From: on behalf of Panel Registry [CEAA]
Subject: FW: Lower Churchill project

Attachments: SUSTAINABILITY EIS cmments.doc; protectingfishhabitatparl_cesd_200905_01_e[1].pdf; Rosenberg et al. (1995).pdf; Rosenberg et al. (1997).pdf; Quigley no net loss.doc

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From: Roberta Frampton Benefiel <email address removed>
Sent: May 23, 2009 2:45 AM
To: Lower Churchill Review [CEAA]; Tom Graham
Subject: Lower Churchill EIS comments

Hello Tom and Maryse:

Please find attached Grand Riverkeeper Labrador's comments on the Environmental Impact Statement for the Lower Churchill Hydroelectric Project along with various referenced documents. Please advise if there are any problems with the attachments and thank you for forwarding this on to the Panel.

Please expect one more message with attachments. My Yahoo account only allows 5 attachments per message.

Roberta Frampton Benefiel
Grand Riverkeeper Labrador, Inc.
[redacted]

709-[redacted]164 or [redacted]008

GRAND RIVERKEEPER LABRADOR, INC.

[redacted]

PHONE: 709-[redacted]008

FAX: 709-[redacted]008

Comments on the Lower Churchill Hydroelectric Generation Project Environmental Impact Statement
Registry number 07-05-26178

Attention:
Maryse Pineau, Panel Co-Manager
Canadian Environmental Assessment Agency
160 Elgin Street, Ottawa ON K1A 0H3
Tel: 1-866-582-1884/613-948-1364
Fax: 613-582-1884
Lowerchurchill.review@ceaa-acee.gc.ca

Tom Graham, Panel C0-Manager
Lower Churchill Joint Review Panel Secretariat
33 Pippy Place, St. John's, NL A1B 4J6
Tel: 709-729-7720
Fax: 709-729-5693
comments@lcsec.nl.ca

To: Panel co-chair's Leslie Griffiths and Herbert Clark, panel members Jim Igloliorte, Meinhard Doelle and Keith Chaulk:

Submission of Grand Riverkeeper Labrador Inc. (GRKL) on the adequacy of the Environmental Impact Statement for the Lower Churchill Hydroelectric Project:

May 22, 2009

ENVIRONMENTAL ASSESSMENT IS RECOGNIZED IN MANY SOCIETIES AS ONE OF THE MOST IMPORTANT TOOLS WE CAN USE IN OUR EFFORTS TO ACHIEVE SUSTAINABILITY BY INTEGRATING ENVIRONMENTAL AND ECONOMIC FACTORS INTO OUR DEVELOPMENT DECISIONS. The importance of public participation in those decisions has also been recognized for some time; in fact, the assumption that effective public participation is an important tool to ensure we make decisions on projects that result in sustainability is now consistent with the stated purpose of most environmental assessment processes! As well, the adjacency principal is accepted in this Country and this Province as meaning; when development of natural resources occurs, those closest to the proposed development must derive the most benefits!

How does the Lower Churchill Hydroelectric Generation Project EIS and the entire EA process surrounding this project facilitate an outcome that produces a sustainable project that adheres to the adjacency principle and produces "meaningful" public participation?

It is the opinion of Grand Riverkeeper Labrador, Inc, that neither of these fundamental outcomes is being met and that various other issues and concerns need more attention.

These and various other issues are covered in GRKL's critique of the Environmental Impact Statement for the Lower Churchill Hydroelectric Project. A descriptive heading begins each separate issue.

We appreciate your consideration of these comments.

ADJACENCY PRINCIPLE

The Adjacency Principle is a policy that has been adopted by various governments in an effort to ensure that citizens living closest to development projects are the PRIMARY beneficiaries of any economic benefits accruing from those projects.

The communities closest to the Lower Churchill Hydroelectric project *may* experience a few jobs during the construction phase of the project and one or two particular groups *may* find themselves with some extra cash for a short period of time after the project is built, but the bulk of any *speculated* profits will go to an off shore government whose future political aspirations will determine how much or indeed if *any* funds will trickle down to the affected communities! With only 29,000 souls in Labrador versus over 500,000 on the Island portion of this Province, it is a well-documented fact that politicians make promises to the minorities in Labrador in order to glean as many votes as possible, but when limited funds are allocated, it's the area of the province where the most votes are garnered that usually gets their wheels greased!

Studies on past hydro projects in northern communities in Canada bare these statements out! For example, James B Waldran, in his book "As Long as the Rivers Run Hydroelectric Development and Native Communities in Western Canada" p179, states the following:

> *The hydro potential of Canadian rivers is viewed as a common property resource to be developed for the benefit of all provincial residents, and in a wider context, all Canadians…Indeed,.the "common good" ideology has been an important feature of most hydroelectric developments in Canada. But a closer look at these developments would likely reveal that they were proposed and constructed for reasons other than simply the production of cheap power for domestic consumption. Politics, and the machinations of politicians, have frequently become so intertwined with hydroelectric power projects that the improvement of political fortunes, rather than the production of power for the "common good", has been the real goal of provincial governments. The "common good" more and more looks like "the good of the party" in power".*

In order to ensure that the communities affected would be the primary beneficiaries of the project, GRKL recommends that there must be an Impact Benefits Agreement signed between ALL residents of Labrador, the Provincial Government and Nalcor Energy! This is the only way that the most affected and adjacent communities can ever hope to be the "primary" beneficiaries of this project!

However, instead of making certain that these communities are the "primary" beneficiaries, it appears Nalcor and the NL Government are ensuring exactly the opposite: i.e. the recently registered Labrador-Island Transmission Link project specifically by-passes Labrador's coastal communities for power from the Lower Churchill project even though those communities pay the highest rates for home heating in the Province! As well, this proposed 800mw transmission line by-passes Labrador completely. That's correct! Not one megawatt is slated for Labrador's use! Oh, but Nalcor says if the need arises for more power in Labrador they will make sure some of the re-call power is available! But Labradorians wonder which needs to come first, the industry that needs the power or the availability of the power? It would seem that industries planning to locate in Labrador would need to KNOW first that the power they need is available! One of the biggest problems with Nalcor's statement that if Labrador needs more power for a specific industry that it will be made available is that the current transmission lines from Churchill Falls to Happy Valley-Goose Bay are at capacity so any new power needs would necessitate the building or upgrading of new power lines. Not exactly something that can be accomplished overnight, and not necessarily even in any one year, given our short construction season. So the question is: How long would a new business/industry be willing to wait?

Also, Nalcor is signing an Impact Benefits Agreement with the Innu, which they should. However this effectively leaves the Inuit, the Metis and the non-native residents of the communities in Labrador at the mercy of whatever political decisions of the day abound when distribution of resources are decided!

On page 3-26 of Volume 111, the Socio-Economic Assessment, (last paragraph) Nalcor states "Facilitating the participation of Aboriginal people in the Project is an important goal." Then goes on to discuss their possible IBA with the Innu Nation as though no other Aboriginal group exists in the territory of Labrador! Not so! Inuit of Labrador number approximately 6900 and approximately 2310 of those people live directly adjacent to the Project. As well, the Labrador Metis Nation, although they do not yet have a recognized land claims agreement, number around 6000 members, a third or approximately 2000, of whom live adjacent to the project area! The Labrador Metis Nation has been recognized time and time again by both the Provincial and Federal Governments through specific programs, specific consultation, and other forms of recognition. However, it seems this Proponent chooses to treat these Aboroginal people as non-aboriginal!

It is incumbent on Nalcor and the Governments of NL and Canada to consult directly with Aboriginal communities affected by the Project. However, the consultation described in the EIS does not adequately address this need to consult, except in the case of one of the regions Aboriginal groups, the Innu Nation! Grand Riverkeeper Labrador recommends that the Proponent be instructed to re-visit the consultation process of the EIS and include meaningful consultation with the Nunatsiaviut Government and the Labrador Metis Nation.

On Page 2-3 of Volume 1, Part A, section 2.4.2.3, the Proponent states the following:

> "Employment opportunities and business activity resulting from the construction and operation of the Project are the primary direct benefits." and "A substantial portion of the secondary employment and business opportunities will occur naturally in Labrador. Nalcor Energy will focus its efforts on maximizing benefits to Labrador through training and supplier development and will require that qualified Labrador residents have first consideration for employment on the Project."

In a survey of local businesses and the local College of the North Atlantic, as of this writing, Nalcor Energy has made very limited contact with businesses who might benefit from purchasing agreements in connection with the Project, with the possible exception of businesses which are partnered with Innu Development and while there was a meeting with the college in March of 2008 to outline some of the particular kinds of jobs that would be available, they have not been contacted yet regarding the specific training needs for the Project! With only a year or possibly less until Nalcor Energy predicts this project will begin construction , it would seem that if the proponent was truly dedicated to the Adjacency Principle, activity would be under way to ensure that anyone living in Labrador who wants a job on this project would be evaluated and some form of specific training opportunities would be either already underway or at least planned. That does not appear to be the case! Nor does it appear that local businesses will benefit from supply contracts since by Nalcor's own statement in section 2.3 of the Executive Summary; **"Newfoundland and Labrador businesses will have full and fair opportunities to participate in the Project, understanding that price, quality and delivery will be evaluated on a competitive basis.",** This statement immediately throws up red flags, first because it states Newfoundland and Labrador,and does not state Labrador first with Island businesses benefiting next and also because it is common knowledge that goods supplied by Labrador businesses are almost always going to be more expensive due to the high cost of shipping over 1200 km of gravel roads where tractor trailers have full loads in but empty loads out of the territory and therefore have to charge local businesses the full round trip price for shipping!

Also by Nalcor's own admittance, "From a local economy perspective, one of the implications of a commute workforce living in construction camps is that workers have limited need or ability to spend locally……..businesses in the region where the project is located may capture relatively little of that income." ((Volume 111-Section 3.2.3, Page 3.5) and "Unless addressed explicitly, expenditures by the project proponent on materials, goods, equipment and services may also flow to communities outside the work region. Proponents may prefer to access known suppliers in non-local centers to bring in the required items. The result is a loss of potential benefits to the project area through fly-over effects (Storey 2001)."

Nalcor then refers us to sections 3.6.5 and 3.7.5 to allay the fears that the above two statements instill. However, those sections of the EIS simply give statistics on the GENERAL number of workers that will be needed during the construction and maintenance phases of the Project and without a specific IBA or specific legal agreement with Labradorians as a whole, it is again questionable whether Labrador and Labradorians will be the "primary" beneficiaries of this development!

Grand Riverkeeper Labrador Inc. recommends that the Government of Newfoundland and Labrador be required to follow its own policies on adjacency and require Nalcor Energy to consult with all affected groups in Labrador and that an Impact Benefits Agreement be negotiated that would guarantee specific benefits to all residents of the territory both during the construction phase of the Project and for something similar to an infrastructure fund which would come from the profits from the sale of the power once the project was up and running! Otherwise Labrador residents will again feel, as with many past developments, that the bulk of jobs and spin off benefits will go to companies and workers from the Island portion of the province and other areas of Canada! At the very least, in order to fulfill the Adjacency Policy, Nalcor and the Newfoundland and Labrador Government should be expected to negotiate a financial agreement covering the future profits from the project!

How can such a huge project, in a territory of such diverse and few peoples, proceed without meaningful consultation and Impacts Benefits Agreements with all affected communities? We, in Labrador, live in a Colonial Territory, in as true a sense of those words as any Colonial Territory anywhere in the world was ever described! In other parts of the world colonially owned and controlled territories have won their freedom and the right to self government! Not so in Labrador! It is imperative that our resources be developed to benefit Labradorians first and foremost and our only hope of that ever happening is if we have legally binding documents between all Labradorians and our off -shore Government that gives us some legal recourse! Expecting that benefits which accrue to the Provincial coffers will automatically trickle down to a minority population is not realistic!

<u>SUSTAINABLE DEVELOPMENT and THE PRECAUTIONARY PRINCIPLE:</u>

Following are two of the stated purposes of the Canadian Environmental Assessment Act, Section 4 (1) states: The purposes of this Act are

(a) to ensure that projects are considered in a careful and *precautionary* (emphases added) manner before federal authorities take action in connection with them, in order to ensure that such projects do not cause significant adverse environmental effects; and

(b) to encourage responsible authorities to take actions that promote sustainable development and thereby achieve or maintain a healthy environment and a healthy economy; etc. etc.

Also: The Rio Declaration on Environment and Development defines the "Precautionary Principle" as follows: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to "**prevent**" (emphases added) environmental degradation." (Principle 15)

The Proponent, on the Executive Summary on page 56, uses the meaning of the Precautionary Principle wrongly and twists the words to suit their ends! For example, in Nalcor's example of the loss of habitat for Wetland Sparrows they state unequivocally that habitat for Wetland Sparrows will be inundated and that although they believe enough habitat will remain above the reservoir to assure sustainability of the affected populations, they nevertheless intend to create riparian marsh wetland habitat preferred by these birds even though there is no scientific knowledge or certainty that it will work, and are quoting this as an example of how well they are adhering to the precautionary principle.

It is the opinion of Grand Riverkeeper Labrador that this is a very poor example of adherence to the precautionary principal and that in fact, Nalcor has totally ignored the precautionary principal and blatantly forged ahead knowing there will be destruction of habitat, not only for Wetland Sparrows but for many other wildlife species and fish and what they should be considering where they unequivocally know this project is going to cause habitat loss is other "alternatives to the project" or as the Precautionary Principle states, PREVENTION of the loss of habitat rather than MANAGEMENT of the losses!

Alternatives to the project are covered in greater depth elsewhere, but here is a particular area where proper consideration of other alternatives could PREVENT the loss of habitat for the Wetland Sparrow, but Nalcor has refused to see beyond this one project as a means for energy creation!

Under section 2, page 2-1, of Volume 1, Part A, of the EIS, the need, purpose, alternatives to and rationale for the project are listed.

The needs include future demand for electricity, provision of electric energy for sale to third parties and the development of the Province's natural resource assets for the benefit of the Province.

The main "purpose" of the project as stated in the first two sentences of section 2.3 is two fold; first, "to develop the hydroelectric potential of the lower Churchill River" and second, "In achieving this purpose, the Project will generate revenue for the Province, reduce fossil fuel use and contribute to security of energy supply for the Province and Canada"

With this stated purpose in mind the Project, as registered, therefore cannot be considered sustainable because, technically, this entire "partial" project is registered and being assessed as a construction project only, without a market or a transmission route to get the power to that market, and therefore there is no possibility to accomplish what the Proponent states is the justification/rationale/purpose for the project!

When the Bruntland report, Our Common Future was published in 1987, the stated purpose of "sustainable development" was development that could meet the needs of the present without compromising the ability of future generations to meet their own needs!

While on the face this Project might appear to be satisfying that statement, if one believes that future generations of Labradorians will only want the bit of trickle down money that comes from the off-shore government in Newfoundland. However, if ,on the other hand, we give future Labradorians a bit more credit then we can see that they may be a bit angry at those of us who squandered the natural capitol of the region for short-term monetary benefits!

Sustainable development can be described in terms of several types of capitol; natural, physical, economic, human, social and cultural to name a few! Global resource depletion and pollution are forcing us to recognize that existing patterns of development and resource use are not sustainable. We are now, (at lease many of us), realizing that destroying our natural capitol cannot continue on the path it has been on in the last 100 years. The finite capacity of natural systems like Grand River to produce true "renewable resources" such as forestry products, water supplies, fish, wildlife, flushing and sediment movement, etc. cannot continue if the natural system from which these "renewable resources" are drawn are over-exploited.

Large dam projects like the Lower Churchill Project over-exploits the natural system of rivers; too much habitat is destroyed, too many fish are poisoned or chewed to bits in the turbines or die of bubble disease, the old-growth high-yield fiber forests will be cut unsustainably leaving too many to rot in the reservoirs or beside them as does the wood from the clearing for the third phase of the Trans Labrador Highway still today! None of these actions can be considered sustainable when you consider them in the context of natural capitol!

This kind of natural capitol, the river, flowing freely, supplying the life force needed for the animals, fish and plants it supports is a rare commodity in this world these days! If we destroy even one significant natural asset like this river it can be likened to the destruction of one single body organ or system. How many of these organs or systems can we change or destroy until the entire system fails? This is a question to which the answer is not known exactly by scientists! However, they are today warning us that we may have already reached the point of no return. Now here is a true example of where the Precautionary Principle should come into play!

Considering the number of rivers in the world today that have been damaged by large dams, (some 45,000), and considering the number just on the Quebec/Labrador Peninsula alone and the range of extensive impacts those dams have had on rivers, watersheds and ecosystems where, according to the World Commission on Dams report, "these impacts are more negative than positive and, in many cases, have led to irreversible loss of species and ecosystems.", and considering that "Efforts to date to counter the ecosystem impacts of large dams have met with limited success owing to the lack of attention to anticipating impacts, the poor quality and uncertainty of predictions, the difficulty of coping with all impacts, and the only partial implementation and success of mitigation measures." (ppxxxi), there is no way that this Project can be considered sustainable! (The subject of mitigation and the only marginal possibility of the proposed mitigation measures for lost fish habitat ever being successful in this Project is covered extensively in another section of this submission called FISH HABITAT MITIGATION.)

It is the opinion of Grand Riverkeeper Labrador, Inc. that this "partial" Project must be struck from the CEAA registry and re-registered for a proper assessment once transmission routes for the entire 3074 MW are identified and once potential markets for this power have been established, or, the Proponent must be instructed to register its plans to transmit the balance of power over and above the 800 megawatts in the Labrador-Island Transmission Link registration so that concerned citizens, the Joint Panel and other stakeholders have an opportunity to review these projects that are so closely related that they can and should be considered as one project for the purpose of the assessment! It must also be noted that even though the decision to combine such projects is, in the case of Joint Panel reviews, at the discretion of the Minister, as per Section 15(2) of the CEA Act, it could be concluded that based on Subsection 16 (3) of the Act, the Minister may only be able to exclude or eliminate issues from the scope of the assessment if those issues are not relevant for the final determination of whether the Project is likely to cause significant adverse environmental effects. Based on the statements in the EIS guidelines and the terms of reference for the Panel regarding cumulative effects, it is the opinion of Grand Riverkeeper Labrador that the Ministers made every effort to ensure that any and all cumulative environmental effects from "any past or reasonably foreseeable projects or activities" be considered in this assessment and that transmission lines to take the "for sale" electricity to market represents many adverse environmental effects like deforestation, river crossings, road building, fish and wildlife habitat destruction, radiation from power lines and transformers etc. and that these adverse environmental effects must be considered along with the environmental effects of building the dams! Otherwise, the environmental assessment is being done piece-mill where neither the full range of cumulative effects on the environment nor economic benefits or costs can be properly assessed!

In truth, this "partial Project" can be and is, viewed by many as being in contravention of sections of the Canadian Environmental Assessment Act, specifically: section 15 (2)" *For the purposes of conducting an environmental assessment in respect of two or more projects, (a)the responsible authority, or (b) where at least one of the projects is referred to a mediator or review panel,"* {which this project is} "*the Minister, after consulting with the responsible authority, may determine that the projects are so closely related that they can be considered to form a single project."* Or section 15 (3) "*Where a project is in relation to a physical work, an environmental assessment shall be conducted in respect of every construction, operation, modification, decommissioning, abandonment or other undertaking in relation to that physical work that is proposed by the proponent or that is, in the opinion of (a) the responsible authority, or (b) where the project is referred to a mediator or a review panel, the Minister, after consulting with the responsible authority."*

To assess this project, as it was registered, flies in the face of good Environmental Assessment practices and has the effect of decreasing the public's faith in the entire process!

Along with assessing the cumulative effects of the necessary transmission lines to take this power to market, it is recommended that the proponent do a proper job of laying out the "alternatives to this project" in a way that citizens can properly determine the costs of the alternatives, both economically and ecologically and make an informed decision as to whether they prefer this Project or one of the possible alternatives such as true run-of-river hydro, wind supplemented by the current Churchill Falls Project, or other various scenarios/possibilities of energy creation including the scenario of "do-nothing". (The issue of Alternatives to the Project is covered more extensively in another section of this submission.)

<u>HYDRO AS GREEN ENERGY:</u>

Refer to section 2.4, Volume 1, Part A, Project Rationale:
The proponent makes the following statement: "The value of the Project lies not only in financial benefits from the development itself, but also in the beneficial environmental effect it will have by displacing a large amount of GHG emissions. The displacement of emissions in eastern Canada will help the federal government meet its international

commitments to GHG reductions. The Project will be in an optimal position to make a substantive contribution to meeting the targets established by the federal regulatory framework.", and, "As a source of clean, renewable power, the Project expects to benefit economically from opportunities associated with the various compliance mechanisms outlined in the framework."

The federal regulatory framework for managing greenhouse gas emissions in Canada was released in April 2007 and included as a key element regulated emissions intensity targets for industry as well as a number of flexibility mechanisms that can be used to meet those targets. In March 2008 the government elaborated on its plan with additional details on targets for new units and on the application of flexibility mechanisms. The framework includes an overall national target to reduce GHG emissions to 20% below 2006 levels by 2020 and 60-70% below 2006 levels by 2050 with one of the key elements of the framework being the emissions targets for industrial emitters and their associated flexibility mechanisms. As stated by the Toxics Watch Society of Alberta (TWSA) "The federal framework includes targets that are out of step with climate change science as well as many potential loopholes that threaten to erode the environmental integrity of the system."[1] Also the TWSA states this intensity based system would allow emissions to continue to grow rather than decrease GHGs and recommends a true cap-and-trade system which mirrors that of the European Union's trading system.

Obviously the Proponent has based its statement above on these intensity targets rather than the absolute emissions which a cap-and-trade system would demand. However in the last Speech from the Throne the federal government committed to a North American cap-and-trade system. Reuters reporter David Ljunggren reported on Nov.19, 2008 "Canada's Conservative government shifting positions in the wake of Barack Obama's election as U.S. president, said on Wednsday that it will work to develop a North America-wide cap-and-trade system to limit emissions of greenhouse gases."[2] And, just a few weeks ago, on April 2nd, 2009 an important bill that would set national climate change targets and commit Canada to a responsible international role in dealing with climate change received second reading in the House and is expected to go to third reading sometime in mid June, The Climate Change Accountability Act (BillC-311) will commit Canada to cut GHGs by 25% of 1990 levels by 2020 and 80% below 1990 levels by 2050.

A 2002 article in the journal *World Resource Review* by a team led by Eric Duchemin of the University of Quebec shows the upper limit of gross emissions from Churchill Falls hydro scheme in Labrador to be 70 kt CO_2e/TWh.[3] Also, the Proponent estimates the emissions for the reservoirs will be 1,160,000 tonnes C/yr during the first five years and 125,000 tonnes C/yr in perpetuity. (GHG Emissions study P8-4) This estimate does not include the emissions for the transmission route nor the emissions of nitrous oxide, nor

[1] http://www.toxwatch.ca/node/69

[2] http://www.reuters.com/article/environmentNews/idUSTREKA170120081119

[3] Duchemin *et al* . (2002).

does it include emissions from the construction and decommissioning of the dam sites nor the cumulative effects on the region of the construction of the Labrador-Island Transmission link and future construction of whatever method of delivery for the balance of the power is finally decided on!

To the knowledge of GRKL there is no certification scheme and no international carbon trading organization to date that will agree that "mega" hydro projects can qualify for carbon credits or green certification. The jury is still out even on the Kyoto Clean Development Mechanism. It is therefore incumbent upon the Proponent to provide specific information as to which carbon –trading scheme or certification organization this project will qualify for and provide a copy of the application for certification based on the project description and the final decision made by the qualifying organization. Otherwise claims such as those made in the above referenced section of the EIS should be stricken from the record because they are mere speculation!

Also, since it appears the current government is set to adopt new legislation that will require absolute cuts in GHG emissions rather than the weak intensity based system, it is incumbent on the Proponent to consider "alternatives to this Project" with an emphasis not only on environmental, social and economic sustainability but also with respect to greenhouse gas emissions. GRKL calls for "explicit assessment of future net greenhouse gas emissions of the Project", "through full Life Cycle Assessments to compare available options."[4], for this Project and all **alternatives** to this Project that the Proponent is required to, but has not yet properly presented.

A statement by Philip Raphals of the Helios Centre in the executive summary of his book "Restructured Rivers", Page xiii- under the heading Green power market certification follows:

> "Restructuring" (of the electricity sector) "is radically transforming the electric power industry. Should the process reach its logical conclusion, electric supplies will be chosen by consumers, not utilities, and decisions about future resources will be made not by a regulatory planning process, but rather-like other competitive industries-by private companies making at-risk investments, based on their own estimations of future consumer demand and preferences.
>
> The arrival of competitive markets and subsequent market fragmentation allows environmentally-consious consumers to "vote with their pocketbooks" by choosing to avoid certain energy sources or to support others."[5]

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[4] WCD Press Releases and Announcements www.dams.org/news_events/press357.htm

[5] Restructured Rivers Hydropower in the Era of Competitive Markets, A report prepared by Philip Raphals of the Helios Center and published by International Rivers Network, 2001, E-mail: sec@helioscentre.org Web: http://www.helioscentre.org

The Proponent also states "As a source of clean, renewable power, the Project expects to benefit economically from opportunities associated with the various compliance mechanisms outlined in the framework."

Here again the Proponent is making claims that this Project will qualify to be sold as certified green energy. GRKL has researched the criteria that would need to be met in the United States under the Low Impact Hydropower Institute's certification program[6] and others and the criteria /guidelines for certification under Environment Canada's Eco Logo certification program and based on their criteria this Project would not qualify as Green Energy and would therefore not benefit from being sold to environmentally-conscious consumers as Clean/Green energy. In fact it is likely that cheaper coal-produced electricity would displace this more expensive "renewable" energy!

Again, the Proponent must show exactly which certification program it has applied to or intends to apply to for certification as green energy and prove that this Project will fulfill the criteria for certification before they can make sweeping statements about being a source of clean, renewable power and they must re-assess benefiting economically from opportunities associated with various compliance mechanisms in the wake of highly likely policy and legislative changes on greenhouse gas emissions.

ALTERNATIVES TO THE PROJECT

A very short and sweet section on alternatives to the project is supposed to satisfy the reader that the Proponent has made every effort to determine whether the best use of 12 to 15 billion dollars of tax payers money is for this proposed project rather than another

[6] Low Impact Hydropower Institute. Portland, Maine, www.lowimpacthydro.org

type of project or combination of projects. There simply isn't enough information to even make an assumption. As stated by Lutterman [7]

> "Although development of the Lower Churchill has been considered for decades, it has not been evaluated openly, relative to alternative societal level objectives and specific courses of action. These may be various possible uses of the land, methods of producing and using energy, economic opportunities, lifestyles, etc. If alternatives are not thoroughly scoped at the initial planning stages, launching into a detailed study of one proposed project may create unnecessary expenditure and effort if that project is not ultimately carried out.
>
> The first step in a planning procedure, before considering a detailed EIA for such a large energy production project affecting public lands and using public funds should be a process of consensus seeking involving the investigation of the pros and cons of various possible competing alternatives (Oud and Muir 1997). This must have full participation of the interested parties, particularly those most directly affected by the proposed project.
>
> Issues to be considered would include the various social, environmental, economic. Technical, financial, institutional and political benefits and risk factors involved in different development scenarios, with and without mega-projects. It is essentially a policy and planning review of the energy sector with well I nformed public participation. Scenarios which focus on demand-side management (DSM) must be included, with recognition that in the long term, continued human population and economic growth, fuelled by massive energy consumption, may not be sustainable or desirable."

These are the criteria which must be followed if the Proponent is to truly adhere to section 16 (1) (e) The Panel should instruct the Proponent to go back to the drawing board and do their homework. There are many and varied other ways to create energy that is less damaging to the environment and likely less expensive and there are many and varied ways to spend 12 to 15 billion dollars that could enhance the lives of Newfoundlanders and Labradorians beyond what this proposed Hydro project can.

RED WINE CARIBOU HERD

As the river valley floods, moose and wolves currently living in the riparian zone will necessarily have to move up the side of the river valley and onto the plateau above. This area is the traditional foraging grounds for the Red Wine herd. The Proponent has not made it clear what effect the appearance of more wolves will have on the herd. What

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[77] Lutterman A "Assessing Further Hydroelectric Development on the Lower Churchill River, Labrador: What can we hope to achieve? Assessment and Impacts of Mega Projects Proceedings of the 38th Annual Meeting of the Canadian Society of Environmental Biologists in collaboration with the Newfoundland and Labrador Environment Network, St. John's Nfld. Canada, October 1-3, 1998

Nalcor does say is that other factors are already greatly affecting the survival of the heard and that it may disappear anyway, whether the hydro project is built or not. This should be no reason for Nalcor to neglect its duty to fully protect this endangered herd. Two wrongs do not a right make! Please ask the Proponent to do the studies necessary to ensure the Red Wine Herd is fully protected.

CUMULATIVE EFFECTS:

To introduce this section we quote a couple of important paragraphs from Chapter 3, Page 88 of the World Commission on Dams report "Dams and Development" [8] (copy attached) Section heading:

> Cumulative Impacts
>
> "Many of the major catchment areas in the world now contain multiple dams. Within a basin, the greater the number of dams, the greater the fragmentation of river ecosystems. An estimated 60% of the world's large river basins are highly or moderately fragmented by dams(see figure 3.6). The magnitude of river fragmentation can be very high. In Sweden, for example, only three major rivers longer than 150 km and six minor rivers have not been affected by dams. [46]
>
> Although seldom analyzed, cumulative impacts occur when several dams are built on a single river. They affect both the physical (first-order) variables, such as flow regime and water quality, and the productivity and species composition of different rivers. The problems may be magnified as more large dams are added to a river system, resulting in an increased and cumulative loss of natural resources, habitat quality, environmental sustainability and ecosystem integrity.

We also quote from Schedule 1- Terms of Reference for the Panel: Under Part 11-Scope of the Environmental Assessment:

"The Panel shall consider th e following factors in the EA of the Project/Undertaking as outlined in Sections 16 (1) and 16 (2) of the CEAA and Sections 57 and 69 of the EPA:" Item # 10 in the Terms of Reference for the Panel, " Any cumulative Environmental Effects that are likely to result from the Project/Undertaking, in combination with other projects or activities that have been or will be carried out;"

As well, section 4.5.3, **Cumulative Effects** on page 35 of the Environmental Impact Statement Guidelines states as follows:

> "The Proponent shall identify and assess the Project's cumulative environmental effects. Cumulative environmental effects are defined as changes to the

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> environment due to the Project where those overlap, combine or interact with the environmental effects of other existing, past or reasonably foreseeable projects or activities. In the cumulative effects assessment, the Proponent shall consider guidance provided by the Canadian Environmental Assessment Agency in its Cumulative Effects Assessment Practioners Guide (1999) and other literature and experience with environmental assessment in Canada or elsewhere that it finds helpful in framing the cumulative environmental effects analysis."

(copy of the 1999 Cumulative Effects Assessment Practioners Guide is attached)

In interpreting the above statements, the effects of the existing Upper Churchill project must be considered when determining "significant adverse environmental effects". This "existing" "past" project's effects on the land, the water, the fish and wildlife, and all other Valued Ecosystem Components also must be considered under cumulative effects! The understanding of these statements is also that the environmental effects of the "reasonably foreseeable" Labrador-Island Transmission Route must be considered along with whatever other means of transmission the Proponent eventually uses to transport all of this power to markets. **GRKL sees no other possible interpretation of these statements!**

Currently the Proponent devotes only a few short paragraphs in the Biophysical Assessment, Volume 11 Part A and Volume 11 Part B to cumulative effects and discusses only the Trans Labrador Highway, Cultural and Recreational Land Use, the NATO Special Forces Training, Commercial forestry, and the additional Transmission lines between the proposed dams and Churchill Falls. "The Churchill River watershed has already undergone substantial alterations with the construction of the hydroelectric complex on the upper river system in the early 1970's. The environmental and socioeconomic effects of this project have yet to be fully assessed to the best of our abilities. This fact seriously weakens the potential for cumulative assessment within the watershed and the broader landscape. A broad, eco-regional planning approach is necessary to begin to gain an integrated understanding of the changes created by the totality of human activities on this landscape.[9]The Proponent is working within a narrow conceptual framework that considers cumulative effects to mean only those project effects that directly overlap spatially. In the past, Innu and Metis have repeatedly emphasized the importance of thoroughly considering the environmental degradation that has already occurred as a result of the Churchill Falls project prior to and in concert with evaluating the effects of new hydroelectric facilities in the region. They want to see that cumulative effects assessment is conducted using a broad spatial and temporal scope that at the very least includes other developments within the water shed. [10] This restrictive

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[9] Lutterman, A, "Assessing Further Hydroelectric Development on the Lower Churchill River, Labrador: What Can We Hope to Achieve? Assessment And Impacts of Megaprojects, Proceedingsof the 38th Annual Meeting of the Canadian Society of Environmental Biologists in collaboration with the Newfoundland and Labrador Environment Network, St. John's, Nfld. Canada, October 1-3, 1998 - p87

[10] Luttermann, A, 2007 Historical Changes in Riparian Habitats of Labrador's Chirchill River Due to Flow Regulation: The Imperative of Cumulative Effects Assessment. Submitted in partial fulfillment of the reqirements for the degree of Doctor of Philosophy at Dalhousie University, Halifax, Nova Scotia July 2007

way of dealing with cumulative impacts does not conform to the understanding of the wording in the Act, the Terms of Reference for the Panel nor in the EIS Guidelines!

RESERVOIRS AND FLOODING:

In table 1B-1-, Environmental Impact Statement Issues Concordance-Public Consultation, Volume 1, Part B, the Proponent lists chapters in the EIS where specific concerns of the public have been addressed: One of those questions reportedly asked by Grand Riverkeeper is listed as follows:

> "EIS should include an analysis of the "true" amount of land that would be flooded by the project-not just the area "looking straight down" (85km^2), but the total area taking into consideration the topography and slope of land. Could the project cause flooding of Mudlake"

The question, as reported by Nalcor above does not accurately quote what Grand Riverkeeper asked about the reservoir flooding. We might add, we have asked that this information be provided not on just one occasion, but on at least 3 occasions in various meetings with NL Hydro and with Nalcor and finally in our submission/comments on the draft EIS Guidelines.

