The most often heard claims in support of large scale hydroelectric development are: (1) hydropower generation is 'clean', (2) water flowing freely to the ocean is 'wasted', and (3) local residents (usually aboriginals) will benefit from the development. These three claims are critically examined using case histories from Canada and elsewhere in the world. The critique is based mainly on journal articles and books, material that is readily available to the public, and reveals that the three claims cannot be supported by fact. Nevertheless, large scale hydroelectric development continues on a worldwide basis. The public needs to be well informed about the environmental and social consequences of large scale hydroelectric development in order to narrow the gap between its wishes for environmental protection and what is really occurring.

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Environmental and social impacts of large scale hydroelectric development: who is listening?

D M Rosenberg, R A Bodaly and P J Usher

Proponents of hydropower development claim a number of benefits in support of their projects. First, they insist that hydropower generation is 'clean', that is, it has fewer environmental consequences than other sources of power generation. Secondly, they argue that water flowing unimpeded to the ocean is 'wasted'. Thirdly, they assure us that residents — especially aboriginal peoples — of areas affected by the creation of reservoirs or the diversion of water will derive social and economic benefits from the project. The main objective of this article is to examine critically these three claims; information from hydroelectric developments in different countries will be used but the emphasis will be on Canada. A second objective is to show that considerable amounts of freely available information exist on the environmental and social impacts of hydroelectric development, so that each new project need not be regarded as unique by decision makers; effects can be predicted in broad outline.

Hydropower is 'clean'

In an imperfect world, hydroelectric power is a form of energy which has the fewest imperfections of all. It is virtually non-polluting.

Contrary to the sentiment expressed in the above quotation, large scale hydroelectric development produces a broad range of environmental impacts. Chief among these impacts are landscape destruction, contamination of food webs by mercury, and possibly the evolution of greenhouse gases. A consideration of these impacts follows.

Landscape destruction

The flooding of vast areas of forest in the formation of reservoirs (Figure 1), desiccation of water bodies because of water diversion for hydropower generation or irrigation (Figure 2), and shoreline erosion caused by lake impoundment (Figure 3) or diversion of waters through existing river channels with insufficient hydraulic capacity are examples of landscape destruction.

For example, ~760 m³/sec of Churchill River water was diverted into the


For example, Kierans, 1988, op cit, Ref 2; and Hydro-Québec, 'Grande Baleine complex', Bulletin 4, Hydro-Québec, Montreal, 1991

The term 'decision makers' is meant to include senior government bureaucrats, senior hydro managers, and politicians

Bourassa, op cit, Ref 1, pp 125–126


System wide changes are described in G McCullough 'Flow and level effects of Lake Winnipeg regulation and Churchill River diversion on northern Manitoba rivers', in P J Usher and M S Weinroitin, 'Towards assessing the effects of Lake Winnipeg regulation and Churchill River diversion on resource harvesting in native communities in northern Manitoba', Canadian Technical Report of Fisheries and Aquatic Sciences, No 1794, 1981, pp 68–69 and Map 1; and Environment Canada and Department of Fisheries and Oceans, 'Federal Ecological Monitoring Program. Final Report Vol 1', Environment Canada and Department of Fisheries and Oceans, Winnipeg, 1992, pp 2.4 to 2.15

The Rat River, route of the Churchill-Nelson River diversion in northern Manitoba. (a) Before formation of the Notigi Reservoir and start of diversion flows; (b) After flooding and diversion. Note the large areas of floating peat. Photos: Allen P Wiens.
The magnitude of landscape destruction caused by the Churchill-Nelson diversion is best understood by doing an analysis of redirected power.\textsuperscript{10} The distribution of potential power throughout the system before and after diversion is summarized in Table 1. Most of the power can be recovered as hydroelectric plants are built along the Burntwood and lower Nelson rivers. However, the power not used until these plants are built, and the displaced power remaining after the last installation is completed, are both available to rework the landscape.

The extent of damage to the landscape depends on the landforms involved.\textsuperscript{11} For example, wave energy redirected at a flooded bedrock cliff causes no damage; however, flooding permanently frozen backshore zones composed of unconsolidated materials causes a protracted cycle of melting and shoreline erosion. Thus, much of the 25 MW of wave energy on Southern Indian Lake (Table 1) has been directed at the highly erodable shorelines during the open water season. The 16–38 times greater power of the diverted flows has begun to reform a new lower Churchill River along the Rat and Burntwood systems with consequent extensive landscape destruction. The redirected natural forces are often too large or too dispersed to be overcome or even hastened by further remedial construction. As a result, the instabilities created in the environment are essentially beyond

\textsuperscript{10}Newbury, \textit{op cit}, Ref 8
\textsuperscript{11}ibid
Existing and planned development of the hydropower potential of rivers in northern Québec dwarf the Churchill-Nelson diversion by comparison. Development of James Bay involves a total of 30 000 MW of power (cf. =10 000 MW in northern Manitoba). Three major river catchments are involved: (1) La Grande, (2) Great Whale, and (3) Nottaway-Broadback-Rupert. Phase I of La Grande development has been completed; it involved the creation of five major reservoirs that have flooded 9675 km² of boreal forest, and two major river diversions totalling = 1600 m³/sec, about twice the flow of water diverted out of the Churchill River. How long the instability will last under the subarctic conditions of the area is unknown.

