

Claims for loss of commercial fishing on Split Lake were settled by Manitoba Hydro in 1990. Claims for loss of domestic fishing are yet to be negotiated.

Mercury: Environment Canada (1979a, b) provided a summary of mercury data for the SIL - Rat/Burntwood system. Whitefish, northern pike, and walleye were tested for mercury levels for selected years between 1969 and 1977. Sample sizes were generally too small to be conclusive. Environment Canada (1979a, b) summarized available mercury data for water samples and fish from Split Lake between 1972 and 1979. They concluded that, despite the fact that mercury content of fish differed between years, no trend was apparent.

McGregor (1980) summarized fish muscle mercury concentrations for northern pike, walleye and lake whitefish from Split Lake between 1970 and 1979. There were significant differences in mean muscle mercury content between years for Split Lake, but no trend in these levels was apparent.

A Canada Department of Fisheries and Oceans (1982) report summarized historical mercury concentrations in commercial and survey samples of fish from Split Lake.

Rannie and Punter's (1984) survey (see "NELSON HOUSE: Mercury") included Split and Stephens Lake areas.

Hilderman Witty Crosby Hanna and Associates and I.D. Engineering (1985) indicated that the Split Lake commercial fishery was closed either completely or partially prior to development (between 1971 and 1976) due to high mercury levels.

Williamson (1986) attempted to correlate extractable mercury concentrations from water (1977-1984) and sediment (1979-1983), collected from Split Lake, with the effects of CRD. The majority of results were below the detection limit of 0.02 $\mu g \cdot L^{-1}$ and displayed little or no difference among sites examined in areas affected by CRD and LWR.

The objective of the study by Green (1986) and Derksen and Green (1987) (for details, see "NELSON HOUSE: Mercury") was to determine which fish species posed the greatest health risk to residents of Split Lake and other communities. These reports stated that the piscivorous species, walleye, sauger, and pike, consistently had the highest mercury levels. There was a positive correlation between mercury, fish size, and degree of flooding for lake whitefish, northern pike, and sauger. Mercury content of Split and Sipiwesk lakes walleye and pike averaged 0.6-0.7 $\mu g \cdot g^{-1}$ between 1972 and 1985 and displayed no decline with time. The report also stated that, although a significant relationship between flooded area and mercury content in fish could be demonstrated, geological, water quality, and vegetation differences complicated this relationship.

YORK LANDING

Physical and chemical parameters

Water levels and flows: Mollard and Associates (1965) conducted an early pre-impact study of the physiographic and hydraulic features of Split Lake.

Cleugh (1974) conducted an extensive hydrographic survey of the Nelson River diversion route in 1971 and 1972, documenting inlet and outlet flow rates to and from Split Lake.

Water Resources Branch (1974, 1975) documented mean water levels and flow rates of the Nelson River at Split Lake since 1927. Water surface elevation levels and discharge from Notigi to Split Lake, including the Nelson and Burntwood rivers, were included. Effects of changes in levels and flows as a result of diversion were predicted.

The Lower Nelson River Overview Study Team (1981) examined effects of regulation by the Kelsey Generating Station and effects of CRD on Split Lake. The annual fluctuation in water levels and flow rates had increased and the average annual water level on the lake was 0.5 m higher. The report also stated that annual water levels and flows in Split, Sipiwesk, and Stephens lakes were variable, complicated, and subject to the combined influence from Kelsey inflow, CRD, and Kettle outflow. For example, water levels in Stephens Lake increased by 237% above pre-development levels as a result of diversion and regulation, whereas levels in Split Lake increased by less than 1%.

Underwood McLellan Ltd. (1983e, 1984e) concluded that water levels of Split Lake, and by inference, levels of the Aiken River adjacent to the community, had not increased beyond historic lake levels as expected. Hydrometric data for Split Lake indicated that, with the exception of a two month period in 1979, lake levels had not exceeded historic maximum or minimum levels.

Lake and river shorelines: The University of Manitoba (1973) described pre-impact shoreline characteristics of the Nelson River, including Split Lake. Expected impacts on shoreline characteristics at Split Lake by LWR and CRD were discussed.

A detailed technical report on hydrologic and hydraulic studies prior to diversion, was prepared by R.W. Newbury and F. Penner as part of a Water Resources Branch (1974) study. The document provided pre-diversion data on shoreline development and classification profiles, elevation profiles, river discharge, and flow conditions along the Rat and Burntwood rivers from First Rapids to Split Lake, and from Split Lake to Hudson Bay.

