Proceedings of a Workshop on the Potential Cumulative Impacts of Development in the Region of Hudson and James Bays, 17-19 June 1992

Edited by J.N. Bunch and R.R. Reeves

Physical and Chemical Sciences
Department of Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

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J.N. Bunch and R.R. Reeves[1]

Physical and Chemical Sciences
Department of Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

[1] Okapi Wildlife Associates, 27 Chandler Lane, Hudson, Québec, J0P 1H0

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The contents of this report summarize the opinions of the workshop participants and do not necessarily reflect the views of the Canada Department of Fisheries and Oceans.

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ABSTRACT

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An intradepartmental scientific workshop held in Ottawa on 17-19 June 1992 was attended by Department of Fisheries and Oceans (DFO) scientists and managers, representing all Regions. The purpose of the workshop was to begin developing a DFO response to concerns about cumulative environmental effects of development in the Hudson/James Bay region. The main product of the workshop was a series of working hypotheses referring to potential cumulative effects under four headings: a) physics; b) inorganic nutrients, organic carbon, and suspended matter fluxes; c) mercury and other contaminants; and d) biological resources. Several of the hypotheses, such as those concerning the direction of physical changes due to modification of the timing and location of freshwater discharge, problems of mercury mobilization and contamination, and decreased productivity of anadromous fish populations, were considered well-supported by available data. Other hypotheses, such as those related to primary and secondary productivity in estuarine and marine environments, effects on isolated populations of harbour seals and Atlantic salmon, and the likely responses of fish and marine mammals to altered conditions in estuaries (ice, sediment, salinity, vegetative regime, etc.), were judged as needing more focussed research.

RÉSUMÉ

Bunch, J.N. and R.R. Reeves (ed.). 1992. Proceedings of a workshop on the potential cumulative impacts of development in the region of Hudson and James bays, 17-19 June 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1874: iv+ 39 p.

Des scientifiques et des gestionnaires représentant toutes les régions du ministère des Pêches et des Océans (MPO) ont participé à Ottawa, du 17 au 19 juin, à un atelier à caractère scientifique. L'atelier avait pour objectif d'amorcer l'élaboration de la réaction du MPO aux préoccupations ayant pour cause les effets environnementaux cumulatifs de la mise en valeur de la région de la baie d'Hudson et de la baie James. Les principaux résultats de l'atelier ont pris la forme d'un ensemble d'hypothèses de travail traitant des effets cumulatifs éventuels des travaux. Ces hypothèses se divisent en quatre grandes catégories: a) les incidences physiques; b) les flux de matières nutritives inorganiques, de carbone organique et de matières en suspension; c) le mercure et d'autres contaminants et d) les ressources biologiques. Plusieurs de ces hypothèses, notamment celles ayant trait à la direction des modifications physiques résultant de la variation du moment et du lieu de l'écoulement des eaux douces, les problèmes liés à la mobilisation et à la contamination par le mercure et la baisse de productivité des populations de poissons anadromes, ont été jugées bien étayées par les données actuelles. Il a cependant été jugé que d'autre hypothèses, notamment celles ayant trait à la productivité primaire et secondaire des milieux estuariens et marins, aux effets sur les populations isolés de phoque commun et de saumon atlantique et aux réactions probables de la faune aquatique et des mammifères marins aux conditions modifiées des estuaires (glaces, sédiments, salinité, régime végétatif, etc.) devraient faire l'objet de recherches plus approfondies.

BACKGROUND AND CONTEXT OF THE WORKSHOP

DEPARTMENTAL RESPONSIBILITIES AND ROLE IN IMPACT ASSESSMENT

The Department of Fisheries and Oceans (DFO) has responsibilities for ensuring the sustainability of fisheries and for managing the quality and productivity of Canada's aquatic habitats. Habitat protection is essential for meeting these responsibilities. Increasingly, it is recognized that large-scale development projects can have far-reaching, permanent, and cumulative effects as well as local, immediate, and site-specific effects on the environment. Hydroelectric developments in boreal and subarctic regions of Canada have acquired a high public profile in recent years. The realized and potential impacts of such projects on human communities and on the biotic resources which sustain them have been, and will continue to be, vigorously debated.

Much of the public discussion of issues surrounding northern development is necessarily political. Decisions as to who controls or has access to resources can only be made in a political forum. However, underlying all of the discussions and decisions about resources is the need for scientific understanding to facilitate good management. What are the physical, chemical, and biological forces that produce and limit the resources? How do these forces interact? What natural processes determine the shape and amount of biological productivity in a region? How does a particular kind of development modify these processes? What are the likely consequences of a given development in terms of its impact on the productivity and availability of natural resources for human use?

DFO has substantial expertise in the areas of physical, chemical, and biological aquatic science, and much of this expertise has been developed through field research in northern regions. The Department, through its mandate for habitat management, has a special responsibility and opportunity to contribute to the decision-making process in the case of development in Hudson and James bays (Fig. 1). The federal initiative for assessing and managing cumulative effects of such development is led by the Department of Environment (DOE). DFO has a major responsibility for responding to public panel reviews conducted pursuant to the Environmental Assessment and Review Process (EARP) and the James Bay and Northern Québec Agreement. While DOE has primary responsibility for the federal cumulative-effects initiative, DFO is expected to provide scientific background and management advice, together with scientists and managers in DOE. The DFO cumulative effects workshop was conceived as a first step towards implementing this department's intentions and contributing to the coordinated process of federal review and comment. Subsequent steps in the process will involve participation by all interested parties through a series of DOE-sponsored workshops leading to a federal government strategy for managing development in the region of Hudson and James bays.

CUMULATIVE EFECTS: A NEW DIMENSION IN IMPACT ASSESSMENT

The *Canadian Environmental Assessment Act* (CEAA) received Royal Assent in June 1992 and is expected to be proclaimed early in 1993. Every assessment under the CEAA, whether an initial screening, a comprehensive study, a mediation, or a public panel review, must include consideration of "any cumulative environmental effects that are likely to result from the project in combination with other projects that have been or will be carried out." Thus, the study of cumulative effects is becoming an integral aspect of federal environmental impact assessment in Canada.

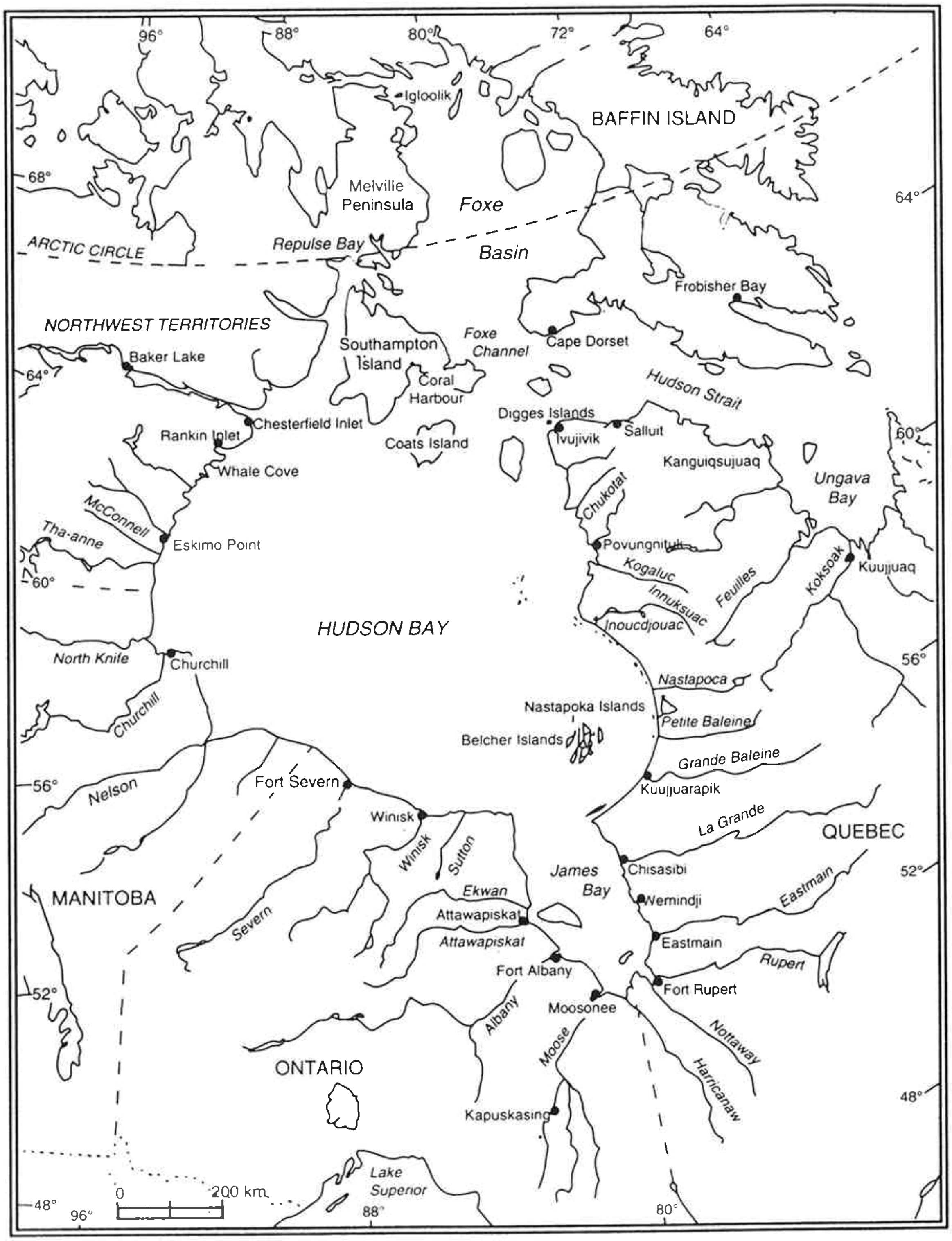

FIGURE 1. Region of Hudson and James bays showing the major rivers and townsites.

