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The Role of Hydropower in a Carbon-Constrained Energy Future for Canada

Briefing paper for the National Roundtable on the Environment and the Economy

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Executive Summary

Hydropower is the largest single source of electric power in Canada, with an installed capacity of about 64,000 MW, accounting for some 62% of Canada's annual electric generation. More than any other generating technology, the environmental impacts of hydropower vary enormously depending on the characteristics of the individual facility.

The fundamental characteristics of a hydro site depend on the river's topography and the seasonal flow pattern. Within these constraints, the developer has a great range of choices, all of which are inter-related and affect both the economics and the eventual environmental impacts of the facility. These choices will to a large extent determine the project's costs, the value of the power it generates and the extent of its environmental impacts.

It is important to realize that these design choices are suggested — but not dictated — by the physical and hydrological characteristics of site itself. Traditionally, hydro facilities are designed in order to optimize their economic and energy performance, with measures to mitigate their environmental impacts only added at a later stage. However, certain design choices create major — and largely unmitigable — environmental impacts.

The regime under which a hydro facility is operated can also substantially affect its environmental impacts, though perhaps to a lesser extent than design choices. The operating regime refers primarily to the question of flows — the volumes of water that are passed through the turbines or over the spillway, or that are released from diversion dikes. The temporal pattern of these releases, in combination with the temporal pattern of inflows (due to seasonal and meteorological variability) determine the variation of water levels in the reservoir and of flow rates downstream. As we have seen above, these water level and flow variations are very significant determinants of the facility's effects on a wide variety of ecosystem components.

Generally speaking, the greater the drawdown and the more its frequency and timing are out of sync with natural rhythms, the greater the ecological impacts on the reservoir and its surroundings. Downstream, impacts are related to flows below or above those provided by the natural regime, and to flow variations unconnected to natural rhythms. Defining a low-impact flow regime thus involves specifying not only minimum flows but also seasonal limits and ramp rates (the rate at which flows can be "ramped" up or down).

Many small hydro projects are run-of-the-river; their energy production thus varies with the stream's flow. Adding a reservoir to provide storage capacity changes the picture dramatically. Once there is storage capacity, production can be timed to correspond to periods of peak demand. Thus, even if the turbine is sized well below the river's natural peak flow, no water needs to be spilled (e.g., during the spring flood); it can be stored in the reservoir and turbined at a later time.

It should also be noted that, if other dams have been built (or are planned) upstream, the facility may obtain the benefits of flow regulation ("buffering" of flood and drought flows, shaping of flows to approximate demand shape) even if there is no storage capacity directly associated with it. If the facilities are part of an integrated complex, flows will be optimized taking both dams into account, even though the downstream facility is technically "run-of-the-river." A better term for this type of facility would be "run-of-the-reservoir," as its flows are determined not by nature but by the operations of the upstream dam.

If the run-of-the-river facility is built after the upstream storage dam, it is often thought of as a low-impact development, since it produces relatively few impacts beyond those of the original dam. It is probably more appropriate, however, to think of it as increasing the energy production of the original project and thereby diminishing its level of impacts per unit of energy. Unfortunately, while such ratios are standard practice in describing fossil fuel generation (e.g., grams of SO_2 or of CO_2 per kWh), they are practically impossible to calculate for hydropower. Many of the impacts of hydropower development can only be described qualitatively. Even when they can be described quantitatively, there exists no clearly understandable and scientifically legitimate common metric to which all the various types of impacts can be reduced.

Various measures have been developed and implemented to mitigate the environmental impacts of hydropower development, with varying degrees of success. Indeed, the effectiveness of these measures is often hard to assess, as post-construction monitoring often leaves much to be desired.

Despite the enormous technical potential for hydropower development in Canada, there are important issues that constrain the use of this resource to meet future electricity needs. These constraints include economic and infrastructure constraints as well as ecosystem, biodiversity and social and aboriginal impacts.

Ecosystem impacts are the direct consequence of modification of the flow regime, which represents perhaps the most important driving force in a river ecosystem. Dams alter the natural distribution and timing of streamflows and, as such, they also alter essential processes for river ecosystems, modifying sediment and nutrient regimes, water temperature and chemistry, both above and below the dam. These parameters are the basic building blocks of freshwater ecosystems and when these change, many species, habitats and functions that depend directly or indirectly on these forces decline or disappear.

The natural world is characterized not only by large numbers of living individuals and communities, but also by the *diversity* of those communities. That diversity consists both of species diversity and of genetic diversity within a species. Dams have the potential of affecting both types of diversity, depending of course of the scale on which the development occurs. According to an important Canadian study, the rate of extinctions for freshwater fauna in North America is 1,000 times higher than the background rate of extinction — five times higher than those for terrestrial fauna and three times higher than those for coastal marine mammals. While many other factors are at play, dams are probably responsible for a significant share of these impacts.

The social impacts of dams is the subject of a voluminous literature, consisting in large part of detailed and depressing case studies from around the world. For large-scale hydro projects, the critical social impacts are clearly displacement of populations and loss of subsistence resources, but loss of other resources is also very significant. In this regard, mercury contamination deserves special mention. Similar in many ways to the processes that generate greenhouse gases, flooding results in the stimulation of bacteria that methylate mercury that already present, making it bioavailable and leading to its concentration in piscivorous fish. Methylmercury (CH_3Hg, or MeHg) is highly toxic, and levels in certain species of fish typically remain at three to five times their background level for at least two decades. The only practical way to limit exposure is to discourage consumption of fish from affected reservoirs, a limitation with significant implications for fish-eating societies.

While hydropower is generally assumed to be a GHG-free energy source, reservoirs do emit both CO_2 and methane. It is remarkably difficult, however, to draw firm conclusions regarding the amounts of these emissions. This can be attributed on the one hand to the difficulty of the scientific challenge and the relatively few resources that have been devoted to addressing it, and on the other to the highly charged ideological space in which the debate has taken place.

All else being equal, projects with rapidly fluctuating water levels probably produce a higher proportion of methane — and thus higher total GHG emissions — than do those with stable water levels, though this has not been conclusively demonstrated. In sum, though knowledge of the factors influencing net GHG emissions for reservoirs is increasing, it is not possible at this time to predict with any degree of certainty the actual GHG emissions of an existing or planned reservoir.

For small and medium hydropower facilities, the social impacts are of a very different nature. Here, recreational and ecotourism issues are often cited, whether due to the loss of key rapids used for whitewater sports or to the artificialization of exceptional sites. This latter issue, indeed, is common to hydropower projects of all sizes. It is an unfortunate coincidence that, in a great number of cases, the sites with the greater energy generation potential are precisely those that are … the most beautiful. Whether characterized as loss of scenic resources or landscape fragmentation, these are issues that are addressed only partially and incompletely by economists and engineers, yet which are not far from the hearts and minds of ordinary people.

Whether viewed as a spiritual or an aesthetic issue, the fact remains that these are exceptional sites about which many people care deeply. While this factor generally plays a relatively small role in formal environmental assessment processes, it plays a large one in the political arena where most decisions about hydropower development are ultimately made.

Few questions arouse passions on both sides of the hydropower debate as does the simple question, "Is hydropower green?" Traditionally, the hydropower industry vigorously defended the notion that all hydropower is "clean, clean, clean." At the same time, a purist river protection view held that there is no such thing as a good dam.

Increasingly, however, voices from both sides of the divide are recognizing that there are indeed shades of gray, and that some dams are indeed better (and worse) than others. On the industry side, there is growing recognition that some dams cause considerable environmental harm, at times outweighing the benefits they create. And on the environmental side, there is recognition that, given the growing importance of climate change, a dam that is designed and managed so as to minimize its ecological footprint may be less bad than the alternatives.

How to tell the one from the other, and where to draw the lines? Alas, the devil is in the details and, given the multiple layers of complexity surrounding every aspect of hydropower, it should come as no surprise that there are no easy answers. The two main vehicles for favoring environmentally preferable generation choices in a market context are the voluntary green power market and the obligatory renewable portfolio standard. The role of hydropower in each of these mechanisms has been hotly debated in recent years.

Thusfar, our discussion has focussed on traditional hydropower, a technically and commercially mature technology. However, there is now considerable interest and development activity with regard to "dam-free" hydropower, usually referred to as free-flow hydropower or "instream energy generation technology." These technologies involve inserting turbines into flowing water, whether in a riverine, ocean current or tidal environment, in order to extract kinetic energy from the moving water without obstructing its flow. If the technical and economic challenges can be met, these technologies appear to offer an enormous energy potential with very limited environmental and social consequences.

A number of different turbine technologies are being explored for this purpose, including axial-flow rotor turbines, which resemble wind turbines, vertical-axis turbines, and helical turbines that can be installed either vertically or horizontally. Several demonstration projects are currently in operation, and there is every reason to believe that interest free-flow hydropower will continue to grow in coming years.

Due to the extraordinary variety of sites, designs and operating regimes, hydropower defies simple characterization. There is thus no easy answer to the question, "What should be hydropower's role in a carbon-constrained energy future for Canada?"

It is clear, however, that, for the vast majority of hydropower projects, low-carbon energy comes at a price, measured in the ecological and social disruption caused by flooding, alteration of flow regimes, artificialization of wilderness and of natural sites that are highly valued for their recreational, aesthetic and/or spiritual value.

It is thus difficult to generalize as to the role that new hydropower development should play in Canada's energy future. There is little doubt that, with the possible exception of free-flow hydropower technologies, which are not yet commercially mature, hydropower remains an option which imposes significant environmental and social costs in compensation for its GHG benefits. In this respect, it is in sharp contrast to options with substantial co-benefits, such as energy efficiency improvements or improved mass transit systems. Indeed, in many ways it resembles nuclear power, which also combines a very low GHG profile with significant environmental and social costs.

For all these reasons, public perceptions of hydropower remain fickle. More than ever, in this post-Kyoto era, hydropower's profile — renewable, GHG- and pollution-free power — is seductive. But as one gets closer to actual projects, polarization sets in between development and conservation interests, both powerful forces in 21st century Canada.

It is thus safe to predict that hydropower development will remain controversial, despite its substantial benefits in a carbon-constrained world.

