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GHG Fluxes (CO

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GHG Fluxes (CO₂, CH₄) of the first three years after flooding of the Eastmain-1 reservoir (Quebec, Canada)

Alain Tremblay, Claude Demers and Julie Bastien

Growing concern regarding the long-term contribution of freshwater reservoirs to atmospheric greenhouse gases (GHG) led Hydro-Québec, the largest electric power company in Canada, to study net GHG emissions from Eastmain-1 reservoir, which are the emissions related to the creation of a reservoir minus those that would have been emitted or absorbed by the natural systems over a 100-year period. Follow up of the CO₂ and CH₄ fluxes showed a rapid increase in both CO₂ and CH₄ emissions the first year after flooding and a rapid return to natural aquatic ecosystems values within 2 and 3 year for CH₄ and CO₂, respectively. Overall GHG emissions from Eastmain-1 reservoir are very low in comparison to thermal power plant.

1 Introduction

The major greenhouse gases (GHGs) are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (IPCC 2001). These gases are emitted from both natural aquatic (lakes, rivers, estuaries, wetlands) and terrestrial (forest, soils) ecosystems as well as from anthropogenic sources (e.g., reservoirs; Cole et al. 1994, Hope et al. 1994) and are crucial for life on earth as they contribute to maintain a mean annual temperature of about 15°C. Hydropower plants represent about 20 % of the world's electricity generation capacity. According to IAEA (1996), hydroelectric power plants emit 35–70 times less GHGs per terawatt-hour than thermal power plants. Nevertheless, there is a growing concern to determine the contribution of freshwater reservoirs to the increase of GHGs in the atmosphere (e.g., St. Louis et al. 2000, Tremblay et al. 2004). Most of the data available in literature are gross emissions measured at the surface of the water bodies and from established reservoirs (>10 years old; e.g. Tremblay et al. 2005, Bastien & Tremblay 2009). Net emissions are the emissions related to the creation of a reservoir minus those that would have been emitted or absorbed by the natural systems over a 100-year period. The evaluation of the net GHG emissions from reservoirs is becoming more and more relevant to ensure that methods of energy

production are compared adequately and for CO₂ credits evaluation (Tremblay et al. 2005). In overall gross emissions of boreal reservoirs, degassing and bubble fluxes are very small, therefore we only present here, gross diffusive emission of a young boreal reservoir in a context of the first study evaluating net GHG emissions from a reservoir.

2 Study area and methodology

The Eastmain-1 reservoir is located in the boreal ecoregion of Quebec, Canada at 54°N about 1 000 km north of Montreal (Fig. 1). The Eastmain-1 powerhouse is equipped with 3 turbines generating 160 MWh each for a total of 480 MWh. The main dam, along with 33 dikes, form the Eastmain-1 reservoir with a surface area of 603 km². More details can be found in Demarty et al. (2008)

Over fifty stations were spread over natural lakes and rivers, the new Eastmain-1 reservoir (1, 2, 3 years) and the old Opinaca reservoir (>30 years). They were visited either with a hydroplane or a 8 m boat. Sampling was realized mainly during ice free season (May to October) but we have also sampled during winter (December to March) to a lesser extent to calculate the GHG concentration under the ice and an annual GHG flux (from ice melting to ice build-up).

CO₂ and CH₄ fluxes were measured with a floating chamber with a surface area of 0.2 m². The floating chambers technique is widely used for measurement of GHG fluxes over water bodies (e.g., Duchemin et al. 1999). The air is sampled through an opening at the top of the floating chamber and is returned at the opposite end of the chamber. This configuration allows the trapped air to be continuously mixed and enables a more representative measurement of gas concentrations (Lambert & Fréchette 2005). The CO₂ is measured with a NDIR (Non-Dispersive Infrared) instrument (PP-System model Ciras-SC), and CH₄ is measured with a FTIR (Fourier Transform Infrared) instrument (Temet, Gasetmet DX-4010). The gas measurement accuracy is 0.1 % and 1 % for the NDIR and FTIR instruments, respectively. The instrument takes continuous reading, and the data logger stores a value every 20 seconds over a period of 5 to 10 minutes. All samples are plotted on a graph to obtain a slope and to calculate the flux of CO₂, CH₄, or N₂O per m². More details can be found in Lambert & Fréchette (2005) and Demarty et al. (2008a,b). CO₂ and CH₄ fluxes were also calculated using the dissolved gas concentration, the Thin Boundary Layer equation and Cole and Caraco (1998)'s gas transfer coefficient. CO₂ concentrations were measured with an EGM-4 from PP Systems and CH₄ concentrations were analysed with a gas chromatograph.