In our submission/comments on the draft Guidelines, **under SECTION 1-Background, Purpose of the Guidelines, Proposed Project,** we make it as clear as we know how that what we want the Proponent to do is not to simply show us maps of what the river will look like once the inundation takes place, but explain to us what analytical methods they used to come to those inundation amounts. We quote here exactly what we stated in our submission/comments on the guidelines, which can be found on the CEAA web site:

> "Regarding total area of inundation for the Gull Island and Muskrat reservoirs: Newfoundland and Labrador Hydro has been asked to provide information on the calculation methods used to determine the area of land that will be inundated. Thus far we have not received a response. We recommend the guidelines ask that NL Hydro provide, in layman's terms, a complete and transparent report on exactly how the inundation figures were determined, what methods were used and what the percentage of error is for those methods."

Again, Grand Riverkeeper Labrador asks that the Proponent provide the "math" or the "methods" or whatever model, assumptions, calculations etc. were used to determine the amount of km^2 of "land" that will be inundated! We continue to ask for this information because we feel there are significant errors in the calculations. However, unless we know the methods used by Nalcor to calculate the inundation it is impossible for us to have our GIS expert re-create the inundation! What Nalcor has done in answer to our repeated questions on this matter is to simply refer us back to their maps of the inundation. We repeat, we feel there may be errors in their calculations but unless we know what methods they used to calculate, then we have no way of verifying whether they are right or wrong!

OLD GROWTH FORESTS OF THE GRAND (A.K.A.CHURCHILL) RIVER VALLEY NOT CONSIDERED AS A VALUED ECOSYSTEM COMPONENT

According to the Canadian Environmental Assessment Agency, a widely recognized approach to identify Valued Ecosystem Components (VECs) is:

> *Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process. Importance may be determined on the basis of cultural values or scientific concern (CEAA, 1999)*

OR: Valued Ecosystem Components (VECs) are features of the environment selected to be a focus of the EA study because of their ecological, social, cultural and economic value, and their potential vulnerability to the effects of a project.

While it is not practicable to assess every potential effect on every component, assessment must therefore focus on the components that have the greatest relevance in terms of value and sensitivity to the particular circumstances of the development under review! It can be shown that in most submissions/comments about the potential adverse environmental effects of the Lower Churchill Hydroelectric project, the old growth boreal forests of the Grand River valley have been mentioned time and time again. It is therefore surprising and disappointing that these forests were not considered as a valued ecosystem component except in the context of how or if they were to be cut.

The CEAA states, “To be considered a VEC the component must be known to occur in the project study area, and there must be reasonable likelihood that it would be affected by or have an influence on the project.” The old-growth forests in the river valley surely qualify on both counts!

We have lost nearly half--almost three billion hectares--of the forests that once blanketed the earth. In the past five decades alone, nearly a fifth of the earth's forested areas have been cleared. Industrial logging, a major factor in the loss of forests, has doubled since 1950. Seventy-six countries have lost all of their frontier forest (large tracts of relatively undisturbed original forest). The numbers don't lie--our forests are disappearing.

Forests are vital to the health of the planet. Old-growth forests in particular play a critical role in storing water and carbon, filtering air, moderating the climate, conserving soil and providing habitat for wildlife. Yet according to the U.N., we are losing over 16 million hectares of forest each year. The consequences of this loss for biodiversity, global warming and indigenous cultures has caused great concern for members of Grand Riverkeeper and, not surprisingly, some of us have doubled as members of the local concerned citizen’s forestry group!

As stated above, the forests of the Grand (a.k.a. Churchill) River valley are old-growth boreal forest, considered so important that for years this area was completely removed from the Annual allowable cut of the District 19A forestry plan and considered "pristine"

forest! Why now then is it first; OK not only to cut this forest at an alarming rate, i.e. around 200,000 m^3 per year for the next 8 to 9 years, (an amount equal to the AAC for the entire District 19A's forestry plan,) but also, there appears to be no specific plan to utilize the fibre from those trees and, this valuable ecosystem doesn't even rate its own VEC studies within this environmental assessment!

Grand Riverkeeper Labrador recommends that the Proponent be required to assess the potential of these old growth forests both in the context of economic benefit to local harvesters over the next 9 years should that option become available to them (and we understand from local foresters that the wood in the river valley is mostly high dollar fibre) and also in the context of the forests services as carbon sinks, air filtering, soil conservation, wildlife habitat and climate moderation if the forests were left alone to continue to produce!

PUBLIC PARTICIPATION/CONSULTATION

Nalcor "consulted' with the people, but it was not a totally effective process for several reasons. One fault is that is was not a real consultation process, but rather a presentation of what they planned to do and at the end they listed the concerns that were brought up. As well, there were practical and technical issues to do with meetings and presentations.

In Nalcor's Executive Summary, P.25, they state that they rely "on a program of consultation whereby the interested public learns of the Project and documents areas of concern…" In Vol. 1 Part A, 7.3, methods used are listed, including Website, Newsletter, Information Sheets, Posters, Exit surveys, Open House, Technical Workshops. In Vol. 1, Part A, 7.4.2, "a second energy alternatives workshop is planned for Happy valley-Goose Bay, as a number of interested parties were unable to participate in the first workshop."

With regards to the statement "consulted with the people". While Nalcor did carefully present what it had planned and heard people's questions and yes, documented them, it was not an effective process because there was no dialogue and consensus encouraged. (This is in contrast to the Forest Management Plan of District 19A which did engage in an effective process where the diverging parties were able to work out acceptable solutions).

The technical workshops lacked an agenda, did not provide background information before the workshop, were not open to the public (but instead Nalcor selected who they judged might be interested). In the case of the Alternatives Workshop for Happy Valley-

Goose Bay, only three days notice was given, (so many could not attend) and, although another has been promised, it has not happened.

As an added note, the EIS materials may have been available on CD from the internet, but Mac users were not able to open them, even though they were PDF files.

However, most importantly, the process that Nalcor chose for some of their "consultations" does not accomplish a consensus of approval by the people of Labrador who are most affected by this project. It leaves the potential for even greater political rift between the Island of Newfoundland and Labradorians.

GRKL recommends that Nalcor now proceed with the effort of consensus-building on this Project and adopt newer ways of relating to the people of Labrador. It resembles 'going back to the drawing board' bit it is only in this manner that the Project in a newer form may be accepted by the people of Labrador. Nalcor also needs to question its assumptions that a Labrador economy of aluminium smelters and uranium mines after the destruction of the Lower Grand (Churchill) River is the best use of the money required for the project. Nalcor representatives who are involved in consultation in Labrador need to learn best principles for consultation like that practised by the Forestry Officials. Also, many groups who are working on the review of the environmental assessment of this project are doing so at their own personal cost while Nalcor employees are well paid for their input. Yet, volunteer groups are often expected to attend meetings during working hours or evenings after work. Nalcor could consider minimal support for these groups, such as milage and meeting preparation costs (e.g. photocopying).

EMERGENCY PREPAREDNESS PLAN

In Volume 1, Part A, 4.11.3.2 states: When addressing Countermeasures/Prevention of Dam Failure, that "an Emergency Preparedness Plan (EPP) will be prepared and in place for the full cycle of the Project, including the construction phase". The components of the Emergency Preparedness Plan are outlined.

In order to understand the Project and the risks, (even though they might be unlikely-if they were to happen they would be catastrophic),the comprehensive details of the EPP need to be part of the EIS. The community needs to know the specific areas that might be affected in dam failure and the explicit plans for their rescue need to be spelled out. Rather than saying an EPP "will" be prepared (presumably at some point in the process), there is sufficient information to allow the EPP to be prepared now.

As described in Vol. 1, Part A, 3.4.1.3, Nalcor's SHERP would contain the plans of responding authorities. E.g. Emergency Measures Organization.

As an added note, a SHERP "was developed and implemented during the engineering and environmental field program". But, this does not explain why a tug boat now rests at the bottom of Grizzle Rapids! More care must be taken.

ICE DNAMICS/MUDLAKE

The Hydrology study, Component Studies Aquatic Environment (2) report 4 of 8, Ice Dynamics of the Lower Churchill River page 7-2 makes the following statement:

> "*Mud Lake: Based on the results presented above, it is expected that there will be a delay of approximately two weeks for an ice road between Mud Lake and Happy Valley to become usable. The warm up period is expected to be delayed by about one week, hence the overall duration of usage will be reduced by about one week.*"

This statement must now be re-considered and new studies done in light of traditional knowledge of the river crossing provided by residents of Mud Lake and agreed to by members of Nalcor.

Other ice problems must also be considered: Example: Rosenberg et al state:

> "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, but also the fouling of fish nets by debris."[11]

The project is very likely to create such "hanging ice" making winter travel hazardous and mitigation measures must be put in place to warn people where these places might exist. If mitigation is not possible then compensation must be considered for those hunters/trappers and wood harvesters who currently use the river for travel during the winter.

[11] [11] Rosenberg, D M, Environmental and social impacts of large scale hydroelectric development: who is listening? *Glbal Environmental Change Vol.5 no.2, p 127-1481995*

FISH HABITAT CREATION AND COMPENSATION

Vol.11 Part A, section 4.10.2 states: "While it is likely that the dominant change resulting from the Project will be an increase in the available quantity of fish habitat and an overall gain in productive capacity, some Project features or conditions will result in a HADD."

This statement is suspect! For example, P M Ryan of Ryan Environmental, Mobile, Newfoundland, retired Fisheries and Oceans Scientist states in an article entitled A Model For Freshwater Habitat Compensation Agreements based on relative salmonid production potential of lakes and rivers in insular Newfoundland, Canada [12] (article attached)

> "In this paper, estimated average values of Atlantic salmon (Salmo salar) smolt production in Newfoundland lakes and rivers are used in a calculation of the relative production potential of the two habitat types. The calculated relationship suggests that appropriate compensation for a hectare of lake habitat which is to be harmed, altered, disrupted or destroyed might be the creation of, or making available for use, 0.023 hectare of river suitable for salmonid habitat. Alternatively, appropriate compensation for a hectare of river habitat which is to be harmed, altered, disrupted, or destroyed might be the creation of, or making available for use, 42.857 hectares of lake suitable for salmonid habitat."

While Ryan admits there might be special circumstances such as trophy fish stocks and particular habitats like very popular fishing areas or critical spawning areas that might influence these figures somewhat, generally the correspondence of potential salmonid production between the two habitat types may serve as a model for use in the preparation of freshwater habitat compensation agreements.

The Proponent appears to be using a one-for-one ratio of compensation for lost riverine habitat which is not acceptable. GRKL recommends the Proponent be required to adjust the number of hectares of lake (reservoir) habitat that must be created to

[12] Ryan, P M, "A Model for Freshwater Habitat Compensation Agreements Based on Relative Salmonid Production Potential of Lakes and Rivers in Insular Newfoundland, Canada, Assessment and Impacts of Megaprojects, Proceedings of the 38th Annual Meeting of the Canadian Society of Environmental Biologists in collaboration with the Newfoundland and Labrador Environment Network, St. John's, Nfld, Canada, October 1-3, 1998, Edited by Patrick M. Ryan

compensate for the lost riverine habitat using the production potential model set out by former DFO Scientist Patrick Ryan.

GRKL is also concerned that any compensation package proposed by the Proponent and agreed upon by DFO would not be worth the paper it was written on and we base our opinion on studies done by current DFO scientists Jason Quigley and others. (copy attached) In the abstract of Quigley's article he states the following:

Published online: 2 February 2006

Abstract Fish habitat loss has been prevalent over the last century in Canada. To prevent further erosion of the resource base and ensure sustainable development, Fisheries and Oceans Canada enacted the habitat provisions of the *Fisheries Act* in 1976. In 1986, this was articulated by a policy that a "harmful alteration, disruption, or destruction to fish habitat" (HADD) cannot occur unless authorised with legally binding compensatory habitat to offset the HADD. Despite Canada's progressive conservation policies, the effectiveness of compensation habitat in replicating ecosystem function has never been tested on a national scale. The effectiveness of habitat compensation projects in achieving no net loss of habitat productivity (NNL) was evaluated at 16 sites across Canada. Periphyton biomass, invertebrate density, fish biomass, and riparian vegetation density were used as indicators of habitat productivity. Approximately 63% of projects resulted in net losses in habitat productivity. These projects were characterised by mean compensation ratios (area gain:area loss) of 0.7:1. Twenty-five percent of projects achieved NNL and 12% of projects achieved a net gain in habitat productivity. These projects were characterised by mean ratios of 1.1:1 and 4.8:1, respectively. We demonstrated that artificially increasing ratios to 2:1 was not sufficient to achieve NNL for all projects. The ability to replicate ecosystem function is clearly limited. Improvements in both compensation science and institutional approaches are recommended to achieve Canada's conservation goal.
As well a just recently released report of the Commissioner of the Environment and Sustainable Development-Spring 2009 called Protecting Fish Habitat: below is an excerpt from pages 12 & 13. The complete article is attached.

"**What we found** • Fisheries and Oceans Canada and Environment Canada cannotdemonstrate that fish habitat is being adequately protected as the *Fisheries Act* requires. In the 23 years since the Habitat Policy was adopted, many parts of the Policy have been implemented only partially by Fisheries and Oceans Canada or not at all. The Department does not measure habitat loss or gain. It has limited information on the state of fish habitat across Canada—that is, on fish stocks, the amount and quality of fish habitat, contaminants in fish, and overall water quality. Fisheries and Oceans Canada still cannot determine the extent to which it is progressing toward the Policy's long-term objective of a net gain in fish habitat. There has been little progress since 2001, when we last reported on this matter.

• Fisheries and Oceans Canada has made progress in implementing the Environmental Process Modernization Plan (EPMP) so that it can better manage risks that various projects pose to fish habitat. Under the Plan, the Department does not require that proposals for low-risk projects be submitted to it for review, relying instead on project proponents to voluntarily comply with habitat protection measures and conditions. This streamlining of the review process was intended to free up departmental resources for review of projects that pose a higher risk to habitat. For those projects that it has reviewed, however, the Department has little documentation to show that it monitored the actual habitat loss that occurred, whether habitat was protected by mitigation measures required as a condition for project approval, or the extent to which project proponents compensated for any habitat loss. Moreover, the Department reduced enforcement activity by half and at the time of our audit had not yet hired habitat monitors to offset this reduction.

• Environment Canada has not clearly identified what it has to do to fulfill its responsibility for the *Fisheries Act* provisions that prohibit the deposit of substances harmful to fish in waters they frequent. It has not established clear priorities or expected results for its administration of the prohibition. Since 2005, departmental initiatives have identified the need for national guidance and coordination in administering the Act's provisions. However, the Department's activities have been largely reactive and inconsistent across the country.

• Environment Canada does not have a systematic approach to addressing risks of non-compliance with the Act that allows it to focus its resources where significant harm to fish habitat is most likely to occur. Further, it has not determined whether the stringent pollution prohibition of the *Fisheries Act* is being satisfied by the combination of the results achieved from its own activities under both the *Fisheries Act* and the *Canadian Environmental Protection Act, 1999*, and those achieved by other levels of government.

• Many of the issues raised in this report are long-standing and have been identified in previous audits that we have carried out. For example, we have previously observed that Fisheries and Oceans Canada had not implemented aspects of the Habitat Policy; that it did not know whether it was progressing toward the ultimate objective of a net gain in fish habitat; and that it needed to devote more time and effort to monitoring compliance with the habitat protection provisions of the *Fisheries Act*.

The departments have responded. Fisheries and Oceans Canada and Environment Canada agree with our recommendations. Their detailed responses follow each recommendation throughout the chapter."

And this is the Department of Government that the people of Labrador are asked to trust when they tell us they will review the Proponents habitat compensation package and monitor to ensure that the compensation works and there is no net loss of fish habitat and production! We at GRKL do not accept any compensation package from the Proponent and agreed upon by DFO, until the entire package has been peer reviewed by an independent organization and we find it extremely difficult to believe that anyone else in the territory or in the country for that matter would accept it either.

The Proponent must accept that this project will result in harmful alteration, disruption and destruction of fish habitat causing significant adverse environmental effects and take their chances with the environmental assessment. Mitigation is not possible based on the figures quoted by Ryan and even if there were enough lake habitat to replace the river habitat that will be lost, we cannot imagine who would take the risk that DFO would properly assess the Proponents mitigation measures and do the follow-up necessary to ensure that there is no net loss of habitat!

DOWNSTREAM EFFECTS OF THE PROJECT

Throughout the entire Environmental Impact Statement, the Proponent assures us that there will be no environmental effects from this Project felt out past the mouth of the River. They even go so far as to explain that any flooding from a dam failure would peak at Happy Valley at approximately 6.7 M but then go on to say that no flooding would extend past the mouth of the river which is just a short distance further!

We believe the Proponent is careful to insist that everything stops at the mouth of the river because to admit otherwise means many other studies would have to be done on Lake Melville. We question the Proponents assumptions based on information from a report they have used themselves in some of the component studies; namely, Rosenberg et al, Large Scale Impacts of Hydroelectric development[13]. Rosenberg states the following:

> "Ironically, changes in the natural hydrological cycle as a result of water storage for power production and interbasin water diversion ultimately cause downstream freshwater and marine resources to be wasted. This impact can operate at the

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[13 13 13] Rosenberg, D M, Environmental and social impacts of large scale hydroelectric development: who is listening? *Glbal Environmental Change Vol.5 no.2, p 127-1481995* scale of thousands of kilometres from the source of the problem, although some predicted effects on marine currents and changes in climate expand the spatial scale even more. Temporally changes to downstream areas can be regarded as very long term, unless some effort is made to operate upstream facilities in a way that mimics natural hydrological flows."

GRKL recommends the Proponent re-assess their insistence that no effects will pass the mouth of the river and do the appropriate studies to reflect this.

Thank you for considering our comments and should you need clarification or copies of referenced work please do not hesitate to get in touch with either Roberta Frampton Benefiel at <email address removed> or Clarice Blake Rudkowski at <email address removed>
or telephone <contact information removed>

Chapter

1

Protecting Fish Habitat

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Protecting Fish Habitat

Main Points

What we examined

Healthy habitat—places where fish can spawn, feed, grow, and live—is a fundamental requirement for sustaining fish. Fisheries and Oceans Canada is responsible for administering and enforcing the fish habitat protection provisions of the *Fisheries Act*. This includes reviewing proposed development projects in or near water to ensure that they do not damage fish habitat—or, if habitat loss is unavoidable, that habitat is created elsewhere to compensate. This is the "no net loss" principle of the Habitat Policy. In the 2006–07 fiscal year, Fisheries and Oceans Canada spent $70 million on activities related to protecting fish habitat.

The pollution prevention provisions of the *Fisheries Act* prohibit the deposit of substances that can harm fish; they can enter habitat in several ways, for example, in municipal wastewater and industrial effluent. These provisions of the Act have been Environment Canada's responsibility since 1978. For the 2008–09 fiscal year, Environment Canada planned to spend $5.5 million to administer the pollution prevention provisions.

Our audit examined how both departments carry out their respective responsibilities for fish habitat protection and pollution prevention under the *Fisheries Act*. We also looked at their arrangements with others, such as provinces and stakeholders, that support the administration and enforcement of these provisions. In addition, we looked at Fisheries and Oceans Canada's Environmental Process Modernization Plan (EPMP), its continuous improvement plan introduced in 2004.

Our audit work focused mainly on fish habitat in fresh water and estuaries rather than the marine environment.

Why it's important

Fish habitat represents national assets that provide food and shelter for aquatic and terrestrial wildlife and water for human consumption and other uses. For Canada, with over one million lakes and the world's longest coastline, protecting fish habitat is a challenge, given the impact of economic activity and the number of jurisdictions where inland waters and fish habitat are found. The fish habitat protection and pollution prevention provisions of the *Fisheries Act* are among the federal government's important pieces of environmental legislation, especially as it relates to aquatic ecosystems.

The state of fish habitat is of concern to Canadians who make their living from commercial fishing or who enjoy recreational fishing—industries that together contribute billions of dollars to Canada's economy.

About one quarter of all petitions sent to our Office by Canadians relate to fish habitat issues.

What we found

- Fisheries and Oceans Canada and Environment Canada cannot demonstrate that fish habitat is being adequately protected as the *Fisheries Act* requires. In the 23 years since the Habitat Policy was adopted, many parts of the Policy have been implemented only partially by Fisheries and Oceans Canada or not at all. The Department does not measure habitat loss or gain. It has limited information on the state of fish habitat across Canada—that is, on fish stocks, the amount and quality of fish habitat, contaminants in fish, and overall water quality. Fisheries and Oceans Canada still cannot determine the extent to which it is progressing toward the Policy's long-term objective of a net gain in fish habitat. There has been little progress since 2001, when we last reported on this matter.
- Fisheries and Oceans Canada has made progress in implementing the Environmental Process Modernization Plan (EPMP) so that it can better manage risks that various projects pose to fish habitat. Under the Plan, the Department does not require that proposals for low-risk projects be submitted to it for review, relying instead on project proponents to voluntarily comply with habitat protection measures and conditions. This streamlining of the review process was intended to free up departmental resources for review of projects that pose a higher risk to habitat. For those projects that it has reviewed, however, the Department has little documentation to show that it monitored the actual habitat loss that occurred, whether habitat was protected by mitigation measures required as a condition for project approval, or the extent to which project proponents compensated for any habitat loss. Moreover, the Department reduced enforcement activity by half and at the time of our audit had not yet hired habitat monitors to offset this reduction.
- Environment Canada has not clearly identified what it has to do to fulfill its responsibility for the *Fisheries Act* provisions that prohibit the deposit of substances harmful to fish in waters they frequent. It has not established clear priorities or expected results for its

administration of the prohibition. Since 2005, departmental initiatives have identified the need for national guidance and coordination in administering the Act's provisions. However, the Department's activities have been largely reactive and inconsistent across the country.

- Environment Canada does not have a systematic approach to addressing risks of non-compliance with the Act that allows it to focus its resources where significant harm to fish habitat is most likely to occur. Further, it has not determined whether the stringent pollution prohibition of the *Fisheries Act* is being satisfied by the combination of the results achieved from its own activities under both the *Fisheries Act* and the *Canadian Environmental Protection Act, 1999*, and those achieved by other levels of government.
- Many of the issues raised in this report are long-standing and have been identified in previous audits that we have carried out. For example, we have previously observed that Fisheries and Oceans Canada had not implemented aspects of the Habitat Policy; that it did not know whether it was progressing toward the ultimate objective of a net gain in fish habitat; and that it needed to devote more time and effort to monitoring compliance with the habitat protection provisions of the *Fisheries Act*.

The departments have responded. Fisheries and Oceans Canada and Environment Canada agree with our recommendations. Their detailed responses follow each recommendation throughout the chapter.

Introduction

Importance of fish and fish habitat

1.1 Fish are an important renewable marine and freshwater resource for Canada. For First Nations, fish are a central part of their culture and a vital food source. For other communities throughout Canada, fish have an economic significance for both commercial and recreational purposes. For example, in 2005

- the total value of commercial fish landed was $2.1 billion; 52,805 people were employed in fishing and 29,342 in fish processing; and
- more than 3.2 million adult anglers participated in recreational fishing, which contributed $7.5 billion to the Canadian economy.

1.2 Fish habitat represents assets that are important not only for fish, but also for human health and recreational use. Healthy habitat—places where fish can spawn, feed, grow, and live—is a fundamental requirement for sustaining fish, providing food and shelter for aquatic and terrestrial wildlife, and contributing to water quality for human consumption and other uses. Canada has more than one million lakes, and nine percent of the country's surface is covered by fresh water. It also has the world's longest coastline, and there are interjurisdictional issues with provinces. Fish habitat is under constant pressure from population growth and urban expansion. Many studies have indicated that damage to habitat is one of the key factors in threats to fish stocks.

The federal role in protecting fish habitat

1.3 The federal government is responsible for sea-coast and inland fisheries under the *Constitution Act*, 1867. The *Fisheries Act* contains provisions directed at protecting fish and fish habitat from certain human activity. The two principal sections of the Act examined in this audit are

- the fish habitat protection provisions that prohibit the harmful alteration, disruption, or destruction of fish habitat; and
- the pollution prevention provisions that prohibit the deposit of deleterious or harmful substances into waters frequented by fish.

1.4 The Minister of Fisheries and Oceans is responsible for the administration and enforcement of the *Fisheries Act*. However, in 1978, the Prime Minister assigned responsibility for the administration of the pollution prevention provisions to the Minister of the Environment. The Minister of the Environment was to introduce new environmental protection legislation that included water pollution protection, and repeal aspects of the *Fisheries Act* pollution prevention provisions. While the *Canadian Environmental Protection Act, 1999* provides protection against water pollution, the *Fisheries Act* pollution protection provisions were not repealed.

1.5 The 1986 Policy for the Management of Fish Habitat (Habitat Policy) remains the current policy for the protection of fish habitat. The Policy established a long-term objective of a net gain of habitat for Canada's fisheries resources. It also set out policy goals and strategies for the management of fish habitat supporting freshwater and marine fisheries. Environment Canada's administration of the Act's pollution prevention provisions is covered by the Habitat Policy, but it primarily focuses on Fisheries and Oceans Canada.

1.6 The 2001 Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the *Fisheries Act* (Compliance and Enforcement Policy) applies to both departments. It sets out the general principles for promoting, monitoring, and enforcing the *Fisheries Act* and explains the role of regulatory officials in enforcing the Act.

Habitat Management Program

1.7 Under the *Fisheries Act*, the Minister of Fisheries and Oceans has exclusive responsibility for decision-making authority related to habitat management. Within Fisheries and Oceans Canada, the Habitat Management Program has the primary responsibility for habitat. The Program is a major federal regulator for development projects occurring in, around, or with fresh and marine fish-bearing waters across Canada. It collaborates and works with the Fisheries and Aquaculture Management Sector's Conservation and Protection Program that carries out enforcement and the Science Sector's programs that provide research, scientific advice, monitoring, data management, and products.

1.8 The Habitat Management Program also works with other federal departments and agencies and with provinces, territories, municipalities, industry, and conservation groups, as well as consulting with First Nations, on the following objectives:

- to protect and conserve fish habitat in support of Canada's coastal and inland fisheries resources;
- to ensure that environmental assessments are conducted under the *Canadian Environmental Assessment Act*, or other

environmental assessment regime, before Fisheries and Oceans Canada makes a regulatory decision under the habitat provisions of the *Fisheries Act;* and

- to ensure that the requirements of the *Species at Risk Act* are met.

1.9 The Habitat Management Program is delivered across 6 regions in about 65 offices. From 2004 to 2008, the total number of full-time equivalents decreased from 460 to 430. In the 2006–07 fiscal year, Fisheries and Oceans Canada spent $70 million on activities related to protecting fish habitat.

Pollution prevention provisions

1.10 Environment Canada administers the pollution prevention provisions of the *Fisheries Act* within its existing organizational structure that also supports its other legislative responsibilities, such as the *Canadian Environmental Protection Act, 1999*. It does not have a separate *Fisheries Act* program. The Department's Environmental Stewardship Branch administers the *Pulp and Paper Effluent Regulations* and the *Metal Mining Effluent Regulations* under the *Fisheries Act's* pollution prevention provisions and is developing regulations for wastewater effluent.

1.11 For the 2008–09 fiscal year, Environment Canada planned to spend $5.5 million and employ about 55 employees to administer the pollution prevention provisions.

1.12 Environment Canada's 2008–09 planned spending for the Department's enforcement activities was $43.1 million, including spending on enforcement activities related to the *Fisheries Act*. As of October 2008, the Department's Enforcement Branch employed 198 enforcement officers. These officers are designated as inspectors under the *Fisheries Act* and are therefore responsible for enforcing the pollution prevention provisions, among other duties related to other legislation.

Previous audits

1.13 Our Office has included fish habitat in the scope of previous audits in the following reports:

- December 1997 Auditor General's Report, Chapter 28, Fisheries and Oceans Canada—Pacific Salmon: Sustainability of the Resource Base

- May 1999 Report of the Commissioner of the Environment and Sustainable Development, Chapter 5, Streamlining Environmental Protection Through Federal-Provincial Agreements: Are They Working?
- October 2001 Report of the Commissioner of the Environment and Sustainable Development, Chapter 1, A Legacy Worth Protecting: Charting a Sustainable Course in the Great Lakes and St. Lawrence River Basin
- October 2004 Report of the Commissioner of the Environment and Sustainable Development, Chapter 5, Fisheries and Oceans Canada—Salmon Stocks, Habitat, and Aquaculture

Focus of the audit

1.14 The audit focused on the administration and enforcement of the fish habitat protection and pollution prevention provisions of the *Fisheries Act* and the two policies (Habitat Policy and Compliance and Enforcement Policy) that set out the government's intentions related to these provisions. The audit included the policies, programs, and activities of Fisheries and Oceans Canada and Environment Canada, and the arrangements with provinces and stakeholders that support the administration and enforcement of these provisions. The audit largely focused on the protection of fish habitat in fresh water and estuaries rather than the marine environment.

1.15 More details on the audit objective, scope, approach, and criteria are in **About the Audit** at the end of this chapter.

Observations and Recommendations

Protecting fish habitat

1.16 Fisheries and Oceans Canada's principal activity in the protection of fish habitat involves the review of proposals for projects, in or near water, that are sent to the Department by those carrying out the projects. These reviews are intended to determine whether the projects will result in damage to fish habitat and, if so, whether the projects can be amended to avoid the damage. The Department conducts project reviews under the 1986 Habitat Policy's "no net loss" guiding principle, striving to balance unavoidable habitat losses with habitat replacement, on a project-by-project basis.

1.17 We looked at how Fisheries and Oceans Canada reviews these projects and monitors compliance with the project approval terms.

We also reviewed how the Department enforces the habitat protection provisions of the *Fisheries Act.* We reviewed the Department's implementation of the Environmental Process Modernization Plan, a continuous improvement plan aimed at improving efficiency, effectiveness, transparency, timeliness, and consistency of delivery of the Habitat Management Program. We also looked at the Department's collaboration with provinces, industry, and conservation groups.

1.18 The Habitat Policy provides direction, mainly to Fisheries and Oceans Canada, on how to administer and enforce the fish habitat protection provisions (section 35) of the *Fisheries Act.* We looked at whether the Department could demonstrate that it is making progress toward the Habitat Policy's long-term objective of an overall net gain in habitat. Finally, we reviewed the Department's overall progress in implementing the Habitat Policy.

Fisheries and Oceans Canada needs to improve its quality assurance system for project referrals

1.19 The Habitat Policy provides guidance in dealing with project proposals that are referred to Fisheries and Oceans Canada for review to determine whether changes to fish habitat are likely to occur if a project proceeds as proposed. Department staff reviewing proposals may make recommendations to alter project designs to mitigate potential impacts to habitat by issuing a Letter of Advice to **project proponents**. The proponent is responsible for redesigning or relocating the project so that the mitigation objective is met.

Project proponent—A person or organization planning a project that may affect fish habitat.

1.20 Based on departmental experience, about 10 percent of projects assessed by the Habitat Management Program will have harmful effects on fish habitat. If damage to fish habitat cannot be avoided, a *Fisheries Act* authorization—a ministerial permission to harm habitat—may be issued. This allows the project to proceed but triggers an **environmental assessment**, which ultimately results in a report and a recommendation on whether or not the project should proceed, with a proposed mitigation and follow-up program.

Environmental assessment—An assessment that, under the *Canadian Environmental Assessment Act*, may be one of four different types—a screening, a comprehensive study, mediation, or a panel review; the type of assessment varies depending on the project's size, complexity, and environmental impacts.

1.21 We expected to find evidence in the project files that project reviews are conducted, documented, and reviewed for quality assurance to ensure that project risks were being assessed and that decisions made by departmental staff on project referrals were consistent and predictable. Without good-quality assurance controls, there is a risk that projects could be approved that may cause more harm to habitat than authorized, mitigation measures may be inadequate, and compensation for damaged habitat may be insufficient.

1.22 We examined the Department's project referral processes by randomly selecting a sample of 16 ministerial authorizations and 30 projects in which letters of advice were issued. The sample was chosen in the 2007–08 fiscal year from a total population of 267 ministerial authorizations and 4,514 projects that resulted in a Letter of Advice. We found weaknesses in the Department's documentation and review of projects.

1.23 **Required review processes.** Our review of ministerial authorizations indicated that while there was much project-related information in the files, documentation required by departmental policies was often not found, such as

- identification of the project's potential impact on fish habitat;
- risk assessments of the impacts on habitat to determine their significance (for example, only 25 percent of the files we reviewed contained documentation on risk assessment);
- the Department's assessment of a proponent's analysis of habitat impacts;
- reasons why the Department required additional mitigation measures; and
- monitoring plans on mitigation measures and documentation of compensatory work prepared by the proponents.

1.24 For the 30 projects we reviewed that received letters of advice, we found that required steps were not followed consistently. None of the project files we reviewed contained all of the information that the Department requires to assess a project. For example, there was no documentation of how mitigation measures were arrived at in 27 (90 percent) of the project files.

1.25 **Compensation plans.** All authorizations we reviewed required habitat compensation (enhancement or creation of habitat to offset damage to existing habitat). Compensation is required to result in no net loss of habitat under the Habitat Policy. Proponents are required to provide the Department with the compensation plans that result from the review under the *Canadian Environmental Assessment Act*. Department staff must review the plan and include it in the project file before issuing a ministerial authorization. In our review of 16 authorizations, we found that 4 projects were issued ministerial authorizations without the required compensation plans on file.

1.26 For the 12 authorizations with compensation plans on file, 3 of the proponents' compensation plans had not been developed at the time the authorization was issued. For the other 9 authorizations with compensation plans on file, 4 of these plans did not include the required detailed measures to compensate for habitat loss. Without these measures, the Department cannot properly evaluate whether the compensation was appropriate.