1. Introduction

In considering energy paths for Canada in a carbon-constrained future, the potential interest in hydropower is unavoidable. Together with nuclear power, hydropower represents one of the only electric generating technologies that can be deployed with existing technology on a scale large enough to make a dramatic impact on future greenhouse gas (GHG) emissions.

At the same time, also like nuclear power, large-scale hydropower development brings with it significant environmental and social impacts which, while having nothing to do with climate change, have created and will in all likelihood continue to create a significant impediment to its unbridled expansion.

The purpose of this brief paper is to provide an overview of these issues, and to introduce the reader more generally to the complex world of hydropower. Indeed, while it is technologically relatively simple (falling water turns a turbine), in almost every other aspect, hydropower is far more complex than most other electric generating technologies. The reasons are simple. Unlike other technologies where the generating process takes place within controlled conditions (usually in a building), hydropower generation takes place in a natural setting, embedded in complex riverine ecosystems where the direct effects are felt over a wide area. Furthermore, precisely because the technology is so scalable, it can be and is applied in installations ranging from several kilowatts to several thousand megawatts. Given the enormous diversity of hydropower projects, how can we even begin to make order? Traditionally, hydro projects are categorized by size, and by whether or not they provide for storage.[1] In section 2, we will introduce the many types of hydropower installations, focussing on the choices of design and operating regime that contribute to determining their characteristics with respect to both energy production and environmental impacts.

In section 3, we will describe the various constraints that limit the future development of new hydropower resources, focussing in particular on their environmental and social impacts. these impacts are diverse and complex, reflecting the great diversity of hydropower designs and the complex natural settings in which they occur. We will also look at economic and other constraints.

[1] We will not address pumped storage here, as it is a means of providing peaking service, not of meeting energy needs.

Hydropower is considered a renewable resource, but on that differs in many ways from other renewables. This distinction is seen, for example, in the many studies and reports that make a category of "non-hydro renewables," and in the special treatment reserved for hydropower in many renewables portfolio standards and by certification agencies for the green power market. These issues are presented in section 4.

In section 5 we will look at the development prospects for new hydropower technologies designed to capture the energy of moving water without need for dams.

Finally, some concluding thoughts are presented in section 6.

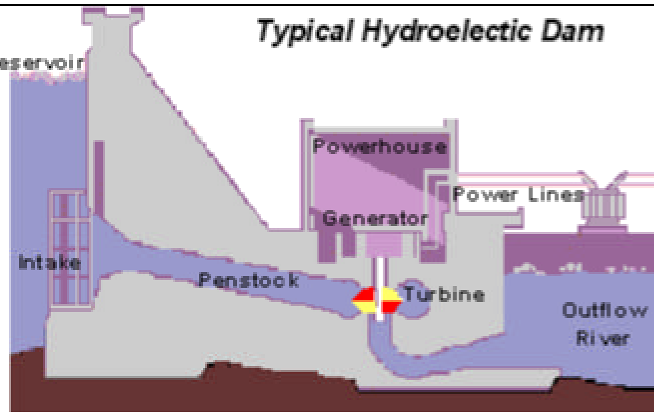
2. The many faces of hydropower

2.1. Basic concepts

Common to all hydropower developments is the principle that the kinetic energy of moving water, passing through a turbine, is used to turn a shaft which drives a generator or alternator to produce electricity. The laws of physics prescribe that the amount of electrical power produced at any given moment will be proportional to the volume and the speed of the moving water. If, as in the vast majority of hydropower projects, the water is falling when it hits the turbine, the speed is in turn a function of the height the water falls ("head"). Thus, water flow (volume per unit of time) and head are the primary determinants of the power output of a hydro facility.

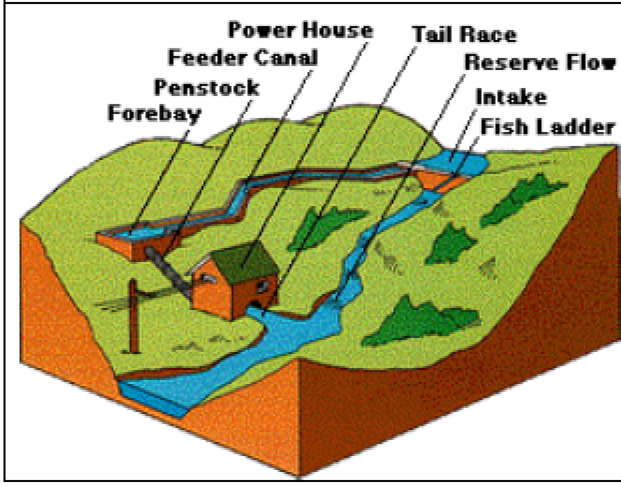
A typical hydro powerhouse is portrayed in the following image. When the intake gates are opened, water flows out from the reservoir, through the penstock, turning the turbines. The turbines in turn spin the intake shaft of the generator, producing electricity.

Figure 1



In this image, the head results entirely from the height of the dam. In many designs, however, landscape features are used to increase the head available. One such arrangement is shown in Figure 2. Here, the head results from the difference in elevation between the forebay and the powerhouse.

Figure 2



Note that, if all the stream's water were to be diverted from the intake to the forebay, the segment between the intake and the tailrace (the "bypassed reach") would be left dry. The term "reserved flow" designates the amount of water allowed to flow in the bypassed reach for environmental or other purposes — water which is thus not available for power generation. The length of the bypassed reach and the amount of reserved flow allotted to it are important determinants of a project's impacts (see section 3.2, below).

In other, more complex schemes, the twists and turns in a river's course can be turned to the developer's advantage. For example, in Canadian Hydro's 30 MW Pingston Creek project in British Columbia, water flows through a 4-km tunnel under a ridge to create a 590 meter head.[2] In so doing, the tunnel bypasses some 15 km of the Pingston Creek's streambed, with a reserved flow of just 0.3 m^3/s.

A variety of approaches to hydropower which do not require dams are discussed in section 5, below.

2.2. Potential

Hydropower is the largest single source of electric power in Canada, with an installed capacity of about 64,000 MW, accounting for some 62% of the country's annual electric generation. The vast majority of this installed capacity is found in Quebec, British Columbia, Newfoundland and Labrador, and Ontario, as shown in the following table.[3]

	installed capacity (MW)	annual generation (TWh)
Quebec	31,346	170.5
B.C.	10,207	44.5
Ontario	8,150	32.4
Newfoundland/Labrador	6,367	37.8
Manitoba	4,999	18.5

Most of this installed capacity consists of large hydro. While half of the 475 hydropower plants in Canada have an installed capacity of less than 10 MW, they together account for only 1% of the total generation.

Natural Resources Canada has estimated Canada's undeveloped hydropower potential at more than 182,000 MW, of which 34,000 MW are considered "promising for further development."[4] However,

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[2] J. Ross Keating and John D. Keating, "Developing Private Hydro: The Story of Pingston Creek," *Hydro Review*, November 2003, pp. 2-4.

[3] Manitoba Wildlands, *The State of Hydro,* November 2004, p. 5; data from diverse sources.

[4] http://www2.nrcan.gc.ca/es/ener2000/online/html/chap3f_e.cfm. The Canadian Hydropower Association sets the potential at 118,000 MW.

there are many important constraints that make the development of most of this potential unlikely. These constraints are briefly described in section 3, below.

For small hydro, the situation is rather different. Natural Resources Canada has identified some 5500 potential sites with a combined technical potential of around 11,000 MW, but it considers only 15% of this potential (1560 MW) to be economically feasible at this time. However, as with large hydro, the potential varies greatly depending on assumptions as to what is economic and feasible.

2.3. Design issues

More than any other generating technology, the environmental impacts of hydropower vary enormously depending on the characteristics of the individual facility.

The fundamental characteristics of a hydro site depend on the river's topography and the seasonal flow pattern. Within these constraints, the developer has a great range of choices, all of which are inter-related and affect both the economics and the eventual environmental impacts of the facility. The choices to be made include:

- how to design the facility in order to maximize the head (the vertical distance the water can be made to fall before hitting the turbines),
- whether to impound a reservoir above the dam, in order to shift flows from one time period to another and to increase the head, and if so, of what size (storage capacity),
- the size and number of turbines to install (installed capacity),
- whether to direct other watercourses into the impoundment (or into the dammed river farther upstream), in order to increase flows and thus annual energy production,
- whether the dam is to be part of an integrated hydro complex involving several dams on the same river system,
- whether the turbined water is to be returned to the streambed immediately below the dam, or whether to increase the head by guiding it further downstream via a long penstock, bypassing part of the streambed (the "bypassed reach"),
- the temporal pattern of flows through the turbines, and

- the amount of water, if any, that will be allowed to flow down the bypassed reach (or over the diversion dikes upstream) in order to mitigate environmental harm.

These choices made by the developer will to a large extent determine the project's costs, the value of the power it generates and the extent of its environmental impacts.

2.3.1. Run-of-the-river and storage hydro

The question of whether or not to create an impoundment is perhaps the most important choice facing a developer. If there is no impoundment at all, and hence no storage capacity, every litre of water must be turbined (or spilled) as it arrives from the catchment area. Such a facility is referred to as "run-of-the-river."[5] Such a facility will cost less to develop than a storage facility, but its power benefits will also be lower (limited ability to produce during periods of peak demand; need to spill during flood periods).

For run-of-the-river facilities, the choice of installed capacity (turbine size and number) determines how much water can be turbined at any given moment and, by extension, how much of the river's annual flow will be available for electricity generation. Most free-flowing rivers display significant seasonal flow variation. The larger the installed capacity, the greater the percentage of the peak flow that will be usable for generation.

Greater installed capacity will thus provide more power during the high-flow periods and more energy over the course of the year. However, it means the facility will run below its full capacity much of the time, or even be unable to produce at all.[6] If the developer chooses instead to install smaller or fewer turbines, the project's power output will be much more constant, but water will be spilled whenever flows exceed their capacity. As turbines are among the most expensive elements of building a hydro station, developers pay great attention to optimizing installed capacity on an economic basis.

