Dead trees from the Balbina reservoir.
(Photo: Marcio Ruiz, ruizmarcio@gmail.com)

Dirty Hydro:

DAMS AND GREENHOUSE GAS EMISSIONS

Hydropower is often believed to be an inherently "climate-friendly" technology. But scientific studies indicate that the rotting of organic matter in reservoirs produces significant amounts of the greenhouse gases carbon dioxide, methane and nitrous oxide. The warming impact of tropical reservoirs can be much higher than even the dirtiest fossil-fuel power plants.

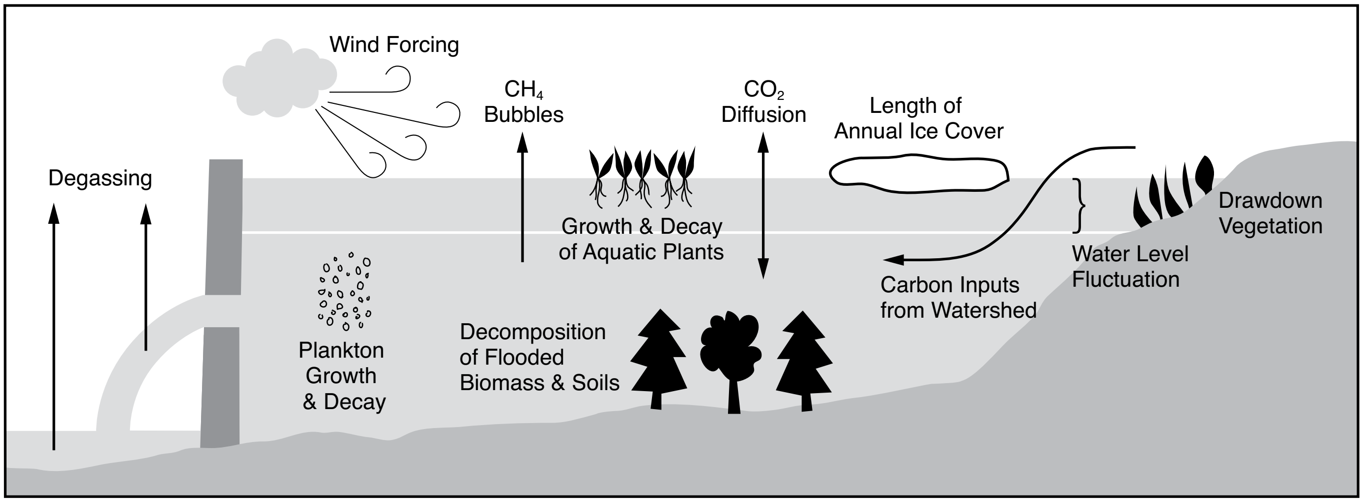
HOW DO DAMS BOOST GLOBAL WARMING?

Carbon dioxide (CO_2) is formed by the decomposition of organic carbon in the reservoir. The main sources of this carbon are the vegetation and soils flooded when the reservoir was first filled; organic matter washed into the reservoir from upstream (which may be from natural ecosystems, farms or sewage); plankton and aquatic plants which grow and die in the reservoir; and the vegetation that grows on the "drawdown" land temporarily exposed during low reservoir periods (Figure 1). Reservoirs absorb atmospheric CO_2 due to photosynthesis by plankton and aquatic plants; this uptake can occasionally exceed CO_2 emissions.

Methane (CH_4), a greenhouse gas that is 25 times more potent than CO_2, is formed by bacteria that decompose organic matter in oxygen-poor water and reservoir-bottom sediments. The lowest layer of water in tropical reservoirs tends to be depleted in oxygen. A portion of the methane is oxidized to CO_2 as it rises to the reservoir surface. Shallow tropical reservoirs where bubbles have less time to become oxidized tend to have the highest methane emissions. New research suggests that methane production could be higher in small reservoirs in temperate zones than previously thought (see Box 1).

Nitrous oxide (N_2O) is a powerful greenhouse gas formed by the bacterial breakdown of nitrogen. There have been only a handful of measurements quantifying nitrous oxide fluxes from reservoirs. Emissions appear to be minor from boreal regions,[1,2] but significant for at least some tropical reservoirs.[3] Since N_2O is almost 300 times more potent than CO_2, more studies are imperative to better quantify its emissions.

FIGURE 1: A SCHEMATIC OF KEY FACTORS INFLUENCING RESERVOIR GREENHOUSE GAS EMISSIONS.



HOW ARE THE GASES EMITTED?

The gases are released via diffusion across the water surface, in bubbles that rise from the reservoir bottom, and in the downstream degassing of water released through turbines and spillways. When water from below the surface of the reservoir is discharged at the dam, the pressure acting upon it suddenly drops and – according to the chemical principle of Henry's Law – it is able to hold less dissolved gas. Degassing emissions are also due to the greater air/water interface created when water is pulverized at the bottom of a long spillway.

