Acting on Climate Change:

Extending the Dialogue Among Canadians

A collection of texts in response to

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A CREE FISHERMAN ON ONE OF THE LA GRANDE COMPLEX RESERVOIRS. THIS PHOTO ILLUSTRATES OUR STATEMENT ON THE NEED FOR MULTIPURPOSE HYDROELECTRIC RESERVOIRS.

Contributed by

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Hydropower:

Energy Production Par Excellence in Canada, But Not Quite Green

Original text in French available at *www.sustainablecanadadialogues.ca/fr/vert/versundialogue*

Hydroelectricity: a major form of energy production in Canada

According to the Canadian Hydropower Association[1], hydropower enables Canada to meet its energy needs while simultaneously reducing air pollution and greenhouse gas (GHG) emissions. Major investments and improvements have taken place from 1950 - 1990, making Canada the third largest producer of hydroelectricity in the world, with an average production of 376 million megawatt hours and more than 10 000 dams with 511 major works[2]. In Canada, more than 63% of electricity production is hydroelectric and, in the provinces of Quebec, Manitoba, Yukon, British Columbia, Newfoundland and Labrador, hydroelectricity accounts for 90% of electricity production (Table 1). In anticipation of the growing energy needs of Canadian society, interest in hydropower generation remains strong, and several large dam projects are underway (Romaine River in Quebec) or under study (Conawapa in Manitoba).

In the most productive provinces (Quebec and Manitoba), it is interesting to note the considerable length of transmission lines, with large dams being located several hundred kilometres from urban areas. The remoteness of the resource inevitably leads to energy losses during transport, estimated at about 5% over the entire Hydro Québec transmission network. Many interconnections between provinces and between Canada and the United States enable the export of hydroelectricity at a relatively low cost outside of the most productive provinces (Manitoba and Quebec, in particular).

Large dams built for energy purposes accounted for 67% of total Canadian dams constructed from 1969 - 2002. Large dams are also used for irrigation (Alberta, British Columbia and Saskatchewan), suppressing floods, and production of drinking water. Each of these uses unrelated to hydropower represents 4-7% of all built dams.

1 Canadian Hydropower Association (2008). Hydropower in Canada: Past, Present and Future, https://canadahydro.ca/pages/cha-reports-and-publications

2 http://www.imis100ca1.ca/cda/Main/Dams_in_Canada/CDA/Dams_In_Canada.aspx?hkey=63e199b2-d0e3-4eaf-b8ad-436d9415ad62

Replace a terrestrial boreal ecosystem by an aquatic ecosystem?

Flooded forest ecosystems

Reservoirs are located in relatively preserved continental ecosystems, since they are most often far from urban areas. The shield coniferous forest and the boreal shield ecozones are the most affected by dams, with 20 311 km^2 (1.42% of the surface) and 27 690 km^2 (1.46% of the surface) flooded, respectively[3]. The continental ecosystem is thus lost under water and, with it, all the continental biomass (soil and plants). Wildlife is doubly impacted by both the disappearance of resources under water, which forces migration, as well as by division of the territory. For example, the ancient lake Michikamau in Labrador saw its surface triple after it was dyked. Flooding of 4000 km^2 of caribou calving areas has contributed to the decline of the caribou population[4]. Besides the effects of flooding, these enlarged lakes also create an insurmountable obstacle of several thousand km^2 that can divide the territory, as well as block managed access roads leading to the heart of the forest.

Altered riparian ecosystems

The ecosystem that is characterized by running water suffers from two alterations: it is divided by the dams, and it is partially replaced by a system of artificial lakes characterized by water that is stagnant, deep, and seasonally stratified. This dual alteration results in decreased biodiversity[3], due to the introduction of invasive species by diversion facilities and especially due to the disruption of the river continuum. Splitting the river continuum limits the movement of fish species, for example leading to high mortalities in wild salmon in British Columbia[5]. Division of the river also isolates each species present in the continuum into smaller communities that are therefore more vulnerable[6]. Finally, the artificial management of flow also disrupts aquatic ecosystems in the reservoir and especially downstream. A natural river in Canada sees its flow rates increase sharply during the snowmelt, while flow rates are normally near zero in winter[3]. Conversely, the flow of a river exploited for hydroelectricity sees its rates increase in winter during peaks in electricity demand. The spring flood is maintained but at a reduced intensity, as was shown in a study on the Peace River in British Columbia[7]. This artificial flow has major consequences downstream, including on wetlands that dry up in the summer, on decreases in salinity in estuaries in periods of high electricity production, and on biological productivity in general. For example, an imbalance of the coastal ecosystem has been clearly observed in the Peace-Athabasca delta downstream of the Bennett dam in Alberta, which saw stocks of muskrats and fish collapse, depriving indigenous communities of an important resource[8]. A total length of 130 000 km of river has been artificialized in Canada[9].