Many small hydro projects are run-of-the-river; their energy production thus varies with the stream's flow. Adding a reservoir to provide storage capacity changes the picture dramatically. Once there is

[5] This term is sometimes used — inappropriately — to describe facilities with limited storage capacity.

[6] Hydraulic turbines require a certain percentage of their maximum flow capacity to generate electricity.

storage capacity, production can be timed to correspond to periods of peak demand.[7] Thus, even if the turbine is sized well below the river's natural peak flow, no water needs to be spilled (e.g., during the spring flood); it can be stored in the reservoir and turbined at a later time.

Storage hydro can thus be designed to turbine the river's entire annual flow without spillage, except insofar as environmental flows are required. When these are meant to ensure minimum flows in the downstream environment, these flows limit the operator's flexibility; however, when they are designed to provide minimum flows in the bypassed reach or downstream of a diversion dike, they directly reduce total power generation. In either case, it is in the owner's economic interest to keep them to a minimum, to the extent allowed by regulators.[8]

It should also be noted that, if other dams have been built (or are planned) upstream, the facility may obtain the benefits of flow regulation ("buffering" of flood and drought flows, shaping of flows to approximate demand shape) even if there is no storage capacity directly associated with it. If the facilities are part of an integrated complex, flows will be optimized taking both dams into account, even though the downstream facility is technically "run-of-the-river." A better term for this type of facility would be "run-of-the-reservoir," as its flows are determined not by nature but by the operations of the upstream dam.

The following diagram shows simplified layouts for storage and run-of-river projects on a large river. Here, the first dam has a high head, created by the elevation of the water stored in the reservoir. Many large hydro facilities in Canada are designed in this way, including the Robert-Bourassa and Manic-5 dams, in Quebec, and the W.A.C. Bennett Dam on the Peace River in British Columbia.

The second dam is low head, and consequently produces much less power and energy for a given flow level. However, it creates little additional flooding and does not modified water flows, as does the storage project. Examples of this type of facility are the LG-1 dam on Hydro-Québec's La Grande system, which is regulated by the large Robert-Bourassa and Caniapiscau reservoirs upstream, and the projected Gull Island (Lower Churchill) project in Labrador.

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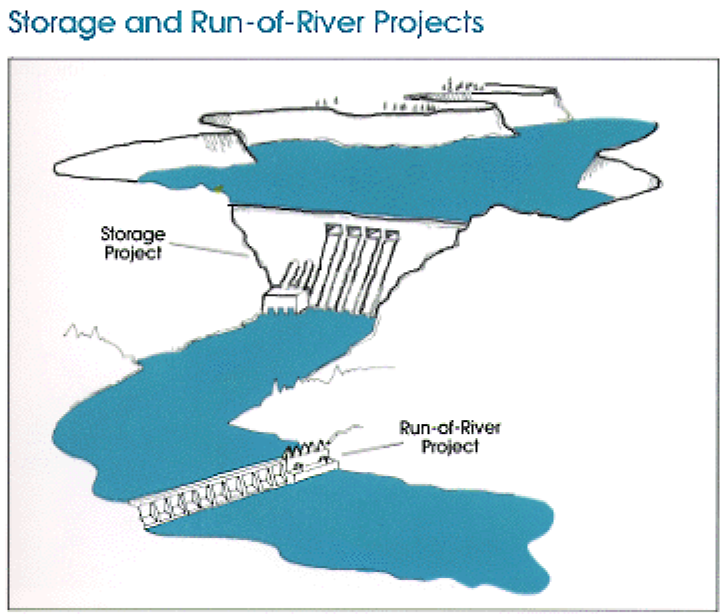
[7] In a monopoly context, this helps the utility to meet its obligation to provide service at all times. In a market context, it allows the generator to sell his output when prices are highest.

[8] There is great variation in these requirements from one jurisdiction to another.

Figure 3



If the run-of-the-river facility is built after the upstream storage dam, it is often thought of as a low-impact development, since it produces relatively few impacts beyond those of the original dam.[9] It is probably more appropriate, however, to think of it as increasing the energy production of the original project and thereby diminishing its level of impacts per unit of energy. Unfortunately, while such ratios are standard practice in describing fossil fuel generation (e.g., grams of SO_2 or of CO_2 per kWh), they are practically impossible to calculate for hydropower. As we shall see in the next section, many of the impacts of hydropower development can only be described qualitatively. And even when they can be described quantitatively, there exists no clearly understandable and scientifically legitimate common metric to which all the various types of impacts can be reduced.

[9] These impacts can still be substantial. LG-1 had a significant social impact due to the loss of the first rapids, important to the Cree community of Chisasibi located at the mouth of the river. In the case of the Lower Churchill, the new dam will require a major new transmission corridor, with ecological impacts probably greater than those of the dam itself.

2.3.2. Design choices

As we have seen, the developer's design choices can dramatically affect the environmental and social impacts of a hydro project for a given site. Among those design choices that lead to higher impacts are:

- **river diversions.** Unlike thermal power plants, the energy output of a hydro facility is limited by the amount of runoff in the drainage basin. Thus, increasing turbine size (installed capacity) does not increase total energy output, but only the instantaneous power output. Generally speaking, the only way to increase the energy output of an existing hydro facility, or to increase the energy potential of a facility being planned, is to divert water from an adjacent water basin. Thus, for example, the energy output of Quebec's La Grande system has been dramatically increased by the diversion of waters from the Eastmain River, and will be further increased if the waters of the Rupert River are diverted northward into the Eastmain basin.[10] The loss of flow on a permanent basis from the diverted river can irreversibly alter the downstream ecosystem, and the increased flow in the recipient river can also be ecologically disruptive.[11]

- **flooding.** All else being equal, there is little doubt that impacts increase with the territory flooded. However, all habitat is not equal, and detailed ecosystem studies are necessary in order to adequately assess the importance of the lost habitat. As for greenhouse gas emissions, they vary not only with the extent of the flooding, but also with the climatic region, the type of lands that are flooded and the operating regime. Methane emissions are highest in tropical areas; in northern regions, flooded peat bogs produce greater emissions than do forest soils. Shallow reservoirs and those with substantial drawdown zones generally produce greater emissions than do deep ones with stable banks.

- **bypassed reach.** Unless substantial environmental flows are provided for in the bypassed reach, the local ecological impacts may be quite drastic.[12] The larger significance of these impacts depend on the extent of the bypassed reach and on the importance of the lost habitat for the larger ecosystem. One of the most extreme examples was the Great Whale project in

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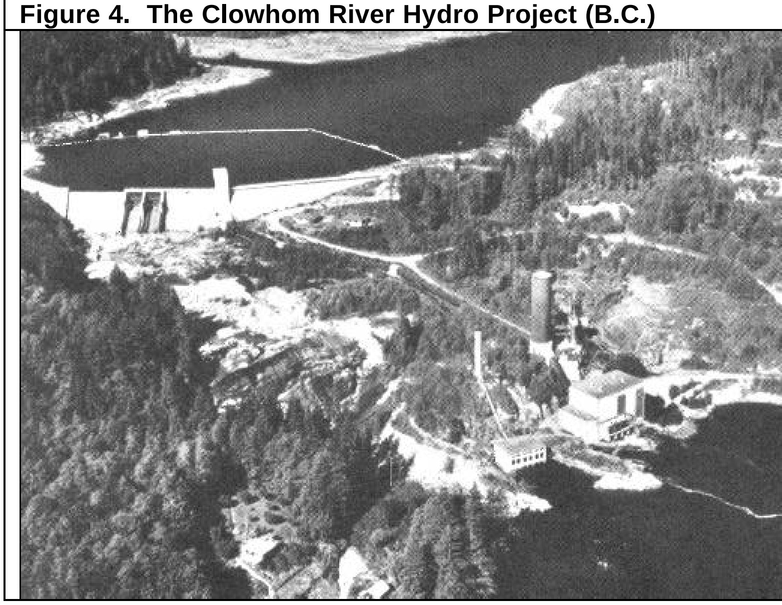
[10] This diversion is currently under environmental assessment.

[11] The lower Eastmain River lost 92% of its flows to the La Grande project, and average annual flows in the lower La Grande have doubled from pre-project levels, with winter flows some eight times greater than they were under natural conditions.

[12] Sophisticated flow management can go a long way toward mitigating these impacts. However, the reduction in energy production — and hence the increase in unit costs — can be substantial.

northern Quebec (proposed in the late 1980s and withdrawn in 1994), which would have bypassed the last 40 km of the Great Whale River. The Clowhom project in British Columbia, pictured in Figure 4, includes a bypassed reach which is relatively short (350 metres), but biologically quite significant, in that it cuts off the Clowhom River from the Sechelt Inlet, which empties into the Georgia Straight separating Vancouver Island from the mainland.

Figure 4. The Clowhom River Hydro Project (B.C.)



- **chain of reservoirs.** A great deal of effort goes into the design of large hydro facilities to maximize power production and minimize unit costs. In many river systems, this has led to the development of chains of reservoirs in which the flooding from one dam reaches or almost reaches the outflow from the next dam upstream. The engineering benefits of such a design are obvious, as it allows the full head of the river, from headwaters to discharge, to be utilized for power production purposes. At the same time, this design approach also tends to maximize environmental impacts, as no reach of the river is left untouched. With most or all of the river converted to flatwater, no habitat remains for species that require rapids, riffles or pools for all or part of their lifecycle;

- **high dams.** For rivers that are home to migratory species of fish, high dams often pose impossible obstacles. Enormous quantities of money have been spent in the last 10 to 20 years to mitigate these impacts, but with only limited success. These issues are particularly acute in B.C. and in the U.S. Northwest, where the Bonneville Power Authority's federally owned power system has had dramatic impacts on salmon stocks. These issues are the subject of ongoing litigation, with many parties seeking the removal of four dams on the Snake River, a tributary of the Columbia River.

It is important to realize that these design choices are suggested — but not dictated — by the physical and hydrological characteristics of site itself. Traditionally, hydro facilities are designed in order to optimize their economic and energy performance, with measures to mitigate their environmental impacts only added at a later stage. However, certain design choices create major — and largely unmitigable — environmental impacts.

It is also useful to distinguish impacts that are caused by the facility's construction (which are immutable once the facility is built), from those that result from its operations. These latter impacts can be altered or mitigated by changes in the project's operating regime.