Figure 2  The lower Churchill River, northern Manitoba. (a) Before diversion; (b) After diversion. Photos: Allen P Wiers.
Figure 3 Southern Indian Lake, northern Manitoba. (a) A beach in the southern part of the lake before impoundment; (b) The same beach after impoundment; (c) Aerial photo of shoreline erosion. Photos: Allen P Wiens.

Despite advances in scientific capability to predict the environmental effects of hydroelectric developments, a great deal of uncertainty still surrounds this activity. Indeed, even some major impacts resulting from hydroelectric development are still being identified. For example, discovery in the last decade of contamination of fish by mercury in new reservoirs ... challenges the sanguine view that all significant impacts associated with reservoir formation in temperate regions are known...

The first indication that mercury may be a by-product of reservoir formation came from South Carolina in the mid-1970s. Since then, elevated mercury levels in fish have been recorded from reservoirs in a variety of locations (e.g. boreal zone – northern Manitoba, northern Québec, Labrador, Finland, temperate areas-southern Saskatchewan, Illinois, South Carolina, tropical areas- Thailand). Fish mercury concentrations have increased in all reservoirs for which pre- and post-impoundment data have been collected.

Mercury in fish can attain very high levels in reservoirs. For example, in the LG2 Reservoir (see above) mercury concentrations in predatory fish...
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(dictionary) 132

(pike: Esox lucius; walleye: Stizostedion vitreum) reached almost six times the Canadian marketing limit of 0.5 μg/g (Figure 5). Although mercury in lake whitefish (Coregonus clupeaformis) in the SIL Reservoir has declined to pre-impoundment concentrations, levels in lake whitefish in LG2 and in pike and walleye in both reservoirs remain elevated 9–12 years after impoundment.

Elevated mercury levels in fish are related to the degree of flooding of terrestrial areas involved in reservoir creation: the more land flooded proportional to the size of the reservoir the higher the mercury levels in fish.28 Mercury levels in all three species shown in Figure 5 increased significantly after flooding in both reservoirs but increases were greater in the extensively flooded LG2 Reservoir than the marginally flooded SIL Reservoir.

Experimental studies in mesocosms have demonstrated that the methylmercury accumulating in fish is microbiologically transformed from ambient natural mercury sources.29 All organic material tested in these experiments (moss/peat, spruce boughs, prairie sod) stimulated methylmercury uptake by yellow perch (Perca flavescens). In addition, greatly enhanced rates of conversion of inorganic mercury to methylmercury have been demonstrated in flooded sediments of new reservoirs.30
Experience from river systems in northern Manitoba, northern Quebec (James Bay), and Labrador indicates that significant elevations of fish mercury concentrations also can be expected for many kilometers downstream of reservoirs. For example, mercury concentrations in lake whitefish and pike, in and downstream of reservoirs in the La Grande River development are shown in Figure 6. Such downstream effects are a result of predation on fish that have been weakened by passing through turbines and/or downstream transport of dissolved methylmercury in water or invertebrates (and consequent uptake in the food chain).

Fish mercury levels in boreal reservoirs probably will remain elevated for decades following impoundment, for example, after a decade of impoundment, mercury levels in pike and walleye in LG2 were still increasing (Figure 5). Similar predictions cannot be made for reservoirs in warmer areas because of a lack of data. The removal, burning, or covering of vegetation and organic soil layers may reduce the severity of the problem because it is the presence of organic material that tends to stimulate the microbial production of methylmercury. However, the degree to which this mitigation is successful has not been experimentally verified and, at any rate, it would be impractical to do for the reservoirs that characterize many contemporary
Figure 4 Hydroelectric development along the Churchill and Nelson rivers, northern Manitoba, indicating altered flow regime of the rivers. Dark tone indicates relative magnitude of lower Churchill River discharge after diversion; mid-tone indicates Churchill River diversion at Southern Indian Lake; light tone indicates Nelson River discharge.

Source: R W Newbury et al, op cit, Ref 7. Adapted by permission of the Canadian Journal of Fisheries and Aquatic Sciences.

Legend
- Generating Station
- Proposed Generating Station
- Control Structure
- Railroad
- Major Highway

Source: R W Newbury et al, op cit, Ref 7. Adapted by permission of the Canadian Journal of Fisheries and Aquatic Sciences.
large scale hydroelectric projects. For example, SIL has a post-impoundment shoreline length of 3788 km.\(^3\)

**Greenhouse gases**

The release of greenhouse gases \(\text{CH}_4\) and \(\text{CO}_2\) caused by the flooding of upland forest and peatland areas, two major land types in parts of northern Canada where large hydroelectric reservoirs are located, may be the newest ‘surprise’ connected with reservoir creation.\(^3\) Under natural conditions, peatlands are sinks for \(\text{CO}_2\) but they are slight sources of \(\text{CH}_4\) to the atmosphere; forests are slight sinks for \(\text{CH}_4\) but they are neither sources nor sinks for \(\text{CO}_2\); therefore, the total ‘greenhouse effect’ is estimated to be about zero.\(^3\) Microbial decomposition caused by the flooding of forest uplands and peatlands in the course of reservoir creation may upset these natural balances and increase the flux of greenhouse gases to the atmosphere.\(^3\) In fact, the rate of emission of greenhouse gases to the atmosphere after flooding may be similar to that of power plants run by fossil fuels (Table 2).