1.27 As mentioned earlier, the Habitat Management Program has the primary responsibility for habitat. The Program reviews major natural resource and industrial development projects, such as mines, hydroelectric, and infrastructure projects. The Minister may authorize a major project, even if there are large-scale losses of fish habitat, if it is believed that the project is in the best interests of Canadians because of socio-economic implications. The Department advised us that it is currently developing a policy that addresses large-scale habitat loss. This policy would clarify the approach for projects that are unlikely to achieve no net loss and would help to ensure transparency and consistency in decision making.

1.28 **Key aspects of quality assurance.** We looked at the guidance the Department provides to its staff. The *Fisheries Act,* the Habitat Policy, the Department's Risk Management Framework, and the project referral system all establish controls for the review and approval of projects, with the goal of no net loss to fish habitat. Staff use the Risk Management Framework to review the information and assess the project's risk, mitigation measures, and compensation plans for addressing unavoidable habitat damage.

Operational statements—Guidelines that describe the conditions and measures to be incorporated by a proponent into a lower-risk project in order to avoid negative impacts to fish and fish habitat, thereby allowing the project to proceed without a review by department staff. Examples of lower-risk projects range from dock construction in fresh water to routine maintenance dredging in marine waters.

1.29 Other than **operational statements**, which are used for the lowest-risk projects, we found that the Department does not have detailed guidance to help staff assess the proposed mitigation measures and make consistent decisions for similar projects. This guidance, together with random file reviews to ensure that guidance is being followed, would be a key element of a quality assurance system.

1.30 We also found that there is no national guidance on what compensation ratio to use under various habitat conditions or how to calculate habitat negatively affected. A compensation ratio is intended to make up for habitat that will be damaged during a project by having a proponent build or create compensatory habitat on a particular ratio, such as one-for-one or greater.

1.31 We found that the regions use different methods and elements to calculate the impact and determine the compensation ratio. For example, one region uses a simple calculation of the area affected, another uses a percentage of area deemed to be high-quality habitat, and another uses an estimate of affected habitat's productivity based on the pounds of fish per unit of habitat. Similarly, the compensation ratios vary. The Maritimes Region uses a compensation ratio of 3 to 1, while other regions use a 1-to-1 ratio. In some cases, it was not possible to determine the ratio used.

1.32 **Lack of guidance and file reviews.** Our review of project files found a lack of documentation, a lack of compliance with departmental controls, and varying approaches by the regions. The Department has several elements of a quality assurance system for project referrals—the Habitat Policy, a Risk Management Framework, and standard operating policies that consist largely of practitioners' guides and operational statements. However, it also needs to develop more guidance and carry out periodic reviews of project files to ensure that documentation is in place and controls are being applied.

1.33 **Recommendation.** In order to make consistent decisions on project referrals, in accordance with departmental expectations, Fisheries and Oceans Canada should ensure that an appropriate risk-based quality assurance system is in place for the review of these decisions.

Fisheries and Oceans Canada's response. The Department accepts this recommendation. Over the past number of years, Fisheries and Oceans Canada has made efforts to improve the quality, consistency, and transparency of its decision making by implementing the Risk Management Framework. Although much progress has been made, the Department recognizes that there is still much work to be done with respect to documentation standards. With that in mind, by 31 March 2010, Fisheries and Oceans Canada will implement a risk-based quality assurance system to verify that documentation standards are being applied consistently by staff.

There is little monitoring of compliance and evaluation of effectiveness

1.34 The Habitat Policy states that proponents may be required to carry out follow-up monitoring on the effectiveness of habitat mitigation and compensation activities established as a condition of project approval by Fisheries and Oceans Canada.

1.35 To ensure that proponents meet the requirements of the Habitat Policy, the Habitat Management Program has two ways for the Department to evaluate proponents' activities and its decisions (ministerial authorizations and letters of advice):

- monitoring of the proponent's compliance with terms and conditions attached to the approval to proceed (including monitoring mitigation and compensation work); and

- follow-up monitoring at a later date to assess the effectiveness in achieving no net loss of fish habitat.

1.36 We reviewed the Department's monitoring efforts and expected it to use a risk-based approach to monitor projects. In our past audits, we identified a number of problems with monitoring activities and made recommendations for improvements.

1.37 In our review of 30 project referral files involving letters of advice, we found little or no evidence of compliance monitoring, as required by departmental guidance. We also found little documentation to show that the Department is assessing

- what habitat was lost in development projects,
- whether required mitigation measures protected habitat, and
- whether project proponents are compensating for lost habitat by developing new habitat.

1.38 Proponents are normally required to carry out project monitoring activities, and the Department may monitor projects directly or rely on monitoring by the proponent. We found that the Department does not have a risk-based approach to monitoring proponents' compliance with the terms and conditions of ministerial authorizations and letters of advice. For example, we found that proponents had carried out the required monitoring in only 6 of 16 (38 percent) sample items involving ministerial authorizations and 1 of 30 sample items involving letters of advice. Further, the Department directly monitored the proponent's compliance in only one of the cases we reviewed. We found no documentation to show that the Department had followed up or evaluated the effectiveness of its decisions—that is, whether implementing the conditions of the ministerial authorizations or letters of advice had resulted in no net loss of habitat.

1.39 At the time of our audit, the Habitat Management Program was implementing a Habitat Compliance Decision Framework to provide a nationally consistent approach to monitoring projects. The regions were at various stages of implementation, and none had fully implemented the Framework.

1.40 The Department does not have a systematic approach to monitoring proponents' compliance with the conditions of its project approvals. Nor does it evaluate whether its decisions on mitigating measures and compensation are effective in meeting the no net loss principle. As a result, projects may be causing damage to habitat beyond the amount authorized, and mitigating measures and compensation may not be effective (see the case study below).

Fraser River Gravel Removal Plan Agreement

Project proposal. Fisheries and Oceans Canada, the Province of British Columbia, local governments, and First Nations agreed to gravel removal from the Fraser River, largely for flood and erosion management. Gravel deposits and the shifting flow of the Fraser River create bars, islands, and secondary channels between Hope and Mission, British Columbia. This area has high-quality habitat for at least 28 species of fish. The Department determined that gravel removal was harmful to fish habitat.

In 2004, the Department signed a Letter of Agreement with the Province of British Columbia to develop a five-year Gravel Removal Plan. Numerous project proponents (companies interested in removing gravel and selling it) submitted proposals to the Department. A number of ministerial authorizations have been issued and continue to be issued.

The following information provides examples of the Department's approach to approving and monitoring these proposals and highlights some of the challenges it faces in implementing the Habitat Policy.

Flood control. Engineering and scientific studies at different sites, some commissioned by the Department, concluded there was no reduction in the flood profile after gravel removal. These studies stated that changes in the flood profile were minimal in the removal area and were local to the removal site. Thus, gravel removal would not significantly affect the potential for flooding.

Damage to sensitive habitat. Projects in areas that are sensitive habitat for both salmon and sturgeon are high risk, but adequate information on fish stocks to assess project impacts was lacking for a number of the ministerial authorizations for gravel removal. In 2006, improper construction of a causeway for accessing one gravel removal site resulted in a side channel downstream drying up, exposing salmon nests and resulting in the loss of up to 2.25 million pink salmon.

Lack of compensation plans. The ministerial authorizations did not include compensation plans. The Department believes that compensation plans are not required on the assumption that new gravel will replace gravel removed over one to three spring runoffs. We found no documentation in the project files to support this position for large gravel removals, although there is evidence to the contrary. For example, 300,000 tonnes of gravel were mined from Foster Bar in 1995, but it has not been replaced to date. The Department advises us that the requirement for habitat compensation will be reviewed as part of the renegotiation of the 2004 Letter of Agreement, using the results of post-construction monitoring studies, lessons learned from removals under the 2004 agreement, and contemporary research.

Lack of monitoring. Although proponents are required to submit monitoring plans and surveys, there were few on file. These documents specify the conditions prior to gravel removal, during removal, and after removal, as required under the terms of the 2004 Letter of Agreement.

Lack of enforcement. The Department did not take enforcement action after a proponent failed to comply with the conditions of a ministerial authorization by exceeding the volume of gravel allowed to be extracted, destroying habitat, and mining outside the approved area. We could not find documentation to support the Department's lack of enforcement action. The Department advised us that it was short of resources at the time of the proponent's actions and that it is considered too late to pursue charges.

1.41 **Recommendation.** Fisheries and Oceans Canada should accelerate the implementation of its Habitat Compliance Decision Framework to ensure that there is an adequate risk-based approach to monitoring projects and providing assurance that proponents are complying with the *Fisheries Act* and all terms and conditions of departmental decisions. The Department should also determine whether the required mitigation measures and compensation are effective in meeting the no net loss principle.

Fisheries and Oceans Canada's response. The Department accepts this recommendation. Fisheries and Oceans Canada currently applies a risk-based approach, but recognizes that opportunities for improvement remain. Once the Habitat Compliance Modernization initiative is fully implemented, the Department will be able to provide better assurance that proponents are complying with the terms and conditions of the Department's decisions. Considering this, the Department commits to fully implement the Habitat Compliance Decision Framework and report on results of project monitoring activities by 31 March 2010 and annually thereafter.

Fisheries and Oceans Canada will continue to work with proponents to design and implement follow-up monitoring studies. Between now and the end of 2011, the Department will review and develop standard scientific methodologies to examine the effectiveness of compensation in achieving the no net loss guiding principle so that these methodologies can be used by proponents when designing monitoring studies.

Enforcement decisions need to be better documented

1.42 We reviewed the Department's approach to enforcement to determine if it could demonstrate that it was inspecting and investigating those suspected of violating section 35 of the *Fisheries Act*. The requirements and general procedures for habitat-related enforcement are found in the Habitat Policy and its associated Compliance and Enforcement Policy.

1.43 We expected enforcement of the habitat protection and pollution prevention provisions to be carried out in accordance with the Compliance and Enforcement Policy through inspections, investigations, issuance of warnings and directions by inspectors, and court actions. Notably, the Policy does not require documentation of most of these actions.

1.44 The Conservation and Protection Program is part of the Fisheries and Aquaculture Management Sector, and habitat protection is only one of the Program's ten areas of activity. As a result, it spends more time nationwide on fisheries-related compliance issues.

Occurrence—Information or a complaint that is logged in the Departmental Violation System. Whether the *Fisheries Act* has been violated can only be determined when the complaint or information is investigated.

1.45 We selected a random sample of 15 fish habitat **occurrences** recorded in the Departmental Violation System (DVS) in the 2007–08 fiscal year. We reviewed the sample items to determine if they complied with the Compliance and Enforcement Policy.

1.46 **Lack of documentation.** Overall, there was a lack of documentation in the files we reviewed. For example, for three cases of possible violations of subsection 35(2) of the *Fisheries Act,* the assessment of the violations and the factors considered to achieve the desired result with the alleged violator were not documented. A verbal warning was issued for one of the files we reviewed, but there was no documented acknowledgement by the alleged violator and no documentation of follow-up monitoring to ensure that corrective action requested in the warning was actually carried out. In one case, Habitat Management Program staff recommended that the Conservation and Protection Program proceed with charges against the alleged violator. No charges had been laid at the time of our audit, which was more than one year after the occurrence.

1.47 **Enforcement.** Due to the lack of documentation for the DVS files we reviewed, we could not determine whether the Department is following the Compliance and Enforcement Policy. We could not find evidence of what, if any, actions the Department had taken to inspect or investigate alleged violations or what enforcement actions it had taken. A quality assurance system for enforcement, including establishing appropriate procedures, documenting decisions, and periodically reviewing violation files would allow the Department to demonstrate that its decisions are made in accordance with departmental policies and expectations.

1.48 **Recommendation.** Fisheries and Oceans Canada should ensure that its enforcement quality assurance and control processes are sufficient to demonstrate that its actions have been taken in accordance with the Compliance and Enforcement Policy. The Department should provide guidance on the type of complaints that fishery officers should respond to and take action on, and the Department should specify minimum documentation requirements for occurrences.

Fisheries and Oceans Canada's response. The Department accepts this recommendation and, by 31 August 2010, will establish, disseminate, and communicate to regions an operational protocol to ensure better documentation of enforcement actions and monitoring of activities to ensure consistency with the Compliance and Enforcement Policy.

Guidance on the nature of complaints that warrant the attention of fishery officers has also been identified as a need by the Department. By 31 March 2011, the Department will examine the process currently in use and, by 31 March 2012, the Department will examine the Habitat Compliance Decision Framework to improve its guidance to staff, clarify documentation protocols, and establish minimum documentation standards for occurrences.

Modernization of the Habitat Management Program is progressing

1.49 In 2004, the Department created the Environmental Process Modernization Plan (EPMP), which was part of a series of continuous improvement initiatives. The EPMP focused on key elements in modernizing the Habitat Management Program, including streamlined reviews of low-risk activities, strengthened partnership arrangements, and modernization of habitat compliance.

1.50 We reviewed the Department's progress in implementing the EPMP by reviewing departmental policies, procedures, and documents; analysing referral totals by year; and reviewing project files. We expected the Department to have fully implemented the EPMP into the Habitat Management Program and to have adjusted the EPMP accordingly to reflect implementation experience.

1.51 The Department has implemented parts of the EPMP but has made little progress in some areas—in particular, the Habitat Compliance Modernization initiative, which was introduced in 2005.

1.52 **Streamlining.** The Department developed operational statements to streamline its review of projects so that it could focus its reviews on higher-risk projects. The statements, available on its Internet site, outline measures and conditions to avoid harming habitat in order to comply with subsection 35(1) of the *Fisheries Act*. Project proponents who comply with the statements do not have to submit their proposal for review by the Department. The implementation of the EPMP is one of the contributing factors that has led to a decrease in referrals from 13,234 in the 2003–04 fiscal year to 7,333 in 2007–08.

1.53 **Partnering arrangements.** In 2005, the Department completed a formal cooperative Memorandum of Understanding (MOU) with Nova Scotia. The provinces of British Columbia, Prince Edward Island,

and Manitoba already had agreements in place. These agreements outline collaborative work with the provinces to carry out activities related to protection of fish habitat. The Department has also signed agreements with industry groups and non-governmental conservation organizations.

1.54 **Modernization of habitat compliance.** The Department decided to move the focus of the Habitat Management Program from enforcement, which is largely reactive in responding to complaints, to compliance promotion, such as communication and publication of information, public education, consultation with stakeholders, and technical assistance. The Department advised us that most activity of the Conservation and Protection Program related to habitat issues is determined by the level of risk associated with habitat occurrences that are assessed by habitat managers.

1.55 As a result of the new direction, the Conservation and Protection fishery officers have spent significantly less time on habitat-related enforcement matters—from 78,057 hours in 2003 to 38,249 hours in 2007 (a percentage decrease of total time from 6.4 percent to 3.3 percent). The Department advised us that this reduction is largely due to the Department's decision to move to a new habitat compliance strategy. In 2004, the number of fishery officers in the Central and Arctic Region was reduced from 56 to 24, and officers in the Pacific Region were directed to focus more on enforcement of other matters and less on habitat issues.

1.56 The Department implemented a National Habitat Compliance Protocol to clarify the roles, responsibilities, and accountabilities of the Habitat Management Program and the Conservation and Protection Program. Habitat monitors, staff who would work in the Habitat Management Program on both compliance promotion and enforcement, were to be engaged and carry out much of the work being done by fishery officers. Although originally planned for 2006, the hiring of habitat monitors was still in progress during our audit.

1.57 **Compliance promotion.** We found that the Department's compliance promotion is limited and that it has no overall strategy for this activity. As a result, it has not realized an improvement in habitat conservation and protection through increased compliance promotion and risk-based strategies for monitoring and enforcement.

1.58 **Implementation progress.** The Department has made progress in implementing the EPMP so that it can better manage its risks. However, we noted that some elements, such as Habitat Compliance

Modernization, are not yet fully implemented. The Department has identified future needs for the EPMP, including consultation, partnering and accountability for agreements, and a formal evaluation of the EPMP. These initiatives have to be incorporated fully into the Habitat Management Program before the Department can confirm that the Program is being risk-managed.

Accountability in agreements is weak

1.59 The Habitat Policy calls for cooperation by encouraging and supporting involvement by government agencies, public interest groups, and the private sector to conserve, restore, and develop fish habitat. In the delivery of its Habitat Management Program, the Department relies on the support of and input from a number of internal and external groups. Without their help, the Department would need more resources to deliver its mandate.

1.60 The Department is required, through inter-agency cooperative agreements, to participate in the provincial project review systems and in provincial environmental assessment reviews for projects.

1.61 Jurisdictional responsibilities over water matters are complex as the provinces have many responsibilities in this area. Provincial water powers include flow regulation, authorization of water use development, water supply, pollution control, thermal and hydroelectric power development, and agriculture and forestry practices.

1.62 The responsibility for inland fisheries (for example, fishing licences and limits) has been delegated to the provinces, but the federal government has retained the responsibility for habitat. Fisheries and Oceans Canada relies on provincial government programs to administer some of its fish habitat protection responsibilities. Habitat agreements are in place with four provinces, but implementation of the agreements varies considerably by province.

1.63 As provincial officials are designated as fishery officers by the Department, we expected an appropriate accountability framework to be in place that includes the delivery of reports to the federal government on the status of habitat, enforcement actions taken, and monitoring carried out.

1.64 We found that Fisheries and Oceans Canada has made progress in working with stakeholders to identify development practices that reduce the potential for impact on fish habitat and promote compliance with the *Fisheries Act*. The Department has also worked with environmental groups, including those on the Canadian Environmental Network, to engage them in improving the delivery of its desired results.

1.65 For example, since 2001, the Department has developed agreements with 36 conservation authorities in Ontario to help deliver the habitat program. The authorities do this by, for example, reviewing project referrals (most of the low-risk files) and issuing letters of advice on the Department's behalf.

1.66 We found that there are weaknesses in the oversight process for the agreements with Ontario conservation authorities. The agreements have few accountability mechanisms, such as performance measures, audit provisions, or formal evaluation requirements. Thus, there is no formal means for the Department to know if the assigned activities have been carried out according to its policies and guidelines. While the agreements state that the Department is responsible for reviewing the letters of advice prepared by conservation authorities, we found that the Department did not receive copies of these letters to review.

1.67 In our 2001 audit of the Great Lakes Basin, we recommended that the Department develop suitable accountability arrangements with its partners—notably the provinces and others it relies on to achieve the objectives of the *Fisheries Act*.

1.68 These issues from seven years ago still remain and they are relevant to the Habitat Management Program today.

1.69 **Recommendation.** Fisheries and Oceans Canada should clarify the parts of the Habitat Management Program that it will continue to administer, the extent that it wants others to deliver the program on its behalf, and the resource implications. The Department should also assess whether accountability mechanisms in all of its existing agreements are working effectively enough to report and assess the results achieved through its collaboration with others. In addition, it should review the agreements to ensure that they are aligned with its view of the long-term goals of the Habitat Management Program.

Fisheries and Oceans Canada's response. The Department accepts this recommendation and, by 31 March 2011, will have reviewed and evaluated its memoranda of understanding with provinces and territories. The Department will continue to work with its partners to strengthen the governance and accountability mechanisms and ensure that the partnership arrangements are aligned with the Department's goals and its strategic vision.

Habitat loss or gain is not being measured

1.70 The approach under the Habitat Policy is to achieve no net loss of habitat on each project and, together with habitat restoration and development, achieve a gain in habitat overall. We expected that Fisheries and Oceans Canada would be collecting and analyzing habitat data to determine whether it is achieving the Policy's objective of a net gain in habitat.

1.71 Measuring aspects of habitat is a complex process. In our past audits, we recommended that Fisheries and Oceans Canada collect and analyze information to provide up-to-date assessments on habitat conditions. In this current audit, we found no significant improvement in the quantity and quality of information on fish habitat. The Department lacks information on fish stocks, quantity and quality of fish habitat, contaminants in fish, and overall water quality.

1.72 Provinces and other government agencies, First Nations, and stewardship groups collect habitat information in discharging their responsibilities. There continues to be no simple access to current and complete data, and key technical data for many watersheds is lacking. As a result, the Department lacks the scientific information needed to establish a baseline for the state of Canada's fish habitat. To address this, the Department has begun a project to access habitat databases managed by others to more easily gather habitat information. However, establishing national baseline data for habitat remains a challenge.

1.73 The Department can also use indicators of habitat quality, such as water quality, water flow, and fish stock data, to arrive at an assessment of the quality of habitat in select ecosystems. Ecosystems to be reviewed could focus on those with significant human activity as the Department cannot regulate natural changes to habitat. However, the Department has not made much progress in developing such indicators. The Department's ongoing challenges in collecting data and selecting habitat indicators means that it still does not know whether it is progressing toward the Habitat Policy's long-term objective of a net gain in fish habitat.

1.74 **Recommendation.** Fisheries and Oceans Canada should develop habitat indicators to apply in ecosystems with significant human activity. The Department should use these indicators to assess whether it is making progress on the Habitat Policy's long-term objective to achieve an overall net gain in fish habitat.

Fisheries and Oceans Canada's response. The Department accepts and agrees with this recommendation and is committed to moving toward an ecosystems approach and the increased use of biological indicators, particularly in areas of significant human activity. However, this task is far from trivial as it will require significant new scientific understanding to ensure that the indicators adopted do in fact tell us what we need to know about the health of the aquatic ecosystem.

The Habitat Policy is not fully implemented after 23 years

1.75 We expected that Fisheries and Oceans Canada would have substantially implemented the Habitat Policy. Without such implementation, unmanaged human activity could result in further decline of fish habitat, fish stocks, and the benefits derived by Canadians from both.

1.76 In our October 2001 Report, we noted that 15 years had passed since the Habitat Policy was adopted and that it had not been fully applied. In our current audit, we found that the Department had implemented parts of the Policy, but progress in some areas did not advance as expected.

1.77 For example, the Policy indicates that the Department is to ensure a uniform and equitable level of compliance with statutes, regulations, and policies. However, as noted earlier, the Department cannot demonstrate that projects it reviews have been adequately assessed on a consistent basis, as required by the Habitat Policy. It needs to carry out better compliance monitoring and effectiveness evaluation—other key elements required under the Policy.

1.78 **Research.** The Habitat Policy also requires the Department to conduct scientific research to provide the information and technology necessary for the conservation, restoration, and development of fish habitat. In 2001, we reported that the Department lacked scientific information that it needed to carry out its mandate effectively, including information on the quality of fish habitat. According to the Department, implementation of an **ecosystem science approach** is in the early stages, and assessment of habitat is not yet possible. It notes that data does not exist for many aquatic habitat features, or available information may not be organized in ways that allow staff to access it efficiently and systematically.

Ecosystem science approach—An approach to science that focuses on identifying and understanding the key relationships in nature and their links to human needs and actions.

1.79 To address these gaps, the Department advised us that it has a five-year research plan to address the impact from human activities. External to government, there are recently formed Centres of Expertise that study the impacts of hydro and of oil and gas on habitat, and a new Centre of Expertise is being created to provide science support to the Habitat Management Program. In addition, Ecosystem

Research Initiatives, whose objective is to deploy an ecosystem science approach, were recently established in seven areas across the country.

1.80 **Recommendation.** Fisheries and Oceans Canada should determine what actions are required to fully implement the 1986 Habitat Policy and confirm whether it intends to implement all aspects of the Policy.

Fisheries and Oceans Canada's response. The Department accepts this recommendation and, by March 2010, will determine what actions are required to fully implement the Habitat Policy.

Pollution prevention provisions

Deleterious substances—Substances that are directly or indirectly harmful to fish and that can take many different routes to enter the aquatic environment. Examples of sources of these substances include municipal wastewater, industrial effluent, agricultural run off, urban and natural resource development, landfills, and abandoned mines.

1.81 The pollution prevention provisions of the *Fisheries Act* prohibit all deposits of **deleterious substances** into waters frequented by fish. This type of prohibition has been a part of the *Fisheries* Act since its enactment in 1868. The only exception to this general requirement is when harmful deposits are authorized by regulations under the Act.

1.82 Six regulations are currently in force under the *Fisheries Act's* pollution prevention provisions. These regulations allow deposits of specific harmful substances from the regulated industry within specific discharge limits.

1.83 Environment Canada has been responsible for the administration of the pollution prevention provisions of the *Fisheries Act* since 1978. Environment Canada administers the Act within its existing organizational structure and processes that also support its other legislative responsibilities, such as the *Canadian Environmental Protection Act, 1999*. It does not have a separate *Fisheries Act* program.

Accountability for addressing *Fisheries Act* responsibilities is lacking

1.84 We focused on Environment Canada's processes for determining how it fulfills its *Fisheries Act* responsibilities. We expected to find the following two conditions:

- Environment Canada has clearly identified what it must do to meet its *Fisheries Act* responsibilities, including establishing results expectations and appropriate accountability arrangements for delivering those responsibilities.
- Environment Canada has identified and assessed the risks associated with substances that are harmful to fish, developed and implemented compliance strategies to manage significant risks, and regularly updated approaches to mitigate or address risks.

The following paragraphs present our findings related to these expectations:

1.85 **Results expectations.** Environment Canada has not established clear objectives or results expectations for meeting its *Fisheries Act* responsibilities.

1.86 Environment Canada has identified its priorities for administration of the *Fisheries Act* in its 2008–2009 Report on Plans and Priorities (RPP). Its RPP points to the *Pulp and Paper Effluent Regulations* (about 115 mills are subject to these regulations), *Metal Mining Effluent Regulations* (about 100 mines are subject to these regulations), development of new regulations for wastewater effluent, and enforcement of the Act as its priorities.

1.87 Environment Canada has not clearly established what it plans to achieve with its main *Fisheries Act* responsibility—ensuring compliance by industries and activities with the Act's prohibition against the deposit of harmful substances in water frequented by fish (the Department estimates that this could apply to hundreds of thousands of organizations or individuals).

1.88 **Administration of the Act's prohibition requirement.** In 2005, Environment Canada established a *Fisheries Act* working group to develop and implement a national approach for administering the Act's prohibition against the deposit of harmful substances in water frequented by fish. The working group identified nine national priorities and additional regional priorities (sectors, industries, or activities) where water pollution issues should be addressed through administering the Act's prohibition requirement. The working group recommended a plan of action to address these priorities. It has not met since 2006, and no one is clearly assigned the responsibility for action on the issues identified.

1.89 Further, the working group observed that Environment Canada's focus was on its administration of the *Canadian Environmental Protection Act, 1999* and that the Department no longer had the management structure to administer the *Fisheries Act*.

1.90 In November 2007, Environment Canada officials reviewed the working group's findings and did further analysis to identify challenges with administering the pollution prevention provisions. It identified specific challenges faced by the Department in ensuring compliance with the *Fisheries Act* prohibition requirement, including a lack of clear priorities, difficulties in determining compliance, and reactive activities, with inconsistent responses across regions and across sectors.

1.91 No further coordinated action was taken on these departmental initiatives, leaving Environment Canada without a national approach to provide coordination, focus, and guidance on administration of the Act's prohibition requirement.

1.92 Environment Canada has not clearly identified what it has to do to meet its *Fisheries Act* responsibilities, including establishing results expectations and appropriate accountability arrangements for delivering those responsibilities.

1.93 **Recommendation.** Environment Canada should set out clear objectives and results expectations for its *Fisheries Act* responsibilities, and establish accountability for achieving the desired results, including providing national coordination and guidance on the administration of the Act.

Environment Canada's response. The Department accepts this recommendation and will put in place a Results-based Management and Accountability Framework in 2009–10 for Environment Canada's *Fisheries Act* responsibilities. The framework will clearly identify the objectives, responsibilities, and expected results, including how national coordination and guidance on Environment Canada's administration of the Act will be provided.

1.94 **Compliance strategy.** We expected to find that Environment Canada had developed and implemented a compliance strategy to address significant *Fisheries Act* responsibilities. A compliance strategy would address areas of greatest risk to fish habitat based on integrated information gathering and the use of scientific knowledge. It would then set departmental priorities for using tools such as compliance promotion, education, promotion of technology development, and targeted enforcement to increase rates of compliance.

Environmental effects monitoring—Activity that assesses the aquatic ecosystems downstream from the site of effluent discharge to determine the impacts of the effluent on fish and the aquatic environment over the long term.

1.95 Environment Canada has a compliance strategy, **environmental effects monitoring**, and an enforcement plan in place for each of the two regulations it actively administers and enforces—*the Pulp and Paper Effluent Regulations* and the *Metal Mining Effluent Regulations*.

1.96 However, Environment Canada does not have a *Fisheries Act* compliance strategy for the industries and activities that must comply with the Act's prohibition requirement against the deposit of harmful substances in water frequented by fish. The Department informed us that the number of parties potentially subject to the Act's prohibition requirement numbers in the hundreds of thousands. The size of this population represents a challenge in developing a compliance strategy and setting priorities for the use of compliance promotion and enforcement resources.

1.97 Environment Canada has not instituted an overall risk-based approach to the *Fisheries Act* to identify, assess, and address risks of non-compliance with the Act that could result in significant harm to fish habitat. The use of risk-based methodologies would allow the Department to focus its resources on those areas where significant risks to fish habitat are highest and ensure that they are adequately addressed in a consistent manner.

1.98 The absence of a risk-based approach to the *Fisheries Act's* prohibition requirement also hampers the ability of the Department's Enforcement Branch to plan its enforcement activities based on significant risks to fish habitat identified by the Department. The 2008–2009 National Enforcement Plan reflects a largely reactive approach, based on complaints, to the Act's prohibition requirement. However, the Plan does include planned inspections for some cruise ships, fish plants, and abandoned mines.

1.99 **Identification of substances harmful to fish.** We expected to find that Environment Canada had identified and assessed the risks associated with substances that are potentially harmful to fish and incorporated this information into its decision-making processes. We found that many sources of pollution that are harmful to fish are known to Environment Canada, but that information is incomplete and, in the absence of a compliance strategy for the *Fisheries Act* prohibition requirement, the Department is not using information that it does have to its full potential.

1.100 There are many substances or combinations of substances that have the potential to harm fish. Environment Canada has different means to identify such substances, including scientific and some working knowledge of sources of pollution and some individual substances that are harmful to fish and the aquatic environment. For example, during the late 1990s, the Department's Science Branch conducted a series of threat assessments that were summarized in a 2001 report. While this work is now becoming dated, it identified sources of pollution by industries and activities, such as municipal wastewater effluent, that have a significant impact on aquatic ecosystems.

1.101 Environment Canada has knowledge about chemical substances through its scientific assessments under the *Canadian Environmental Protection Act, 1999* and about the sources of some pollution that are harmful to fish from the Department's other initiatives, such as the processes supporting the 1987 Great Lakes Water Quality Agreement. However, the Department's 2006 Science Plan identified the need for additional information to adequately assess the impacts of substances, especially the combination of substances entering fish habitat.

1.102 In June 2008, Environment Canada reported that "there is no national network of water quality monitoring sites designed specifically for the purpose of reporting the state of Canada's water quality in a fully representative way at different geographic scales across Canada." While such monitoring is not designed to identify individual substances harmful to fish, Environment Canada has indicated that information from water quality monitoring in sensitive watersheds could be used to supplement information about impacts on fish and fish habitat.

Complementary roles of related legislation and other jurisdictions have not been assessed

1.103 As noted earlier, Environment Canada does not have a separate organizational structure or processes to manage its overall *Fisheries Act* responsibilities; it uses the structures and processes that support its other legislative responsibilities, including the ***Canadian Environmental Protection Act, 1999*** (CEPA).

Canadian Environmental Protection Act, 1999—Environment Canada's primary legislation for controlling industrial and commercial chemicals and wastes that present an unacceptable risk to human health and the environment. The Act gives Environment Canada authority to regulate substances that are determined to be toxic.

1.104 Environment Canada has informed us that CEPA can play a complementary role to reduce the risk of violations of the *Fisheries Act* and reduce discharges of CEPA-regulated substances, thereby protecting fish habitat.

1.105 **Reliance on CEPA.** We expected to find that Environment Canada had determined the extent that the results achieved from its administration of CEPA could be relied on to meet its mandate for the *Fisheries Act*'s prohibition against the deposit of harmful substances into waters frequented by fish. The Department could also use such an assessment to help it determine the resources needed for administering its *Fisheries Act* responsibilities. However, Environment Canada has not completed such an assessment.

1.106 The case study (page 38) shows how the Department has used and proposes to use CEPA and the *Fisheries Act* to address significant risks to fish habitat from wastewater effluent.

1.107 **Reliance on other jurisdictions.** We focused on Environment Canada's approach to cooperation with other jurisdictions, most notably provinces. Environment Canada relies on water legislation and enforcement in other jurisdictions to protect water from the effects of pollution and complement its *Fisheries Act* responsibilities. We expected that Environment Canada had determined the extent that it could rely on the water legislation and enforcement by other jurisdictions to meet its mandate for the *Fisheries Act's* prohibition requirement. We found that Environment Canada had not done this.

1.108 There is a history of cooperation on water pollution prevention where federal, provincial, and territorial governments have worked together through the Canadian Council of Ministers of the Environment (CCME) to address wastewater effluent, water quality monitoring, and water quality guidelines. Such cooperation is widely recognized as being important to implementing successful pollution prevention programs.

1.109 The Government of Canada has entered into formal agreements with Alberta and Saskatchewan to administer aspects of the *Fisheries Act's* pollution prevention provisions. In a 1999 Report, the Commissioner of the Environment and Sustainable Development reported that these agreements did not always work as intended and that many activities that are essential to implementing the agreements were not working as well as they could.

Efforts to address risks posed by wastewater effluent

Wastewater effluent has long been identified as a major risk to aquatic ecosystems. It is one of the largest sources of pollution in water by volume and is a significant source of releases of nitrogen and phosphorus into water, both substances that can be harmful to fish. The issues that all governments must address to reduce the risks to water quality from wastewater effluent are complex and costly.

