

Figure 4.11 Mercury Levels in Residents of Split Lake and York Landing

<b>Mercury Levels in Residents of Split Lake</b>				
Year	Sample Number	0 - 19 ppb	20 - 99 ppb	>99 ppb
1976	31	25	6	0
1977	22	20	2	0
1978	0	0	0	0
1979	170	145	25	0
1980	54	33	21	0
1981	240	204	36	0
1982	167	142	25	0
1983	9	9	0	0
1984	111	94	17	0
1985	66	53	13	0
1989-90	192	189	3	0

1989-90 Groups	Sample Number	0 - 19 ppb	20 - 50 ppb	50 - 80 ppb
Men	31	28	3	0
Women:				
12-45 yrs	26	26	0	0
over 45 yrs	9	9	0	0
Children:				
1-4 yrs	9	9	0	0
5-12 yrs	117	117	0	0

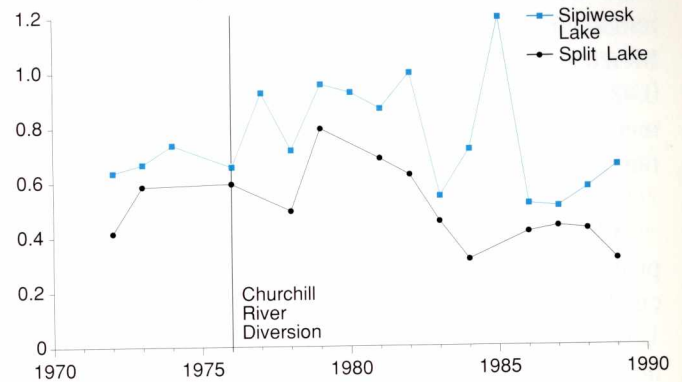
  

<b>Mercury Levels in Residents of York Landing</b>				
Year	Sample Number	0 - 19 ppb	20 - 99 ppb	>99 ppb
1976	17	9	8	0
1977	21	15	6	0
1978	0	0	0	0
1979	73	56	17	0
1980	0	0	0	0
1981	169	159	10	0
1982	6	3	3	0
1983	5	5	0	0
1984	41	26	15	0
1985	37	31	6	0
1989-90	102	100	2	0

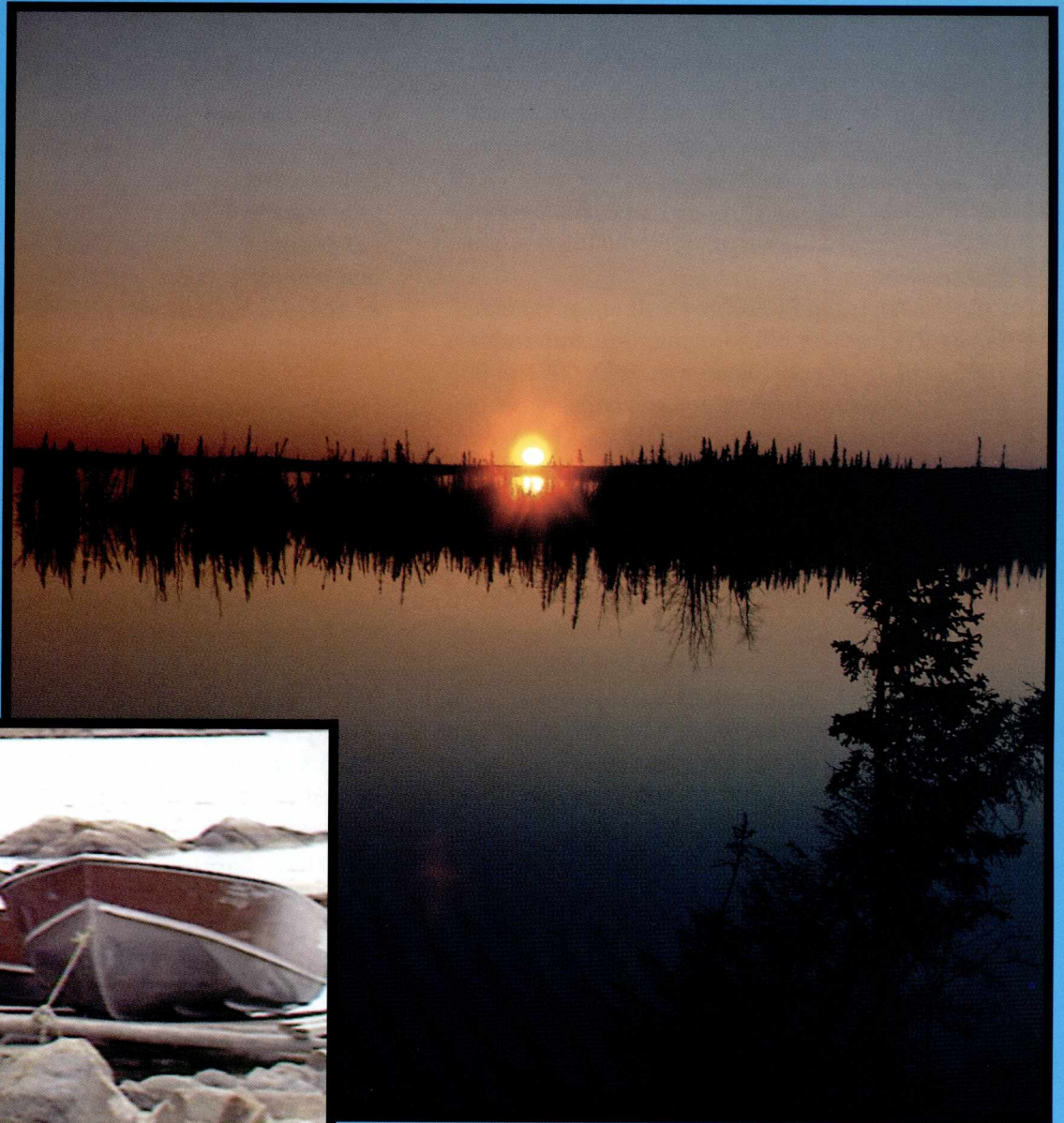
  

1989-90 Groups	Sample Number	0 - 19 ppb	20 - 50 ppb	50 - 80 ppb
Men	23	21	2	0
Women:				
12-45 yrs	29	29	0	0
over 45 yrs	11	11	0	0
Children:				
1-4 yrs	14	14	0	0
5-12 yrs	25	25	0	0

Figure 4.12 Mean Total Mercury Concentrations in Northern Pike from Split and Sipiwek Lakes, 1972 - 1989



The most likely explanation is that there is a methyl mercury source situated upstream in the Nelson River. Sipiwek Lake, the Kelsey Dam forebay, and fish killed in the Kelsey Dam turbines are potential sources. The potential for methyl mercury export to Split Lake could be examined through a series of measurements of methyl mercury in water along the Nelson River and in the other major inflows to the lake. These data would indicate the locations of any site of elevated methyl mercury production and determine if the methyl mercury is entering Split Lake. The importance of fish movements from Sipiwek Lake and the Kelsey forebay could be documented using a tagging program, as has been employed at Missi Falls, at the outlet of Southern Indian Lake. If neither of these studies find a methyl mercury source which can explain the fish mercury levels in Split Lake, then the potential effect of fish killed in the Kelsey turbines or of a site of elevated net methylation within Split Lake should be investigated.



## **CHAPTER 5**

# **FEMP CONCLUSIONS AND RECOMMENDATIONS**

## INTRODUCTION

This chapter presents the major FEMP conclusions and recommendations. The material in this chapter is organized into seven main topics: Water Quantity and Quality; Sediment and Morphology; Mercury; Fisheries and Aquatic Life; Waterfowl; Resource Harvesting; and Future Studies. The foundation for the conclusions and recommendations presented in this chapter was laid in the previous nine chapters of this two-volume Final Report.

## CONCLUSIONS

### Water Quantity and Quality

*The hydrologic regime of the lakes and rivers in the FEMP study area under regulated conditions, for the period 1979 to 1988, was dramatically different from that for estimated natural flow conditions, for the same period. The type and magnitude of the changes in the hydrologic regime within the FEMP study area varied according to location relative to the hydroelectric control structures and dams, and included changes in annual mean flows, seasonal distribution of flows, range of daily fluctuations, and lake surface areas.*

Regulation of the lakes and rivers of the FEMP study area by the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project has been extensive: 1) most of the Churchill River has been diverted at Southern Indian Lake into the Rat and Burntwood rivers and from these rivers into the lower Nelson River; 2) Lake Winnipeg has been regulated by a series of control structures in the Outlet Lakes area at the north end of Lake Winnipeg; and 3) five dams have been built along the Nelson River - Jenpeg, Kettle, Kelsey, Long Spruce, and Limestone, with approval currently being sought to proceed with a sixth dam, Conawapa. Construction of the LWCN project began in the early 1970s and is expected to continue well into the next century.

The flows of natural rivers, those unregulated by man-made structures, are affected by many factors such as the river basin's climate, (especially precipitation patterns and evaporation rates), topography, soil permeability, and vegetation; consequently, the river's flow can vary over the course of the year and from year to year. Thus, it is necessary, in assessing the impact of regulation, to

estimate natural flows for the period of interest for comparison to regulated flows; average pre-regulation flows may not accurately represent what the natural flows would have been in the post-regulation period, without regulation.

Annual mean flows at Missi Falls decreased from an estimated natural range for the period 1979 to 1988 of 600 to 1700  $\text{m}^3\text{s}^{-1}$  to a range, usually, of 13 to 200  $\text{m}^3\text{s}^{-1}$  under regulation (except for brief excursions to flows as high as 1400  $\text{m}^3\text{s}^{-1}$ ). Flows at Thompson, on the Burntwood River, increased from an estimated natural annual mean of 93  $\text{m}^3\text{s}^{-1}$  to 888  $\text{m}^3\text{s}^{-1}$  under regulation. Flows along the lower Nelson River, downstream of its confluence with the Burntwood River at Split Lake, increased significantly following regulation. For example, the annual mean flows at Kettle Dam increased from an estimated value of 2170  $\text{m}^3\text{s}^{-1}$  under natural conditions, for the period 1979 to 1988, to 2980  $\text{m}^3\text{s}^{-1}$  under regulation. The long-term mean for this location is 2276  $\text{m}^3\text{s}^{-1}$ ; the 1980s was a dry decade in comparison to the long-term record for the FEMP study area.

Changes in the seasonal distribution of flows were most apparent on the Nelson River as it enters Cross Lake. While the estimated natural annual mean flow for 1979 to 1988 was not significantly different here from that under regulation (1829  $\text{m}^3\text{s}^{-1}$ ), the mean June to August discharge for the period 1979 to 1988 was 670 to 770  $\text{m}^3\text{s}^{-1}$  lower than estimated natural flows and the mean December to February discharge for this same period was 520 to 750  $\text{m}^3\text{s}^{-1}$  higher than estimated natural flows. The reversal of the seasonal pattern is obscured on the lower Nelson River by the addition of the diverted Churchill River flows which have caused even regulated low summer flows to be as high or higher than what they would have been otherwise. For example, at Kettle, the mean June to August discharge for 1979 to 1988 was approximately 190  $\text{m}^3\text{s}^{-1}$  more than the estimated natural flow for this period, without regulation and diversion. Overall, the alteration in seasonal distribution of flows has shifted 7% of the combined annual delivery of the Churchill and Nelson rivers to Hudson Bay from open-water season to the ice-covered months of November to May.

Perhaps the most dramatic effect of regulation on the lower Nelson River flows is that seen in the day-to-day regime. At Kettle Dam, for the period 1979 to 1988, most of the day-to-night drops in hourly mean discharge were

over 2000 m<sup>3</sup>·s<sup>-1</sup> in winter, and were commonly almost 3000 m<sup>3</sup>·s<sup>-1</sup> in summer. Short-term fluctuations can have a dramatic effect on the ice cover. In particular, under-ice currents can result in thin ice that diminishes the strength and stability of the ice cover, affecting over-ice trafficability for both man and animals. Upstream, at Kelsey and Jenpeg dams, such large day-to-day fluctuations never occurred.

Lake surface areas have also changed significantly as a result of the LWCN project. In Cross Lake, 300 km<sup>2</sup> of lake bottom were intermittently dewatered by the seasonal fluctuations in water levels; while three of the larger lakes along the lower Churchill River - Partridge Breast, Northern Indian and Fidler - have been reduced in area by 39 to 76%. Along the Churchill River Diversion Route and the lower Nelson River, new lakes (reservoirs) have been created and others greatly increase in area; for example, Southern Indian Lake increased in area from 2082 km<sup>2</sup> to 2377 km<sup>2</sup>, Notigi Reservoir, with an area of 733 km<sup>2</sup> was created by the extensive flooding of a series of small lakes with a pre-project area of 182 km<sup>2</sup>, and Kettle Dam created the new 288 km<sup>2</sup> Stephen's Reservoir.

*The water quality in the FEMP study area, during the 1987 - 1989 FEMP study period, generally met the Canadian Water Quality Guidelines for drinking water, recreational uses, and protection of aquatic life, although there were some exceptions. A number of significant changes occurred in the water quality since the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project, many of which could be attributed to the mixing of water masses from different sources or to changes in shoreline stability.*

From January 1987 to October 1989, 61 water quality variables, including physical data, ions, nutrients, metals, and biological data, were measured at 11 sites, on regulated and natural rivers in the FEMP study area.

Canadian Water Quality Guidelines, established in 1987, were used as a means for assessing the water quality in the FEMP study area. Major uses of water for which Guidelines have been developed include drinking water, recreational use and the protection of aquatic life. Variations in environmental conditions across Canada will affect water quality in different ways; hence, many of the Guidelines may need to be modified according to

these local conditions. The use of the Guidelines for assessing adverse effects in the FEMP study area is limited in that they have not been established for all variables, they are not based on site-specific cause and effect studies in northern Manitoba, and they do not take into account the effect of cumulative stresses caused when the values of two or more water quality variables simultaneously exceed the guideline values. They are thus a suggestive, rather than a definitive, basis for assessing adverse effects in the FEMP study area.