The geomorphology of Split and Stephens Lake shoreline types was described by the Lower Nelson River Overview Study Team (1981) as part of the impact assessment of completed and proposed generating stations on the lower Nelson River.

MacLaren/InterGroup (1984) determined that shoreline morphometry at Split Lake had not been severely impacted because of the limited amount of flooding that had occurred. The most active areas of erosion and alteration of shoreline occurred upstream of Split Lake on the Burntwood River.

Erosion, sediment transport, and deposition: Manitoba, Water Resources Branch (1979) provided an analysis of the impact of CRD on erosion and sedimentation along the Rat-Burntwood River system; the report also reviewed the sediment sampling program conducted by Manitoba Hydro from 1969 to 1977, and by the Water Resources Branch in 1979.

During 1981 and 1982, Manitoba Hydro (1982d) examined shoreline erosion at 19 sites between Southern Indian Lake and Split Lake. The Split Lake site was a stable bedrock shoreline which had not been significantly eroded.

Shoreline erosion along the lower Burntwood River, Split Lake, and areas in the vicinity of Split Lake was evaluated as part of the MacLaren/InterGroup (1984) study. Due to limited erosion of the Burntwood River, little if any increase in suspended sediment concentrations were observed at First Rapids Reach, Split Lake, and areas immediately downstream of Split Lake. However, changes in the ice regime, because of increased flows associated with CRD and LWR, resulted in increased erosion during winter.

Northwest Hydraulic Consultants Ltd. (1987, 1988) used satellite imagery to interpret differences in turbidity and to detect erosion patterns before and after CRD and LWR in Split Lake. Despite the fact that total suspended sediment ($mg \cdot L^{-1}$) had not increased subsequent to CRD, total sediment load ($tonnes \cdot yr^{-1}$) to Split Lake had increased 10x (due to increased flows). This was still five times less than predicted by pre-impact studies. Significant increases in turbidity and suspected substantial deposition of sediment in Split Lake occurred as a result of CRD. Major areas affected by increases in turbidity and sediment deposition were the west basin of the lake and mouth of the Burntwood River. Detailed studies on sediment loading and deposition had not been conducted in Split Lake, and specific effects on aquatic resources remained unknown.

Debris: MacLaren/InterGroup (1984) stated that little or no increase in debris had been noticed by Split Lake residents either in the lake or along shorelines. Transportation, net damage, and aesthetics apparently were not affected by debris as a result of CRD or LWR.

Ice: Manitoba Hydro has compiled extensive and detailed hydrometric and hydraulic data for the Lower Nelson River at Split Lake during the winter beginning in 1978. Accumulated field reports, published annually through to the winter of 1986/87, are entitled "Churchill River Diversion and Lower Churchill River Ice Surveys and Hydrometric Program" (Manitoba Hydro 1987h). Included are winter ice data from First Rapids and the mouth of the Burntwood River at Split Lake.

Water chemistry/quality: Morelli (1973) presented extensive water chemistry data for Split Lake between 1970 and 1973. This was a data summary only with no methods, results, or discussion.

Cleugh (1974) conducted an extensive hydrographic survey of the Nelson River diversion route in 1971 and 1972, and presented limnological and water chemistry data for Split Lake. Parameters measured included: ions, nutrients, conductivity, solids, carbon, nitrogen, phosphorus loading rates, and gases.

Underwood McLellan Ltd. (1983e, 1984e) reviewed and assessed the potable water supply at the York Landing Indian community. Water chemistry parameters included ions, heavy metals, alkalinity, pH, and "water quality" parameters such as nitrate-nitrite, colour, odour and coliform bacteria. Because the water supply for York Landing is obtained from the Aiken River, no data on water chemistry prior to diversion existed; therefore, pre- and post-diversion conditions could not be compared. The Aiken River water supply did not meet Canadian Drinking Water Guidelines, particularly in terms of colour and bacterial content. The community believed that water quality (sediment load, odour, taste, colour) had declined since CRD and LWR were initiated.

MacLaren/InterGroup (1984) stated that CRD and LWR had little effect on water chemistry of Split Lake. Conductivity and alkalinity declined as a result of the introduction of softer Churchill River water. Although total sediment load had increased due to increased flows, the concentration of suspended sediments and turbidity of the water had not increased significantly.

Duncan and Williamson (1988) found that 10 water quality parameters were linearly correlated with discharge at Split Lake. They concluded that the relationships established varied temporally and spatially and were too simple to have predictive value.