2.3.3. Operating regime

The regime under which a hydro facility is operated can also substantially affect its environmental impacts, though perhaps to a lesser extent than design choices. The operating regime refers primarily to the question of flows — the volumes of water that are passed through the turbines or over the spillway, or that are released from diversion dikes. The temporal pattern of these releases, in combination with the temporal pattern of inflows (due to seasonal and meteorological variability) determine the variation of water levels in the reservoir and of flow rates downstream. As we have seen above, these water level and flow variations are very significant determinants of the facility's effects on a wide variety of ecosystem components.

Generally speaking, the greater the drawdown and the more its frequency and timing are out of sync with natural rhythms, the greater the ecological impacts on the reservoir and its surroundings. Downstream, impacts are related to flows below or above those provided by the natural regime, and to flow variations unconnected to natural rhythms.

Defining a low-impact flow regime thus involves specifying not only minimum flows but also seasonal limits and ramp rates (the rate at which flows can be "ramped" up or down). More sophisticated flow regimes modulate the required flows depending on whether it is a wet or dry year, and provide for seasonal flood flows as well.

While project siting and design are set once the facility is built, the operating regime can be changed at any time, making it the most important way to reduce the impacts of an existing project. In the U.S., most hydropower facilities are licensed by FERC. Because the current licensing standards are so much stricter than they were 50 years ago, relicensing hearings before FERC have become the prime forum for addressing the environmental impacts of existing hydro facilities. This has led to increasingly more restrictive flow regimes, as mentioned above.

It is difficult to generalize as to Canadian practice in this regard, as each province is largely responsible for its own licensing procedures.[13] Many projects have been approved, even in recent years, without any flow requirements at all. In other cases, simple minimum flows have been established, but without seasonal limits or ramp rates, much less the sophisticated features that have emerged from FERC relicensing proceedings over the past decade.

In Canada, water licences generally are not time limited, so there is normally no occasion to review conditions established when the dam was first authorized. In 1996, however, British Columbia instituted a process designed to do just that, in order to ensure that environmental impacts are not excessive.[14]

The Water Use Planning (WUP) process was first announced by the BC government in 1996 in order "to revisit provincial water management in light of changing public values and environmental needs." WUPs are intended to specify the operating conditions for the water licences issued by the provincial government, and it is anticipated that a WUP will be developed for every significant hydro plant in BC – both new and existing — as well as for other water projects. To date, however, BC Hydro is the only dam operator to undertake WUPs.

Responsibility for developing the WUP rests with the project owner, in consultation with regulatory agencies and NGOs. Technical support is provided by the BC government, to explore the environmental and economic implications of a range of alternate operating regimes developed by the consultative group.

The draft WUP, prepared by the project owner, is then reviewed by the water Comptroller, who can conduct an inquiry or hold require further hearings, if there is no consensus. Once authorized by the Comptroller, the WUP is also subject to review by the federal fisheries department with respect to

[13] Projects across Canada are subject to the federal *Fisheries Act* but, due in part to administrative agreements with several provinces, there are important differences between regions in how the Act is applied.

[14] A similar process, known as Water Management Planning, has also been initiated in Ontario.

flows. It must include measures for monitoring compliance and for subsequent review, which may take the form of adaptive management.

To date, WUPs have been completed at 20 BC Hydro facilities, and three others are currently underway. For BC Hydro, the benefits of WUPs are to obtain "public consent to operate" and operational certainty. Local NGOs have been very much involved in the processes to date, and working relationships have been generally productive and harmonious.

The results of this process have been impressive. In many of the dams studied, operations modifications were identified that resulted in significant ecological improvements with little or no economic losses for the operator — and sometimes even with economic gains. The annual cost of the WUP program in terms of lost revenue for B.C. Hydro was estimated in 2003 at about $3.6 million per year, reflecting operational changes at eight facilities.[15] A notional cap of $50 million has been established for such modifications.

2.3.4. Impact mitigation

Various measures have been developed and implemented to mitigate the environmental impacts of hydropower development, with varying degrees of success. Indeed, the effectiveness of these measures is often hard to assess, as post-construction monitoring often leaves much to be desired.

More and more, however, the limitations of mitigation methods are being recognized. Thus, many of the most effective so-called mitigation measures are in reality lower-impact choices with regard to the siting, design or operating regime of the planned hydropower facility.

This conclusion emerges from a report issued by the IEA Hydropower Agreement,[16] which found that the most effective measures to mitigate the impacts of reservoir impoundment are to avoid them in the first place — by minimizing the areas to be flooded (design) and by reducing the water residence time (operating regime). Similarly, the most effective steps identified by the report to avoid loss of biodiversity are also primarily based on siting and design, together with increased protection for areas not affected by the dam.

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15 Government of British Columbia, *Financing Water Use Plans,* http://www.bchydro.com/wup/financing.pdf.

16 International Energy Agency Hydropower Agreement, *Hydropower and the Environment: Present Context and Guidelines for Future Action, Vol. I: Main Report* (May 2000), p. 88. This widely quoted report has often been mistakenly attributed to the IEA itself.

In addition to impact avoidance, mitigation measures include the use of weirs, fish ladders, fish capture and transportation, planting and seeding of banks, and so on. Space does not permit a full review of the effectiveness of these types of measures. However, the net benefits of mitigation efforts tend to be small compared to the environmental impacts they seek to mitigate, and the costs of more effective measures are often prohibitive.

These same conclusions were reached by the World Commission on Dams (WCD), which found that "efforts to avoid or minimise impacts through choice of alternative projects or alternative designs were more successful than efforts to manage the impacts once they were built into the design of the dam." In its survey, the WCD found that only 20% of mitigation measures worked effectively, and that 40% did not mitigate the impact at all.[17]

The World Commission on Dams

Born out of a 1997 workshop jointly sponsored by the World Bank and the International Union for the Conservation of Nature, the 11-member World Commission on Dams was mandated to conduct a rigorous and independent review of costs and benefits of large dams and to propose practical guidelines for future decision-making. Its 300-page report, released in November 2000, builds on a 30-month process including public consultations on four continents, nearly a thousand written submissions, eight independent in-depth case studies, 17 thematic reviews (building on over 100 peer-reviewed expert papers), and a global survey of 125 dams.

While recognizing that dams have made an important and significant contribution to human development, the Commission concluded that in many cases, the social and environmental costs have been unacceptable and often unnecessary. It proposes a new framework for decision-making, including strategic priorities and practical guidelines, issuing a challenge to governments and other interested parties to change the way they view energy and water resources development.

The Commission's recommendations are based on detailed findings as to the impacts on ecosystems and human societies, as well as on the technical, financial and economic performance of large-scale dams. It found that large dams have led to significant losses of wildlife habitat and aquatic biodiversity, especially when they involve considerable storage, peaking capability or interbasin transfers. It further emphasized that these problems can be exacerbated when multiple dams are built on a single river system, especially when they affect the main stem of the river.

One of its more striking findings is that almost 60% of the major ecosystem impacts of the dams studied were not anticipated prior to construction. Even for dams built in the last decade, more than a third of the impacts were unanticipated.

[17] World Commission on Dams, *Dams and Development: A New Framework for Decision-Making* (Cape Town, November 2000), p. 90. www.dams.org/report.

Furthermore, the Commission concluded that only a small percentage of ecosystem impacts have actually been mitigated effectively. It noted, however, that sophisticated environmental flow requirements with seasonal and inter-annual variability can be effective in reducing the inevitable environmental harm.

On a human scale, the Commission found that there has been a pervasive and sytematic failure to assess and account for the range of potential negative impacts on displaced and resettled people and on downstream communities, and that these impacts tend to be borne disproportionately by indigenous peoples and other vulnerable groups. This has led to the impoverishment and suffering of millions and given rise to growing opposition by affected communities worldwide.

Perhaps most important, the Commission found that most problems associated with dams result from faulty decision-making processes, often incapable of assessing the full breadth of energy and dam design options. It concludes with a call for making such choices based on a broader set of inputs and criteria, as well as for significant steps to ensure transparent and inclusive stakeholder involvement.

Finding that "business as usual" is neither feasible nor desirable, the Commission proposes a new approach to decision-making about dams based on five core values: equity, sustainability, efficiency, participatory decision-making and accountability. It proposes strategic priorities based on recognizing rights and assessing risks, as well as a series of detailed guidelines for good practice.

3. Constraints to future development

Despite the enormous technical potential for hydropower development in Canada, there are important issues that constrain the use of this resource to meet future electricity needs. These constraints are addressed in the following sections.

3.1. Economic and infrastructure constraints

While in the existing supply mix hydropower is a low-cost resource, this is unlikely to be true in the future. Hydro utilities make considerable efforts to develop the most cost-effective resources first, which means that, in mature grids like that of Quebec and B.C. where the best sites have been developed long ago, the unit costs for remaining sites are considerably greater. Furthermore, since the annual costs of a hydro project decline over time as the original investment is amortized, the unit cost also declines over time. Thus, in Quebec, for example, the unit costs of the large projects built in the 1970s are now less than 1.4 cents per kilowatthour. In contrast, the costs of the Romaine project, currently under study by the Canadian Environmental Assessment Agency, are estimated at over

8¢/kWh, on a real levelized basis.[18] The actual unit costs for the first decades of operation will be considerably higher.

Hydropower has of course the great advantage of being insulated from fuel price volatility. However, hydropower costs are extremely sensitive to interest rates, as annual costs are made up for the most part of financing charges on the initial construction expenditures. For example, estimated unit costs for Hydro-Québec's Eastmain 1-A/Rupert Diversion project increased by 32% from March 2004 to December of the same year, during which time the applicable long-term interest rates increased from 6.6% to 7.25%.[19]

Historically, the drive to develop the least expensive hydropower resources first has also meant developing those closest to load centres, as long-distance transmission networks are costly to build. The remoteness of remaining sites is thus a significant obstacle to their development, especially given the increasing awareness of the environmental implications of building transmission corridors through wilderness areas. A similar problem exists with respect to energy markets. Each of Canada's hydropower provinces has well developed transmission links with neighbouring regions of the U.S., but not with adjoining provinces.[20] In order for new hydropower resources to displace fossil fuel generation in other provinces, a new and costly East-West high-voltage transmission link would be required.