Under the *Fisheries Act*, wastewater effluent can contain substances harmful to fish. Environment Canada does not presently have a compliance strategy to ensure that municipal and other communities' wastewater facilities comply with the Act's prohibition requirement. However, Environment Canada's Enforcement Branch responds to complaints involving wastewater facilities. Since 1999, several high-risk substances often found in wastewater effluent have been regulated under the *Canadian Environmental Protection Act, 1999* (CEPA).

In 2003, Environment Canada started working with the Canadian Council of Ministers of the Environment (CCME) to address wastewater effluent issues. In October 2007, the CCME released the draft Canada-wide Strategy for the Management of Municipal Wastewater Effluent (the Strategy) for consultation. At the same time, Environment Canada consulted on its proposal to develop and use *Fisheries Act* regulations to implement the Strategy.

The Strategy is to be implemented over a long time frame, as long as 30 years, with the high-risk facilities having to meet the proposed regulatory requirement within 10 years. The rationale for this lengthy time frame is the complex nature of the issues being addressed and the large costs involved to construct or upgrade wastewater facilities.

The necessary *Fisheries Act* regulations have yet to be established. However, this is an example of how CEPA and the *Fisheries Act* can be used to address significant risks to fish habitat.

1.110 We examined the Canada–Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the *Fisheries Act*. We found that the agreement was out of date and not being fully implemented (see the case study below).

1.111 We found that Environment Canada cannot demonstrate that the agreements with the provinces are active and being implemented, and it does not know the extent that the legislative frameworks of other jurisdictions can be relied on to support Environment Canada's administration and enforcement of the pollution prevention provisions of the *Fisheries Act*.

Canada-Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the *Fisheries Act*

In 1994, the Governments of Canada and Alberta entered into the Canada-Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the *Fisheries Act* (the Agreement). The purpose of the Agreement was to establish terms and conditions for the cooperative administration of the pollution prevention provisions of the *Fisheries Act* and relevant provincial legislation. The rationale behind this was to streamline and coordinate the regulatory activities of Canada and Alberta and to reduce duplication. We examined the mechanisms that were in place under the Agreement to report to Environment Canada on the results achieved for specific responsibilities administered on its behalf.

We found that the Management Committee that governs the implementation and administration of the Agreement has not met in over two years. Environment Canada informed us that it meets regularly at the staff level with Alberta to discuss issues, including enforcement activity and reported releases of substances. Although Environment Canada has not formally assessed these working-level arrangements, it informed us that they are working effectively.

To determine how this collaboration has occurred in practice, we examined the arrangements for implementation of the Agreement with respect to oil sands operations. The Pembina Institute, an Alberta-based environmental non-governmental organization, has reported that oil sands operations are producing about 1.8 billion litres of tailings per day, storing them in tailing ponds. These tailings contain substances that are potentially harmful to fish. According to several environmental impact assessments of oil sands projects, leaching of the substances contained in the tailing ponds can be expected.

Environment Canada participates in environmental impact assessments and a number of oil sands working groups and research initiatives. Environment Canada has informed us that it does not have its own independent monitoring program because Alberta prohibits the release of tailing pond contents to surface water and monitors for leaching into local rivers and lakes. Alberta has a process in place to report spills to Environment Canada, including incidents that potentially fall under the *Fisheries Act*.

Environment Canada relies on the Agreement and the arrangements with Alberta to meet its *Fisheries Act* responsibilities. However, the Agreement's Management Committee has not provided its oversight role in over two years and Environment Canada has not formally assessed the extent that the arrangements with Alberta fulfill the Department's *Fisheries Act* responsibilities.

1.112 Recommendation. Environment Canada should develop a risk-based approach to the *Fisheries Act* pollution prevention provisions to identify, assess, and address significant risks associated with non-compliance with the Act. As part of this approach, Environment Canada should determine whether there are significant risks to fish habitat associated with non-compliance with the *Fisheries Act* that are not being addressed by the combination of its own administration and enforcement of the Act, and the administration of other federal and provincial legislation.

Environment Canada's response. The Department accepts this recommendation and has assigned responsibility to the Public and Resources Sectors Directorate of the Environmental Stewardship Branch to coordinate risk management and compliance promotion priorities for subsection 36(3) of the *Fisheries Act* and associated regulations.

In 2009–10, Environment Canada will develop a work plan to identify current risks and risk management activities in non-regulated sectors, including *Fisheries Act* compliance promotion activities and other federal and provincial legislation. In 2010–11, the Department will complete the review of risks and risk management activities and will adjust departmental work plans as required.

Some regulations and guidance are outdated

1.113 We expected that Environment Canada would actively administer the *Fisheries Act* regulations pursuant to the pollution prevention provisions, and ensure that the regulations, and guidance on compliance with the Act, are adequate, up-to-date, relevant, and enforceable.

1.114 Regulated industries. Of the six *Fisheries Act* pollution prevention regulations currently in force, Environment Canada actively administers two—the *Pulp and Paper Effluent Regulations* and the *Metal Mining Effluent Regulations*. The four remaining regulations date back to the 1970s and are based on outdated technology and practices, making them difficult to enforce.

1.115 For example, the *Petroleum Refinery Liquid Effluent Regulations* contain outdated effluent sampling methods and requirements that are used to determine whether refineries are complying with the *Fisheries Act*. In addition, these regulations only apply to the five refineries that began operations on or after 1 November 1973 when the regulations came into force. The 14 refineries that were operating before that date are not subject to the regulations but are covered by voluntary guidelines.

1.116 In 1998, the Standing Committee on Environment and Sustainable Development recommended that the Minister of the Environment undertake a review of *Fisheries Act* regulations to ensure that they were adequate, up-to-date, and enforceable. Further, regulations that were found to be deficient were to be amended to ensure their enforceability. The government responded that a review was not needed at that time. Consequently, the regulations that the Committee was concerned about 10 years ago have yet to be reviewed by Environment Canada and have not been updated.

1.117 Under the 2007 Cabinet Directive on Streamlining Regulations, departments are responsible for ensuring that regulations continually meet their initial policy objectives and for renewing their regulatory frameworks on an ongoing basis. While Environment Canada officials have raised concerns about these outdated regulations, the Department has no plans to address the concerns.

1.118 Guidelines and best practice statements. Between 1970 and 1977, the Minister of Fisheries and the Environment issued six *Fisheries Act* guidelines to specific industries. These guidelines recommend voluntary measures that could be applied to control effluent discharged from operations and thereby demonstrate compliance with the Act. The guidelines are based on technology and best practices dating back to the 1960s. Consequently, the guidelines represent an impediment to Environment Canada's current enforcement of the Act's prohibition requirement, as industrial practices and technology have changed significantly in the intervening decades.

1.119 Environment Canada has also issued many industry-specific best practice statements over the years. However, the Department has no process to review and recall these statements should they become outdated.

1.120 Recommendation. Environment Canada should review existing *Fisheries Act* regulations, guidelines, and best management practices to ensure that they are adequate, up-to-date, relevant, and enforceable.

Environment Canada's response. The Department accepts this recommendation. Over the 2009–2012 period, Environment Canada will undertake a review of the continued relevance of the four regulations noted below in light of *Fisheries Act* guidelines, provincial standards, and industry best management practices, and will take the necessary steps to update or repeal them as appropriate:

- Chlor-Alkali Mercury Liquid Effluent Regulations
- Meat and Poultry Products Plant Liquid Effluent Regulations

- Petroleum Refinery Liquid Effluent Regulations
- Potato Processing Plant Liquid Effluent Regulations

Enforcement quality assurance and control have weaknesses

1.121 We focused on Environment Canada's enforcement activities that prevent, deter, and detect non-compliance with the pollution prevention provisions of the *Fisheries Act*. Enforcement activities include

- inspections to verify compliance;
- investigations of suspected violations; and
- measures to compel compliance, such as written directives and warnings, and charges under the Act.

1.122 We expected that Environment Canada could demonstrate that its enforcement actions had been taken in accordance with the Compliance and Enforcement Policy, which states that the Act must be administered and enforced in a "fair, predictable and consistent manner" and provides general guidance on how this is to be achieved.

1.123 We examined the Enforcement Branch's quality assurance and control practices for its enforcement activities. There are a number of important quality assurance and control practices in place. For example, Environment Canada has provided reporting independence to its Enforcement Branch as it now reports directly to the Deputy Minister, and the Department and Fisheries and Oceans Canada jointly developed the 2001 Compliance and Enforcement Policy in response to recommendations from a 1998 Report of the Standing Committee on the Environment and Sustainable Development. However, we found the following:

- There is no overall process by which headquarters reviews regional enforcement activities to assess whether the Policy was followed and consistently enforced.
- The Enforcement Branch has limited information on the nature and extent of *Fisheries Act* compliance issues. The Enforcement Branch believes that about 40 to 50 percent of the public complaints it receives arise from *Fisheries Act* concerns, but it has not completed an analysis of the nature of these complaints or the subsequent enforcement activities.

1.124 We selected a random sample of 15 enforcement actions—inspections, investigations, and measures to compel compliance—taken in the year ended 31 March 2008 to determine whether they were taken in accordance with the Compliance and Enforcement Policy. We found that the enforcement actions we reviewed demonstrated compliance with the Policy.

1.125 Nevertheless, the weaknesses in the Enforcement Branch's quality assurance and control practices limit the Branch's ability to demonstrate that its actions have been taken in accordance with the Compliance and Enforcement Policy.

1.126 Recommendation. Environment Canada should ensure that its enforcement quality assurance and control practices are sufficient to demonstrate that its actions have been taken in accordance with the Compliance and Enforcement Policy.

Environment Canada's response. The Department accepts this recommendation. The Enforcement Branch is continuing to develop a framework, standardize processes, and establish accountabilities to enhance its quality assurance and its quality control. More specifically, the quality assurance and quality control framework is being both developed and implemented over the 2009–10 and 2010–11 fiscal years and maintained thereafter. At the same time, the Enforcement Branch is establishing a quality assurance unit, as well as a working group, to oversee and support the quality of enforcement data. Collectively, their responsibilities will include developing new procedures for data entry, implementing a systematic data quality and control monitoring process that will involve both regional management teams as well as headquarters, conducting periodic quality assurance analysis of enforcement files, and providing training to Enforcement Officers.

Interdepartmental cooperation

Cooperation between the two departments is lacking

1.127 The Minister of Fisheries and Oceans continues to be legally responsible to Parliament for all sections of the *Fisheries Act*, including administration of the pollution prevention provisions that have been assigned to Environment Canada. The Habitat Policy and the Compliance and Enforcement Policy promote the concept of Fisheries and Oceans Canada and Environment Canada working cooperatively to achieve the policies' objectives. We expected to find that the two departments had formal arrangements to establish the expectations for administration of the pollution prevention provisions of the *Fisheries Act* and that they had implemented the cooperative arrangements reflected in the policies.

1.128 A 1985 Memorandum of Understanding (MOU) between Fisheries and Oceans Canada and Environment Canada sets out their collective responsibilities for administration of the pollution prevention provisions of the *Fisheries Act*. It is not being actively implemented by the two departments. For example, the MOU calls for regular, at least annual, meetings between senior officials to discuss operational, regulatory, and national policy considerations. These meetings are not held.

1.129 In response to our 2001 audit, Fisheries and Oceans Canada noted that the Memorandum of Understanding would be reviewed in the near future to further clarify the respective roles and expectations of the two departments in administering the pollution prevention provisions. This has not been done.

1.130 **Implementing the policies.** We found that Fisheries and Oceans Canada and Environment Canada have few formal interactions related to the policies. The Habitat Policy indicates that Fisheries and Oceans Canada is to work with Environment Canada to establish federal priorities. The Policy also stipulates that Fisheries and Oceans Canada is to provide criteria for fisheries protection to Environment Canada to guide it in its effort to protect fish and fish habitat from pollution. This has not been done.

1.131 The 2001 Compliance and Enforcement Policy called for a joint review of its implementation by the two departments after five years. Seven years later, we found that neither department was aware of this requirement and the joint review has not been done.

1.132 While there are many ongoing working-level interactions between officials of the two departments, we found that this has not been translated into the specific actions called for under the Habitat Policy and the Compliance and Enforcement Policy.

1.133 **Establishing expectations.** There are no formal arrangements by which Fisheries and Oceans Canada and Environment Canada establish the expectations for administration of the pollution prevention provisions of the *Fisheries Act*. Environment Canada's administration of the provisions has been left to its discretion.

1.134 **Recommendation.** Fisheries and Oceans Canada, with the support of Environment Canada, should clearly establish the expectations for Environment Canada's administration of the pollution prevention provisions, including the expected interactions between the two departments to support the delivery of the 1986 Habitat Policy.

Environment Canada's and Fisheries and Oceans Canada's response. The departments accept this recommendation and, by 31 March 2011, will review the administration of section 36 of the *Fisheries Act*. By 31 March 2012, a renewed Memorandum of Understanding that better establishes expectations and responsibilities for Environment Canada will be in place.

Conclusion

1.135 Fisheries and Oceans Canada and Environment Canada cannot demonstrate that they are adequately administering and enforcing the *Fisheries Act*, and applying the Habitat Policy and the Compliance and Enforcement Policy in order to protect fish habitat from the adverse impacts of human activity.

1.136 **Habitat Policy.** In the 23 years since the Habitat Policy was adopted, Fisheries and Oceans Canada has not fully implemented the Policy, and little information exists about the achievement of the Policy's overall long-term objective of a net gain in productive fish habitat. Fisheries and Oceans Canada needs to gather information on the state of fish habitat and develop habitat indicators to assess the state of Canada's fish habitat. Through improved information about the state of fish habitat, Canadians will be better informed about whether progress is being made toward the Policy's long-term objective.

1.137 **Environmental Process Modernization Plan (EPMP).** Fisheries and Oceans Canada has made progress in implementing the EPMP so that it can better manage its risks. The EPMP has resulted in a reliance on Canadians' self-compliance with the *Fisheries Act* habitat protection provisions for common, low-risk projects, to allow the Department to use its resources on projects that represent a greater risk to fish habitat. There are shortcomings in implementation of the EPMP. We found that the Department does not have adequate quality assurance and control processes for its new risk-based decision making. It cannot demonstrate that projects that represent a risk to fish habitat have been adequately assessed and a consistent approach has been applied. We found that Fisheries and Oceans Canada reduced its enforcement by half before implementing its new compliance approach. Further, the Department rarely monitors whether project proponents actually comply with the Department's conditions of approval or whether proponents' actions effectively maintained the expected no net loss in habitat.

1.138 Pollution prevention provisions. Environment Canada has not clearly identified what it has to do to meet its *Fisheries Act* responsibility for the pollution prevention provisions, including establishing results expectations and appropriate accountability arrangements that provide national coordination and guidance on the administration of the Act. Environment Canada does not use a risk-based approach to the *Fisheries Act* to identify, assess, and address risks associated with non-compliance with the Act that could lead to significant harm to fish habitat. It does not have a *Fisheries Act* compliance strategy for the industries and activities that must comply with the *Act's* prohibition against the deposit of harmful substances in waters frequented by fish. Environment Canada has not determined whether the results achieved through other legislation (such as the *Canadian Environmental Protection Act, 1999*), other levels of government, and its own enforcement activities meet the Act's stringent pollution prohibition requirement.

1.139 Review of regulations. Regulations under the pollution prevention provisions of the *Fisheries Act* allow regulated industries to deposit specified substances into waters frequented by fish within discharge limits. Environment Canada actively administers only two of the six *Fisheries Act* regulations for which it has responsibility. The two regulations cover the pulp and paper industry and metal mines, which have in the past represented risks to fish. However, the remaining four regulations, all of which date to the 1970s, are not actively being administered. The Department considers them to be outdated and difficult to enforce. By not reviewing these regulations to determine whether they still meet their initial policy objectives, Environment Canada is not following the 2007 Cabinet Directive on Streamlining Regulations.

1.140 Continuing issues. Many of the issues raised in this chapter have been raised before in previous audit reports, especially as they relate to Fisheries and Oceans Canada. For example, we have previously observed that Fisheries and Oceans Canada had not implemented aspects of the Habitat Policy, did not know whether it was progressing toward the ultimate objective of a net gain in fish habitat, and needed to devote more time and effort to compliance monitoring.

About the Audit

All of the audit work in this chapter was conducted in accordance with the standards for assurance engagements set by The Canadian Institute of Chartered Accountants. While the Office adopts these standards as the minimum requirement for our audits, we also draw upon the standards and practices of other disciplines.

Objective

The audit objective was to determine whether Fisheries and Oceans Canada and Environment Canada can demonstrate that they are adequately administering and enforcing the *Fisheries Act*, and applying the Habitat Policy and the Compliance and Enforcement Policy in order to protect fish habitat from the adverse impacts of human activity.

Scope and approach

The audit included the administration of the fish habitat protection and pollution prevention provisions of the *Fisheries Act* and the two policies (the Habitat Policy and the Compliance and Enforcement Policy) that set out the government's intentions related to these provisions. The audit included the policies, programs, and activities of Fisheries and Oceans Canada and Environment Canada, and certain arrangements with others that support the administration and enforcement of these provisions.

The audit did not focus on the environmental assessments required by the *Canadian Environmental Assessment Act* that may be triggered by ministerial authorizations under the provisions of the *Fisheries Act*.

Our approach included reviewing documents from the headquarters and regional offices, interviewing management and employees, examining databases, examining a sample of project proposals referred to Fisheries and Oceans Canada, examining a sample of enforcement actions taken by both departments, and analyzing procedures. We also reviewed a number of relevant environmental petitions and the related responses from department ministers.

Criteria

Listed below are the criteria that were used to conduct this audit and their sources.

Criteria	Sources
Fisheries and Oceans Canada and Environment Canada should administer and enforce the fish habitat protection and pollution control provisions of the *Fisheries Act* in a fair, predictable, and consistent manner so as to achieve the Habitat Policy and the Compliance and Enforcement Policy.	• Department of Fisheries and Oceans, Policy for the Management of Fish Habitat, 1986 • Environment Canada, Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the Fisheries Act, 2001 • Cabinet Directive on Streamlining Regulation, 2007

Criteria	Sources
Fisheries and Oceans Canada and Environment Canada should work collaboratively with provinces, communities, and stakeholders to implement the fish habitat protection and pollution control provisions of the *Fisheries Act*, and the Habitat Policy and the Compliance and Enforcement Policy. Where specific responsibilities are administered by others on behalf of Fisheries and Oceans Canada and Environment Canada, mechanisms should be in place to report to Fisheries and Oceans Canada or Environment Canada on the results achieved in the conduct of these responsibilities.	• Department of Fisheries and Oceans, Policy for the Management of Fish Habitat, 1986 • Environment Canada, Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the Fisheries Act, 2001 • CCME, A Canada-wide Accord on Environmental Harmonization • 1999 CESD Report—Streamlining Environmental Protection Through Federal-Provincial Agreements: Are They Working?
Fisheries and Oceans Canada's Environmental Process Modernization Plan should support the achievement of the Habitat Policy and the Compliance and Enforcement Policy, and be implemented fully, adapting its implementation to reflect experience.	• Department of Fisheries and Oceans, Policy for the Management of Fish Habitat, 1986 • Environment Canada, Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the Fisheries Act, 2001 • DFO Change Agenda • DFO, Environmental Process Modernization Plan, 2004 • Cabinet Directive on Streamlining Regulation, 2007
Fisheries and Oceans Canada and Environment Canada should measure and report on the extent to which their programs and activities contribute to the achievement of the Habitat Policy and the Compliance and Enforcement Policy and meet the reporting requirements under the *Fisheries Act*.	• Department of Fisheries and Oceans, Policy for the Management of Fish Habitat, 1986 • Environment Canada, Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the Fisheries Act, 2001 • Results for Canadians: A Management Framework for the Government of Canada

Audit work completed

Audit work for this chapter was substantially completed on 3 October 2008.

Audit team

Assistant Auditor General: Neil Maxwell
Principals: Eric Hellsten and Kevin Potter
Directors: Lana Dar and John Sokolowski

Erika Boch
Sébastien Bureau
Joanne Butler
Don MacNeill
David Wright

For information, please contact Communications at 613-995-3708 or 1-888-761-5953 (toll-free).

Appendix List of recommendations

The following is a list of recommendations found in Chapter 1. The number in front of the recommendation indicates the paragraph number where it appears in the chapter. The numbers in parentheses indicate the paragraph numbers where the topic is discussed.

Recommendation	Response
Protecting fish habitat	
1.33 In order to make consistent decisions on project referrals, in accordance with departmental expectations, Fisheries and Oceans Canada should ensure that an appropriate risk-based quality assurance system is in place for the review of these decisions. **(1.19–1.32)**	**Fisheries and Oceans Canada's response.** The Department accepts this recommendation. Over the past number of years, Fisheries and Oceans Canada has made efforts to improve the quality, consistency, and transparency of its decision making by implementing the Risk Management Framework. Although much progress has been made, the Department recognizes that there is still much work to be done with respect to documentation standards. With that in mind, by 31 March 2010, Fisheries and Oceans Canada will implement a risk-based quality assurance system to verify that documentation standards are being applied consistently by staff.
1.41 Fisheries and Oceans Canada should accelerate the implementation of its Habitat Compliance Decision Framework to ensure that there is an adequate risk-based approach to monitoring projects and providing assurance that proponents are complying with the *Fisheries Act* and all terms and conditions of departmental decisions. The Department should also determine whether the required mitigation measures and compensation are effective in meeting the no net loss principle. **(1.34–1.40)**	**Fisheries and Oceans Canada's response.** The Department accepts this recommendation. Fisheries and Oceans Canada currently applies a risk-based approach, but recognizes that opportunities for improvement remain. Once the Habitat Compliance Modernization initiative is fully implemented, the Department will be able to provide better assurance that proponents are complying with the terms and conditions of the Department's decisions. Considering this, the Department commits to fully implement the Habitat Compliance Decision Framework and report on results of project monitoring activities by 31 March 2010 and annually thereafter. Fisheries and Oceans Canada will continue to work with proponents to design and implement follow-up monitoring studies. Between now and the end of 2011, the Department will review and develop standard scientific methodologies to examine the effectiveness of compensation in achieving the no net loss guiding principle so that these methodologies can be used by proponents when designing monitoring studies.

Recommendation	Response
1.48 Fisheries and Oceans Canada should ensure that its enforcement quality assurance and control processes are sufficient to demonstrate that its actions have been taken in accordance with the Compliance and Enforcement Policy. The Department should provide guidance on the type of complaints that fishery officers should respond to and take action on, and the Department should specify minimum documentation requirements for occurrences. **(1.42–1.47)**	**Fisheries and Oceans Canada's response.** The Department accepts this recommendation and, by 31 August 2010, will establish, disseminate, and communicate to regions an operational protocol to ensure better documentation of enforcement actions and monitoring of activities to ensure consistency with the Compliance and Enforcement Policy. Guidance on the nature of complaints that warrant the attention of fishery officers has also been identified as a need by the Department. By 31 March 2011, the Department will examine the process currently in use and, by 31 March 2012, the Department will examine the Habitat Compliance Decision Framework to improve its guidance to staff, clarify documentation protocols, and establish minimum documentation standards for occurrences.
1.69 Fisheries and Oceans Canada should clarify the parts of the Habitat Management Program that it will continue to administer, the extent that it wants others to deliver the program on its behalf, and the resource implications. The Department should also assess whether accountability mechanisms in all of its existing agreements are working effectively enough to report and assess the results achieved through its collaboration with others. In addition, it should review the agreements to ensure that they are aligned with its view of the long-term goals of the Habitat Management Program. **(1.49–1.68)**	**Fisheries and Oceans Canada's response.** The Department accepts this recommendation and, by 31 March 2011, will have reviewed and evaluated its memoranda of understanding with provinces and territories. The Department will continue to work with its partners to strengthen the governance and accountability mechanisms and ensure that the partnership arrangements are aligned with the Department's goals and its strategic vision.
1.74 Fisheries and Oceans Canada should develop habitat indicators to apply in ecosystems with significant human activity. The Department should use these indicators to assess whether it is making progress on the Habitat Policy's long-term objective to achieve an overall net gain in fish habitat. **(1.70–1.73)**	**Fisheries and Oceans Canada's response.** The Department accepts and agrees with this recommendation and is committed to moving toward an ecosystems approach and the increased use of biological indicators, particularly in areas of significant human activity. However, this task is far from trivial as it will require significant new scientific understanding to ensure that the indicators adopted do in fact tell us what we need to know about the health of the aquatic ecosystem.

Recommendation	Response
1.80 Fisheries and Oceans Canada should determine what actions are required to fully implement the 1986 Habitat Policy and confirm whether it intends to implement all aspects of the Policy. **(1.75–1.79)**	**Fisheries and Oceans Canada's response.** The Department accepts this recommendation and, by March 2010, will determine what actions are required to fully implement the Habitat Policy.
Pollution prevention provisions	
1.93 Environment Canada should set out clear objectives and results expectations for its *Fisheries Act* responsibilities, and establish accountability for achieving the desired results, including providing national coordination and guidance on the administration of the Act. **(1.81–1.92)**	**Environment Canada's response**. The Department accepts this recommendation and will put in place a Results-based Management and Accountability Framework in 2009–10 for Environment Canada's *Fisheries Act* responsibilities. The framework will clearly identify the objectives, responsibilities, and expected results, including how national coordination and guidance on Environment Canada's administration of the Act will be provided.
1.112 Environment Canada should develop a risk-based approach to the *Fisheries Act* pollution prevention provisions to identify, assess, and address significant risks associated with non-compliance with the Act. As part of this approach, Environment Canada should determine whether there are significant risks to fish habitat associated with non-compliance with the *Fisheries Act* that are not being addressed by the combination of its own administration and enforcement of the Act, and the administration of other federal and provincial legislation. **(1.94–1.111)**	**Environment Canada's response.** The Department accepts this recommendation and has assigned responsibility to the Public and Resources Sectors Directorate of the Environmental Stewardship Branch to coordinate risk management and compliance promotion priorities for subsection 36(3) of the *Fisheries Act* and associated regulations. In 2009–10, Environment Canada will develop a work plan to identify current risks and risk management activities in non-regulated sectors, including *Fisheries Act* compliance promotion activities and other federal and provincial legislation. In 2010–11, the Department will complete the review of risks and risk management activities and will adjust departmental work plans as required.

Recommendation	Response
1.120 Environment Canada should review existing *Fisheries Act* regulations, guidelines, and best management practices to ensure that they are adequate, up-to-date, relevant, and enforceable. **(1.113–1.119)**	**Environment Canada's response.** The Department accepts this recommendation. Over the 2009–2012 period, Environment Canada will undertake a review of the continued relevance of the four regulations noted below in light of *Fisheries Act* guidelines, provincial standards, and industry best management practices, and will take the necessary steps to update or repeal them as appropriate: • Chlor-Alkali Mercury Liquid Effluent Regulations • Meat and Poultry Products Plant Liquid Effluent Regulations • Petroleum Refinery Liquid Effluent Regulations • Potato Processing Plant Liquid Effluent Regulations
1.126 Environment Canada should ensure that its enforcement quality assurance and control practices are sufficient to demonstrate that its actions have been taken in accordance with the Compliance and Enforcement Policy. **(1.121–1.125)**	**Environment Canada's response.** The Department accepts this recommendation. The Enforcement Branch is continuing to develop a framework, standardize processes, and establish accountabilities to enhance its quality assurance and its quality control. More specifically, the quality assurance and quality control framework is being both developed and implemented over the 2009–10 and 2010–11 fiscal years and maintained thereafter. At the same time, the Enforcement Branch is establishing a quality assurance unit, as well as a working group, to oversee and support the quality of enforcement data. Collectively, their responsibilities will include developing new procedures for data entry, implementing a systematic data quality and control monitoring process that will involve both regional management teams as well as headquarters, conducting periodic quality assurance analysis of enforcement files, and providing training to Enforcement Officers.
Interdepartmental cooperation	
1.134 Fisheries and Oceans Canada, with the support of Environment Canada, should clearly establish the expectations for Environment Canada's administration of the pollution prevention provisions, including the expected interactions between the two departments to support the delivery of the 1986 Habitat Policy. **(1.127–1.133)**	**Environment Canada's and Fisheries and Oceans Canada's response**. The departments accept this recommendation and, by 31 March 2011, will review the administration of section 36 of the *Fisheries Act*. By 31 March 2012, a renewed Memorandum of Understanding that better establishes expectations and responsibilities for Environment Canada will be in place.

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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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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, ≃760 m^3/sec of Churchill River water was diverted into the

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

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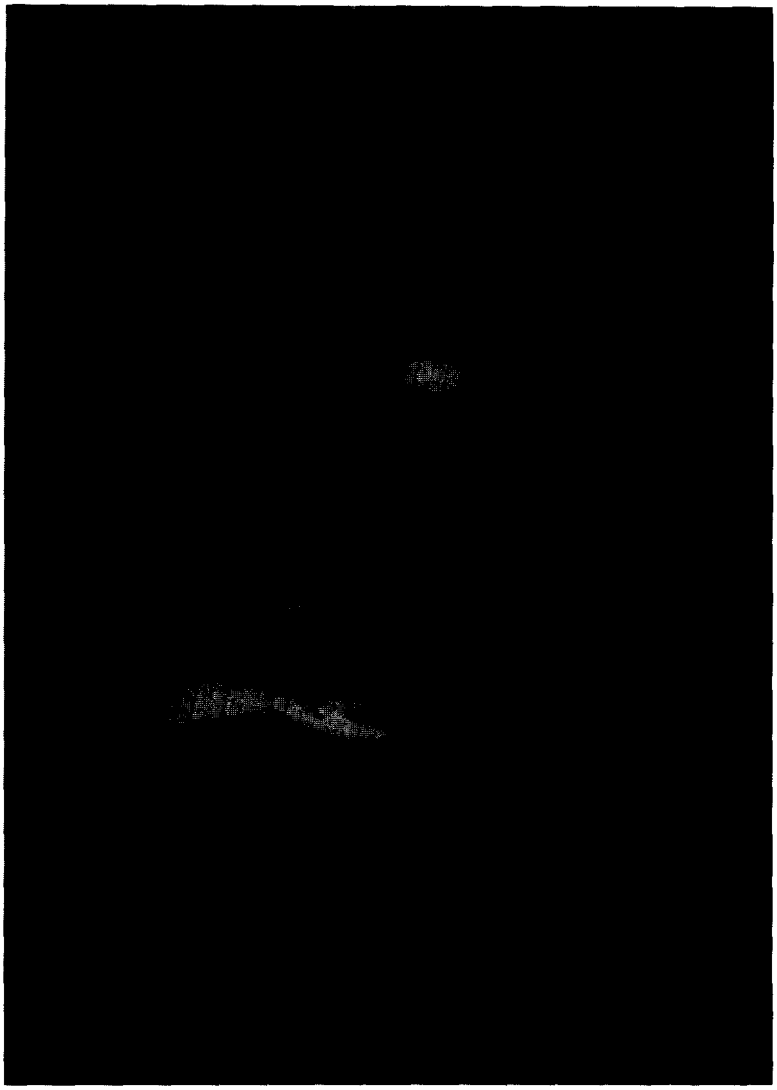

Figure 1 The Rat River, route of the Churchill-Nelson River diversion in northern Manitoba. (a) Before formation of the Notigi Reservoir and start of diversion flows; (b) After flooding and diversion. Note the large areas of floating peat. Photos: Allen P Wiens.