Mean turbidity levels exceeded the Canadian drinking water guideline and mean extractable aluminum (Al) and total copper (Cu) exceeded the aquatic life guidelines at all sites. Mean extractable iron (Fe) exceeded the drinking water and aquatic life Guidelines at all 3 natural sites, at sites along the Churchill River Diversion (CRD), and at the outlet of Split Lake. The high levels in Split Lake appear to be a direct result of CRD; mean extractable Fe was below the Guidelines in the Nelson River at sites upstream of Split Lake and in the Jack River. Similarly, there were sporadic occasions when the aquatic life guidelines were exceeded for total lead (Pb), cadmium (Cd), and zinc (Zn) in the natural rivers and at sites on the CRD, but never in the Jack River or the Nelson River upstream of Split Lake. Total lead (Pb) occasionally exceeded the aquatic life guideline at the outlet of Split Lake, although these occasional high levels are not directly attributable to CRD. Two of the natural rivers (Burntwood River above Threepoint Lake and Footprint River above Footprint Lake) were distinguished by considerable stability in water quality between the 1972 - 1973 pre-development sampling period and the 1987 - 1989 FEMP study. There were no significant changes in the 17 variables for which comparable pre- and post-development data existed due to any cause other than a change in analytical methodology. At the third natural site, the Aiken River, lack of pre-development water quality data precluded an analysis of temporal trends.

At the Rat River above Threepoint Lake, there was a 3-fold increase in turbidity caused by bank and shoreline erosion. Other significant changes, such as decreases in hardness and alkalinity and increases in sodium and potassium, were directly attributable to diversion and were a reflection of differences in water quality between the Churchill River and the pre-existing Rat River. In most cases, the changes were no greater than the difference in concentrations between the Rat and Churchill rivers. The two exceptions were a larger than expected

decrease in total organic carbon (TOC) and no change in the phosphorus (P) concentration in the Rat River following diversion, despite the lower concentration in the Churchill River. The mechanism for the loss of TOC remains to be determined. The lack of a decrease in P was attributed to the continued release of P from flooded soils and vegetation. Impacts of diversion on water quality in the Burntwood River at the outlet of Threepoint Lake, the other FEMP site in the Nelson House area, could not be quantified due to the lack of pre-development data. It is likely that changes at this site would be qualitatively similar to those in the Rat River, except for a smaller impact on turbidity.

The Burntwood River at Thompson site had the most extensive water quality database of any site in the FEMP study area. Although most of the changes in water quality did not occur until after the autumn of 1977, when the diversion was fully operational, several changes were evident during the CRD construction, when Rat River flows were cut off at the outlet of Notigi Lake (e.g. an increase in turbidity and hardness) or during the immediate post-diversion period, as flows were gradually increased (e.g. an approximate doubling of P concentrations between the construction and immediate post-impoundment periods, with a return to pre-development levels by 1987). Significant water quality changes between the pre-development and FEMP study periods included decreases in hardness, alkalinity and dissolved calcium (Ca). These decreases were due to the introduction of softer Churchill River water. An approximate doubling of turbidity was attributed to bank and shoreline erosion along the Burntwood River below Threepoint Lake.

Impacts of the LWCN project on the water quality at the two FEMP sites in the Outlets Lakes area, Sea River Falls and Jack River, could not be assessed because of the lack of pre-development data.

No quantitative assessment of water quality changes at the Burntwood River inlet to Split Lake since CRD was possible due to the lack of pre-development data; however, it is likely that changes at this site caused by CRD were similar to those documented upstream at Thompson. Several significant differences in water quality were noted at the Nelson River inlet to Split Lake between the 1971 - 1974 pre-development and the 1987 - 1989 FEMP study periods, but none of these changes could be directly attributable to the LWCN project. The very low Nelson

River flows during the entire FEMP water quality study period, caused by drought conditions in western Canada, could have caused, or substantially contributed to, the observed changes.

Statistical analysis of pre- and post-development data at the outlet of Split Lake revealed significant declines had occurred in a number of variables, e.g. hardness, conductivity, calcium, potassium, etc. These decreases were a direct result of the diversion. It is interesting to note that a significant increase in annual mean water turbidity or suspended sediment concentration (NFR) was not observed, nor a decrease in water transparency, despite the much higher suspended sediment concentrations in the Burntwood River than in the Nelson River. Much of the suspended sediment load of the Burntwood River appears to settle out near the mouth, preventing a general increase in suspended sediment levels in the lake or downstream. An increase in extractable Fe was inferred, such that the annual mean concentration at the outlet, from 1987 to 1989, exceeded the Canadian Water Quality Guidelines by 30%. This increase, and significant decreases in total dissolved arsenic (As) were inferred on the basis of current differences in concentration between the Burntwood and Nelson rivers and the relative contribution of these rivers to total inflow at Split Lake.

Studies of fecal coliform levels in the recreational waters of the 5 Northern Flood Committee (NFC) communities indicated that contamination was not a significant concern. No clear evidence of contamination was found at any site, including the vicinity of sewage treatment plant outfalls where contamination might be expected. However, the limitations of the sampling program with respect to the number and frequency of samples prevent concluding that fecal coliform levels comply with Canadian Water Quality Guidelines.

*The water quality - water discharge relationships and the seasonal variations in water quality were examined to further assess the impact of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project on the water quality in the FEMP study area. With several important exceptions, the water quality - water discharge relationships derived from the FEMP study data offered limited potential for impact prediction or management. A number of distinct seasonal trends were evident in the comparison of water quality under*

ice-cover and in the open-water season during the 1987 - 1989 FEMP study period; however, while several apparent changes in seasonal patterns were noted, none could be conclusively attributed to the LWCN project.

The strongest water quality - water discharge relationship correlations were found at sites where there is the least need for their application, i.e. the natural rivers and the Nelson River at Sea River Falls. Most relationships at sites on the Churchill River Diversion (CRD) were too weak to have much predictive ability although there were several important exceptions, including the relationships for non-filterable residue (NFR) and turbidity in the Burntwood River at Thompson and for turbidity and alkalinity in the Burntwood River at the inlet to Split Lake.

The natural rivers, sites on the Nelson River upstream of Split Lake, and impacted sites prior to development were characterized by having many discharge-correlated variables, with negative correlations dominating (e.g. sodium, potassium, chloride, hardness, etc.). The discharge relationships at sites along the CRD, however, were profoundly different. In the Rat River above Threepoint Lake and in the Burntwood River below Threepoint Lake, at Thompson, and at the inlet of Split Lake, all correlations with discharge were positive following diversion. This is evidence of the increased importance of eroded shoreline materials in regulating water quality. Whereas water quality typically was highest during periods of peak flow prior to diversion, water quality now decreases with increasing river flows.

A similar shift from negative correlations prior to development to positive correlations during the FEMP study was evident in the Nelson River at the outlet to Split Lake as well. Although consistent with the changes in the discharge relationships in the Burntwood River following CRD, these changes at the outlet of Split Lake cannot conclusively be attributed to the diversion. Similar changes in the discharge relationships in the Nelson River at the inlet to Split Lake suggest a possible influence of the low Nelson River flows during the FEMP study or possibly some impact of the LWCN project in the upper Nelson River area.

Distinct seasonal trends that were evident included lower chlorophyll a concentrations under ice cover at several sites (e.g. Jack River, Burntwood River at

Thompson, and the inlet to Split Lake) and elevated nitrite-nitrate ( $\text{NO}_2\text{-NO}_3$ ) concentrations under ice cover at most sites. These trends might have been the result of the imposition of light limitation on algal growth by accumulated snow and ice cover and a lower photosynthetic demand for nitrogen at the lower light levels and cooler temperatures under ice cover.

A variety of other variables displayed marked seasonality at specific sites, with more seasonally variant parameters in the smaller natural rivers than in the larger Burntwood, Rat and Nelson rivers. Most of these variables (e.g. major ions, conductivity, hardness, and in some cases metals) increased under ice-cover, although NFR was typically lower in winter. For variables that were correlated with discharge, these seasonal differences were accounted for by seasonal variations in river discharge.

An examination of changes in seasonal patterns related to the LWCN project was restricted to a qualitative analysis because of the limited pre-development, under ice-cover data and by the few variables that were common to the pre- and post-development periods at many sites. Several apparent changes in seasonal patterns were noted, but none could be conclusively attributed to the LWCN project. For the site where the most complete analysis was possible, the Burntwood River at Thompson, only chlorophyll a showed marked seasonality in any of the pre-development, construction, or FEMP study periods.

## Sediment and Morphology

*Changes in the hydrologic regime in the FEMP study area have substantially altered the shorelines of the lakes and rivers. Characterization of shorelines has been limited, both temporally and spatially, and in terms of providing required input to assess related changes, such as sediment sources, access problems, etc.*

The focus of the FEMP sediment and morphology investigations was the CRD area where the most dramatic changes in the shorelines within the FEMP study area occurred, following the LWCN project. These investigations consisted of: 1) a review of all relevant literature; 2) feasibility studies to assess morphological changes, using air photos and Landsat images; and 3) preparation of a sediment budget.

The only previous shoreline classifications conducted in the FEMP study area were based on a scheme developed as part of the LWCN study in 1975. This scheme was of limited usefulness in classifying post-project shorelines, and in particular shoreline changes from pre-project conditions, because it did not include such post-project shoreline features as inundated vegetation, floating organic material, cleared shorelines, or riprap. Consequently, a feasibility study was conducted under FEMP to assess the usefulness of air photo interpretation in analyzing shoreline features.

The results of the feasibility study showed that it was possible to quantitatively estimate changes in the shorelines. For example, from an analysis of 1972 and 1985 air photos for Footprint Lake and Honeymoon Lake, a small lake connected by flooding to Footprint Lake, located southeast of Nelson House, it was estimated that the length of shorelines for these lakes containing standing debris increased from 0.2 km to 56 km and that 37% of the total post-diversion shorelines contained standing debris. Changes that have occurred in the shorelines of these two lakes are typical of the changes in many other CRD lakes. Quantification of the shoreline characteristics of these lakes, and of the changes to them, could also be undertaken using air photo analysis.

*Most of the morphological changes that have already occurred have not been quantified. A FEMP pilot study was conducted that provided rough estimates of shoreline erosion and sediment production at key locations along the CRD route.*

Previous studies had identified approximately 20 “erosion hot spots” along the CRD i.e. areas of localized active shoreline erosion; however, there had been no estimates of the areas or volumes of material eroded at these sites. Under FEMP, a pilot project was initiated in which a series of comparative analyses of air photos generated data on the displacements in shoreline positions; these data, coupled with topographic data, were used to provide a rough calculation of the volume of material eroded at some of the previously identified erosion hot spots.

For example, one such area that was part of this pilot project was a small island near the southern shore of Footprint Lake, immediately east of the Footprint River. Based on a comparison of 1972 and 1985 air photos, this island’s area was found to have de-

creased by approximately 6200 m<sup>2</sup>, while the shoreline perimeter decreased by 170 m. On the assumption that 50% of the shoreline recession was due to erosion (rather than inundation) and that the depth of eroded sediment was 2 m, the total volume of material removed from this site was estimated to be 6000 m<sup>3</sup> or 27 m<sup>3</sup> per metre of present shoreline length. Estimates of material that has eroded from other sites along the CRD were generated in a similar manner; high and low estimated values were based on different assumptions of eroded versus inundated areas and on different assumed bank heights.

Rough estimates of erosion rates ranged from approximately 6 m<sup>3</sup> per meter of shoreline from low-lying sites to somewhat slower rates of shoreline retreat for shorelines with much higher bank heights. However, given the larger amount of material which must be eroded from these higher relief sites, the inferred slower rates of bank retreat do not necessarily mean that smaller volumes of sediment are being produced from these areas. Material characteristics and orientation of the shore in relation to the prevailing wind direction are important determinants in the rate of bank retreat.

In general, erosion to date has not been nearly as serious along the CRD as was predicted in pre-diversion studies. For example, sediment delivery to Split Lake from the CRD is estimated at slightly less than 1 million tonnes/year; while this amount is approximately 10 times pre-diversion levels, it is much less than the projected estimates of 6 million tonnes/year.

It might be overly optimistic, however, to assume that erosion rates will necessarily diminish in the near future. As sites erode, an increasing length of bank tends to be exposed so that volumetric rates of erosion could increase with time, even if the rate of bank recession slows down. Also, if gradual river bed degradation is proceeding at some points, banks that appear stable may eventually be undermined and begin to crumble. (The extent to which this may be occurring is unknown, as only one cross section along the CRD has ever been resurveyed.) On the other hand, initial erosion at some sites can slow or stop as bedrock is reached. It thus appears that projection of future erosion rates and quantities of sediment subsequently generated are subject to considerable uncertainty and could not be improved substantially without extensive field studies.

*There have been documented changes in the sediment regime along the Churchill River Diversion (CRD) route. Completion of the FEMP sediment budget will provide additional insight into these changes.*

Active shoreline erosion along the CRD route has increased sediment production, some of which is redeposited near shore and some of which is transported to be redeposited further downstream. Pre-FEMP studies conducted by DFO of the sediment regime of Southern Indian Lake (SIL) showed that eroded sediment was temporarily redeposited near shore and then subsequently remobilized to become part of the lake's general suspended load. The increased input of sediment into SIL resulted in increased bottom deposition, increased sediment concentrations, and increased sediment output, which was mostly transported to and redeposited in the upper Notigi Reservoir.

Notigi Reservoir is thought to be acting as a sediment sink, with the upper portion trapping most of the sediment output from SIL and the lower part showing sediment deposition resulting from local shoreline erosion. Turbidity measurements taken under FEMP in 1987 were significantly greater than those measured in the late 1970s, suggesting that shoreline erosion in the lower part of Notigi Reservoir may be increasing, perhaps facilitated by the decay and removal of the inundated vegetation.