With small hydro, as with large, acceptability from the perspective of local communities is a major obstacle. While small hydropower is often praised in general, there is frequently significant local opposition to proposals to develop waterfalls or rapids, which are often highly valued for their scenic qualities. Losing a waterfall to hydropower development can significantly affect tourism, which potentially offers far greater opportunities for job creation than does a remotely operated small hydro plant. Thus, in 2002, the Quebec government was forced to backtrack on plans to make 36 sites available for new small hydro development, due to a well organized and highly publicized *Adoptez une rivière* campaign, which focussed largely on scenic issues and local development.[21]

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[18] Data submitted by Hydro-Québec to Régie de l'énergie (file R-3526-04).

[19] Philip Raphals, *Projet Eastmain 1-A/dérivation Rupert : Rapport sur la conformité de l'étude d'impact,* report to the Federal Review Commission, March 18, 2005, p. 17. http://www.ceaa-acee.gc.ca/010/0001/0001/0017/001/1092/1-a-comex.pdf.

[20] The exception of course is Newfoundland and Labrador, whose only transmission interconnection is with Quebec.

[21] One of the leaders of this campaign, Alain Saladzius, was named "Hero of the Year" by the French edition of Readers' Digest. http://www.selectionrd.ca/heros/heros2003.html

3.2. Ecosystem impacts

The flow regime represents perhaps the most important driving force in a river ecosystem. Every natural river ecosystem has evolved to take advantage of the physical characteristics and processes that formed, and continue to shape, the river basin. Any modification to a river that modifies these parameters inevitably affects the river ecosystem.

Dams are intended to alter the natural distribution and timing of streamflows and, as such, they also alter essential processes for river ecosystems. By changing the pattern of downstream flow (i.e., intensity, timing and frequency), they modify sediment and nutrient regimes and alter water temperature and chemistry, both above and below the dam. These parameters are the basic building blocks of freshwater ecosystems and when these change, many species, habitats and functions that depend directly or indirectly on these forces decline or disappear.

To make sense of the numerous interconnected physical and biological effects of dams, river ecologists have developed a framework that distinguishes three distinct orders of impacts. **First order impacts** are the direct physical effects caused by constructing the dam and altering the river's flow. **Second order impacts** are the resulting changes in primary production and ecosystem structure,[22] and **third order impacts** are the long-term effects on invertebrates, fish, birds and mammals resulting from the integrated effect of all the first and second order changes. By the same logic, one can think of impacts on human society (social impacts) as **fourth order impacts.** Not all impacts fit neatly into this hierarchy, but it is nevertheless a useful guide for understanding how dam impacts increase in scale or scope through a river system. The following table summarizes this framework.[23]

[22] Primary productivity is the transformation of chemical or solar energy to biomass. Most primary production occurs through photosynthesis, whereby green plants convert solar energy, carbon dioxide, and water to glucose and eventually to plant tissue.

[23] Drawn from G. E. Petts, Impounded Rivers: Perspectives for Ecological Management (Wiley & Sons, Chichester, UK, 1984).

Location in Relation to Dam	Category of Impact	Impact
Upstream	First Order	Modification of thermal regime
		Accumulation of sediment in the reservoir
		Water quality changes
	Second Order	Changes in plankton and periphyton communities and populations
		Changes in aquatic macrophyte communities and populations
		Riparian vegetation inundated/modified
	Third Order	Communities of invertebrates, fish, birds and mammals affected by altered ecosystem characteristics and processes
Downstream	First Order	Daily, seasonal and annual flows modified
		Water quality changes
		Sediment flows reduced
		Changes to channel, floodplain and delta morphology
	Second Order	Changes in plankton and periphyton communities and populations
		Changes in aquatic macrophyte communities and populations
		Riparian and floodplain vegetation affected by altered flows
	Third Order	Communities of invertebrates, fish, birds and mammals affected by altered ecosystem characteristics and processes
		Estuaries negatively affected by loss nutrient and sediment sources and beneficial effects of flooding
		Marine systems negatively affected by loss of nutrient and sediment and degradation of marine organism breeding areas

While third and fourth order impacts are of most direct interest to human society, they cannot be properly predicted or understood without analyzing associated first and second order impacts. “If [a] stream’s physical foundation is pulled out from under the biota, even the most insightful biological … program will fail to preserve ecosystem integrity.”[24] And of course, each of these impacts in turn depends on the interaction between the precise characteristics of the pre-dam ecosystem and the particular modifications imposed on it by the development.

Space does not permit a detailed discussion of these impacts. For a more detailed discussion, the reader is referred to chapter 5 of *Restructured Rivers.*[25]

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[24] Ligon, F.K., Dietrich, W.E. & Trush, W.J. 1995. “Downstream Ecological Effects of Dams,” in *Bioscience,* Vol 45: 183-192 (quoted in Bergkamp *et al.,* p. 19.

[25] Philip Raphals, *Restructured Rivers : Hydropower in the Era of Competitive Markets* (2001), pp. 36-46 (http://www.centrehelios.org/downloads/reports/2001_EN_IRN_Restructured_Rivers.pdf).

3.3. Impacts on biodiversity

The natural world is characterized not only by large numbers of living individuals and communities, but also by the *diversity* of those communities. That diversity consists both of species diversity and of genetic diversity within a species. Thus, it is important to ask not only how a dam affects the populations of one or more key species, but also how it affects biodiversity in the watershed or region.

Freshwater covers only 0.8% of the planet's surface, but 2.4% of the world's species occur in freshwater, making the "species richness" of the this environment 10% greater than the terrestrial environment and fully 15 times greater than the marine environment.[26] According to an important Canadian study, the rate of extinctions for freshwater fauna in North America is 1,000 times higher than the background rate of extinction[27] — five times higher than those for terrestrial fauna and three times higher than those for coastal marine mammals. In fact, according to the study's authors Ricciardi and Rasmussen:

> Even more remarkable is that [North American] freshwater [extinction] rates fall within the range of estimates for tropical rainforest communities (1-8% loss per decade), which are thought to be being depleted faster than any other biome. This is compelling evidence that North American fresh-water biodiversity is diminishing as rapidly as that of some of the most stressed terrestrial ecosystems on the planet.[28]

They add that, although larger absolute numbers of species are involved in the tropics, "the elimination of even a few species in temperate habitats can promote further extinctions and disrupt ecosystem functioning." Other studies estimate that 20% to 35% of freshwater fish species are extinct, endangered or vulnerable.[29] Reservoirs also tend to reduce biodiversity of fish species, even if total numbers are not affected:

> Fish diversity in reservoirs is usually not as extensive as in natural lakes, because natural lakes have more stable conditions under which the fishes evolve. … As the reservoir fills, rifles, runs and pools of the river are lost beneath the rising waters

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[26] Berkamp, G., McCartney, M., Dugan, P., McNeely, J., Acreman, M. 2000. *Dams, ecosystem functions and environmental restoration*, Thematic Review II.1 prepared as an input to the World Commission on Dams, Cape Town, http://www.dams.org/kbase/thematic/tr21.htm, p. 37.

[27] The rate of extinction that would be expected to occur naturally without human intervention, either positive or negative.

[28] Anthony Ricciardi and J. B. Rasmussen, "Extinction rates of North American freshwater fauna," *Conservation Biology,* Vol. 13 (October 1999), pp. 1220-1222.

[29] Bergkamp *et al.,* p. 42.

> leading to the extinction of habitat-sensitive riverine species with tightly defined niche requirements.[30]

Recent studies show that species richness of freshwater molluscs in the U.S. has declined by 40% to 80% over the last 50 years, mainly because of habitat disruption caused by dams. Their decline will likely have significant impacts on riverine ecosystems, as they are a major food source for fish.

3.4. Social and aboriginal impacts

The social impacts of dams is the subject of a voluminous literature, consisting in large part of detailed and depressing case studies from around the world. While time and space do not permit even a cursory review of this literature, it is nevertheless possible to describe the main types of social impacts associated with different types of hydropower projects.

For large-scale hydro projects, the critical social impacts are clearly displacement of populations and loss of subsistence and other resources. To a large extent, the populations exposed to these impacts are already poor, marginalized and often aboriginal.

> Areas with people who are well off and well connected do not make good reservoir sites.[31]

In recent years, there has been a strong trend toward a greater recognition of the need for informed consent of local communities for major hydro projects, especially in North America. In the developing world, however, this battle is still being fought. The November 2000 report of the World Commission on Dams was widely seen to be a major step forward in this regard, but its cool reception by many utilities and nations — and by the World Bank itself, one of the Commission's sponsors — has raised some doubts in that regard.

Relocation is of course the most serious of these issues and, while many existing hydro facilities in Canada did involve relocation of aboriginal populations,[32] it is unlikely that such projects would be deemed acceptable in the future. Loss of resources, however, is a much more prevalent problem. The WCD described the relationship between these two issues in the following terms:

[30] Ibid., p. 43.

[31] Patrick McCully, *Silenced Rivers: the Ecology and Politics of Large Dams* (Zed Books, 1996), p. 70.

[32] Notable examples include the La Grande project, which caused the relocation of the Cree communities of Fort George (to Chisasibi) and Nemaska, and Alcan's Kemano project in B.C. (Cheslatta Carrier Nation).

> In the narrow sense, displacement results in the physical displacement of people living in the reservoir or other project area. … However, the inundation of land and alteration of riverine ecosystems — whether upstream or downstream — also affects the resources available for land- and riverine-based productive activities. In the case of communities dependent on land and the natural resources base, this often results in the loss of access to traditional means of livelihood, including agricultural production, fishing, livestock grazing, fuelwood gathering and collection of forest products, to name a few. Not only does this disrupt local economies, it effectively displaces people — in a wider sense — from access to a series of natural resource and environmental inputs into their livelihoods. This form of livelihood displacement deprives people of their means of production and dislocates them from their existing socio-cultural milieu. The term 'affected' thus applies to people facing either type of displacement.[33]

In this regard, mercury contamination deserves special mention. Similar in many ways to the processes that generate greenhouse gases (discussed in the next section), flooding results in the stimulation of bacteria that methylate mercury that already present (whether from geological or atmospheric sources), making it bioavailable and leading to its concentration in piscivorous fish. Methylmercury (CH_3Hg, or MeHg) is highly toxic, and levels in certain species of fish typically remain at three to five times their background level for at least two decades.[34] The only practical way to limit exposure is to discourage consumption of fish from affected reservoirs, a limitation with significant implications for fish-eating societies.