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]

Continued from page 127
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

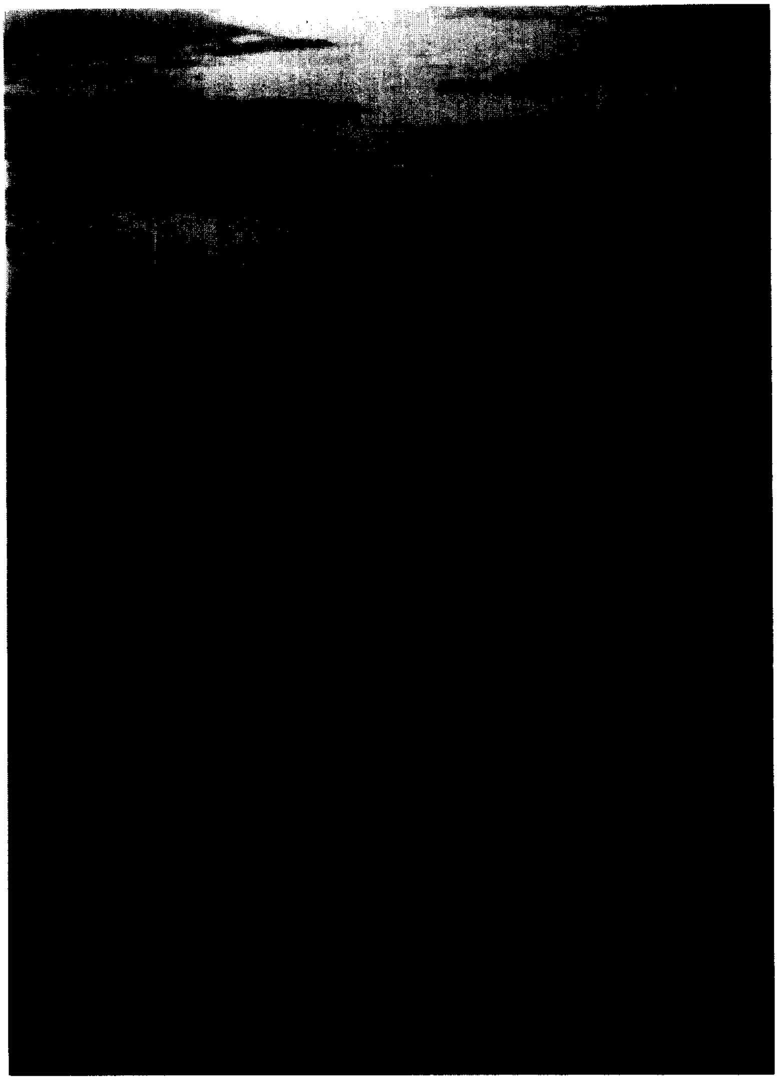

Figure 1b

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*

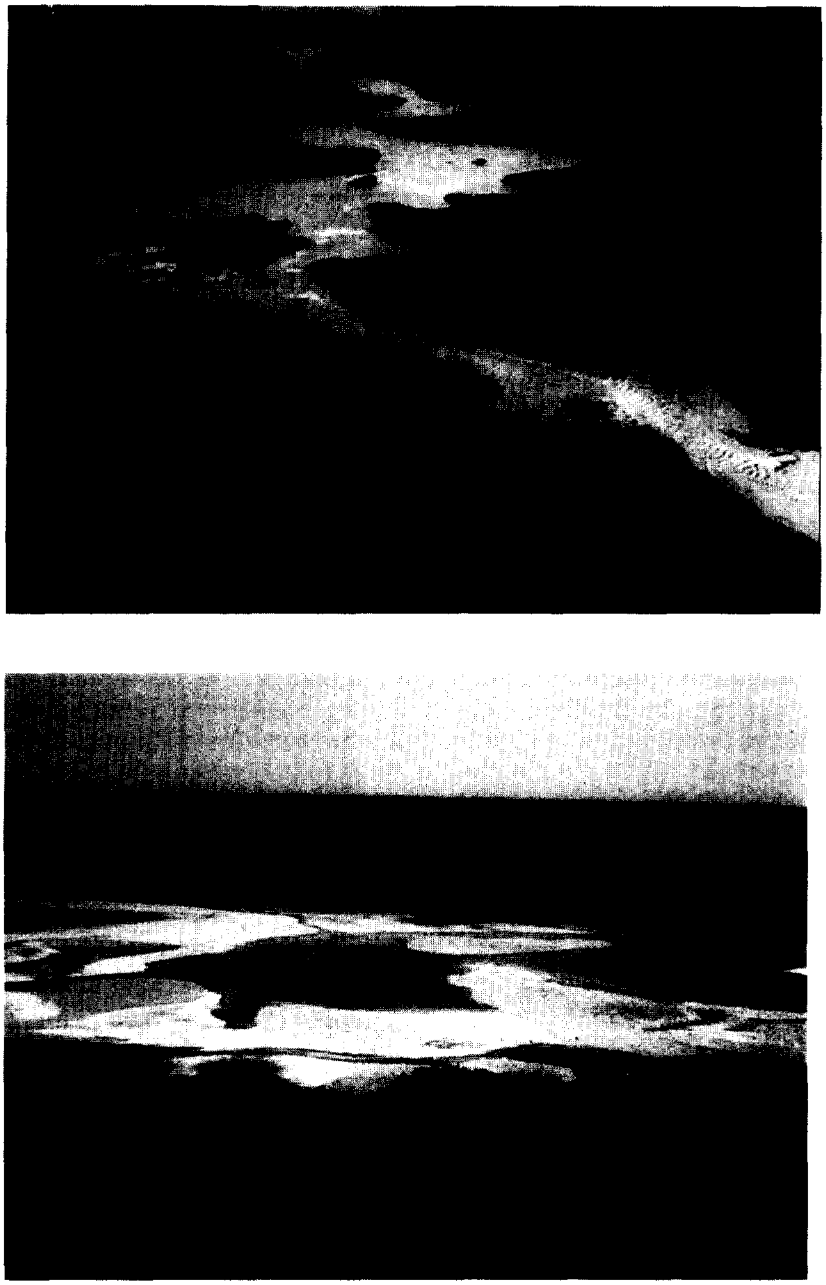

Figure 2 The lower Churchill River, northern Manitoba. (a) Before diversion; (b) After diversion. Photos: Allen P Wiens.

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

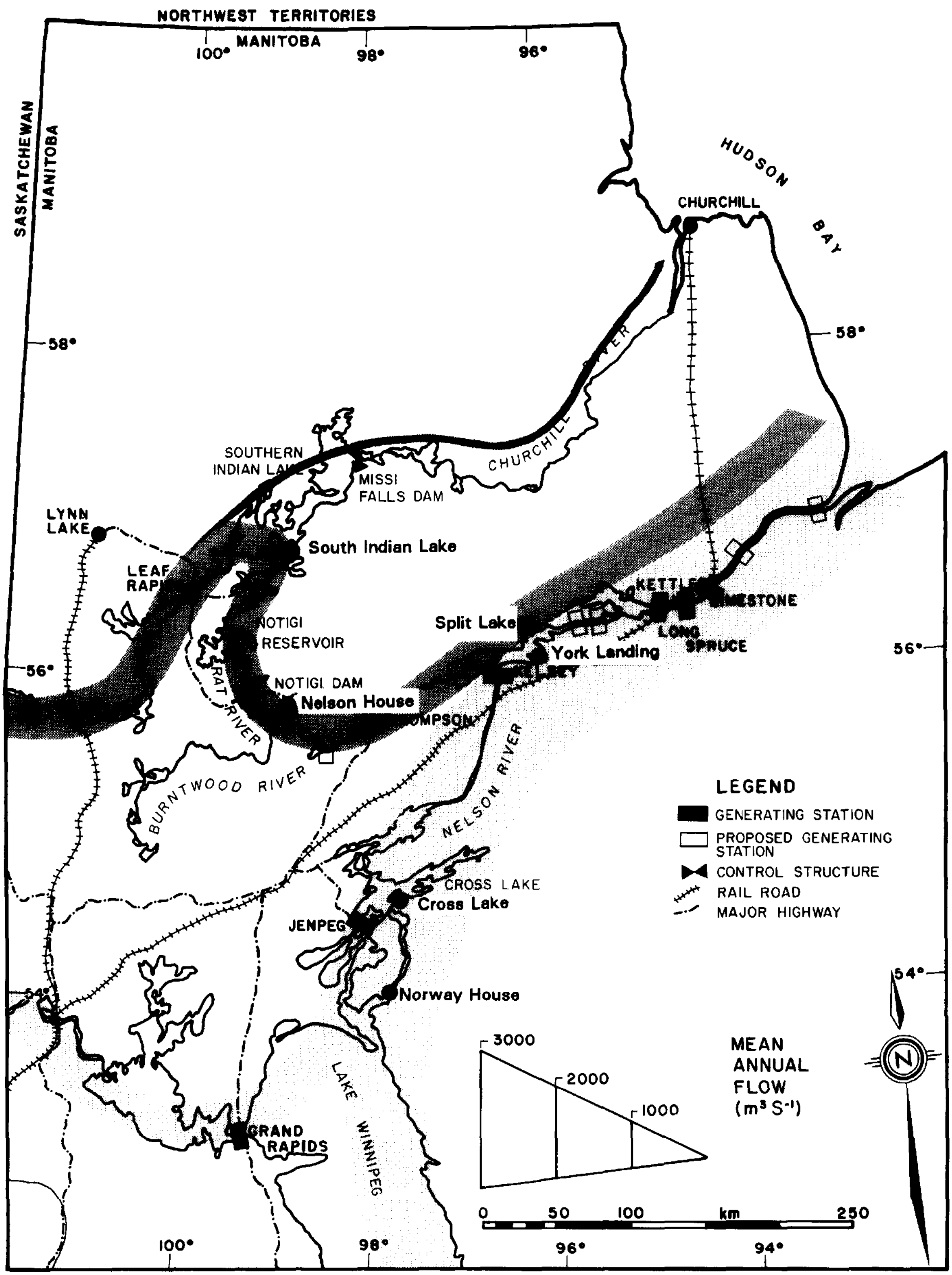


Figure 4 Hydroelectric development along the Churchill and Nelson rivers, northern Manitoba, indicating altered flow regime of the rivers. Dark tone indicates relative magnitude of lower Churchill River discharge after diversion; mid-tone indicates Churchill River diversion at Southern Indian Lake; light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

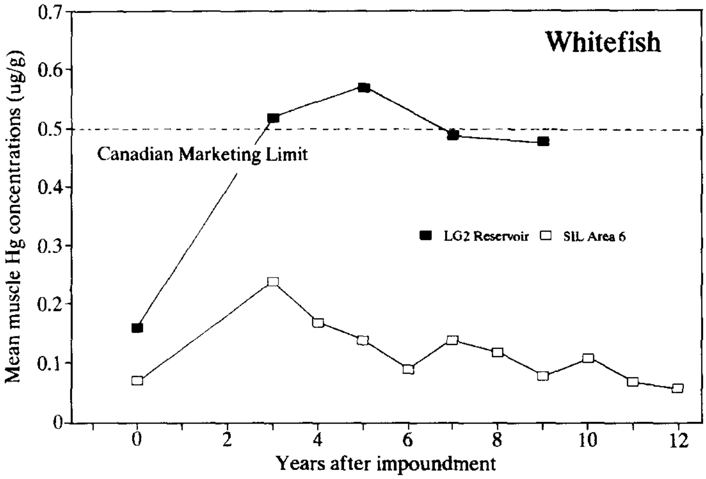


Figure 5 Mercury concentrations in the muscle tissue of (a) lake whitefish (*Coregonus clupeaformis),* (b) pike (*Esox lucius*), and (c) walleye (*Stizostedion vitreum*) in the Southern Indian Lake (SIL) Reservoir, northern Manitoba, and the La Grande (LG)2 Reservoir, northern Québec. Mean mercury concentrations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

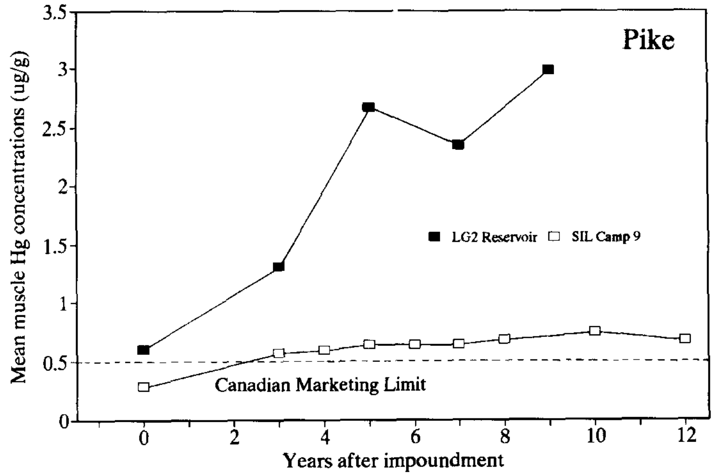


Figure 5b

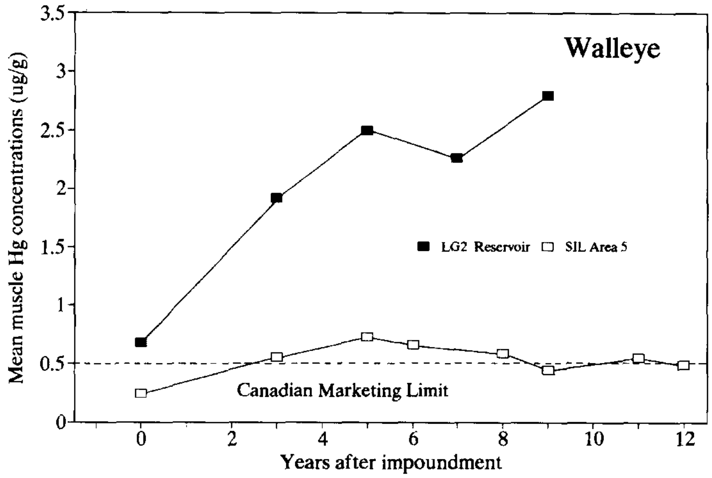


Figure 5c

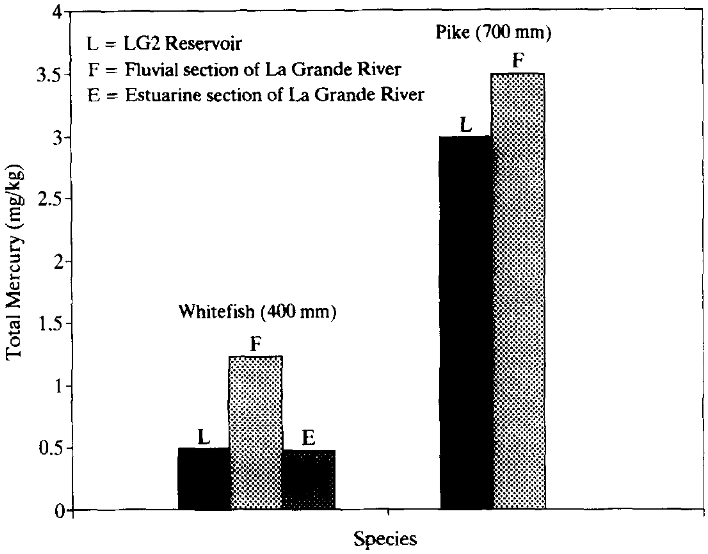
flooding experiment being conducted at the Canadian Department of Fisheries and Oceans' Experimental Lakes Area (ELA) in northwestern Ontario. Should the experimental results support the preliminary observations, the implications are significant: the total surface area of impounded water in five extant 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



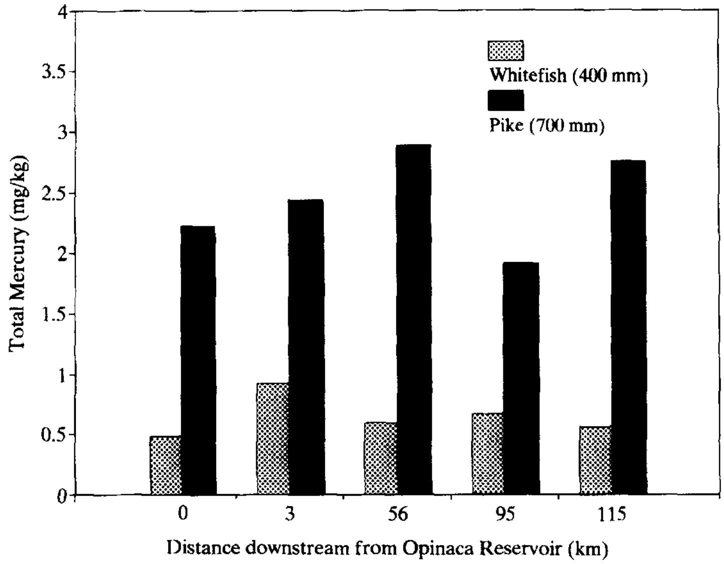


Figure 6b

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.

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]

[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

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 ≈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*

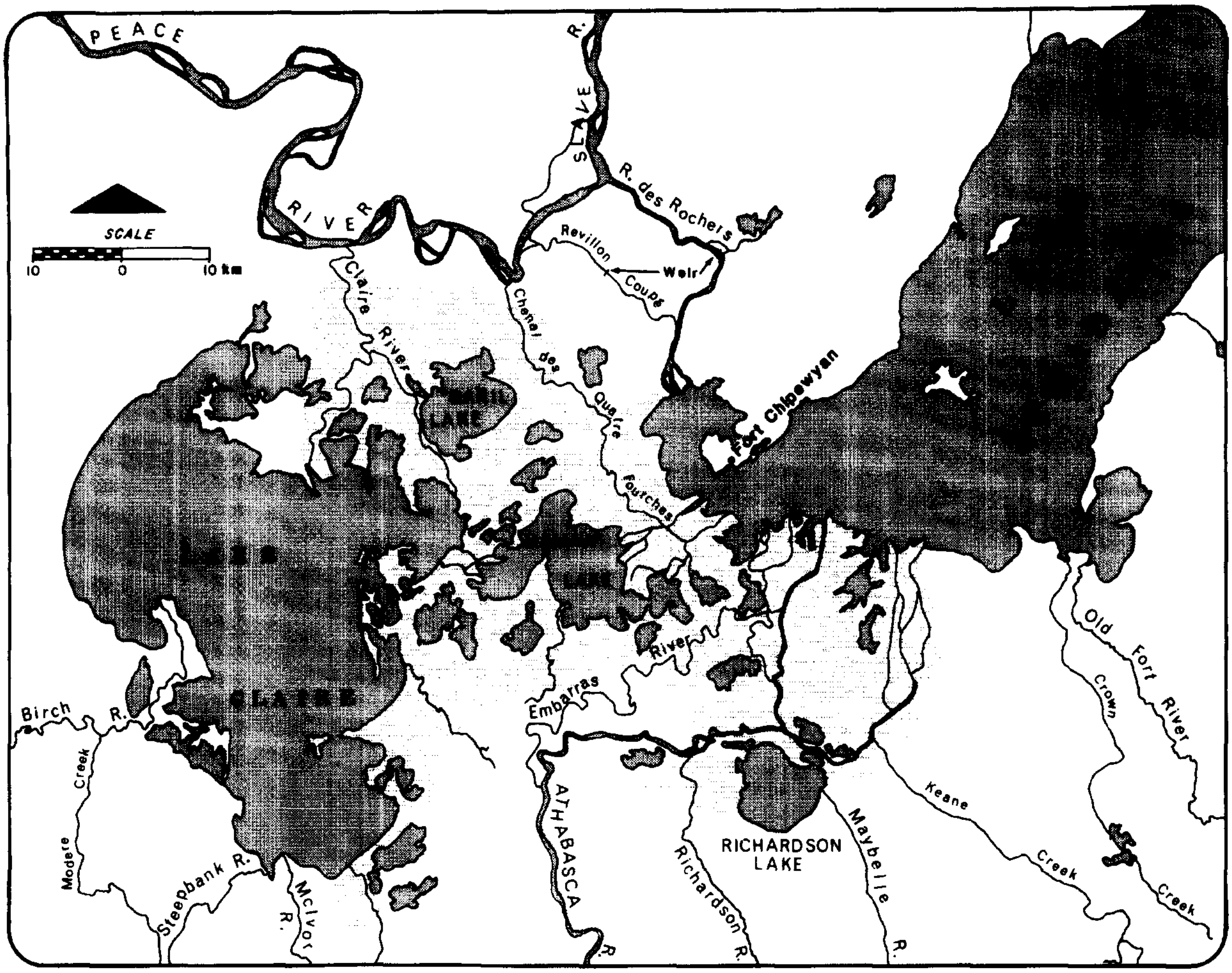


Figure 7 The Peace-Athabasca Delta, northern Alberta, Canada.

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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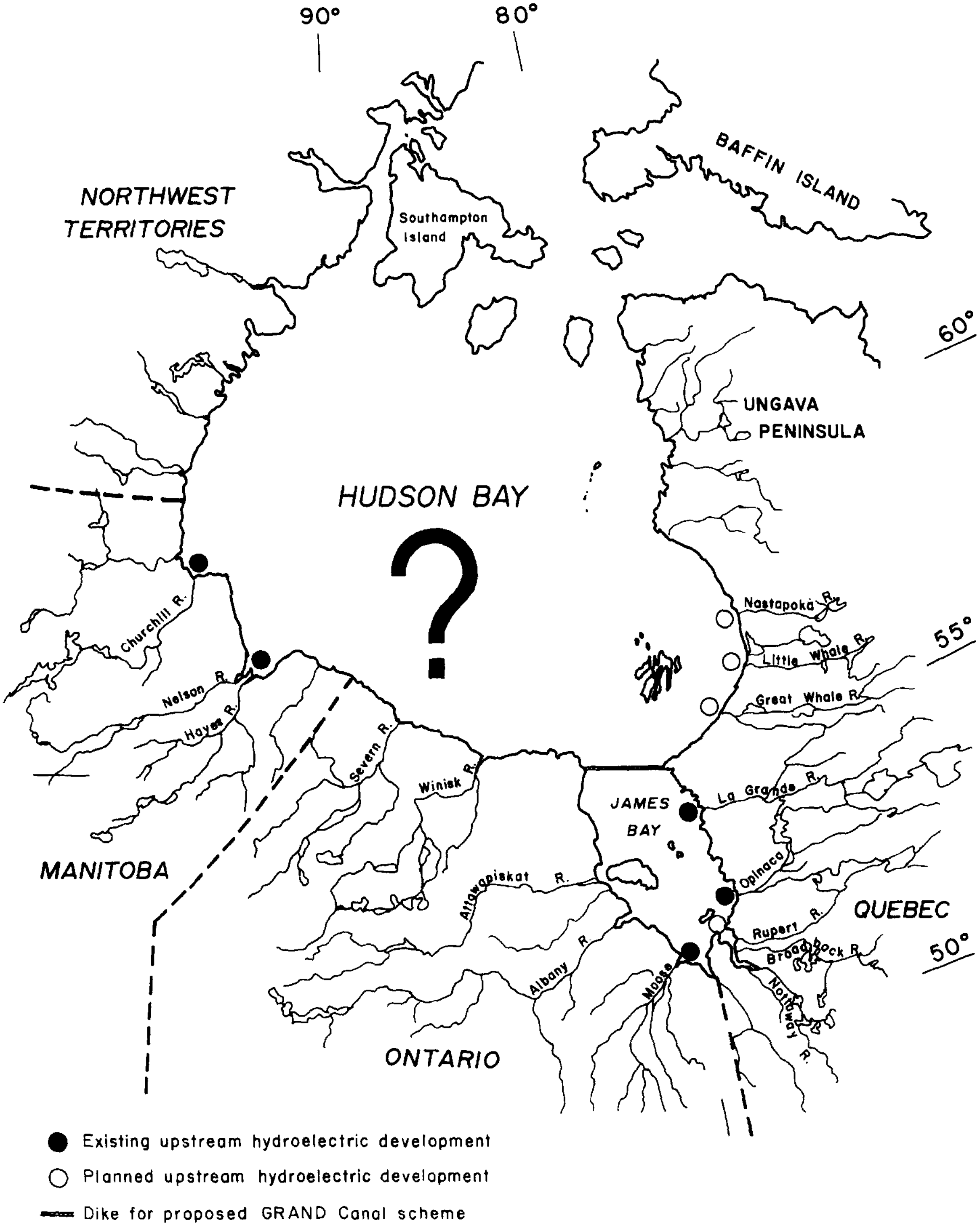

Figure 8 Major hydroelectric developments and water diversions existing and planned in the Hudson and James Bay catchments, northern Canada. Further hydroelectric development is planned for already developed river systems.

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 $\approx$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 $\approx$12 400 MW; Phase II involves the creation of 4 more reservoirs and 6 or 7 more powerhouses yielding another $\approx$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 $\approx$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 $\approx$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 hydroelectric 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 ≃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

Large-scale impacts of hydroelectric development

D.M. Rosenberg,[1] F. Berkes, R.A. Bodaly, R.E. Hecky, C.A. Kelly, and J.W.M. Rudd

Abstract: The substantial size of some hydroelectric projects and the extensive total surface area covered by reservoirs globally require that research determining the impacts of these developments be done at ever-increasing spatial and temporal scales. As a consequence of this research, new views are emerging about the spatial extent and longevity of the environmental and social impacts of such developments. New findings challenge the notion of hydroelectric development as a benign alternative to other forms of power generation. This review examines the intertwined environmental and social effects of methylmercury bioaccumulation in the food web, emission of greenhouse gases from reservoirs, downstream effects of altered flows, and impacts on biodiversity, each of which operates at its own unique spatial and temporal scales. Methylmercury bioaccumulation occurs at the smallest spatial and temporal scales of the four impacts reviewed, whereas downstream effects usually occur at the largest scales. Greenhouse gas emissions, the newest surprise connected with large-scale hydroelectric development, are relatively short term but eventually may have important global-scale consequences. Limitation of biodiversity by hydroelectric development usually occurs at intermediate spatial and temporal scales. Knowledge developed from working at expanded spatial and temporal scales should be an important part of future decision making for large-scale hydroelectric development.

Key words: hydroelectric development, large-scale, environmental impacts, social impacts.

Résumé : La dimension considérable de certains projets hydroélectriques et les vastes surfaces totales globalement couvertes par les réservoirs nécessitent que la recherche menée pour déterminer les impacts de ces développements soit conduite à des échelles d'espace et de temps de plus en plus grandes. Comme conséquence de cette recherche, de nouvelles perceptions prennent naissances concernant l'ampleur spatiale et la longévité des impacts sociaux et environnementaux, suite à ces développements. De nouvelles constatations mettent en doute la notion que le développement hydroélectrique serait une alternative bénigne par rapport à d'autres forme de production d'énergie. Dans cette revue, les auteurs examinent les effets sociaux et environnementaux intercroisés de la bioaccumulation du mercure méthylé dans la chaîne alimentaire, de l'émission de gaz à effet serre à partir des réservoirs, des conséquences en aval des perturbations des rivières ainsi que des impacts sur la biodiversité, lesquels agissent chacun à leurs échelles spatiales et temporelles. Parmi les quatre impacts considérés, la bioaccumulation du mercure méthylé survient aux échelles spatiales et temporelles les plus petites, alors que les perturbations en aval des cours d'eau surviennent aux échelles les plus grandes. Les émissions de gaz à effet serre, la dernière surprise reliée aux développements hydroélectriques sur de grandes surfaces, sont de durée relativement courte mais pourraient éventuellement avoir des conséquences importantes à l'échelle globale. La limitation de la biodiversité par le développement hydroélectrique se manifeste habituellement à des échelles spatiales et temporelles intermédiaires. La connaissance provenant du travail à des échelles spatiales et temporelles plus vastes devrait jouer un rôle importante dans les processus futures de prise de décision lors des développements hydroélectriques à grande échelle.

Mots clés : développement hydroélectrique, grande échelle, impacts sociaux, impacts environnementaux.
[Traduit par la rédaction]

Introduction

Contemporary research on the environmental effects of hydroelectric development is pursued at a variety of spatial and temporal scales. These scales extend from short-term studies following formation of single, small reservoirs (e.g., Aggus 1971; Bass 1992; Koskenniemi 1994) to studies of huge reservoir and water-diversion complexes drawn from decades of data (e.g., Pligin and Yemel'yanova 1989; Rozengurt and Hedgpeth 1989; Marchand 1990). At the very largest scales, Chao (1991, 1995) reported that worldwide impoundment of water has reduced sea levels by 3 cm, and the concentration of reservoirs built in the last 40 years at high latitudes has caused the earth to spin faster!

The global extent of reservoirs, including hydroelectric facilities is enormous. There are ~39 000 large dams in the

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D.M. Rosenberg,[2] R.A. Bodaly, R.E. Hecky,[3] and J.W.M. Rudd. Freshwater Institute, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada.
F. Berkes. Natural Resources Institute, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.
C.A. Kelly. Department of Microbiology, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.

[1] The following coauthors are arranged in alphabetical order.
[2] Author to whom all correspondence should be addressed (e-mail: rosenbg@cc.umanitoba.ca).
[3] Present address: Canada Centre for Inland Waters, 867 Lakeshore Road, Burlington, ON L7R 4A6, Canada.

Table 1. Selected estimates of regional spatial coverage by reservoirs (estimates may not agree).

Region	Types of reservoirs	Area covered (km^2)	Ref.
Global	Hydroelectric	600 000 (larger than the North Sea)	Pearce 1996
	All types and sizes	500 000 (~2× the Laurentian Great Lakes)	Kelly et al. 1994
	All types, large (>10^8 m^3 of water)	California or France	Dynesius and Nilsson 1994
Canada	Hydroelectric, five, extant, large (≥1000 MW of power)	~20 000 (Lake Ontario)	Rosenberg et al. 1987
	Hydroelectric, new, planned for northern Québec	~10 000 (~1/2 covered by forest)	Rougerie 1990
United States	All types and sizes (>100 000; 5500 are large, i.e., dams ≥15 m height)	New Hampshire and Vermont	Devine 1995
India	All types and sizes (>1550 are large; >100 000 are medium and small; meaning of size not specified)	Large, >14 500; medium and small, >11 000	Foote et al. 1996

world (World Register of Dams 1988, in Dynesius and Nilsson 1994); some 5500 of these (≥15 m height) are in the United States (Devine 1995) and 618 (≥10 m) are in Canada (Environment Canada 1990). The usable man-made reservoir capacity is ~9% of the annual global river runoff (Dynesius and Nilsson 1994). The present storage capacity of large dams amounts to 5500 km^3 (Postel et al. 1996). Of this, 3500 km^3 are actively used in regulating river runoff; by 2025 another ~1200 km^3 will have been added to active storage (Postel et al. 1996). It has been estimated that reservoirs of all types and sizes occupy 500 000 km^2 globally, an area approximately twice that of the Laurentian Great Lakes (Kelly et al. 1994). Table 1 summarizes some regional estimates of the areal extents of reservoirs and Table 2 presents the extent of local flooding caused by selected major hydroelectric developments.

Projects like La Grande River development in Canada (Berkes 1981), the Sardar Sarovar development in India (Morse and Berger 1992), and the Three Gorges development in China (Fearnside 1988) indicate continuing global interest in the construction of megaprojects that produce significant amounts of power (i.e., ≥1000 MW), although Postel et al. (1996) contend that the average number of large dams (≥15 m) constructed in the world is dropping and will continue to do so into the next century (see also Majot 1996). In Canada, hydroelectric development over the past few decades has moved from relatively contained project configurations in the populated south of the country to relatively uncontained configurations in the sparsely populated north, which indicates that the best (i.e., most cost effective) sites have been used (see Devine 1995 for a similar comment about the United States). Some large-scale Canadian hydroelectric projects are reviewed in Rosenberg et al. (1987).

Past and present development of hydroelectric megaprojects has required environmental and social researchers to work at ever-increasing spatial and temporal scales. This review will deal with these expanded scales rather than with the smaller scale, in-reservoir and immediately downstream processes (e.g., changes in sedimentation regime, primary productivity, and faunal populations) of more traditional reviews (e.g., Baxter 1977; Baxter and Glaude 1980). Research at larger scales has begun to lead to new views about the spatial extent and longevity of the environmental and social effects of such projects, and cumulative effects on a global basis. These findings challenge the notion of hydroelectric development as a relatively benign form of power generation and raise questions about whether hydroelectric projects can ever be made environmentally sustainable (Goodland et al. 1993).

This review will focus on four, large-scale impacts attributable to hydroelectric developments, each of which operates at its own unique spatial and temporal scales (Fig. 1): (*i*) methylmercury bioaccumulation; (*ii*) emissions of greenhouse gases; (*iii*) downstream effects; and (*iv*) limitation of biodiversity. Each of these impacts have environmental and social effects, both of which are considered in this review, although environmental effects receive more emphasis. We have chosen to interweave the presentation of environmental and social effects to emphasize the linkages between them. The material presented concentrates on Canadian experiences, but examples from elsewhere in the world are used to demonstrate that broadly applicable principles are involved. This review will not address alternative energy sources to hydroelectric generation or hydroelectric conservation programs, which are both subjects broad enough to deserve separate attention.

Methylmercury bioaccumulation

Methylmercury bioaccumulation by fish and the consequent consumption of fish by humans is of concern in the creation of reservoirs. Methylmercury is an organic molecule produced mainly by bacteria (Berman and Bartha 1986) from inorganic mercury naturally present in materials flooded during the course of reservoir creation (Bodaly et al. 1984*a*; Hecky et al. 1991; Kelly et al. 1997). Methylmercury is a neurotoxin to which the human fetus is particularly sensitive (e.g., Weihe et al. 1996).

Methylmercury bioaccumulation is the most spatially restricted of the four environmental impacts being reviewed (Fig. 1). Methylmercury problems in fish are confined to the reservoirs themselves and short (<100 km) distances downstream. Temporally, methylmercury contamination in reservoirs can last 20–30 years or more; for example, methylmercury levels in predatory fish in boreal reservoirs of Canada and Finland can be expected to return to background levels 20–30 years after impoundment (Bodaly et al. 1997).

Environmental effects

The first indication that methylmercury was a problem in new reservoirs came from South Carolina (Abernathy and Cumbie 1977). Alerted by the American experience, researchers elsewhere began reporting similar occurrences (Table 3). Research on northern reservoirs, especially in Canada and Finland, has

Table 2. Extent of flooding involved in selected major hydroelectric developments.

Project and location	Total surface area of impounded water (km^2)	Area of newly flooded land (km^2)	Comments	Ref.
			Canada	
Kemano, Phase I, B.C.	890	NA	Includes the Nechako Reservoir	Rosenberg et al. 1987
Williston Reservoir, B.C.	1645	NA	Involves Peace River	Peace–Athabasca Delta Project Group 1972
Churchill–Nelson, Man.	3299	~750	Includes Southern Indian Lake (SIL), Notigi, and Stephens Lake reservoirs; preimpoundment surface area of SIL, 1977 km^2	Newbury et al. 1984; Rosenberg et al. 1987, 1995
Manic 5, Qué.	2072	NA	—	R. Harris, personal communication
La Grande, Phase I, Qué.	11 345	9675	Includes La Grande (LG) 2, 3, and 4, Opinaca, and Caniapiscau reservoirs. DesLandes et al. (1995) report that Phase 1 covers a total area of 13 520 km^2	Berkes 1988
La Grande, Phase II, Qué.	~2000	NA	Includes Laforge-1 and Eastmain-1 reservoirs	A. Penn, personal communication
Churchill Falls, Labrador	6705	NA	Includes Smallwood, Ossokmanuan, and Jacopie Lake reservoirs	Rosenberg et al. 1987
			United States	
Missouri mainstem reservoirs, Mont., N.Dak., S.Dak., Nebr.	6260	NA	Includes Lake Ft. Peck (991 km^2), Lake Sakakawea (3060 km^2), Lake Francis Case (420 km^2), Lewis and Clark Lake (113 km^2), Lake Oahe (1450 km^2), and Lake Sharpe (226 km^2) reservoirs	Rosenberg et al. 1987
			Russian Federation	
Volga River	26 010	50–69% of area inundated was highly fertile cropland	Includes 11 reservoirs, 8 in the Volga River catchment and 3 in the Kama River catchment. The largest of these are Kuibyshevskaya (6450 km^2) and Rybinskaya (4550 km^2) reservoirs, both in the Volga catchment. Poddubny and Galat (1995) report the following total : shallow-water areas (km^2) for the four reservoirs of the Upper Volga River: Ivankova, 327:156; Uglich, 249:89; Rybinsk, 4450:950; Gorky, 1591:368	Rozengurt and Hedgpeth 1989
River Don	5500	NA	>130 reservoirs in the catchment	Volovik 1994
			Ukraine	
Dnieper River	~7000	NA	Dnieper reservoir cascade. Exact number of reservoirs involved is not given	Romanenko and Yevtushenko 1996
			South America	
Balbina Reservoir, Amazonas State, Brazil	2360–4000	NA	Exact size is not known because of survey's margin of error	Fearnside 1989
	3147	3108	Columns 7 and 8 of Table III in Fearnside 1995	Fearnside 1995
Tucurai Reservoir, Pará State, Brazil	2160	NA	—	Monosowski 1984
	2247	1926	Columns 7 and 8 of Table III in Fearnside 1995	Fearnside 1995

Table 2 (*concluded*).