Dissolved greenhouse gases in reservoir water that are not released at the spillway and turbine may be emitted to the atmosphere further downstream. Elevated emissions of CO_2, CH_4 and N_2O were detected up to 40 kilometers downstream of the Petit Saut Reservoir in French Guiana.[4] In the case of the Balbina Reservoir in Brazil, downstream emissions of methane represented the equivalent of 3% of all methane released from the central Amazon floodplain.[5]

The major component of the warming impact of boreal reservoirs is diffusive CO_2; the major component of the warming impact from the surfaces of tropical reservoirs is methane bubbles. For at least some tropical reservoirs the majority of their warming impact is due to methane degassing.

WHAT IS THE DIFFERENCE BETWEEN NET AND GROSS EMISSIONS?

Ideally, a calculation of the warming impact of reservoirs should be based on *net* emissions. This requires adjusting measurements of gross emissions at the reservoir surface and dam outlets to allow for whatever sinks and sources of greenhouse gases existed in the reservoir zone before submergence, the uptake of carbon through photosynthesis in the reservoir, and the impact of the reservoir upon the pre-dam flows of carbon throughout the wider watershed.

It is particularly difficult to assess the net impact of dams upon CO_2 fluxes. Net CO_2 emissions may be significantly smaller than gross emissions, mainly because some of the carbon emitted from the reservoir will be offset by the consumption of atmospheric CO_2 by plankton through photosynthesis. The difference between net and gross emissions for methane is not likely to be significant, since reservoirs produce such huge amounts of methane relative to background fluxes.

A team of Brazilian researchers led by Elizabeth Sikar has calculated fluxes of greenhouse gases before and after construction of Manso and Serra da Mesa dams in the Brazilian *cerrado* (savanna) ecosystems. The researchers found that the flooding switched the *cerrados* from a source to a sink of CO_2. In contrast, the reservoirs produced significant net emissions of methane and turned nitrous oxide sinks into sources.[6]

Another study quantified the carbon fluxes after the construction of five small dams in Canada and concluded that the primary source of emissions was the rotting of flooded organic matter,[7] which contributes to net emissions. A carbon balance calculation carried out for the Petit Saut Reservoir in French Guiana found that the carbon and methane emissions during the first ten years were primarily due to the inundation of the vegetation, which means that the emissions can be considered net.[8] Forests in the Amazon are carbon sinks, while the region's aquatic ecosystems are a source of roughly the same order of magnitude. Researchers believe that net CO_2 emissions from the areas flooded by Amazonian reservoirs were approximately zero prior to dam construction.[9]

Accurately calculating the global warming impact of dams requires a life-cycle analysis, which should include the impacts of dam construction and decommissioning. Dam construction releases greenhouse gases due to the use of fossil fuels by machinery and the production of building materials, in particular cement. Construction emissions could make

The Flatulent Wohlensee

Wohlensee, a small run-of-river hydro reservoir in central Switzerland, emits 780 metric tonnes of methane a year, according to a recent study from Eawag, the Swiss Federal Institute of Aquatic Science and Technology.[1] The study only measured methane bubbles at the reservoir surface: Actual emissions may be several times higher due to the degassing of methane at the dam's turbines and spillway, and in the river downstream.

It has usually been assumed that methane emissions are negligible from dam reservoirs in temperate regions and from run-of-river projects. Run-of-river dams have relatively small reservoirs and because of their small storage capacity, it was thought that water would not remain in the reservoir for enough time to form methane. This Eawag study throws both these assumptions into the air. The study also destroys the hydro industry's claims that reservoirs are only high emitters for their first decade or so after construction – the Wohlensee was built in 1920.

Wohlensee's methane bubbles have a warming impact equivalent to 119 grams of CO_2 for every kilowatt-hour generated. This is 10 times higher than emissions for wind power, if calculations take into account emissions during wind-turbine manufacture and installation. The comparison is not a fair one as it does not include the cement and fossil fuel consumption from building the Wohlensee, or the likely initial spike in emissions due to rotting vegetation when the reservoir was first filled.

Currently, run-of-river dams that apply for carbon credits from the Clean Development Mechanism do not have to account for any greenhouse gas emissions. The Eawag study suggests that these run-of-river projects are being granted permission to generate many more carbon credits than they deserve.

1. Del Sontro, T. et al. (2008) Wohlensee: Lake Flatulence and Global Warming, Eawag – Annual Report 2007, Switzerland.

up a significant component of the life-time emissions from a boreal dam, but would likely be insignificant compared to total emissions from a tropical project. Dam decommissioning may result in the mobilization of a significant amount of accumulated sediments, potentially leading to a large pulse of carbon emissions.

WHAT IS THE GLOBAL CONTRIBUTION OF DAMS TO GLOBAL WARMING?

Ivan Lima and colleagues from Brazil's National Institute for Space Research (INPE) have calculated that the world's large dams (those taller than 15 meters) emit 104 million metric tonnes of methane annually from reservoir surfaces, turbines, spillways and rivers downstream.[10] This calculation implies that dam methane emissions are responsible for at least 4% of the total warming impact of human activities. It also implies that dams are the largest single anthropogenic source of methane, being responsible for nearly a quarter of all methane emissions due to human activities.

