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The International Rivers Network statement on GHG emissions from reservoirs, a case of misleading science

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GHG emissions from reservoirs:
an issue that has been studied in the last 10 years

Between 1993 and 1999, GHG emissions at the surface of reservoirs were measured on many boreal reservoirs and a few tropical reservoirs. It was then assumed that dams were responsible for these emissions, that were caused by decomposition of the flooded biomass. The state of science has advanced significantly in 2000 and 2001, notably because of more extensive measurement programs, on a wider variety of ecosystems. These programs are helping to build consensus on many issues, changing completely the original perception:

- Most of the flooded biomass at the bottom of reservoirs has not decomposed after decades under water.
- The quantity of flooded and decomposed biomass is much too small to explain the measured level of emissions. It can only explain the short-term pulse in emissions measured in the first few years after impoundment.
- After these first few years, GHG emissions from reservoirs are similar to those of nearby natural lakes. Many research programs have confirmed significant GHG emissions at the surface of all water bodies (reservoirs, natural lakes and rivers).
- These emissions, either natural or from old reservoirs, are mainly due to organic carbon that is flushed in reservoirs from surrounding ecosystems.
- As a consequence, there is now strong evidence that considering only GHG measurements at the surface of reservoirs would be misleading and these measurements represent "gross" emissions. "Net" emissions for which dams are responsible must consider the emissions from ecosystems before building the dam. This is clearly stated in the report of the World Commission on dams:

> WCD p. 76 *"Calculations of the contribution of new reservoirs to climate change must therefore include an assessment of the natural pre-dam emission or sink in order to determine the net impact of the dam"*.

Appendix A at the end of this paper is a summary of research steps required to produce an accurate estimate. There appears to be no controversy on the method, only on the interpretation of various research data and on what can be considered a typical hydro project.

IRN report entitled "Flooding the land, warming the earth"

The International Rivers Network has recently published a report which concludes that many hydropower plants emit more greenhouse gas emissions than thermal generation. This conclusion is based on a few selected estimates, using worst cases of gross emissions, chosen to achieve the goal of discrediting hydropower.

IRN essentially quotes 4 sources, 3 of which are long-time opponents of hydropower:
- For tropical reservoirs, IRN quotes articles by Philip Fearnside who has spent the last 30 years opposing any project of any type in the Amazon region. P. Fearnside has not made measurements of GHG emissions from reservoirs. He has made theoretical calculations on potential emissions that are quoted by IRN as the state of science.
- For boreal reservoirs, IRN quotes mainly Eric Duchemin who is an environmental activist of the Union Québécoise pour la Conservation de la Nature, a Canadian environmental group that has opposed any hydro project in the last 15 years.
- For boreal reservoirs, IRN also quotes a report from Philip Raphals, a long-time opponent to hydro projects. But Philip Raphals was recently under contract by IRN, to write a report in which he mainly quotes Eric Duchemin !

To add to its false credibility, IRN then refers to a table in the World Commission on Dams report, which shows very high emissions from the Tucurui plant in Brazil. It neglects to mention that the WCD is also quoting the same article by Philip Fearnside. The WCD added the following comments (which were omitted by IRN):

> WCD report p. 77 *"Background emissions from natural pre-impoundment habitats have not yet been measured for Tucurui, so true comparisons of net emissions with alternatives remain elusive"*

IRN also ignored some key publications that contradicts most of their conclusions:

- Richey, J.E., J.M. Melack, A.K Aufdenkampe, V.M. Ballester, L.L.Hess, "Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO_2", *Nature*, vol. 416, 11 April 2002, p. 617-20
- Cole, J.J., N.F. Caraco, "Carbon in catchments: connecting terrestrial carbon losses with aquatic metabolism", *Marine & Freshwater Resources*, 2001, 52, p. 101-10
- Melak, J.M., B.R. Forsberg, "Biogeochemistry of Amazon Floodplain Lakes and Associated Wetlands", in *The Biogeoschemistry of the Amazon Basin*, Oxford University Press, 2001, p. 235-74
- Devol, A.H., J.I. Hedges, "Organic Matter and Nutrients in the Mainstem Amazon River", in *The Biogeoschemistry of the Amazon Basin*, Oxford University Press, 2001, p. 275-306
- Piedade,M.T.F., Martin Worbes, W.J. Junk, "Geoecological Controls on Elemental Fluxes in Communities of Higher Plants in Amazonian Floodplains", in *The Biogeoschemistry of the Amazon Basin*, Oxford University Press, 2001, p. 209-34
- Hope,D., S.M. Palmer, M.F. Billett, J.J.C. Dawson, "Carbon Dioxide and methane evasion from a temperate peatland stream", *Limnology and Oceanography*, (46)4, 2001, p. 847-57
- Tremblay, A., M. Lambert, J.L. Fréchette et L. Varfalvy, 2001. Comparison of Greenhouse Gas Emissions from Hydroelectric Reservoirs and Adjacent Lakes. *28th congress of the Societas Internationalis Limnologiae* (SIL), February 2001, Melbourne, Australia.
- Schetagne, R., 1994. Water quality modifications after impoundment of some large northern reservoirs. Arch. Hydrobiol. Beih., 40: 223-229.

We will discuss the implications of these publications in the next few pages.

The real issue: Do reservoirs emit more GHG than the natural ecosystems they replace?

These articles show that natural aquatic ecosystem are emitters of GHG emissions, at a level similar to those measured on reservoirs. Scientific uncertainty persists, mainly because of the distinction between "gross" emissions (measured) and "net" emissions. But the state of research allow the following general statement : "gross" emissions (measured on reservoirs) systematically overestimate the level of GHG emissions for which reservoirs are really responsible, because these measurements do not factor in the emissions that would have occurred in the absence of a dam.

In the future, it is possible that "net" emissions from reservoirs will be assessed at close to zero. This conclusion is now premature but many dimensions of recent research point in that direction:

1. Tropical rivers, floodplains and wetlands, in their natural state, are large emitters of greenhouse gases.
2. Natural lakes and rivers, in boreal and temperate climate, have level of emissions similar to reservoirs older than 10 years.

3. Dams have little effect on overall emissions, because virtually all the carbon flowing in rivers tend to be emitted to the atmosphere and only a very small fraction will sediment permanently in the ocean.
4. In tropical forests, seasonal rain naturally floods huge areas, that have similar ecological conditions as tropical reservoirs.
5. In boreal reservoirs, a few years after impoundment, aquatic productivity and water quality are similar to natural lakes.
6. Contrary to popular perceptions, forests are only very modest, not large carbon sinks.

Each of these topics will be discussed further.

1. The GHG emissions from natural tropical rivers, floodplains and wetlands

The article by J. E. Richey *et al*. on Amazonia arrive at the following main conclusion:

> (In abstract, p. 617) *"outgassing (evasion) of CO_2 from rivers and wetlands of the central Amazon basin constitutes an important carbon loss process, equal to 1.2 (+ or – 0.3) Mg Carbon per ha per year. This carbon probably originates from organic matter transported from upland and flooded forests, which is then respired and outgassed downstream."*

This overall emission rate (per ha) is about half the rate that has been measured on some tropical reservoirs. Much scientific uncertainty remain concerning these estimates, but they do show that using gross emissions to assess the contribution of reservoirs would be misleading.

Research on Amazonia also confirms that flooding of forest ecosystems is not specific to the creation of reservoirs. Naturally, the seasonal weather patterns create very large flooded areas:

> J. E. Richey *et al*., p. 102 *"As computed from the radar mosaics, the flooded area of the mainstream and tributaries rose from 79 000 km^2 (about 4% of the quadrant area) in October 1995 to 290 000 km^2 (16% of the quadrant area) by May-June 1996."*
> M.T.F. Piedade *et al*., p. 210 *"...the estimated extent of floodplain areas can reach 1,350,000 km^2 or about 27% of total area of the Amazon."*

2. GHG emissions from natural lakes and rivers, in boreal and temperate climate

In the article by Cole and Caraco, data on 46 rivers is presented. The authors make the following conclusion:

> J.J. Cole *et al*., p. 102 *"This paper demonstrate that a majority of large rivers for which we can obtain data are net sources of CO_2 to the atmosphere."*
> p. 105 For the Hudson river studied in detail *"The 8-year record of direct measurements of pCO_2 showed that the water was consistently supersaturated in CO_2 with respect to the atmosphere, indicating that the Hudson is nearly always a net source of CO_2 to the atmosphere."*

Specific emission levels are not presented for each of these rivers but concentration of CO_2 in the water is always many times the concentration in the atmosphere, leading to inevitable outgassing from the river.