Project and location	Total surface area of impounded water (km^2)	Area of newly flooded land (km^2)	Comments	Ref.
	2830	NA	Tocantins–Araguaia catchment, the southeasternmost Amazonian tributary, integrates the seasonally dry Cerrados with the hot humid Amazonian rain forest	Ribeiro et al. 1995
Itaipu, Brazil and Paraguay	1350	NA	—	Goldsmith and Hildyard 1984
Guri, Venezuela	3280	NA	—	Goldsmith and Hildyard 1984
			Africa	
Lake Kariba Reservoir, Zimbabwe and Zambia	5364	NA	Dam on middle part of Zambezi River at Kariba Gorge; forested and savannah regions	Balon 1978; Obeng 1981
Volta Lake Reservoir, Ghana	8500	NA	Dam on Volta River at Akosombo. Reservoir occupies two climatic zones: forest in south and savannah–woodland in north	Petr 1971; Obeng 1977, 1981
Lake Kainji, Nigeria	1280	NA	Dam on Niger River at Bussa; forested and savannah regions	Obeng 1981
High Dam at Aswan, Egypt and Sudan	3000–6000	NA	Dam on Nile River. Reservoir is known as Lake Nasser (Egyptian part) and Lake Nubia (Sudanese part)	White 1988
	6276		Reservoir lies in desert region	Obeng 1981
Cabora Bassa Dam, Mozambique	3800	NA	Dam on lower Zambezi River at Cabora Bassa Gorge	Goldsmith and Hildyard 1984; Bolton 1984
			Middle East	
Southeast Anatolia Project, Turkey	1857	NA	Euphrates River development: Keban Dam (680 km^2), Karakoya Dam (300 km^2), and Ataturk Dam (877 km^2); other smaller developments on Euphrates. Developments on Tigris are planned	Hillel 1994
			Southeast Asia	
Brokopondo, Suriname	1500	NA	—	Goldsmith and Hildyard 1984
Kabalebo, Suriname	1450	NA	—	Goldsmith and Hildyard 1984
			China	
Three Gorges Reservoir, Yangtze River	1150	632	Mostly in mountainous terrain	Chau 1995
Danjiangkou Reservoir, Han River	745–1000	NA	Largest extant reservoir in China	Zhong and Power 1996

Note: NA, not available.

been extensive; fewer reports come from temperate and tropical reservoirs. However, the problem appears to be less severe in warmer areas (Yingcharoen and Bodaly 1993).

Research in northern Canadian reservoirs has revealed the following characteristics of methylmercury in fish.

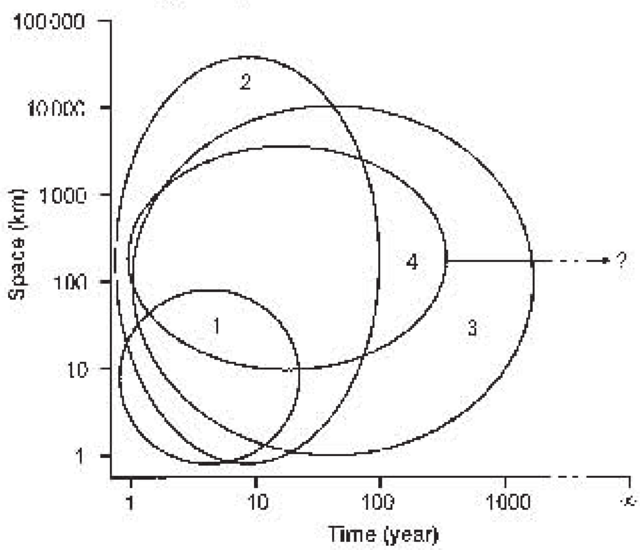
(1) It can reach very high levels. For example predatory fish (pike: *Esox lucius*; walleye: *Stizostedion vitreum*) in La Grande (LG) 2 Reservoir in the James Bay region of Québec reached approximately six times background levels or more than seven times the Canadian marketing limit of 0.5 µg/g (Verdon et al. 1991). Mean concentrations in predatory fish almost always exceed 1.0 µg/g in northern reservoirs (Bodaly et al. 1997).

(2) Levels in predatory fish usually remain elevated for 2–3 decades following impoundment, whereas levels in water and zooplankton remain elevated for 10 and 10–15 years, respectively (Bodaly et al. 1997). The difference between fish and lower trophic levels is probably the result of a longer half-life of methylmercury in fish and a slower turnover of fish populations. Methylmercury levels in predatory fish from the LG2 Reservoir and from reservoirs in northern Manitoba remain above marketing levels 10–20 years after reservoir creation (Strange et al. 1991; James Bay Mercury Committee 1995; Bodaly et al. 1997). Average levels in LG2 were still >3.0 µg/g 13 years after flooding.

Table 3. Examples of elevated methylmercury levels in fish from new reservoirs.

Location	Species	Ref.
	Boreal zone	
Northern Manitoba	*Stizostedion vitreum* (walleye), *Esox lucius* (northern pike), and *Coregonus clupeaformis* (lake whitefish)	Bodaly et al. 1984*a*
Northern Québec	As for northern Manitoba plus *Catostomus catostomus* (longnose sucker) and *Salvelinus namaycush* (lake trout)	Boucher et al. 1985
Labrador	*Esox lucius*, *Salvelinus namaycush*, and *Coregonus clupeaformis*	Bruce and Spencer 1979
Finland	*Esox lucius* and *Coregonus lavaretus* (whitefish)	Lodenius et al. 1983
	Temperate areas	
Southern Saskatchewan	*Stizostedion vitreum* and *Castostomus commersoni* (common sucker)	Waite et al. 1980
Illinois	*Micropterus salmoides* (largemouth bass)	Cox et al. 1979
South Carolina	*Micropterus salmoides*, *Morone chrysops* (white bass), and *Perca flavescens* (yellow perch)	Abernathy et al. 1985
	Tropical area	
Thailand	*Pristolepis fasciatus*, *Puntioplites proctozysron*, *Hampala macrolepidota*, and *Morulius chrysophekadion*	Yingcharoen and Bodaly 1993

Fig. 1. Spatial and temporal scales at which impacts resulting from large-scale hydroelectric development manifest themselves. 1 = methylmercury bioaccumulation; 2 = emission of greenhouse gases; 3 = downstream effects; 4 = limitation of biodiversity. (Note that axes are in log scales.)



(3) Methylmercury can be elevated in biota downstream of reservoirs. For example, fish downstream of dams have higher methylmercury concentrations than fish in the reservoir upstream, because the downstream fish feed on fish that are injured passing through the turbines (Brouard et al. 1994). Fish and invertebrates downstream of reservoirs also can have elevated methylmercury concentrations in the absence of generating stations (Johnston et al. 1991; Bodaly et al. 1997), apparently because of the transport of methylmercury in water and invertebrates. This second kind of downstream transport of methylmercury probably extends for <100 km but may be a more common occurrence than elevated levels caused by fish feeding on injured fish.

Why is methylmercury a by-product of flooding and how is it bioaccumulated by fish? At the outset, methylmercury elevation in fish is related to the degree of flooding of terrestrial areas involved in reservoir creation. A high proportion of land flooded to the final surface area of the reservoir produces higher methylmercury levels than when a low proportion of the surface area is flooded land (Bodaly et al. 1984*a*; Johnston et al. 1991). This relationship appears to explain why fish methylmercury levels in the LG2 reservoir, which was created by flooding a river valley, were so much higher than those in Southern Indian Lake (SIL), Manitoba, an already existing lake whose water level was raised 3 m (Verdon et al. 1991; cf. Strange et al. 1991). Linear models developed by Johnston et al. (1991) can be used to predict fish methylmercury levels in boreal reservoirs based on the ratios of flooded terrestrial area to water volume of the reservoir itself (within-lake effects) and of flooded terrestrial area to water volume of inflowing waters (upstream effects). Models developed by Hydro-Québec (1993*a*) also depend on the terrestrial area flooded but include data on reservoir volume and flushing rate, decomposable organic matter, and methylmercury dynamics in fish.

Experimental studies done in mesocosms demonstrated that methylmercury accumulating in fish originates by microbial transformation of inorganic mercury naturally present in the soil and vegetation that are flooded (Hecky et al. 1987, 1991). All organic materials (moss, spruce boughs, and prairie sod) added to the mesocosms stimulated methylmercury bioaccumulation by yellow perch (*Perca flavescens*). Hecky et al. (1991) also demonstrated greatly enhanced rates of conversion from inorganic mercury to methylmercury in newly flooded sediments of reservoirs compared with natural lake sediments.

Methylmercury production and uptake into the aquatic food web are being examined by the Experimental Lakes Area Reservoir Project (ELARP) in northwestern Ontario (Kelly et al. 1997). Natural wetlands in the northern boreal ecotone are sites of methylmercury production and important sources of methylmercury to downstream ecosystems (St. Louis et al. 1994, 1996). Boreal wetlands flooded to form reservoirs become even larger sources of methylmercury because of increased methylmercury production in flooded vegetation and peat. This problem was studied in an experimentally flooded wetland in which methylmercury production increased 35-fold (to ~6 $\mu g \cdot m^{-2} \cdot year^{-1}$) after flooding (Kelly et al. 1997). Bacteria converted inorganic mercury (present prior to flooding) to methylmercury in the process of decomposing flooded vegetation. The system responded within weeks to the increased methylmercury production. Concentrations of methylmercury in surface water and peat increased ~10-fold (to ~1 ng/L and 10 ng/g dry weight, respectively); the proportion of methylmercury to total mercury in water increased from ~5 to >30%. Methylmercury concentrations also increased after flooding in zooplankton (to ~340 ng/g dry weight (10-fold); M.J. Paterson, personal communication); predatory shoreline insects (to ~180 ng/g dry weight (2-fold); footnote 4); caged floater mussels (*Pyganodon grandis*; Malley et al. 1996); finescale dace (*Phoxinus neogaeus*; to ~0.30 µg/g wet weight (3-fold); Kelly et al. 1997); and 18-day old nestling tree swallows (*Tachycineta bicolor;* to ~100 ng/g dry weight (2-fold); V. St. Louis, personal communication). In addition, an experiment done in nearby reference Lake 240 showed that food was the dominant pathway of methylmercury uptake by fish (*P. neogaeus*; 85 versus 15% by passive uptake from water) at natural levels of methylmercury (Hall et al. 1997). It will be important to determine the duration of elevated rates of methylmercury production in the experimental reservoir. Methylation rates still remain high 3 years after flooding.

The link between newly flooded organic matter, the stimulation of methylmercury production, and increased methylmercury bioaccumulation in fish has led to an obvious recommendation for remediation: removal, burning, or covering of vegetation and soil organic matter before flooding to reduce the severity of the mercury problem. However, this recommendation has not been experimentally verified and, in any case, is impractical to carry out in large reservoirs. For example, the SIL reservoir has a shoreline length of 3788 km (Newbury et al. 1984). Alternatives would be to minimize the area flooded when creating reservoirs and avoid flooding natural wetland areas (Kelly et al. 1997).

It is not clear whether concentrations of methylmercury in predatory fish from reservoirs are sufficiently high to affect their populations (Niimi and Kissoon 1994; Wiener and Spry 1996). However, the main concern has been the effect of consumption of these fish on human populations.

Social effects

Canada has been a focus for the study of social impacts of methylmercury bioaccumulation resulting from hydroelectric development. The movement of large-scale hydroelectric development into Canada's subarctic boreal forest region has put at risk residents of the area, who are mainly aboriginal and live in small villages that are usually located on major rivers and lakes. The villages are characterized by mixed subsistence-based economies and rely on access to the fish and wildlife resources of customary territories that range in size from thousands to tens of thousands of square kilometres of land and water (Usher and Weinstein 1991). The term subsistence refers to the production of local renewable resources for non-market home and community use. Subsistence in contemporary northern aboriginal communities is integrated at the household level with wage labor, commercial resource harvesting, and other economic activities (Wolfe and Walker 1987; Usher and Weinstein 1991; Berkes et al. 1994).

Large-scale hydroelectric development in northern Canada has entailed relocation of some communities away from flooded zones, encroachment by outsiders on traditional territories, harvest disruption caused by the physical and biological effects of the projects, and methylmercury contamination (Rosenberg et al. 1995; Berkes and Fast 1996). All of these events affect subsistence-based economies in often complex ways. The problem of methylmercury contamination, and resultant closed fisheries, in northern communities is particularly serious (Bodaly et al. 1984*a*; Boucher et al. 1985; Anonymous 1987; Berkes 1988), although to date no medically documented cases are available of mercury poisoning caused by eating fish from new reservoirs (e.g., Wheatley and Paradis 1995). In addition, the social impact of elevated mercury levels is difficult to distinguish from impacts of a range of social changes caused by hydroelectric development (Waldram 1985; Niezen 1993).

Research reported in Rosenberg et al. (1995) and Berkes and Fast (1996) indicated that approximately one quarter to one third of the wild food harvested by Cree communities in northern Manitoba, Ontario, and Québec came from fishing, residents of these communities routinely caught and ate large quantities of fish over extended periods of the year. A public health strategy that advised native people not to eat contaminated fish also advised them not to fish, which is a common activity of great economic and cultural importance (e.g., Wheatley and Paradis 1995). In addition, the substitution of natural food with store-bought food posed its own threats to the health of native populations (Szathmary et al. 1987; Thouez et al. 1989). Last, the pervasive effects of methylmercury contamination on the social and mental well-being of natives and communities at risk needs to be mentioned. Whether or not individuals were exposed to or actually ingested injurious levels of methylmercury, the threat alone caused anxiety and the native communities suffered adverse social and psychological effects (Usher 1992; Wheatley and Paradis 1995).

Greenhouse gases

The release of greenhouse gases (CH_4 and CO_2) caused by the flooding of organic matter such as in forested peatlands may be the newest surprise connected with reservoir creation (Rudd et al. 1993). The problem is reasonable to expect given the considerable decomposition of flooded organic material and frequent oxygen depletion that usually accompany reservoir creation.

Bacterial decomposition of flooded organic material is at the base of both the methylmercury bioaccumulation problem discussed above and greenhouse gas emissions. On a temporal scale, greenhouse gas emissions from northern boreal reservoirs should slow with time but may last longer than 100 years where peat has been flooded, whereas the process should be faster in tropical areas because they have no peat tied up as organic carbon in soils and have higher year-round temperatures

[4] B.D. Hall, D.M. Rosenberg, and A.P. Wiens. Methylmercury in aquatic insects from an experimental reservoir. In preparation.

Table 4. Possible rates of greenhouse gas produced and energy generated by (*i*) fossil-fuel generation, and reservoirs having a (*ii*) low and (*iii*) high ratio of flooded area to energy produced.*

Site used in estimation	Category of energy generated	Ratio of flooded area to energy produced $\left(\frac{km^2}{TWh \cdot year^{-1}}\right)$	Rate of greenhouse gas production (equiv. Tg $CO_2 \cdot TWh^{-1}$)
(A) Manitoba (details given in Rudd et al. 1993)			
Coal-fired generation	*i*	—	0.4–1.0
Churchill-Nelson diversion	*ii*	88	0.04–0.06
Grand Rapids (Cedar Lake)	*iii*	710	0.3–0.5
(B) Brazil (details given in Fearnside 1995)			
Manaus fossil fuel	*i*	—	1.30
Tucurai	*ii*	64	0.58
Balbina reservoir	*iii*	1437	26.20

Note: TWh = terawatt hours; Tg = teragrams; T = 10^{12}.

*Caution should be used in comparing the results of Rudd et al. (1993) and Fearnside (1995) because of differences in (*a*) calculating the global warming potential of CH_4; (*b*) considering indirect and direct effects of CH_4; and (*c*) time scales used. In addition, Fearnside (1995) relied on modeling, whereas Rudd et al. (1993) took direct measurements.

(Fig. 1). Spatially, greenhouse gas emissions probably represent the most extensive impact of large-scale hydroelectric development, as they may contribute to global climate change (see below).

Environmental effects

The net greenhouse effect in natural boreal forests is about zero: peatlands are natural sinks for CO_2, but they are slight sources of CH_4 to the atmosphere, and forests are slight sinks for CH_4, but they are neutral for CO_2 (Rudd et al. 1993). The flooding of forests in the course of reservoir creation upsets these natural balances and results in a flux of greenhouse gases to the atmosphere. Estimates of greenhouse gas emissions from northern Canadian and Brazilian reservoirs indicate that some reservoirs with a high ratio of surface area to energy produced can approximate (Table 4A) or greatly exceed (Table 4B) emissions from power plants using fossil fuels. Conversely, run-of-the-river installations may be much less polluting than power plants run by fossil fuels.

The dramatic difference in greenhouse gas emissions between Cedar Lake Reservoir in Manitoba and Balbina Reservoir in the Brazilian Amazon (Table 4) is probably real. The much higher emissions calculated for Balbina are a result of recent flooding in a tropical setting (see below). There is a need for more of these kinds of geographic comparisons and research to explain the differences.

The following factors may be involved in regulating the intensity and duration of greenhouse gas emissions after reservoir creation (Kelly et al. 1994).

(1) The amount of flooding involved. Extensive flooding of terrestrial areas will lead to large releases of gases (e.g., Table 4), a factor also important in determining bioaccumulation of methylmercury in fish (see above).

(2) The age of the reservoir. Decomposition rates appear to decrease with time, as indicated by data on oxygen depletion (Baxter and Glaude 1980; Schetagne 1989). 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 slowing of rates means that the longer the life of a reservoir, the lower will be the average flux per year of gases. However, even after decomposition of organic material is complete, greenhouse gas emissions will be similar to the rates produced by natural lakes, which are greater than estimated fluxes for the original, undisturbed, terrestrial system (Rudd et al. 1993).

(3) The amount of plant biomass and soil carbon flooded. Plant biomass varies in different ecosystems (e.g., 0.7 kg C/m^2 in grasslands to 20 kg C/m^2 in tropical rain forests; boreal ecosystems are approximately midway in this range) and so does soil carbon (low in the tropics to high in boreal peatlands) (Kelly et al. 1994). Flooding of peatlands is of special concern because the large amount of carbon stored in them could produce greenhouse gases for decades.

(4) The geographic location of a reservoir. Temperature will vary with location, and temperature will affect the rate of decomposition and the ratio of CH_4:CO_2 that is released. Tropical reservoirs will have high water temperatures and fast decomposition, which tend to produce anoxic conditions and a high proportion of CH_4 (Fearnside 1995). The global-warming potential of CH_4 is 20–40 times that of CO_2 (per g basis), so the percentage of CH_4 released is important.

The magnitude and extent of the potential greenhouse gas emission problem is currently being examined along with methylmercury bioaccumulation in the ELARP experiment in northwestern Ontario (see above). Flux of CH_4 to the atmosphere after flooding of the experimental reservoir increased by about 20-fold (to 11 g $C \cdot m^{-2} \cdot year^{-1}$; Kelly et al. 1997). Prior to flooding, the wetland was a net sink for CO_2 (8.2 g $C \cdot m^{-2} \cdot year^{-1}$) because of fixation of CO_2 as organic carbon by plant photosynthesis. After flooding, the wetland became a large CO_2 source (>170 g $C \cdot m^{-2} \cdot year^{-1}$). These postflooding changes were caused by the death of vegetation, which eliminated the photosynthetic CO_2 sink and stimulated the production of CO_2 and CH_4 by decomposition of plant tissue. The increased flux of CH_4 was also caused by an increased level of anoxia in the reservoir and decreased CH_4 oxidation, which reduced the proportion of CH_4 that was consumed by bacteria before it could escape from the reservoir.

Postflood fluxes of CO_2 from the experimental reservoir were similar to measured fluxes of CO_2 from large hydroelectric reservoirs in northern Québec (Kelly et al. 1997). Fluxes of CH_4 from the experimental reservoir at the Experimental Lakes Area (ELA) were faster than from the Québec reservoirs but much slower than the very high rates predicted for tropical reservoirs. Measured fluxes of greenhouse gases from the experimental reservoir were similar to rates predicted by Rudd et al. (1993) and are within a range that is significant in some types of hydroelectric developments. The level of concern is related to the ratio of electricity produced per unit of land flooded; presently available data indicate that greenhouse gas fluxes from northern hydroelectric developments that produce <1 MW of electricity/km^2 of land flooded may be of concern in proposals for new reservoir development (C.A. Kelly, unpublished data). The global significance of reservoirs as sources of greenhouse gases is related to the total area of all types of reservoirs and to fluxes from the major types; however, the global surface area of reservoirs is poorly known and flux measurements are available for only a few locations.

As for the methylmercury problem discussed above, possible remediation would require removal of organic matter from the area to be flooded, an improbable task given the extent of forest flooded in today's large-scale hydroelectric developments. Minimizing the area flooded and avoiding wetlands are possible alternatives (see above).

Social effects

The social effects of greenhouse gas emissions from reservoirs are entwined in the greater problem of global climate warming. The social effects of global climate change are complex and, until recently, somewhat speculative. For example, everyone is familiar with the claim that climate warming will eventually cause rising sea levels, which will inundate low-lying cities (e.g., Gribbin and Gribbin 1996). However, recent news stories indicate that insurance companies worldwide are concerned about the increasing incidence of extreme weather events, thought to be tied to climate warming (e.g., Sterling 1996; Redekop 1996). The above examples indicate that the social effects of climate warming will occur at much broader spatial and temporal scales than, say, elevated methylmercury levels.

A major problem in public perception is the lack of a measurable link between specific greenhouse gas emissions (greenhouse gases are produced by a variety of human activities) and any subsequent environmental or social damage. This strongly contrasts with other local and regional effects of hydroelectric development for which cause and effect are often obvious.

The role played by greenhouse gas emissions from hydroelectric development will be difficult to identify. The overall contribution of greenhouse gas emissions from reservoirs to global climate warming is thought to be small when compared with other major sources of greenhouse gases, such as the burning of fossil fuels (C.A. Kelly and J.W.M. Rudd, unpublished data). Certainly, little evidence exists in the current energy policy literature indicating that reservoir greenhouse gas emissions are deemed to be important (e.g., Goodland 1994–1995). However, Pearce (1996) estimated that CO_2 emissions from reservoirs globally amount to 7% of total, man-made emissions of CO_2. He used a total global reservoir surface area of 600 000 km^2 and Canadian rates of emission (presumably based on Rudd et al. 1993). Canadian reservoirs would add 12% to total Canadian greenhouse gas emissions over the next 50 years if Rudd et al.'s (1993) estimates are correct (Pearce 1996). This source of greenhouse gases may become increasingly important in time as the burning of fossil fuels decreases. Determination of the importance of hydroelectric developments as contributors of greenhouse gases on a global level is an important future research endeavor.

Greenhouse gas emissions from reservoirs may assume greater future importance at the local level as nations move toward CO_2 accounting. Decisions can be made at the local level; tools are available (e.g., Rudd et al. 1993; Fearnside 1995) to choose among alternative hydroelectric development possiblities to minimize greenhouse gas production.

Downstream effects

Proponents of large-scale hydroelectric development often claim that water flowing freely to the ocean is wasted (e.g., Bourassa 1985; White 1988). Ironically, changes in the natural hydrological cycle as a result of water storage for power production and interbasin water diversion ultimately cause downstream freshwater and marine resources to be wasted. This impact can operate at the scale of thousands of kilometres from the source of the problem (Fig. 1), although some predicted effects on marine currents and changes in climate (see below) expand the spatial scale even more. Temporally, changes to downstream areas can be regarded as very long term, unless some effort is made to operate upstream facilities in a way that mimics natural hydrological flows.

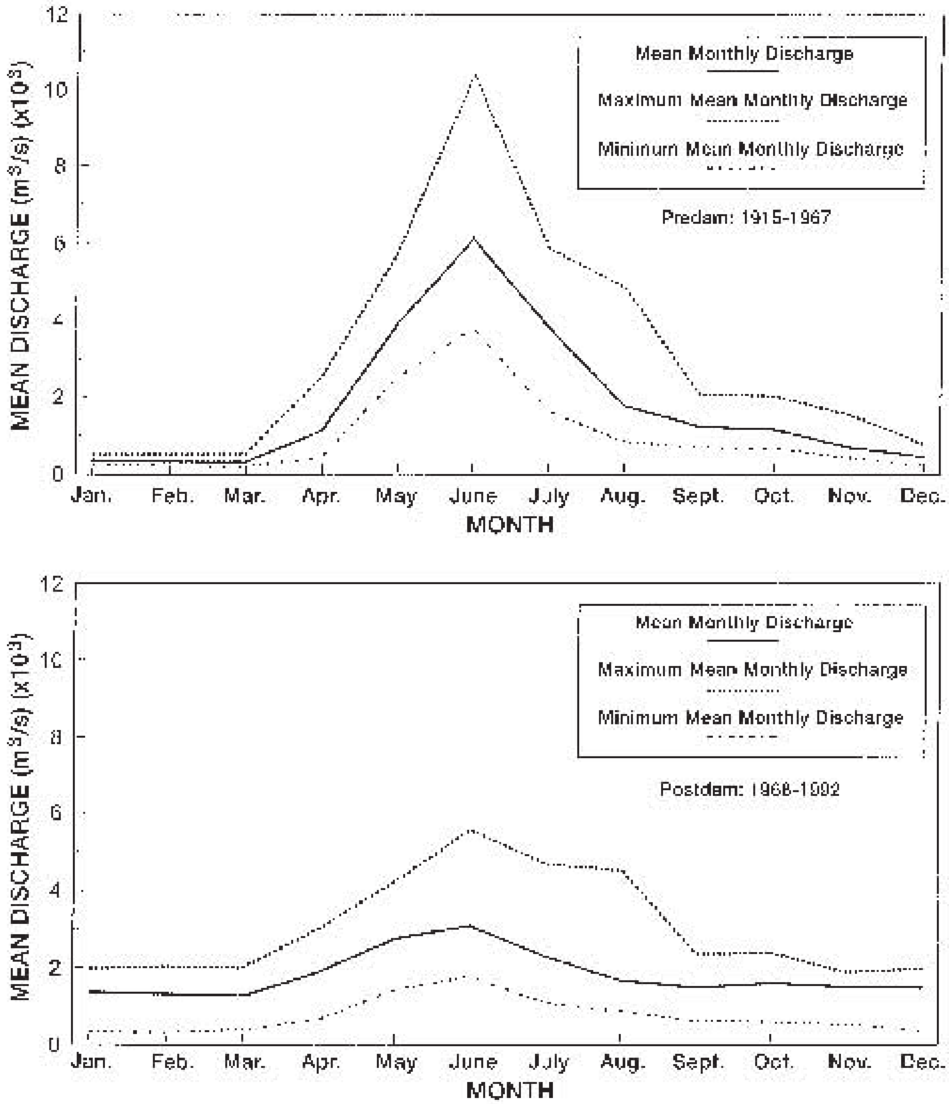
Environmental effects

Natural seasonal runoff patterns influence heavily the ecology of downstream deltaic, estuarine, and marine coastal areas (e.g., Neu 1982*a*, 1982*b*; Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993). These downstream areas are cradles of biological productivity because of the delivery of nutrients to them by freshwater runoff and because, at least in the north-temperate zone, freshwater runoff entering the ocean causes mixing and entrainment of deep, nutrient-rich ocean water into the surface layer (Neu 1982*a*; Milko 1986; Rozengurt and Haydock 1993). Nearshore biological processes such as primary productivity and fish feeding, growth, migration, and spawning are attuned to these seasonal dynamics of flow. In the case of a large, northern freshwater delta like the Peace–Athabasca in Alberta, natural seasonal cycles of flooding maintain the delta vegetation in an early successional stage of high productivity, which leads to a diverse and productive wildlife community (Rosenberg 1986).

Hydroelectric developments on north-temperate rivers characteristically trap high spring flows for storage in reservoirs and release higher-than-normal flows in winter when the power is needed (Fig. 2; see also Fig. 3 of Bergström and Carlsson 1994 for the Luleälven River, Sweden). Thus, the normal hydrograph is attenuated in spring and enhanced in winter (e.g., Devine 1995; see Dudgeon 1992 for different flow modification in tropical Asian rivers). Ecologically, runoff is transferred from the biologically active period of the year to the biologically inactive: it is like watering your garden in the winter (Neu 1982*a*).

Neu (1982*b*) neatly expressed the magnitude of the problem for Canada. All rivers on earth at any one time contain

Fig. 2. Effect of flow control on the natural hydrograph of a north-temperate river, the Peace at the town of Peace River, Alta. (reprinted from Shelast et al. 1994, p. 26, with permission of Sentar Consultants Ltd., Calgary, Alta.). The Bennett Dam is situated upstream in British Columbia (see Rosenberg 1986).



~1300 km^3 of water, which is approximately the same amount of existing artificial (i.e., reservoir) storage in Canada. Canada's rivers annually discharge ~1500–2000 km^3, a value slightly above existing artificial storage. If the live storage amounts to one quarter to one third of this amount, then ~400 km^3 of water is shifted annually from spring to winter. In other words, before any regulation, the spring and winter volumes were 1600 and 400 km^3, respectively; after extensive regulation, the volumes became 1200 and 800 km^3, respectively.

Bergström and Carlsson (1994) documented changes of river runoff into the northern basins of the Baltic Sea as a result of hydropower development. Seasonally, the Bothnian Bay and the Bothnian Sea receive increased winter discharge and decreased discharge at other times of the year. On a monthly basis, both of these areas show evidence of increasing base-flow levels over time.

Physical/chemical changes to downstream areas resulting from significant alteration of seasonal flows include (*i*) desiccation of wetlands, increased offshore salinity, and upstream saltwater intrusion because of reduced flows; (*ii*) collapse of natural deltaic levees and subsidence of coastal deltaic areas because of reduced sediment inputs; and (*iii*) overall reduction of spring nutrient inputs to estuaries (e.g., Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993). Northern areas are particularly affected by the loss of buoyancy flux provided by freshwater inputs and the resulting stable layer that enables high, offshore primary productivity. On an even larger scale, the reduction of river inputs of sediments to the sea because of dam construction has reduced "...the input of natural ballasts which are instrumental in carbon removal and preservation. By changing the sediment load of rivers we are changing biogeochemical cycling of elements in regions where more than 80% of organic carbon is being removed today..." (Ittekkot and Haake 1990).

Biological changes involve (*i*) lowered spring primary productivity because of decreased nutrient inputs and loss of stratification; (*ii*) lowered benthic invertebrate productivity because of changes in primary productivity and increased salinity; and (*iii*) deleterious effects on the most valuable commercial fisheries because of changes in fish-food organisms, nursery grounds, spring spawning, and migration (Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993; Attrill et al. 1996).

Changes to ocean currents and climate as a result of large-scale hydroelectric development (e.g., Neu 1982*a*) and water diversions (e.g., Gribbin 1979; Micklin 1985; Milko 1986) can also be considered downstream effects, albeit of the largest possible extent. However, predictions of such changes and their ecological meanings are uncertain at this point, and the proposed, massive water diversion projects that would cause them are not yet a reality.

Several case histories of downstream effects are available that demonstrate the adverse ecological consequences of grossly altered seasonal water flows, as described above (Table 5). The Aral Sea has not been included because its desiccation is related to upstream irrigation practises rather than hydroelectric development. Nevertheless, it is an excellent example of the ultimate effect of extreme water abstraction on downstream areas (e.g., see Micklin 1988; Ellis and Turnley 1990; Kotlyakov 1991; Precoda 1991; Levintanus 1992; Glantz et al. 1993; Pearce 1995*b*). In addition, Löffler (1993) reviewed irrigation problems of lakes in developing countries, Mirza and Ericksen (1996) described the environmental and social impacts of flood-control/irrigation projects in Bangladesh, and Nichols et al. (1986) described effects of extensive upstream water withdrawal for irrigation on the estuary of San Francisco Bay.

Predicting the cumulative effects on Hudson and James bays of large-scale hydroelectric development in their catchments is a problem currently being faced in Canada (Rosenberg et al. 1995). Major developments exist on the Churchill and Nelson rivers in Manitoba, the Moose River in Ontario, and La Grande River in Québec, and others have been proposed (see Table 4 of Rosenberg et al. 1995). Concerted efforts at cumulative impact assessment on Hudson Bay will be hampered by the meager data base available (especially for the winter period), poor knowledge of ranges of natural variability, incomplete understanding of natural processes, and lack of political will to improve these deficiencies (Rosenberg et al. 1995).

Social effects

Numerous benefits and disbenefits of large-scale hydroelectric development on downstream uses of water have been documented. Benefits may include flood control (e.g., Fearnside 1988; White 1988; Hillel 1994; Chau 1995; Dudgeon 1995; Losos et al. 1995); provision of irrigation water (e.g., White 1988; Hillel 1994; Dudgeon 1995; Losos et al. 1995; Romanenko and Yevtushenko 1996; Zhong and Power 1996); and provision of urban and industrial water supplies (e.g., Hillel 1994; Romanenko and Yevtushenko 1996; Zhong and Power 1996). Disbenefits may include the loss of water for irrigation and urban needs; loss of soil fertility because of elimination of normal flood periods (e.g., White 1988; Hillel 1994); and reduction of productivity of fish and wildlife (e.g., Berkes 1982; Gaboury and Patalas 1984; Ebel et al. 1989; Hesse et al. 1989; Usher and Weinstein 1991). In general, any impacts on mangrove areas, floodplains, wetlands, and deltas will also affect human uses that depend on these productive ecosystems or on high water quality.