According to a recent study for the Canadian Environmental Assessment Research Council:

> Cumulative effects occur when at least one of two circumstances prevail: persistent addition of a material, a force, or an effect from a single source at a rate greater than can be dissipated; or compounding effects as a result of the coming together of two or more materials, forces or effects, which individually may not be cumulative (Peterson et al. 1987).

The study identified four functional pathways that can contribute to cumulative effects (Fig. 2). It was emphasized that those pathways involving persistent *additions* are balanced by analogous pathways involving persistent *losses* of a material, force, or effect at a rate greater than can be replaced (Peterson et al. 1987). Most or all of the pathways identified by Peterson et al. can be applied in attempting to understand and assess the potential cumulative effects of development projects in Hudson and James bays.

The need to assess and manage cumulative effects of development projects presents special challenges to scientists and decision-makers. In situations involving multiple or persistent sources of artificial perturbation, it is often difficult to establish cause-and-effect relationships. This is especially true when the geographic scale of analysis is large and results are confounded by natural variability in environmental conditions. Large sample sizes, long time scales, and multivariate models are often necessary to detect trends and determine causation.

Virtually all hydroelectric developments are superimposed on watersheds that have already been subjected to, and thus altered by, a variety of human activities. In the case of Great Whale, for example, the proposed project has been preceded by the large-scale damming and diversion of other drainage systems flowing into James and Hudson bays, notably the La Grande complex in Québec (Martini 1982) and the Churchill-Nelson complex in Manitoba (Newbury et al. 1984). Some major alterations that have already been made to the pristine Hudson Bay environment may never be documented or described because of the inadequacy of predevelopment "baseline" data. Further similar projects are planned or being considered in northern Ontario (Moose River; Greig et. al., 1992), Manitoba (Conawapa generating station on the Nelson River), and Québec (Nottaway-Broadback-Rupert complex). There is clearly a potential for cumulative effects resulting from past and future development activities in the Hudson/James Bay region. The organizers and participants recognized that the entire scope of developments, including forestry, pulp and paper production, mining, smelting, and commercial fishing, in addition to electrical power generation, could contribute to cumulative effects. It was also recognized that air- and water-borne contaminants from developments elsewhere in North America and from as far away as Asia and Europe could contribute to cumulative effects in the Hudson/James Bay region. Discussions at the workshop nevertheless centred mainly on the major hydroelectric projects that are proposed or under way in Hudson and James bays.

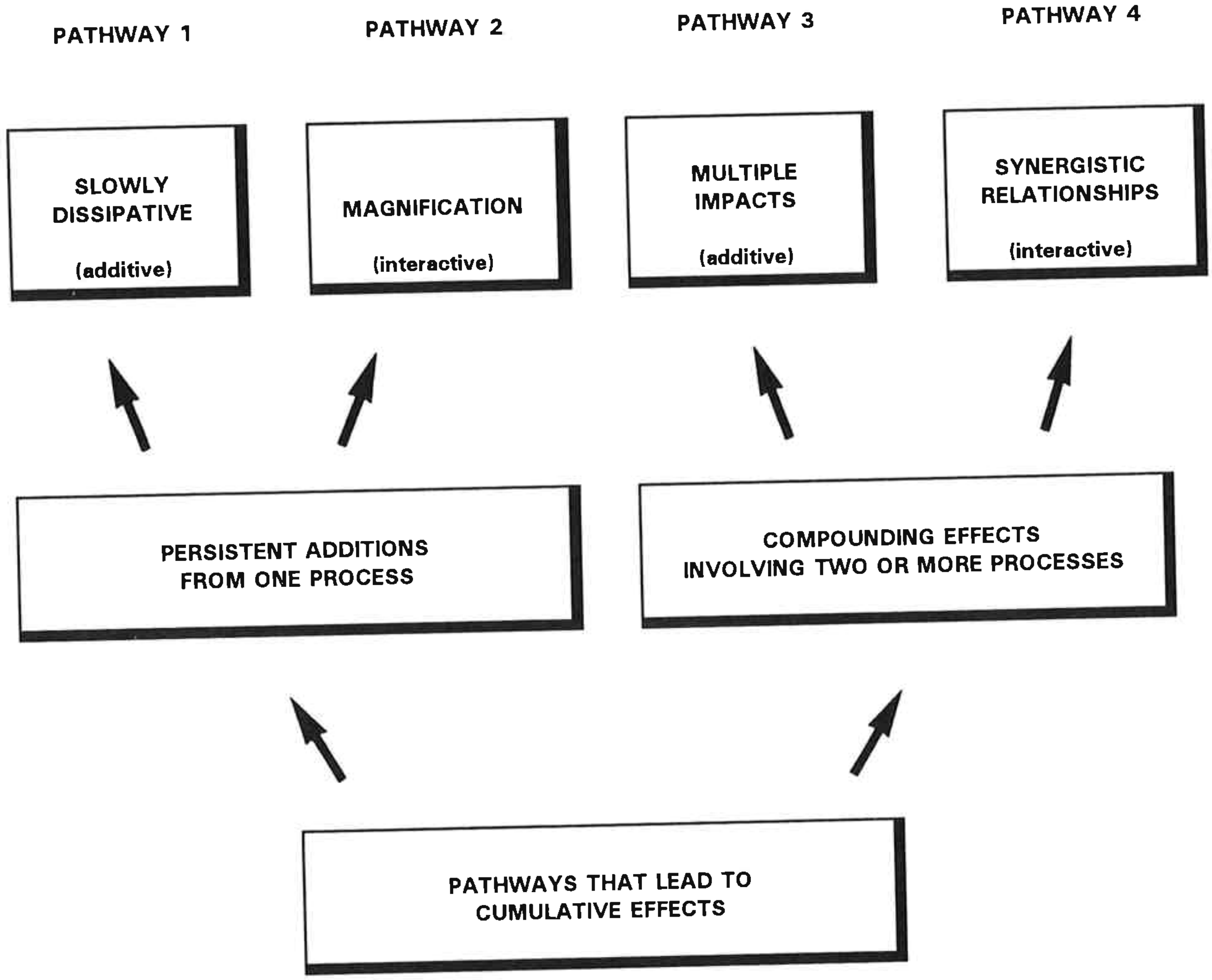

Figure 2. Basic Functional Pathways that Contribute to Cumulative Effects (from Peterson et al. 1987:5).

PURPOSE AND PLANNING OF THE WORKSHOP

The main objective of the workshop was to provide a consensual basis for Departmental responses to questions concerning the cumulative environmental effects of development projects in Hudson and James bays. It was recognized that definitive answers to many such questions were not yet available and that in some cases years of intensive research would be needed to obtain conclusive results. On the other hand, it was felt that in view of the substantial existing Departmental expertise in the areas of physical and chemical oceanography, biochemistry, and biology, a valuable contribution could be made by drawing upon presently available knowledge.

A Steering Committee met in Ottawa on 13 May 1992 to plan the workshop (see Appendix 1 for members). On 21 May a list of issues and questions developed by the Steering Committee was distributed to the Regions with a request that they identify additional issues and questions and that they provide relevant background concerning regional programs in the areas of Hudson and James bays and Hudson Strait.

A suggested list of DFO experts was circulated to the Regions in May, and the Regional Directors were asked to take this list into account when deciding who should attend. Individuals with specific expertise relative to the workshop's objective were asked to prepare short verbal presentations (see summaries, below). Participation in the workshop was restricted to DFO staff but included representatives from all the Regions (Appendix 1).

SCHEDULE AND STRUCTURE OF THE WORKSHOP

The workshop was held at the Relax Plaza Hotel in Ottawa on 17-19 June 1992. The agenda is given in Appendix 2.

G.L. Holland, Director General, Physical and Chemical Sciences, chaired the workshop. During the evening session on 17 June, W.G. Doubleday, A/Assistant Deputy Minister, Science, addressed the theme and objectives of the workshop in an opening presentation. G. Packman, Chief, Atlantic and Marine Operations, Habitat Management and Sustainable Development Branch, explained the role of DFO within the context of the federal government's response to cumulative effects assessment. Participants were briefed on the scope and expected results of the workshop by G.L. Holland. The Steering Committee's list of issues and questions was provided to each participant. Also, the information submitted by the Regions in response to the Steering Committee's 21 May solicitation was made available in two bound volumes - one on "Site-Specific and Generic Issues" and one on "Cumulative Impacts."

The main body of the workshop consisted of three sessions, each emphasizing a different disciplinary approach to, or component of, impact assessment: physics, chemistry, and biology. All participants were assigned to one of two homogeneous working groups which met independently and concurrently following each set of verbal presentations. The working groups were asked to evaluate available information, to agree upon best available answers to key questions, to formulate working hypotheses for guiding further research, and to identify and rank program needs. After the working-group period, the chairperson or rapporteur summarized each working group's discussions during a plenary meeting. Chairpersons and rapporteurs met between sessions to draft hypotheses and list research needs, and this written material was immediately reproduced and distributed to all participants.

The combined written output of the three working-group sessions served as the basis for a final plenary meeting, chaired by G.L. Holland and with R.R. Reeves as rapporteur, during the afternoon of 19 June. Draft working hypotheses were projected onto a screen for discussion and revision. Each hypothesis, once its wording was agreed, was assigned to one of three categories of importance: Critical, Important or Slight; and to one of three levels of certainty based on perceived adequacy of the knowledge base: High, Medium or Low. Insofar as possible, these assignments were made by consensus. The Chairman acknowledged the subjective nature of the process but emphasized the importance of having best available answers based on existing scientific knowledge and expertise. A bibliography of recent scientific literature related to the Hudson/James Bay region is being produced as another workshop contribution.

OVERVIEW OF ISSUES AND QUESTIONS

Two proposed hydroelectric schemes commanded most of the workshop's attention: Great Whale in northern Québec and Conawapa in northern Manitoba. Because of its larger scale and broader public profile, Great Whale received more discussion than Conawapa.