There are a number of actively eroding sites between Notigi Reservoir and Thompson; unfortunately, data on changes in sediment production in this reach are limited. There is, however, a good data base at Thompson. Turbidity briefly returned to pre-development levels, at Thompson following the LWCN construction period, but has since increased significantly. Of particular interest is the apparently increased incidence of higher turbidity levels at Thompson, i.e. turbidity levels in post-project years are higher for a greater proportion of the year than in pre-project years. Although it is not known how representative the Thompson site might be of the rest of the CRD with respect to this apparent change, its location downstream of some of the major erosion sites along the CRD may make it a good indicator site.

A large amount of sediment, most especially from the lower reaches of the CRD route, has been transported and deposited in Split Lake. No studies of sedimentation rates have been conducted in Split Lake; however, on the basis

of turbidity measurements and analyses of satellite images, it appears that most of the sediment has been deposited near the Burntwood River inlet forming a subaqueous delta.

All sediment data, including historical and other non-FEMP data, have been carefully reviewed, standardized, and incorporated into the preparation of a sediment budget for the CRD route; this budget is expected to be available later in 1992.

## **Mercury**

*A mercury duration model was developed based on rates of methylation and demethylation observed in reservoirs of various ages, located primarily in northern Manitoba. This model indicated that there will be a slowly accelerating rate of decline in the net production of methyl mercury over time, with levels returning to estimated pre-development levels approximately 80 years after impoundment.*

Mercury in fish is primarily in the form of methyl mercury. The production of methyl mercury is controlled by the net result of two opposing bacterial processes – the methylation of mercury and the demethylation of methyl mercury. Measurements of mercury methylation (M) and demethylation (D) rates in sediments from reservoirs ranging in age from 10 to 60 years were made, along with the M and D rates in a non-flooded control lake, which was used as a surrogate for pre-development or “normal” M/D conditions. The plotted data indicated that the half life (i.e. the period required for a 50% reduction) of the elevated M/D balance in the FEMP area was an estimated 60 years; an additional 20 years would be required before levels would return to pre-development values.

The validity of the mercury duration model as a means of predicting the rate of decline of mercury levels in fish was evaluated by overlaying pike and walleye mercury data on the predicted M/D decline curve. Data on mercury in fish were selected from reservoirs with similar characteristics (e.g. similar extent of flooding). There was good agreement between the predicted elevation of M/D in a reservoir of given age and the measured mercury concentrations in fish.

It is important to note that it is not the age of the reservoir per se that is the critical factor in determining

mercury levels in fish, but rather the relative availability of fresh organic matter (i.e. the amount and type of vegetation flushed into the water). The model's prediction of a decline in the M/D balance over time was based on a decline over time of the availability of organic matter. This point was clearly illustrated in the case of Sipiwesk Lake.

The M/D sampling of Sipiwesk Lake in 1987 revealed higher mercury levels than would have been expected given the age of this reservoir (flooded in the early 1960s). It was postulated that the way in which this reservoir is regulated determined the unexpectedly high M and D rates. Since the operation of Jenpeg dam in 1976, Sipiwesk Lake levels have been low in summer and high in winter, the reverse of most hydroelectric reservoirs. Recolonization by fast growing vegetation of the drawdown zone in summer and the subsequent flushing of this material into the lake during periods of high water is probably providing a continuous source of fresh organic matter, thus stimulating ongoing mercury methylation.

*FEMP mercury studies confirmed that the availability of organic material, not the total mercury concentrations in water, was the most important factor affecting the net production of methyl mercury in northern Manitoba reservoirs. Oxygen conditions in the sediment and inorganic sediment deposition were other relevant factors.*

Earlier studies conducted in the FEMP study area, under the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA), concluded that the single most important factor affecting net methyl mercury production was the amount and type of flooded organic material. This conclusion was confirmed by the FEMP mercury studies, as evidenced, for example, by the results of a sampling program in Methyl Bay, Southern Indian Lake, in 1986. Considerable variation in methylation activity that was evident among three near shore (flooded) sampling sites was found to be the result of substantial differences in sediment organic content among the sites.

The CMMA study had also concluded that there was no evidence that flooding had caused an increase in mercury concentration in water in any of the reservoirs studied. This conclusion was based on measurements of mercury levels in plankton; this surrogate method of

measuring mercury levels in water was necessary because the best analytical methods then available were not sensitive enough to detect very low levels of mercury in water. Improvements in analytical methods since the completion of the CMMA study enabled the direct measurements of total and methyl mercury concentrations in water in the FEMP mercury studies. It was found that while total mercury concentrations in water were not higher in reservoirs than in Granville Lake, the reference lake, methyl mercury concentrations were. Mean total mercury concentrations ranges from  $1.07 \text{ ng}\cdot\text{L}^{-1}$  (Notigi West, 1989) to  $2.10 \text{ ng}\cdot\text{L}^{-1}$  (Thompson, 1989); mean methyl mercury concentrations ranged from  $0.017 \text{ ng}\cdot\text{L}^{-1}$  (Methyl Bay, 1989) to  $0.054 \text{ ng}\cdot\text{L}^{-1}$  (Stephens Lake, 1989). These values were substantially below the upper limit of the Canadian Drinking Water Guideline for total mercury levels in water of  $1000 \text{ ng}\cdot\text{L}^{-1}$ .

FEMP investigations of the major metabolic groups of bacteria responsible for methylation (M) and demethylation (D) found that methanogens and sulphate reducers jointly accounted for all of the M and D activity in the flooded zone of Methyl Bay and the majority of the M and D activity in Granville Lake. The finding that the same bacterial groups were responsible for both M and D indicates that it may be difficult to develop mitigative measures based on the selective inhibition of the methylators or stimulation of the demethylators. However, the finding that oxygen availability did not significantly influence demethylation rates offered a partial explanation for the differential stimulation of the methylation over demethylation: low oxygen levels favoured for the methylation process are common in flooded sediments.

Another relevant factor in the mercury problem, and in particular one which may affect the duration of the mercury problem, is sediment deposition. For example, a small but significant decline in mercury in northern pike in Rat Lake (from  $1.35$  to  $1.20 \text{ g}\cdot\text{g}^{-1}$ ) occurred in the late 1980s, a time coincident with an increase in shoreline erosion. It is postulated that organic matter was covered with inorganic sediment thus effectively preventing the stimulation of microbial methylation. It must be stressed that it is sediment deposition, and not sediment resuspension, which is suggested as a possible mitigating factor. Tests conducted under the CMMA showed that increased suspended sediment concentrations did not significantly reduce mercury concentrations in fish and, in some cases, caused slight increases.

*Mercury levels in whitefish from all lakes sampled in the FEMP study area were below the Canadian guideline of 0.5 ppm; mercury levels in pike and walleye varied considerably between lakes and over time with levels in many cases being above 0.5 ppm. The majority of the people sampled from the six native communities in the FEMP study area had levels in the 0 - 20 ppb level, which is considered normal, with virtually all of the remaining values being less than 80 ppb. A few women of child-bearing age in four of the six communities, notably South Indian Lake, had mercury levels between 20 and 80 ppb.*

Mercury levels in fish from eight major lakes in the FEMP study area were measured in the mid - to late - 1980s either under the auspices of the FEMP or as part of a concurrent program conducted by the Manitoba Department of Natural Resources; these data extended the historical record of a number of lakes that had previously been sampled under the auspices of the CMMA. While mean standardized mercury levels in whitefish were below 0.5 ppm in all lakes sampled, only the walleye and pike in Cross Lake and the pike in Split Lake had mean standardized mercury levels below 0.5 ppm. Mean standardized mercury levels in walleye in Split Lake hovered around the 0.5 ppm mark, ranging from 0.42 to 0.61 ppm. Mean standardized mercury levels for pike and walleye from Southern Indian, Issett, Sipiwesk, and Stephens lakes ranged from 0.5 to 1.0 ppm, and those from Rat and Threepoint lakes ranged from 1.0 to 1.5 ppm.

A number of conclusions can be drawn from an examination of the complete data record - current and historical. Predatory fish from the most extensively flooded lakes had the highest mean mercury concentrations; after more than a decade since flooding, these fish still had mercury levels too high to permit their being sold anywhere in the world. Some significant declines in mean mercury concentrations have been recorded in recent years. For example, the mean mercury concentration in walleye in Rat Lake declined from 1.92 ppm in 1984 to 1.09 ppm in 1989; however, even with such declines, mean mercury concentrations in predatory fish are still generally much higher (e.g. 2 - 4 times higher) than estimated pre-development levels. Large variability in the mercury concentrations of individual fish still exist; for example, mercury concentrations in pike in Issett Lake in 1988 ranged from 0.15 ppm to 2.67 ppm. Such variability is due, at least in part, to variability in the size of fish. Collectively, these findings reaffirm the conclu-

sion of the CMMA that mercury concentrations in fish vary according to species, size of fish, lake of origin, and length of time since the lake was flooded.

Mercury levels in the residents of the six native communities within the FEMP study area continued to be tested by Health and Welfare Canada. During the late 1980s, all values were below 80 ppb, with the exception of one individual in South Indian Lake whose level was between 80 and 100 ppb; the majority of the values were less than 20 ppb, the level which is considered "normal" for adults. A few women of child bearing age in four of the six communities, most notably South Indian Lake, had values between 20 and 80 ppb. Values greater than 20 ppb for women of child bearing age are a concern because of the uncertainty of the risk of mercury exposure to the fetus.

Health and Welfare Canada's mercury program began in these communities in the late 1970s. An examination of the full data record showed that, in general, mercury levels in people have been highest in the residents of South Indian Lake and Nelson House, followed by the levels in people from Split Lake and York Landing; the lowest mercury levels have been recorded in people from Cross Lake and Norway House. A number of factors make it difficult to assess trends in mercury levels: 1) large variability in the number of community residents tested each year; 2) no identification in the published data record of values from the repeated testing of the same individuals; and 3) annual reporting of test results, which obscures any seasonal patterns.

As was evidenced in the interviews conducted for "Changes", the FEMP videotape, the elevated mercury levels in fish have caused concerns about possible health consequences among the residents of the six native communities in the FEMP study area. As a result, there appears to be a loss of confidence in fish as a healthy staple in their diet; some people noted that they are either more cautious about the source of their fish and/or that they have reduced their fish consumption. There is also a concern about the possible impact of further developments (e.g. Wuskwatim Dam) or remedial measures (e.g. Cross Lake weir) on future mercury levels in fish.

## **Fisheries and Aquatic Life**

*The biological status of the Southern Indian Lake (SIL) whitefish fishery has improved since the immediate post-impoundment period, but has not re-*

turned to pre-impoundment conditions. Additional monitoring would be necessary to determine whether the whitefish fishery ultimately recovers or stabilizes at levels lower than pre-impoundment values. A study of pike in Wupaw Bay, an isolated bay of SIL, suggested that they have also been negatively affected by post-impoundment changes.

The commercial fishery at SIL was the largest in northern Manitoba prior to impoundment; about 333,500 kg of fish were taken yearly. Approximately 85% by weight of the commercial catch was composed of whitefish; the rest was made up of pike and walleye. A reduction in grade, and consequently in price, and a reduced catch per unit effort (CPU) led directly to the collapse of the commercial whitefish fishery at SIL following impoundment. Two FEMP studies assessed the current status of the whitefish population at SIL; a third FEMP study, reinvestigated the pike population in Wupaw Bay, an isolated bay in the south west portion of SIL.

Grade is a major determinant of price for whitefish; for example, the price of an export grade whitefish can be double that of a continental grade. Grade classifications are based on the number of cysts of the parasite *Triaenophorus crassus* per 45 kg of whitefish (dressed weight). Grade classifications are as follows: export grade, 0 to 40; continental grade, 41 to 80; and cutter grade, over 80.

Historically, SIL was an export grade whitefish fishery; however, in 1982, the lake was downgraded to continental grade. The average cyst count for fish sampled under the FEMP study in 1987 was 51.9 from Region 4 (historically, the most important commercial fishing area of SIL), 74.1 from Region 5 (currently, an important commercial fishing area), and 81.1 for the southern portion of the lake. Cyst counts, in 1987, for sub-areas in Region 4 were: 59.9 for Region 4A; 21.3 for Region 4B (small sample size); and 64.1 for Region 4C. Analysis of cyst counts by whitefish external colour showed that the chance of a light-coloured whitefish (the preferred colour) being export grade was only 48%. Thus, it appears that neither selective fishing by sub-area of Region 4 or by colour for light-coloured whitefish would likely result in a reclassification of the commercial catch from continental to export. However, it should be noted that Region 4 still produces export fish in significant quantities and has the best quality of the lake regions sampled. Moreover, sub-Region 4B may still have re-

tained its export grade status.

CPU in 1987 for Region 4 (8.44) and Regions 4 and 5 combined (9.75) was still depressed in comparison to pre-impoundment levels (e.g. the 1972 value was 23.1). A number of factors can affect CPU such as the fouling of nets with debris and/or non-commercially valuable rough fish that reduce the amount of commercially valuable species caught and increase net cleaning time. An increase in the frequency of net relocation (which may be necessary due to net fouling) increases fishermen effort. The number of days nets are left in one location has been reduced from a pre-impoundment average of 18 to an average in 1987 of 6.3 in Region 4 and 5.0 in Region 5.

The main factor affecting CPU, however, is the abundance of fish and their movements. The results of an age analysis conducted as part of the FEMP study suggests that SIL is a light to moderately exploited commercial whitefish fishery; this low level of commercial exploitation would render unlikely an hypothesis that considers over-fishing as a casual factor in the decreased levels of CPU on traditional fishing grounds. Bodaly et al. (1984) showed an absence of genetic differences in whitefish in SIL after impoundment compared to the presence of at least 3 genetically distinct whitefish populations prior to impoundment. This suggests a post-impoundment mixing of stocks within SIL. Emigration of whitefish from SIL was suggested as an important cause of the post-impoundment decline in CPU (Bodaly et al. 1984 b); this suggestion was pursued under FEMP by an investigation of the whitefish populations immediately downstream of Missi Falls.

