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Environmental and social impacts of large scale hydro-electric development: who is listening?

D M Rosenberg, R A Bodaly and P J Usher

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.

D M Rosenberg and R A Bodaly are with the Department of Fisheries and Oceans, 501 University Crescent, Winnipeg, MB, R3T 2N6. P J Usher is at P J Usher Consulting Services, Box 4815, Station E, Ottawa, ON, Canada K1S 5H9.

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[1]For example, R Bourassa, *Power from the North*, Prentice-Hall, Scarborough, 1985; T Kierans, 'Recycled water from the

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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.[1] Secondly, they argue that water flowing unimpeded to the ocean is 'wasted'.[2] 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.[3] 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;[4] 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.[5]

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, $\simeq$760 m^3/sec of Churchill River water was diverted into the

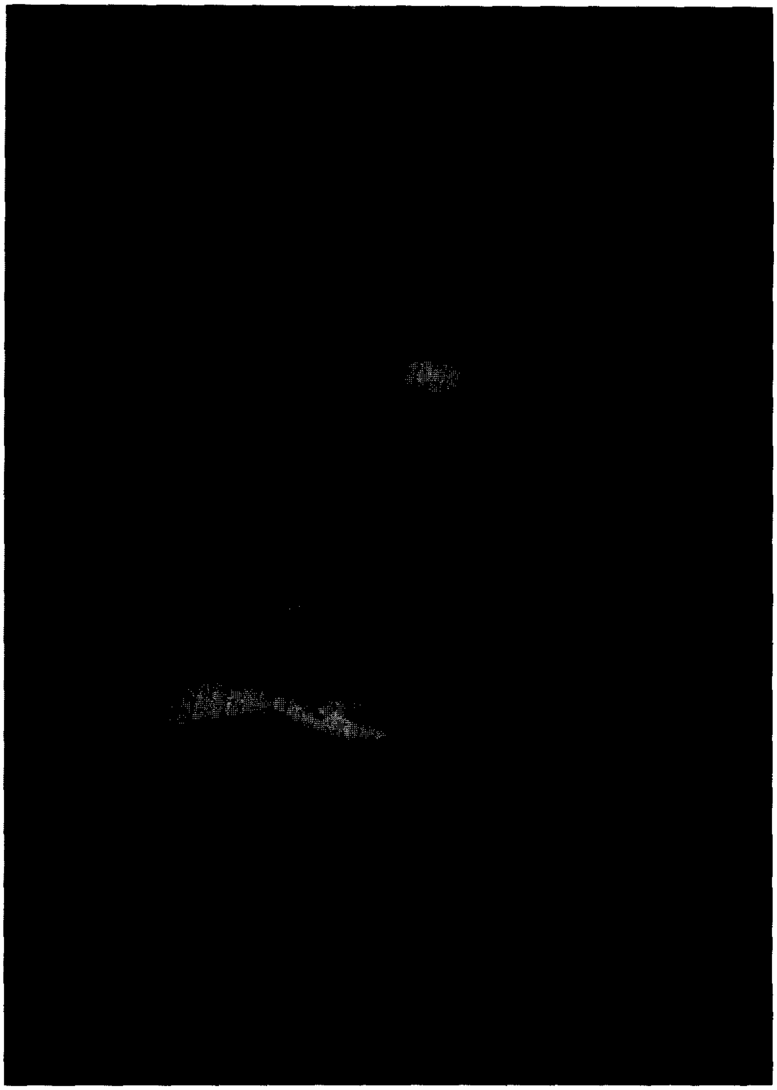

Figure 1 The Rat River, route of the Churchill-Nelson River diversion in northern Manitoba. (a) Before formation of the Notigi Reservoir and start of diversion flows; (b) After flooding and diversion. Note the large areas of floating peat. Photos: Allen P Wiens.

nearby Nelson River to enhance flows through a series of large dams constructed along the lower Nelson in northern Manitoba (Figure 4).[6] The point of diversion was Southern Indian Lake (SIL). The natural outlet of the lake (Missi Falls shown in Figure 4) was blocked by a control structure, the lake was impounded 3 m above its long term mean level, and the Churchill River flow was diverted through a newly excavated channel from the southern part of the lake into the Nelson River catchment. Prior to diversion, the area between Southern Indian Lake and the Notigi dam (Figure 4) was allowed to fill to the same level as Southern Indian Lake. The combined Southern Indian Lake-Notigi Reservoir flooded $\approx$750 km^2 of land to yield a reservoir of $\approx$2800 km^2 total surface area.[7] The Rat and Burntwood rivers, into which the diversion flows were routed, carried <100 m^3/sec before diversion but $\approx$880 m^3/sec after.[8] As a result of the diversion, the lower Churchill was dewatered (Figure 2), extensive shoreline erosion occurred in Southern Indian Lake (Figure 3), and flooding and erosion occurred along the diversion route (Figure 1).[9]

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north. The alternative to interbasin diversions' in W Nicholaichuk and F Quinn (eds) *Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada,* 9–10 November 1987, Environment Canada, Saskatoon, SK, 1987, pp 59–70; and D Phantumvanit and W Nandhabiwat, 'The Nam Choan controversy: An EIA in practice', *Environmental Impact Assessment Review,* Vol 9, 1989, pp 135–147

[2]For example, P H Abelson, 'Electric power from the north', *Science,* Vol 228, 1985, p 1487; Bourassa, *op cit,* Ref 1; Kierans, *op cit,* Ref 1; T Kierans, 'Recycled run-off from the north', *Journal of Great Lakes Research,* Vol 14, 1988, pp 255–256; and G F White, 'The environmental effects of the High Dam at Aswan', *Environment,* Vol 30, No 7, 1988, p39, note 8

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

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

[5]Bourassa, *op cit,* Ref 1, pp 125–126

[6]R A Bodaly *et al,* 'Ecological effects of hydroelectric development in northern Manitoba, Canada: The Churchill-Nelson River diversion', in P J Sheehan *et al* (eds) *Effects of Pollutants at the Ecosystem Level,* John Wiley, New York, 1984, pp 273–309

[7]Bodaly *et al, op cit,* Ref 6; R W Newbury, G K McCullough, and R E Hecky, 'The Southern Indian Lake impoundment and Churchill River diversion', *Canadian Journal of Fisheries and Aquatic Sciences,* Vol 41, 1984, pp 548–557

[8]R W Newbury, 'Some principles of compatible hydroelectric design', *Canadian Water Resources Journal,* Vol 6, 1981, pp 284–294; Bodaly *et al, op cit,* Ref 6

[9]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 Weinstein, '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, 1991, 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

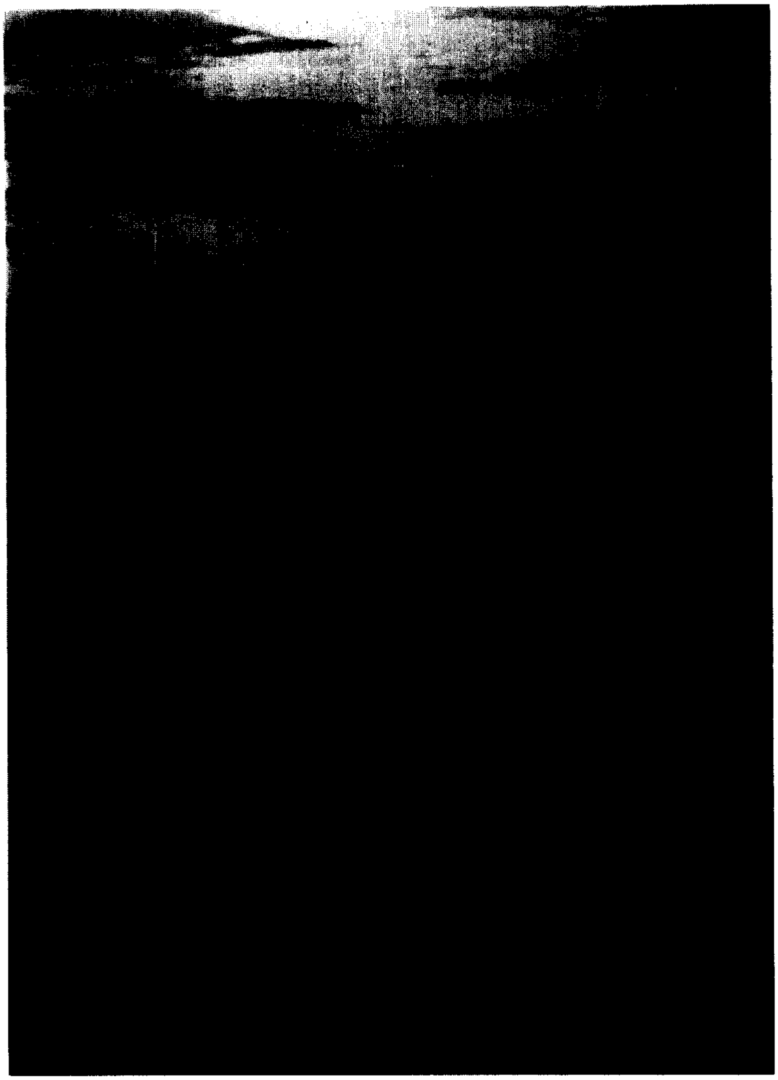

Figure 1b

The magnitude of landscape destruction caused by the Churchill-Nelson diversion is best understood by doing an analysis of redirected power.[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.[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

