A REVIEW OF THE QUESTION OF HYDROPOWER GENERATION AND GREENHOUSE GAS EMISSIONS

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Abstract

Some important questions regarding dam debate relating greenhouse gases are uncertain until now. The hydro reservoirs like as others human induced projects have several effects on the environment. These effects are very well studied over two last decades.

Hydropower reservoirs like as other natural water bodies have intense biota, since microorganisms to aquatic vertebrates. The microorganism (bacteria) decomposes the organic matter producing biogenic gases under water. Some of these biogenic gases are effective in terms of global warming such as methane, carbon dioxide and nitrous oxide.

The dam impoundment changes the carbon movement by flowing much slower than the original river. This new condition favors the establishment of phytoplankton and nutrients increase in which methanogenesis replaces the oxidative water generating biogenic gas production.

To determine accurately the net emissions caused by hydro reservoir formation is required significant improvement of carbon budgets studies on different representatives' hydro reservoirs at tropical, boreal, arid, semi arid and temperate climate.

GHG emissions from hydro reservoir are a subject of extreme strategic importance and comparisons with other types of electric generation like as thermopower should be required.

To promote comparisons, the emissions by the equivalent thermo-power plants must be calculated and characterized as generating the same annual amount of energy as each power dams, burning different fuels and with technology efficiency levels that vary from steam turbines to coal, fuel oil / natural gas turbines and combined cycle.

This paper brings the state-of-the-art regarding this subject and some proposals for future studies.

1 - Introduction

Regarding the question of greenhouse emissions from hydroelectric reservoirs the studies are much more recent. Researchers are been identified significant fluxes of CO_2, CH_4 and N_2O from the air-water interface at the beginning of 90´s (*Rudd et al*. 1993; Rosa and Schaeffer 1994; *Duchemin et al*. 1995; *Galy-Lacaux et al.* 1997). Other important contributions are (Galy-Lacaux, 1999; *Delmas et al.* 2001; *Rosa et al.* 2003; *Soumis et al.* 2004; *Tremblay et al.* 2004).

These studies have important uncertainties. Many questions arise from the development of this research like as the data extrapolation of one area to another as well as from one reservoir to another and the behavior of emissions along the time and possible sources of organic matter for decomposing process.

2 - The sources of gas emissions from hydro reservoirs

Initially the bottom of the reservoir contains flooded biomass (mainly terrestrial vegetation and detritus before the dam impoundment) and other organic matter that falls from water column that decomposes by bacteria.

Bacteria decompose the organic matter anaerobically, producing as a by-product principally CH_4 and N_2, and secondarily CO_2. In aerobic decomposition only CO_2, N_2O and N_2 are produced.

At the bottom of the reservoir there is the flooded terrestrial biomass and some fresh sediment formed by plankton decay and other organic matter detritus. The decomposition of this fresh organic matter demands oxygen at higher rates than diffusion can supply from the atmosphere, thereby establishing an anaerobic regime.

The gas emitted from the decomposition of flooded biomass is a fraction of total of gas produced within the reservoir, because the live organisms have distinct demands of dissolved gases in the water and are producers at the same time.

The gas emitted by the reservoir originates, then, from decomposition of material from three sources. One is the original flooded biomass, the other is the biomass formed during the ongoing photosynthesis always under way in the water of the reservoir and the third is the organic matter that comes from the watershed. The decomposition of the original biomass progressively reduces the stock of carbon moves towards biological inertia, and thus its proportion of the emissions of gases diminishes over time.

3 - Fluxes of greenhouse gases into and out of reservoir

The greenhouse gases are generated molecularly and initially stay dissolved in the interstitial water within the sediments. But in the case of less soluble methane and nitrogen gas, these segregate into bubbles.

These bubbles grow in size until they can no longer be retained within the sediments, and they break free and rise to the surface.

Carbon dioxide tends to remain in solution because it is more soluble, but a small fraction enters the bubbles formed. Not all the methane generated is transported in the vertical gradient of the water by bubbles.

Part of it diffuses through the water in the direction of the surface. But on the way through the upper layers there is a growing concentration of oxygen. In the water column it is possible to both gases react with the oxygen and trend to be suffer oxidation action.