3 Rosenberg, D. M., Bodaly, R. A. and Usher, P. J. (1995). Environmental and social impacts of large scale hydroelectric development: who is listening? Global Environmental Change, 5: 127-148.

4 Hummel, M. and Ray, J. C. (2008). Caribou and the North: A Shared Future. D. Press, Ed., pp. 288.

5 Wissmar, R. C., Smith, J. E., McIntosh, B. A., Li, H. W., Reeves, G. H. and Sedell, J. R. (1994). A history of resource use and disturbance in riverine basins of eastern Oregon and Washington (early 1800s-1990s). Northwest Science, 68: 1-35.

6 Humpesch, U. H. (1992). Ecosystem study Altenwörth: impacts of a hydroelectric power-station on the River Danube in Austria. Freshwater Forum, 2: 33-58.

7 Shelast, B.M., Luoma, M.E., Brayford, K.T. and Tarpey, T. (1997). Environmental effects monitoring of the Peace River for Daishowa-Marubeni International Ltd., Peace River, Alberta. Canadian technical report of fisheries and aquatic sciences.

8 Rosenberg, D. M. , Bodaly, R. A. and Usher, P. J. (1995). Environmental and social impacts of large scale hydroelectric development: who is listening? Global Environmental Change, 5: 127-148.

9 MacAllister, D. (2000). In Biodiversity in Canada: Ecology, Ideas, and Action, B. Stephen, Ed. University of Toronto Press, pp. 426.

Unstable lake ecosystems

Finally, the reservoirs are characterized by amplitudes between high and low water levels of several meters over a few years, since exceptionally heavy rainfall is stored and, conversely, deficits in precipitation lower the lake level. This "drawdown" range, coupled with ice action, erodes the riparian zone and reduces its biological support capabilities. Thus, in a sample of 17 lakes in Quebec, researchers observed only 8% of banks were biologically active[10]. The high mobility of the shoreline of shallow lakes keeps banks relatively unproductive and susceptible to erosion. Modification of biogeochemical cycles will favour some fish species at the expense of diversity; pike and whitefish will come to represent the majority[11].

Necessary adaptation of local populations

Although major Canadian hydroelectric reservoirs are almost all located in sparsely populated areas, they still cause significant displacement, as occurred with the Cree population in Fort George Island, northern Quebec. This community of Chisasibi was entirely relocated in 1981 following the creation of the La Grande Complex, which resulted in erosion on the Island and loss of winter ice cover, limiting mobility. In addition, the flooding of traditional hunting territories has either forced communities affected by the creation of dams to turn to fishing, an activity that has generated a worrisome exposure to mercury, or discouraged some members of these communities from practicing traditional land use activities.

10 Denis, R., Foisy, M., Desmarais, M., Marcoux, J. and Côté, P. (1991). Érosion des berges des réservoirs hydroélectriques. Tome I : Rapport final – Tome II : Dossier cartographique. Montréal, Consultants SOGEAM, 2: 107.

11 Astrade, L. (1998). La gestion des barrages-réservoirs au Québec : exemples d'enjeux environnementaux. Annales de Géographie, 107(604): 590-609.

Aquatic biogeochemical cycles disrupted in reservoirs and downstream

Eutrophication of artificial lakes is a common alteration of the aquatic ecosystem. Flooding of terrestrial ecosystems generates a massive influx of organic matter that will be partially preserved at the bottom of lakes in ancient soils and will partially accumulate in the form of surface debris. The process follows the classic chain reaction of eutrophication, namely: organic matter accumulation, increased remineralization, decreased oxygenation of water, water acidification and intensification of primary production with declining biodiversity.