[10]Newbury, *op cit*, Ref 8
[11]*Ibid*

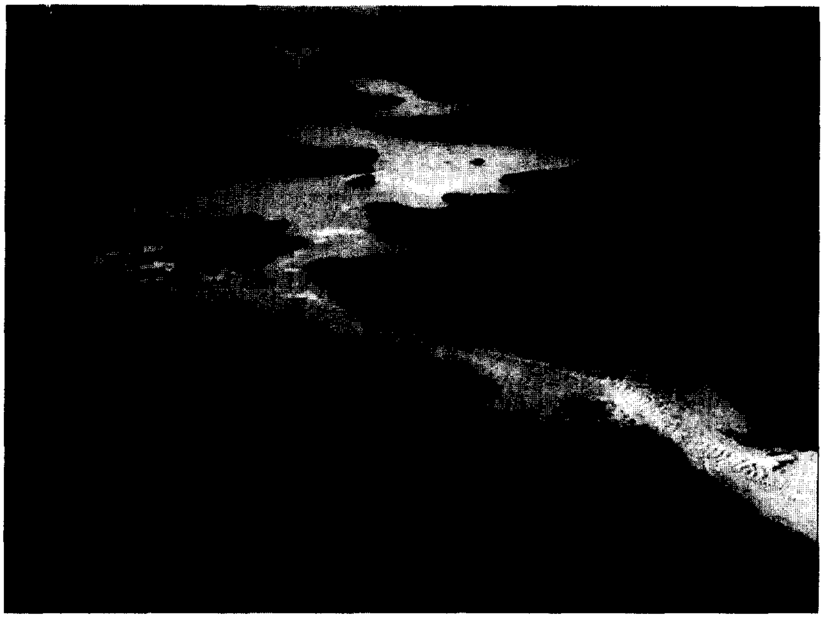

Figure 2 The lower Churchill River, northern Manitoba. (a) Before diversion; (b) After diversion. Photos: Allen P Wiens.

control'.[12] How long the instability will last under the subarctic conditions of the area is unknown.

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 km^2 of boreal forest, and two major river diversions totalling ≃1600 m^3/sec, about twice the flow of water diverted out of the Churchill River.[13] In addition, riverbank

[12] *Ibid*, p 288

[13] F Berkes, 'The intrinsic difficulty of predicting impacts: lessons from the James Bay hydro project', *Environmental Impact Assessment Review*, Vol 8, 1988, pp 201–220; D Roy and D Messier, 'A review of the effects of water transfers in the La Grande hydroelectric complex (Québec, Canada)', *Regulated Rivers: Research and Management*, Vol 4, 1989, pp 299–316

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.

erosion has resulted downstream of the La Grande (LG)2 Reservoir[14] because discharge in the La Grande River increased from 1760 m^3/sec to 3400 m^3/sec; furthermore, 'dead zones' surround the reservoirs because of drawdown.[15] Development is continuing on the La Grande,[16] but attention has shifted northward to the Great Whale River. Although development there will produce less power than on the La Grande River, the scale of reservoirs and river diversions involved will also produce extensive landscape destruction.[17]

Mercury contamination

> 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 . . .[18]

The first indication that mercury may be a by-product of reservoir formation came from South Carolina in the mid-1970s.[19] Since then, elevated mercury levels in fish have been recorded from reservoirs in a variety of locations (eg boreal zone – northern Manitoba,[20] northern Québec,[21] Labrador,[22] Finland;[23] temperate areas-southern Saskatchewan,[24] Illinois,[25] South Carolina;[26] tropical areas-Thailand[27]). 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

[14]See map in P Gorrie, 'The James Bay Power Project', *Canadian Geographic*, Vol 110, No 1, 1990, p 25, for locations of the La Grande Reservoirs

[15]F Berkes, 'The James Bay hydroelectric project', *Alternatives*, Vol 17, No 3, 1990, p 20

[16]For example, creation of the Laforge-1 and Eastmain-1 reservoirs involved additional river diversions and ≈2000 km^2 of flooding (A Penn, Cree Regional Authority, Montreal, personal communication)

[17]Power figures can be found in J-F Rougerie, 'James Bay development project. Hydroelectric development in northwestern Québec', *Canadian Water Watch*, Vol 3, 1990, pp 56–58; and J I Linton, 'The James Bay hydroelectric project - Issue of the century', *Arctic*, Vol 44, No 3, 1991, pp iii–iv. The scale of development in the Great Whale River project can be seen in Hydro-Québec, *op cit*, Ref 3. The Great Whale project was postponed in December 1994

[18]D M Rosenberg *et al*, 'The environmental assessment of hydroelectric impoundments and diversions in Canada,' in M C Healey and R R Wallace (eds) 'Canadian Aquatic Resources,' *Canadian Bulletin of Fisheries and Aquatic Sciences*, Vol 215, 1987, p 98

[19]A R Abernathy and P M Cumbie, 'Mercury accumulation by largemouth

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bass (*Micropterus salmoides*) in recently impounded reservoirs', *Bulletin of Environmental Contamination and Toxicology*, Vol 17, 1977, pp 595–602

[20]R A Bodaly, R E Hecky, and R J P Fudge, 'Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 682–691

[21]R Boucher, R Schetagne, and E Magnin, 'Teneur en mercure des poissons des réservoirs La Grande 2 et Opinaca (Québec, Canada) avant et après la mise en eau', *Revue Francaise des Sciences de l'Eau*, Vol 4, 1985, pp 193–206

[22]W J Bruce and K D Spencer, 'Mercury levels in Labrador fish, 1977–78', *Canadian Industry Report of Fisheries and Aquatic Sciences*, No 111, 1979, pp 1–12

[23]M Lodenius, A Seppänen, and M Herranen, 'Accumulation of mercury in fish and man from reservoirs in northern Finland', *Water, Air, and Soil Pollution*, Vol 19, 1983, pp 237–246

[24]D T Waite, G W Dunn, and R J Stedwill, 'Mercury in Cookson Reservoir (East Poplar River)', WPC-23, Saskatchewan Environment, Regina, 1980

[25]J A Cox *et al*, 'Source of mercury in fish in new impoundments', *Bulletin of Environmental Contamination and Toxicology*, Vol 23, 1979, pp 779–783

[26]A R Abernathy, M E Newman, and W D Nicholas, 'Mercury mobilization and biomagnification resulting from the filling of a Piedmont reservoir', Report No 119 (Technical Completion Report G-932-07), Water Resources Research Institute, Clemson, 1985

[27]D Yingcharoen and R A Bodaly, 'Elevated mercury levels in fish resulting from reservoir flooding in Thailand', *Asian Fisheries Science*, Vol 6, 1993, pp 73–80

[28]Bodaly *et al*, *op cit*, Ref 20; T A Johnston, R A Bodaly, and J A Mathias, 'Predicting fish mercury levels from physical characteristics of boreal reservoirs', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 48, 1991, pp 1468–1475

[29]R E Hecky *et al*, 'Evolution of limnological conditions, microbial methylation of mercury and mercury concentrations in fish in reservoirs of northern Manitoba. A summary report for Project 2.4 of the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion', Technical Appendices to the Summary Report, Canada-Manitoba Mercury Agreement, Winnipeg, 1987

[30]R E Hecky *et al*, 'Increased methylmercury contamination in fish in newly formed freshwater reservoirs', in T Suzuki, A Imura, and T W Clarkson (eds) *Advances in Mercury Toxicology*, Plenum Press, New York, 1991, pp 33–52

Figure 3b

(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 microbially 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]