Large numbers of fish were caught below Missi Falls in 1986 and 1987; whitefish dominated the catch in nearly all samples. Estimated numbers of whitefish reached a high of 88,764 in September, 1986. The seasonal distribution of whitefish at Missi Falls was variable and depended on environmental conditions. In 1986, a year when the mean discharge from June to August approximated that of pre-impoundment conditions, the number of whitefish was highest in the autumn. Most of these fish, which were in good condition, appeared to have originated from SIL. It was concluded that these fish were trying to return to SIL to spawn. In 1987, a year of lower flows and higher water temperatures than 1986, the number of whitefish was highest in the summer. Most of these fish appeared to have originated from the lower Churchill River lakes downstream of Missi Falls and

were in poorer condition than the 1986 fish (e.g. they had significantly thinner bodies and a higher incidence of empty digestive tracts). It was concluded that they were trying to escape the warmer waters of the downstream lakes. Thus, it would appear that the Missi Falls Control Structure was blocking normal seasonal migrations of whitefish into and out of SIL and that this was a cause of the reduction in CPU in the SIL whitefish fishery.

Northern pike can be an important part of the SIL fishery (as discussed in the next section); they are also important as the final host in the life cycle of the parasite *Triaenophorus crassus*. A study of the northern pike population dynamics that was begun in 1976 in Wupaw Bay, SIL, a bay that is not completely typical of much of post-impoundment SIL, was extended to 1988 under FEMP. A downward trend in CPU and in condition factor indicate that the adult northern pike population in Wupaw Bay has suffered since lake impoundment. The decline in northern pike was attributed to post-impoundment changes, such as increased water depth, which rendered Wupaw Bay habitats less suitable for pike.

Shiners are an important component of the adult pike diet in Wupaw Bay. Beginning in 1981, the relative abundance of emerald and spottail shiners changed noticeably; this change was due to an increase in emerald shiners rather than a decrease in the number of spottail shiners. Habitat changes thus appear to have favoured the pelagic emerald shiner, relative to the more littoral species, such as the spottail shiner.

In summary, studies of the SIL whitefish fishery and the more geographically-limited pike study showed that these populations had been adversely affected both in terms of quantity (reduced CPU) and in quality (lower grade or poor condition). The whitefish fishery may be showing marginal improvement or stabilizing at levels lower than pre-impoundment values (e.g. an improved CPU since the immediate post-impoundment period); however, grade analysis of the whitefish catch suggests that it may not be possible to return to an export quality fishery. The pike population in Wupaw Bay has not shown any signs of recovery. Additional data for subsequent seasons would be needed to assess the longer term status of the SIL whitefish and Wupaw Bay pike.

*A study of the economic performance of the commercial fishery at Southern Indian Lake (SIL) in 1988 showed that the fishery is now financially viable;*

*however, approximately 36% of the revenue to the fishery came from a compensation fund and from a provincial freight subsidy program. The average income per firm increased 32% from \$6,299 in 1980 (in 1988 dollars) to \$8,289 in 1988.*

Since the inception of a commercial fishery at SIL in 1942, it has been a major component in the economy of the South Indian Lake community. For example, prior to impoundment (1972), it was estimated that the fishery provided 43% of the community's income, making it the single most important source of livelihood in the community. However, following impoundment the commercial fishery collapsed.

Under FEMP an evaluation was undertaken of the economic performance of the SIL fishery in 1988. Three approaches were used in this evaluation: 1) determination of average net incomes, using the same methods as those in a 1980 study; 2) an alternative analysis that more closely reflected the fishermen's view of the economics of the fishery (e.g. loan payments instead of depreciation and interest amounts on boats and motors); and 3) an estimation of the total community income from the fishery.

A comparison of the 1988 average income per firm of \$8289 (which included revenues from a compensation fund and from a provincial freight subsidy program) to the 1980 average income per firm of \$6299 (in 1988 dollars) showed an increase of 32% in real income. This increase was the result of factors which affected both price and cost. Whitefish prices are extremely important to a northern lake, like SIL, that is remote from southern markets; an examination of whitefish prices and output for SIL since 1982 showed that output followed closely the average price per kilogram. In 1988, a year when whitefish prices were relatively high, there was a significant increase in catch per firm. There was also a reduced replacement rate for capital items in 1988, which may have been due to a reduction, since 1980, of debris in the water resulting from flooding.

There have been a number of changes in the SIL fishery since 1980: 1) a reduction in the mesh size legally allowed for the harvesting of whitefish; 2) a shift in fishing intensity from Region 4 of SIL to Regions 4 and 5; 3) a change in the administration of the SIL compensation fund; 4) the provision of financial assistance to fishermen utilizing outlying lakes; and 5) the introduction of regular ferry service to the community in 1985.

Although fishermen had been operating in the southwest region of the lake for some time, it appears that the ferry service has increased participation in the fishery in this part of SIL. Although CPU was greater in the north end (in the order of 25 tubs for every 20 nets set versus 8 to 10 tubs in the region near the community), only 9 of the 23 firms sampled in 1988 delivered their catches to Missi Falls. Average income per firm in the northern region of SIL was \$13,754 versus \$4,776 for those firms delivering to the South Indian Lake community. Greater distance from the community and rougher waters require a greater commitment to the fishery in the northern portions of the lake, whereas the south end attracts more families, elderly people, and novice fishermen.

Results of the other two economic evaluations of the SIL fishery more closely approximated the real economic value of the fishery to the community fishermen and to the community in general. In addition to the difference in assessing the cost of capital items, the alternative analysis of firms' net incomes also considered estimated UIC benefits; this alternative calculation was significant because it more closely reflected the net cash income that was received by the fishermen. Under this method, the average net income per firm was \$9,751.

Using the data generated from the sampled firms, which represented over 80% of the active licensed fishermen in the study area, the total community income from the fishery was estimated to be \$232,326; if the wage labour paid out by the firms is added back in, the total net income to the community rises to \$242,631. In addition to the cash income from the fishery, the community also benefited from a substantial amount of food from the fishery. Not only was a large quantity of fish consumed in the community but the fishermen were able to shoot moose while on the lake fishing. Rough estimates of the economic value of amount of fish consumed (30 to 60 kg per capita), and moose harvested (20) added an additional \$166,000 to \$286,000, giving an estimated total value of \$398,326 to \$518,326 of the commercial and subsistence fisheries of Southern Indian Lake.

In summary, the economic evaluation of the SIL fishery in 1988 depended upon the point of view used (e.g. firm or community) and on the method of calculation. The fishery seems secure from a financial point of view; however, it should be noted that the revenues from a compensation fund and a provincial freight subsidy program were included in all calculations.

*Preliminary analysis indicate that the genetic structure of the whitefish stocks in Playgreen Lake and the northern basin of Lake Winnipeg has not changed since the construction of the Lake Winnipeg regulation (LWR) project. Further analysis will be required to confirm or contradict this preliminary finding.*

In response to claims by Playgreen Lake fishermen that the spatial distributions and seasonal movements of separate stocks of whitefish in the northern end of Lake Winnipeg and Playgreen Lake have changed since LWR, an investigation was initiated of the genetic structure of these populations. A fish stock is, by definition, a population that shares a common environment and gene pool. This definition implies a degree of reproductive isolation between various stocks of a particular fish species in a particular area; this reproductive isolation will generally be expected to result in genetic differences between stocks, which will tend to accumulate due to random genetic drift and/or selection. The genetic differences expected among various stocks of fish and the environmental differences expected in their habitats have allowed the application of methods to identify and differentiate stocks.

Direct assessment of genetic differences is possible by a number of means, the most common of which is the electrophoresis of isozymes. This method was used in a FEMP study to compare the genetic stock of the whitefish population in 1989 to the genetic stock structure that was present in 1975.

The results of the analysis indicated that at least two different stocks of whitefish exist in the northern Lake Winnipeg/Playgreen Lake areas. One stock uses sites in the north basin of Lake Winnipeg for spawning and the other utilize Little Playgreen Lake for spawning. The same genetic similarities and differences among stocks were found in 1975, before LWR, and in 1989, after LWR. The preliminary results of this study, therefore, do not provide support for the observations of commercial fishermen on Playgreen Lake that the population structure of whitefish may have changed due to LWR construction and operation. This conclusion is tentative and preliminary, however, for a number of reasons.

First, the analysis was based on only a limited genetic comparison; further genetic analyses should be undertaken as genetic models are refined and a more extensive data set is interpretable. Second, an analysis of morpho-

logical data on both the 1975 and 1989 samples is yet to be conducted. Morphological data may allow the identification of additional stocks not ascertained by genetic analysis. Morphological differences are not based solely on genetics, but rather may be at least partly environmentally induced; this is especially the case for some fish, such as whitefish.

*Changes were observed in the benthic standing stocks in lakes along the Churchill River Diversion (CRD) route and downstream of Missi Falls, following impoundment of Southern Indian Lake (SIL) and the diversion of the Churchill River. These changes varied according to the nature of the changes in the hydrologic regime in each area. The observed changes in the benthic standing stocks in Notigi Reservoir were attributed primarily to changes in the availability of water-borne nutrients for primary producers and particulate matter for the deposit-feeding benthic invertebrates. In the lower Churchill River lakes, changes in nutrients and a reduction in lake surface areas resulted in reduced standing stocks.*

A survey of benthic invertebrates in the lakes in the vicinity of SIL, which had been conducted at regular intervals since 1973, was continued under FEMP. Four groups of lakes were studied, based on the changes in their water flow regime. The first group consisted of three lakes on the lower Churchill River: Partridge Breast, Northern Indian, and Fidler lakes; the second group included five lakes flooded by the Notigi Reservoir: Karsakuwigamak, Rat and Notigi lakes on the diverted flow; and West and Central Mynarski lakes off the direct flow; and the third group consisted of two lakes below the Notigi Control Structure: Wapisu and Wuskwatim lakes. The fourth group, East Mynarski and Wood lakes, were unaffected by water manipulations.

The three lakes along the lower Churchill River, where flows were greatly reduced following diversion, lost almost the entire productive littoral zone; establishment of a new littoral zone has been hampered by fluctuations in the water released from Missi Falls. These lakes also suffered a decline of one-half of the profundal invertebrate standing stock over a decade. The benthic invertebrates of the lower Churchill River lakes will maintain a reduced population, primarily in those portions of the lakes below the range of water-level fluctuations. Total biomass of benthic invertebrates in the lower Churchill River has been reduced to about one-quarter of pre-impact levels.

In Notigi Reservoir, an increase in river-borne nutrients for primary producers and particulate matter for the deposit-feeding benthic invertebrates from the diverted Churchill River is maintaining post-impact standing stocks at a level about twice that which existed before the diversion; such levels of benthic invertebrates were seen only in the lower Churchill River before damming. Total standing stocks have decreased only slightly in later years, likely because the diverted Churchill River continues to be a major source of nutrients to the reservoir. Benthic invertebrate productivity is likely to remain high in this reservoir.

The overall trend for benthic invertebrates in Wapisu and Wuskwatim lakes was one of an increase in population numbers after the diversion, followed by a slow decline to values approximately equal to or less than the pre-impoundment abundances. The magnitude of the change in the invertebrate standing stock in Wuskwatim Lake, however, was not as great as that seen in Wapisu Lake. The intervening Threepoint Lake and the approximately 55 km of river between the two lakes may have moderated the response of the invertebrates in Wuskwatim Lake.

The benthic standing stock in the two unaffected lakes studied showed some variation over the years, especially in East Mynarski Lake. Total invertebrate standing stocks in Wood Lake were low, usually about one-half of the riverine lakes, indicating the extent of the influence of river-borne nutrients and their effect on benthic populations.

*Benthic standing stocks within Playgreen and Kiskittogisu lakes varied according to their location relative to 2-Mile and 8-Mile channels. The total and relative abundances of taxa in these lakes in 1987 and 1989 usually differed from those found in the pre-project survey conducted in 1971.*

The southern basin of Playgreen Lake, located south of 8-Mile Channel, had significantly more invertebrates than the northern basin in both 1987 and 1989. Examination of the 1987 mean standing stock in each of the western, central, and eastern sections in the southern basin revealed that the western section, which is located in the sediment plume from 2-Mile Channel, was more productive than either of the central or eastern sections. A similar, but weaker situation was observed in 1989. The region north of the 8-Mile Channel showed no

significant differences between western, central and eastern sections in either 1987 or 1989.

The numbers of invertebrates in 1987 were substantially higher than those reported in the 1971 survey (probably because of methodological differences) and the areal difference between the north and south basins, which had existed in 1971, was intensified in 1987. Mean standing stocks in 1989 were considerably lower than in 1987, probably because of drought conditions, but were still higher than in 1971. In 1987, the basic order of abundances of individual taxa was the same as in 1971; however, there was a change in the abundance ranking in 1989 due to the differences in abilities among taxa to tolerate the increased water temperatures and/or reduced flows that accompanied the drought conditions.

Standing stocks in the southern portion of Kiskittogisu Lake, the part of the lake that receives direct inflow from the 8-Mile Channel, were significantly higher in 1989 than those of the more remote northern portion of the lake. This is in contrast to the almost identical distribution between these two areas in 1971. As was the case with Playgreen Lake, mean standing stocks in Kiskittogisu Lake were much lower in 1971 than in 1989, probably because of methodological differences. The 1989 survey also revealed shifts in the order of abundance of the individual taxa in both the northern and southern portions of the lake in comparison to 1971.

The most productive and diverse region of the two lakes, in 1971, 1987 and 1989 was the southern basin of Playgreen Lake, which probably reflected the stabilizing influence of the large mass of water in Lake Winnipeg. High invertebrate populations found in the south basin north of 2-Mile Channel likely resulted from increased organic material washed from the shores of Lake Winnipeg and carried through 2-Mile Channel. Similarly, invertebrates in the southern portion of Kiskittogisu Lake probably also benefited from the increased nutrients carried in by the inflow from 8-Mile Channel. The diversion of this nutrient and food laden water away from the northern areas of Playgreen Lake resulted in the reduction of the benthic populations there relative to the southern basin.