Disruption of the mercury biogeochemical cycle is certainly the best documented form of pollution in Canadian reservoirs. Flooding of soils and forests facilitates transformation of a portion of non-toxic inorganic mercury stocks in soils into an organic form (mercury methylation) that is highly neurotoxic and bioaccumulates throughout the aquatic food web. Anaerobic conditions in flooded soils thus promote the bacterial process of mercury methylation. In addition, bank erosion contributes to re-suspension of sediment enriched with methylmercury[12]. In the La Grande Complex (Quebec), mercury methylation was still observed 20-30 years after impoundment of the dam, and the flesh of high trophic level fish still contains concentrations higher than those measured before development of the river[13].

Although less studied than mercury methylation, artificial management of water resources could affect nutrient cycling, as evidenced in other coastal areas[14]. Lengthening of

12 Lucotte, M., Shelagh, M. and Bégin, M. (1999). In Mercury in the Biogeochemical Cycle. Springer, pp. 165-189.

13 Schetagne, R. and Verdon, R. (1999). In Mercury in the Biogeochemical Cycle. Springer, pp. 235-258.

14 Ludwig, W., Dumont, E., Meybeck, M. and Heussner,

water residence time compared to a natural river, sediment trapping of organic matter produced in the lake, and "artificialization" of flow all disrupt the transfer of nutrients downstream, including the coastline area. In the Canadian context, this could be particularly significant since 51% of managed watersheds are drained into Hudson Bay[15]. The average freshwater flow to Hudson Bay has dropped by 13% from 1964 - 2000 and the winter snowmelt is less intense[16]. However consequences on the primary production of Hudson Bay have not yet been well evaluated.

Hydropower: limited GHG emissions relative to other sources of energy production

The notable advantage of hydroelectricity compared to thermal electricity is that it does not emit GHGs by burning carbon or "fossil" energy. However, degradation of organic matter will also produce GHGs. The GHG production of a reservoir is difficult to quantify because of its spatial and temporal variability, but there is qualitative scientific consensus on three elements: the flooding of large areas of boreal forest will (1) stimulate degradation of the most unstable organic matter and (2) typically generate a flow of GHGs (CO_2 and CH_4) for 5-20 years, according to the Global Forest Watch report[17]. Yet even after depletion of the flooded unstable organic matter, (3) GHG emissions from a reservoir are higher than those of natural lakes and continue to be so for decades, due to the large tidal range that erodes organic matter in the banks and due to *in situ* production of more unstable organic matter in reservoirs[18]. Recent quantitative work across Canada suggests gross emissions range from 0.5-48 kg of CO_2 per MW/h produced[19]. It must therefore be noted that these emissions are about 10-15 times lower than those of conventional coal power plants, per unit of energy produced.

Dialogue for green hydropower in Canada

Most of the socio-environmental imbalances caused by hydroelectricity generation in Canada are due to: impoundment of large boreal land areas flooded solely to produce energy; the mercury contamination of commonly eaten fish populations; and production and emission of GHGs. These imbalances are magnified by the exclusive industrial management of the reservoir, which produces irregular drawdown ranges of several meters' amplitude. Implementation and management of environmentally sustainable and socially acceptable reservoirs should be considered. Hydroelectric reservoirs should not only be regarded as single mega-volumes of water solely driving turbines according to energy needs, but also as artificial aquatic ecosystems requiring appropriate management to achieve socio-ecological balance. Turbining should be achieved in a manner that minimizes abrupt fluctuations in water levels and simulates natural flows as much as possible. For all existing hydroelectric dams, as well as those yet to be built, multiple uses of water reser-

S. (2009). River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? Progress in Oceanography, 80: 199-217.

15 Lee, P. G., Hanneman, M. and Cheng, R. (2012). Hydropower Developments in Canada: Number, Size and Jurisdictional and Ecological Distribution, Global Forest Watch, Edmonton, Alberta.

16 Déry, S. J., Stieglitz, M., McKenna, E. C. and Wood, E. F. (2005). Characteristics and trends of river discharge into Hudson, James, and Ungava Bays, 1964-2000. Journal of Climate, 18: 2540-2557.

17 Lee, P. G., Hanneman, M. and Cheng, R. (2012). Hydropower Developments in Canada: Greenhouse Gas Emissions, Energy Outputs and Review of Environmental Impacts, Global Forest Watch, Edmonton, Alberta.

18 Weissenberger, S., Lucotte, M., Houel, S., Soumis, N., Duchemin, E. and Canuel, R. (2010). Modeling the carbon dynamics of the La Grande hydroelectric complex in northern Québec. Ecological Modelling, 221: 610-620.