SITE-SPECIFIC AND GENERIC EFFECTS: GREAT WHALE HYDROELECTRIC COMPLEX

The Great Whale project, with an expected generating capacity of 3,168 MW, will involve the diversion of the Great Whale and Little Whale rivers in southeastern Hudson Bay. Most of the outflow from these rivers will be redirected to a coastal region where the freshwater outflow is presently negligible. In the context of DFO's mandate, the major environmental issues identified by the Steering Committee were:

1. freshwater ecosystems within the project area,
2. the mercury burdens in freshwater and marine biota,
3. dynamics of the Great Whale and Little Whale river plumes,
4. dynamics of the seasonal landfast ice cover in southeastern Hudson Bay,
5. the physical and chemical characteristics of water and sediments in the coastal and marine environment,
6. the population of Atlantic salmon centred in the Nastapoka River,
7. inshore and offshore productivity in eastern Hudson Bay,
8. survival of fish larvae in southeastern Hudson Bay,
9. the population of harbour seals in Lac-des-Loups-Marins, and
10. the distribution, abundance, reproduction, and feeding of belugas (white whales), ringed seals, and bearded seals in eastern Hudson Bay.

Among the questions expected to be raised by the panels of the Environmental Assessment and Review Process, non-governmental organizations, and the public in general are:

1. What is the current status of freshwater and anadromous fish species and their habitats in the proposed project area?
2. How will the diversions and flooding affect fish habitats and thus fish production?
3. Will the availability of fish be altered significantly, and what impact will any change have on subsistence fisheries?
4. Will reservoir formation increase levels of mercury in freshwater and anadromous fish and in coastal marine fish and mammals?
5. If mercury levels are predicted to increase, what measures can be taken to mitigate this effect?
6. How will the physical and chemical characteristics of the freshwater in the project area be modified by the creation of reservoirs?
7. Will the flooding associated with reservoir formation significantly increase the production of methane and carbon dioxide (the so-called "greenhouse gases")?
8. How will alteration of the freshwater flow affect downstream fish habitats, estuarine productivity, and the physical and biological processes contributing to coastal ice dynamics?
9. How will the re-routing of freshwater flow into southeastern Hudson Bay affect oceanographic processes?
10. Will there be fewer marine fish and mammals along the east coast of Hudson Bay because of the Great Whale project?
11. Will the Great Whale project have a negative impact on the habitats of marine fish and mammals?

SITE-SPECIFIC AND GENERIC EFFECTS: CONAWAPA HYDROELECTRIC PROJECT

The proposed Conawapa project includes installation of a fourth generating station on the lower Nelson River, Manitoba, following those at Kettle Rapids (brought into full service in 1974), Long Spruce (1979), and Limestone (1992) (see Newberry et al. 1984 for locations). Since 1977, flow in the lower Nelson River has been augmented by the partial diversion of the Churchill River (Newberry et al. 1984). Major environmental issues associated with the Conawapa project, as identified by the Steering Committee, were its potential impacts on:

1. the already-altered freshwater flow in the Nelson River,
2. the physical and chemical characteristics of the freshwater outflow, leading to altered oceanographic processes,
3. the Nelson River freshwater plume in western Hudson Bay,
4. mercury levels in fish,
5. the current composition of fish species,
6. habitats of freshwater and anadromous fish,
7. fish passage, particularly the upstream movement of anadromous species,
8. productivity in the Nelson River estuary, and
9. marine mammals that use the Nelson River estuary.

Questions similar to those posed for the Great Whale project could be framed for the Conawapa project.

POTENTIAL CUMULATIVE EFFECTS: HUDSON AND JAMES BAYS

Current and proposed hydroelectric developments within the drainage basins flowing into Hudson and James bays will significantly alter the freshwater systems. Resultant changes in the timing, location, and amount of freshwater entering the bays will also affect the marine environment. A set of "cumulative-effects" questions was identified by the Steering Committee:

1. To what degree will hydroelectric development contribute to the net production of "greenhouse gases"?
2. Will the mobilization, downstream transport, and bioaccumulation (via the food chain) of methyl mercury and other contaminants -
   a. have an adverse effect on organisms living in otherwise pristine ecosystems,
   b. interrupt the use of some stocks in food fisheries, or
   c. increase harvesting pressure on relatively uncontaminated stocks?
3. Will the alteration and destruction of habitats be sufficient to cause long-term declines in the quality or productivity of freshwater fisheries?
4. Will the migrations of marine mammals be affected, and will areas used by these animals for reproduction and other physiological processes (e.g. moulting) be affected?
5. Will unique or threatened species (or stocks) be adversely affected by development?
6. How will altered freshwater flows into Hudson and James bays affect -
   a. water-mass characteristics, circulation, and mixing rates,
   b. the ice regime,
   c. sediment loads and carbon and nutrient fluxes,
   d. nearshore habitats, and
   e. the availability, quality, and productivity of any marine species?

7. Will hydroelectric developments in Hudson and James bays have adverse effects on productivity in Hudson Strait or the Labrador Sea?

Although hydroelectric development was acknowledged as being the principal concern of the workshop, participants were reminded that the net effects of all types of human activities were to be considered. Among the most obvious activities in the Hudson/James Bay region other than hydroelectric development would be forestry, pulp and paper production, mining, fishing, and hunting. These activities already occur in parts of the region, but their potential contributions to cumulative effects were not considered during the workshop discussions. The indirect and confounding effects of processes such as atmospheric transport of contaminants also would need to be taken into account when assessing potential cumulative effects.

SUMMARIES OF VERBAL PRESENTATIONS

PHYSICS

Greenhouse Gases (Drew Bodaly):

The principal hypothesis - that reservoirs can be significant sources of greenhouse gases (CO_2 and CH_4) - has not yet been verified by experimentation or extensive field testing. Calculations based on rates of gas production by peatland ponds and observations in one northern Manitoba reservoir suggest that a potential problem exists. Calculations were made assuming that 60% of the organic carbon in a flooded upland would be released into the atmosphere as CO_2 or CH_4 within the first 50 years after flooding. For a given amount of power generation the CO_2 equivalent from burning coal or natural gas is in the range of 0.4-1.0 Tg CO_2 equivalent per TWhr. This compares with 0.2-0.4 (low end of assumptions) or 0.7-2.0 Tg CO_2 equivalent per TWhr (high end of assumptions) for the Grand Rapids reservoir, and 0.02-0.04 or 0.09-0.2 Tg CO_2 equivalent per TWhr for the Churchill/Nelson development (both in northern Manitoba).

An experimental approach to estimating the magnitude of greenhouse gas production by a boreal reservoir is being taken within the Experimental Lakes Area Reservoir Project (ELARP). A 3-hectare lake is scheduled to become a 10-hectare reservoir after two years of pre-impoundment monitoring. Programs for monitoring gas production in some existing reservoirs are beginning. These studies will help verify observations on the magnitude of greenhouse gas production from reservoirs generated by ELARP and provide clues to the duration of the problem.

Circulation and Mixing (Pierre Larouche):

Hudson Bay is one of the largest inland seas in the world, but it can also be regarded as a large estuary, with salinity increasing from south to north. This salinity gradient is the result of a large influx of freshwater from rivers in southern Hudson Bay and James Bay that gradually moves towards Hudson Strait. Salt balance is conserved through an influx of saltier water from Hudson Strait. Freshwater is most prevalent along the coast and generates a baroclinic coastal current flowing anticlockwise around the bay, a major characteristic of water circulation in Hudson Bay.

Rivers flowing into Hudson and James bays have a yearly mean freshwater runoff of approximately 22,000 $m^3 s^{-1}$, which is twice the St. Lawrence system runoff. Ice melting contributes at least as much to the freshwater budget in the Hudson/James Bay system as does river discharge. If spread over the entire area, the yearly freshwater input in James Bay would be proportionally 8 times as thick as that in Hudson Bay. This buoyancy input leads to a more energetic system in James Bay. Freshwater is the most important factor of the density-driven component of circulation in Hudson/James bays.

Besides freshwater input, which is a very low-frequency signal, circulation in the bay is driven by interacting processes at various frequencies such as weather systems (6-10 days), wind (inertial), and astronomical forcing (tidal frequencies). The annual cycle of water properties is characterized by autumn cooling of surface waters, rejection of salt when ice forms which causes vertical mixing, a well-mixed water column by the end of winter, and re-stratification of the water caused by ice melt in spring.

Understanding of oceanographic processes, and therefore the ability to predict the cumulative impacts of hydroelectric developments, is hindered by the size and remoteness of the system, the lack of long-term measurements, and the large interannual variability. Knowledge of this system rests on only a few sets of measurements. It is important to bear in mind that in addition to the system-wide mean conditions of circulation and mixing (described above), there is much variability at smaller spatial scales. The Hudson/James Bay system is thus extremely complex, and major efforts will be needed to understand it.

Ice Regime (Simon Prinsenberg):

Ice formation in Hudson Bay begins in the northwest and advances towards the southeast. The process can be understood as an "ice conveyor belt." Initially, while the southeastern part of the bay is ice-free, the ice and ice edge (front) move rapidly southeastward due to wind. As the bay fills up with ice, the ice moves more slowly. The basic dynamic involves salt rejection due to freezing in the northwest and freshwater melting in the southeast. Ice ridging is an important factor that needs to be taken into account for ice and heat budgets. The frequency of ice ridging ranges from about 2 ridges per km in the northwest to 10 per km in the southeast of Hudson Bay. It is also important to know the thickness of offshore ice, but most available measurements are taken from the stable landfast ice only.

Ice disintegration starts independently in the northwestern and southeastern corners of Hudson Bay. The prevailing northwesterly wind opens a shore lead in the northwest, and a James Bay-Belcher Islands corridor is opened in the southeast by currents and heat. The last ice to clear in spring is usually in the southwestern corner of Hudson Bay off Winisk. An area south and southeast of Southampton Island is sometimes ice-bound year-round.

Ice contributes more to the Hudson Bay freshwater budget than runoff and precipitation combined (Prinsenberg 1988). Changing runoff and stability in the bay is unlikely to have a detectable effect on the start of ice formation because ice-cover properties are mainly determined by atmospheric conditions (jet stream, El Niño events). When freshwater is discharged under the ice cover, one can expect an increase in ice thickness and a delay in melting. However, changes in these variables are difficult to measure because there is so much natural variability and because the global effects of climate change may swamp the local effects of hydroelectric development.