## Waterfowl

*Surveys of ducks and geese conducted in the Nelson House area in September 1988 showed considerable variation in numbers, depending on species, lake, and date of survey; but, as a rule, numbers were generally low. Data are too limited, both temporally and spatially, to estimate changes in the level of waterfowl use of this area with any degree of confidence. The data suggest, however, that there may have been a decline in dabbling duck use of this area following diversion.*

A series of three low-altitude aerial surveys were flown over parts of the Rat - Burntwood river system, including Wapisu, Threepoint, Wuskwatim and Honey-moon lakes. Comparison of the results of this 1988 survey with the 1973 survey conducted as part of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Study showed a substantial reduction in numbers of dabbling ducks (97%), diving ducks (89%), and Canada geese (57%). It is risky, however, to draw broad conclusions about waterfowl numbers on the basis of the 1973 and 1988 surveys, because both surveys provide only a limited number of "point-in-time" counts. Furthermore large between-year changes are not uncommon in waterfowl counts derived from aerial surveys. In addition, the small numbers of diving ducks and Canada geese observed in both surveys make it difficult to state, definitively, that a decline has occurred in all survey areas.

The only other available waterfowl data for this area are annual breeding-pair surveys conducted in northern Manitoba by the United States Fish and Wildlife Service (USF&WS). Analysis of this data for the periods 1964 - 1975 and 1977 - 1988 showed marginally higher (0.2%) dabbling ducks in the latter period. However, large year-to-year fluctuations occurred during these periods; thus the means on which these changes were based would vary somewhat as individual year counts were added or subtracted. The apparent reduction in the dabbling duck use of the diversion area does not appear to be a reflection of a long-term decline in regional populations, as represented by the USF&WS data, since no such trends were evident in this data.

It is postulated that habitat modifications resulting from the Churchill River Diversion (CRD) may have rendered the Rat - Burntwood area less attractive for

staging dabblers and to a lesser extent divers. Higher duck densities observed in the September 26, 1988 survey of Notakikwaywin Lake, a lake unaffected by the CRD, than in the affected lakes surveyed supports this hypothesis. The apparent reduction in waterfowl availability, combined with boat navigation and access problems, have limited opportunities for Nelson House Band members to view and hunt waterfowl.

*Surveys of ducks and geese conducted in the Norway House area in September 1986 and October 1987 showed considerable variation in numbers, depending on species, lake, and date of survey; but as a rule, numbers were generally low. Data are too limited, both temporally and spatially, to estimate changes in the level of waterfowl use of this area with any degree of confidence. The data suggest, however, that there may have been a decline in diving duck use of this area following the regulation of Lake Winnipeg.*

A series of five low-altitude aerial surveys were flown over parts of the Outlet Lakes area, including 8-Mile Channel and Playgreen, Kiskitto, and Kiskittogisu lakes. Comparison of the results of the 1986/1987 survey with the 1972/73 survey conducted as part of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Study showed a decline in diving ducks of approximately 96%. It is risky, however, to draw broad conclusions about diving duck numbers on the basis of the 1972/1973 and 1986/1987 surveys, because both surveys provide only a limited number of "point-in-time" counts. Furthermore large between-year changes are not uncommon in waterfowl counts derived from aerial surveys. The data suggest that the Outlet Lakes area did not attract large numbers of dabbling ducks in either of the two survey periods. Similarly, only relatively small numbers of Canada geese were observed on individual surveys in both survey periods; indeed, no geese were observed on several surveys.

The only other available data for this area are annual breeding-pair surveys conducted in northern Manitoba by the United States Fish and Wildlife Service (USF&WS). Analysis of this data for the periods 1964 - 1975 and 1977 - 1988 showed a small increase (approximately 2.6%) in diving ducks in the latter period. However, large year-to-year fluctuations occurred during these periods; thus, the means on which these changes are based would vary somewhat as individual year counts were added or subtracted. The apparent reduction in the diving duck use of the Outlet Lakes area does not appear

to be a reflection of a long-term decline in regional populations, as represented by the USF&WS data, since no such trends were evident in this data.

The greatest apparent reduction in diving duck use occurred in Playgreen Lake. It is postulated that changes in the quality of the Playgreen Lake habitat may have been sufficient to reduce the attractiveness of Playgreen Lake to diving ducks in the fall. Many, if not most, of the preferred duck hunting areas traditionally used by Norway House Band hunters are located in the south basin of Playgreen Lake. The apparent reduction in waterfowl availability, most especially diving ducks, has limited opportunities for Norway House Band members to view and hunt waterfowl.

## Resource Harvesting

*A FEMP examination of the existing data on resource use by the NFC communities (primarily fishing data) indicated a number of major socioeconomic effects such as substantial declines in per capita subsistence fisheries harvests at Cross Lake and Split Lake (for which pre- and post-project data exist), a sharp decline in commercial fish production at Cross Lake, partial contamination by mercury at Nelson House, and increased unit costs of production at Norway House and, possibly, Split Lake. Existing data do not reveal the full suspected range of adverse effects; for example, production levels may be maintained as a result of intensified effort.*

The five NFC communities and South Indian Lake are mixed, subsistence-based economies, dependent upon the active use of the local resources, a pattern that has evolved from historic use and occupancy of the region. Physical and biological resource bases (the focus of the FEMP studies) provide the socioeconomic foundation for these communities; changes to the resource bases can trigger a number of interrelated harvesting and subsequent socioeconomic changes.

The first record of commercial fishing in the NFA area is for Sipiwesk Lake in 1937; the Southern Indian Lake commercial fishery, the largest in the FEMP study area, began in 1942. Commercial fishing is not only important as a major source of cash, but it provides capital items, such as boats and motors, necessary for travel, recreational activities and perhaps most importantly for domestic harvesting. In addition to Southern Indian Lake and its

58 associated inland lakes fisheries, 78 lakes were commercially fished in the FEMP study area.

Trapping is the other major commercial resource harvesting activity for which an extensive data base exists in the FEMP study area. Records of the trapping harvests begin shortly after the introduction of the registered trapline system in the mid-1940s. There are about 226 traplines, totalling 102,650 km<sup>2</sup>, in the 4 registered trapline zones of the NFC communities; up to 15 species of fur bearers are harvested. The South Indian Lake registered trapline section, the second largest in Manitoba with an area exceeding 35,000 km<sup>2</sup>, contains an additional 50 traplines. As documented in a recent study (Hrenchuk 1991), this area is extensively and intensively used by the residents of South Indian Lake.

Fishing and trapping data bases for the five NFC communities were examined to assess their potential to provide indicator data on the socioeconomic effects of the LWCN project. Some preliminary observations on resource harvesting impacts were also made to the extent that existing data permitted; observations were limited almost exclusively to fishing because the task of organizing the fur harvest data for this purpose was beyond the scope of this study. Although South Indian Lake was excluded from this FEMP study, partly because it was the subject of other socioeconomic studies, the conclusions from the FEMP resources harvesting study, in general, apply equally well to this community.

It was concluded that the commercial fishing and trapping data bases could provide reasonably reliable indications of harvest level that could be identified (for the most part) at satisfactory levels of geographic detail; moreover, these data have substantial historical depth. However, the fisheries data provide only limited information on harvesting effort, and the trapping data provide none at all. There are no other continuous records that can be used as impact indicators for resource harvesting. Estimates of subsistence harvesting are discontinuous in time and space, and idiosyncratic in method. Also, there are insufficient data on other resource harvesting activities such as hunting of waterfowl and large and small game, as well as the gathering of berries and medicinal plants, to permit any assessment of the LWCN project on them.

In addition to the limited existing data on resource harvesting, there is a problem of interpretation. For

example, effort and return in fishing have responded to market forces, such as fish prices and alternative employment opportunities, and perhaps also to changes in the community and reserve economies, in addition to project effects. Furthermore, focusing exclusively on economic losses likely undervalues the importance of fishing to the affected communities. Therefore it is important that fishing and all resource harvesting activities not be assessed in isolation and out of context. Unfortunately, there has been no comprehensive social impact assessment, which would provide such a context, conducted in any of the six native communities within the FEMP study area; until this occurs, it will not be possible to fully understand the implications, including those for impact assessment of the biophysical changes on the FEMP native communities.

## Future Studies

*The hydrologic regime of the Churchill and Nelson rivers and their associated ecosystems is a dynamic system; natural and man-made factors interact to produce a constantly evolving environment. The FEMP investigated a few, important changes in this environment in some depth. Broader understanding of these changes will require an integration of the results of all research and monitoring programs in this area and new, innovative approaches for future studies.*

As noted in chapters 1 and 2 of Volume 1 of this report, the richness of northern Manitoba's natural resources has provided a strong base for the development of forestry, mining, and hydroelectricity. The importance of the area's resources has always extended beyond its geographic boundaries - from its historic role as the gateway to western Canada, through its navigable waters and abundant supply of beaver, to its promise of continued provincial economic strength, through the potential power sales and expected job creation resulting from future hydroelectric projects. These developments have altered terrestrial and aquatic environments, beyond the range of natural variability; possible future climatic change may further exacerbate these alterations.

As discussed in chapters 3 and 4 of Volume 1, the objective of FEMP was to conduct an environmental research and monitoring program to examine changes since the Lake Winnipeg, Churchill, Nelson (LWCN)

Rivers Hydroelectric Project, and to increase our understanding of the significant factors that could affect future ecological conditions in the FEMP study area. This area focused on the immediate vicinity of the six native communities located in the LWCN project area. Of the many factors considered in the selection of FEMP projects, one of the most important was scientific methodology. Although some FEMP projects were new initiatives, many were a continuation of research and monitoring activities previously initiated in the FEMP study area. This resulted in the creation of a number of long-term data bases that were invaluable in assessing environmental changes.

It is apparent from the results of those FEMP projects with long-term data bases that short-term conditions were not necessarily indicative of long-term conditions (e.g. the status of the pike population in Wupaw Bay, Southern Indian Lake; benthic populations along the Churchill River Diversion; water quality conditions at Thompson). Furthermore, data bases that are long-term and fairly extensive, such as the water quality data at Thompson, can be segmented into discrete periods that can be used to develop an understanding of impacts which are specific to a particular period of time. (e.g. a doubling in total phosphorus concentration between the pre- and immediate post-development periods).

FEMP also clearly demonstrated the importance of research, and not just monitoring, activities in assessing environmental change. For example, it was a combination of long-term data and research that ascertained that the changes in the mayfly population in Southern Indian Lake following impoundment and diversion were mainly due to the influence of natural factors. Similarly, research has been the basic component of an ongoing mercury program along the Churchill River Diversion route that has attracted worldwide attention.

To a considerable degree, an attempt was made to incorporate the results of concurrent, non-FEMP environmental programs in the FEMP study area into the analysis of the FEMP data and report preparation: integration of all results, however, must await full completion of all individual project reports, both federally and provincially. However, even with such integration, a number of important environmental changes, affecting either the FEMP study area or beyond it, will not have been addressed. The downstream impact on Hudson Bay of the LWCN project is one outstanding example. The

cumulative impacts of all changes in the FEMP study area since the LWCN project (e.g. 1989 forest fires) is another example. Addressing this full range of environmental impacts will require the development and application of innovative approaches, which ideally should result in an integrated long-term, multi-party research and monitoring program.

*The ultimate test of FEMP will be our ability to accurately predict future conditions in the FEMP study area, based on the improved understanding of post-development environmental conditions that FEMP has generated.*

FEMP results have improved our understanding of the pre- and post-development environmental conditions in the FEMP study area. This understanding will be invaluable in the continuing determination of a just and fair compensation settlement to the people adversely affected by the LWCN project and in the assessment of potential, effective mitigation measures. FEMP's results may prove to be equally valuable in predicting future conditions.

The results of the FEMP research and monitoring activities have led to an improved understanding of post-development environmental conditions in a major northern Canadian river system. This understanding forms the basis for projecting future conditions, e.g. the estimated time it will take for mercury levels to return to normal, and for shorelines along certain reaches of the Churchill River Diversion to stabilize. In short, this understanding has been used to make predictions.

These predictions must now be tested. If proven accurate, the predictions will be a verification that our perceived understanding of the post-development conditions was correct. Even if the predictions prove to be only partly accurate, they will have identified issues requiring further attention.

These predictions must first be tested in the FEMP study area, where the knowledge on which the predictions were based was gathered. If the results of the prediction testing are promising here, further testing of the predictions, can be expected in other northern regions experiencing similar environmental conditions. In this manner, FEMP may contribute to the growing scientific understanding of aquatic ecosystems in boreal regions.

*The significance and implications of the FEMP results will depend upon the point-of-view and time horizon chosen in the interpretation of these results.*

FEMP results have been presented in an accurate, clear, and objective manner, with only limited interpretation of their significance and implications. This format was necessary because interpretation of these results depends upon the reader's perspective. For example, erosion to-date along the riverine reaches of the CRD has not been nearly as serious as was predicted in pre-diversion studies; nor does it appear that the erosion has been serious enough to substantially affect flows and water levels. Yet, as shown by a FEMP pilot project, measurable differences in shorelines have occurred over time causing varying degrees of shoreline erosion and sediment generation. This erosion, along with inundation, has resulted in debris-clogged shorelines, which have impeded access to and from the shorelines and travel along the waterways. Thus it would depend on the point-of-view chosen (e.g. viewing the river as a source of hydro generation or as a transportation corridor) whether the changes in the shorelines are perceived to be significant.

Another example is the mercury issue. There is no evidence that elevated mercury levels found in the fish along the CRD, the highest in the FEMP study area, have been sufficiently high to cause problems in the fish populations (e.g. death, reproductive failure, etc.). However, the elevated mercury levels in fish have been the source of considerable concern to the native residents of the FEMP study area, particularly with respect to their health. This concern, which clearly emerged as an issue in the community interviews conducted for the FEMP videotape, has been strong enough to cause distrust of what has been a traditionally important staple in their diet, even though most mercury levels in the adult population are within the normal level.