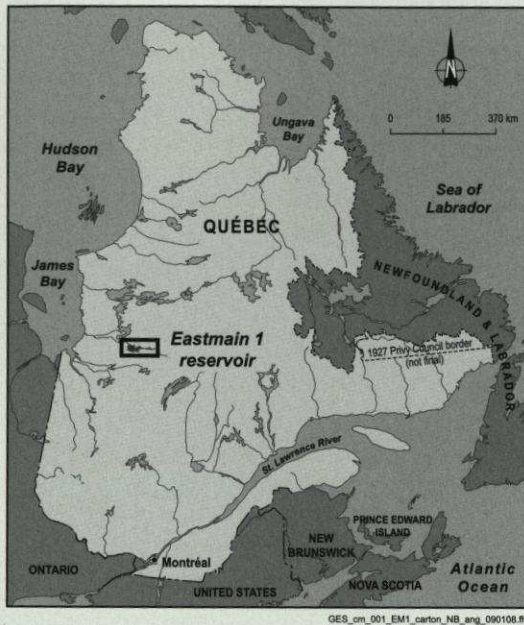


Figure 1 Location of the Eastmain-1 reservoir area, Quebec, Canada

The Eastmain-1 Reservoir Net GHG Emissions Research Project (EM-1 net GHG project, www.eastmain1.org) is a 7-year research project started 3 years before the beginning of flooding of the reservoir in November 2005. The filling of the reservoir took 7 months. This is done in partnership with McGill University, University of Québec in Montréal and Environnement Illimité Inc. In the EM-1 project, many other measuring techniques such as automated systems measuring CO₂ and CH₄, mapping of CO₂ dissolved in surface waters, dissolved concentrations of CO₂ and CH₄ and Eddy covariance systems are also used and the results are reported elsewhere. Net GHG emissions will be determined by adding or subtracting the fluxes from natural systems that were present before impoundment to those related to the creation of the reservoir.

Various physico-chemical and meteorological variables were measured at each station: geographic coordinates, depth, water and air temperature, wind speed, dissolved oxygen, pH, alkalinity, and water transparency. More details can be found in Demarty et al. (2008a,b)

3 Results and discussion

Mean CO_2 emissions from the newly flooded Eastmain-1 Reservoir were about 5 times higher (mean $6580 \pm 3567 \text{ mg CO}_2 \text{ m}^{-2} \text{ d}^{-1}$; Fig. 2) the first year after flooding (2006) than those of natural aquatic ecosystems before impoundment (2003–2005: mean $1352 \pm 1431 \text{ mg CO}_2 \text{ m}^{-2} \text{ d}^{-1}$) the first year after flooding (2006). These emissions decreased rapidly the second year after flooding (2007), with a mean about 2 times lower (mean $3042 \pm 1776 \text{ mg CO}_2 \text{ m}^{-2} \text{ d}^{-1}$; Fig. 2) and returned to values not significantly different than natural aquatic ecosystems the third year after impoundment (2008: mean $1943 \pm 1176 \text{ mg CO}_2 \text{ m}^{-2} \text{ d}^{-1}$; Fig. 2)

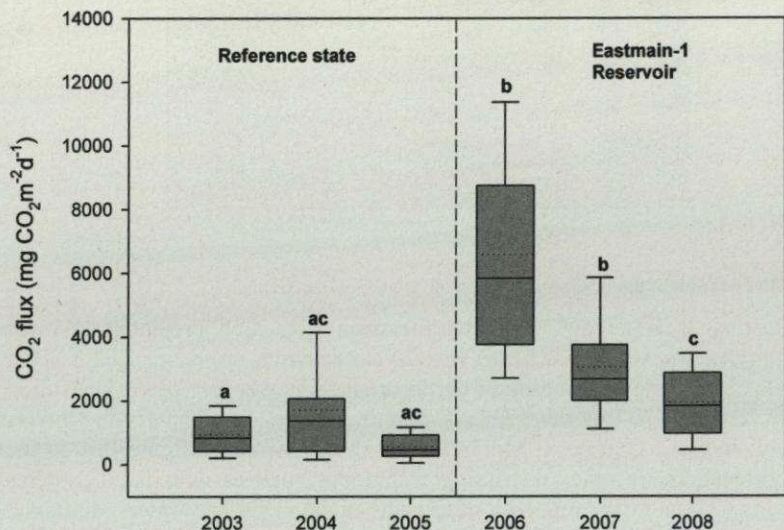


Figure 2 Mean CO_2 fluxes ($\text{mg CO}_2 \text{ m}^{-2} \text{ d}^{-1}$; dotted lines), medians (solid lines), 25th and 75th percentiles (boxes), and 10th and 90th percentiles (error bars) measured in Québec aquatic ecosystems. Similar letter means that the data are not significantly different, different letters means that the data are significantly different. Data are from various instruments and techniques.