CHEMISTRY

Mercury (Drew Bodaly):

The main concern about mercury in reservoirs is related to the health effects on humans who eat mercury-contaminated fish. It is well established that methylmercury levels in fish from reservoirs are much higher than normal background (e.g. Bodaly et al. 1984a). As an example, levels of 3 ppm have been recorded in fish from LG2 in James Bay (Brouard et al. 1990). This is 6 times the limit for marketing in Canada and 15 times the 0.2 ppm limit for long-term human consumption. It normally takes decades for levels of methyl mercury to return to pre-impoundment levels.

The problem of mercury contamination extends downstream from reservoirs (Brouard et al. 1990; Johnston et al. 1991). Methylmercury moves downstream dissolved in the water and attached to sediments. Also, fish that spill over the dam or pass through the turbines can be eaten by fish, birds, and mammals downstream of generating stations. Whereas the effects of mercury contamination in reservoirs are quantitatively predictable, the downstream effects in estuarine and marine systems are poorly known. There is transport throughout the freshwater plume. At Great Whale, where water from the dam will be channelled directly into Manitounuk Sound, a strong pulse in mercury contamination may occur.

Mitigative measures are difficult to envision. Most, such as clearing vegetation from the land before flooding or adding selenium, are considered too expensive and are probably not practical or are controversial. The best that can be hoped for may be to minimize the amount of land that is flooded. The Experimental Lakes Area Reservoir Project may improve understanding of mitigative measures. Tests under way at LA1 and EM1 may lead to the development of some experimental mitigation tools.

Mercury (Lyle Lockhart):

This presentation focussed on two concerns: the long-range transport of contaminants (mercury, organochlorines, PAHs) and the elevated mercury levels in people living "downstream" of point sources. Mercury profiles in sediment cores taken from northern lakes indicate an approximate doubling since 1900 (Lockhart 1992). The sediment flux correlates with levels of muscle mercury in fish (see Johnson 1987). Recently-published work by Slemr and Langer (1992) demonstrates that mercury levels in air increase with latitude in the northern hemisphere. Furthermore, these authors suggested that atmospheric concentrations of mercury in the northern hemisphere are increasing at a rate of 1.46% per year, which suggests a doubling time of less than 50 years.

Three sources of mercury are recognized: natural geological background, hemispheric atmospheric transport and deposition, and local point sources such as reservoirs and pulp and paper mills. Human blood mercury levels in 478 communities across Canada were compared. This analysis showed that human blood mercury levels (measured in the late 1970s and early 1980s) in people from arctic coastal communities, including several on the coast of Hudson Bay, already exceeded the normal range in high proportions of the test results, unlike aboriginal communities in virtually all other parts of Canada. Similarly, PCB levels in milk from women in coastal communities of northern Québec are much higher than those from several southern locations (Dewailly et al. 1989; Jacobson and Jacobson 1988).

Mercury (Rudy Wagemann):

Levels of mercury (liver and kidney) and lead (liver and muscle) in belugas taken at six different sites in Canada (St. Lawrence River, Nastapoka River in eastern Hudson Bay, Eskimo Point in western Hudson Bay, Pangnirtung in southeastern Baffin Island, Grise Fiord in the eastern High Arctic, and the Mackenzie Delta) were compared. Whales from the St. Lawrence had much higher mercury and lead burdens than any other belugas sampled. Levels of both compounds were higher for belugas taken in the Nastapoka River than for those taken at Eskimo Point. The Nastapoka and Eskimo Point whales had higher levels than the whales from Pangnirtung and Grise Fiord (Wagemann et al. 1990).

Lead and mercury levels in walrus liver (ppm dry weight) were compared for five sites in eastern Canada - two in eastern Hudson Bay (Inukjuaq and Akulivik), two in northern Foxe

Basin (Igloolik and Hall Beach), and one in southeastern Baffin Island (Iqaluit). Lead levels were significantly higher in the animals from Hudson Bay, and mercury levels were especially high for walruses from Inukjuaq (0.58 compared with 0.42 at Akulivik, 0.33 at Iqaluit, 0.26 at Igloolik, and 0.23 at Hall Beach). Although the sample sizes from Hudson Bay were small (9 animals from Inukjuaq, 4 from Akulivik), these data suggest a gradient of decreasing mercury and lead levels with increasing distance from James Bay. Samples of walrus liver from Igloolik were available for different years (1982, 1983, 1987, and 1988), and these revealed essentially constant mean mercury levels. This result was interpreted to mean that, at least during the 7-year period of the study, walruses in northern Foxe Basin were being affected mainly by background levels of mercury and were not subjected to contamination from a point source. Walruses are benthic feeders, so changes in heavy-metal burdens in their tissues cannot be simply explained by surface transport mechanisms alone.

The preliminary findings reported here demonstrate the value of time-sequence studies to track heavy-metal levels in high-order predators. If levels remain constant, background sources only are suspected. If levels increase, there is reason to suspect pollutant input from one or more point sources.

Suspended Matter and Nutrients/Carbon (Rod Morin):

Freshwater runoff is a direct source of carbon, suspended material, and inorganic nutrients in estuaries. The peak of discharge occurs immediately after break-up. Most of the discharge consists of fine and very fine particulates. Once in the estuary, coarse particulates are much less subject to transport by currents than are the finer particulates, and much of the coarse particulate matter is deposited and thus helps shape the bathymetry of the estuary.

It has been estimated that on an annual basis, approximately 135,000 metric tons of sediment (ash-free dry weight) as well as 10,000-12,000 metric tons of particulate organic carbon, which serves as a substrate for bacteria and microalgae, are discharged into Hudson Bay by the Great Whale River. Probably 10 times as much dissolved organic material is discharged. This source of particulate and dissolved organic carbon is probably important to the estuarine and marine food webs, at least locally.

Chlorophyll concentrations at the mouth of the Great Whale River are high relative to those in surface waters elsewhere in Hudson Bay. A greater concentration of chlorophyll is associated with coarse seston (particle size greater than 1 mm) than with finer-sized fractions of seston.

Maximum bacterial activity and abundance occur at the time of river break-up, probably due in part to terrestrial scouring. Seasonal patterns in the abundance of particulates, bacterial biomass and activity, and chlorophyll associated with particulates, suggest that production in the lower Great Whale River is heterotrophically driven. The loss of particulate organic carbon through impoundment is of evident concern for production dynamics of the lower river drainage. Data on benthic communities and the components of the inshore marine food web are insufficient to evaluate how riverine exports of bacteria and particulate carbon contribute to the marine food web.

Nearshore Habitats (Christiane Hudon):

The shoreline morphology of southern Hudson Bay and eastern James Bay is defined by the pre-Cambrian Shield and provides a variety of habitats for wildlife and fish. Little systematic work has been done to characterize habitats in Hudson Bay and James Bay (but see the recent publication by Dignard et al. 1991). Different types of coast support different communities of organisms. For example, low-grade depositional coasts, characterized by mud and sand flats with marshes, support large populations of deposit-feeding molluscs and polychaete worms and serve as important feeding and moulting grounds for waterfowl. High-grade exposed coasts, with high flushing rates, low sediment accumulation, and coarse rocky bottoms support laminarian beds. These in turn provide shelter for filter feeders and sessile epifauna which serve as a food base for juvenile and adult fish. Eelgrass beds form in the well-consolidated soft sediment of medium-grade sheltered coasts, providing physical shelter for fish, trapping sediments, and facilitating nutrient regeneration.

Estuaries are important habitats, used year-round by a variety of organisms. The large quantities of insects and other organic material discharged at the mouths of large rivers help explain the concentrations of fish and benthic invertebrates that occur in estuaries. Also, the larvae of freshwater and anadromous fish (e.g. burbot, coregonids) pass into estuaries in freshets. Juvenile fish often remain in the estuarine plumes for their first one or two years of development. Estuaries are also used by marine mammals and waterfowl.

The lack of a classified inventory of coastal and estuarine habitats in Hudson and James bays is a serious impediment to impact assessment. Modifying the freshwater flow into the bays will certainly alter habitats, but presently available information is not sufficient for predicting the nature, direction, and magnitude of change.

BIOLOGY

Freshwater Fish Quality and Products (Drew Bodaly):

The "trophic surge" that occurs in reservoirs immediately after impoundment is a standard process that is fairly well understood (Hecky et al. 1984). Production in freshwaters on the Canadian shield is generally phosphorus-limited and thus usually responds to the introduction of large amounts of phosphorus and organic carbon from inundated organic matter. As a reservoir ages, production declines, usually to an equilibrium level that is lower than the one that prevailed before impoundment. Reservoirs tend to be deeper and colder than natural lakes, and this helps explain their lower productivity. Most of the LaGrande reservoirs appear to be following the typical surge pattern. The trophic surge of a boreal reservoir often lasts for a few decades before passing its peak.

Four factors can be identified as contributing to the degradation of fish habitat in reservoirs. These factors can modify the magnitude and time course of the trophic surge in reservoirs. "Drawdown" (artificial regulation of the water level) occurs on a daily and seasonal cycle. It exposes the littoral zone and limits the reproductive success of some fishes. Fall spawners such as coregonids are particularly vulnerable to drawdown effects

(Gaboury and Patalas 1984). Oxygen problems often arise in summer due to eutrophication, the breakdown of flooded organic matter, and high surface water temperature. Fish passage is an obvious problem for anadromous species, but even non-anadromous species can suffer because of the way dams limit their natural dispersal and migratory processes (Bodaly et al. 1984b). Turbidity upstream of the dam can limit fish spawning success by covering eggs (Fudge and Bodaly 1984) and can cause primary productivity to be light-limited rather than nutrient-limited (Hecky et al. 1984). In these ways turbidity tends to dampen the trophic surge.