Specifically in boreal and temperate climate, many measurements have been made to compare natural lakes with reservoirs. Research in Quebec (A. Tremblay et al.) and in

Finland show that emissions from natural lakes are similar to those of reservoirs older than 10 years. A research on a natural Scottish upland stream (D. Hope) also concludes to high levels of CO_2 and methane emissions.

3. Dams have little effect on overall emissions, because virtually all the carbon flowing in rivers tend to be emitted to the atmosphere and only a very small fraction will sediment permanently in the ocean.

Some opponents to hydro projects have accepted the need to define "net" emissions, but claim that dams will slow down the flow of carbon to the ocean, allowing for a more important portion of flowing carbon to be decomposed and emitted. They assume that, without dams, much of this carbon would be permanently sedimented (stored) in the ocean. Both articles from Richey *et al.* and Cole and Caraco strongly contradict these claims.

> J. E. Richey *et al*. p. 618 *"the waters of the Amazon export about 13 times more carbon by CO_2 evasion to the atmosphere than by the export of total organic carbon or of dissolved inorganic carbon to the ocean."*

This quote shows that the effect of dams cannot be significant because, in natural conditions, nearly all the flowing carbon will generate GHG emissions. Cole and Caraco addressed the issue even more directly, by looking at the age of carbon in nearby ocean sediments. They also conclude that there is nearly complete decomposition of flowing carbon in natural watersheds:

> J.J. Cole *et al*., p. 101 *"It is tempting to equate riverine delivery with sedimentary burial or dissolved organic carbon accumulation in the ocean but, intriguingly, new chemical and isotopic evidence suggests that very little of this terrestrial carbon actually accumulates in the ocean. The inference is that it must decompose on the continental margins, in river deltas or perhaps in the lower reaches of the river themselves."*
> p. 109 *"This high rate of decomposition of terrestrial organic matter in the lower reaches of some rivers may help to explain, in part, a large question in the global carbon cycle, that terrigenous material leaves land but does not accumulate in the ocean".*

4. In tropical forests, naturally flooded areas have similar ecological conditions as tropical reservoirs.

In his calculations, P. Fearnside managed to multiply the overall emissions from tropical reservoirs by assuming that new reservoirs create large areas of *varzea* ecosystems, characterized by intense development of macrophytes, which can increase emissions of methane. One quote summarizes how he uses this approach to dramatize reservoir emissions:

> Philip M. Fearnside, "Greenhouse Gas Emissions from a Hydroelectric Reservoir (Brazil's Tucurui Dam) and The Energy Policy Implications", *Water, Air and Soil Pollution*, 133: 69-96, 2002, p. 69-96
> p. 75 *"In seven studies in Varzea (floodplain) lakes, areas with macrophytes had 3.25 times mores CH_4 emissions than open water. At Tucurui, in September 1992, an area with macrophytes had 1056 times more CH_4 emission by bubbling than open water in the river channel, 0.8 times as much as open water with standing trees, and 5.8 times as much as open water in a cove without standing trees".*

These comparisons may be true, but they are totally irrelevant because they compare various ecosystems, without considering which ecosystems existed before or after the creation of the reservoirs. The following quotes describes the **natural** floodplain role and conditions:

> J.M. Melak, B.R. Forsberg, p. 246 "Floodplain lakes and their associated wetland habitats play an important role in the organic carbon balance of the Amazon River system… They are also a major source of methane and other biogenic gases to the troposphere"
> p. 248 "At lowest water, the surface area of many lakes is reduced and much of the lake bed is dry mud flats. These dry areas are colonized by a variety of perennial and annual macrophytes. Some of these plants have both terrestrial and aquatic growth phases… When flooded, the obligate terrestrial species die and decompose while transitional species continue growing as emergent aquatic macrophytes and dominate the herbaceous plant community during the early rising water period. As these water levels continue to rise, some of these species become free-floating and, together with other obligate floating species form and extensive floating meadow community… When the water level falls, the aquatic macrophyte community begins to decompose"