A number of factors may be involved in regulating the duration and intensity of greenhouse gas emissions.\(^3\) An initial period of rapid decomposition of easily degraded organic material probably will be followed by a period of slower decomposition of more refractory organic material; the estimates given in Table 2 are for the latter period. Given certain nutrient conditions, the slow period could last for decades. After decomposition is essentially complete, greenhouse gas emission will still be greater than estimated fluxes for undisturbed terrestrial systems. The ratio of flooded area to energy produced is another important factor (Table 2). As noted above, the area of flooding involved in reservoir creation is also an important determinant of mercury uptake in fish.

The magnitude of the problem is currently being examined in a wetland...
flooding experiment being conducted at the Canadian Department of Fisheries and Oceans' Experimental Lakes Area (ELA) in northwestern Ontario. Should the experimental results support the preliminary observations, the implications are significant: the total surface area of impounded water in five extant major Canadian hydroelectric developments is >20 000 km² – an area the size of Lake Ontario. New reservoirs planned for the James Bay area of northern Quebec will cover another ~10 000 km², involving ~4650 km² of newly flooded land.

Water flowing unimpeded to the ocean is 'wasted'

... Quebec is a vast hydroelectric plant in-the-bud, and every day millions of potential kilowatt-hours flow downhill and out to the sea. What a waste!

The attitude that hydrological resources are wasted unless they are harnessed for industrial and domestic use is commonplace. In the case of north temperate rivers, natural seasonal run-off patterns heavily influence the ecology of downstream deltaic, estuarine, and coastal areas; modification of this natural run-off by interbasin water diversion and water storage for power production can have severe environmental impacts. Hydro developments on
Environmental und social impacts of large scale hydroelectric development: D M Rosenberg, R A Bodaly and P J Usher

Figure 6 Mercury concentrations in lake whitefish (Coregonus clupeaformis) and pike (Esox lucius) in and downstream of (a) La Grande (LG2) and (b) Opinaca Reservoirs, northern Quebec. Mean mercury concentrations are standardized for fish length. Sampling sites (km) shown in (b): 0 = Opinaca Reservoir - Opinaca station; 3 = Boyd-Sakami diversion (BSD) - Cote station; 56 = BSD - Sakami station; 95 = BSD - Ladouceur station; 115 = LG2 Reservoir - Coutaceau station.
Source: R Verdon et al, op cit, Ref 31

41 Discussed by White, op cit, Ref 2, p 38

Detailed studies of the effects of hydro megaprojects on downstream resources are rare for a number of reasons: (1) downstream areas often are out of the jurisdiction of the agency responsible for doing the upstream water development project and studying its resultant impacts; (2) a lack of interest in pursuing post-audits of major projects; and (3) cumulative impact assessment is highly complex, expensive, and requires good, long term databases from before and after the project; such databases are seldom available.

Nevertheless, some excellent case history studies of downstream effects are available to warn us of the adverse ecological consequences of large scale interruptions of natural seasonal water flows. Perhaps the best known of these involve the creation of extensive reservoirs for hydropower generation and/or the withdrawal of water for irrigation purposes affecting the four great inland seas (Black, Azov, Caspian, and Aral) of the southwestern (former) Soviet Union, and downstream effects of the High Dam at Aswan in Egypt.
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A Manitoba reservoir having a low ratio of flooded area to energy produced.
A Manitoba reservoir having a high ratio of flooded area to energy produced.

Source: Adapted from J W M Rudd et al, op cit, Ref 34, where details of calculations can be found.34


Effects of extensive hydro development and water regulation in the catchment of the St Lawrence River, Canada, on the Atlantic coastal region are more speculative.43 Here, we will present a Canadian freshwater example, drying of the Peace-Athabasca Delta, and consider the effects of hydro development in Manitoba, Ontario, and Québec on Hudson and James bays in Canada.

Peace-Athabasca Delta, Alberta, Canada

The Peace-Athabasca Delta in northern Alberta includes the active delta of the Athabasca River, which flows from the south into the western end of Lake Athabasca; the active delta of the much smaller Birch River, which flows in from the west; and the inactive delta of the Peace River to the north (Figure 7).44 The main outflow from Lake Athabasca is the Rivière des Rochers, which joins the Peace River to form the Slave River, which flows northward into Great Slave Lake. The Revillon Coupé and Chenal des Quatre Fourches are two major outlets that connect Lake Athabasca to the Peace River. The Delta covers 3800 km² and is one of the most extensive inland deltas in the Western Hemisphere. Much of the Delta lies within Wood Buffalo National Park, which has been designated a World Heritage site.

Under natural conditions, high early summer flows in the Peace River blocked flows out of Lake Athabasca, which caused Lake Athabasca water to flood the Delta. In due course, discharge on the Peace River declined, the major outflows from Lake Athabasca would no longer be blocked, water from the Lake resumed its northward flow, and the flood waters receded. This seasonal cycle of flooding maintained Delta vegetation in an early successional stage of high productivity, which in turn led to a diverse and productive wildlife community: 215 species of birds, 45 species of mammals, and 20 species of fish. Flooding also removed accumulated dissolved salts from Delta lakes and filled perched basins, thus maintaining aquatic communities and extensive shorelines.