Two factors affect the quality of fish products. First, high mercury levels can limit commercial fisheries and affect subsistence fish consumption (Bodaly et al. 1984a). Publicity about mercury problems can limit subsistence consumption even in waters that do not have mercury problems. Second, levels of infestation by *Triaenophorus*, a parasitic cestode found in the muscle tissue of whitefish, tend to be higher in reservoir fish (Bodaly et al. 1984b). This creates a grading problem for commercial fisheries.

Marine Mammals (Mike Hammill):

Marine mammals are important to the economy and culture of aboriginal communities. Many non-aboriginals have strong feelings about marine mammals, and threats to whale and seal populations have a high public profile.

Bowhead whales were sufficiently abundant to support a commercial hunt in the northwestern part of Hudson Bay from 1860 to 1915. They are now rare but are still seen occasionally throughout much of the bay. Bowheads feed on small zooplankton, but very little else is known about their ecology in the Hudson Bay region.

A total population of approximately 26,000 belugas summers in Hudson and James bays. Most of this population probably overwinters in Hudson Strait. Since belugas congregate in estuaries during summer, modifications to the estuarine environment are a source of concern (e.g. Lawrence et al. 1992). Belugas moult during the period of estuarine occupation. They also feed to some extent, at least in the Churchill River. Characteristics of estuaries that are important for beluga moulting may include higher temperatures, lower salinity, and the nature of the substrate (for rubbing). Much more information is needed on the duration of estuarine occupation by individual whales, movement between estuaries, distribution and activities offshore, stock relations, diet, and seasonal fat cycles.

Bearded seals are benthic feeders that occur primarily in unstable pack ice. Walruses are also benthic feeders that haul out on pack ice and offshore islands. Very little is known about the current status and ecology of bearded seals and walruses in Hudson Bay. Walrus populations are thought to have been reduced by hunting for food and ivory.

Ringed seals are the most abundant pinnipeds in Hudson Bay. They are pelagic feeders that depend mainly on fast ice for pupping habitat. Ringed seals have a relatively long lactation period (42 days), and females must feed during lactation. These seals are thus especially sensitive to disturbance (e.g. snowmobile and icebreaker traffic, hunting) during the spring pupping and pup-rearing season. Ringed seals have been studied intensively elsewhere in their range, but little is known about populations in Hudson and James bays.

Harbour seals are not abundant but are distributed throughout much of Hudson Bay. They are often found in estuaries and may at times haul out on pack ice. Populations of harbour seals living in freshwater ("landlocked") habitats are of special concern in the present context because of the possibility that flooding and reservoir formation could destroy their habitat. Public interest has focussed on the harbour seals in the Lower Seal Lakes region of Québec, whose provisional status as a separate subspecies needs to be reviewed.

Endangered Fish Stocks (Rod Morin):

The small population of Atlantic salmon centred in the Nastapoka River is believed to be isolated in eastern Hudson Bay, with limited movement of a few individuals to as far north as the Kogaluc River (Morin 1991). This population is likely a relict of post-glacial colonization of the region, which occurred approximately 5000 years ago. Harvest studies during the 1970s revealed that salmon were caught regularly by the people of Inukjuak. Biological sampling with gill nets in the lower Nastapoka in the 1980s resulted in a catch of roughly half salmon, followed in abundance by brook trout. Since there is only about 1.5 km of river below the falls, and a salt wedge extends well inside the river mouth, the amount of freshwater habitat available to the salmon is small. Salmon do occur above the falls, but there is no evidence that they reach the Seal Lakes. The salmon apparently overwinter in the Nastapoka River.

The Nastapoka salmon reach an asymptotic length of slightly more than 400 mm and live to ages of 10 or more years. Local brook trout reach maximum body size earlier in life than salmon, are shorter-lived, and have a linear growth pattern. Brook trout typically mature earlier and have higher fecundity than salmon. Given the greater reproductive potential of trout compared with salmon, this raises the question as to why salmon should be dominant in the Nastapoka River. Perhaps the reduced space and rapid currents make this river more suited to salmon than to trout. A reduction in the Nastapoka's flow would likely limit or exclude salmon and could favour other salmonids.

Quality and Production of Marine Species in Hudson Bay (Buster Welch - condensed from his written Regional submission and other sources):

Hudson Bay is strongly stratified in summer due to ice melt and runoff, and nitrate/oxygen analysis of deep water below the pycnocline (ca 60 m) suggests that deepwater recharge averages 5-10 years. The deep water has lower nitrate concentrations than would be expected if undiluted deep Atlantic water was its source. Phytoplankton production is apparently low throughout the bay. It is higher near shore and lowest near the middle, with August chlorophyll *a* values typically in the range 0.3-1.0 microgram per litre. However, given the highly stratified nature of the water column, the initial bloom would be expected to occur shortly after break-up, i.e. between May and early July depending on location. Sampling of offshore waters has not been done at those times. If hydroelectric developments were to result in increased summer stratification, this would decrease phytoplankton production by reducing nutrient flow upward to surface waters.

As a shallow, clear sea, Hudson Bay has a great deal of kelp production in shallow water. Kelp sequester nitrate in winter before microalgae begin to grow, possibly reducing subsequent ice algal production in shallow water (Welch et al. 1991). This effect would not be important to the Bay as a whole. The relative importance of kelp to the Hudson Bay ecosystem needs to be assessed.

Ice microalgae are an important source of food for zooplankton and larval fish before the summer phytoplankton bloom begins. These algae have been shown to fluctuate in direct relation to nitrate levels, as well as light, in nearshore environments. Their overall importance in the Hudson Bay ecosystem has not been determined.

Secondary production can be expected to fluctuate in direct proportion to primary production. This includes invertebrates with potential economic importance to man, such as bivalves, and marine mammal food-chain components such as fish and copepods. It is difficult to predict effects of altered freshwater flows on reproduction and production of invertebrates because virtually nothing is known about the dynamics of plankton and benthos in the main bodies of Hudson and James bays.

Recent work by Drolet et al. (1991), Gilbert et al. (1992) and Ponton and Fortier (1992) has shown that the dynamics of the Great Whale River plume and ice-cover conditions in spring influence the local survival of planktonic fish larvae, especially sand lance and arctic cod (*Boreogadus saida*), in southeastern Hudson Bay. The influence of such coastal processes on the recruitment or abundance of fish populations in Hudson Bay cannot be assessed without more information. Does estuarine fish larvae production account for 0.1, 1.0, 10, or 50% of the total secondary production, and what is the relative contribution of different species? Capelin are particularly important to the biological economy of southern Hudson Bay, but we know nothing about their spawning sites, abundance, movements, or production in this region.

Quality and Production of Hudson Strait (Jon Percy):

Hudson Bay is an open system in which oceanographic factors structure the biotic communities offshore and along the coast. Much of the water and biota are arctic and diversity is low. Hudson Bay has always been considered to have low productivity overall but near shore and towards the northeastern corner of the bay, where stratification of the water column begins to break down, productivity may be relatively high. The major gradients in the Hudson Bay system result from freshwater inputs (rivers, ice melt) and the penetration of Labrador Shelf and North Atlantic water well into Hudson Strait, such that it sometimes reaches northern Hudson Bay.

Within the upper 100 m in Hudson Strait there is a marked cross-strait difference in the zooplankton communities, reflecting the different water properties of the two zones. Also, there are important east-west differences, with western Hudson Strait having a more arctic character and eastern Hudson Strait being a more diverse subarctic system. Inuit communities in the region tend to be concentrated around Hudson Strait because of the increased availability of marine resources there.

There is considerable interest in developing commercial fisheries in Hudson Strait for scallops, shrimp, cod, mussels, and other marine resources. Among the more important marine mammals, from the standpoint of subsistence hunting, are walruses, belugas, and in some areas ringed and bearded seals. Seabird colonies centred in western Hudson Strait/northeastern Hudson Bay, dominated by thick-billed murres, remove approximately 5 times more energy per unit of area than do the seabirds in Hudson Bay. These large colonies are probably limited by their marine food supply, which consists mainly of small fish and crustaceans.

Quality and Production of the Labrador Sea (Ken Drinkwater):

Freshwater leaving Hudson Bay follows the south shore of Hudson Strait. Tidal mixing in Ungava Bay obscures the flow of low-salinity water east of Cape Hopes Advance. The alongshore flow near Cape Hopes Advance peaks from September to November, with the salinity minimum reached in approximately November or December. Thus, the outflow of warm, low-salinity water through Hudson Strait occurs late in the calendar year.

Tidal currents in Hudson Strait are 3-5 knots in some areas, and these very strong currents cause intense vertical mixing. Well-mixed sites have been identified at the eastern and western entrances to the Strait, and these areas are positively correlated with high concentrations of surface nutrients and chlorophyll *a*. Thus, summer productivity in Hudson Strait is closely tied to the effects of tidal mixing, which can extend to depths as great as 200 m.

Sutcliffe et al. (1983) found an inverse relationship between surface salinity in summer at St. John's, Newfoundland, and river runoff in southern Hudson Bay in the previous spring. This was interpreted as suggesting that the residual outflow of low-salinity water through Hudson Strait could ultimately affect cod production off Newfoundland. However, more recent data show that the timing of this outflow is inconsistent with such an interpretation. Myers et al. (1990) estimated that the surface-salinity minimum in Hudson Strait occurs in October rather than August as suggested by Sutcliffe et al. (1983). The latter authors had not adequately accounted for the travel time of river-discharge induced, low-salinity water within Hudson Bay. Melting of sea ice in Davis Strait and along the Labrador coast is probably a more important factor in seasonal salinity changes observed off Newfoundland. Any contribution made by freshwater runoff in Hudson Bay would likely be obscured by the large natural interannual variability.

DFO WORKING HYPOTHESES RELATED TO CUMULATIVE EFFECTS

The principal aim of the workshop was to generate working hypotheses that reflect current scientific opinion and provide a basis for critical evaluation of the potential cumulative effects of developments in Hudson and James bays. Some of the hypotheses are more likely than others to prove true in their present form once they have been subjected to rigorous scientific scrutiny using field data or laboratory experimentation. Most of the hypotheses have been stated positively rather than as null hypotheses. This was done to prevent the possibility of their being interpreted, out of context, to mean that a particular change would have no statistically significant effect.