The last quote can be used to describe either natural conditions or reservoirs conditions. And as mentioned before, these floodplain ecosystems are extensive in natural conditions: 16% of area in one study and it can represent up to 27% of all Amazonia. To understand the extent of these natural conditions, it is relevant to mention that the normal water fluctuations are **10 meters**:

> A. H Devol, J.I. hedges, p. 277 *"The seasonal cycle of discharge in the Amazon mainstem is accompanied by a dramatic change of roughly ten meters in river height. At high water the river overflows its banks and enters the surrounding floodplain through a complex network of channels. Within Brazil, the floodplain is typically 10-50 km wide and is occupied by numerous permanent and seasonal lakes. Extensive flooded forests and beds of floating grasses plus other macrophytes also cover the mainstem floodplain (Varzea)."*

P. Fearnside and IRN assume, without demonstration, that hydro reservoirs increase dramatically the area of floodplain ecosystems. It is probably true that new floodplain ecosystems are created in the periphery of new reservoirs, but a fair assessment must consider the fact that, prior to impoundment, floodplain ecosystems existed in the area of the reservoirs. These large sources are replaced by deep water in the main portion of the reservoir, dramatically reducing methane emissions. So overall, it is possible that this is a zero-sum issue.

5. In boreal reservoirs, a few years after impoundment, aquatic productivity and water quality are similar to natural lakes.

If uncertainty persists on tropical reservoirs, detailed research has been conducted on boreal reservoirs for more than 20 years. The results of this research has been published in various papers by R. Schetagne (Hydro-Quebec) and others by Dolors Planas (Université du Québec à Montréal). They conclude that, after 5 to 10 years, parameters of water quality have come back to levels similar to natural lakes: pH, turbidity, color, nutrients, etc. Primary and secondary production (plancton, zooplankton and fish) are also back to natural levels.

6. Forests are not large carbon sinks

When authors want to dramatize the issue of GHG emissions from reservoirs, they often claim that reservoirs replace forests that are large carbon sinks. This is clearly a methodological mistake, that looks strictly at photosynthesis. For example, IRN quotes an article by V. St-Louis, who produced an assessment of Canadian reservoirs, based on the following rate of carbon fixation by boreal/temperate forests: 2100 mg CO_2/m^2/day, or 0,57 g C /m^2/day or 2 tonnes of C /Ha/year.

This type of estimate is at the base of calculations of "net" emissions from reservoirs. But if we simply extend this rate to the fact that boreal and temperate forests have been there for at least 10 000 years, there should be, on the ground, 20 000 tonnes of carbon per Ha. In the boreal forest, research has established that the quantity is about 108 tonnes of organic mater per Ha, or about 50 tonnes of carbon per Ha.

So V. St. Louis estimate of the rate of carbon fixation of forests is **400 times too high**. This huge error can be explained by the fact that two important factors were neglected:
- Forest fires occur, in boreal forests, at a regular interval of 60 to 100 years, returning a large portion of the carbon to the atmosphere.
- Another large portion (leaves) of the carbon fixation by forests is flushed in various water bodies, creating natural emissions from lakes, reservoirs and rivers.

This has an important effect on defining "net" emissions, both in boreal or tropical climate: **forests appear as sinks and aquatic ecosystems appear as sources, but in reality, the overall carbon balance is probably close to zero, no matter if a dam has been built or not.**

Conclusion on future research needs

Recent research tend to show that dams, over a few decades, do not change significantly the carbon balance of ecosystems. This could be confirmed by detailed research looking at the amount of carbon stored at the bottom of reservoirs, in forest soils, in river deltas and in the lower reaches of rivers.

More measurements of emissions are also needed to reduce uncertainties, over many types of ecosystems:
- In delta or estuary of rivers, in boreal, temperate and tropical climate;
- In a wider variety of tropical ecosystems.
- Measurements are also needed in arid or semi-arid conditions, where reservoirs have never been studied.