In Canada, the vast majority of large hydropower development has taken place on lands inhabited by or claimed by aboriginal peoples. Some of these developments have been addressed in settlement agreements or treaties, such as the Northern Flood Agreement (Manitoba) and the James Bay and Northern Quebec Agreement (JBNQA). Others, such as the Manic-Outarde complex and the Churchill Falls development in Newfoundland, form the background for ongoing land claim negotiations.

The *Agreement Concerning a New Relationship Between the Government of Quebec and the Crees of Quebec* signed in 2002 represents a new phase in this story, in that, for the first time, an aboriginal nation gave its consent to a major hydropower development before construction began. In the agreement, the Grand Council of the Crees consented to the Eastmain 1A/Rupert Diversion project, subject to the outcome of the environmental assessment processes required by the Canadian Environmental Assessment Act and the JBNQA.[35] In return, they obtained settlement of a large

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[33] World Commission on Dams, *op. cit.*, p. 103.

[34] Bodaly et al., "Experimenting with Hydroelectric Reservoirs," Environmental Science and Technology, September 15, 2004, pp. 347A-352A.

[35] It must be noted that these processes are strictly advisory; decision-making power rests firmly with the Quebec cabinet.

number of outstanding issues from the JBNQA, as well as royalty payments based on the total value of all natural resources extracted from their traditional territory over the next 50 years.

This agreement, often referred to as the *Paix des Braves*, has been rightly praised as a great step forward, in terms both of recognition of aboriginal nations and of the use of royalties to compensate First Nations for resource extraction. However, the agreement remains highly controversial among the Crees. The chiefs of several Cree communities remain firmly opposed to the Rupert project, and questions have been raised about the adequacy of the information provided to the communities prior to the 2002 referenda on the agreement. The agreement was the key issue in the last general election, won by the incumbent Grand Chief Ted Moses with a majority of only 19 votes. While the Agreement has been signed and ratified, it is unclear if it could or would be implemented without continued Cree support.

For small and medium hydropower facilities, the social impacts are of a very different nature. Here, recreational and ecotourism issues are often cited, whether due to the loss of key rapids used for whitewater sports or to the artificialization of exceptional sites. This latter issue, indeed, is common to hydropower projects of all sizes. It is an unfortunate coincidence that, in a great number of cases, the sites with the greater energy generation potential are precisely those that are … the most beautiful. Whether characterized as loss of scenic resources or landscape fragmentation, these are issues that are addressed only partially and incompletely by economists and engineers, yet which are not far from the hearts and minds of ordinary people.

Whether viewed as a spiritual or an aesthetic issue, the fact remains that these are exceptional sites about which many people care deeply. While this factor generally plays a relatively small role in formal environmental assessment processes, it plays a large one in the political arena where most decisions about hydropower development are ultimately made.

3.5. Greenhouse gas emissions

It is remarkably difficult to draw firm conclusions regarding the greenhouse gas emissions from reservoirs. This can be attributed on the one hand to the difficulty of the scientific challenge and the relatively few resources that have been devoted to addressing it, and on the other to the highly charged ideological space in which the debate has taken place.

In early 2000, the World Commission on Dams convened a workshop that brought together the leading researchers in this field from around the world, including those directly associated with or employed by the hydro industry. Following the workshop, a consensus statement was issued,[36] which indicated agreement on among others, the following points:

- All reservoirs emit greenhouse gases and continue to do so for decades, at least,
- GHG emissions result not only from flooded biomass, but also from carbon transported by the river from the catchment area,
- the multiplier commonly used to convert methane emissions to "equivalent CO_2" significantly under-estimates the climate change impact of reservoirs over the first several decades,
- the appropriate framework for the comparison of reservoir GHG emissions with alternative energy sources. It was agreed that these should be on a life-cycle basis and based on net emissions, taking into account the baseline emissions in the watershed before hydro development,
- emissions of methane and CO_2 from water passing through the turbines, over the spillway and down-stream of the dam. It found that these may be significant, and that they depend largely on the depth of the turbine intake, and
- the range of factors influencing GHG emissions. It was agreed that these include the reservoir's depth, shape and size, operating regime and water residence time, as well as the size and nature of the watershed.

Beyond these general points of agreement, however, there is little solid ground. Some of the litigious points include:

- **GHG emissions.** According to the International Hydropower Association, net emissions for northern reservoirs are just 10 g CO_2-equivalent (CO_2e) per kWh. Canadian researchers cite values of 40 to 60 g/kWh, and a recent study from the University of California suggests the value for submerged boreal forests to be over 1200 g/kWh.[37]

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[36] World Commission on Dams, *Dam Reservoirs and Greenhouse Gases: Workshop Held on February 24-25, 2000, Final Minutes,* http://www.dams.org/docs/kbase/thematic/tr22pt3.pdf.

[37] Arpad Horvath, "Decision-making in Electricity Generation based on Global Warming Potential and Life-cycle Assessment for Climate Change," June 2005, *University of California Energy Institute,* p. 9.

- **accounting for methane emissions.** Based on modelling by Stuart Gaffin, currently with the Center for Climate System Research at the NASA Goddard Institute for Space Studies, this author has calculated that, for continuous emissions of equivalent amounts of methane and CO_2, methane has 39.4 times the global warming effect of CO_2, on a 100-year time-frame.[38] This contrasts with the multiplier of 22 established by the IPCC, which accurately reflects the relative impacts of one-time emissions but not of continuous emissions.

- **baseline emissions.** While there is general agreement with the principle that gross emissions should be compared with those of the pre-impoundment ecosystem, this remains theoretical due to the cost and difficulty of carrying out actual baseline emissions studies of areas to be flooded. Important research is being carried out in this regard on two experimental sites operated by Fisheries and Oceans Canada, known as the Experimental Lakes Area Reservoir Project (ELARP) and the Flooded Uplands Dynamics Experiment (FLUDEX). Preliminary results have been published, but they shed only limited light on real-world estimations.[39]

All else being equal, projects with rapidly fluctuating water levels probably produce a higher proportion of methane — and thus higher total GHG emissions — than do those with stable water levels, though this has not been conclusively demonstrated. In sum, though knowledge of the factors influencing net GHG emissions for reservoirs is increasing, it is not possible at this time to predict with any degree of certainty the actual GHG emissions of an existing or planned reservoir.

3.6. Climate-related uncertainties

The understanding of a site's hydrology is critical to the design of any hydropower project. Hydrology is by its very nature a stochastic science, one that uses historical records to estimate the probability of varying levels of streamflows throughout the year.

Traditionally, the underlying hydrological premise has been that the future would be like the past, from a statistical point of view. However, the growing realization that greenhouse gas emissions are changing the climate itself has created uncertainties in forecasting future hydrological conditions, the implications of which are only beginning to be understood. These uncertainties exist on two levels: cost effectiveness and safety.

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[38] Raphals, *Restructured Rivers,* pp. 53-54.

[39] Bodaly *et al.,* op. cit.

Cost-effectiveness. In designing a hydro project, engineers optimize turbine size and, when applicable, reservoir size based on the forecast rate and variability of hydraulic inflows (runoff). If, in the future, these inflows are significantly less than these forecasts, the project's income will be reduced accordingly. Costs, however, remain fixed, consisting largely of the financing costs for the initial construction.

Safety. All dams are designed to allow passage of the greatest flows that can reasonably be expected (the "design flood"). These floods are expressed in terms of their frequency of recurrence. Thus, a dam designed for a hundred-year flood is one which is capable of withstanding the greatest flood that can be expected within a hundred-year period, based on the historical record. As climate change may affect the likelihood of different weather events, it may also in some cases increase the probability of the extreme floods. While highly unlikely, such events are of great importance, a reservoir that cannot evacuate inflows may be at risk of catastrophic failure, as occurred in the the Saguenay region of Quebec in 1996.

3.7. Environmental assessment regime

The environmental assessment processes applicable to hydroelectric projects are generally quite complicated. This complexity is often denounced by the hydro industry. Thus, in a brief to Parliament, the Canadian Hydropower Association called attention to the length and unpredictability of the review process, to the lack of coordination between federal agencies and the lack of harmonization with provincial or territorial processes, and to the excessive emphasis on local impacts, especially in the assessment of changes in aquatic ecosystems.[40]

Environmental assessments of hydropower projects are indeed complex, and with good reason. As noted earlier, hydropower is unique among electricity generation technologies in that it directly modifies a defining element of complex ecosystems spread out over a large area. Determining the consequences of those modifications, and their consequences in turn on other ecosystem components, is a complex, site-specific and data intensive exercise for which unfortunately few shortcuts are available.

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[40] Canadian Hydropower Association, *Bill C-19, an Act to Amend the Canadian Environmental Assessment Act,* Brief to the Standing Committee on Environment and Sustainable Development, November 2001, p. 9.

There are also signficant institutional complexities. First, of course, is the constitutional distinction between federal and provincial jurisidictions. While natural resources are clearly a provincial matter, the federal government has jurisdiction over fisheries, navigable waters, migratory birds and Native peoples. Large hydro projects thus typically involve both federal and provincial review processes. Furthermore, some aboriginal land claim settlements — notably the James Bay and Northern Quebec Agreement, signed with the Quebec Cree and Inuit in 1975 — impose their own environmental assessment requirements that replace or supplement existing mechanisms.

Considerable efforts have been made to harmonize these processes, but there remains much room for improvement. The same can be said of efforts to improve the efficiency of the processes themselves, by focussing on the essential issues rather than on exhaustive inventories. That said, the notion that hydropower environmental assessment could or should become as simple as that of natural gas-fired combined cycle plants — the impacts of which vary little from one installation to another — remains illusory.