Similar results were also observed the first few years after flooding in Ste-Marguerite, Toulouste reservoirs on the north shore of the St. Lawrence River, and at LaForge-1 in Northern Québec. Many parameters can influence the GHG fluxes such as water residence time, the type of flooded vegetation (peat, forest soils, agricultural lands, etc.) and the ratio of surface area flooded to water volume. These parameters influence both the intensity (the maximum fluxes reached) and the duration of these emissions. Generally, in boreal ecosystems, the CO₂ maximum flux is reached within the first year and the time to return to natural values is always within the first 10 years after impoundment. The increase of GHG emission in the newly formed reservoir is always coupled to an overall increased biological production (fish communities, invertebrates, planktonic communities, etc., Tremblay et al. 2005). Because trees barely decomposed, the CO₂ emitted is related to the natural decomposition of a fraction of the labile organic matter of flooded soils. After this transition period (<10 years), CO₂ emissions are comparable to natural water bodies and are related to the carbon entering the reservoir as runoff from the watershed, the reservoir effect is over after that period.

Mean CH₄ emissions from the newly flooded Eastmain-1 reservoir increased the first year after flooding to about 4 times higher (2006: mean $7.8 \pm 9.5 \text{ mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$) than those of natural aquatic ecosystems before impoundment (2003–2005: mean $1.7 \pm 1.8 \text{ mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$) and returned to values not significantly different than natural aquatic ecosystems the second year after impoundment (2007: mean $3.2 \pm 3.1 \text{ mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$; Fig. 3). In the third year, EM-1 reservoir fluxes are still comparable to natural aquatic ecosystems (2008: mean $1.4 \pm 1.7 \text{ mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$). Reservoirs built in boreal ecosystems generally have a well oxygenated water column from the surface to the bottom which favours CH₄ oxidation by methanotrophic bacteria at the sediment surface (Frenzel et al, 1990). Most of the CH₄ is produced in deeper anoxic sediment and very little CH₄ is reaching the reservoir water surface, therefore CH₄ fluxes are rarely an issue in boreal ecosystems.

Both CO₂ and CH₄ fluxes measured in aquatic ecosystems of Eastmain-1 area are comparable to those reported in the literature for boreal natural lakes and reservoirs on the Cote-Nord and James Bay region of Quebec and Labrador (Demarty et al. 2008a,b, Bastien et al. 2009, Tremblay & Bastien 2009).

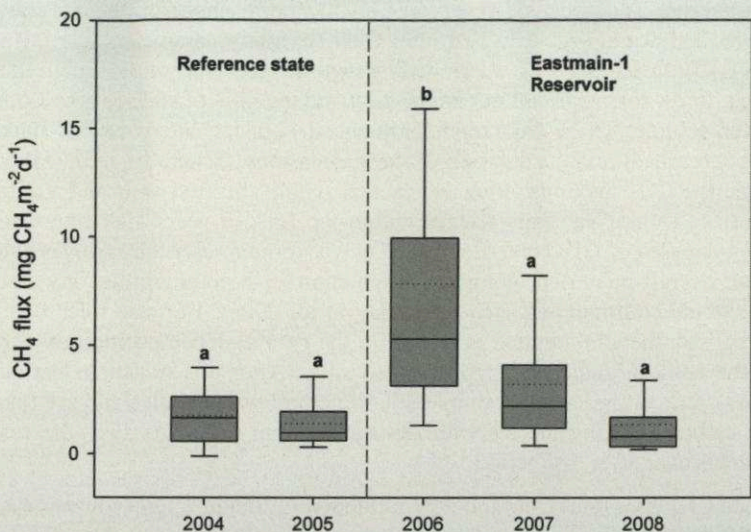


Figure 3 Mean CH_4 fluxes ($\text{mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$; dotted lines), medians (solid lines), 25th and 75th percentiles (boxes), and 10th and 90th percentiles (error bars) measured in Québec aquatic ecosystems. Similar letter means that the data are not significantly different, different letters means that the data are significantly different. Data are from various instruments and techniques.

4 Conclusions

Our study have shown that the overall gross GHG emissions from Eastmain-1 reservoir are low, with CH_4 and CO_2 emissions similar to natural aquatic systems, respectively within 2 years and 3 years after impoundment, which are well within the 10 years generally observed for boreal reservoirs (Duchemin et al. 2006).

Reservoir surface area to volume ratio is a key parameter in GHG emissions. When designing a new hydroelectric project, one should aimed at having the smallest surface area flooded and the biggest water volume as possible to reduce overall GHG emissions to most benefit from the future CO_2 credits. With a relatively small surface area and a very short water residence time for an installed capacity of about to 500 MW, the Eastmain-1 reservoir is a good example of project emitting small amount of GHGs. The most efficient thermal power plant, natural gas combined cycle, emit about 380 000 tons of CO_2 equivalent per TWh, which is 23 times more than EM-1 (Tremblay et al. 2008).

This good EM-1 reservoir performance will be improved as an additional 780 MW power plant is being installed with the construction of the Eastmain-1A-Rupert diversion.

Measurements of GHG emissions from boreal hydroelectric reservoirs are now available and they are clearly indicating that boreal hydroelectric reservoirs are low GHG emitters. Boreal hydropower plants should therefore be considered as part of the solution to reduce the impact of climate change.

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