There is a gradient of dissolved gas from the bottom to the surface. The gas concentration is more intense at the bottom and when goes to the direction of surface exist a great diminishing of this concentration.

Important transportation of gas from the bottom to the surface is promoted by advection and convection processes.

At the water/atmosphere interface there is a continuous process of gas exchange. The gases dissolved in the water emanate to the air and the components of the air dissolve in the water. In this process a dynamic equilibrium tends to be established, which is reached for a given gas when its rate of emanation is equal to that at which it dissolves.

The diffusion processes relevant to this work can be easily represented if the concentration of each gas is expressed in terms of partial pressure. In the gaseous phase the partial pressure of a given component is the fraction of the total pressure, which results from that component.

The bacteria at oxygenated layer of the reservoir are probably a sink for methane, which even has the capacity to break the methane molecule. In some conditions could be a depletion of the methane concentration contained in the water column, producing a flow of methane from air to water. Similarly, photosynthesis forms a sink for carbon dioxide, and there can also be a flow of this gas from the atmosphere to the water.

Along with the gases emitted, during decomposition biologically inert residues are formed, which are humus and humic and fulvic acids, and the latter can be leached out, carried by the water or fix in the permanent sedimentation at depth layers of sediment (the insoluble and inert phenol residue, humus, that can be incorporated into the bottom of the reservoir as sediment, and which, together with the silica and clay sediments, can proceed to fossilization). These inert compounds are phenol polymers and originate principally from lignin, present in woody material

At the bottom of the reservoir there is lower boundary at the surface below which all carbon is permanent (i.e. not susceptible to mobilization and on its way to fossilization). There is a boundary is somewhere between 5–20 cm below the water-sediment interface. At this depth humic substances are already resistant to further carbon decomposition and the carbon goes to the fossilization functioning like as a sink of carbon produced within the reservoir.

4 – Previous Studies and Recommendations

Four previous important reports address recommendations for research of greenhouse gases and hydro reservoirs: the Hydro-Quebec Meeting in Montreal (WCD, 2000b), the World Commission on Dams (WCD, 2000c), the Rio GHG Working Team Report (Sikar et al., 2001) and the Lannemezan Working Group Report (Delmas et al., 2004). The most important for further research into greenhouse gas emissions by power-dams, based on the points listed below:

a) Carbon dioxide and methane form during the decomposition of organic matter. In dams, the source of organic matter may be submerged pre-existing biomass, dissolved organic carbon and particulate organic carbon (DOC and POC) swept down from neighboring onshore areas, as well as biomass generated within the dam itself. N_2O forms also by denitrification process within the water column and at the bottom of reservoir;
b) Until now only `gross emissions` has been studied in several parts of world. The term 'gross emissions' means gas flux measurements from the reservoir surface without natural pre-impoundment emissions by natural bodies such as the river channel, seasonal flooding and terrestrial ecosystems. The net emissions result from deducting pre-existing emissions by the reservoir;
c) The intensity of gases emissions in a dam reservoir does not remain unchanged over time. There are fluctuations over periods whose duration also varies. However, the variation is modulated by a set of influences, with the main factors being: temperature, wind system, sunshine, physical and chemical water parameters and biosphere composition;
d) The mean values obtained until now have a level of uncertainty and new research on GHG emission from hydro reservoirs require improvement like as on line measurements by long periods of time;
e) The experimental measures and assessment of specific sites can give only a partial view, reservoirs vary greatly from one to another. However, such studies are necessary to supply data on the variability issue;
f) Due to the variability within and among the dams, we must to be extrapolate with criteria the data from one reservoir to another, far less estimate the global contributions of these power-dams;
g) The compared findings indicate quite clearly that the problem should be analyzed on a case-by-case basis, as significant variations may occur from one hydro-plant to the next.
h) The full life-cycle assessment should be included in future studies, as well as consider emissions pre-existing dam construction. Carbon cycle studies, like the preliminary experience conducted here should be encouraged, to determine carbon origin (natural and anthropogenic) in the whole watershed area;
i) It is important to include in the IPCC a discussion of the role of the GWP index in comparing thermo power and hydro reservoir emissions;
j) The carbon emitted to the atmosphere by the free surface of the water in hydroelectric reservoirs comes in part from organic material carried from the headwaters areas to the bed of large rivers and to the hydroelectric reservoirs. If this carbon, in the case of CO_2 emissions, is