19 Environment Canada (2011). National Inventory Report 1990-2009: Greenhouse Gas Sources and Sinks in Canada - Executive Summary, http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=a07097EF-8EE1-4FF0-9aFB-6c392078d1a9

voirs should be considered, whether related to energy, recreation, transport of goods or fishery resources. Moreover, planning of new hydroelectric dams should consider, over the period of decades, minimizing GHG productions from their reservoirs by minimizing the ratio of surface flooded to unit of energy produced (for example, by having reservoirs in steep valleys or run-of-the-river dams). These are some of the objectives of Hydro Québec's 2009-2013 Strategic Plan, realized with the construction of four dams along the Romaine River. The flooded area (279 km^2) is relatively modest, which will limit the impact on GHGs and mercury methylation. However, the project's detractors rightly criticize the loss of riparian wetlands and the inevitable fragmentation of the river continuum. Finally, the large open bodies of water of hydroelectric reservoirs could also be used for wind energy production, which can be channelled through existing transmission lines.

Table 1. Inventory of hydroelectric generation in each province in Canada

	Number of large dams[20]	Surface area of hydroelectric reservoirs (km^2) [20]	Share of hydropower in total electricity production (%)	Export	Import	Length of transmission lines (km)	Potential and planned sites [21]
Alberta	57	166	6 [21]	-	3% [22]	-	2
British Columbia	93	4 589	22.3 [22]	Yes[22]	Occasional[23]	-	9
Prince Edward Island	0	0	0	0	-	-	-
Manitoba	40	7 136	96 [23]	31,3% [23]	-	12 800 [23]	11
New Brunswick	16	97	22 [24]	Occasional[24]	Occasional[24]	6 849 [24]	-
Nova Scotia	34	240	9 [25]	-	5% [25]	5 300 [25]	-
Ontario	114	7 370	23 [26]	-	Yes[26]	-	85
Quebec	325	24 108	96 [27]	12% [27]	Occasional[27]	33 900 [27]	20
Saskatchewan	44	6 348	20 [28]	0 [28]	Yes[28]	-	1
Newfoundland & Labrador	85	7 500	80 [29]	0 [29]	20% [29]	3 700 [29]	2
Nunavut	0	0	0	-	-	-	-
Northwest Territories	5	162	76 [30]	-	-	-	-
Yukon	4	5	94 [31]	-	-	-	-
TOTAL	**817**	**58 015**	**63** [20]	**Yes**	**-**	**-**	**130**

20 Lee, P. G., Hanneman, M. and Cheng, R. (2012). Hydropower Developments in Canada: Number, Size and Jurisdictional and Ecological Distribution, Global Forest Watch, Edmonton, Alberta.

21 Energy Alberta, http://www.energy.alberta.ca

22 BC Hydro https://www.bchydro.com

23 Manitoba Hydro http://www.hydro.mb.ca

24 Energie NB Power http://www.nbpower.com

25 Nova Scotia Power http://www.nspower.ca

26 Ontario Ministry of Energy http://www.energy.gov.on.ca/en/

27 Hydro Québec http://www.hydroquebec.com/about-hydro-quebec/

28 Sask Power http://www.saskpower.com/

29 Newfoundland Power https://www.newfoundlandpower.com/

30 Northwest Territories Power Corporation https://www.ntpc.com/

31 Yukon Government http://www.energy.gov.yk.ca/index.html

ABOUT THE INITIATIVE

SUSTAINABLE CANADA DIALOGUES

This contribution is part of a collection of texts, *Acting on Climate Change: Extending the Dialogue Among Canadians*, stemming from interactions between Sustainable Canada Dialogues, an initiative of the UNESCO-McGill Chair for Dialogues on Sustainability, and business associations, First Nations, non-governmental organizations, labour groups, institutions, organizations and private citizens.

Sustainable Canada Dialogues is a voluntary initiative that mobilizes over 60 researchers from every province in Canada, representing disciplines across engineering, sciences and social sciences. We are motivated by a shared view that putting options on the table will stimulate action and is long overdue in Canada.

Together, the contributions enrich the scope of possible solutions and show that Canada is brimming with ideas, possibilities and the will to act. The views expressed in *Acting on Climate Change: Extending the Dialogue Among Canadians* are those of the contributors, and are not necessarily endorsed by Sustainable Canada Dialogues.

We thank all contributors for engaging in this dialogue with us to help reach a collective vision of desired pathways to our futures.

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