Perhaps the most dramatic social consequence of altering natural flows to downstream areas is the reduction or collapse of the commercial fisheries in these areas. The declines in commercial fish catches from 1950 to 1970 to 1990 in the four great inland seas of the former Soviet Union and the eastern Mediterranean off the coast of Egypt are shown in Table 6. Rozengurt and Haydock (1994) attribute these declines to impoundment of major river systems, but other anthropogenic activities such as overfishing and chemical pollution are almost certainly also involved. The ensuing hardship on fishers has been mentioned explicitly for the Azov Sea (Rozengurt and Haydock 1993) and the Danube Delta (Pringle et al. 1993). However, similar effects probably resulted from the precipitous decline of commercial fisheries in the Caspian Sea (Rozengurt and Hedgpeth 1989) and the Black Sea (Tolmazin 1979). Construction of the High Dam at Aswan in Egypt has been implicated in the serious decline of the sardine fishery in the eastern Mediterranean, but cause-and-effect has been difficult to prove (White 1988).

Several hydroelectric projects in the Canadian north have documented negative impacts on downstream aboriginal communities (Rosenberg et al. 1995). For example, the Peace–Athabasca Delta in northern Alberta is located 700 km downstream of the Bennett Dam in British Columbia. The Delta, one of the largest inland deltas in the Western Hemisphere, provided productive muskrat, fish, and waterfowl habitat, which supported the aboriginal economy of Ft. Chipewyan (Peace–Athabasca Delta Project Group 1973). Reduced spring flooding in the Delta as a result of the upstream dam (Table 5) negatively affected the harvest of muskrat, and some species of fish and waterfowl, with consequent adverse effects on the aboriginal community. The damage was only partially remedied by mitigative measures (Dirschl et al. 1993).

A subsistence fishery at Chisasibi on La Grande River downstream of the LG2 Reservoir in northern Québec declined when the river was blocked in 1978 to allow filling of the Reservoir (Berkes 1982). However, the effect was short lived and the fishery recovered, only to be closed later because of high methylmercury levels (Berkes 1988). A number of other problems at the mouth of La Grande resulted from hydroelectric development upstream: (*i*) upstream movement of saline water from James Bay, which affected the local water supply; (*ii*) debris in the river, which affected the fishery, and (*iii*) problems of access to the north shore of the river because of unpredictable ice conditions resulting from operation of the LG2 Reservoir (Berkes 1981, 1982, 1988). The last problem was solved by building a road across the recently completed LG1 Dam (Anonymous 1995). Similar problems were encountered by the Inuit of Kuujjuaq (Fort Chimo) at the mouth of the Koksoak River following blockage of the Caniapiscau River in 1982 to fill the Caniapiscau Reservoir: (*i*) increased salinity of the drinking water; (*ii*) fouling of nets by algae, which limited fishing; and (*iii*) difficult access and navigation because of glacial boulders exposed at low water (Bissonnette and Bouchard 1984).

Limitation of biodiversity

"River systems and their riparian zones play key roles in the regulation and maintenance of biodiversity in the landscapes." (Dynesius and Nilsson 1994)

"Loss of biodiversity compromises the structure and function of ecosystems, which can in turn compromise the economic well-being of human populations." (Coleman 1996)

Biodiversity can be defined as "...the variety and variability among living organisms and the ecological complexes in which they occur" (OTA 1987, in Angermeier and Karr 1994). More simply put, biodiversity is "...the variety of life and its processes" (Hughes and Noss 1992). These definitions encompass a number of different levels of biological organization, including genes, species, communities, ecosystems, and landscapes (Hughes and Noss 1992; Biodiversity Science Assessment Team 1994). These definitions also involve components of composition, structure, and function (Hughes and Noss 1992).

Although the idea of impacts on biodiversity caused by large-scale hydroelectric development is quite new, the hydroelectric industry in North America has recognized it as a serious issue (e.g., Mattice et al. 1996). The concern is that these kinds of development may cause losses of biodiversity well in excess of natural, background losses (Coleman 1996). For example, the reduction or extirpation of native species through alteration of physical habitat or introduction of exotic species is a form of biodiversity loss connected with large-scale hydroelectric development (Power et al. 1996).

Impacts to biodiversity can occur over extensive spatial scales (several 1000 km^2 in the case of chains of reservoirs operated as a single unit; e.g., see Rancourt and Parent 1994 for La Grande River development) and over extended periods of time (Fig. 1). In fact, species extinctions (see below), an extreme form of biodiversity limitation, are permanent.

Environmental effects

The degree of biodiversity loss from all anthropogenic causes in fresh waters is not fully known but must be substantial because of the extent of physical impact of man on streams and rivers, especially in developed countries such as the United States (Hesse et al. 1989; Benke 1990; Allan and Flecker 1993; Dynesius and Nilsson 1994; Devine 1995). For example, a survey of the species listed under the Endangered Species Act in the United States done by Losos et al. (1995) indicated that water development projects affected higher numbers of species (256 or ~30%) than any other resource-extraction activity. Water-flow disruption and water diversion were among the most disruptive categories of water development. Animals were affected more than plants; water developments endangered ~95% of listed clam and mussel species (see also Devine 1995), and ~85% of listed fish species (Losos et al. 1995).

Nehlsen et al. (1991) identified 214 native, naturally spawning stocks of Pacific salmon, steelhead, and sea run cutthroat (*Oncorhynchus* spp.) from the Pacific northwest that are endangered (1 stock), are facing high (101 stocks) or moderate risk (58 stocks) of extinction, or are of special concern (54 stocks). Eighteen of the high-risk stocks may already be extinct. The chief causes of the plight of these stocks were (*i*) habitat loss or damage, impeded movement, and low flows (caused by hydroelectric development, agriculture, logging, etc.); (*ii*) overfishing, and (*iii*) negative interactions with other species of fish, including hatchery stocks. Seventy-six of these at-risk stocks originated from the Columbia River catchment, which has undergone extensive hydroelectric development (see below). At least 106 major populations of salmon and steelhead on the West Coast are extinct; one of the major reasons is dam construction (Nehlsen et al. 1991). "With the loss of so many populations prior to our knowledge of stock structure, the historic richness of the salmon and steelhead resource of the West Coast will never be known. However, it is clear that what has survived is a small proportion of what once existed, and what remains is substantially at risk" (Nehlsen et al. 1991).

Slaney et al. (1996) extended the Nehlsen et al. (1991) study to British Columbia and the Yukon Territory in Canada. Status classifications were possible for 5491 stocks or 57% of the stocks identified. Of these, 932 stocks were at high (11.4%) or moderate (1.4%) risk of extinction, or were of special concern (4.2%). An additional 142 stocks (2.6% of those classified) were driven to extinction in this century mainly because of logging, urbanization, and hydroelectric power development. Major rivers in British Columbia that support anadromous salmon do not have mainstream dams, but dams on the Columbia River in the United States have caused the extinction of various stocks in the Canadian portion of the Columbia catchment (Slaney et al. 1996). Hydroelectric development has also led to stock losses on smaller British Columbia rivers. Conflicts between water requirements for power and fisheries have led to stock depressions in a number of British Columbia and Yukon Territory rivers (Slaney et al. 1996).

Landscape and ecosystem levels

Habitat alteration or destruction affects all levels of biodiversity. The flooding of vast areas of land in the creation of reservoirs, dewatering of water bodies by diversion, and erosion caused by increased flows have their initial effects on landscape and ecosystem levels. As mentioned above, it has been estimated that reservoirs of all sizes and types now occupy 500 000 km^2 globally (Kelly et al. 1994). Up-to-date data on the total surface area occupied by major hydroelectric developments in various countries or ecological zones are not easily available; however, large areas of landscape-level habitat alteration are involved in major projects (Table 2).

At the ecosystem level, perhaps the greatest cost of changing the nature of a river by turning it into chains of reservoirs is the interruption of energy flow into the system from allochthonous and autochthonous sources. Biotic communities are probably structured along resource gradients and downstream communities at least partly depend on upstream processes (Vannote et al. 1980; Johnson et al. 1995). Impoundments along river courses can interrupt natural longitudinal gradients, causing longitudinal shifts in physical and chemical variables, which in turn cause biotic shifts (Ward and Stanford 1983). This reset mechanism ultimately affects biodiversity (e.g., Lehmkuhl 1972; Harding 1992). For example, transport of sediment and organic matter to downstream reaches is interrupted by reservoirs (especially by erosion control measures in them) and this probably affects carbon and nutrient cycling (e.g., see Hesse et al. 1989 for the Missouri River, U.S.A.). Furthermore, intermittent and permanent aquatic habitats outside the main channel are also important to normal river functioning; the predictable advance and retreat of water onto the floodplain are thought to control adaptations of most of the

Table 5. Selected examples of the downstream effects of altered flows caused by large-scale hydroelectric development. (Note this table reads across facing pages and continues on the following two facing pages.)

Area affected	Upstream development	Physical effects
Gulf of St. Lawrence, Canada	Hydroelectric development in the St. Lawrence catchment	>8000 m^3/s of spring discharge withheld (~1/4–1/3 of peak discharge) Twenty to thirty percent reduction in normal spring quantity of nutrients
Peace–Athabasca Delta, Alta.	W.A.C. Bennett Dam and Williston Reservoir, Peace River, B.C.	Williston Reservoir filled with 62 km^3 of Peace River water (1968–1971); normal Peace River flows (4000–9000 m^3/s) reduced to 280 m^3/s during filling; flood flows of Peace River adjacent to Peace–Athabasca Delta reduced by as much as 5600 m^3/s; water levels in Peace River dropped 3–3.5 m below normal; Lake Athabasca waters flowed out of the Delta without causing flooding Forty percent decrease in shorelines and surface areas of perched basins; 500 km^2 of mud flats of larger lakes desiccated; computer simulations using operating conditions of the Dam predicted: continued marked departures from natural flow patterns (reduced peak flows), continued drying of perched basins, and accelerated ageing of the Delta
Danube Delta, Romania and The Ukraine	Hydroelectric development (>30 dams and other engineering works along the mainstem); water removal for drinking, irrigation, and industrial processing; transportation; disposal of municipal and industrial wastes	Floodplain reduced by 290 000 ha because of hydrologic modifications to mainstem (e.g., embankments); resulting loss of 4.3 km^3 of water retention capacity so nutrients and heavy metals are carried straight to Delta Severe coastal erosion (up to 17 m/year) because dams and other hydrologic changes have reduced transport of sediments
Volga Delta and Caspian Sea	Major water users in the Caspian catchment: (*i*) agriculture, (*ii*) hydroelectric power plants, (*iii*) industry, (*iv*) municipal government, (*v*) shipping, and (*vi*) commercial fisheries Volga–Kama catchment: 11 large hydropower stations (most built in period 1955–1965); 200 small and large reservoirs inundating ≈ 26 000 km^2 of the catchment (≈50–69% of this was highly fertile cropland)	190–200 km^3/year of water accumulated to form reservoirs; freshwater flows to Caspian significantly reduced Spring flows reduced as much as 37% (98.9 cf. 155.8 km^3; 1967–1979); 1051 km^3 of spring flows retained over period 1961–1979 (= 4× normal annual runoff from Volga); regulated releases showed deviations of 30–50% below normal natural mean flows (cf. ±10–15% for normal, natural spring flows) Regulated winter runoff increased to 2.2× normal Mean annual salinities of north basin of Caspian increased from 8 to 11 ppt since 1955; estuarine mixing zone compressed and moved up Delta; extent of brackish water increased because of excessive water removal and dry years of 1973–1977 Reduced sediment load (2–4× less than normal); stability of river banks and levees affected Nutrient fluxes increased by 10–35% in winter and decreased by 25–40% in spring; annual amount of inorganic and organic phosphorus delivered to Caspian decreased by 1.5–2.0×, reducing primary production in north basin of Caspian by 50%; organic nitrogen (industrial and municipal sources) increased >2.5×

Biological effects	Comments	Ref.
Drastic decline in fish catches in the late 1960s and early 1970s corresponding to a period of naturally low discharges and increased regulation (4000 to 8000 m^3/s); mid-1970s recovery corresponding to a period of increased natural discharge; quantitative proof difficult because of the many other variables involved	The article is speculative	Neu 1982*a*, 1982*b*
Muskrat (*Ondatra zibethicus*) numbers harvested declined from 144 000 (winter 1965–1966) to <2000 (winter 1971–1972); vegetational succession continued unchecked (creating new meadow and willow communities); computer simulations (under operating conditions) predicted: continued vegetational succession, 20–25% reduction in duck production, and 40–60% reduction of fall muskrat populations; other studies indicated reduced spawning success of walleye (*Stizostedion vitreum*) but no effects on goldeye (*Hiodon alosoides*) and lake trout (*Salvelinus namaycush*)	Despite remedial efforts, the Delta continues to desiccate and will disappear within 50 years unless new management approaches are adopted	Townsend 1975; Rosenberg 1986; Nichol 1991; Rosenberg et al 1995
Decline in commercial fish catches (1970–1990) from 7000–9000 to 4000–5000 tons/year; "...attributed to the loss of fish habitat and the general deterioration of water quality..." Increased eutrophication and turbidity in Delta waters caused by increasing input of nutrients, metals, and pesticides in combination with changes of surface water flow and sediment loading; reductions in biodiversity, major shifts of ecosystem primary productivity (from rooted macrophytes to phytoplankton), and large declines in fish yields caused by degradation of water quality Bird populations much reduced over historical levels because of degraded habitat; impoundments partly to blame Declining water quality of Black Sea partly because of eutrophication of the Danube; valuable fisheries destroyed because chemocline has ascended from 170 to 110 m (see also Tolmazin 1979)	Causes of biological effects in the Delta are difficult to disentangle. Hydropower development is thought to be at least partly responsible for those listed here	Pringle et al 1993
Area of nursery grounds of semianadromous fish able to tolerate salinity fluctuations of 0.2–5 ppt during spawning and up to 8 ppt during feeding decreased from 25 000 (1959–1971) to 6200 km^2 (1977); optimum salinity of 2 ppt for mussels (important food for semianadromous fish) reduced to 30% of historical area, leading to large declines of mussels; biomass of phytoplankton, zooplankton, and zoobenthos in north basin of Caspian decreased by as much as 2.5× Catches of commercially important fish species declined by almost an order of magnitude from 1930 to 1972; commercial fishery became dominated by the less valuable sprat (*Clupeonella delicatula*), which increased 107× between 1930 and 1972; Volga – North Caspian endemic herring *Alosa kessleri volgensis* virtually disappeared (1913–1916, 130 000–160 000 t; 1960s, 5000–6000 t; 1969–1972, 10 t); similar patterns of reduction in commercial fishery reported from other parts of Caspian catchment that also suffered alterations in water flow; declines of commercially valuable fish attributed to (*i*) chronic water shortages and acute temperature fluctuations in Volga Delta nursery area, which negatively affected spawning, food supply, and feeding; and (*ii*) inadequate water supply during spring, which hindered spawning activities and migration of juveniles	More than 300 rivers exist in the Caspian Sea catchment, but the Volga River exercises major control over the physical and chemical oceanography and biological productivity of the Sea, because the Volga's catchment represents 40% of the total Caspian catchment and provides 85% of the natural historical average annual discharge of 300 km^3. Water levels of the Caspian Sea have been rising since 1977, perhaps because of a natural increase in the volume of water discharged by the Volga River (Williams 1996)	Rozengurt and Hedgpeth 1989

Table 5 (*concluded*).

Area affected	Upstream development	Physical effects
Azov Sea, Russian Federation	On the River Don: hydroelectric facilities, heavy industry, and irrigation; >130 reservoirs containing 37 km^3 of water and covering 5500 km^2	Average water flow reduced to 21.4 km^3/year or 76% of normal (pre-1952); spring flow (March–May) normally 70% of annual flow and now 37%; flow during other seasons increased 2.5–3.0×; floodplain spawning grounds reduced from 950 to 270 km^2; flood period reduced from 49 to 11 days; changes in mineral fluxes in River Don Delta (e.g., total phosphorus decreased from 11.3 × 10^3 to 2.3 × 10^3 tons/year, total suspended solids decreased from 3.6 × 10^6 to 1.1 × 10^6 tons/year, sulphate increased from 1860 × 10^3 to 3550 × 10^3 tons/year, chloride increased from 970 × 10^3 to 2650 × 10^3 tons/year)
Nile Delta, Egypt	High Dam at Aswan is the major problem; built to control floods, to store water to allow "water security" for year-round agricultural production, and to generate hydroelectric power	High Dam designed to store average flow of 84 km^3/year so no excess flow would exist beyond needs of 55.5 km^3 Downstream turbidity dropped from 30–3000 to 15–40 mg/L and from characteristic seasonal peak during flood season to regular level throughout the year; lowest levels at time of incoming flood Total dissolved solids increased from 110–180 to 120–230 mg/L, with similar change in seasonal distribution described for turbidity; salt burden increased; increased volume of water delivered to perennial irrigation systems resulted in large return flow through cultivated soil, which led to increased burden of dissolved salts in receiving drains and canals; more salt reached the Delta than before construction of the Dam, but less reached Mediterranean Sea; result is average annual accumulation of chlorides and sodium in the Delta soils; potential water quality problems not anticipated Widespread coastal erosion because of (*i*) silt deprivation from upstream, although the vast system of irrigation canals in the Delta itself may be to blame (Stanley 1996); (*ii*) removal of Delta sediment by marine waves and currents; and (*iii*) subsidence and rising sea level over low-laying northern areas of the Delta; areas of northern Delta threatened by increased salinization of groundwater and incursion of salt water; Nile water reaching the coast highly polluted by agricultural runoff and industrial municipal waste; Delta constitutes two thirds of Egypt's habitable land, so losses are critical

biota (Johnson et al. 1995). Prevention of this natural flooding would, therefore, constitute a disturbance (Bayley 1995). For example, channel-bed degradation below mainstem dams in the Missouri River has eliminated many of the backwater and subsidiary channels, which provided much of the river's autochthonous primary and secondary production. Loss of these habitat types has had a major impact on energy flow to higher trophic levels (Hesse et al. 1989; see also Power et al. 1996). Alienating sections of floodplains or reducing the frequency of flood recurrence may seriously affect the substantial stores of resting-stage invertebrates in dry floodplain sediments, thus removing a potentially important food source for juvenile fish (Boulton and Lloyd 1992). Hesse (1995) discusses alternative plans to restore natural functioning of the Missouri River ecosystem by operating mainstem dams to approximate the pre-regulation hydrograph (see below).

Still in the context of function, Hydro-Québec (1993*b*) has argued that the replacement of northern boreal forest by large expanses of reservoir results in a net gain of productivity (as the production of fish biomass) over what is provided (as terrestrial fauna) by pre-existing forest habitat. However, this "more-is-better" argument does not account for changes in biodiversity involved in conversion from a terrestrial to an aquatic system, and ignores the many natural services provided by the boreal forest as a carbon sink (Gorham 1991; Mackenzie 1994; Kelly et al. 1997) and as a source of food and fur for aboriginal communities (Charest 1982; Berkes et al. 1994).

Community, species, and genetic levels

The effects of large-scale hydroelectric development on biodiversity can also be manifested at community, species, and genetic levels. Habitat alterations create the main effects, but the introduction of non-native biota by water diversions and stocking activities is also important.

Biological effects	Comments	Ref.
Terrestrial and aquatic plants: general decrease of native species; increased number of introduced species and weedy plants characteristic of disturbed environments Many native mammal, bird, reptile, fish, and insect species almost extinct or endangered Only 3 years out of last 50 have been good for reproduction of fishes Blue-green algae and diatoms increased, whereas green algae declined in the lower Don; overall phytoplankton biomass increased from 0.45 (1960) to 2.9 g/m^3 (1980–1990); biomass of zooplankton decreased from 1.15 g/m^3 (pre-1952) to 17–25 mg/m^3 (1980–1991) Before 1952, >20 commercial fish species and catches ≥ 75 000 tons/year in the Azov–Don fishery; by 1991, 6 commercial fish species and catches of 3000–5000 tons/year	Greatest changes in River Don catchment occurred from the 1930s–1960s with the construction of large hydroelectric facilities and damming of rivers. The River Don system is polluted by oil, metals, and pesticides, among others, from industries, agriculture, and municipalities. Major water regulation schemes have also affected the Black Sea and its commercial fishery (Tolmazin 1979)	Tolmazin 1979; Volovik 1994
Downstream phytoplankton density increased from 160 to 250 mg/L because of reduced levels of silt in the water Commercial fishery affected: (*i*) number of species, number of fish, and average size declined at two locations in Delta, although numbers and size increased at a third; (*ii*) sardine fishery in eastern Mediterranean declined probably because of water quality problems rather than overfishing; (*iii*) shrimp catches declined after closure of the Dam, partly because of overfishing of immatures in north Delta lakes; (*iv*) demersal fish catches declined after closure, but then partly rebounded probably because of increase in motorized boats in decade after 1970; and (*v*) accelerated migration of Red Sea fish into the Mediterranean that began with the Suez Canal but that had been prevented by flow of Nile into the Sea	Nile River water has been manipulated historically. Changes immediately following the commissioning of the High Dam included (*i*) reduction of nutrient concentrations reaching the Mediterranean Sea; (*ii*) failure of phytoplankton blooms to develop; (*iii*) drop in sardine (*Sardinella*) catches; and (*iv*) decline in fisheries in brackish Delta lakes (for further details see Aleem 1972). Authors on the subject of the effects of the High Dam usually are careful to point out the benefits that accrued from the development: (*i*) control over water supplies that allowed perennial agriculture; (*ii*) flood control; and (*iii*) contribution to Egypt's national electrical grid. Many of the disbenefits are surrounded by controversy because of a lack of comprehensive study. As White (1988) commented: the Aswan High Dam "...demonstrates the difficulty on scientific grounds of making a definitive evaluation of the full consequences of a massive, unique intervention in physiological, biological, and human systems"	White 1988; Stanley and Warne 1993; Pearce 1994

Habitat alterations: Several kinds of habitat alterations act together to limit biodiversity. Blockages preventing migration, habitat simplification, and unnatural discharge regimes are all characteristic of large-scale hydroelectric development. Examples of each are given in Table 7.

The fragmentation of river systems by the construction of hydroelectric dams (other blockages such as irrigation or navigation barrages have the same effect (see Natarajan 1989; Reeves and Leatherwood 1994)) impedes the free passage of fauna and its use of various kinds of habitat (Table 7). This can lead to the diminished abundance or even extirpation of species over wide areas (Table 8).

Extinction of species means the loss of a unique genetic base that has probably evolved over a very long time (Meffe 1986). A more subtle threat is the erosion of genetic diversity that underpins long-term persistence and adaptability

Table 6. Commercial fishery catches in 1950, 1970, and 1990 in the four great inland seas of the former Soviet Union and in the eastern Mediterranean off the coast of Egypt (data from Fig. 6 of Rozengurt and Haydock 1994).

	Catches (× 10^3 tons)		
Location	1950	1970	1990
Western Black Sea	200	75	5
Sea of Azov	300	36	2
Caspian Sea	400	100	10
Aral Sea	50	18	0
Mediterranean – Egypt	40	6	7

Table 7. Limitation of biodiversity by habitat alterations resulting from large-scale hydroelectric development.

Type of habitat alteration	Location	Effects	Comments
Blockage by dams/habitat fragmentation	Columbia River, U.S.A.	Reduced numbers of anadromous salmonids (Ebel et al. 1989), as follows Salmon and steelhead runs reduced from $10 \times 10^6 - 16 \times 10^6$ fish/year in the 1880s (before major development in the catchment) to an average of 2.5×10^6 fish/year in the 1980s (Ebel et al. 1989; Meffe 1992); by 1990, only 1.2×10^6 salmon and steelhead returned to the Columbia, of which only 25% were wild stocks (Feldman 1995) Snake River (a major tributary): $>1.5 \times 10^6$ spring, summer, and fall chinook salmon adults returned annually during the 1800s; only 1800 returned in 1994 (Williams and Williams 1995); sockeye nearby extirpated (probably past reasonable hope); steelhead numbers declining fast (Williams and Williams 1995) Compensation for losses led to extensive hatchery–rearing programs; these have negatively affected wild stocks (Ebel et al. 1989; Meffe 1992)	Hydropower development is the major cause, although other developments (e.g., agriculture, irrigation, logging, mining, water pollution) also helped alter the river ecosystem (McIntosh et al. 1994; Rhodes 1994; Feldman 1995). Mortalities of upstream and downstream migrants at dams are one of the main causes of the declines in anadromous runs (Devine 1995; Losos et al. 1995). Mortality of juvenile fish moving downstream in the regulated Columbia system is ~77–96%, whereas mortality of adult fish moving upstream is ~37–51% (Wissmar et al. 1994). Meffe (1992) warned about negative genetic changes to natural populations of Pacific salmon as a result of major, hatchery–rearing programs meant to replace wild stocks diminished by hydroelectric and other impacts on large rivers. Resident (nonanadromous) fish are also affected (Geist et al. 1996). Possibilities of operating the Columbia system in a more benign way are currently being examined (e.g., Wernstedt and Paulsen 1995; Geist et al. 1996)
	Tucurai Dam, Tocantins River, Brazil	Interrupted upstream, reproductive migrations of long-distance migratory species (e.g., large catfishes: *Brachyplatystoma flavicans*, *Brachyplatystoma filamentosum*; characins: *Prochilodus nigricans*, *Anodus elongatus*); populations of these species negatively affected in lower Tocantins, downstream of dam (Ribeiro et al. 1995)	"The impacts of current basin-wide developments on biodiversity is [sic] difficult to assess for there are both direct and indirect effects and monitoring is not being carried out" (Ribeiro et al. 1995)
	Upper Volga River, Russian Federation	Changes to fish fauna following construction of four major reservoirs (Poddubny and Galat 1995): number of species increased from 44 before regulation to 46 after; 7 species (mainly anadromous rheophils) disappeared, and 9 species immigrated or were introduced; none of these 9 are reproducing naturally and will probably disappear because stocking discontinued; 39 species currently resident	
Habitat simplification	Missouri River, U.S.A.	"Transformation of the Missouri River into a single channel has resulted in the elimination of most side channels, islands, backwater areas, and sloughs which are important feeding, nursing, resting, and spawning areas for fish and wildlife" (Hesse et al. 1989) "...changes in basin and floodplain physiography and channel morphology have reduced commercial fish harvest by more than 80% and are implicated in the demise of native species" (Hesse et al. 1989)	The Missouri River is 3768 km long; 1233 km of the mainstem is impounded, and another 1333 km is semi-free flowing (i.e., usually downstream from large dams; Hesse 1995). The river has been channelized 75 km downstream from the last large dam (Gavins Point) for 1202 km to its confluence with the Mississippi River (Hesse 1995). Effects described are the result of overall river development and operation, of which hydroelectric generation is a part

Table 7 (*concluded*).

Type of habitat alteration	Location	Effects	Comments
	Columbia River, U.S.A.	Lower yields of white sturgeon (*Acipenser transmontanus*) populations in reservoirs in the lower Columbia River than in unimpounded part because control of annual floods and creation of homogeneous reservoirs reduced habitat diversity and dams prevent movement among many different riverine habitats normally used (see above) (Beamesderfer et al. 1995)	Only ~75 out of ~950 km of the Columbia River between the ocean and the Canadian border remain lotic; the remainder have been transformed into reservoirs (Devine 995). The resident *Acipenser transmontanus* has been listed as endangered under the U.S.A. Endangered Species Act (Geist et al. 1996)
	Upper Volga River, Russian Federation	Limited bioproductivity in reservoirs because of considerable changes in major biotopes after reservoir construction (Poddubny and Galat 1995): "Typical riverine fish habitats...remain only in the upper reaches of tributaries and in the forewaters of dams and account for no more than 1% of the total water surface area"	Poddubny and Galat (1995) recommended a number of habitat improvements to foster greater fish production
	River Rhine, Lower Rhône River, Europe	Impoverishment of benthic invertebrate species in River Rhine (Broseliske et al. 1991) and reduced biodiversity of benthic invertebrates, fish, and water birds in Lower Rhône (Fruget 1992), partly because of habitat simplification as a result of river regulation	The Rhine and the Rhône rivers have responded similarly to regulation and pollution (Fruget 1992)
Unnatural discharge regimes	Colorado River, U.S.A.	Elimination of 2 year classes of endemic Colorado squawfish (*Pteichocheilus lucius*) from its most productive remaining nursery habitats in the Green River catchment, perhaps because of extreme flow fluctuations and alteration of seasonal flow regimes (Jones and Tyus 1985, in Carlson and Muth 1989)	The operation of Colorado River dams has shown little regard for the minimum flow needs of fish fauna (Carlson and Muth 1989)
	Moose River system, Ont.	Low lake sturgeon (*Acipenser fulvescens*) populations in Mattagami River probably because of commercial overharvesting and negative effects on spawning of water-level fluctuations caused by power generation: (*i*) low water conditions after spawning expose eggs to variable water temperatures, low oxygen concentrations, and desiccation; (*ii*) fry trapped in shallow pools and exposed to predation, high temperatures, and oxygen depletion (Brousseau and Goodchild 1989)	Lake sturgeon populations appear to be healthy in the Frederick House, Abitibi, and Groundhog rivers (Brousseau and Goodchild 1989). Random water fluctuations and winter drawdown of some lakes for low-flow augmentation of power production also negatively impact fish in the system (Brousseau and Goodchild 1989)

(Vrijenhoek et al. 1985; Meffe 1986). Habitat fragmentation, as occurs when a number of dams are built along a river system, has the potential to subdivide species into small, isolated local populations (Humpesch 1992; Dynesius and Nilsson 1994) that may lose genetic variability through inbreeding and genetic drift. Erosion of genetic variability may further reduce fitness and adaptive potential. Among populations, loss of genetic variability leads to convergence to one type and a narrow range of options for that species.

Habitat simplification seriously threatens the native fish and other fauna of major river systems that have had extensive hydroelectric development (e.g., Brousseau and Goodchild 1989; Carlson and Muth 1989; Ebel et al. 1989; Hesse et al. 1989; Natarajan 1989; Fruget 1992; Beamesderfer et al. 1995; Geist et al. 1996; Table 7). Other kinds of river development are usually also involved, but hydroelectric development is a major contributor to the problem.

Unnatural discharge regimes downstream of major dams involve both extreme fluctuations and alteration of normal seasonal flow regimes (Table 7). Both conditions can severely affect biodiversity of lotic communities (e.g., Blinn et al. 1995) because these communities have adapted over eons to the natural pattern of discharge. For example, Power et al. (1996) discuss the many ways that natural flushing flows maintain riverine biota.

Unfortunately, water releases from dams generally only

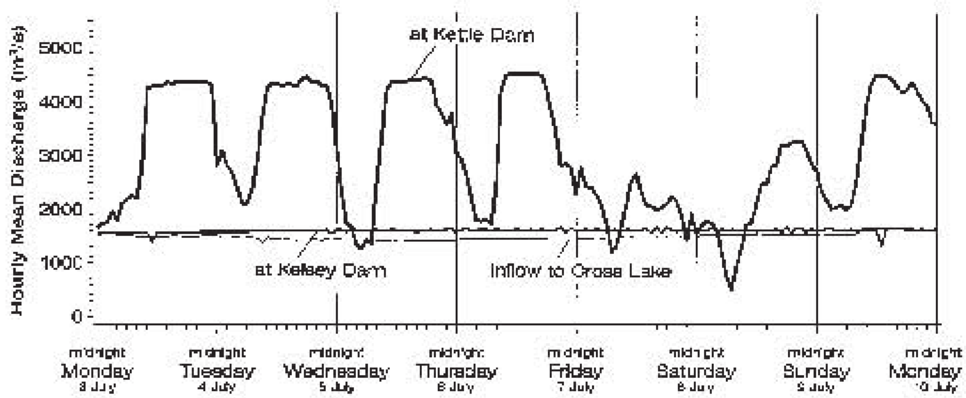
Table 8. Selected examples of species affected by habitat fragmentation resulting from hydroelectric development on river systems.

Species	Developments	Comments	Ref.
		River dolphins	
Platanista minor (Indus dolphin)	Dams and barrages on the Indian subcontinent	Now exists as a metapopulation of four to five artifically isolated subpopulations	Reeves and Leatherwood 1994
Platanista gangetica (Ganges dolphin)		Only a few subpopulations remain: (*i*) confined to upstream ends of Ganges tributaries; (*ii*) population in lower Ganges also partitioned; and (*iii*) subpopulation entrapped in a reservoir on the Karnapuli River, Bangladesh	Reeves and Leatherwood 1994
		Dolphins were abundant in the Narayani River, Nepal, in the past, but they are disappearing from the upstream parts of the river; disappearance attributed to a variety of causes, including blockage of migration by (irrigation) barrages	Shrestha 1993
Lipotes vexillifer (Yangtze dolphin)	Dams and floodgates that interrupt flow between the Yangtze River and adjoining lakes	<200 remain; Three Gorges Dam will further degrade habitat	Reeves and Leatherwood 1994
	Gezhouba Dam	The number of dolphins between Ouchikou and Chenglingji declined from nine groups and 43 individuals (1986) to three groups and 11 individuals (1991)	Zhong and Power 1996
		Fish	
Hilsa ilisha	Farakka Barrage, Ganges River, India	Riverine fishery upstream of barrage virtually eliminated; new remedial construction unlikely to restore hilsa fishery to earlier importance; yield of major carp species in lower Ganges also reduced (50% of 1964 levels); the Ganges suffers from other impact, too (see also Dudgeon (1992, 1995) for multiple impacts in other tropical Asian rivers)	Natarajan 1989
Macrura reevesii (Chinese shad), *Clupanodon thrissa* (gizzard shad)	Dams in lower reaches and reservoirs in the upper reaches of the East River, tributary to the Pearl River, China	Migratory pathways blocked; the fish virtually disappeared from the river by 1970; fry of Chinese carps (many species of Cyprinidae, especially *Cirrhinus molitorella*) also affected	Liao et al. 1989
Macrura reevesii	Fuchunjiang and Hunanzhen dams, Qiantang River, China	Drastically reduced and finally eliminated from the river; the number of fish species in the region of the Xinanjiang Reservoir on the Qianting River decreased from 107 to 66–83 because migration was blocked by the Xinanjiang Dam	Zhong and Power 1996
Acipenser sinensis (Chinese sturgeon), *Myxocyprinus asiaticus* (Chinese sucker), *Psephurus gladius* (white sturgeon), *Coreius guichenoti*	Gezhouba Dam, Yangtze River, China	Spawning runs detained below Dam and these species were endangered by overfishing; many *Acipenser sinensis* were hurt or killed trying to ascend Dam; *Acipenser sinensis* and *Myxocyprinus asiaticus* now artificially bred and released into river each year	Zhong and Power 1996
Probarbus jullieni (giant cyprinid)	Chenderoh Dam, Perak River, Malaysia	Declines partly a result of blockage of migration routes by the Dam	Dudgeon 1992
Alosa spp. (mostly *fallax*) (shad)	Dams on the lower Rhône River	Only 15% of the mainstem remains accessible; shad catches have declined from 53 t in 1927 (before development) to ~8 t in the early 1970s (cf. shad in the River Rhine, which have completely disappeared)	Fruget 1992
Petromyzon marinus (sea lamprey), *Acipenser sturio* (sturgeon), *Alosa alosa* (allis shad), *Alosa fallax* (twaite shad), *Anguilla anguilla* (eel), Mugilidae (mullets)	Dams on major rivers in Spain	All anadromous and catadromous fishes are considered "threatened" in Spanish and Portuguese Red Books; range distributions of the species shown have been reduced by an average of 50–100% along the lengths of major Spanish rivers	Nicola et al. 1996

Table 8 (*concluded*).