The first large hydro project built in the Mackenzie River catchment was the W A C Bennett Dam on the upper Peace River in British Columbia.45 The Bennett Dam was closed in 1967 and Williston Reservoir behind it was filled with ≈62 km³ of water from 1968 to 1971. During filling, normal Peace River peak flows of 4000–9000 m³/sec were reduced to 280 m³/sec; flood flows in the Peace River adjacent to the Delta were reduced by as much as 5600 m³/sec. Water levels in the River dropped 3–3.5 m below normal and Lake Athabasca waters flowed out of the Delta without causing normal seasonal flooding.46

The Delta landscape began to change dramatically during the period 1968–71. Perched lake basins suffered a nearly 40% decrease in shorelines and water surface areas; larger lakes connected to Lake Athabasca or to river channels in the Delta began drying out: 500 km² of mudflats were exposed. Numbers of the common muskrat (Ondatra zibethicus) were reduced from 40 000 (autumn 1971) to 17 000 (March 1973) because many marshes were too shallow for overwintering, and perched basins were abandoned.47 Vegetational succession continued unchecked, creating new meadow and willow communities.

Formation of a task force is a common Canadian response to environmental
disasters and the Peace Athabasca Delta situation was no exception. The Peace-Athabasca Delta Project Group was a cooperative study team that included the governments of Canada, Alberta, and Saskatchewan (part of Lake Athabasca lies in Saskatchewan) but not the government of British Columbia despite the fact that one of its Crown (i.e., government-owned) corporations caused the problem.

Long-term effects of operating the Bennett Dam, predicted by hydrological and wildlife computer simulation models created after problems in the Delta became obvious, indicated the following fate for the Delta:

1. A marked departure from past flow patterns of the Peace River and long-term reductions in summer and peak flows; levels in Lake Athabasca would be insufficient to flood the Delta;
2. Extensive vegetational succession and drying of perched basins (50–55% decrease in shorelines); greatly accelerated ageing of the Delta; and
3. Downward trends in duck production (20–25%); reductions (40–60%) of autumn populations of muskrat.

Fish populations were not included in the simulations (because of a lack of quantitative data), but other studies indicated reduced spawning success of walleye. However, goldeye (Hiodon alosoides) and lake trout (Salvelinus namaycush) would be unaffected. Reductions in muskrat and walleye...
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According to G H Townsend, 'An evaluation of the effectiveness of the Rochers Weir in restoring water levels in the Peace-Athabasca Delta', Canadian Wildlife Service, Edmonton, 1982, the weirs have raised minimum (winter) levels of Lake Athabasca, without raising maximum (summer) levels although the objective was to do the latter. In contrast, the Peace-Athabasca Delta Implementation Committee, 'Status report for the period 1974-1983. A report to the Ministers', Peace-Athabasca Delta Implementation Committee, Canada, Alberta, Saskatchewan, 1983, claimed that summer lake levels have been positively affected.

P Nichol, 'Bleak future predicted for delta', Fort McMurray Today, 16 December, 1991, p 1

R Neu, op cit, Ref 43, p 11


Gorrie, op cit, Ref 14; Rougerie, op cit, Ref 17

Gorrie, op cit, Ref 14; Hydro-Québec, op cit, Ref 3

Gorrie, op cit, Ref 14; Hydro-Québec


Canadian Arctic Resources Committee, Environmental Committee of Sanikiluaq, and Rawson Academy of Aquatic Science, 'Sustainable development in the Hudson Bay/James Bay bioregion', unpublished research proposal, 1991

For example, see Department of Fisheries and Oceans, EIS scoping work shop submission presented to the

Implications of past experience to the future: James and Hudson bays, Canada

The consequences of drastic alterations in the natural seasonal hydrograph characteristic of many north-temperate hydro developments are summarized by Neu in his comments on the St Lawrence River:

Obviously, such a hydrograph is unrelated to and in outright conflict with natural conditions. Runoff is transferred from the biologically active to the biologically inactive period of the year. This is analogous to stopping the rain during the growing season and irrigating during the winter, when no growth occurs. Yet, we can only wonder why Canada has been so slow to learn from past experience at home and abroad when it comes to Hudson and James bays, the downstream focus of major hydro developments in Manitoba, Ontario, and Québec.

Figure 8 shows the existing and planned major hydroelectric developments on river systems draining into James and Hudson bays. Location of the dike across James Bay for the proposed Great Recycling and Northern Development (GRAND) Canal scheme is also shown. Table 3 summarizes the salient features of these projects.

The question mark in Figure 8 signifies that little is known about the cumulative effects of these developments on the Hudson Bay ecosystem, even though the largest of these developments (the Churchill-Nelson River diversion in Manitoba and the La Grande River development in Québec) were completed in the mid-1970s. The problem is one of jurisdiction and unfulfilled responsibilities. Neither the provincial utilities (all are publicly owned) nor the provincial governments have addressed the impacts of their projects outside of provincial borders because they have no mandate or authority to do so. The waters of Hudson and James bays are exclusively a federal responsibility, but the federal government has been slow to react to the need for downstream cumulative impact assessment of provincial projects.