Another area where more research is required is methane (CH_4) emissions from tropical reservoirs, natural wetlands and naturally flooded forests. This issue is important due to the fact that the *global warming potential* of one kg of CH_4 is 23 times stronger than a kg of carbon dioxide (CO_2),

The 2001 IPCC report confirms the large uncertainty on wetlands:

> (p. 194) "The balance between CH_4 release and CO_2 uptake and release is highly variable and poorly understood".
> "Local emissions from most type of natural wetland can vary by a few orders of magnitude over a few metres"

Another key issue is defining the areas involved, both before and after reservoirs are created. This does not seem to have ever been studied. But again, it would be a methodological mistake to assume that reservoir only create wetlands, never replace existing wetlands.

Opponents to hydro projects must become more coherent:
- When discussing GHG emissions, they blame reservoirs for creating new wetlands, increasing methane emissions.
- When discussing biodiversity, they blame reservoirs for destroying existing wetlands, removing important ecological habitat.

In reality, this is possibly a zero-sum issue, new wetlands replacing old wetlands. Detailed research on this issue would surely be useful to those who want to produce, in good faith, an accurate estimate of life-cycle emissions of hydropower.

Conclusion on IRN report

The IRN report is misleading in many ways, because it gives the impression that there is scientific consensus that dams have high emissions levels. First, there is no consensus and second, most of the scientific evidence points to very low emissions.

For a typical boreal reservoirs (63 km^2 / TWh), a reasonable estimate of "gross" emissions is 11 kt of CO_2 equivalent / TWh. These GHG emissions are 90 times lower than those of coal-fired power plants and 35 times lower than emissions from efficient natural gas plants. And this comparison is based on "gross" emissions of reservoirs, which exaggerate their real emissions.

Appendix A: The research steps required to define GHG emissions from reservoirs

The creation of a hydro reservoir will modify ecological processes in the flooded terrestrial ecosystems. This modification affects GHG emissions from ecosystems: input of CO_2 and output of CO_2, CH_4 and N_2O.
To correctly estimate GHG emissions, it is essential to determine the emissions from the various ecosystems in the watershed **before and after** creation of the reservoir. This will make it possible to calculate the **"net" emissions** for which the reservoir is responsible. Emissions measured directly on reservoirs must be regarded as "gross" emissions.

First research step: Determine net emissions <u>per square meter</u>
Based on the current state of knowledge, several factors must be taken into consideration in determining net emissions from reservoirs. A simple equation can be written, with each element defined in the table below:

"Net" emissions = "Gross" emissions - A - B - C + D - E

"Net" =	
"Gross"	Emissions, as measured directly over reservoirs
minus A	Portion of gross emissions due to exchanges of inorganic carbon, that are not a net source of atmospheric CO_2
minus B	Portion of gross emissions that would have occurred even without a reservoir (emissions due to decomposition of organic matter)
minus C	Emissions reduction due to the fact that reservoir cover such sources as wetlands
plus D	Loss of long-term storage of carbon within the flooded area, for example in forest soils
minus E	Long-term storage of carbon as sediments in reservoirs

Second research step: Determine <u>annual</u> reservoir emissions, <u>per unit of energy</u>
The next step is to extrapolate the estimate per square meter to a whole reservoir, or to a group of reservoirs in one hydro complex. In theory, this step should assign a specific emission factor (per m^2) for each zone of a reservoir, depending on the type of ecosystem flooded, depth, currents, etc. The surface area of each zone should be quantified and multiplied by the appropriate emission factor.

Third research step: Determine reservoir emissions, <u>per unit of energy for the life-cycle</u>
The third step is to estimate the change in emissions over a long period. This can be done by examining similar reservoirs of different ages. The total emissions over the life of the reservoir should then be divided by the amount of energy to be produced over that period.

Fourth research step: Determine <u>representative</u> reservoir emissions, per unit of energy
When comparing energy options, site-specific projects may not be known and there is a need to define what is a representative hydro project. An average size of reservoir should be used.