Results of Ramsey et al.'s (1989) comparison of water chemistry data collected from Split and Stephens lakes by DNR during 1986 and 1987 with pre-LWR and CRD data are recounted in "SPLIT LAKE: Water chemistry/quality", above.

Biological parameters

A fisheries survey of Split Lake was conducted in 1966 by Schlick (1968b). Lake morphometry, rudimentary water chemistry, benthos collections, and experimental gillnetting were carried out, and the data were used to calculate commercial catch quotas for Split Lake.

Ayles et al. (1974) provided fisheries data, collected in 1973, for Split Lake and the Kettle reservoir. Information included species composition, population and catch statistics, growth, production, diet of major species, and commercial fishing statistics prior to 1973.

Patalas (1984b) provided Split Lake fish population data on relative abundance, species composition, growth rates, and age composition for whitefish, walleye, sauger, and pike collected during 1983. These data were not compared with data collected from previous years; therefore, changes to the Split Lake fish populations were unknown.

Kirton (1986) and Hagenson (1987a, b, 1988) presented information on species composition, relative abundance (CPUE), age-size frequency, growth, maturity, and mortality for whitefish, walleye, sauger, and northern pike in Split Lake. The data were not interpreted.

Ramsey et al.'s (1989) summary of phytoplankton and zooplankton data collected from Split and Stephens lakes by DNR during 1986 and 1987, and comparison to pre-LWR and -CRD data is described under "SPLIT LAKE: Biological parameters", above). Likewise, details of the Hagenson (1989) study, which collected fisheries data for Claim #18 of the NFA and to provide information to assist in management of fish stocks, is described under "SPLIT LAKE: Biological parameters", above.

Mercury: The summaries presented for Environment Canada (1979a, b), McGregor (1980), DFO (1982), Rannie and Punter (1984), Williamson (1986), Green (1986), and Derksen and Green (1987) under "SPLIT LAKE: Mercury", above, also apply to York Landing.

SUMMARY OF EFFECTS OF CHURCHILL RIVER DIVERSION (CRD) AND LAKE WINNIPEG REGULATION (LWR) ON AQUATIC ECOSYSTEMS, AND IDENTIFICATION OF DATA GAPS

The following tables summarize the effects of CRD and/or LWR on aquatic ecosystems, as they impact the five communities signatory to the NFA. Physical, chemical, and biological parameters are assessed independently according to the text of the "LITERATURE REVIEW" section, above. Data gaps are also identified where insufficient information existed to make an accurate determination of the effects of CRD and/or LWR.

The conclusions presented here represent the views of North/South Consultants Inc., based upon published and unpublished literature, consultation with experts, and personal communication from respondents to the Phase I report. The conclusions of North/South Consultants Inc. may not necessarily reflect the opinions of authors of referenced reports or of the sponsoring agency.

Three summary tables are provided. Table 1 addresses impacts of CRD and/or LWR on a community by community basis, and is organized into three sections. The first section is a qualitative assessment of the extent of documentation of pre- and post-project information. This qualitative assessment does not reflect the quality of research conducted; rather it gauges the amount of information which exists. The extent of documentation is, of course, relative and is considered according to the following scale:

0 = no documentation
1 = poor documentation
2 = fair documentation
3 = good documentation
4 = very good documentation
5 = complete documentation

The second section of Table 1 assesses whether effects of CRD and/or LWR have been positive (+), negative (-), have had negligible impact (0), or are unknown (?). Again, this assessment is solely the opinion of North/South Consultants Inc., based on our review of the available data. The third section summarizes major impacts on the physical, chemical, and biological parameters evaluated, and identifies data gaps.

Table 2 compares the impacts of CRD and/or LWR (negative, neutral, positive, or unknown) on physical, chemical, and biological parameters across communities.

Table 3 summarizes data gaps which have been identified for each physical, chemical, and biological parameter for the five resource areas as a whole.

Table 1. Impacts of the Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR) on the five communities signatory to the Northern Flood Agreement (NFA). (See text for explanation of symbols under "Documentation" and "Effect of CRD and/or LWR" columns).