The Canadian Department of Fisheries and Oceans has begun to rectify this situation by including a requirement for cumulative impact assessment in its environmental impact assessment guidelines for the (now postponed) Great Whale River project in Québec and the (now postponed) Conawapa Dam on the lower Nelson River in Manitoba, and Manitoba Hydro had announced its willingness to cooperate in this regard. These are welcome positive signs, although the actual extent of commitment to cumulative impact assessment remains to be seen.

A number of independent preliminary attempts have been made to predict the effects of water development projects in the Hudson Bay catchment. It is even possible that major changes in Hudson Bay will be felt in 'downstream' areas such as the Labrador coast. However, concerted efforts at cumulative impact assessment will be severely hampered by the meager database that exists for Hudson Bay, especially for the very important winter
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NORTHWEST TERRITORIES

BAFFIN ISLAND

UNGAVA PENINSULA

ONTARIO

QUEBEC

Hudson Bay

Figure 8 Major hydroelectric developments and water diversions existing and planned in the Hudson and James Bay catchments, northern Canada. Further hydroelectric development is planned for already developed river systems.

Continued from page 140

Federal-Provincial Environmental Review Panel for the Conawapa project, Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg, 22 May 1992

For example, S J Prinsenberg, ‘Man-made changes in the freshwater input rates of Hudson and James Bays’, Canadian Journal of Fisheries and Aquatic Sciences, Vol 37, 1980, pp

Continued on page 142

period. Natural cause-and-effect relationships are only poorly understood, and ranges of natural variability have not been established. The implications of long term neglect of research in one of the world’s largest inland seas will become increasingly apparent as the Canadian federal government begins to fulfil its responsibilities.
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Table 3. Existing and proposed water development projects in the Hudson Bay catchment.

<table>
<thead>
<tr>
<th>Project*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churchill-Nelson rivers diversion and Lake Winnipeg regulation, Manitoba</td>
<td>Development of ~6000–10 000 MW of power along the lower Nelson River; Lake Winnipeg regulated within natural maximum and minimum levels to act as storage reservoir; license allows 850 m³/sec to be diverted from Churchill River into Nelson River to supply extra flow in lower Nelson55</td>
</tr>
<tr>
<td>Moose River, Ontario</td>
<td>14 sites to be developed; 6 of the 14 are already developed but would be enhanced; 2150 MW would be added; development to occur on the 2 major tributaries (Mattagami and Abitibi rivers), and on the Moose mainstem; no diversions planned59</td>
</tr>
<tr>
<td>La Grande River, Québec</td>
<td>A part of the development of the Québec portion of James Bay; Phase I involved the creation of 5 reservoirs, 4 river diversions, and 3 powerhouses yielding ~12 600 MW; Phase II involves the creation of 4 more reservoirs and 6 or 7 more powerhouses yielding another ~3200 MW54</td>
</tr>
<tr>
<td>Great Whale River, Québec</td>
<td>The second part of Québec’s development of James Bay: involves the creation of 4 reservoirs, a number of river diversions (not yet decided), and 3 powerhouses yielding ~3000 MW (still to be done)55</td>
</tr>
<tr>
<td>Nottaway-Broadback-Rupert rivers, Québec</td>
<td>The last part of Québec’s James Bay development; involves the creation of 7 reservoirs; 2 major river diversions (the Nottaway and Rupert rivers into the Broadback), and 11 powerhouses yielding ~8400 MW (still to be done)56</td>
</tr>
<tr>
<td>Great Recycling and Northern Development (GRAND) Canals scheme</td>
<td>James Bay will be dammed turning it into a freshwater lake by capturing run-off from surrounding rivers; water will be diverted through a series of canals into the Great Lakes (where it will supposedly stabilize water levels) and from there to (mid- and southwest) water-short areas of Canada (the Prairies) and the USA57</td>
</tr>
</tbody>
</table>

*For development of the Québec part of James Bay, see also Bourassa, op cit, Ref 2. Developments in the Quebec part of James Bay are still being planned, so descriptions are ‘composites’ using references cited.

Local residents will benefit from hydroelectric development

... A newly formed economic development committee would ensure that the ‘people are not hurt by the Forebay Development but will in fact be able to earn as good a living as before, and we hope, a better living’.51

This assurance by the Premier of Manitoba to the Chief of the Chemawawin Cree with regard to flooding caused by the Grand Rapids Dam in north-central Manitoba proved to be groundless.64

And 24 years later, from an article promoting the GRAND Canal scheme: James Bay’s native people will enjoy long overdue opportunities to live and prosper in their ancient homeland by creating valuable fresh water at sea level.65

In reality, what are the effects of major water development projects on local residents, especially aboriginal peoples? To answer this question, we examine case history information mostly from Canada, and identify common trends elsewhere in the world. The Canadian examples reveal a close connection between biophysical impacts (discussed above) and social impacts.

Lake Winnipeg regulation/Churchill River diversion and La Grande River development

The impact zones of both Lake Winnipeg regulation and Churchill River diversion (LWR/CRD) in Manitoba, and La Grande River development (LGRD) in Québec are located in the subarctic boreal forest region of the Canadian Shield. Because of relatively low elevations and relief throughout the region, lowest cost engineering designs require river diversion and flooding to achieve optimum volume and head for project operation. Thus, LWR/CRD and LGRD are characterized by substantial transformation of landscapes and hydrological regimes, and this has directly affected local residents.66

The areas directly affected by LWR/CRD and LGRD are inhabited largely
"Subsistence" refers to the production of local renewable resources for non-market home and community use. In contemporary northern aboriginal villages, subsistence is integrated at the household level with wage labour, commercial resource harvesting, and other economic activities (see R J Wolfe and R J Walker, 'Subsistence economies in Alaska: Productivity, geography, and development impacts', Arctic Anthropology, Vol 24, 1987, pp 56-81; Usher and Woinostin, op cit, Ref 9).