from biomass, then it was previously removed from the atmosphere and thus its emission does not result in increased greenhouse effect. Thus the problem emerges of quantifying these contributions and the emissions of CH_4 and N_2O. This requires studies of the carbon cycle in the watershed/reservoir system;

k) At some dams, it was noted that the operating system may also influence gas emissions. Depending on how the plant is operated, the water level in its dam may drop rapidly, exposing its shallower branches to periodic colonization by land-based plants.

l) It is important study the role of accumulation basin of the reservoirs in provide a sink of carbon by sedimentation at the bottom of reservoir. A better knowledge of fossilization processes of organic matter as humic and fulvic acids can be stimulated;

m) Future studies should include emissions caused through downstream release by the turbines. It is important assesses the contribution of downstream dams by water passing by turbines. With regard to the concentration of dissolved gases downstream, we consider that a profile along the river some kilometers away from the dam will be enable to establish were gas emission are intense and equal to or less than those in the surface water of the dam;

5- Methods

Regarding measurement methodologies were essentially the same in all cases. At each of the selected dams, emissions of carbon dioxide, methane and nitrous oxide were assessed by sampling, whether produced through bubbles or diffusive water-air exchanges, extrapolating these findings to obtain a value for each dam. The intensity of these emissions varied widely, due to factors that included temperature, measurement point depth, wind system, sunlight, physical and chemical water parameters, biosphere composition and the operating system of the dam in question.

All this suggests greater difficulties in separating out the anthropogenic emissions from emissions that would occur even without the dam.

Because of these factors, together with the limited number of dams studied, and the space and time constraints of the samples, these findings are somewhat uncertain.

The measured values for hydro-power plants include emissions that are not fully anthropogenic.

Monitoring studies over lengthy periods should be encouraged in order to draw up an emissions behavior curve.

The main scientific dispute is centered on extrapolating emissions measured at selected parts of the dam to the total area of the reservoir.

About models according the report edited by (Tremblay et al, 2005) the following information will be necessary:

-Inter calibrate sampling and measuring GHG techniques and optimize sampling strategies in order to increase spatial and temporal coverage;

-Measure GHG over a wider range and diversity of reservoirs to determine temporal and spatial heterogeneity for both ebullitive and diffusive emissions;

-Measure GHG from reference sites, such as rivers, lakes, forested areas and wetlands in order to determine temporal and spatial heterogeneity;

-Determine the proportion of GHGs emitted in relation to the carbon inputs from flooded soils or sediments and from the drainage basin;

-Determine the transience of carbon in reservoirs, natural lakes and downstream estuaries.

Concerning experimental works, the main points to concentrate efforts are presented in reference (Santos, M. et al in Tremblay et al, 2005):

- the mean values obtained until now have a level of uncertainty and new research on GHG emission from hydro reservoirs require improvements like on line measurements;
- the experimental measures and assessment of specific sites can give only partial view as emissions from reservoirs vary greatly from one to another. However, such studies are necessary to supply data on the variability issue;
- the full life-cycle assessment should be included in future studies, as well as consider emissions pre-existing dam construction. Carbon cycle studies should be encouraged, to determine carbon origin (natural and anthropogenic) in the whole watershed area;
- Carbon emitted to the atmosphere by the free surface of the water in hydroelectric reservoirs comes in part from organic material carried from the headwaters areas to the bed of large rivers and to hydroelectric reservoirs. If this carbon, in the case of CO_2 emissions, is from biomass, then it was previously removed from the atmosphere and thus their emission does not result in increased greenhouse effect.

Thus the problem emerges of quantifying these contributions and the emissions of CH_4 and N_2O. This requires studies of the carbon cycle in the watershed/reservoir system.

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