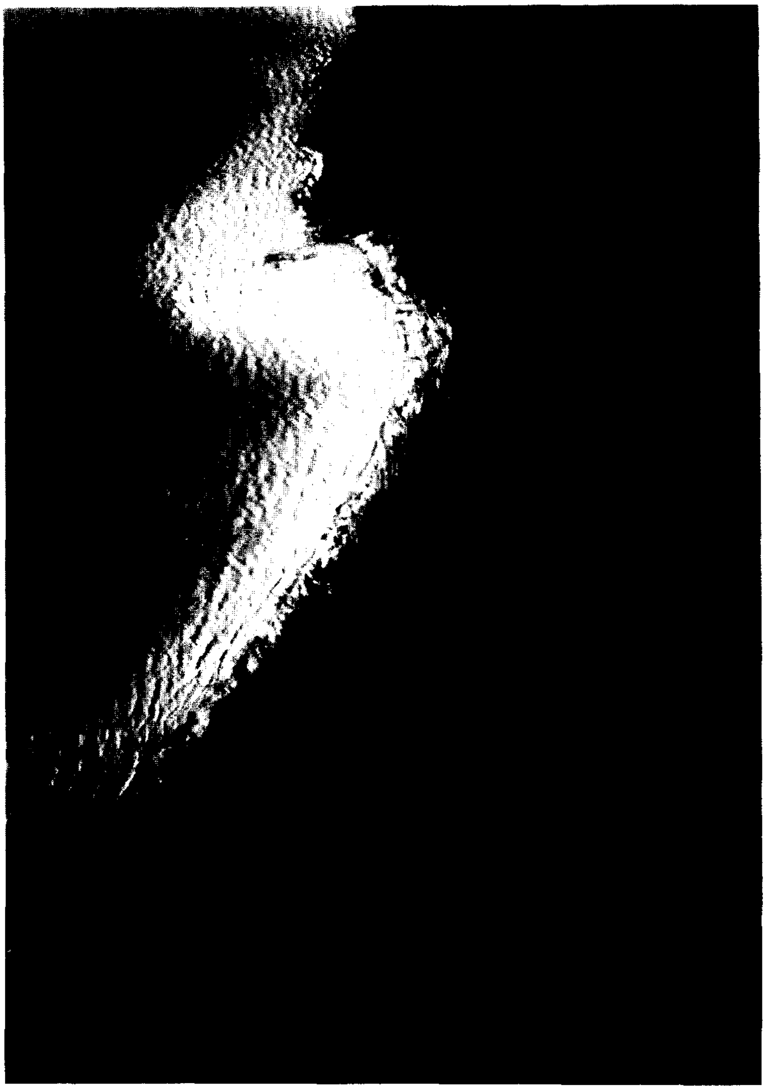

Figure 3c

Experience from river systems in northern Manitoba, northern Québec (James Bay), and Labrador indicates that significant elevations of fish mercury concentrations also can be expected for many kilometers *downstream* of reservoirs.[31] 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:[32] 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

[31] R Verdon *et al*, 'Mercury evolution (1978–1988) in fishes of the La Grande hydroelectric complex, Québec, Canada', *Water, Air, and Soil Pollution*, Vol 56, 1991, pp 405–417; Johnston *et al*, *op cit*, Ref 28

[32] Canada-Manitoba Mercury Agreement, 'Summary report', Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion, Winnipeg, 1987; Verdon *et al*, *op cit*, Ref 31

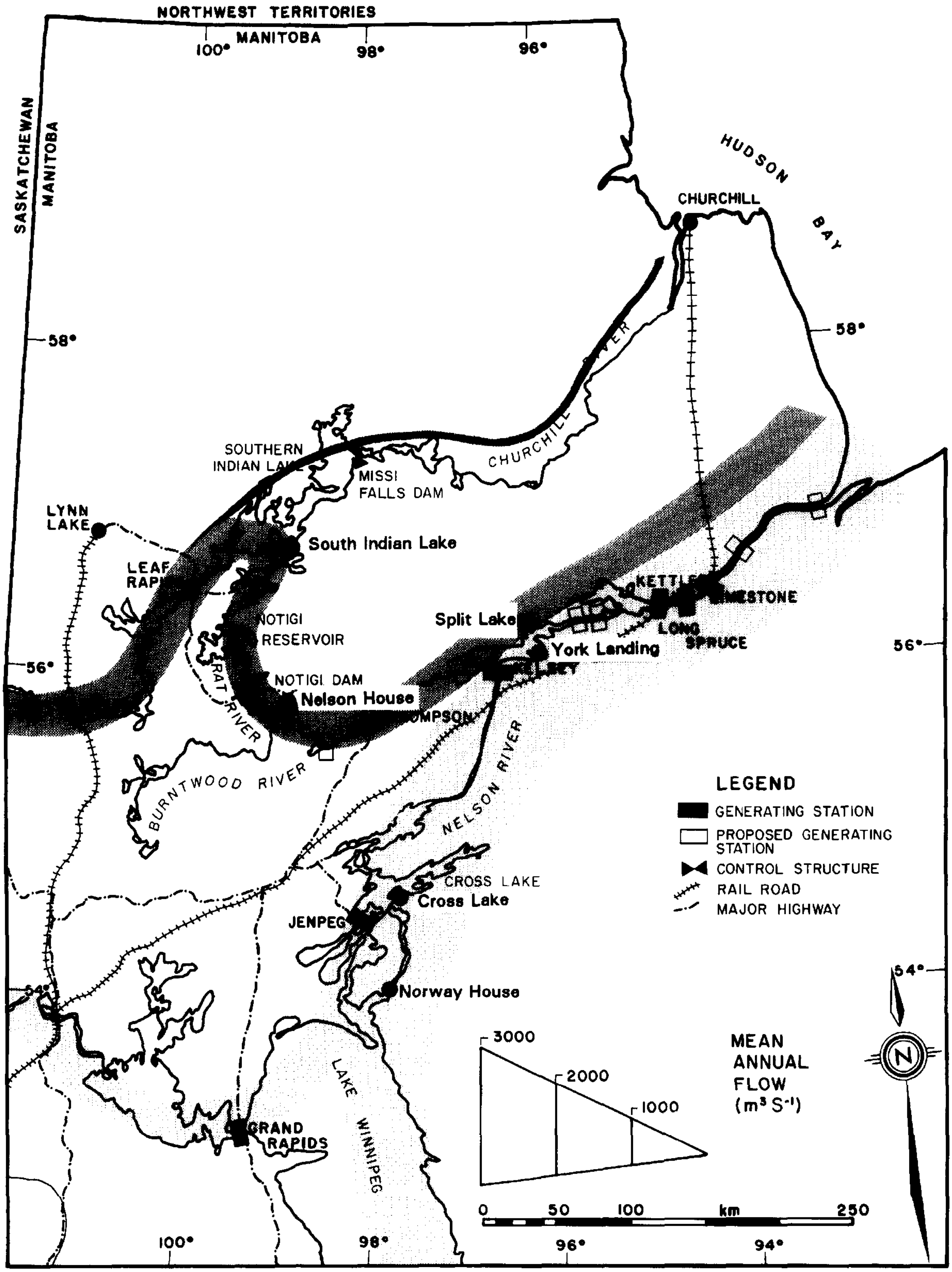

Figure 4 Hydroelectric development along the Churchill and Nelson rivers, northern Manitoba, indicating altered flow regime of the rivers. Dark tone indicates relative magnitude of lower Churchill River discharge after diversion; mid-tone indicates Churchill River diversion at Southern Indian Lake; light 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*.

Table 1. Changes in power distribution in the Churchill and Nelson River systems as a result of hydroelectric development.[a]

Location	Pre-diversion(MW)	Post-diversion(MW)	Change(x)
Lower Churchill River	2462	448	−0.2
Southern Indian Lake (wave power)	0	25[b]	NA
Rat River	4	153	+38
Burntwood River	45	716	+16
Lower Nelson River	Natural	Natural +1194	+1.3

[a]The analysis is based on mean annual flows (rivers) and average open water conditions (Southern Indian Lake). NA = not applicable.
[b]This represents pre-impoundment wave power available to act on a new, highly erodable shoreline.

Source: R W Newbury, *op cit*, Ref 8.