It was assumed that hydroelectric developments would normally involve: (a) the impoundment of rivers into reservoirs on the land, (b) the alteration of river flow between drainages, and (c) changes in the seasonality of runoff, with increased flow in winter and decreased flow in summer. All of the hypotheses are rooted in these assumptions. Participants emphasized repeatedly the importance of scale in assessing cumulative effects. The larger the scale of analysis, the more difficult it becomes to link causes and effects. In other words, the farther one moves geographically "downstream" of a dam, the greater is the difficulty of establishing which development or set of developments is responsible for an observed change in the environment. No attempt was made at the workshop to consider all of the possible combinations and interactions of the hypotheses, i.e. the synergistic and additive complications involving two or more individual impacts (Fig. 2, pathways 3 and 4).

Each hypothesis is followed by a short commentary based on the written submissions from the Regions, working-group reports, and plenary discussions. The commentaries provide an indication of the importance and degree of certainty attributed to the hypotheses by workshop participants. Although not always stated explicitly, the importance of a given hypothesis was usually measured in terms of its implications for some aspect of biological productivity. Some of the commentaries point out areas of open disagreement or lack of consensus among participants.

PHYSICS

Although modelling has suggested that altered freshwater flows will affect mixing rates, water and ice-cover properties, and circulation in Hudson and James bays, actual changes are difficult to verify with field measurements because of the large natural interannual variations present in the system and because of the confounding effects of extrinsic factors such as global climate change and natural long-term cycles.

Hypothesis A1.

In summer, decreased freshwater flow into the bays will:

a) decrease stratification, increase vertical mixing, and increase nutrient inflows to the surface layer (euphotic zone);
b) have only local effects on circulation since buoyancy-driven flow in summer in Hudson Bay is small relative to wind-driven circulation;
c) cause a delay in ice break-up offshore and alter ice-cover properties in nearshore areas (landfast ice).

Hypothesis A2.

In winter, increased freshwater flow into the bays will:

a) increase stratification, decrease vertical mixing, and decrease nutrient inflows to the surface layer (euphotic zone);
b) increase density-driven circulation in general and, in combination with changes in discharge location, lead to overlap (merging) of adjacent river plumes;
c) cause earlier and thicker ice formation;
d) change the timing of freshwater outflow from Hudson Bay into Hudson Strait.

Commentary:

The changes in stratification, vertical mixing, and nutrient flux predicted by Hypotheses A1(a) and A2(a) were considered important at least on a local scale (plume areas). Participants were less certain of the regional importance of these changes. It was felt that the direction of change could be accurately predicted with reasonable certainty, but the magnitude and areal extent of the hypothesized effects would be much less certain.

Hypothesis A1(b) was considered critically important from the point of view of overall circulation in Hudson Bay. If, as is generally assumed, wind is the principal factor driving circulation during summer, then changes in freshwater flow may have little impact on the summer circulation in Hudson Bay.

Hypothesis A1(c) was interpreted to mean that the total period of ice coverage in Hudson and James bays would be lengthened as a result of hydroelectric developments, and it was recognized that such a change could have a critical influence on biological processes. Although all participants agreed on the likelihood that break-up would be delayed offshore, there was less agreement on questions of how the changes in freshwater flow would affect ice thickness near shore. Saucier suggested that the winter increase in stratification (Hypothesis A2(a)) would lead to reduced vertical heat flux and thus increase ice thickness offshore. Prinsenberg noted that Hudson Bay ice dynamics are on a 6- or 12-year cycle driven principally by atmospheric and climatic factors. These factors complicate and confound models of ice dynamics that relate ice properties to local or regional factors such as rate, timing, and location of freshwater flow.

The overlap, or merging, of freshwater plumes predicted in Hypothesis A2(b), as a consequence of increased freshwater outflow in winter, was regarded as important because it would change the density-driven circulation in the Hudson/James Bay system. It would also affect organisms that use plumes as markers for migration. Participants agreed that present knowledge is probably sufficient to confirm that this hypothesis is true.

Hypothesis A2(c) generated some controversy but was not adequately discussed at the workshop. Prinsenberg argued that in spite of its intuitive appeal, the hypothesis would be very difficult to test because of the complexity of atmospheric forces that trigger and sustain the process of ice formation and because of the large interannual variability of these atmospheric forces.

Participants attributed only slight importance to Hypothesis A2(d) and were unable to reach a consensus concerning the possible biological effects of such a change. It has been suggested that an artificial increase in winter discharge into James and Hudson bays would cause a decrease in surface salinity early the following winter in the Labrador Sea, thus inhibiting deep-water formation and reducing productivity on the Labrador shelf. This hypothesis relates to the suggestion by Sutcliffe et al. (1983) that seasonal salinity changes off Newfoundland correspond with the seasonal runoff cycle in Hudson and James bays. However, Drinkwater referred to recently published work (Myers et al. 1990) and new data indicating that seasonal salinity changes off Newfoundland are influenced mainly by the melting of sea ice along the Labrador coast.

INORGANIC NUTRIENT, ORGANIC CARBON, AND SUSPENDED MATTER FLUXES

Rivers are important sources of soluble and particulate carbon to the food chain in estuaries and nearshore marine habitats. All participants agreed that altered freshwater discharge into Hudson and James bays would affect the flux of nutrients and suspended matter (including organic carbon) by changing transport regimes.

Hypothesis B1.

Vertical mixing, upwelling, and entrainment of marine waters near shore are important direct sources of inorganic nutrients to the euphotic zone, compared with the contribution of inorganic nutrients made by rivers.

Commentary:

This hypothesis was not considered particularly important on a regional scale. However, the contribution of inorganic nutrients from river effluent may be more important locally, in the shallow waters of James Bay, than it is in Hudson Bay proper. Participants acknowledged that the contribution of inorganic nutrients by rivers had been little studied, at least in the Hudson/James Bay system.

Hypothesis B2.

Changing the timing and location of freshwater inputs will

(a) alter the seasonal pattern and magnitude of vertical mixing locally and
(b) indirectly influence the timing, strength, and areal distribution of inorganic nutrient inputs into surface waters by affecting vertical mixing processes.

Commentary:

This two-part hypothesis was judged to be of considerable importance, although a scale factor needs to be applied. Locally, the effects could be critically important, but on a regional scale they could be less consequential. The group agreed that the knowledge base for evaluating this hypothesis was poor.

Hypothesis B3.

Impoundment of terrestrial drainage will reduce the amount of biologically available organic carbon supplied by rivers to estuarine and nearshore marine food webs, which will be altered as a result.

Commentary:

Although the amount of organic carbon supplied to estuaries may increase during the early stages of reservoir formation, in the longer term this hypothesis is almost certainly true. Reservoirs act as sinks or traps for organic carbon. Once again, scale is relevant. The effect is likely to be critical locally but may be much less significant on a wider geographic scale. Relatively little research has been done to address this hypothesis.

Hypothesis B4.

There is a transient increase in (inorganic and organic) nutrient concentrations downstream of dams and in estuaries immediately after impoundment.

Commentary:

This hypothesis refers to the "trophic surge" that typically occurs for several years following the creation of a reservoir. It was judged to be important and reasonably well studied.

Hypothesis B5.

Impoundment of terrestrial drainage will reduce sedimentation and thus alter conditions in the estuary.

Commentary:

Just as too much sediment deposition upstream of a dam creates problems of reservoir management, the lessening of sediment deposition downstream is likely to change the bathymetry and configuration of the estuary. This hypothesis was not explicitly discussed at the workshop, but in a Regional submission reference was made to major bathymetric changes in the Churchill River estuary following the diversion of 85% of the Churchill's flow. Many parts of Hudson and James bays lack good bathymetric measurements, and this will impair pre- and post-development comparisons.

Species that depend on specific estuarine conditions for critical physiological processes (e.g. beluga moulting) may be affected, negatively or positively, as this habitat becomes altered. The characteristics that make an estuary suitable for summer occupation by belugas have been studied to some extent, but more research is needed. The dependence of species other than the beluga on pristine estuarine conditions has not been investigated. Reduced turbidity in estuaries downstream of river impoundments could result in increased primary and benthic productivity because of increased light penetration in the water column.

MERCURY AND OTHER CONTAMINANTS

It is well established from experiences with other hydroelectric projects, that changing the natural storage and flow in river drainage systems alters the flux of contaminants, particularly mercury. Concerns about mercury contamination will alter resource use. It is reasonable to expect a major reduction in the availability of edible fish in reservoir areas and downstream of dams due to mercury contamination. Also, increased mercury burdens in marine mammals in coastal areas and far downstream of dams may affect the suitability of these animals for human consumption.

Improved access and cheap power resulting from hydroelectric development may attract secondary industries or activities (e.g. pulp mills, aluminum plants, sewage disposal) that will release additional contaminants into the local and regional environment.

Hypothesis C1

The creation of a reservoir will increase levels of methyl- and other forms of mercury in biota in the estuary, particularly in anadromous fish and marine mammals.

Commentary:

This hypothesis was thought to be true, and workshop participants considered it to be critically important, particularly because of the implications for human health. Lockhart expressed concern that large mercury burdens could compromise the health and fitness of the fish and marine mammals as well as the humans who consume them (see Hypothesis C3, below). It was agreed that the problem of mercury mobilization and contamination has been reasonably well documented in freshwater areas, but it requires further documentation in estuarine and coastal marine systems downstream of reservoirs.

Hypothesis C2

The atmospherically-derived input of mercury to an estuary is as important as the reservoir-derived input.

Commentary:

Participants were uncertain whether this hypothesis is true but agreed that it is important. The knowledge base for evaluating the hypothesis is poor. Core profiles analyzed by Lockhart suggest major increases in mercury inputs to northern freshwater environments during the current century as a result of aerial fallout. Any increase in mercury contamination due to hydroelectric development needs to be interpreted as adding to already-elevated levels.