A: NORWAY HOUSE

	Documentation (0-5) Pre-impact	Documentation (0-5) Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
PHYSICAL AND CHEMICAL PARAMETERS				
Water levels and flows	5	5	?, +	Mean water levels have increased approximately 0.16 m beyond historic pre-regulation levels; the increased rate of fluctuation of level is not believed to have significant negative effects; possible positive benefits of flood control.
Lake and river shorelines	2	3	0	Shorelines do not appear to be significantly affected; lack of post-impact assessment data; short-term, local impacts, possibly unrelated to LWR.
Erosion, sediment transport, and deposition	3	4	0	No evidence for long-term, adverse effects of erosion; negligible difference in erosion and sedimentation between pre- and post-regulation periods.
Debris	0	2	-	Lack of pre-regulation data inhibits comparison; problem of debris inadequately addressed by studies; unpublished data collected by DFO correlates increased debris with proximity to Two-Mile Channel; residents perceive marked increase in debris since LWR.
Ice	4	4	?	No examination of effects of ice on aquatic ecosystem despite extensive data base on ice conditions; local open water in vicinity of hydro structures has no effect on ice conditions of Playgreen, Kiskitto, etc. lakes; DATA GAP: No comparison between pre- and post-regulation ice conditions; relationship between ice and aquatic ecosystems unknown; limited use of Landsat imagery data.
Water chemistry/quality	3	3	?	Changes in water chemistry (increased carbon, phosphorus, turbidity) have occurred and are not identified as being adverse; possible slight decline in water quality; however, this cannot be quantified.
BIOLOGICAL PARAMETERS	4	4	0	Studies indicate no net loss of productivity or quality of fish; conflicting data with regard to changes in primary productivity and productivity of Playgreen Lake fishery; Manitoba Hydro has negotiated final compensation with Norway House for loss of fishing (Claim #16, 103).
Mercury	2	3	0	There is no apparent relationship between mercury levels in fish and LWR.

B: CROSS LAKE

	Documentation (0-5) Pre-impact	Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
PHYSICAL AND CHEMICAL PARAMETERS				
Water levels and flows	5	5	-	Volume has decreased by 53% due to LWR; increased water-level fluctuation, winter drawdown causing fish and egg mortality, reduced feeding habitat, and reduced access to spawning areas.
Lake and river shorelines	3	4	-	Due to drawdown and fluctuations in levels, the integrity and stability of shorelines have been significantly negatively affected; loss of littoral zone.
Erosion, sediment transport, and deposition	0	2	?	No detailed information on sediment at Cross Lake; sediment has not been identified as a problem; reduced water levels may facilitate re-suspension of sediment causing increased turbidity.
Debris	0	1	?	Lack of pre-impact data precludes comparison with post-impact data; debris has not been identified as a concern.
Ice	2	3	?	According to most studies, ice conditions have not been negatively impacted by LWR; however, perception by community is to the contrary; conclusions appear contradictory; local problems with ice conditions near hydro structures and channels; DATA GAP: Information on relationship between ice conditions and aquatic ecosystems is needed.
Water chemistry/quality	4	4	0, -	Increases in carbon, potassium, and turbidity are significant but not identified as a negative impact; access to and quality of drinking water has decreased.
BIOLOGICAL PARAMETERS	4	4	-	Loss of and changes to primary and secondary productivity; loss of feeding, spawning habitat of fish; reduced access to spawning and feeding grounds; reduced reproductive success; shift to undesirable species composition; increased summer- and winterkill; these significant fisheries impacts are linked directly to LWR.
Mercury	2	3	0	Pre- and post-LWR mercury levels in fish are unrelated; no apparent effect of LWR.

C: <u>NELSON HOUSE</u>

	Documentation (0-5) Pre-impact	Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
PHYSICAL AND CHEMICAL PARAMETERS				
Water levels and flows	4	5	-	Well-documented data base; significant increases in water levels and flows (10x) since diversion have caused extensive flooding resulting in a substantial negative impact.
Lake and river shorelines	3	3	-	Detailed surveys of pre- and post-diversion shoreline conditions conducted; despite clearing, extensive alteration of shorelines has occurred; significant negative impact on stability, integrity, morphology, erosion, access to shore;
				DATA GAP: Monitoring of morphological changes to area, particularly Threepoint and Footprint lakes.
Erosion, sediment transport, and deposition	3	4	-	Flooding has caused significant erosion of lake and river shorelines; although difficult to assess, significant increase in sediment load has occurred; erosion is continuing, is severe, site specific, saltatory in nature, and often event-related;
				DATA GAP: Monitoring of dynamics, pattern of erosion, and sediment deposition along CRD route.
Debris	2	2	-	Considerable standing debris still exists in non-cleared areas (i.e. 87% of Threepoint Lake shoreline) which has significant negative impact;
				DATA GAP: A comparative study is required examining difference between cleared and non-cleared areas from biophysical and socioeconomic viewpoints.
Ice	2	5	?	Considerable information on ice conditions exists, however changes to ice regime have not been determined and have had unknown effects on aquatic ecosystems;
				DATA GAP: Determine relationship between ice and aquatic ecosystems.
Water chemistry/quality	3	4	0	No significant detrimental changes in water chemistry have occurred; i.e. decrease in conductivity, alkalinity, ions; increase in phosphorus, carbon, and turbidity.