Species	Developments	Comments	Ref.
		Aquatic invertebrates	
Zelandobius (two species, stoneflies), Eriopterini (two species, crane flies)	Dams for hydropower generation in river systems in New Zealand	Populations of stoneflies and crane flies substantially reduced below impoundments; populations of the snail *Potamopyrgus antipodarum* significantly enhanced	Harding 1992
Leptestheria dahalacensis, *Eoleptestheria ticinensis*, *Imnadia yeyetta* (clam shrimps)	Hydropower development on the Danube River, Austria	Local extirpation of clam shrimp habitats is caused by changes in hydrologic regimes; operation of new hydroelectric plants on the Danube prevents inundation by the River of astatic pools; these species are considered to be endangered	Hödl and Eder 1996
Leptodea fragilis (fragile papershell mussel), *Potamilus alatus* (pink heelsplitter mussel)	Dams on five river systems in the American midwest	Upstream distribution stops at dams; dams are a barrier to the fish (freshwater drum: *Aplodinotus grunniens*) that hosts the glochidia of these mussel species; other unionid species may also be limited by dams in these river systems: *Potamilus ohiensis* (pink papershell), *Truncilla donaciformis* (fawnsfoot), *Truncilla truncata* (deertoe), *Quadrula quadrula* (mapleleaf), and *Epioblasma triquetra* (snuffbox)	Watters 1996; see also Bogan 1993
Simulium gariepense (black fly)	Impoundments in the Orange River, South Africa	This South African endemic, nonpest species appears to be affected by reduced turbidity and peak flows, especially because the Orange River flows through arid areas, which minimizes the potential for colonization from tributaries; the Orange River system may be the only remaining area in which the species is found	Palmer and Palmer 1995

Fig. 3. Hourly mean discharge for the Nelson River, 1984. The large day-to-day fluctuations at Kettle Dam do not occur at Kelsey Dam or the inflow to Cross Lake (Jenpeg Dam), which are upstream installations (reprinted from Environment Canada and Department of Fisheries and Oceans 1992, p. 2.15).



satisfy power generation requirements (but see Olmsted and Bolin 1996 for a dissenting view). For example, in the Missouri River, "...water management within the reservoirs for fish and wildlife occurs only when interference with other purposes does not exist" (Hesse et al. 1989). In the Columbia River, "It is apparent from our modeling that existing operations (represented by the base-case alternatives) are not beneficial to fish and wildlife resources, but are beneficial to power and irrigation interests. This points to an increased urgency to develop alternative ways to operate the Columbia River hydropower system" (Geist et al. 1996).

Very little is known about the ecological effects of extreme fluctuations in daily discharge in the lower Nelson River, northern Manitoba (Fig. 3). Daily discharge fluctuations at Kettle Dam for the period 1979–1988 amounted to >2000 m^3/s in winter and ~3000 m^3/s in summer; mean natural river discharge at that location is 2170 m^3/s (Environment Canada and Department of Fisheries and Oceans 1992). The abnormal patterns of discharge in the highly regulated lower Nelson are tied to weekly energy use in Manitoba. Daily discharge coincides with power demand: it is raised each morning during workdays and lowered again at night. Discharge is lowered over the weekend and begins its daily workday cycle again on Monday morning.

Many of the negative impacts of habitat alteration on the biodiversity of communities, populations, and genes could be ameliorated if the operation of hydroelectric facilities more closely mimicked natural flow regimes (Devine 1995; Feldman 1995; Hesse 1995; Zhong and Power 1996). For example, lake sturgeon spawning activity in the Sturgeon River, Michigan, responded positively to a change in operation of the Prickett hydroelectric facility to near run-of-the-river flows (Auer 1996), and Zhong and Power (1996) showed that Chinese low-head, run-of-the-river projects have lesser impacts than high-head dams on aquatic environments, including fish and fisheries. An ecologically based, water-regulation procedure for lakes affected by hydroelectric power production has been developed in Finland (Hellsten et al. 1996).

Introduction of non-native biota: Exotic species can be introduced by intercatchment water diversions that are part of hydroelectric development or by stocking of hydroelectric reservoirs. Specific examples of the former are difficult to find, perhaps because of a lack of study. The McGregor Diversion, a proposed hydroelectric project in British Columbia, necessitated the mixing of waters from the Peace, an Arctic-draining river, and the Fraser, a Pacific-draining river. The project was cancelled because of the fear of introducing potential harmful fish parasites from the Pacific into the Arctic drainage (Seagel 1987).

The problem of species introductions caused by artificial interconnections among major rivers is apparently widespread in southern Africa (Bruton and van As 1986). These water diversions may involve hydroelectric generation, but their main functions are flood control and agricultural, domestic, and industrial water supply (Cambray et al. 1986). For example, Cambray and Jubb (1977) documented the survival of five species of fish that passed through the Orange-Fish tunnel in South Africa, which diverts irrigation water out of the Orange River system (Atlantic Ocean drainage) into the Great Fish and Sundays rivers (Indian Ocean drainage). The more permanent flow and increased erosional areas in the Great Fish River led to a change in the species composition of the macroinvertebrate fauna, including replacement of the pretransfer dominant black flies *Simulium adersi* and *Simulium nigritarse* by the pest species *Simulium chutteri* (Davies et al. 1993). Intercatchment transfers of water are also common in China, but little information appears to exist on the introduction of exotic species as a result (Dudgeon 1995). Most such transfers are done primarily to satisfy water-supply problems rather than for hydroelectric generation.

Nonindigenous fish and crustaceans were introduced to the Missouri River numerous times to fill new niches and habitats in impoundments, but the consequences to native ichthyofauna were rarely analyzed (Hesse et al. 1989). Stocking activities in Colorado River reservoirs were part of the overall, river-development assault (Table 7) on the unique, endemic fish fauna of this river system (Carlson and Muth 1989). As a result of river development, approximately 100 species of fish are now present; some 67 non-native species have been introduced since the turn of the century and are now predominant in most fish communities. Seventeen of 54 native species are threatened, endangered, or extinct, and the abundance and distribution of most have been drastically reduced (Carlson and Muth 1989).

Social effects

Limitation of cultural diversity by habitat destruction has been observed in a number of communities that lay in the path of major hydroelectric development. Canadian examples reveal a close connection between habitat destruction and negative social impacts in four major ways: (*i*) mercury contamination (see above); (*ii*) relocation; (*iii*) encroachment; and (*iv*) harvest disruption (Rosenberg et al. 1995; Berkes and Fast 1996).

Relocation

Major hydroelectric development often necessitates the relocation of large numbers of people (Table 9) and results in harmful social effects (Table 10). Much of the international literature focuses on involuntary resettlement, not only as the major social impact of dams but perhaps as the single most serious issue of large-scale hydroelectric development (e.g., Scudder 1973; Goodland 1994–1995). In Canada, relocations caused by hydroelectric developments such as the Kemano in British Columbia and Grand Rapids in Manitoba (see below) continue to be a source of grievance and social costs even after half a century (Royal Commission on Aboriginal Peoples 1996). Studies of northern Canadian developments, which involved moving relatively small numbers of people by international standards (hundreds versus tens of thousands; see Table 9), have provided insights into these impacts.

Relocations allow governments to “modernize” traditional aboriginal communities. However, residents of affected villages do not necessarily view the acquisition of new houses and village infrastructure in a positive light. Settlement patterns, which are based on kinship relations and access to shorelines, are disrupted and costs are added to hunting and fishing (Loney 1987; Waldram 1988). Relocation experiences in the Canadian north are similar to those reported elsewhere in the world as a result of large-scale hydroelectric development (Table 10).

Encroachment

Large-scale hydroelectric projects in remote areas involve the encroachment by outsiders into traditional aboriginal territories, whether in the Canadian north, the Brazilian Amazon, or elsewhere. Encroachment is facilitated by new roads and airfields constructed as part of the infrastructure needed for such projects.

In the Canadian north, the Cree land-tenure system is family based, and it is officially recognized through trapline registration. Newly constructed roads often result in an influx of outsiders. External encroachment disrupts the tenure system and the abundance and distribution of fish and wildlife upon which the tenure system is based (Berkes 1981). The consequence is adverse social impacts, which may persist for generations (Niezen 1993; Preston et al. 1995).

The plight of the Waimiri-Atroari tribe in central Amazonia, Brazil, is described by Fearnside (1989). Encroachment has played a large role in reduction of the numbers of this tribe from 6000 at the turn of the century to 3500 by 1973, 1100 by 1979, and 374 by 1986. These effects cannot be attributed to hydroelectric development but nonetheless exemplify what can result from infrastructure development of the land associated with hydroelectric development (e.g., road construction). Flooding of part of the Waimiri-Atroari tribe’s reserve by the Balbina Reservoir added another stress connected with modernization of the remote area in which they live.

Harvest disruption

Harvest disruption is a serious and often permanent impairment to the life of aboriginal communities, especially where

Table 9. Selected examples of major relocations of people to make way for reservoir creation (see also Goodland 1994–1995).

Project	Approximate number of people involved	Comments	Ref.*
Volga River, Russian Federation	>300 000	—	Marchand 1990
Sanmenxia Dam, Yellow River, China	300 000	—	Pearce 1991
Three Gorges Dam, Yangtze River, China	>1 000 000	Project under construction	Fearnside 1988; Pearce 1995*a*
	1 131 800	Relocation by 2008; estimate is conservative because of illegal immigration into the area and high natural rate of population increase†	Chau 1995
Lake Kariba, Zambezi River, Zimbabwe and Zambia	>50 000	Tongans affected	Balon 1978
	86 000	—	Obeng 1981
Volta Lake (Akosombo Dam), Volta River, Ghana	80 000	—	Obeng 1981
Lake Kainji, River Niger, Nigeria	50 000	—	Obeng 1981
Lesotho Highlands Water Project, Lesotho, Africa	20 000	Primary aim of project is to export water to Johannesburg and Pretoria; hydroelectric generation for Lesotho is a minor aim; mountain people have been flooded out rather than resettled; subsequent phases of the development will affect even larger numbers of people	Horta 1995
High Dam at Aswan, Nile River, Egypt and Sudan	≥100 000	Nubians affected, ~1/2 in Egypt and ~1/2 in Sudan	Walton 1981; Pearce 1994; White 1988
	120 000	—	Obeng 1981
	120 000	30 000 Sudanese	Goldsmith and Hildyard 1984
	>50 000	Sudanese villagers displaced; Egyptians not mentioned	Hillel 1994
Sardar Sarovar Dam, Narmada River, India	>100 000	Additional 140 000 farmers will be affected by canal and irrigation system; project currently being built‡	Morse and Berger 1992
Sobradinho Dam, São Francisco River, Brazil	70 000	—	Pearce 1992
Itaparica Dam, São Francisco River, Brazil	40 000	—	Pearce 1992
Southeast Anatolia Project, Turkey	250 000	Tigris and Euphrates rivers	Hillel 1994
Tabqa Dam, Lake Assad, Syria	~70 000	Euphrates River; Bedouins displaced	Hillel 1994

*Some authors provide information on social impacts.
†Water conservancy projects undertaken in China since 1949 have involved the resettlement of >10 000 000 people (Chau 1995; Dudgeon 1995).
‡The entire Narmada Basin Development Programme is expected to displace >1 000 000 people over the next 40 years (U.S. Government Printing Office 1990, in Foote et al. 1996).

the resource base is largely aquatic (Rosenberg et al. 1995). The physical and biological effects of Canadian boreal projects have affected the availability of important species and access to them (Berkes 1981; Usher and Weinstein 1991). For example, fisheries in northern Manitoba have been affected by fluctuating water levels (Gaboury and Patalas 1984) and the blockage of fish migration by a water-control structure (Bodaly et al. 1984*b*; Barnes and Bodaly 1994). Available data indicate declines in per-capita, subsistence catches and for commercial catches in some or all of the communities affected by the Churchill–Nelson diversion (Usher and Weinstein 1991).

In the Grand Rapids project area in Manitoba, previously self-reliant aboriginal communities became dependent on the outside. Social problems such as crime and family violence escalated. The amount of food obtained from the surrounding area declined by a factor of 10 after damming and relocation as compared with before (Loney 1987).

In northern Québec, Cree hunters reported diminished harvests since 1979 of valuable food and fur species from wetland habitats in the lower La Grande River (Berkes 1988). Hunters blamed reduced habitat and feeding areas, loss of riparian productivity, and drowning and freezing-out of several species in winter. Also, many trappers lost their territories to flooding. Six major reservoirs built between 1940 and 1972 in the vast Montagnais territory east of the James Bay catchment caused most hunting/trapping areas to be abandoned by their users because of partial flooding and water-level fluctuations. For example, 47 out of 87 hunting/trapping areas belonging to the community of Bersimis were affected; of those, 24 did not produce any fur in 1975–1976 (Charest 1982).

Increased discharge, unstable ice conditions, or debris resulting from shoreline erosion make access to resources difficult or impossible in many areas affected by hydroelectric development. Operation of upstream reservoirs created winter and spring travel problems across La Grande River (Berkes 1988), the Moose River (Preston et al. 1995), and in many

Table 10. Selected examples of social impacts of relocation necessitated by large-scale hydroelectric development.

Development	Relocation	Comments
Diversion of the Churchill River into the Nelson River and the flooding of Southern Indian Lake, northern Manitoba (Newbury et al. 1984)	The old settlement of South Indian Lake, which was flooded by impoundment, was moved to a new, modern town built nearby	The move was associated with social disruption and disintegration (Waldram 1987; Krotz 1991): former kin-group arrangement of families was not retained in new housing; cheaply built new houses soon deteriorated; electric heat in new houses was too expensive for most villagers; and hauling water from the Lake was a problem, especially for elderly
La Grande River, northern Québec (Berkes 1981)	Erosion caused by increased river discharge threatened the town of Ft. George on the estuary of La Grande River, so the people were moved into the new town of Chisasibi upstream	Move associated with social stress (see Dwyer 1992 for an anecdotal account)
Volta Lake, Ghana (Obeng 1981)	80 000 people from 700 villages, representing 1% of the population of the Volta River catchment, were flooded out by creation of Volta Lake. Most (69 000) were relocated in 52 new towns specially built for them	Relocation brought trauma associated with abandonment of familiar lands, ancestral resting places, farms, and homes; different social conditions/need to preserve cultural identities; the need to learn new skills to survive; and exposure to schistosomiasis (Obeng 1981) Similar difficult relocation described by Balon (1978) for 50 000 Tonga people displaced by creation of Lake Kariba, Zimbabwe and Zambia
High Dam at Aswan, Egypt and Sudan (White 1988)	50 000 – 60 000 Nubians in the Egyptian part of the Lake Nasser Reservoir were moved to new villages 20 km north of Aswan	Serious problems developed because of new agricultural conditions and practices, and inappropriate, nontraditional housing provided (Goldsmith and Hildyard 1984) By 15–18 years after move, the health of people overall had improved, handicraft industry developed, agricultural production remained modest, and many people longed to return to their old homes (Walton 1981; White 1988); many people did return (Goldsmith and Hildyard 1984)
	53 000 Nubians in the Sudanese part of the Lake Nasser Reservoir were moved to the Kashm el–Girba region to the southeast	Social structure of many of the old villages was severely disrupted (Goldsmith and Hildyard 1984): three different ethnic groups were settled together, and aside from cultural differences, agricultural practices of pastoralists (grazing) were incompatible with those of farmers (cultivation); design of housing "...paid little heed to the social needs of the uprooted settlers" (Goldsmith and Hildyard 1984)

other northern Canadian rivers affected by hydroelectric development (Berkes and Fast 1996). In northern Manitoba, extensive shoreline erosion resulted in reservoirs containing hazardous debris and inaccessible shorelines; it also caused the fouling of fish nets (Newbury and McCullough 1984; G.K. McCullough, personal communication). Local hydrology and fish behavior were so changed and access to well-known fishing areas were so impaired that traditional knowledge was no longer a guide for fishing success (Rosenberg et al. 1995). Costs increased and catches per unit of effort decreased in both the subsistence and commercial fisheries (Usher and Weinstein 1991).

Conclusions

> "Large dams are among the most awe-inspiring monuments to modern society." (Pearce 1991)

> "Few creations of big technology capture the imagination like giant dams." (Anonymous 1992)

The fascination of politicians with hydro megaprojects at least partly explains why these projects are built. The politician's job is mostly done after the switch is thrown to start electrical generation at a massive new dam, but the work of the environmental and social scientists responsible for postaudits has just begun. It is regrettable that so little support is usually available for the postaudit part of a project compared with its planning and construction phases (White 1988). Even given adequate support, the task of disentangling impacts of a project from the natural variability of ecosystems can be difficult (e.g., Gribbin 1979).

This review has addressed the need for considering large spatial and temporal scales in assessing the cumulative effects of hydroelectric development, and in so doing, has revealed the interconnections between environmental and social impacts. For example, habitat alteration or destruction lies at the base of the four large-scale impacts examined. Environmental changes resulting from habitat destruction lead to the social and economic problems experienced by communities dependent on local natural resources. A holistic view is therefore needed to discern these interconnections.

We are at an early stage in our understanding of large-scale impacts. What needs to be done to further this understanding?

Mercury research requires more spatial and temporal data from reservoirs that flood different land types with different vegetation, especially in temperate and tropical areas. Emphasis is needed on the time course of microbial production of methylmercury and its uptake by lower trophic levels. It would also be useful to determine the important factors involved in downstream transport and bioaccumulation of methylmercury, and to establish the exact spatial extent of this phenomenon. A thorough understanding of microbial methylation/demethylation processes would, perhaps, enable effective mitigation of mercury contamination by either uncoupling methylation or enhancing demethylation.

More comparative data from temperate and tropical zones are needed to determine the global significance of greenhouse gas emissions from reservoirs, especially data on the relative durations and amounts of CH_4 and CO_2 emitted in the different settings. In this context, it is important to have adequate data on the surface area of reservoirs and to know the proportion of this surface area that is flooded land. Better understanding of greenhouse gas fluxes under different geographic/climatic conditions combined with better estimates of the world's surface area occupied by reservoirs would enable estimation of the contribution made by reservoirs to global climate warming. Mathematical models calibrated by data collected in the field appear to hold the most promise for predicting the generation of both greenhouse gases and methylmercury in reservoirs.

Better understanding is needed of the effects of interference with freshwater flows to the ocean by upstream reservoir developments that involve substantial discharge regulation. A prime example is Canada's Hudson Bay, which is surrounded by large-scale hydroelectric development (Rosenberg et al. 1995). However, Neu (1982*b*) warns, "The problem is so large and complex that it would take years, even decades, of intensive studies before some of the elements given in this analysis could be verified in detail." An improved understanding of physical/chemical and geomorphic changes would lead to better explanations of changes in the biota of areas downstream of large-scale hydroelectric development.

Research into effects on biodiversity is initially limited by poor, general inventories of different levels of biodiversity (e.g., Savage 1995). Such inventories need to be improved on a world-wide basis. Furthermore, few large-scale hydroelectric developments have tried to document, even partially, structural and functional changes in biodiversity after completion of a project. The task is daunting because of the number of biodiversity levels potentially involved, and because disturbed ecosystems take a long time to reach new equilibria (Dynesius and Nilsson 1994). Yet, only after such an accounting is done can we hope to understand biodiversity losses and gains resulting from such developments.

Postaudits of large-scale hydroelectric developments require more support because they provide a storehouse of information and experience that may be usefully applied to future projects. The need for long-term monitoring is especially important with respect to social impacts, not only to understand the mechanisms of change but also for the adaptive management and mitigation of impacts. Experiences such as with La Grande River project in Canada indicate that many of the combined environmental and social impacts are unpredictable and become apparent only after a time lag (Berkes 1988). Much can be learned from the accumulated literature of social impact assessments (e.g., Scudder 1973). Such assessments can be improved by the following: (*i*) more focused investigation of linked social–environmental systems, with appropriate attention to cross-scale effects in both space and time; (*ii*) identification of key ecosystem processes; and (*iii*) development of testable hypotheses as opposed to the generation of merely descriptive social and economic data.

Finally, decision makers need a better understanding of the environmental and social problems surrounding large-scale hydroelectric development. Although prevailing political philosophies and values of decision makers in developed and developing countries are not likely to support the necessary time and work needed to study large-scale impacts, the continued effort by environmental and social scientists in trying to understand and describe these impacts, as evidenced by the studies cited in this review, may eventually contribute to more enlightened decision-making for hydroelectric development.

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Jason T. Quigley[1] and David J. Harper[2]

(1) Oceans, Habitat and Enhancement Branch, Fisheries and Oceans Canada, Suite 200, 401 Burrard Street, Vancouver, BC, V6C 3S4, Canada

(2) Habitat Policy and Regulatory Affairs, Fisheries and Oceans Canada, Suite 12E, 200 Kent Street, Ottawa, ON, K1A 0E6, Canada

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Abstract Fish habitat loss has been prevalent over the last century in Canada. To prevent further erosion of the resource base and ensure sustainable development, Fisheries and Oceans Canada enacted the habitat provisions of the *Fisheries Act* in 1976. In 1986, this was articulated by a policy that a "harmful alteration, disruption, or destruction to fish habitat" (HADD) cannot occur unless authorised with legally binding compensatory habitat to offset the HADD. Despite Canada's progressive conservation policies, the effectiveness of compensation habitat in replicating ecosystem function has never been tested on a national scale. The effectiveness of habitat compensation projects in achieving no net loss of habitat productivity (NNL) was evaluated at 16 sites across Canada. Periphyton biomass, invertebrate density, fish biomass, and riparian vegetation density were used as indicators of habitat productivity. Approximately 63% of projects resulted in net losses in habitat productivity. These projects were characterised by mean compensation ratios (area gain:area loss) of 0.7:1. Twenty-five percent of projects achieved NNL and 12% of projects achieved a net gain in habitat productivity. These projects were characterised by mean ratios of 1.1:1 and 4.8:1, respectively. We demonstrated that artificially increasing ratios to 2:1 was not sufficient to achieve NNL for all projects. The ability to replicate ecosystem function is clearly limited. Improvements in both compensation science and institutional approaches are recommended to achieve Canada's conservation goal.

Keywords Habitat compensation - Effectiveness - No Net Loss - Field evaluation - *Fisheries Act* - Authorisation - Habitat productivity - Policy - Canada

A Model for Freshwater Habitat Compensation Agreements Based on Relative Salmonid Production Potential of Lakes and Rivers in Insular Newfoundland, Canada

by

Patrick M. Ryan

Ryan Environmental, P. O. Box 58, Riverhead Road,
Mobile, Newfoundland, Canada A0A 3A0

Abstract

Under the Policy for the Management of Fish Habitat and the "no net loss" guiding principle of the Department of Fisheries and Oceans Canada, no harmful alteration, disruption, or destruction (HADD) of fish habitat may proceed without an authorization by the Minister under Subsection 35(2) of the Fisheries Act. Authorizations are not normally to be issued until adequate measures have been developed to compensate for the habitat which is to be harmed, altered, disrupted, or destroyed. In Newfoundland's lakes and rivers occupied by migratory salmonids, substantial variation in habitat use occurs both seasonally and annually and fish numbers or biomass measured over a short term cannot be considered as representative of potential productivity. In this paper, estimated average values of Atlantic salmon (Salmo salar) smolt production in Newfoundland lakes and rivers are used in a calculation of the relative production potential of the two habitat types. The calculated relationship suggests that appropriate compensation for a hectare of lake habitat which is to be harmed, altered, disrupted, or destroyed might be the creation of, or making available for use, 0.023 hectare of river suitable for salmonid habitat. Alternatively, appropriate compensation for a hectare of river habitat which is to be harmed, altered, disrupted, or destroyed might be the creation of, or making available for use, 42.857 hectares of lake suitable for salmonid habitat.

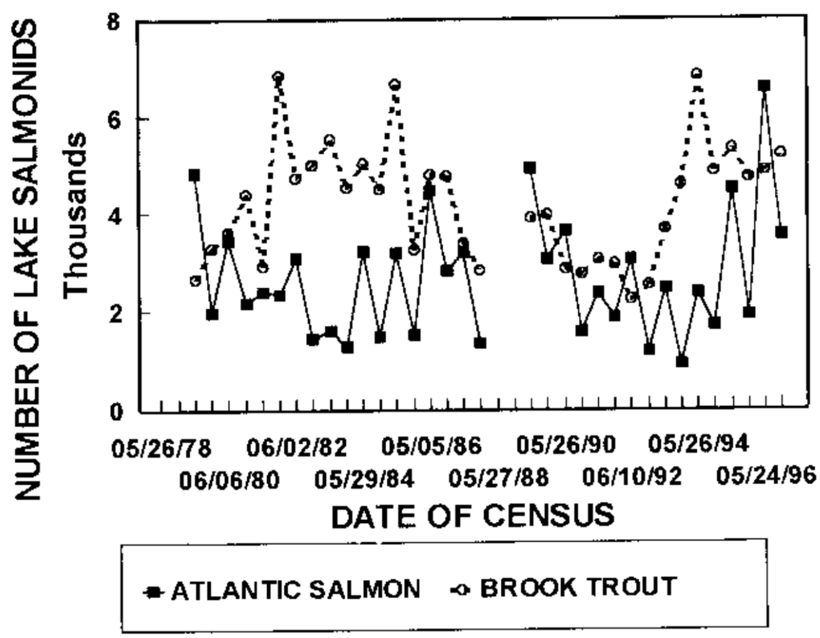
Introduction

As described in the Directive on the Issuance of Subsection 35(2) Authorizations (Anon. 1995), an objective of the Department of Fisheries and Oceans Canada is the maintenance of the productive capacity of fish habitats supporting Canada's fisheries resources. Under the Policy for the Management of Fish Habitat and the "no net loss" guiding principle of the Department, no harmful alteration, disruption, or destruction (HADD) of fish habitat may proceed without an authorization by the Minister under Subsection 35(2) of the Fisheries Act. Authorizations are not normally to be issued until adequate measures have been developed to compensate for the habitat which is to be harmed, altered, disrupted, or destroyed.

In cases where habitat loss will occur in lake (lacustrine, pond, or standing water) or river (fluvial, riverine, or running water) habitats of river systems and compensation measures are being developed, it would be advantageous to have a measure of the relative production potential of these two major habitat types. If a correspondence existed, lost lake habitat (ie. in the case of reservoir creation) might be compensated for by creation of river habitat, provided that the overall productive capacity of the total fish habitat was maintained. A measure of the correspondence between the production potentials of the two habitat types would increase the options available for satisfactory compensation agreements.

In Newfoundland fresh waters occupied by river-spawning salmonids such as Atlantic salmon (Salmo salar) and brook trout (Salvelinus fontinalis), substantial variation in habitat use occurs both seasonally and annually due to the migrations of the species to and from the available habitat types (ie. Knoechel and Ryan 1994, Ryan 1993a, Ryan 1994) (Fig. 1).

Figure 1. Variation in salmonid lake habitat use as exemplified by variation in population sizes of brook trout and Atlantic salmon in two lakes (area = 112.6 ha) of central Newfoundland. For further details on these lakes and the methods employed in the calculation of population sizes see Ryan (1993a, 1993b).



Financial and temporal constraints often apply to environmental assessment processes and fish numbers or biomass measured over a short term cannot be considered as representative of potential productivity. The following method employs estimated average values of Atlantic salmon smolt production in Newfoundland lakes and rivers in the calculation of relative production potential of the two habitat types. The calculated relationship may be used as an aid in the calculation of habitat of one type required to replace habitat of the other type which is to be harmed, altered, disrupted, or destroyed.

Methods

As described by Dempson and O'Connell (1993) and O'Connell and Dempson (1995), smolt production figures considered representative of average values of Atlantic salmon smolt production in lakes and rivers are used in the assessment of target spawning requirements for salmon stocks in Newfoundland river systems. These estimates factor in the potential contribution of both fluvial and lacustrine habitats (Fig. 2).

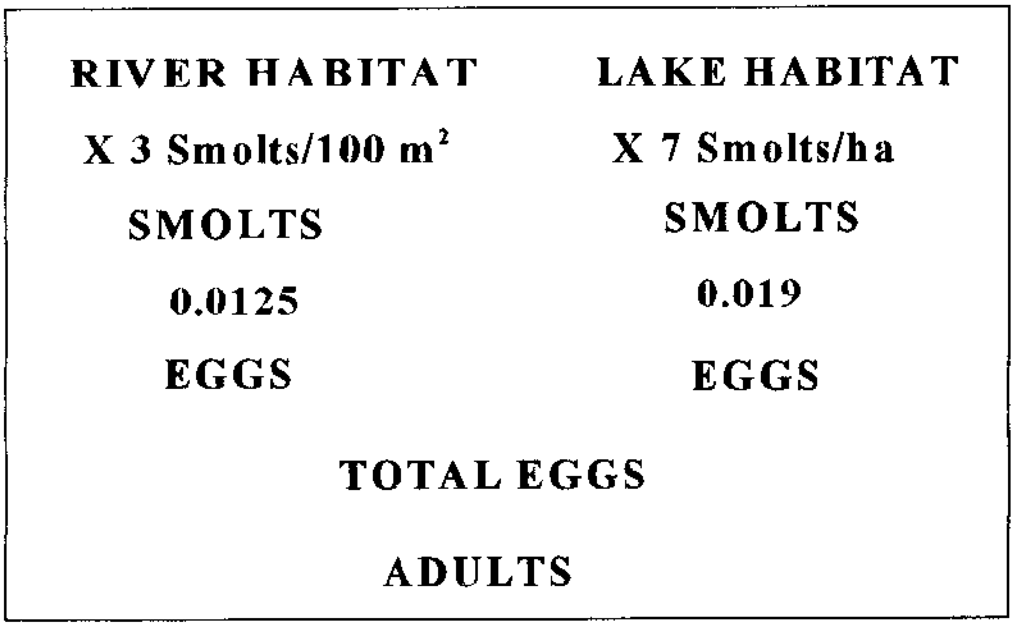


Figure 2. Representation of the model used to calculate target Atlantic salmon egg deposition requirements in Newfoundland river systems. The values 0.0125 and 0.019 are estimated egg-to-smolt survival rates in the two habitat types. Redrawn from Dempson and O'Connell (1993).

Average production values in the two habitat types have been calculated from data such as recommended salmon egg deposition rates for rivers in Atlantic Canada (Elson 1975), relative amounts of lake and river habitat on different rivers systems, and the use of salmon counting fences. Smolt production values from each habitat type are converted to egg deposition using egg-to-smolt survival rates.

Based upon this model used for salmon stock assessment purposes, salmon production potentials in lacustrine (or lake) and riverine (or river) habitats can be related as follows:

Since:

-lake production = 7 smolts/hectare; and

-river production = 3 smolts/100 square metres or 300 smolts/hectare; then

-one hectare of river potential production = 300/7 = 42.857 hectares potential lake production; or

-one hectare of lake potential production = 7/300 = 0.023 hectare potential river production.

This comparison suggests that appropriate compensation for a hectare of lake habitat which is to be harmed, altered, disrupted, or destroyed might be the creation of, or making available for use, 0.023 hectare of river suitable for salmonid habitat.

Alternatively, the comparison suggests that appropriate compensation for a hectare of river habitat which is to be harmed, altered, disrupted, or destroyed might be the creation of, or making available for use, 42.857 hectares of lake suitable for salmonid habitat.

Discussion

Use of the Atlantic salmon stock assessment model does not appear to preclude the application of a correspondence between the habitat types in the case of other salmonids or species mixes. There is strong evidence that similar salmonids occur in patterns of reciprocal abundance in waters of Newfoundland (Ryan 1993b) and elsewhere (Rose 1986). Since the stock assessment model employs figures representative of average values of Atlantic salmon smolt production, it can be expected that varying population sizes of similar salmonids would have occurred in the locations used in the calculation of model parameters.

Application of a correspondence between the habitat types requires consideration of habitats critical to the survival and well-being of the species in question. For example, the lack of availability of suitable river spawning areas near newly available lake habitat would obviously be detrimental to the long-term survival of river-spawning fish. Similarly, the availability of deeper water habitats for greater overwinter survival would provide for a more optimum use of newly available river areas.

Application of the correspondence between habitat types as described above cannot be considere mandatory or optimal in any given situation due to a variety of circumstances such as the possib presence of exceptional stocks (ie. trophy fish stocks) and particular habitats (ie. very popul fishing areas or critical spawning areas). However, the correspondence of potential salmoni

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production between the two habitat types described above may serve as a model for use in the preparation of freshwater habitat compensation agreements in many circumstances in insular Newfoundland.

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