Hypothesis C3

Increased body burdens of mercury and other contaminants can affect the health of fish and marine mammals.

Commentary:

This hypothesis was not discussed explicitly during the workshop. Although it is potentially important, the hypothesis cannot be evaluated, or made more specific, by reference to available information. Lockhart noted that mercury has an affinity for certain proteins and that it could have deleterious effects on organ systems or physiological processes of fish and marine mammals.

Hypothesis C4

Reservoirs will not have significant effects, synergistic or otherwise, on organochlorine, PAH, heavy metal (excluding mercury), or acid rain contamination.

Commentary:

This hypothesis is unproven but workshop participants did not attribute a high level of importance to it. Direct effects of increased contamination due to hydroelectric developments seem unlikely, but subtle effects may result if, for any reason related to the developments, animals have reduced body fat in which to store these compounds. There is a need for better information on other metals besides mercury, such as selenium, in the Hudson/James Bay environment.

Hypothesis C5

Reservoirs will increase production of carbon dioxide and methane.

Commentary:

The group deferred to Bodaly on this subject. His view was that although the hypothesis is likely true, the magnitude of "greenhouse gas" production by reservoirs is uncertain. Within the next three years, with the completion of ongoing experimental work, it should be possible to make conclusive statements about the magnitude of carbon dioxide and methane production in reservoirs, both in absolute terms and in relation to other methods of producing equivalent energy (e.g. fossil-fuel burning). The importance of this hypothesis was judged to be slight in terms of the regional aquatic environment.

BIOLOGICAL RESOURCES

Based on what has been observed in previously completed hydroelectric projects, it can be stated with certainty that alteration of flow will affect the species composition and production of fish in freshwater habitats. Changes to habitat, in part because of their longevity, tend to have cumulative effects. Altered freshwater flows will cause changes at a variety of scales, from local, site-specific effects in rivers and estuaries, to generic, cumulative effects throughout James and Hudson bays. The processes involved are highly scale-dependent.

The lack of basic information on the presence and abundance of species throughout Hudson and James bays was noted repeatedly during the workshop. Ecological processes and relations are difficult to model even when ample information is available. Without a more detailed biotic inventory than presently exists, models for Hudson and James bays will remain rudimentary and unsatisfactory.

Hypothesis D1

There will be negative downstream impacts on anadromous and river-dwelling fish species and their migration habits caused, for example, by changes in flow, siltation, and obstructions.

Commentary:

Participants attributed critical importance and a high degree of certainty to this hypothesis. While it was recognized that the populations of some fishes, such as suckers, perches, and pikes, will likely increase because of the expanded lacustrine habitat provided by reservoirs, those species adapted to the conditions found in unimpeded rivers will suffer. Atlantic salmon, coregonids, and lake sturgeons are believed to be particularly at risk. It was felt that the knowledge base is adequate for establishing that this hypothesis is true.

Hypothesis D2

A reduction in flow of the Nastapoka River drainage will have an adverse impact on the Hudson Bay population of Atlantic salmon by reducing the amount of suitable habitat available.

Commentary:

Some uncertainty was expressed concerning the intentions of Hydro-Québec and whether the Nastapoka drainage would in fact be affected by the Great Whale project. On the assumption that there would be a 15% flow reduction in the Nastapoka River, the group considered this hypothesis important. The knowledge base was considered adequate for supporting the hypothesis. Apart from the direct impact on salmon due to habitat loss, reduced flow in the Nastapoka estuary could benefit other salmonids such as brook trout that compete with the small population of Atlantic salmon for food and space.

Hypothesis D3

There will be a negative impact on freshwater harbour seals in impounded watersheds due to increased accessibility for hunters and to habitat reduction.

Commentary:

The same uncertainty about Hydro-Québec's plans, as noted for Hypothesis D2, applies here. Very little is known about the ecology and behaviour of the freshwater harbour seals. More research is necessary to develop specific hypotheses related to the likely impact of hydroelectric developments. The significance of this impact will be increased if the freshwater harbour seal of the Ungava Peninsula proves to be a distinct, and endangered, subspecies.

Hypothesis D4

Flow alteration will modify salinity and temperature regimes in estuaries, which will affect the distribution and survival of fish (including larval, juvenile, and adult stages) and marine mammals.

Commentary:

This hypothesis was believed to be true and was ranked as critically important. However, salinity and temperature sensitivities of the various life stages of estuarine fish and marine mammal species are poorly known.

Hypothesis D5

Changes in ice characteristics and the timing of break-up will alter the use of the affected area by marine mammals and consequently modify the harvesting opportunities for humans.

Commentary:

This hypothesis refers principally to ringed and bearded seals which are hunted, mainly by the Inuit, on or near sea ice. Ringed seals rely on stable ice for pupping and moulting in the spring, so changes in the ice regime are likely to have direct effects on their survival and distribution (as well as on the hunting success of polar bears). The impacts on traditional timing, locations, and methods of Inuit hunting could be substantial, but such potential impacts are difficult to predict with available information. It was also recognized that the use of estuaries by belugas could be affected by any change in the nearshore ice regime. Participants agreed that this hypothesis was critically important and that the knowledge base for it was inadequate.

Hypothesis D6

Altered freshwater flow will cause changes in the distribution and quality of benthic macrophytes and their associated fauna.

Commentary:

This hypothesis was thought to be true, but little information was available with which to evaluate it or make it more specific. The group agreed on the critical importance of the hypothesis.

Hypothesis D7

In the area affected by the plume, altered flow rates will affect the balance between ice algal and planktonic production and its transfer to zooplankton.

Commentary:

This hypothesis generated much discussion. The net effect on production could be positive or negative, depending on the location and season in question. It was agreed that the hypothesis is important and that the knowledge base for evaluating it is good. The relative importance of ice algae and phytoplankton to overall productivity in the Hudson Bay ecosystem has not been assessed, but the contribution of ice algae could range between 10-50%. Ice algal production and the timing of ice breakup, which influences the start of primary production in the water column, are critically important to grazers such as sympagic and pelagic invertebrates, which are the principal source of food for larval fish.

Hypothesis D8

Changes in salinity patterns will induce changes in the use of coastal areas by fish and marine mammals (the latter probably mainly by virtue of their trophic relationship to migratory fish).

Commentary:

The group considered it likely that fish distribution would be strongly affected by changes in salinity. Some of these effects may be indirect, resulting, for example, from salinity-caused changes in vegetation. Others may be direct due to physiological requirements of the fish themselves. Piscivores would be affected indirectly to the extent that they come to coastal areas in search of prey. There may also be some direct effects on marine mammals, e.g. if belugas derive a physiological benefit of some sort from the relative freshness of water in estuaries.

CONCLUSIONS

Because relatively little research has been done on many important aspects of the Hudson/James Bay ecosystem, the hypotheses generated by the workshop cannot be considered exhaustive nor were the hypotheses exhaustively considered. Unanticipated impacts are likely to be revealed as more research effort is applied. Detailed information is lacking on such basic features of the system as its bathymetry, species composition and abundance, nutrient dynamics, and habitat types. Although studies of some freshwater and anadromous fishes have been done, more such work is needed. The pelagic fish communities (e.g. capelin and arctic cod) which are important to the food base of large vertebrates (e.g. cetaceans, pinnipeds, and indirectly polar bears) have not been studied in this region. Nor have all the populations of marine mammals. In particular, the abundance and distribution of seals and walruses are uncertain.

There is a critical and immediate need for better information on the existing biological resources in Hudson and James bays and on the processes that determine their composition and abundance. Changes caused by development can only be measured if an adequate baseline of pre-development data is available. Exploited species present special problems because their status has been altered by harvesting activities; the effects of environmental change are thus experienced by populations that may already be under stress. Populations of marine mammals and fish should be assessed and harvests monitored. Biological sampling is an important aspect of population assessment and harvest monitoring.

Estuarine, coastal, and marine habitats need to be described and quantified. They should also be classified according to the types of resources that they sustain. Changes in habitat could have ramifications at many trophic levels. While some effects, such as the loss of suitable fast-ice pupping habitat for ringed seals (Hypothesis D5), would be obvious, others, such as the competitive advantage gained by brook trout over Atlantic salmon in the Nastapoka River due to reduced flow in the estuary (Hypothesis D2), would be more subtle. The cumulative reduction of pristine estuarine habitats by successive impoundment projects is an example of Pathway 1 in Figure 2. It cannot be assumed that organisms displaced from one area of altered habitat will simply shift to another area. The effects of habitat loss may be compounded if the animals are at the same time acquiring increased body burdens of mercury and other contaminants (Hypothesis C3) and experiencing a decrease in the availability of prey (e.g. Hypotheses D1, D4, and D8). This would be an example of Pathway 3 or 4 in Figure 2.

Several of the hypotheses developed at the workshop, such as those concerning the direction of physical changes due to modification of the timing and location of freshwater discharge, mercury contamination, and decreased productivity of anadromous fish populations, are supported by available data. A much-improved understanding is required of the dynamics of atmospheric transport of mercury, other metals, and organochlorines, particularly in the marine environment. Work will begin as early as this summer to investigate mercury accumulation in marine sediments.

Other hypotheses, such as those related to primary and secondary productivity in estuarine and marine environments, effects of development on isolated populations of harbour seals and Atlantic salmon, and the likely responses of marine mammals to altered conditions in estuaries, need more focussed research. Some of the necessary work has begun or is scheduled to begin soon. For example, progress towards a three-dimensional baroclinic circulation model of Hudson Bay in summer and winter, with runoff modifications and multiple locations of river outflows, is expected to be made next year. Understanding of currents in Hudson Bay and the western entrance to Hudson Strait should improve following completion of field work planned for this summer. Planned satellite telemetry of belugas in eastern and western Hudson Bay may improve understanding of these whales' activities, their dependence on estuaries, and stock identity. Problems such as identifying and measuring carbon sources and understanding the estuarine and nearshore food webs will be addressed in western Hudson Bay next year, and similar work should continue in eastern Hudson Bay.