The mercury issue is also an example of the importance of the selected time horizon in assessing the implications of the FEMP results. The estimated return to pre-impoundment mercury levels of 80 years means that mercury will still be an issue for the next few generations.

## RECOMMENDATIONS

### Water Quantity and Quality

*It is recommended that documentation of the FEMP hydrologic investigations be widely circulated.*

Results from the FEMP hydrologic investigation became available too late to allow full documentation of the methodology in the FEMP Final Report. It is imperative that this documentation be widely circulated to ensure that the basis for the derivation of the hydrologic results is well understood, since an understanding of the changes in the hydrologic regime is essential to an understanding of the changes in the aquatic ecosystem.

For example, research has identified the importance of the amount of flooded organic terrestrial material to mercury methylation, the process that is responsible for elevated mercury levels in fish in the FEMP study area. Thus, an increase in lake surface area due primarily to the flooding of terrestrial material, as opposed to the incorporation of existing water bodies, would be expected to result in elevated mercury levels in fish. In Notigi Reservoir, 551 km<sup>2</sup> of the 580 km<sup>2</sup> increase in surface area was due to the flooding of terrestrial material; mercury levels in this reservoir are among the highest in the FEMP study area.

*The FEMP water quality study identified three areas of investigation that should be pursued to improve our understanding of current water quality conditions: 1) an investigation of the potential for inferring water quality changes at the FEMP water quality sites in the Outlet Lakes area by using surrogate pre-development data; 2) monitoring water quality in the Split Lake area during periods of higher Nelson River flows to differentiate water quality changes due to low flows, such as those that occurred during the FEMP study, from changes due to the LWCN project; and 3) an evaluation of the inferred sediment deposition in Split Lake near the mouth of the Burntwood River on local water quality, e.g. deposition and future potential mobilization of associated heavy metals.*

The FEMP water quality study was a comprehensive investigation in which all relevant historical water quality data and data on current water quality conditions were examined to assess water quality changes. In general,

additional data collection in the future will not enable any further understanding of those water quality changes which have already occurred in the FEMP study area. There are, however, three potential areas of investigation that may provide additional insight on some localized changes.

The impact of the LWCN project on the water quality at the FEMP water quality sites in the Outlet Lakes area could not be determined due to the lack of sufficient pre-development data. This deficiency can not be alleviated by further sampling; however, pre-development water conditions at these sites may be inferred from existing pre-development data at upstream sites. An investigation would be necessary, however, to determine if the pre-development data from these surrogate sites could be used for this purpose, e.g. information on natural erosion sites and locations of man-made facilities would have to be assessed to determine if there were any natural differences in water quality between the FEMP sites and their respective surrogates.

The low Nelson River flows during the FEMP study period made it difficult to determine if the apparent changes in water quality at the inlet to Split Lake, and in the water quality - water discharge relationships at the inlet and outlet to Split Lake, were due to the LWCN project or to low flow conditions. There is a need for continued monitoring over a wider range of flows to discriminate natural from project-induced changes, if any have occurred. The monitoring program should be consistent with the design of the FEMP study, with a similar sampling frequency, although the number of variables measured could be reduced without any significant reduction in information. A 2-year program would be the minimum required to enable statistical analysis.

The Churchill River diversion has undoubtedly had a substantial impact on sediment deposition rates in Split Lake near the mouth of the Burntwood River, and possibly has affected sediment chemistry in this region. Documentation of the extent and magnitude of sediment-related impacts in this part of the lake is required. Variables monitored should include the rate and location of sediment deposition and the chemical composition of the sediments with emphasis on metals and on factors regulating metal mobilization.

*The FEMP water quality data has provided a substantial baseline for the assessment of the impacts of future projects; however, this data base should be*

*augmented by the continued monitoring of water quality at Thompson, to assess the long-term changes on the Churchill River Diversion, and the collection of water quality data at additional stations where future hydro dams will be built, to examine specific or localized impacts. Further study should also be considered of those issues that offer the potential for improved understanding of future impacts, e.g. the predictive ability of certain water quality - water discharge relationships.*

Although the major changes in water quality appear to have occurred along the Churchill River Diversion (CRD), the length of time required for the system to reach a new equilibrium is unknown. Thus there is strong justification for continued monitoring of water quality at a minimum of one site. Thompson is an excellent site for this purpose because: 1) it is located below the major reservoirs on the CRD; 2) it has the most complete data record of any site in the FEMP study area; and 3) it is readily accessible. Annual monitoring is probably unnecessary, with a 5-year interval between monitoring periods providing adequate coverage. Each monitoring period should be a 2-year study which repeats the FEMP study sampling and analytical methods exactly.

Additional water quality stations may be necessary at, or near, the sites of future hydro dams to examine specific or localized impacts. It would be premature to identify additional station locations at this time without more information on the planned dams. As the results of the FEMP study clearly indicated, there is really no substitute for solid pre-development data. Thus, it is recommended that three years of data be collected prior to construction, with a sampling frequency comparable to that of the FEMP study, to establish pre-development baseline conditions at any new sampling station.

Any future field activities should include an examination of the predictive ability of the water quality - water discharge relationships identified in the FEMP water quality study. Such studies would involve the measurement of discharge-correlated variables over a range of discharges, and the comparison of predicted and observed values.

Another issue that warrants further consideration is the need to develop an estimate of the expected duration of elevated turbidity levels along the CRD. The eroding banks and shoreline should gradually stabilize over time,

but the lack of a significant decline in turbidity since diversion indicates this may be a very slow process. An estimate of duration is necessary both for complete documentation of the impact of the CRD on the sediment regime in the Burntwood River, as well as for an assessment of the impact of future modifications to the operation regime.

## Sediment and Morphology

*A classification system to characterize shoreline types in the FEMP study area should be developed and implemented; this system should enable quantification of the amount of each shoreline type and of the changes in these amounts. Rates of shoreline erosion and changes in these rates over time must be an integral part of this classification scheme.*

There have been widespread changes in the land-water interface throughout the FEMP study area and in some areas, such as along the CRD, these changes have been dramatic. Yet, to date, there has been only limited documentation of the magnitude and the extent of these changes. Continuing, and perhaps increased, bank instability from past hydro developments, along with expected changes from future planned developments, will further alter the shorelines of the lakes and rivers in the FEMP study area.

A vital first step in improving our understanding of the past and expected future changes in the shorelines of the FEMP study area is to develop and implement a classification system to map the distribution of shoreline characteristics. A few examples of such characteristics include standing inundated debris or vegetation, actively eroding areas of shoreline, bed rock controlled shorelines, treed muskeg shorelines, treed muskeg shorelines with permafrost, etc. The classification system could be developed by building on the classification scheme used in the LWCN study and incorporating appropriate modifications derived from relevant models elsewhere, such as the classification system used in the La Grande project in Quebec.

It is strongly recommended that representatives from all four parties to the NFA participate in the prioritization of shoreline areas for classification and in the development of the classification criteria. The high cost of even a limited morphological field program in the FEMP study area necessitates the prioritization of sites. Techni-

cal criteria, such as the availability of large-scale current and historical air photos (e.g. 1:20,000) and the physical characteristics of the site (e.g. the presence of permafrost) must be considered in the selection of sites for field studies. However, undoubtedly, the most important criterion will be the representativeness of the chosen sites as indicators of the changes of greatest interest. Care must also be taken to ensure that the classification scheme accurately portrays all of the shoreline features of most concern to the area's users.

Field investigations are necessary to provide clarifying additional information in those instances where a definitive classification of shoreline types is not possible from an air photo interpretation, e.g. in distinguishing between near shore areas of floating vegetation and areas of shallow water with emergent vegetation. The determination of the rates of shoreline recession also require field investigations. For example, on-site verification of bank heights and of the ice content of eroded material would enable more accurate calculation of the volume of material eroded. Similarly, resurveying established cross sections would identify any areas of bed degradation which may be undermining bank stability. (It should also be noted here that in addition to field investigations, a knowledge of stage-discharge relationships would be required to accurately distinguish between shoreline changes due to inundation versus erosion.)

Results of this shoreline characterization program, including measurements of bank stability, along with the application of erosion models, such as the one developed for Southern Indian Lake, could provide insight on the expected alteration of active shorelines and thus of the duration of related changes such as increased rates of sediment production and the availability of organic material to stimulate methyl mercury production. In addition, it may also lead to the identification of localized sites where remedial measures, such as bank protection, may prove viable.

*A field investigation should be conducted to document major sediment sinks along the CRD and most especially at Split Lake, where evidence suggests that active delta formation is occurring at the inlet of the Burntwood River to Split Lake. This program would complement the identification of sediment sources which will be one result of the shoreline classification and monitoring program previously recommended.*

Within the FEMP study area, sediment deposition has been investigated only in Southern Indian Lake and to a much lesser extent in Playgreen Lake. The importance of sediment deposition to fisheries and water quality and the knowledge that the sediment load carried by the CRD has increased argues for the need to have a better understanding of the locations and rates of sediment deposition, at least for the major sediment sinks. Suggested study locations include Footprint Lake, Threepoint Lake, Rat Lake, and especially Split Lake.

Sediment deposition in Split Lake is of particular concern because the incoming sediment load is largest there, the lake is large enough to ensure significant deposition, and there is an established fishery used by the residents of Split Lake and York Landing. Therefore, an intensive sediment deposition study is recommended for this location, including repetitive topographic and bathymetric surveys off the mouth of the Burntwood River, and a repetitive program of lake sediment coring to determine the rate, spatial extent and grain size of deposited sediment. To provide an independent assessment of sedimentation rates, a number of sedimentation pans should be set out in representative locations.

## Mercury

*Investigations should be continued into the following mercury issues examined under FEMP: 1) additional studies into the microbial demethylation process, the more poorly understood of the two microbial processes regulating the net production of methyl mercury; 2) the potential contribution of downstream transport of methyl mercury to elevated mercury levels in fish; and 3) the continued monitoring of mercury levels in fish from lakes that are important domestic fisheries to the six native communities in the FEMP study area.*

Studies to date have suggested that microbial demethylation rates like microbial methylation rates are regulated by organic matter availability and total microbial activity; however, these observations need to be confirmed. There is also a need to determine why demethylation appears to be independent of sediment oxygen conditions, whereas methylation increases under anoxic conditions. Such investigations may result in the identification of possible measures for stimulating demethylation and thus potential mitigatory action. Cur-

rently, fish management activities, such as the selective harvesting of fish with lower mercury levels, are the only viable mercury mitigatory measures. Fish management activities, however, may have potential negative impacts (e.g. future spawning stocks) that could have socioeconomic effects on the resource users in the FEMP study area.

Investigations should be conducted into the range and mechanism of the downstream transport of mercury in the FEMP study area. In particular, the relative importance of water, the movement of mercury-contaminated fish, and the movement of mercury-contaminated food for fish (e.g. zooplankton, invertebrates, and prey fish) as the pathway(s) for the downstream transport of methyl mercury is unknown. A recommended geographic focus for the downstream transport study is Split Lake where mercury levels in pike and walleye appear to be uncharacteristically high for a non-flooded lake on the Nelson and Burntwood rivers. This study could include: 1) measurements of methyl mercury in water in the major inflows to Split Lake; 2) a tagging program to document fish movements from Sipiwesk Lake and the Kelsey forebay; and 3) an examination of the potential effect of fish killed in the Kelsey turbines or of a site of elevated net mercury methylation within Split Lake.

Commercially harvested fish are routinely monitored by the Department of Fisheries and Oceans for mercury concentrations; however, there is no on-going program to monitor mercury levels in fish from lakes that are important domestic fisheries in the FEMP study area. It is recommended that regular, periodic monitoring of mercury levels in fish be conducted in these lakes.

*All future hydro projects in northern Manitoba, and most especially those along the CRD route, should include mercury research and monitoring activities, as well as possible preventative measures, which apply and build on the results of the FEMP mercury program.*

Environmental impact assessments of proposed hydro projects, such as Wuskwatim Dam, should include mercury studies undertaken before, during, and after the construction of the planned hydro dam and reservoir creation. These studies should include such activities as the measurement of methyl mercury in water in the reservoir and immediately upstream and downstream, the monitoring of mercury levels in fish in the reservoir

and immediately downstream, and the measurement of methylation (M) and demethylation (D) rates in the reservoir. "Pre-development" measurements (i.e. measurements taken before the construction of Wuskwatim Dam) of M and D rates, which currently do not exist for any location in northern Manitoba, along with the M and D rates for the construction and immediate post-operation period, would provide valuable additional data for the mercury duration model. (It is important to note, that Wuskwatim Lake has already been affected by the increased flows along the Churchill River Diversion and hence can not be considered a "pristine" lake.)

Shoreline characterization of future reservoirs, such as Wuskwatim, as recommended previously in this chapter, would provide information on the terrestrial organic materials (e.g. plant species, soil types) to be flooded. This information could be used in a pilot project of controlled burning of organic material to evaluate the effectiveness of this technique as a preventive measure and to assess potential adverse environmental side-effects. In addition, sediment deposition studies in the reservoir could be conducted to assess the role of sediment deposition in the net production of methyl mercury.

The newly-constructed weir at the outlet of Cross Lake has caused concern among the residents of the Cross Lake community because of its potential impact on mercury levels in fish. The weir is intended to raise the low water level without affecting the high water level; no back flooding of bog or forest terrain is expected. Thus, the weir is not expected to cause increased fish mercury levels. However, this assessment should be confirmed by a fish mercury monitoring program for at least two years after the weir is constructed.

## **Fisheries and Aquatic Life**

*A limited research and monitoring program to complete and/or follow-up on the results of fisheries and benthic studies in the FEMP study area is recommended. These activities include periodic sampling of biological indicators of the Southern Indian Lake fishery, completion of the whitefish morphological study in the Playgreen Lake area, and completion of the study on the fish migration through 2-Mile Channel.*

The results of the FEMP studies of the Southern Indian

Lake whitefish fishery suggest that it may be showing marginal improvement or stabilizing at levels lower than pre-impoundment values. Periodic sampling should be conducted to collect data on key indicators such as catch per unit effort, grade, and condition in order to assess the long-term status of the Southern Indian Lake whitefish. Consideration should also be given to a concurrent program of data collection to assess the long-term status of the pike population in Wupaw Bay, Southern Indian Lake.