4. Is hydropower "green"?

Few questions arouse passions on both sides of the hydropower debate as does the simple question, "Is hydropower green?" Traditionally, the hydropower industry vigorously defended the notion that all hydropower is "clean, clean, clean." At the same time, a purist river protection view held that there is no such thing as a good dam.

Increasingly, however, voices from both sides of the divide are recognizing that there are indeed shades of gray, and that some dams are indeed better (and worse) than others. On the industry side, there is growing recognition that some dams cause considerable environmental harm, at times outweighing the benefits they create. And on the environmental side, there is recognition that, given the growing importance of climate change, a dam that is designed and managed so as to minimize its ecological footprint may be less bad than the alternatives.

How to tell the one from the other, and where to draw the lines? Alas, the devil is in the details and, given the multiple layers of complexity surrounding every aspect of hydropower, it should come as no surprise that there are no easy answers.

The two main vehicles for favoring environmentally preferable generation choices in a market context are the voluntary green power market and the obligatory renewable portfolio standard. The role of hydropower in each of these mechanisms has been hotly debated in recent years. The following sections provide an overview of these debates.

4.1. Certification for green power markets

Whether, or to what extent, hydropower should qualify for marketing as "green power" is a highly contentious question. The hydropower industry argues that it is one of the "greenest" of power sources, in that it makes it possible to avoid most of the air emissions associated with fossil fuel generation. On this basis, some industry representatives go so far as to suggest that *all* hydropower should be certified for sale in the green power market.

However, as we have seen, hydropower is responsible for very significant environmental and social impacts, which vary greatly from project to project, depending not only on the site and the project design but also on the way the facility is operated. It goes without saying that hydro projects which are responsible for such impacts would not be regarded as environmentally benign by a fully informed consumer, and thus should not be certified as "green" by organizations whose mandate is to help those consumers make informed choices.

How, then, should those organizations go about distinguishing high-impact from low-impact hydropower? In Canada, this question has fallen to the Environmental Choice Program (ECP), which is responsible for EcoLogo, a owned by Environment Canada. The ECP is managed by the Ontario-based TerraChoice Environmental Services Inc. and covers a broad range of products, from appliances to office products to electricity. Guidelines for each product category are developed by TerraChoice and then submitted to the Canadian Government for approval.[41]

An EcoLogo guideline has been adopted that establishes certification criteria for all types of renewable power.[42] These criteria require:

- that the generation process as well as the disposal of any waste products must meet the requirements of all applicable laws, regulations and safety and performance standards,

[41] http://www.environmentalchoice.com.

[42] Guideline CCD-003, Renewable Low-Impact Electricity (December 15, 2003), http://www.environmentalchoice.com/grouppdf/CCD-003%20-%20Dec%202003%20w%202005%20add%20(E)._5.pdf.

- that appropriate consultation with communities and stakeholders has occurred, that their issues of concern have been reasonably addressed, that all reasonable mitigation of adverse impacts has been employed, that conflicting land use, biodiversity losses and scenic, recreational and cultural values have been reasonably "addressed" during project planning and development, and

- that there be no adverse impacts for endangered or threatened species.

Additional criteria are specified for each generating technology separately (wind, solar, biomass, hydro). For example, wind power can only be certified if it is shown that structures do not obstruct migratory routes and are not located in an area of high bird concentration or of endangered bird species. For solar power, it must be demonstrated that all solid waste (including disposal of equipment containing measurable levels of cadmium) be properly disposed of or recycled. Biomass and biogas must meet a series of requirements concerning air emissions, and biomass certification also depends on a number of source restrictions.

The EcoLogo criteria include the following provisions regarding hydropower:

- the facility must be in compliance with all regulatory licenses regarding fisheries, water levels and flows, and must not operate under a conditional authorization allowing the harmful alteration, disruption or destruction of fish habitat,

- it must be run-of-the-river, with a maximum of 48-hours of storage capacity,

- any reduced flows must not be detrimental to indigenous aquatic and riparian species, and in-stream flows must be adequate to support such species at pre-project ranges,

- water quality must be similar to that in free-flowing or unaltered bodies of water or waterways in the area,

- any temperature changes caused by the project must not be detrimental to indigenous aquatic species, and

- fish passages must be provided when necessary to allow pre-existing upstream and downstream migration patterns.

Unfortunately, the Ecologo certification process is carried out without any public involvement, and without any disclosure of the basis on which certification was made. In this sense, it compares poorly with its American cousin, the Low Impact Hydropower Institute, in which all stages of the review process are open to public scrutiny and involvement.[43]

4.2. Renewables Portfolio Standards

Among the key market mechanisms for fostering development of green power technologies within the competitive marketplace is the "renewables portfolio standard" (RPS). An RPS requires that a certain percentage of power sold or generated in a given jurisdiction be derived from environmentally preferable energy resources. Under a typical RPS, renewable generators earn credits based on their annual output. Retailers are obliged to obtain a sufficient number of credits (set as a percentage of annual sales); penalties are assessed against any retailer that fails to comply.

Following the energy crises of the 1970s, the term "renewable" began to be casually used as a synonym for all that is environmentally preferable in electricity generation. This usage has since been adopted in statutes and in regulatory orders, in the form of "renewables portfolio standards" and other instruments. In most cases, it is clear that the intent was not to rely exclusively on technical renewability to the exclusion of all other environmental considerations, regardless of their significance.[44] The important questions thus turn on the multi-dimensional question of environmental preferability, of which renewability is just a part.

The underlying purpose of the RPS is thus to create a market for environmentally preferable technologies which are not yet competitive from a purely economic perspective. The cost curves of new technologies often decline precipitously, due both to technological maturity and to economies of scale.

In recent years, the RPS has become a mechanism of choice to favour low-impact generation, especially in the United States. To date, 22 U.S. states (and the District of Columbia) have adopted RPS legislation.[45]

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[43] http://www.lowimpacthydro.org/. For a fuller analysis of LIHI and other certification regimes for hydropower, see Raphals, *Restructured Rivers,* chapter 8 (pp. 66-88).

[44] The term "renewables portfolio standard" was initially proposed in Nancy A. Rader and R. B. Norgaard, "Efficiency and Sustainability in Restructured Electricity Markets: The Renewables Portfolio Standard," *Electricity Journal* (July 1996). While the term "renewable" was not defined, Rader confirms that the intent was never to guarantee benefits to every conceivable renewable energy resource (pers. comm.).

[45] The North American Commission for Environmental Cooperation maintains a database of RPS legislation.

Any jurisdiction designing an RPS must decide which resources to include based on the goals they seek to accomplish through the policy. These goals may include improving the diversity of the resource mix serving the jurisdiction, environmental benefits and technology advancement. Policy makers may exclude certain types of resources if they do not provide these benefits are not judged sufficient or if the resource does not require additional policy support to provide them.

In order to ensure that the main objective of the RPS — significant market penetration by new, green power technologies — is achieved, it has been argued that eligible resources should be limited to those that share the following characteristics:

1. current costs must be above the market,
2. the technology must still be immature, with significant potential for improvement and cost reductions, and
3. its environmental benefits should be comparable to those of other resources included in the RPS.

Given these criteria, it is not surprising that hydropower is often excluded in whole or in part from RPS eligibility. Indeed, while hydropower is considered a renewable resource, it differs in many ways from other renewables. Unlike other renewables:

- hydropower development generally has substantial environmental consequences, some of which follow inevitably from the initial development and others that vary according to how the project is operated,
- there exists a large stock of existing hydropower generation, much of which was built, and in many cases still operates, under authorizations issued many years ago when environmental standards were far lower than they are today,
- standards for hydropower licensing vary greatly from one jurisdiction to another,
- hydro projects vary enormously from one to another, and the factors that determine the degree of their environmental impacts are complex and subtle.

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http://cec.org/databases/certifications/Cecdata/main.cfm?CategorieID=7299&Varlan=english&WebSiteID=3.

While there is obviously no fuel required to operate a hydro plant, to the extent that irreplaceable resources were lost in developing the site or that its operations create significant stresses on important ecosystem functions, such a facility clearly has non-renewable aspects as well.

> While water may be a renewable resource, the permanent character of hydro projects must be emphasized: the river and its environment are irremediably altered by the construction of hydropower facilities. There is rarely a way back, as dams are hardly ever dismantled to return the site to its natural state. Thus, while water might be a renewable resource, it is dangerous to presume that a hydropower development is renewable as well.[46]

While there is a broad societal consensus that favours maximizing the development of new and currently marginal technologies such as wind and solar, there is no such consensus for hydropower. We have seen earlier that many of the environmental costs of hydropower are "sunk" from the moment when the facility is built. Thus, unlike a thermal plant, shutting down a hydro facility does little to reduce the impacts created by its construction, unless the dam is decommissioned. Rather, the construction of each new hydro facility adds to the cumulative harm to riverine ecosystems to a greater or lesser extent, depending on the project's siting, design and operating regime.

For all these reasons, there is no single right answer to the question, what hydro resources should be eligible for inclusion in an RPS? It should thus come as no surprise that different jurisdictions have chosen very different answers, ranging from the inclusion of all hydropower (e.g. Texas) to none (e.g. Arizona).

5. Free-flow hydropower

Thusfar, our discussion has dealt with hydropower installations that use dams to increase head and/or to modify water flows. Indeed, virtually all existing hydropower installations are of this type.

However, there is considerable interest and development activity with regard to "dam-free" hydropower, usually referred to as free-flow hydropower or "instream energy generation technology." These technologies consist of inserting turbines into flowing water, whether in a riverine, ocean current

[46] *Commission d'enquête sur la politique d'achat par Hydro-Québec d'électricité auprès de producteurs privés,* p. 468 (our translation). The Doyon Commission was a judicial commission of inquiry established in 1995 to investigate allegations concerning in Hydro-Québec's awarding of power purchase contracts in the early 1990s.

or tidal environment, in order to extract kinetic energy from the moving water without obstructing its flow.

The energy potential of tidal power is enormous. For example, it has been estimated that, if harnessed, the tidal currents flowing back and forth through San Franciso's Golden Gate would generate some 2000 MW.