As Hecky et al. (1984) stressed in their analysis of the environmental impact assessment process for the Southern Indian Lake impoundment in northern Manitoba, the process can be considered complete only after predicted impacts have been compared against realized consequences of the development. In their words:

> Predevelopment predictions alone are not adequate to protect the habitat or the resource users. Such predictions should be recognized as planning aids that require testing in the post development period to establish their veracity and complete the environmental assessment process (Hecky et al. 1984:731).

It is imperative that, in addition to assessing the potential cumulative effects of development beforehand, a firm commitment be made to post-development assessment. Cumulative effects are especially difficult to define and track, so the process of documenting them is necessarily long-term.

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The editors sincerely thank the workshop participants for making the workshop a success. Their submissions and comments, and particularly their enthusiasm and patience, were invaluable in the preparation of this report. We thank Geoff Holland for his suggestions and guidance. Our thanks go also to Susan Goulet who made things work.

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Note: References cited in this report were only intended to be representative of some recent work on the various subjects. Readers are advised to consult the forthcoming DFO manuscript report containing a more extensive bibliography, covering scientific investigations published since 1980.

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APPENDIX 1

LIST OF PARTICIPANTS

John Anderson
Science Branch
Northwest Atlantic Fisheries Centre
Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland
A1C 5X1

Telephone: (709) 772-2116
Fax: (709) 772-2156

Drew Bodaly
Fish Habitat Research
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-5218
Fax: (204) 984-2404

* Jim Bunch
Physical and Chemical Sciences
Fisheries and Oceans
200 Kent Street
12th Floor
Ottawa, Ontario
K1A 0E6

Telephone: (613) 990-7284
Fax: (613) 990-5510

Bill Doubleday
Science
Fisheries and Oceans
200 Kent Street
15th Floor
Ottawa, Ontario
K1A 0E6

Telephone: (613) 993-0753
Fax: (613) 990-2768

* Hugh Bain
Biological Sciences
Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

Telephone: (613) 990-0283
Fax: (613) 995-0807

Jim Bruce
Canadian Hydrographic Service
Fisheries and Oceans
615 Booth Street
Ottawa, Ontario
K1A 0E6

Telephone: (613) 996-9805
Fax: (613) 996-9053

Serge Demers
Océanographie biologique
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0521
Fax: (418) 775-0542

Ken Drinkwater
Physical and Chemical Sciences
Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S.
B2Y 4A2

Telephone: (902) 426-2650
Fax: (902) 426-2256

Daniel Gauthier
Division de l'Habitat du Poisson
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0826
Fax: (418) 775-0542

Michel Gilbert
Division de l'Habitat du Poisson
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0604
Fax: (418) 775-0542

Mike Hammill
Recherche sur les Pêches
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0580
Fax: (418) 775-0542

Beth Hiltz
Arctic Marine Mammal Ecology and Assessment Research
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-3884
Fax: (204) 984-2403

Sandra George
Fisheries and Habitat Management
Fisheries and Oceans
Bayfield Institute
867 Lakeshore Road
P.O. Box 5050
Burlington, Ontario
L7R 4A6

Telephone: (416) 336-4870
Fax: (416) 336-6437

Yves Gratton
Sciences physiques et des chimiques
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0641
Fax: (418) 775-0542

Gareth Harding
Habitat Ecology
Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S.
B2Y 4A2

Telephone: (902) 426-2692
Fax: (902) 426-7827

* Geoff Holland
Physical and Chemical Sciences
Fisheries and Oceans
200 Kent Street
11th Floor
Ottawa, Ontario
K1A 0E6

Telephone: (613) 990-0298
Fax: (613) 990-5510

* Christiane Hudon
Benthic Fisheries and Aquaculture
Fisheries and Oceans
Halifax Fisheries Laboratory
1707 Lower Water Street
Halifax, N.S.
B3J 2S7

Telephone: (902) 426-5379
Fax: (902) 426-2698

Pierre Larouche
Sciences physiques et chimiques
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0569
Fax: (418) 775-0542

Rob Macdonald
Ocean Chemistry
Fisheries and Oceans
Institute of Oceans Sciences
P.O. Box 6000
9860 West Saanich Road
Sidney, B.C.
V8L 4B2

Telephone: (604) 363-6409
Fax: (604) 363-6807

Serge Metikosh
Fisheries and Habitat Management
Fisheries and Oceans
Bayfield Institute
867 Lakeshore Road
P.O. Box 5050
Burlington, Ontario
L7R 4A6

Telephone: (416) 336-4637
Fax: (416) 336-4819

* Helen Joseph
Habitat Management and Sustainable Development
Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

Telephone: (613) 991-1283
Fax: (613) 993-7493

* Lyle Lockhart
Contaminants Research
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-7113
Fax: (204) 984-2403

* Greg McKinnon
Fisheries and Habitat Management
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-5220
Fax: (204) 984-2402

Rod Morin
Marine and Anadromous Fish Division
Fisheries and Oceans
Gulf Fisheries Centre
P.O. Box 5030
Moncton, N.B.
E1C 9B6

Telephone: (506) 851-2073
Fax: (506) 851-2387

Richard Nadeau
Gestion des pêches et de l'habitat
Pêches et des Océans
Gare Maritime Champlain
C.P. 15 500
901 Cap-Diamant
Québec, Québec
G1K 7Y7

Telephone: (418) 648-4510
Fax: (418) 648-4470

* Glen Packman
Habitat Management and Sustainable Development
Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

Telephone: (613) 990-0207
Fax: (613) 993-7493

* Jon Percy
Océanographie biologique
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0613
Fax: (418) 775-0542

* Simon Prinsenberg
Physical and Chemical Sciences
Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S.
B2Y 4A2

Telephone: (902) 426-3145
Fax: (902) 426-2256

Randall Reeves
Okapi Wildlife Associates
27 Chandler Lane
Hudson, Québec
J0P 1H0

Telephone: (514) 458-7383
Fax: (514) 458-7383

Pierre Richard
Fish and Marine Mammal Management
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-5130
Fax: (204) 984-2402

Jeffrey Runge
Océanographie biologique
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0676
Fax: (418) 775-0542

Francois-J. Saucier
Sciences physiques et chimiques
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0853
Fax: (418) 775-0542

Ross Tallman
Arctic Fish Ecology and Assessment
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-3362
Fax: (204) 984-2404

Alain Vezina
Habitat du poisson
Pêches et des Océans
Institut Maurice-Lamontagne
C.P. 1000
850, route de la Mer
Mont-Joli, Québec
G5H 3Z4

Telephone: (418) 775-0553
Fax: (418) 775-0542

Yvan Vigneault
Gestion des pêches et de l'habitat
Pêches et des Océans
Gare Maritime Champlain
C.P. 15 500
901 Cap Diamant
Québec, Québec
G1K 7Y7

Telephone: (418) 648-2508
Fax: (418) 648-4470

Rudolf Wagemann
Chemical Toxicology and Research
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-5207
Fax: (204) 984-2403

* Harold (Buster) Welch
Fish Habitat Research
Fisheries and Oceans
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

Telephone: (204) 983-5132
Fax: (204) 984-2404

Ken Yuen
Physical and Chemical Sciences
Fisheries and Oceans
200 Kent Street
12th Floor
Ottawa, Ontario
K1A 0E6

Telephone: (613) 990-0311
Fax: (613) 990-5510

* Member of the Steering Committee; other members were Louis Desilets and Gordon Walsh.

APPENDIX 2

WORKSHOP ON THE POTENTIAL CUMULATIVE EFFECTS OF DEVELOPMENT IN THE REGION OF HUDSON AND JAMES BAYS

Trillium Room
Relax Plaza Hotel
402 Queen Street, Ottawa
17-19 June, 1992

AGENDA

17 June

1930 Introduction and Welcome - Geoff Holland (Chair)

Opening remarks - Bill Doubleday

Workshop Overview - Glen Packman

Objectives and Rationale
Definition of Cumulative Effects
Expected Results - Geoff Holland

18 June

0900 Introduction To Physics (Trillium Room)

Presenters:
Greenhouse gases - Drew Bodaly
Circulation and mixing - Pierre Larouche
Ice regime - Simon Prinsenberg

0930 Breakout to two groups

Group I - Room 901
Chair - Ken Drinkwater
Rapporteur - Christiane Hudon

Group II - Room 1001
Chair - Yves Gratton
Rapporteur - Rod Morin

1130 Plenary Session on Physics

Trillium Room
Chair - Geoff Holland
Rapporteur - Randall Reeves

Reports from Groups
Discussion

1330 Introduction to Chemistry (Trillium Room)

Presenters:
Mercury in the environment
- Drew Bodaly
- Lyle Lockhart
- Rudy Wagemann
Sediments, nutrients/carbon - Rod Morin
Nearshore habitats - Christiane Hudon

1400 Breakout to two groups

Group I - Room 901
Chair - Rob Macdonald
Rapporteur - Jon Percy

Group II - Room 1001
Chair - Lyle Lockhart
Rapporteur - Jeff Runge

1600 Plenary Session on Chemistry

Trillium Room
Chair - Geoff Holland
Rapporteur - Randall Reeves

Report from Groups
Discussion

19 June

0800 Introduction to Biology (Trillium Room)

Presenters:
Freshwater fish quality and products - Drew Bodaly
Marine mammals - Mike Hammill
Endangered stocks or species
- Mike Hammill
- Rod Morin
Quality, production of marine species Hudson Bay
- Buster Welch
Quality and production of Hudson Strait/Labrador Sea
- Jon Percy
- Ken Drinkwater

0900 Breakout to two groups

Group I - Room 901
Chair - Christiane Hudon
Rapporteur - Rob Macdonald

Group II - Room 1001
Chair - Buster Welch
Rapporteur - Rudy Wagemann

1100 Plenary Session on Biology

Trillium Room
Chair - Geoff Holland
Rapporteur - Randall Reeves

Reports from Groups
Discussion

1300 General Plenary - Summation

Trillium Room
Chair - Geoff Holland
Rapporteur - Randall Reeves

1500 Conclusion and Close