C: NELSON HOUSE (Cont'd)

	Documentation (0-5) Pre-impact	Documentation (0-5) Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
BIOLOGICAL PARAMETERS	3	4	?	Despite available literature and perceived negative impact of CRD, data have not been analyzed to the point where an impact can be assessed; unknown changes in life-history parameters, species composition, productivity, etc. of aquatic ecosystems; DATA GAP: Comparison between pre- and post-diversion conditions, assessment of changes to aquatic ecosystem over short- and long-term periods.
Mercury	2	5	-	Fish from this region have the highest mercury levels of the NFA communities; a direct link between CRD and mercury has been established; resulted in closure of Wapisu and Wuskwatim Lake fisheries; DATA GAP: Continued monitoring of relationship between mercury and CRD.

D: SPLIT LAKE

	Documentation (0-5) Pre-impact	Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
PHYSICAL AND CHEMICAL PARAMETERS				
Water levels and flows	4	5	0	CRD and LWR have had minimal impacts on water levels; flow rate and turnover time have increased with unknown effect; Split Lake level has increased only 1%, well within historic levels.
Lake and river shorelines	3	4	-	Impacts on the shorelines of Split Lake have been minimal; severe erosion of Burntwood River upstream at First Rapids has resulted in substantial changes to shoreline integrity and stability.
Erosion, sediment transport, and deposition	3	4	-	Significant erosion has occurred at First Rapids which has contributed substantial volumes of sediment to Split Lake; CRD has also increased the transported sediment load to Split Lake; DATA GAP: Unknown pattern, dynamics, destination of sediments entering Split Lake and Nelson River as a result of CRD; unknown effects of erosion and sediment on aquatic ecosystems of Split Lake.
Debris	1	2	?	No pre-impact data on debris; little documentation of post-CRD, LWR effects on debris; little perceived negative impact; appear to be contradictory results; DATA GAP: Evaluation of existing air photo data from pre- and post-diversion times.
Ice	3	4	-	Effects of changes to ice regime on Split Lake unknown; ice formation in vicinity of First Rapids has resulted in considerable negative impact in terms of shoreline erosion and sedimentation, hanging ice dams, and walls; DATA GAP: Information on relationship between ice and aquatic ecosystems, scouring, and altered freezing - thawing regime.
Water chemistry	4	4	?	Water chemistry has been changed to an unknown degree by CRD; conductivity and buffering lowered, carbon and turbidity increased; insufficient analysis of effects of CRD and LWR on impacts to aquatic ecosystems; DATA GAP: Establish effects of CRD and Churchill River water introduction on water chemistry in Split Lake.

D: SPLIT LAKE (Cont'd)

	Documentation (0-5)		Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
	Pre-impact	Post-impact		
BIOLOGICAL PARAMETERS	3	4	?	Pre- and post-impact data available; comparisons not made, impacts not assessed; secondary production data unavailable; perceived decline in quantity and quality of fish from Split Lake due to CRD and LWR by residents; Manitoba Hydro denies negative effect; Claim #97 for loss of commercial fishing outstanding; unknown effect of LWR, CRD on aquatic ecosystems; results inadequate; DATA GAP: A more comprehensive analysis and interpretation of pre- and post-impact effects of CRD and LWR on aquatic resources, especially fish populations, is required.
Mercury	3	4	0	Adequate pre-impact data; levels were high prior to and after CRD, with no apparent trend between years; mercury levels cannot be linked to CRD or LWR.