Two related FEMP investigations were undertaken of whitefish populations and their movements in the Playgreen Lake - 2-Mile Channel - Lake Winnipeg area. Results of the genetic analysis component of this investigation were presented earlier in this report; however results from the morphological analysis, which is yet to be conducted, may allow for the identification of additional stocks not ascertained by genetic analysis. This may change the tentative conclusions reported to date. Additionally, a report should be prepared on the results of the study of fish migrations through 2-Mile Channel. This is dependant on the correction of problems with computer software for the analysis of the echosounder digitized data.

*It is recommended that a pilot project be undertaken to test various mechanisms to transfer whitefish over the Missi Falls Control Structure into Southern Indian Lake (SIL) in those years when discharge over Missi Falls is high. Local participation and a scientific assessment of the effectiveness of each mechanism must be integral components of the pilot project.*

In 1986, the mean discharge at Missi Falls from June to August approximated that of pre-impoundment conditions; large numbers of whitefish were observed below the Missi Falls Control Structure, most of which appeared to have originated from SIL. In contrast, in 1987, a year of lower flows than in 1986, lower numbers of whitefish were observed, most of which appeared to have originated from the lower Churchill River lakes downstream of Missi Falls. It is recommended that a pilot project be undertaken, in years of high discharge over Missi Falls, to evaluate mechanisms to transfer whitefish back into SIL.

An evaluation of the mechanisms tested in the pilot project, such as a seining program or fish ladder, should include: 1) documented numbers of fish successfully transferred; 2) an assessment of the critical factors

affecting success; 3) cost; and 4) the impact on the SIL whitefish fishery. The pilot project should be implemented and evaluated with the support of the Southern Indian Lake fishermen, since their long-term involvement will be an important factor in selecting any mitigation measure based on the results of this pilot project.

There is some suggestion that whitefish may also be leaving Southern Indian Lake through South Bay. Consideration should also be given to a research program to investigate this possibility, with the assistance of the fishermen from South Indian Lake and possibly Nelson House.

## Waterfowl

*It is recommended that future surveys of ducks and geese conducted in the FEMP study area be of sufficient intensity and duration to enable assessment of temporal and spatial trends, with some degree of confidence.*

No additional amount of data collection now will enable any further assessment of changes which have already occurred in the numbers of ducks and geese in the FEMP study area since the LWCN project. The FEMP investigation utilized all existing historical and spatial data to assess waterfowl trends to-date. Additional data collection now, however, could provide a more comprehensive understanding of the current usage of the FEMP study area by waterfowl and provide baseline data for an assessment of future changes.

Potential specific locations for future surveys include the sites of proposed future dams and areas of particular importance to the domestic harvesting of waterfowl by the residents of the six native communities in the FEMP study area. Ground studies, as well as aerial surveys, should be considered.

The work should be carried out with the cooperation of the native communities in the planning and implementation of these studies. Input from these communities is required to: 1) identify their waterfowl harvesting areas; 2) provide assistance in the field studies; 3) help identify critical sampling times; and 4) provide data on domestic waterfowl consumption.

## Resource Harvesting

*It is recommended that the appropriate parties to the NFA conduct a social impact assessment (SIA) of the LWCN project on the six native communities in the FEMP study area. An SIA involves the selection and justification of a basic paradigm of social change, the identification of appropriate variables and indicators, and a workable system for monitoring these indicators on a continuing basis.*

Post-construction socioeconomic assessments in the project - affected area have been oriented almost exclusively to the accounting and evaluation of damages for the purposes of compensation or mitigation, rather than to the understanding of the processes or the significance of social change as such. Damage accounting, however, has little analytic or predictive value, and it does not provide an adequate basis for systematic monitoring of project effects, without which predictions cannot be verified.

A social impact assessment of the project effects on the six native communities located within the FEMP study area requires a generic model of their economy that specifies its characteristics and properties. One distinctive characteristic of these communities is the place of resource harvesting as a central and integrative activity, and of subsistence as a socioeconomic system. Subsistence activity does not constitute a separate and distinct economy in these communities but is combined at the individual, household and community levels with wage labour and transfer payments. Both subsistence activities and subsistence outputs are essential for the maintenance of the social system. A SIA model for these communities must be based on the central importance of subsistence activities to them.

A review of the existing data identified the type of additional data that would be required to conduct a SIA. These data include the level of harvesting effort, the amount of domestic consumption, and a better understanding of the social and economic organization of resource harvesting activities (e.g. native land tenure). Meeting this entire range of data needs would require a combination of survey, extended interview, participant observation, and archival research. Clearly, satisfying these data needs requires that the SIA must be community based, not only in implementation and execution but also in design and control.

Greater community involvement has been recommended elsewhere in this chapter with respect to environmental monitoring programs. Indeed, continuation of one FEMP-initiated program, an assessment of the bacterial quality of the communities' drinking and recreational water, has been assumed by one NFC community, Split Lake, with the financial and technical support of the International Development Research Council. Further community involvement in environmental monitoring programs is clearly desirable, but community involvement is absolutely essential in order to understand the socioeconomic consequences of environmental changes.

## Future Studies

*It is recommended that future Canadian river basin studies, and more generally environmental studies, be conducted using an ecosystem approach. This will require the design and implementation of integrated programs that encompass inter-disciplinary, inter-jurisdictional research and monitoring activities.*

Canada's large share of the world's fresh water and her status as a world leader in hydroelectric projects behooves us to understand the consequences of altering aquatic ecosystems. There is a growing recognition within Canada of the importance of sound environmental management, which focuses on the anticipation and prevention of environmental damage. Opinion polls of the last few years have consistently shown the Canadian public's strong commitment to environmental action, even in the face of tough economic times. In order for this environmental action to be effective it must be the result of an informed decision-making process.

An attempt to provide a rational framework for a national environmental policy was the motivation for the recently released Green Plan. One of the stated goals in Canada's Green Plan is "to strengthen the nation's environmental science and technology with a special emphasis on understanding regional ecosystems." The need for federal leadership in water science has been an increasing concern as echoed across the country in a series of regional workshops on water science held by the Science Council of Canada in 1987. In particular it was noted that the needed wide-ranging, long-term ecological studies are absent and that "big" issues such as ecotoxicology,

the impact of river diversions, and studies of the marine-freshwater interface have been neglected.

Although the impetus for FEMP was the Northern Flood Agreement, it is clear that FEMP was a definite step along the path prescribed by the Science Council of Canada and by the Green Plan. It was a multi-year, multi-disciplinary research and monitoring program that examined post-development conditions of an area affected by a major river diversion. Above all, it was a scientific investigation that increased our basic knowledge of the physical, chemical, and biological processes related to ecosystem disturbance and recovery.

Progress in attaining Canada's environmental goals will require an increased usage of the ecosystem approach in investigating water issues and a continued improvement in the methodology for conducting ecosystem studies. In this regard, the lessons of FEMP can serve as a guideline with respect to the needed scientific and administrative framework.

*The results of FEMP should be applied to the design and implementation of environmental impact assessment studies at Wuskwatim.*

Current Manitoba Hydro plans are to build the next dam at Conawapa on the lower Nelson River; the relevant FEMP results should be incorporated into the planned environmental impact assessment (EIA) for this dam. However, it would be the construction of a dam at Wuskwatim Lake on the Churchill River Diversion (CRD) that offers the first opportunity to fully incorporate FEMP results into an EIA in this region.

Throughout this chapter, studies have been recommended that would test FEMP predictions, expand the extent of and our confidence in the existing data bases, and address identified needs. Collectively, these recommended studies would further our understanding of this changed, and still changing, ecosystem. Most of these recommendations could be implemented as part of the Wuskwatim EIA. Past hydro development projects have already had an effect on Wuskwatim Lake (e.g. changed surface area, changed benthic invertebrate populations, etc.) that must be considered in the collection of EIA "pre-development" data. However a Wuskwatim EIA could still provide a valuable opportunity for building upon the results of FEMP.

FEMP recommendations on sediment, morphology, and mercury, in particular, offer a wide scope of productive avenues to pursue. Potential sediment and morphology issues include: 1) testing of DFO's Southern Indian Lake erosion model; 2) development of a shoreline classification scheme; 3) continuation of the FEMP airphoto interpretation to generate estimates of erosion; and 4) the initiation of field studies to ground-truth information obtained from remote sensing techniques. Potential mercury issues include: 1) measurement of pre- and post-Wuskwatim Dam methylation and demethylation rates; 2) measurement of mercury concentrations in fish and water; 3) investigation of the possible downstream transport of methyl mercury from Wuskwatim via water and fish; and 4) a pilot project to assess the effectiveness of controlled burning of organic material as a possible preventive measure in the accumulation of methyl mercury by fish. Other potential issues arising from FEMP that could be further investigated include: 1) waterfowl surveys; 2) benthic populations, and 3) measurements of selected water quality variables, such as turbidity, before and after the construction and operation of Wuskwatim Dam.

Other recent or anticipated studies that could be used in a Wuskwatim EIA include: 1) environmental studies in the LWCN impact area conducted by Manitoba Hydro and the Manitoba provincial government; 2) regional environmental studies, such as the planned Boreal Ecosystem - Atmosphere Study (BOREAS), a joint Canada/NASA ecosystem study that will include a study site near Nelson House; and 3) the on-going environmental studies being conducted as part of the James Bay project in northern Quebec. Collectively, these studies, and most especially FEMP, will provide excellent guidance for the design and implementation of a Wuskwatim EIA.

*The necessity for a strong administrative framework should be recognized early and incorporated into the design of all future major environmental research and monitoring programs. Early establishment of this framework is vital to the attainment of a program's goals.*

Like FEMP, all major environmental research and monitoring programs build on the results of past investigations and lay the foundation for similar investigations in the future; these programs do not, or rather should not, exist in isolation. However, in order to ensure that a program benefits from the results of previous studies, a number of administrative "housekeeping" tasks must be initiated

early in the program. These include the retrieval and standardization of existing data and the determination of methods used in past studies. This information is essential if temporal analysis is one of the program's objectives. If multi-disciplinary studies are planned, there will also be a need for common basic information such as current and accurate maps of the study area.

The need for strong administrative support continues throughout the study, especially in the provision of secure and sufficient program funding, and in ensuring enough flexibility to enable reallocation of funds between years and projects as program requirements demand. Other important requirements include the need for program management and for scientific review of all program proposals and project findings; mechanisms for both functions must be in place early. There must also be full documentation and permanent archiving of data if the program is to be useful in the planning of future studies.

Another essential, but unfortunately often undervalued, administrative task is the planning and implementation of a vigorous and effective public information program. In particular, public information activities must be designed to address the specific information needs of the target audience and, to the maximum extent possible, facilitate their active participation in the program.

Even this brief outline of selected key administrative tasks illustrates their critical importance in environmental research and monitoring programs. Yet, frequently, many of these tasks are initiated only relatively late in a program; FEMP was typical in this regard. There are a number of reasons for the late establishment of administrative structures. First, the non-routine nature of these programs takes them outside the normal departmental operational experience. Second, the broad objectives and time frames of such programs places them beyond the mandate and resources of any one department. Third, there are constitutional uncertainties regarding responsibilities in water resource issues. The latter problem can result in a "tragedy of the commons" in that what is in the interest of all parties to have is no one's responsibility to provide.

As noted in the Inquiry on Federal Water Policy (1985) "The respective roles of governments is a sensitive issue in federal-provincial relations and seems to have impeded resolution of some water management problems." Definition of roles is further complicated when the water

resource issue involves substantial alteration of the environment by developments because a third role, that of the proponent's, is introduced.

Clearly, the strong administrative framework that is required to support the scientific and social investigation of complex environmental issues can best be provided through cooperative action of all involved parties. This would remove constitutional uncertainties and provide a large common pool of resources and experience. Cooperative action also offers the advantage that, through their participation, all involved parties will have a better appreciation of the program's conclusions and recommendations and will incorporate this knowledge into their decision-making process. The ultimate success of programs like FEMP will be their influence on the decision makers of today and tomorrow.

## AUTHOR'S ACKNOWLEDGEMENTS

The Federal Ecological Monitoring Program was the work of a large number of people. It is my great pleasure to acknowledge their efforts here.

**Program Implementation** The following are the names of those people who made substantial contributions to the implementation of FEMP, listed by FEMP subject areas. Water Quantity and Quality: hydrologic calculations, G. McCullough; AFFRA data, J. Way; ice information, the late A. Gerard, and T. Prowse; water quality, Agassiz North Assoc., N. Strange, P. Seidl, and J. Wood. Sediment and Morphology: Kellerhals Engineering Ltd., Northwest Hydraulics, G. McCullough, and T. Day. Mercury: Agassiz North Assoc., D. Bodaly, and N. Strange. Fisheries and Aquatic Life: D. Bodaly, D. Rosenberg, N. Strange, A. Wiens, B. Fudge, G. Baker, D. Peristy, and N. Barnes. Waterfowl: I.D. Systems Ltd., P. Boothroyd, and R. Wickstrom. Resource Harvesting: P. Usher, M. Weinstein, and C. Hrenchuk. Additional work was conducted as follows: annotated bibliographies, North/South Consultants Inc., and McLaren Plansearch; meteorological data analysis, I. Hnauta; remote sensing analysis, EMSI Ltd.; map preparation, Geograf and G. McCullough; and student assistant, M. Treble.

**Final Report** The following are the names of those who reviewed earlier drafts of the FEMP Final Report. D. Rosenberg, D. Bodaly, G. McCullough, R. Halliday, D. Ramsey (Agassiz North Assoc.), and T. Day. Report graphics and layout by Geograf. Special thanks to R. Koch for her invaluable skills in word processing and proof reading.

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Thank you one and all.