However, prior to hydroelectric development, their villages remained relatively isolated, the subsistence basis of their economies was viable (and sometimes even thrived), and their cultural identity remained intact. Hydroelectric development profoundly affected their existence in a number of ways:

1) Relocation – Like most large scale hydroelectric developments, LWR/CRD and LGRD involved relocation and resettlement of local populations. Governments have used the opportunity provided by these relocations to 'modernize' traditional communities by providing new houses and new village infrastructure. However, village residents do not experience these events as positive developments but rather as adverse effects: disruption of settlement patterns (based on kinship relations and shoreline access) and added costs of fishing and hunting.

Both LWR/CRD and LGRD involved stressful community relocation. For example, the South Indian Lake settlement (Figure 4) was flooded by impoundment of Southern Indian Lake as part of CRD. In the old village, the houses were spaced along the shore in small clusters of kin groups, but at the new location houses were grouped like a subdivision and assigned randomly. The houses were built cheaply and soon deteriorated, and they were heated by electricity too expensive for most villagers to afford. The houses did not have running water, but in many cases were placed so far from the lake shore that hauling water became a problem, especially for the elderly. The move has been associated with social disruption and disintegration.

In LGRD, increased discharge in the lower La Grande River and the threat of bank erosion necessitated the relocation of the largest Cree settlement in the area, Ft George, from the estuary of the La Grande to a more upstream location. The move split the community; some families stayed at Ft George despite the lack of amenities there.

The new town, Chisasibi, was built in a southern style and, unlike Ft George, does not look out over the River. Soon after its occupation, attitudes and lifestyles of the residents began to change. People who were formerly active outdoors became more sedentary. Youth adopted a southern lifestyle without having a way to support it because of unemployment. The result has been social stress in the community, although this has not been studied in a quantitative manner.

Although hydro-induced relocation results in a new physical infrastructure, it is rarely associated with matching employment benefits. The Cree in northern Manitoba obtained only low paying, short term jobs, and little training, and even this was disruptive of their existing economy.
Relocation experiences in the Canadian north sound similar to those reported elsewhere as a result of large scale hydroelectric development. For example, construction of the High Dam at Aswan, Egypt, resulted in relocation of 50,000–60,000 Nubians in the Egyptian part of the Lake Nasser Reservoir and 53,000 Nubians in the Sudanese part.77 The Egyptian Nubians were moved to new villages 20 km north of Aswan where serious problems developed with land allocation, soil quality, irrigation facilities, distances between allocated land and home villages, the government’s requirement to raise unfamiliar crops (sugar cane), and the inappropriate, non-traditional housing provided.78 By 15–18 years after the move, although the health of the people overall had improved and they had developed a handicraft industry, their agricultural production remained modest and many longed to return to their old home.79

The Sudanese Nubians were resettled in the Kashm el-Girba region to the southeast. Here, the social structure of many of the old villages was severely disrupted because they were split up upon resettlement.80 Social tensions were exacerbated by settling three different ethnic groups together: the farmers flooded out by the Aswan development and two groups of local nomadic pastoralists being ‘sedentarized’ by the government. Aside from cultural differences, the grazing practices of the pastoralists were incompatible with the cultivation practised by the farmers. In addition, like the experience of the resettled Egyptian Nubians, the design of the housing provided ‘... paid little heed to the social needs of the uprooted settlers’.81 The parallels between this example and the Cree of South Indian Lake, Manitoba, and Chisasibi, Quebec, are striking.

(2) Encroachment – Large scale hydroelectric projects necessarily entail the encroachment by outsiders on the traditional territories of the aboriginal population, chiefly through the access provided by new roads and airfields. The Cree land tenure system is family based, a system that is formally recognized by governments in both Quebec and Manitoba through treaty registration. Both the tenure system itself, and the abundance and distribution of fish and wildlife resources, are disrupted by external encroachment, with consequent adverse social impacts.82

(3) Harvest disruption – Harvest disruption is a serious and often permanent impairment of the economic, social, and cultural life of aboriginal communities, especially where the resource base is largely aquatic and access to it is mainly by way of rivers and lakes. The physical and biological effects of both Canadian projects have disrupted harvesting activities such as hunting, fishing, and trapping.84 For example, fisheries in northern Manitoba have collapsed because of the deleterious effects of water level fluctuations on spawning activities,85 and because the emplacement of a water control structure prevented natural seasonal migration of a fish population.86 Available data for five LWR/CRD communities indicate that substantial declines in per capita harvests of subsistence fisheries have occurred at Cross Lake and Split Lake (the two communities for which pre- and post-project data are available). Commercial fisheries appear to have been affected in all the communities: production has declined sharply at Cross lake; the catch at Nelson House has been partially contaminated by mercury; and unit costs of production have increased at Norway House and, possibly, Split Lake and York Landing.87 A more detailed analysis of the South Indian Lake commercial fishery, formerly the largest in northern Manitoba, indicated a substantial decline in economic performance.88
northern Québec, Cree hunters have reported diminished harvests of species valuable for food and fur from wetland habitats in the lower La Grande River area since 1979.\textsuperscript{89} Hunters blame reduced feeding areas, loss of habitat along the river bank, and drowning (especially of muskrat) in winter for these declines.