There are a number of different turbine technologies being explored for this purpose. These include axial-flow rotor turbines, which resemble wind turbines, vertical-axis turbines, and helical turbines that can be installed either vertically or horizontally.

A number of companies in both the U.S. and Canada are involved in developing these technologies. Following are brief descriptions of some of the demonstration projects currently underway:

- Hammerfest Strom has installed a grid-connected axial turbine in a straight with strong tidal currents in Norway, using 15m blades mounted on towers fixed to the seabed (illustrated below). By 2008, it intends to expand the installation to 20 turbines, with an installed capacity of 10 MW and annual generation of 21 GWh.[47]

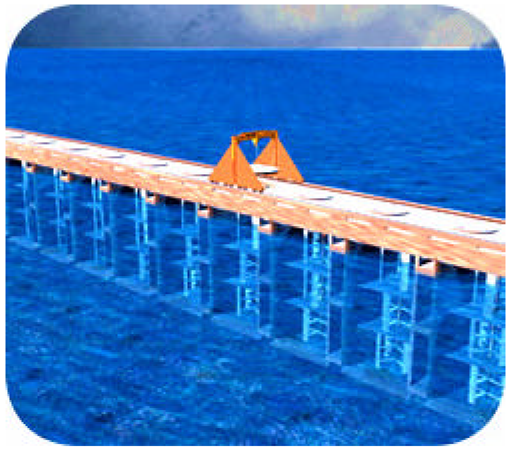
- Verdant Power has deployed a 16 kW axial turbine with 10-foot diameter rotors in the East River in New York City. It intends shortly to expand the installation to a field of six grid-connected machines, and eventually to expand it to 5 to 10 MW.[48]

- Blue Energy Co., based in Vancouver, is developing underwater vertical-axis turbines for ocean and tidal applications. It is pursuing development of a 500 kW project off the coast of British Columbia, which will eventually be integrated with an electrolytic hydrogen generator

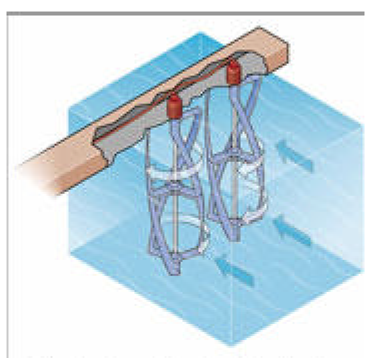
[47] http://www.e-tidevannsenergi.com/index.htm.

[48] http://www.verdantpower.com/initiatives/eastriver.html.

for use with fuel cells. Blue Energy has a long-term interest in developing tidal fences, illustrated below, which would serve both as a transportation bridge and as a large-scale generation facility.[49]



- GCK Technology, based in Texas, is commercializing the Gorlov helical turbine (illustrated below). It is currently installing a 15-foot 1 MW turbine in the Uldolmok Strait off South Korea. When completed, the array should produce 100 MW.[50] Gorlov has identified nine suitable tidal power sites in New England alone, with a combined potential of over 1200 MW.[51]



[49] http://www.bluenergy.com/index.html.

[50] http://www.mos.org/cst/article/2806/5.html.

[51] http://www.gcktechnology.com/GCK/pg2.html.

In the short term, these technologies will no doubt remain marginal. In the longer term, however, they show great promise for allowing hydropower to make a significant contribution to Canada's and the world's energy needs, while avoiding the significant environmental and social impacts that have to date been associated with this technology.

6. Conclusion

As we have seen, due to the extraordinary variety of sites, designs and operating regimes, hydropower defies simple characterization. There is thus no easy answer to the question, "What should be hydropower's role in a carbon-constrained energy future for Canada?"

It is clear, however, that, for the vast majority of hydropower projects, low-carbon energy comes at a price, measured in the ecological and social disruption caused by flooding, alteration of flow regimes, artificialization of wilderness and of natural sites that are highly valued for their recreational, aesthetic and/or spiritual value.

Comparing these disparate externalities with monetary costs and with the low-carbon energy benefits of most hydropower projects is no small challenge. In the 1980s and 90s, a group of methodologies was developed to help electric utilities choose the combination of supply- and demand-side projects and programs which would allow them to meet their customers needs for energy services at the least cost to society. This approach, known as integrated resource planning (IRP), used a variety of sophisticated methods to account for the full range of the economic, environmental and social implications of the choices under consideration.

Unfortunately, the market-oriented evolution of the North American electric industry over the last ten years — based on the principle that wholesale electricity is a commodity which is best managed by markets, not regulators — has tended to marginalize or eliminate the kind of institutionalized planning processes within which such methods can be applied.

The World Commission on Dams, however, rightly concluded that, because of the significant externalities associated with it, participatory planning processes remain essential for new hydropower developments.

> [T]he main challenge for water and energy resource developers in the 21st century will be to improve options assessment and the performance of existing assets. This will

> require *open, accountable and comprehensive planning and decision-making procedures* for assessing and selecting from the available options.[52] (emphasis added)

It added:

> The preferred development plan is selected through a participatory multi-criteria assessment that gives the same significance to social and environmental aspects as to technical, economic and financial aspects and covers the full range of policy, programme, and project options. Within this process, investigations and studies are commissioned on individual options to inform decision making as required; for example, demand-side management studies or feasibility studies.[53]

Thus, for the WCD, a comprehensive and inclusive planning process is essential to making appropriate decisions about dams. Currently, however, decision-making regarding hydropower development remains for the most part *ad hoc*. In the provinces with the greatest hydropower potential, development decisions are made either by Crown corporations or governments, without the benefit of any participative planning process. For each project, the outcome depends largely on the *rapport de force* of the various interests at play.

It is thus difficult to judge the role that new hydropower development will play in Canada's energy future. There is little doubt that, with the possible exception of free-flow hydropower technologies, which are not yet commercially mature, hydropower remains an option which imposes significant environmental and social costs in compensation for its GHG benefits. In this respect, it is in sharp contrast to options with substantial co-benefits, such as energy efficiency improvements or improved mass transit systems. Indeed, while many hydropower advocates would express shock at the comparison, it is in many ways more similar to nuclear power, which also combines a very low GHG profile with significant environmental and social costs.

There is no doubt that, for many reasons, Canada will continue to be confronted with significant choices to make concerning hydropower development in the coming years. These reasons include:

- rising domestic electricity consumption,
- the rising costs of fossil fuels,

[52] World Commission on Dams, *Dams and Development: A New Framework for Decision-Making* (Cape Town, November 2000), p. 167.
[53] Ibid., p. 262.

- increasing evidence of global warming and Canada's failure thusfar to reduce its GHG emissions,
- pressure to close existing coal plants, both to reduce air pollution and GHG emissions,
- the past and (presumably) future profitability of hydropower exports to the United States.

This last point concerning exports merits additional comment. First, from a strict climate change perspective, the GHG benefit related to hydropower is related to the differential between per-kWh emissions of the source hydropower project, on the one hand, and the *marginal* GHG emissions of the receiving grid, at the moment when the export takes place. This last element is important because, in most grids with substantial thermal component, the marginal generation source varies greatly from one time-period to another. For example, in New York and New England, the marginal source during peak periods is natural gas-fired combined cycle generation, whereas during off-peak periods it is either coal (high GHG emissions) or nuclear (very low emissions). Thus, it is difficult to make even an approximate estimate of the GHG implications of hydropower exports without detailed analysis.

This factor is also important with respect to the ongoing debate about building east-west transmission corridors. From the perspective of Canada's GHG inventory, it is of course far more interesting that Quebec's hydropower be consumed in Ontario than in the U.S. However, from the perspective of the global climate, the two cases are very similar.

Secondly, it is hazardous to seek to extrapolate the clear profitability of the export of hydropower from existing sources to future projects. This is true in part because, as noted earlier, hydropower development in each region proceeds from least-cost to greater-cost projects. In most of Canada, the projects currently under consideration have costs per installed MW far greater than those built in the 1960s, 70s and 80s. Furthermore, the very low unit energy costs of these old projects is due in part to the amortization of their construction costs. New projects identical to old ones, if such a thing were possible, would display significantly greater unit energy costs for the first decades of operation. Thus, care must be taken in advocating the construction of new hydro projects for export — the risks of sticker shock are very real.

For all these reasons, public perceptions of hydropower remain fickle. More than ever, in this post-Kyoto era, hydropower's profile — renewable, GHG- and pollution-free power — is seductive. But as one gets closer to actual projects, polarization sets in between development and conservation interests, both powerful forces in 21st century Canada.

These questions are perhaps most acute in Quebec, where hydropower plays such an important role both in the electric grid and in the collective psyche. The defeat of Hydro-Québec's Suroît project — a merchant gas-fired combined cycle plant, justified in large part for its export potential, and vigorously opposed by Quebec's environmental movement — has been interpreted as a vote in favour of hydropower, but the reality is more complex.

It is true that natural gas, seen as part of the solution in coal-burning provinces, is seen rather as part of the problem in Quebec, though a consensus has now developed for the first time in favour of using gas rather than electricity for space heating. With only marginal exceptions, however, the environmental constituency that was largely responsible for the demise of the Suroît project advocates vigorously for wind power and energy efficiency investments, but not at all for hydropower development.

After several years of despair following the deregulation of generation imposed by the Bouchard government in 2000, Quebec's environmental community is now riding high. In just two years, it has seen the collapse of the Suroît project, commitments to purchase 3,000 MW of wind power and a doubling of Hydro-Québec's energy efficiency objective. Together these initiatives have dramatically reduced the need for new thermal or hydropower to meet Quebec's energy needs over the next decade.

These developments have not reduced Hydro-Québec's appetite for new hydro projects as, since functional separation was established in 2000, new project development has been divorced from Quebec's energy needs. However, it may well affect public perceptions, as major projects such as the Rupert diversion and Labrador's Gull Island project – which will reuqire major new transmission lines through the Quebec heartland – hit the news. Generally speaking, public opinion is supportive of Hydro-Québec as a whole, but shifts strongly against it at times of controversy, as we have seen following the 1998 ice storm and during the Suroît debate. It is thus safe to predict that hydropower development will remain controversial, despite its substantial benefits in a carbon-constrained world.