L. McKerness  
FEMP Coordinator

# GLOSSARY, ACRONYMS AND TECHNICAL UNITS

**AFFRA** - Acoustic Flow for Remote Areas

**Al** - Chemical symbol for the element aluminum

**ANOXIC** - deficiency of oxygen

**As** - chemical symbol for the element arsenic

**BACTERIA** - group of single or multi-celled, microscopic organisms, lacking chlorophyll

**BATHYMETRY** - the measurement of depth of water in water bodies

**BENTHIC** - pertaining to BENTHOS

**BENTHOS** - organisms that live on or in the bottom of bodies of water

**BIOMASS** - the amount of living matter (as in a unit area or volume of habitat)

**BLACK ICE (OR COLUMNAR ICE)** - translucent ice formed by freezing water. It has a relatively coarse columnar crystal structure

**BOREAL** - of, relating to, or located in northern regions

**C** - chemical symbol for the element carbon

**Ca** - chemical symbol for the element calcium

**Cd** - chemical symbol for the element cadmium

**CHLOROPHYLL a** - A photosynthetic pigment in plants. The concentration is used as a measure of algal biomass

**Cl** - chemical symbol for the element chlorine

**CMMA** - Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion

**CONDITION FACTOR** - relative plumpness of fish, usually calculated as weight of the fish divided by the length of the fish (or length cubed)

**CORRELATION** - the study of the simultaneous variation of two or more variables. If one variable (e.g. mercury concentration) increases as the other increases (e.g. fish size) and decreases as the other decreases there is said to be a positive correlation.

**CPU** - catch per unit effort, a measure used to describe fishing success

**CRD** - Churchill River Diversion

<sup>137</sup>Cs - a form of the chemical element, cesium

**Cu** - chemical symbol for the element copper

**DABBLING DUCK (OR DABBLER)** - a duck which typically feeds by "tipping up" so that its tail shows above the water surface; mallards and teals are dabblers

**DEMETHYLATION** - a process by which a methyl group (CH<sub>3</sub>) is removed from a compound. In METHYL MERCURY demethylation, methyl mercury is converted into elemental MERCURY.

**DFO** - Department of Fisheries and Oceans

**DIC** - dissolved inorganic carbon

**DIVING DUCK (OR DIVER)** - a duck which typically feeds by diving below the water surface; scaup and goldeneye are divers

**DOE** - Department of the Environment

**DORSAL** - relating to or situated near or on the back, especially of an animal or one of its parts

**ECOLOGY** - a branch of science concerned with the interrelationship of organisms and their environments

**EIA** - environmental impact assessment

**ELECTROPHORESIS** - the movement of suspended particles through a fluid or gel under the action of an

electromotive force applied to electrodes in contact with the suspension

**F** - chemical symbol for the element fluorine

**Fe** - chemical symbol for the element iron

**FECAL COLIFORM** - the type of coliform present in the large intestine and feces of warm-blooded animals

**FEMP** - Federal Ecological Monitoring Program

**FLUVIAL** - of, relating to, or living in a stream or river

**FORAGE** - food for animals, especially when taken by browsing or grazing

**FRAZIL ICE** - small thin discs of ice, typically about 1 mm in diameter

**GLACIO-LACUSTRINE** - of, relating to, or coming from lakes deriving much or all of their water from the meeting of a glacier

**GONAD** - any of the reproductive glands that produce gametes and include the ovaries and the testes

**HALF LIFE** - the time required for half of something to undergo a process

**Hg** - chemical symbol for mercury

**HOLISTIC** - relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into parts; holistic **ECOLOGY** views man and the environment as a single system

**HYDROLOGY** - a science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere

**HWC** - Health and Welfare Canada

**ICE JAM** - a forced, stationary accumulation of fragmented ice and **SLUSH**

**ICE PAN** - rounded pans of ice formed by the congealing of **FRAZIL SLUSH ICE** at the surface after exposure to the cold air. The pans are characterized by a thickening crust of solid ice with an underhang of **SLUSH**

**ICE SKIM** - a thin layer, coating, or film of ice

**INORGANIC** - not **ORGANIC**, not containing carbon or compounds of carbon, with a few exceptions

**INVERTEBRATES** - of or relating to animals that lack a spinal column

**IONS** - an atom or group of atoms that carries a positive or negative charge as a result of having lost or gained one or more electrons

**K** - chemical symbol for the element potassium

**KEEL** - the portion below the water line

**LIMNOCORRALS** - large enclosures that isolate a defined water mass from a larger body of water

**LITTORAL** - of, relating to, or situated or growing on or near a shore

**LODGEMENT** - the bridging of pan and **SLUSH ICE** between the edges of shorefast ice to begin development of the freeze-up pack.

**LWCN** - Lake Winnipeg, Churchill and Nelson Rivers

**M/D** - the ratio of specific methylation rate to specific demethylation rate. Also called the **METHYLATION BALANCE**

**MERCURIC IONS** - a divalent **MERCURY** atom with a double positive charge

**MERCURY** - a naturally occurring metallic element

**METHYL GROUP** - a group that consists of 1 carbon and 3 hydrogen atoms

**METHYL MERCURY** - an ORGANIC form of mercury containing the methyl group ( $\text{CH}_3$ ); methyl mercury has a high affinity for animal tissue and is concentrated up the food chain.

**METHYLATION** - a process by which a methyl group ( $\text{CH}_3$ ) is attached to an atom or molecule. In mercury methylation, MERCURIC IONS are converted to METHYL MERCURY

**METHYLATION BALANCE (M/DRATIO)** - a measure of the net rate of METHYL MERCURY production by BACTERIA

**Mg** - chemical symbol for the element magnesium

**mg·L<sup>-1</sup>** - milligrams ( $10^{-3}$  gram) per litre

**mm** - millimetre ( $10^{-3}$  metre)

**Mn** - chemical symbol for the element manganese

**MORPHOLOGY** - relating to form and structure

**N** - chemical symbol for the element nitrogen

**Na** - chemical symbol for the element sodium

**NFA** - Northern Flood Agreement

**NFC** - Northern Flood Committee

**NFR** - Non-filterable residue. A measure of the concentration of suspended sediments in water. Defined as the mass of material in a volume of water that does not pass through a  $.45 \mu\text{m}$  membrane filter.

**ng·g<sup>-1</sup>** - nanogram ( $10^{-9}$ ) per gram

**NH<sub>3</sub>** - chemical symbol for the compound ammonia

**Ni** - chemical symbol for the element nickel

**NO<sub>2</sub>-NO<sub>3</sub>** - chemical symbol used to identify the compounds nitrite ( $\text{NO}_2$ ) and nitrate ( $\text{NO}_3$ )

**NTU (Nephelometric Turbidity Units)** - a measure of water clarity; the higher the NTU value, the more suspended matter present in the water

**NUTRIENT** - any substance which promotes growth or provides energy for a living organism

**ORGANIC** - relating to, or derived from, living organisms

**P** - chemical symbol for the element phosphorus

**PAB** - Program Advisory Board

**PARADIGM** - an example or pattern, especially an outstandingly clear or typical example or archetype

**<sup>210</sup>Pb** - a form of the chemical element, lead

**PHYTOPLANKTON** - PLANKTONIC plant life

**PLANKTON** - the passively floating or weakly swimming animal and plant life of a body of water consisting chiefly of minute plants and animals that have only weak powers of movements

**PO<sub>4</sub>** - phosphorus occurring as the compound  $\text{PO}_4^{3-}$ . Considered to represent the concentration of inorganic soluble phosphorus, the form directly available to aquatic plants

**ppb** - a concentration expressed in parts per billion

**ppm** - a concentration expressed in parts per million. Equivalent units are  $\mu\text{g}\cdot\text{g}^{-1}$  and  $\text{mg}\cdot\text{L}^{-1}$

**PRESSURE RIDGE** - a raised section of buckled or fragmented ice caused by failure of an ice sheet in compression due to thermal expansion or collision between floes

**PROFUNDAL** - pertaining to the deeper depths of a water body

**r<sup>2</sup>** - a measure of how well the trend in the data is described by a specific mathematical formula, in most cases, a straight line

**REMOTE SENSING** - is the science and art of obtaining information about an object, area, or phenomenon, through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation

**RIPRAP** - a foundation or sustaining wall of stones or chunks of concrete thrown together without order

**RIVERINE** - relating to, formed by, or resembling a river

**SEECHE DISC** - a 1/4 m diameter disc, divided in alternating black and white quadrants. The depth in the water at which the disc disappears from view is used as a measure of the water's transparency.

**SIA** - social impact assessment

**SIL** - Southern Indian Lake

**SLUSH** - unfrozen saturated snow

**SLUSH ICE** - loose accumulations of FRAZIL particles, either on the surface of the water or under an ice cover

**SNOW ICE** - ice formed by the freezing of saturated snow. It has a fine grained structure, and a white appearance due to air inclusions

**STANDARDIZED MEAN MERCURY LEVELS** - mercury levels in fish that are reported on the basis of a standardized fork length in order to provide a consistent standard of comparison between lakes; the standardized fork lengths were 350 mm for whitefish, 400 mm for walleye, and 550 mm for pike

**TDN** - total dissolved nitrogen

**TDS** - total dissolved solids

**TOC** - total organic carbon

**TURBIDITY** - a measure of the scattering and absorption of light by particles suspended in water. Note that it can be affected by the size and refractive characteristics of the suspended particles and thus need not be directly correlated with the total amount of suspended material

$\mu\text{g}\cdot\text{g}^{-1}$  - microgram ( $10^{-6}$ ) per gram

**UNGULATE** - any of the group consisting of the hoofed mammals of which most are herbivorous and many are horned

**USF&WS** - United States Fish and Wildlife Service

**Zn** - chemical symbol for the element zinc

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# Appendix 1

## Federal Ecological Monitoring Program

### Sponsoring Agency, Project Duration and Project Expenditures

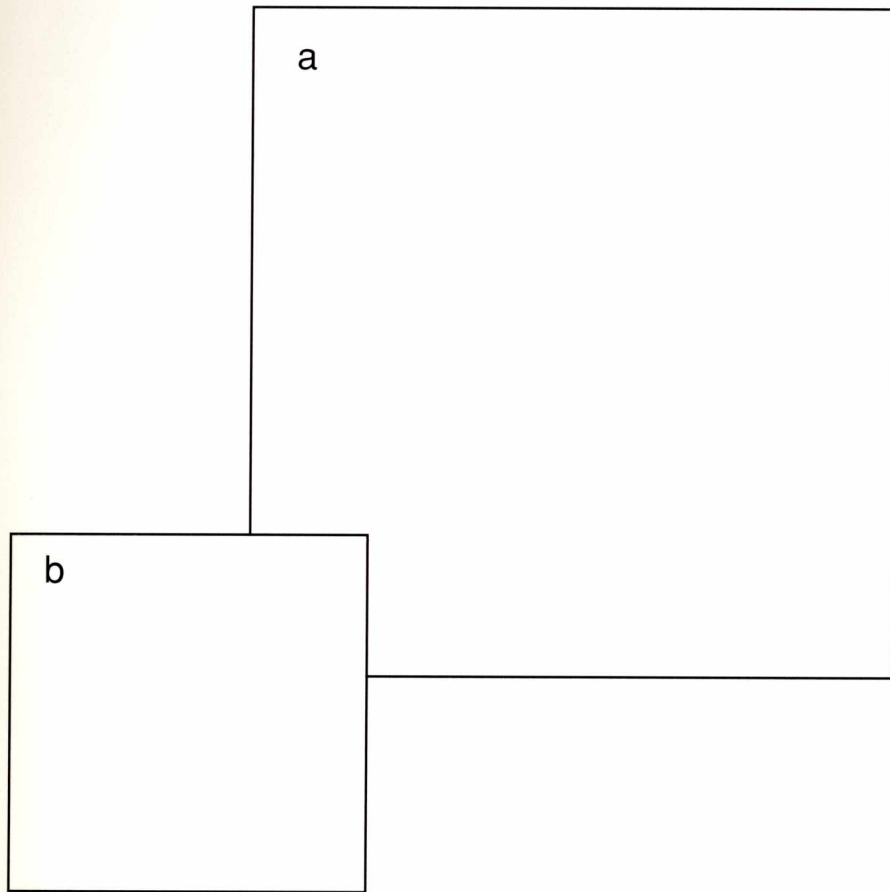
<i>Project DOE Sponsored</i>	<i>Duration</i>	<i>Total Expenditures</i> 1986/87 - 1990/91
Wildlife	1986/87 - 1990/91	\$49,588.25
Water Quality	1986/87 - 1990/91	549,150.35
Hydrology	1987/88 - 1989/90	46,127.87
Sediment and Morphology	1986/87 - 1990/91	131,391.62
Mercury	1986/87 - 1990/91	241,369.89
Ice	1988/89	15,000.00
Information Synthesis	1986/87 - 1989/90	99,767.44
Public Information	1990/91	58,474.29
Management	1986/87 - 1990/91	253,839.33
Fisheries (DFO Projects)	1987/88 - 1990/91	36,313.04
Report Preparation	1990/91	55,793.25*
		\$1,536,815.33

#### *Project DFO Sponsored*

<b>Physical Environment</b>		
- nutrients and primary production	1986/87 - 1990/91	\$148,003.91
- shore erosion and sedimentation	1986/87 - 1990/91	56,170.04
<b>Lower Trophic Levels</b>		
- benthic and zoo- plankton studies	1986/87 - 1990/91	68,248.36
<b>Fish Populations and Fisheries</b>		
- SIL fish populations and whitefish stocks	1986/87 - 1990/91	165,681.63
- Playgreen Lake fish studies	1989/90 - 1990/91	32,385.54
<b>Management</b>		
- SIL camp	1986/87 - 1989/90	201,898.87
- contracted biophysical studies	1988/89 - 1990/91	26,016.00
- contracted natural resource harvesting studies	1988/89 - 1990/91	105,278.63
- project administration	1986/87 - 1990/91	90,314.45
- report preparation	1990/91	24,626.40
- report publication costs	1990/91	9,720.00
		\$928,343.83

\* estimated

# Photo Credits



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