Harvest disruption also occurs because access to hunting, fishing, and trapping areas is rendered more difficult, or even impossible, by debris, increased discharge, or unstable ice conditions.\textsuperscript{90} In the case of LGRD, access to the north shore of the La Grande River is important to the people of Chisasibi because almost half of the person days of land use (36 000 out of 74 000) occur there. Since LG2 became operational, winter flows and water temperatures have been higher than natural so little or no ice forms on the lower La Grande River and its estuary. This created winter and spring travel problems across the river to the north shore; the problems have been solved by building a road to the north shore over the recently constructed most downstream dam on the system (LG1).

Similar access disruptions have occurred in northern Manitoba. Reservoir management for variable power requirements has destabilized the winter ice regime, rendering river travel in winter hazardous. Sudden water withdrawals leave hanging ice upstream, and ‘slush’ (waterlogged snow above the ice cover) downstream. Extensive erosion has not only resulted in inaccessible shorelines and reservoirs containing hazardous debris,\textsuperscript{91} but also the fouling of fish nets by debris.\textsuperscript{92} Access to well known fishing areas has been impaired, and local hydrology and fish behaviour have been so changed that traditional knowledge no longer provides practical guidance for fishing success. The result has been increased costs and reduced catch per unit of effort in both subsistence and commercial harvesting activities.\textsuperscript{93}

\textbf{(4) Mercury contamination – The problem of mercury contamination in northern communities is particularly serious.} In northern Québec, levels of up to 3 ppm occurred in piscivorous species of fish (walleye, northern pike) in LG2 Reservoir (see above). The Cree living in Chisasibi were seriously affected by subsequent closure of the fishery because \(\approx25\%) of the community’s wild food harvest usually came from fishing \((\approx60\) kg/yr/person). The problem necessitated a special mercury compensation agreement, which was signed in 1986.\textsuperscript{95}

In the area of northern Manitoba affected by CRD, mercury levels in piscivorous species seldom exceeded 2 ppm, but they still remain above acceptable levels for both commercial production and subsistence consumption.\textsuperscript{96} Pre-project subsistence consumption rates of fish are poorly documented for LWR/CRD villages, but the more reliable estimates indicate a range from 31.2 150.6 kg/yr/person (edible weight).\textsuperscript{97} Although no precise measures are available, fish probably constituted about 50\% of the wild food harvest of the LWR/CRD communities.

Mercury contamination of fish and elevated body loadings of mercury in humans have been widely reported in native communities in the Canadian Shield area of the central subarctic, where both natural and industrial sources of mercury are high.\textsuperscript{98} Reservoirs are now recognized as a leading cause of this contamination (see above). The effects are compounded for native communities because fish in subarctic fresh waters grow slowly and are thus prone to accumulating methylmercury, and because residents routinely catch and eat large quantities of fish over extended periods of the year.

Medical authorities have tended to view mercury contamination pri-
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Dealing with adverse effects. Both LGRD and LWR/CRD were strongly resisted by the affected Cree populations. When the development scheme on the La Grande River was announced, the Cree and Inuit went to court to protect their title to the land, a title that they had never surrendered. This action forced Hydro-Québec to negotiate an agreement on remedial action and compensation (after construction had begun): the James Bay and Northern Québec Agreement (JBNQA), signed in 1975 for the first phase of James Bay development. The Québec government now claims that the JBNQA is valid for further development of the area, whereas the Cree of the area disagree. As a result, there is renewed resistance by the Cree to the proposed Great Whale River development to the north of LGRD (see above).

In Manitoba, a similar type of agreement, the Northern Flood Agreement (NFA), was signed after major construction was completed. In response to threats of litigation by the native communities affected by LWR/CRD. To date, its implementation is incomplete. Substitute lands have not been transferred, remedial action is partial, monitoring and assessment provisions remain largely unimplemented, and some major compensation claims still await resolution. For both developments, it would have been preferable that governments recognized that compensation would be required, and the principles of compensation be agreed upon, before the developments proceed. Adequate institutional funding and administrative structures are also required to ensure the subsequent smooth functioning of the compensation programmes.

In summary, adverse social impacts created by both Canadian large scale hydroelectric developments were compounded by a failure of governments to apply suitable remedies. In fact, a comprehensive evaluation of the environmental and social impacts of James Bay development still has not been done, for a number of reasons. First, the project is huge and complex. Impacts occur sequentially over time, they may be cumulative, and there is uncertainty in decision making (eg building schedules). Secondly, the monitoring programme established by Hydro-Québec has not taken an ecosystem approach, so putting the individual variables together is difficult. Thirdly, Hydro-Québec probably is interested in minimizing the reporting of environmental and social impacts rather than constructing an accurate case history because more development is to come.