HOW DO EMISSIONS FROM DAMS COMPARE TO THOSE FROM OTHER SOURCES?

Comparing hydroplants with other generating sources indicates that tropical hydropower can have an impact much worse than even the dirtiest fossil-fuel plants. The average "reservoir net"[11] emissions from tropical reservoirs is more than double that of conventional coal power plants (Figure 2). The worst known culprit is the Balbina dam in Brazil, which flooded a vast amount of forest to produce a relatively small amount of electricity. Its long-term "reservoir net" emissions are ten times greater than those from a coal-fired power plant.[12] (Because it is an outlier, Balbina is not included in the tropical reservoir average.)

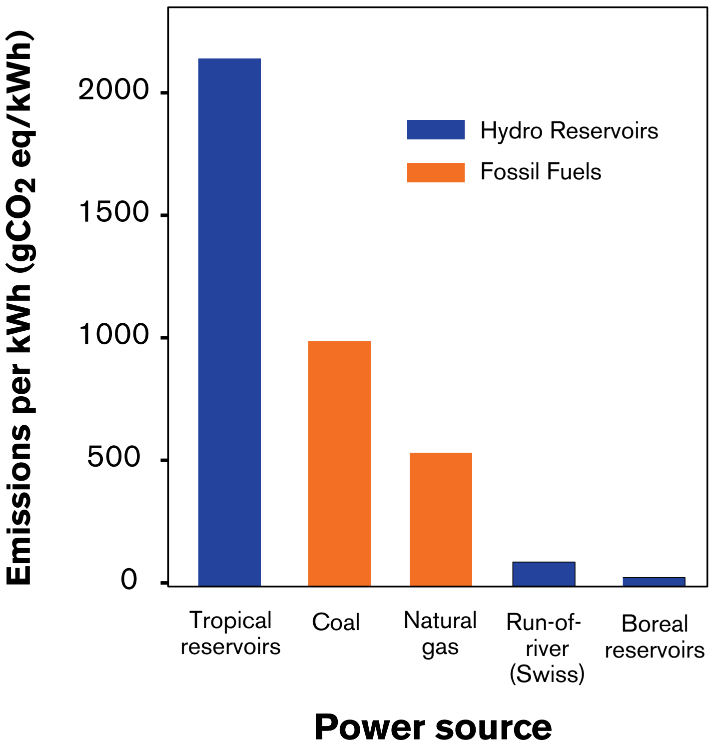
CONCLUSION

Although there has been more than a decade of serious scientific research into this issue, the belief that hydropower is inherently climate friendly is still common among policy makers. Part of the reason for this is that the science is complex and subject to numerous uncertainties. The hydro lobby has exploited these uncertainties, much as climate change deniers have exploited the uncertainties in climate science as a whole and used them to lobby decision makers not to take reservoir emissions seriously.

The Intergovernmental Panel on Climate Change (IPCC) needs to do more to dispel the myth of carbon-free large dams. One important step they should take is to deal with the issue in their forthcoming Special Report on Renewable Energy and Climate Change, which also includes hydropower. The IPCC should also make it obligatory for countries to report reservoir methane emissions in the greenhouse gas inventories mandated by the UN climate convention.

The International Hydropower Association has recently launched a major study on greenhouse gases and reservoirs and is lobbying the IPCC and the UN's Clean Development Mechanism to accept its conclusions. Clearly the results of an industry-group led and funded research project cannot be accepted as reliable without thorough and unbiased scientific review.

FIGURE 2: COMPARISON OF RESERVOIR EMISSIONS WITH FOSSIL FUELS



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Boreal Reservoirs:

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Comparison of emissions per kilowatt-hour (gCO_2 eq/kWh) for various power sources. The tropical reservoir bar represents the "reservoir net" average emissions from three Brazilian reservoirs (Tucuruí, Curuá Una and Samuel). The boreal reservoir bar represents the gross average emissions from five Canadian reservoirs (Sainte-Marguerite, Churchill/Nelson, Manic Complex, La Grande Complex and Churchill Falls). Run-of-River bar refers to the Wohlensee reservoir in Switzerland (see Box). Gross emissions are reported, but degassing is not included. The hydropower emissions listed are only for a single year and so not necessarily representative of their lifetime emissions. The reservoir emissions include carbon dioxide and methane emissions, but not nitrous oxide. A 100-year Global Warming Potential (GWP) of 21 is used for methane to convert its impact into carbon dioxide equivalent (CO_2 eq). The Kyoto Protocol uses a methane GWP of 21; the most recent IPCC assessment gives a methane GWP (100 years) of 25.

ENDNOTES

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4 Ibid.

5 Kemenes, A. et al. (2007) Methane Release Below a Tropical Hydroelectric Dam, *Geophysical Research Letters*, 34.

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9 Ibid.

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11 "Reservoir net" is a calculation for estimating net emissions from reservoirs. It accounts for pre-dam sources and sinks of greenhouse gases. It is not a complete net accounting because it does not include the impact of the reservoir upon carbon flows along the whole length of the river.

12 Kemenes et al. (2008) op.ite cit.