E: YORK LANDING

	Documentation (0-5) Pre-impact	Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
PHYSICAL AND CHEMICAL PARAMETERS				
Water levels and flows	4	5	0	Flow rate has increased and residence time has decreased at Split Lake with unknown effects; Split Lake level has increased only 1%, well within historic levels; water level at York Landing and Split Lake measured with same gauge.
Lake and river shorelines	3	3	0	Lack of flooding has had minimal impacts on shorelines; no apparent long-term negative effects attributable to CRD and/or LWR.
Erosion, sediment transport, and deposition	2	3	?	No studies have been conducted examining effects of erosion and increased sediment transport into Split Lake; effects on aquatic ecosystems unknown; DATA GAP: Investigate effects of increased sediment load on Split Lake aquatic ecosystems.
Debris	1	2	0	No evidence to suggest that debris has been a problem in the vicinity of York Landing.
Ice	3	4	?	Despite extensive amount of existing data on ice regime, effect of changes due to CRD and LWR unknown; no references to effect of CRD and LWR on aquatic ecosystems; DATA GAP: Determine effect of changes to ice regime on aquatic ecosystems.
Water chemistry/quality	3	4	?	Effects of changes to water chemistry as a result of CRD and LWR on aquatic ecosystem is unknown; perceived decline in potable water supply from Aiken River by York Landing community; absence of pre-impact data precludes comparison; DATA GAP: Establish effect of introduction of Churchill River water on the water chemistry of Split Lake.
BIOLOGICAL PARAMETERS	3	3	?	Pre- and post-impact data for Split Lake available; comparisons not made, impacts not assessed; secondary production data unavailable; contradictory claims for fishing loss by residents and Manitoba Hydro; unknown effect of CRD, LWR on fisheries; relative importance of fishery to York Landing community unknown;

E: YORK LANDING (Cont'd)

	Documentation (0-5) Pre-impact	Documentation (0-5) Post-impact	Effect of CRD and/or LWR (+, -, 0, ?)	Summary of effects and data gaps
				DATA GAP: A more comprehensive analysis and interpretation of pre- and post-impact effects of CRD and LWR on aquatic resources, especially fish populations, is required.
Mercury	3	3	0	There is no apparent trend in fish mercury levels between years, and mercury levels cannot be related to CRD or LWR.

* Despite the similarity within the text between Split Lake and York Landing, effects of CRD and LWR on "Lake and river shorelines", "Erosion, sediment transport, and deposition", "Debris", and "Ice" differ between the communities. This is due entirely to the effects of CRD on the Burntwood River, which according to trapline boundaries, we considered specific to Split Lake and not York Landing.

Table 2. Summary of positive (+), negative (-), neutral (0), or unknown (?) effects of Churchill River Diversion and/or Lake Winnipeg Regulation on aquatic ecosystems of the five Northern Flood Agreement communities.

	Cross Lake	Nelson House	Norway House	Split Lake	York Landing
PHYSICAL AND CHEMICAL PARAMETERS					
Water levels and flows	-	-	?,+	0	0
Lake and river shorelines	-	-*	0	-	0
Erosion, sediment transport, and deposition	?	-*	0	-*	?*
Debris	?	-*	-	?*	0
Ice	?*	?*	?*	-*	?*
Water chemistry/quality	0, -	0	?	?*	?*
BIOLOGICAL PARAMETERS	-	?*	0	?*	?*
Mercury	0	-*	0	0	0

* Indicates existence of data gap as identified in Table 1.

Table 3. Summary of data gaps related to the physical, chemical and biological effects of Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR) on the aquatic ecosystem.

Physical and chemical parameters	Data gap
Water levels and flows	General effects of fluctuation in water levels and flow rate on aquatic ecosystems are unknown.
Lake and river shorelines	Monitoring of morphological changes in the Nelson House area, particulary in Threepoint and Footprint lakes, is required.
Erosion, sediment transport, and deposition	Continued monitoring of erosion patterns and sedimentation along the CRD route in the Nelson House area is required; effects and destiny of sediments entering the Nelson River and Split Lake are unknown.
Debris	General effects of increased debris on the aquatic environment are not fully understood; a comparative study is required to examine the differences between cleared and non-cleared areas from biophysical and socioeconomic viewpoints; evaluation of existing air photo data from pre- and post-diversion times on Split Lake is required.
Ice	The general relationship between ice conditions and aquatic ecosystems requires further study.
Water chemistry/quality	The effect of Churchill River water introduction to Split Lake is unknown; relationships between routinely monitored water chemistry parameters and the aquatic ecosystem are unknown.
BIOLOGICAL PARAMETERS	A comprehensive analysis and interpretation of existing pre- and post-project fisheries data is required for the Nelson House and Split Lake resource-use areas.
Mercury	Continued long-term monitoring of mercury in the Nelson House resource-use area is required.

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