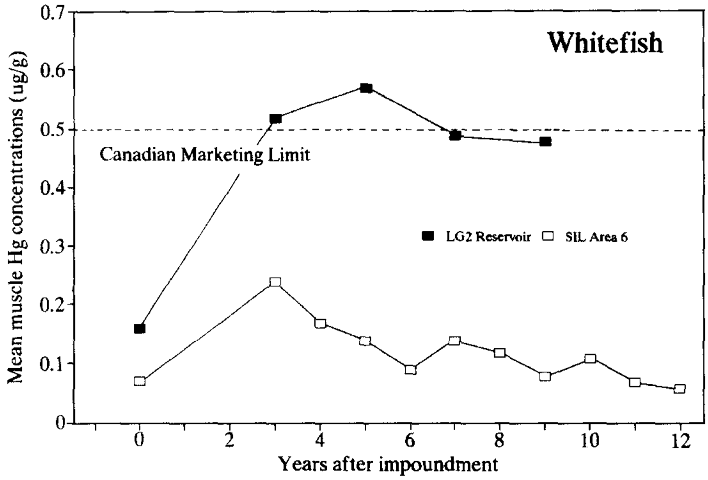

Figure 5 Mercury concentrations in the muscle tissue of (a) lake whitefish (*Coregonus clupeaformis),* (b) pike (*Esox lucius*), and (c) walleye (*Stizostedion vitreum*) in the Southern Indian Lake (SIL) Reservoir, northern Manitoba, and the La Grande (LG)2 Reservoir, northern Québec. Mean mercury concentrations are standardized for fish length by linear interpolation.

Sources: SIL – N E Strange, R A Bodaly, and R J P Fudge, 'Mercury concentrations in fish in Southern Indian Lake and Issett Lake, Manitoba, 1975–88: The effect of lake impoundment and Churchill River diversion', *Canadian Technical Report of Fisheries and Aquatic Sciences*, No 1824, 1991, pp 1–61; SIL locations are shown in figure 1 of R A Bodaly *et al*, *op cit*, Ref 20; LG2 – R Verdon *et al*, *op cit*, Ref 31.

large scale hydroelectric projects. For example, SIL has a post-impoundment shoreline length of 3788 km.[33]

Greenhouse gases

The release of greenhouse gases (CH_4 and 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.[34] Under natural conditions, peatlands are sinks for CO_2 but they are slight sources of CH_4 to the atmosphere; forests are slight sinks for CH_4, but they are neither sources nor sinks for CO_2; therefore, the total 'greenhouse effect' is estimated to be about zero.[35] 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.[36] 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.[37] 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

[33]Newbury *et al. op cit*, Ref 7
[34]J W M Rudd *et al*, 'Are hydroelectric reservoirs significant sources of greenhouse gases?' *Ambio*, Vol 22, 1993, pp 246–248
[35]*Ibid*
[36]*Ibid*
[37]*Ibid*

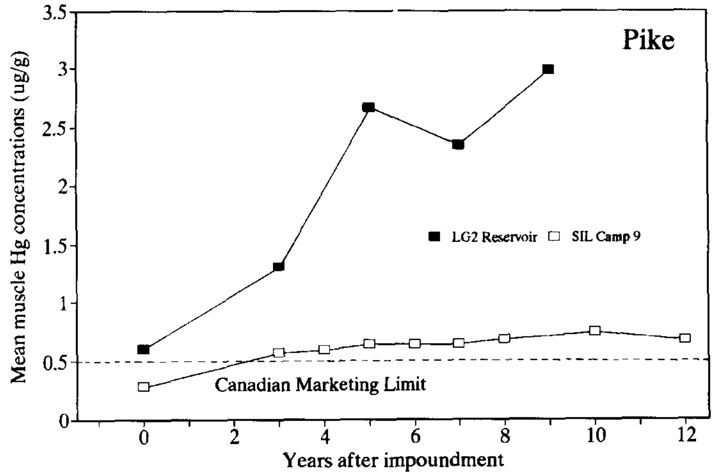

Figure 5b

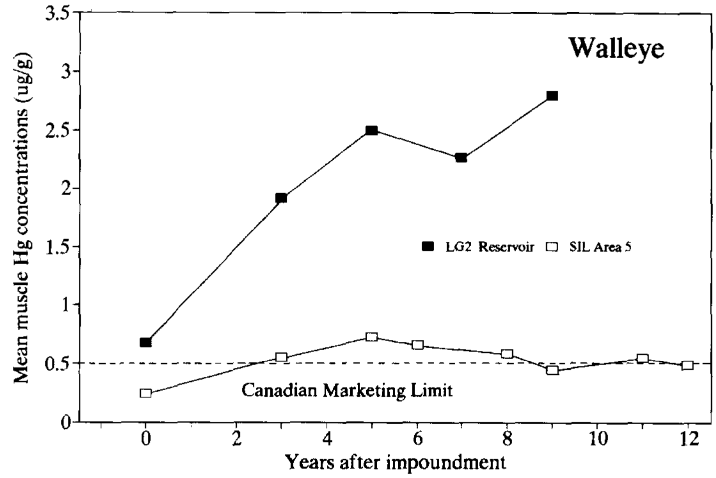

Figure 5c

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 km^2 – an area the size of Lake Ontario.[38] New reservoirs planned for the James Bay area of northern Québec will cover another ≈10 000 km^2, involving ≈4650 km^2 of newly flooded land.[39]

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![40]

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

[38]Rosenberg *et al*, *op cit*, Ref 18
[39]Rougerie, *op cit*, Ref 17. These figures do not include the ≈2000 km^2 of flooding involved in formation of the Laforge-1 and Eastmain-1 reservoirs in Phase II of La Grande development (Penn, *op cit*, Ref 16)
[40]Bourassa, *op cit*, Ref 1, p 4

Figure 6 Mercury concentrations in lake whitefish (*Coregonus clupeaformis*) and pike (*Esox lucius*) in and downstream of (a) La Grande (LG)2 and (b) Opinaca Reservoirs, northern Québec. Mean mercury concentrations are standardized for fish length. Sampling sites (km) shown in (b): 0 = Opinaca Reservoir – Opinaca station; 3 = Boyd-Sakami diversion (BSD) – Coté station; 56 = BSD – Sakami station; 95 = BSD – Ladouceur station; 115 = LG2 Reservoir – Coutaceau station.

Source: R Verdon *et al*, *op cit*, Ref 31.