Comprehensive environmental and social impact assessments have been
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111For example, see Hecky et al, op cit, Ref 52; and Waldram, op cit, Ref 88, for Southern Indian Lake
112Usher and Weinstein, op cit, Ref 9
113In fact, there are precedents for this review: Goldsmith and Hildyard, op cit, Ref 69; E Goldsmith and N Hildyard (eds) 'The social and environmental effects of large dams', Vol 2: Case studies, Wadebridge Ecological Centre, Camelford, 1986; and D Trussell, op cit. 'The social and environmental effects of large dams', Vol III. A review of the literature, Wadebridge Ecological Centre, Camelford, 1992
114Kierans, op cit, Refs 1 and 2; Panu and Oosterveild, op cit, Ref 57
115Rougerie, op cit, Ref 17; Hydro-Québec, op cit, Ref 3
116Hydro-Québec, op cit, Ref 56; Rougerie, op cit, Ref 17
121For example, C Dagenais, former head of the Québec consulting engineering firm Surveyer, Nenninger et Chénevert (SNC), was quoted in McCutcheon, op cit, Ref 103, p 148, as saying: 'In my view, nature is awful, and what we do is cure it'
122R W Newbury, Gibsons, BC, personal communication. See also McCutcheon, op cit, Ref 103, p 86
123Rosenberg et al, op cit, Ref 18; Quinn, op cit, Ref 107
124Newbury, op cit, Ref 8
125Ibid

completed for parts of LWR/CRD, but not for the whole development.111
However, an effective social impact assessment that documents the full range and extent of the socioeconomic effects of the project and links them to the physical and biological effects described has never been done because of improper paradigm selection, insufficient identification of impact hypotheses and indicator data, and inadequate collection of baseline or monitoring data.112 Such a social impact assessment would provide the basis for a continuing monitoring programme and just compensation.

Conclusion
This review has shown the adverse environmental and social effects that result from large scale hydroelectric developments (or other water abstraction projects) in Canada and elsewhere. There should no longer be any claims by the proponents of these developments that hydroelectric power generation is ‘clean’, that water flowing to the ocean unimpeded is ‘wasted’, or that the local residents will benefit from these kinds of developments.

Yet, two facts are inescapable: (1) all the information presented here exists in the public domain, most of it is readily accessible, and it is freely available to decision makers;113 and (2) large hydropower projects and other large water manipulations continue to be proposed and built (Table 4). It is germane to ask: ‘Why?’ Values are at the base of the answer to this question.121 The values of decision makers usually differ from those of people who are concerned with the environment or with the social effects of environmental perturbations. In order for large hydroelectric projects to make economic sense, water resources such as rivers and lakes in their natural state have to be regarded as having no monetary value.122 Thus, whatever results from their ‘development’ has value; it is like turning garbage into gold.

In Canada, most of the best hydroelectric sites in the populated south have been used; therefore, there has been a steady move northward into sparsely populated areas, which are generally regarded as empty hinterlands waiting to be developed.123 Relatively contained southern project configurations have given way to uncontained northern project configurations, as exemplified by the Churchill-Nelson River diversion.124 These northern developments are out of sight and out of mind of most Canadians, one factor that has allowed decision makers to press ahead with such projects.

If energy conservation alternatives are insufficient to meet future power demands and large scale hydroelectric projects must be built, then agencies should consider more benign ways of constructing and operating them. For example, in the case of hydropower development in northern Manitoba, landscape destruction and social costs could have been minimized either by constructing run-of-the-river hydro plants along the lower Churchill River or by digging a deeper diversion channel and operating Southern Indian Lake within its natural 2 m range.125 The latter option at least would have avoided

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
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<tbody>
<tr>
<td>GRAND Canal Scheme</td>
<td>Canada</td>
</tr>
<tr>
<td>Great Whale River</td>
<td>Canada</td>
</tr>
<tr>
<td>Notaway-Broadback Rupert Rivers</td>
<td>Canada</td>
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<tr>
<td>Three Gorges Dam</td>
<td>China</td>
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<tr>
<td>Tehri Dam</td>
<td>India</td>
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<tr>
<td>Ganges and Brahmaputra rivers flood control</td>
<td>Bangladesh</td>
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<tr>
<td>Sardar Sarovar Projects</td>
<td>India</td>
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Table 4. Examples of large hydroelectric and water-diversion projects being proposed or built.
Aboriginal compensation claims stemming from damages caused by the Churchill-Nelson River diversion are expected to reach hundreds of millions of dollars.\textsuperscript{128}

Current operating regimes of large northern hydro projects need to be more ecologically realistic. For example, at Kettle Dam on the lower Nelson River (Figure 4), daily discharge fluctuations over the period 1979–88 exceeded 2000 m$^3$/sec in winter and were $\approx$ 3000 m$^3$/sec in summer, compared to a natural mean river discharge of 2170 m$^3$/sec at that location.\textsuperscript{129}

This substantial departure from natural flows is tied to weekly patterns of energy use in Manitoba. Such a generating regime may service Manitoba Hydro’s customers, and in the process optimize economic benefits to the utility, but it shows little regard for the ecology of the lower Nelson River.\textsuperscript{130}

Eventually, decisions will have to be made to endure the extra costs of operating large northern hydro developments in a more benign fashion if natural resources are to be preserved.

Public support in developed countries for environmental protection has never been higher.\textsuperscript{131} However, decision makers continue to foster hydroelectric projects that belong to a bygone era.\textsuperscript{132} It is important to narrow the gap between the public’s wishes and what is really occurring. We hope that this review will help to do so.