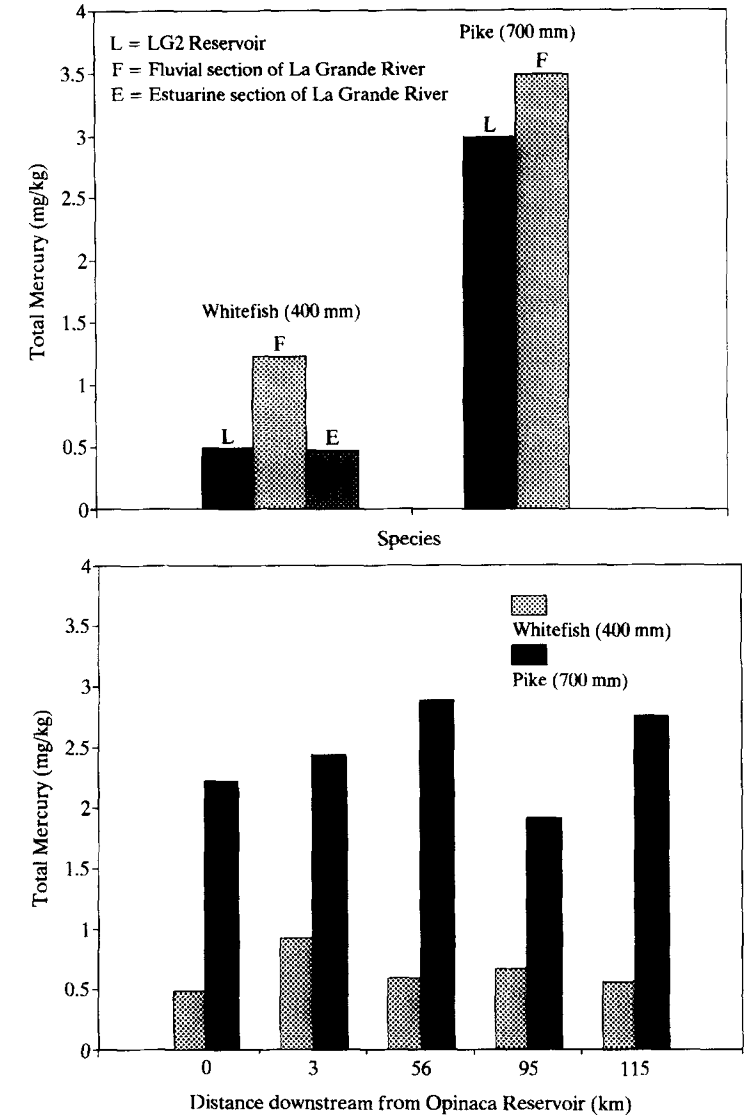

Figure 6b

[41]Discussed by White, *op cit*, Ref 2, p 38

[42]See D Tolmazin, 'Black Sea – dead sea?' *New Scientist*, Vol 84, No 1184, 1979, p 768 and S P Volovik, 'The effects of environmental changes caused by human activities on the biological communities of the River Don (Azov Sea Basin)', *Water Science and Technology*, Vol 29, 1994, pp 43–47, for information on the Azov and Black seas; and M A Rozengurt and J W Hedgpeth, 'The impact of altered river flow on the ecosystem of the Caspian Sea', *Reviews in Aquatic Sciences*, Vol 1, 1989, pp 337–362, for detailed information on the Caspian Sea. For a discussion of the Aral Sea, see P P Micklin, 'Desiccation of the Aral Sea: A water management disaster in the Soviet Union', *Science*, Vol 241, 1988, pp 1170–1176; W S Ellis and D C Turnley, 'The Aral. A Soviet sea lies dying', *National Geographic*, Vol 177, No 2, 1990, pp 70–93; V M Kotlyakov, 'The Aral Sea Basin. A critical environmental zone', *Environment*, Vol 33, No 1, 1991, pp 4–9 and 36–38; N Precoda, 'Requiem for the Aral Sea', *Ambio*, Vol 20, 1991, pp 109–114; M H Glantz, A Z Rubinstein, and I Zonn, 'Tragedy in the Aral Sea. Looking back to plan ahead?' *Global Environmental Change*, Vol 3, 1993, pp 174–198; and J Perera, 'A sea turns to dust', *New Scientist*, Vol 140, No 1896, 1993, pp 24–27. The heroic measures and costs required for conservation and restoration of the Aral Sea are outlined in A Levintanus, 'Saving the Aral Sea', *Journal of Environmental Management*, Vol 36, 1992, pp 193–199. For a discussion of the High Dam at Aswan, see A A Aleem, 'Effect of river outflow management on marine life', *Marine Biology*, Vol 15, 1972, pp 200–208; White, *op cit*, Ref 2; and D J Stanley and A G Warne, 'Nile Delta: Recent geological evolution and human impact', *Science*, Vol 260, 1993, pp 628–634

north-temperate rivers characteristically trap high spring flows for storage in reservoirs, and release higher flows than normal during winter when the power is needed. Thus, the normal hydrograph is attenuated in spring and enhanced in winter. Ironically, because of the alteration of flow patterns in river systems, it is downstream and coastal resources that eventually are 'wasted'.

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;[41] 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 hydroelectric 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.[42]

Table 2. Possible rates of greenhouse gas produced and power generation

	$km^2/(TWh/yr)$	Equivalent Tg CO_2/TWh
Coal-fired generation	–	0.4–1.0
Churchill/Nelson rivers development[a]	88	0.04–0.06
Grand Rapids (Cedar Lake)[b]	710	0.3-0.5

[a]A Manitoba reservoir having a low ratio of flooded area to energy produced.
[b]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 other major outlets that connect Lake Athabasca to the Peace River. The Delta covers 3800 km^2 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 $\approx$62 km^3 of water from 1968 to 1971. During filling, normal Peace River peak flows of 4000–9000 m^3/sec were reduced to 280 m^3/sec; flood flows in the Peace River adjacent to the Delta were reduced by as much as 5600 m^3/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 km^2 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

[43]H J A Neu, 'Man-made storage of water resources – A liability to the ocean environment?' Parts I and II, *Marine Pollution Bulletin*, Vol 13, 1982, pp 7–12 and 44–47
[44]D M Rosenberg, 'Resources and development of the Mackenzie system', in B R Davies and K F Walker (eds) *The Ecology of River Systems*, Dr W Junk Publishers, Dordrecht, 1986, pp 517–540; Rosenberg *et al, op cit*, Ref 18
[45]Mackenzie River Basin Committee, 'Mackenzie River Basin Study report. A report under the 1978–81 Federal-Provincial Study Agreement Respecting the Water and Related Resources of the Mackenzie River Basin', Environment Canada, Regina, 1981
[46]G H Townsend, 'Impact of the Bennett Dam on the Peace-Athabasca Delta', *Journal of the Fisheries Research Board of Canada*, Vol 32, 1975, pp 171–176
[47]*Ibid*

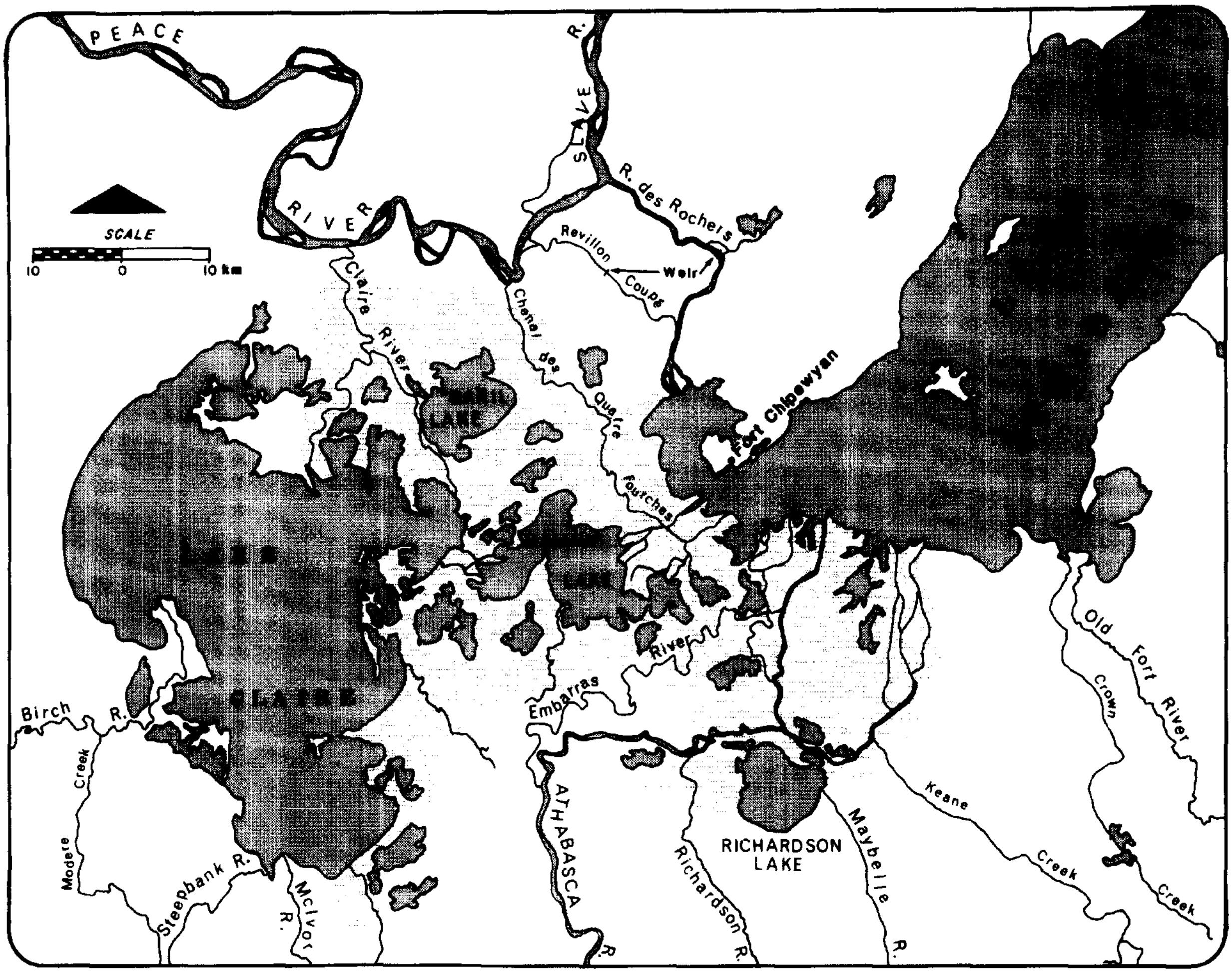

Figure 7 The Peace-Athabasca Delta, northern Alberta, Canada.

Source: Mackenzie River Basin Committee, *op cit*, Ref 45.

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 (ie 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.[48]

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

[48]Peace-Athabasca Delta Project Group, 'The Peace-Athabasca Delta Project. A report on low water levels in Lake Athabasca and their effects on the Peace-Athabasca Delta', Technical Report, Environment Ministers of Canada, Alberta, and Saskatchewan, Edmonton, 1973; Townsend, *op cit*, Ref 46

populations would exacerbate already serious economic problems in the predominantly Indian and Métis Delta community of Fort Chipewyan.

In response to these dire predictions, fixed-crest weirs were built on the Rivière des Rochers and the Revillon Coupé (Figure 7) to recreate the hydraulic damming effect of the pre-impoundment Peace River and, thereby, restore circumannual flooding to the Delta. Their efficacy was controversial,[49] but a recent Parks Canada study confirmed that the Delta continues to dry out and that it will disappear in 50 years unless new management approaches are adopted.[50] Satisfactory resolution of the problem is further complicated by indeterminate plans to develop dams on the Peace River, 62 km from the BC-Alberta border, and on the Slave River, downstream of the Delta.

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.[51]

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.[58] 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,[59] 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.[60] It is even possible that major changes in Hudson Bay will be felt in 'downstream' areas such as the Labrador coast.[61] 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

[49]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.

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

[51]Neu, *op cit*, Ref 43, p 11

[52]Lake Winnipeg, Churchill and Nelson Rivers Study Board, 'Summary Report', Canada-Manitoba Lake Winnipeg, Churchill and Nelson Rivers Study, Winnipeg, 1975; R E Hecky *et al*, 'Environmental impact prediction and assessment: The Southern Indian Lake experience', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 720–732; Newbury *et al*, *op cit*, Ref 7

[53]Ontario Hydro, 'Proposal for hydroelectric development. The Moose River drainage region', Report No 88826, Ontario Hydro, Toronto, 1988

[54]Gorrie, *op cit*, Ref 14; Rougerie, *op cit*, Ref 17

[55]Gorrie, *op cit*, Ref 14; Rougerie, *op cit*, Ref 17; Hydro-Québec, *op cit*, Ref 3

[56]Gorrie, *op cit*, Ref 14; Hydro-Québec, 'NBR Complex', No 1, Hydro-Québec, Montreal, 1990; Rougerie, *op cit*, Ref 17

[57]Bourassa, *op cit*, Ref 1; Kierans, *op cit*, Refs 1 and 2; U S Panu and M Oosterveld, 'Pre-feasibility technical investigations of the cost of water transfer from Lake Superior to United States High Plains region', *Canadian Water Resources Journal*, Vol 15, 1990, pp 231–247. For rebuttals to the scheme, see D J Gamble, 'The GRAND Canal scheme: Some observations on research and policy implications', in W Nicholaichuk and F Quinn (eds) *Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada*, 9–10 November 1987, Environment Canada, Saskatoon, SK, 1987, pp 71–84; and D J Gamble, 'The GRAND Canal scheme', *Journal of Great Lakes Research*, Vol 15, 1989, pp 531–533

[58]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

[59]For example, see Department of Fisheries and Oceans, 'EIS scoping workshop submission presented to the

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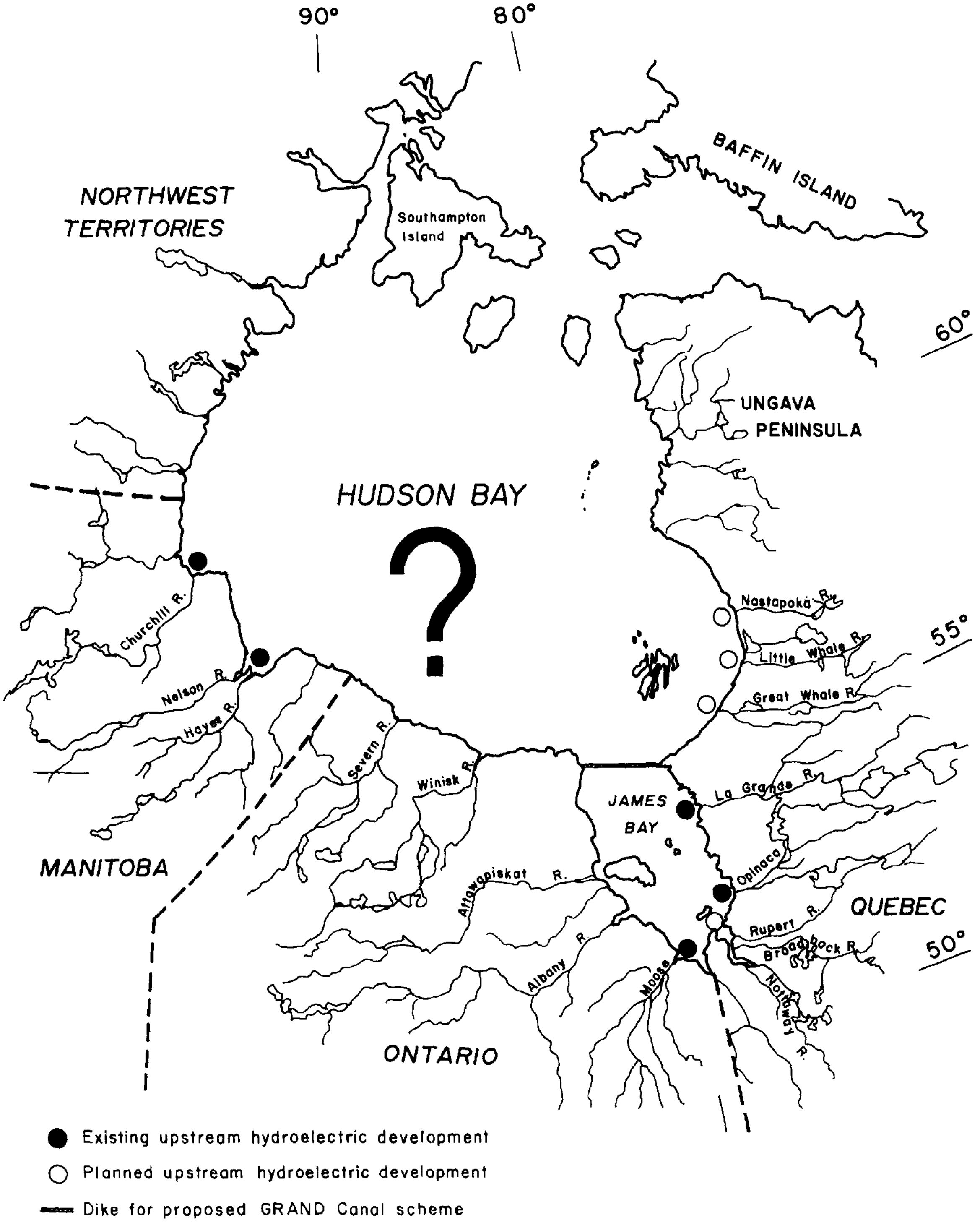

Figure 8 Major hydroelectric developments and water diversions existing and planned in the Hudson and James Bay catchments, northern Canada. Further hydroelectric development is planned for already developed river systems.

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

[60]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.[62] 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.

Table 3. Existing and proposed water development projects in the Hudson Bay catchment.

Project[a]	Description
Churchill-Nelson rivers diversion and Lake Winnipeg regulation, Manitoba	Development of ≈8000–10 000 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 m^3/sec to be diverted from Churchill River into Nelson River to supply extra flow in lower Nelson[52]
Moose River, Ontario	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 planned[53]
La Grande River, Québec	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 ≈12 400 MW; Phase II involves the creation of 4 more reservoirs and 6 or 7 more powerhouses yielding another ≈3200 MW[54]
Great Whale River, Québec	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]
Nottaway-Broadback-Rupert rivers, Québec	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]
Great Recycling and Northern Development (GRAND) Canal scheme	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 USA[57]

[a]For development of the Québec part of James Bay, see also Bourassa, *op cit*, Ref 1. Developments in the Québec 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'.[63]

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

Continued from page 141
1101–1110, described spatial and temporal changes in freshwater inputs into Hudson and James bays as a result of hydroelectric development; and R Milko, 'Potential ecological effects of the proposed GRAND Canal diversion project on Hudson and James Bays', *Arctic*, Vol 39, 1986, pp 316–326; R J Milko, 'The GRAND Canal: Potential ecological impacts to the north and research needs', in W Nicholaichuk and F Quinn (eds) *Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada*, 9–10 November 1987, Environment Canada, Saskatoon, SK, 1987, pp 85–99; W R Rouse, M-K Woo, and J S Price, 'Damming James Bay: I. Potential impacts on coastal climate and the water balance', *Canadian Geographer*, Vol 36, 1992, pp 2–7; J S Price, M-K Woo, and W R Rouse, 'Damming James Bay: II. Impacts on coastal marshes', *Canadian Geographer*, Vol 36, 1992, pp 8–13 described potential ecological effects of the GRAND Canal scheme

61 Milko, *op cit*, Ref 60

62 Prinsenberg, *op cit*, Ref 60; M J Dunbar, 'Oceanographic research in Hudson and James bays', in I P Martini (ed) James and Hudson Bay Symposium, 28–30 April 1981, Guelph, ON. *Le Naturaliste Canadien. Revue d'Ecologie et de Systématique*, Vol 109, 1982, pp 677–683; I P Martini, 'Introduction', in I P Martini (ed) James and Hudson Bay Symposium, 28–30 April 1981, Guelph, ON. *Le Naturaliste Canadien. Revue d'Ecologie et de Systématique*, Vol 109, 1982, pp 301–305

63 Letter, Premier Duff Roblin to Chief Donald Easter, 21 August 1964, cited in J B Waldram, *As Long as the Rivers Run. Hydroelectric Development and Native Communities in Western Canada*, University of Manitoba Press, Winnipeg, 1988, p 97

64 Waldram, op cit, Ref 63

65 Kierans, *op cit*, Ref 2, p 255

66 A summary of physical and biological effects for the whole LWR/CRD system is given in R F Baker and S Davies, 'Physical, chemical and biological effects of the Churchill River diversion and Lake Winnipeg regulation on aquatic ecosystems', *Canadian Technical Report of Fisheries and Aquatic Sciences*, No 1806, 1991, pp 1–53 and Environment Canada and Department of Fisheries and Oceans, 'Federal Ecological Monitoring Program. Summary Report', Environment Canada and Department of Fisheries and Oceans, Winnipeg, 1992. Equivalent references for LGRD do not exist.

by Cree Indians. They live in small villages (populations of 500–4000), all of which are located on major rivers and lakes. These villages are characterized by mixed, subsistence based economies,[67] and each relies on access to the fish and wildlife resources of customary territories that range in size from thousands to tens of thousands km^2 of land and water. Subsistence based economies are sensitive to industrial development because changes in resource use and harvesting patterns directly affect established systems of land tenure and resource management, and the organization of production and distribution. However, measuring changes in these economies is difficult because they are remarkably flexible and resilient, although there are finite limits to their adaptability. These limits can only be established through improved understanding of the subsistence system.

The Cree have been in contact with European, and later Euro-Canadian society for a long time, resulting in new and evolving economic and social relations.[68] 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.[69] 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.[70]

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.[71]

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.[72] The move split the community; some families stayed at Ft George despite the lack of amenities there.[73]

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.[74] 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.[75]

Although hydro-induced relocation results in a new physical infrastructure, it is rarely associated with matching employment benefits. The Crees in northern Manitoba obtained only low paying, short term jobs, and little training, and even this was disruptive of their existing economy.[76]

[67]'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 Weinstein, *op cit*, Ref 9)

[68]F Tough, 'Native people and the regional economy of northern Manitoba: 1870-1930s', PhD Thesis, York University, Toronto, 1987

[69]Berkes, *op cit*, Ref 13. Examples of relocations in other countries are given in E Goldsmith and N Hildyard, (eds) 'The social and environmental effects of large dams. A report to the European Ecological Action Group (ECOPORA)', Vol I: Overview, Wadebridge Ecological Centre, Camelford, 1984, pp 15–48

[70]M Loney, 'The construction of dependency: The case of the Grand Rapids hydro project', *Canadian Journal of Native Studies*, Vol 7, 1987, pp 57–78; Waldram, *op cit*, Ref 63; G Mills and S Armstrong, 'Africa tames the town planners', *New Scientist*, Vol 138, No 1871, 1993, pp 21–25 make the point 'That town planners and architects will not design housing that people want to live in until they discover what people themselves produce when not constrained by town plans – the so-called informal settlements that the experts have traditionally dismissed as chaotic and wholly undesirable'

[71]J B Waldram, 'Relocation, consolidation, and settlement pattern in the Canadian subarctic', *Human Ecology*, Vol 15, 1987, pp 117–131

[72]F Berkes, 'Some environmental and social impacts of the James Bay hydro-electric project, Canada', *Journal of Environmental Management*, Vol 12, 1981, pp 157–172. However, there are claims that the town was moved for the financial convenience of Hydro-Québec (see A Dwyer, 'The trouble at Great Whale', *Equinox*, Vol 11, No 61, 1992, pp 28–41)

[73]F Berkes, University of Manitoba, Winnipeg, personal communication

[74]*Ibid*

[75]*Ibid.* An anecdotal account of social stress and social breakdown in Chisasibi is given in Dwyer, *op cit*, Ref 72. See also L Krotz, 'Dammed and diverted', *Canadian Geographic*, Vol 111, No 1, 1991, pp 36–44, for an anecdotal description of social decay in South Indian Lake.

[76]J B Waldram, 'Native employment and hydroelectric development in northern Manitoba', *Journal of Canadian Studies*, Vol 22, 1987, pp 62–76

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 practises 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, Québec, 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 Québec and Manitoba through trapline 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,[83] 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] In the case of

[77]White, *op cit*, Ref 2. These figures differ from those of Goldsmith and Hildyard, op cit, Ref 69, who claimed that 120 000 people were resettled (p 15), of which 30 000 were Sudanese (p 30)

[78]Goldsmith and Hildyard, *op cit*, Ref 69

[79]White, *op cit*, Ref 2. According to Goldsmith and Hildyard, *op cit*, Ref 69, many did return

[80]Goldsmith and Hildyard, *op cit*, Ref 69

[81]*Ibid*, p 32

[82]In Alaska, per capita harvest levels in native communities are most strongly inversely associated with road accessibility (see Wolfe and Walker, *op cit*, Ref 67)

[83]See, for example, P J Usher *et al*, 'The economic and social impact of mercury pollution on the Whitedog and Grassy Narrows Indian reserves, Ontario', Report prepared for the Anti-Mercury Ojibwa Group, Kenora, 1979; copy on deposit at the library of the Department of Indian Affairs and Northern Development, Ottawa; A F Riordan, 'When our bad season comes: A cultural account of subsistence harvesting and harvest disruption on the Yukon Delta', *Alaska Anthropological Association Monograph Series No 1*, Anchorage, 1986; and G Wenzel, *Animal Rights, Human Rights: Ecology, Economy and Idealogy in the Canadian Arctic*, University of Toronto Press, Toronto, 1991

[84]For a preliminary assessment of harvest disruption resulting from LWR/CRD, see Usher and Weinstein, *op cit*, Ref 9; a schematic representation of cause and effect is presented on p 13. For LGRD, see Berkes, op cit, Ref 72

[85]Bodaly, *et al*, *op cit*, Ref 6; M N Gaboury and J W Patalas, 'Influences of water level drawdowns on the fish populations of Cross Lake, Manitoba', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 118–125

[86]R A Bodaly *et al*, 'Collapse of the lake whitefish (*Coregonus clupeaformis*) fishery in Southern Indian Lake, Manitoba, following lake impoundment and river diversion', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 692–700; N E Barnes, 'Abundance and origin of lake whitefish, *Coregonus clupeaformis* (Mitchill), congregating downstream of the Missi Falls control dam, Southern Indian Lake, Manitoba', MSc Thesis, University of Manitoba, Winnipeg, 1990

[87]Usher and Weinstein, *op cit*, Ref 9

[88]J A Waldram, 'The impact of hydro-electric development upon a northern Manitoba native community', Ph D Thesis, University of Connecticut, Storrs, 1983; M W Wagner, 'Postimpoundment change in financial performance of the Southern Indian Lake commercial fishery', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 715–719

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.[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.[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,[91] but also the fouling of fish nets by debris.[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.[93]

(4) Mercury contamination – The problem of mercury contamination in northern communities is particularly serious.[94] 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 ≃25% of the community's wild food harvest usually came from fishing (≃60 kg/yr/person). The problem necessitated a special mercury compensation agreement, which was signed in 1986.[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.[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).[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.[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-

[89]Berkes, *op cit*, Ref 13. This is poorly documented common knowledge

[90]Berkes, *op cit*, Ref 13; Environment Canada and Department of Fisheries and Oceans, *op cit*, Ref 9, pp 2.16 to 2.21. Again, these effects are commonly known but not widely documented in readily available literature sources

[91]R W Newbury and G K McCullough, 'Shoreline erosion and restabilization in the Southern Indian Lake reservoir', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 41, 1984, pp 558–566

[92]For example, the cutting of a new hydrological channel between Lake Winnipeg and, immediately downstream, Playgreen Lake served to introduce debris into Playgreen Lake (G K McCullough, Freshwater Institute, Winnipeg, personal communication)

[93]Usher and Weinstein, *op cit*, Ref 9

[94]Bodaly, *et al*, *op cit*, Ref 20; Canada-Manitoba Mercury Agreement, *op cit*, Ref 32; Berkes, *op cit*, Ref 13; Boucher *et al*, *op cit*, Ref 21

[95]Berkes, *op cit*, Ref 13

[96]Bodaly *et al*, *op cit*, Ref 20; Environment Canada and Department of Fisheries and Oceans, 'Federal Ecological Monitoring Program. Final report. Vol 2', Environment Canada and Department of Fisheries and Oceans, Winnipeg, 1992, pp 2.18 to 2.20.

[97]Usher and Weinstein, *op cit*, Ref 9, pp 14–21

[98]Canada National Health and Welfare, *Methylmercury in Canada: Exposure of Indian and Inuit Residents to Methylmercury in the Canadian Environment*, Canada National Health and Welfare, Medical Services Branch, Ottawa, 1979

marily as a public health issue, so their efforts are directed to: (a) understanding the uptake of methylmercury and its dose response relationship, (b) monitoring the presence of mercury in fish and in humans, and (c) minimizing health risks by advising avoidance of fish consumption and substitution with other foods. Unfortunately, only limited attention has been given to the less direct but more pervasive effects of mercury contamination on the social and mental well being of natives and communities at risk. Whether or not individuals are exposed to, or are actually ingesting, injurious levels of mercury, the threat alone is the cause of anxiety over many facets of their lives. Although only a small portion of the population is at risk of physical harm, and an even smaller portion is affected, the native community suffers adverse social and psychological effects.[99]

A public health strategy that advises native people not to eat contaminated fish also has the effect of advising them not to *fish*, which is a popular activity of great economic and cultural value. Such advice must be weighed against increasing the reliance of native people on store bought food, with its associated health problems.[100]

Dealing with adverse effects. Both LGRD and LWR/CRD were strongly resisted by the affected Cree populations.[101] 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.[102] 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.[103] 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),[104] was signed after major construction was completed, in response to threats of litigation by the native communities affected by LWR/CRD.[105] 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.[106] 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 proceeded.[107] Adequate institutional funding and administrative structures are also required to ensure the subsequent smooth functioning of the compensation programmes.[108]

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.[109] 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.[110]

Comprehensive environmental and social impact assessments have been

[99]P J Usher, 'Socio-economic effects of elevated mercury levels in fish on sub-arctic native communities', in *Contaminants in the Marine Environment of Nunavik, Proceedings of the Conference*, 12–14 September 1990, Montreal, PQ, Université Laval, Québec, 1992, pp 45–50

[100]E Szathmary, C Rittenbaugh, and C M Goodby, 'Dietary changes and plasma glucose levels in an Amerindian population undergoing cultural transition', *Social Science and Medicine*, Vol 24, 1987, pp 791–804; J P Thouez, A Rannou, and P Foggin, 'The other face of development: Native population, health status, and indicators of malnutrition. The case of the Cree and Inuit of northern Québec', *Social Science and Medicine*, Vol 29, 1989, pp 965–974

[101]B Richardson, *Strangers Devour the Land*, MacMillan, Toronto, 1975; Waldram, *op cit*, Ref 63

[102]Berkes, *op cit*, Ref 13

[103]B Diamond, 'Villages of the dammed', *Arctic Circle*, Vol 1, No 3, 1990, pp 24–34; S McCutcheon, *Electric Rivers. The Story of the James Bay Project*, Black Rose Books, Montréal, 1991, pp 154–156

[104]Northern Flood Agreement, *Agreement Dated December 16, 1977 Between Her Majesty the Queen in Right of the Province of Manitoba of the First Part and the Manitoba Hydro-Electric Board of the Second Part and the Northern Flood Committee, Inc. of the Third Part and Her Majesty the Queen in Right of Canada as Represented by the Minister of Indian Affairs and Northern Development of the Fourth Part*, Winnipeg, 1977

[105]Waldram, *op cit*, Ref 63

[106]Waldram, *op cit*, Ref 63; Usher and Weinstein, *op cit*, Ref 9

[107]For a discussion of mitigation/compensation arrangements as afterthoughts, see F Quinn, 'As long as the rivers run: The impacts of corporate water development on native communities in Canada', *Canadian Journal of Native Studies*, Vol 11, 1991, pp 137–154

[108]J C Day and F Quinn, 'Water diversion and export: Learning from Canadian experience', *Department of Geography Publication Series No 36, University of Waterloo and Canadian Association of Geographers Public Issues Committee, No 1*, University of Waterloo, Waterloo, 1992, discuss failures in implementation of the JBNQA and NFA (pp 122–125 and 144–146)

[109]Berkes, *op cit*, Ref 13

[110]Attitudes of proponents to environmental and social assessments are discussed in White, *op cit*, Ref 2, p 38

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 4. Examples of large hydroelectric and water-diversion projects being proposed or built.

Project	Location
GRAND Canal Scheme[114]	Canada
Great Whale River[115]	Canada
Nottaway-Broadback-Rupert rivers[116]	Canada
Three Gorges Dam[117]	China
Tehri Dam[118]	India
Ganges and Brahmaputra rivers flood control[119]	Bangladesh
Sardar Sarovar Projects[120]	India

[111]For example, see Hecky *et al, op cit,* Ref 52; and Waldram, *op cit,* Ref 88, for Southern Indian Lake
[112]Usher and Weinstein, *op cit,* Ref 9
[113]In 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 (ed) 'The social and environmental effects of large dams', Vol III. A review of the literature, Wadebridge Ecological Centre, Camelford, 1992
[114]Kierans, *op cit,* Refs 1 and 2; Panu and Oosterveld, *op cit,* Ref 57
[115]Rougerie, *op cit,* Ref 17; Hydro-Québec, *op cit,* Ref 3
[116]Hydro-Québec, *op cit,* Ref 56; Rougerie, *op cit,* Ref 17
[117]P M Fearnside, 'China's Three Gorges Dam: "Fatal" project or step toward modernization?' *World Development,* Vol 16, 1988, pp 615–630
[118]F Pearce, 'The dam that should not be built', *New Scientist,* Vol 129, No 1753, 1991, pp 37–41
[119]J K Boyce, 'Birth of a megaproject: Political economy of flood control in Bangladesh', *Environmental Management,* Vol 14, 1990, pp 419–428
[120]B Morse and T Berger, *Sardar Sarovar. The Report of the Independent Review,* Resource Futures International, Ottawa, 1992. See also A McIlroy, 'India's Narmada: Déjà views', *Arctic Circle,* Vol 2, No 6, 1992, pp 28–31; and S K Miller, 'World Bank admits mistakes over dam', *New Scientist,* Vol 134, No 1827, 1992, p 4. Threats posed to other tropical Asian rivers by large scale hydroelectric development are discussed in D Dudgeon, 'Endangered ecosystems: A review of the conservation status of tropical Asian rivers', *Hydrobiologia,* Vol 248, 1992, pp 167–191
[121]For 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'
[122]R W Newbury, Gibsons, BC, personal communication; see also McCutcheon, *op cit,* Ref 103, p 86
[123]Rosenberg *et al, op cit,* Ref 18; Quinn, op cit, Ref 107
[124]Newbury, *op cit,* Ref 8
[125]*Ibid*

shoreline erosion within the lake and would have decreased flooding in the Rat River Valley, two of the most destructive elements of the Churchill-Nelson River diversion. The alternative configurations were estimated to cost an additional 5–15%[126] but were dismissed by Manitoba Hydro.[127] Aboriginal compensation claims stemming from damages caused by the Churchill-Nelson River diversion are expected to reach hundreds of millions of dollars.[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![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.[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.[131] However, decision makers continue to foster hydroelectric projects that belong to a bygone era.[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.

[126] *Ibid*
[127] R W Newbury, personal communication
[128] The potential range of costs ($340-$550 million) is given in J Collinson, Study Team Leader, 'Improved program delivery. Indians and natives. A Study Team report to the Task Force on Program Review', Supply and Services Canada, Ottawa, 1986, p 216. The Cree refused a $250 million settlement offer in 1990 (Day and Quinn, *op cit*, Ref 108 p 125)
[129] See figure 2.21 in Environment Canada and Department of Fisheries and Oceans, *op cit*, Ref 9, pp 2.15
[130] To our knowledge, the ecological effects of extreme daily flow fluctuations on the lower mainstem Nelson River have not been studied
[131] For example, see R E Dunlap, 'Public opinion in the 1980s. Clear consensus, ambiguous commitment', *Environment*, Vol 33, No 8, 1991, pp 11–15 and 32–37.
[132] Linton, *op cit*, Ref 17