FLOODING THE LAND, WARMING THE EARTH

Greenhouse Gas Emissions from Dams

International Rivers Network

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About IRN

International Rivers Network (IRN) is a nongovernmental organization which supports local communities working to protect and restore their rivers and catchments. Since 1985, IRN has worked to halt and reverse the degradation of river systems and to encourage equitable and sustainable methods of meeting needs for water, energy and flood management. We work to promote the wise management of the planet's freshwater resources, to link environmental protection with human rights, to create a worldwide understanding of river ecology, and to reveal the interdependence of rivers' biological, physical and cultural aspects.

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INTRODUCTION

Hydropower lobbyists are eager to promote dams as “climate-friendly.” They hope to benefit from the potentially huge amounts of money to be generated through carbon trading mechanisms intended to curb global warming. But a growing body of scientific evidence shows that hydropower is not as climate-friendly as its proponents have assumed.

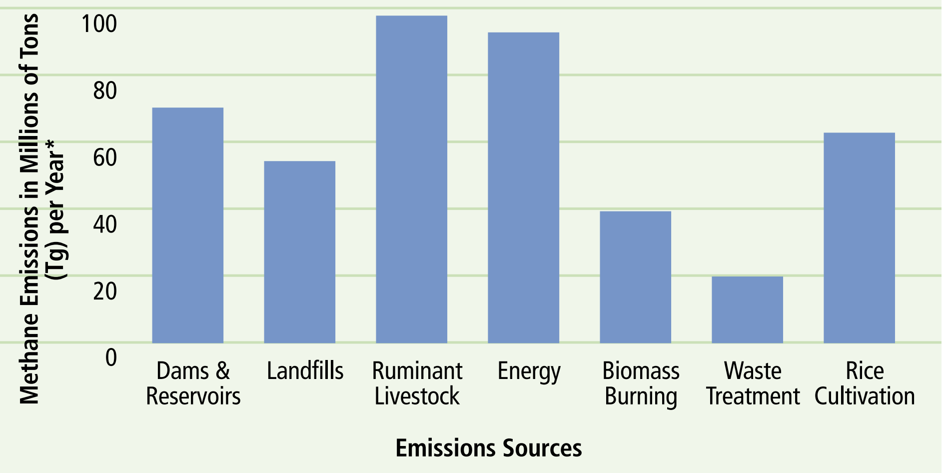
Recent research indicates that dams and their associated reservoirs are globally significant sources of emissions of the greenhouse gases carbon dioxide and, in particular, methane. Scientists have done field studies of emissions of one or both gases at some 30 reservoirs, mostly in Canada and Brazil. Emissions were recorded at all the reservoirs surveyed.

Dams and their associated reservoirs are globally significant sources of emissions of the greenhouse gases carbon dioxide and, in particular, methane.

Gases are produced in reservoirs due to bacteria breaking down organic matter in the water. Methane, a much more powerful greenhouse gas than carbon dioxide, is produced by bacteria in oxygen-poor zones common at the bottom of reservoirs.

Emissions from tropical reservoirs are typically between five and 20 times higher per unit of area flooded than those from reservoirs in temperate and boreal regions. Per unit of electricity generated, the climate change impact of hydropower in Canada and the northern US appears to be well under half that of natural gas power plants (although the advantage of hydropower would be much less if compared to the best fossil fuel option, gas cogeneration plants which make use of the “waste” heat from fuel combustion). The worst tropical reservoirs, however, can contribute many times more to global warming than coal plants generating the same amounts of power.

FIGURE 1 Estimated Methane Releases from Major Anthropogenic Sources



Sources:

For dams and reservoirs, see V.L. St. Louis *et al.* (2000) "Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate," *BioScience* 50:9.

For all other emissions sources, see Intergovernmental Panel on Climate Change (2001) *Climate Change 2001: The Scientific Basis.* *Bars represent midpoints of estimate ranges.

GLOBAL RESERVOIR EMISSIONS

A first attempt at calculating the global contribution of reservoirs to climate change was made by a team of Canadian researchers headed by Vincent St. Louis of the University of Alberta. The research was published in *BioScience*, the journal of the American Institute of Biological Sciences, in 2000.

St. Louis and his colleagues estimate that reservoirs of all types and sizes worldwide release 70 million tons of methane and around a billion tons of carbon dioxide annually. These figures equal about one-fifth of the estimated methane emissions from all other human activities (see Figure 1) and four percent of the carbon dioxide from other known human-related sources. Reservoir releases of the two gases combined contribute an estimated seven percent of the global warming impact of other human activities calculated over a 100-year period. (According to large-dam industry estimates, a quarter of the world's reservoir surface area has been created to provide hydropower — the remainder is primarily for irrigation and water supply.)

The Canadian researchers stress there are numerous uncertainties in the assumptions used to calculate these initial estimates. The results could be either much lower or much higher using different assumptions for average methane emissions per unit of reservoir surface, and for the total area covered by reservoirs. The estimated contribution to global warming of reservoirs would be considerably higher than seven percent if measured over a shorter time span than 100 years.

EMISSIONS INVENTORIES

The various United Nations processes dealing with climate change have largely overlooked the issue of reservoir emissions. The UN's Intergovernmental Panel on Climate Change (IPCC) does not include reservoirs as a source of emissions in its latest listing of greenhouse gas sources, published in its 2001 *Third Assessment Report*. The IPCC did mention reservoirs in its 1996 recommendations for how countries should produce inventories of their emissions from land use change and forestry. But the mandatory guidelines for producing reports of national emissions under the Kyoto Protocol do not include reservoirs. The mandatory guidelines are produced by the Subsidiary Body for Scientific and Technological Advice of the UN Framework Convention on Climate Change. (A new set of IPCC inventory guidelines forthcoming in 2003 will include detailed information on measuring emissions from flooded land. But these IPCC recommendations are separate from the mandatory guidelines under the Kyoto Protocol process.)

Excluding reservoirs from national emissions inventories could significantly under-represent the actual contribution to climate change of some countries, especially of those in the tropics with large reservoir areas such as Brazil and Ghana. According to Éric Duchemin of the University of Quebec at Montreal, accounting for reservoir emissions could increase Canada's estimated greenhouse gas output by around three percent, and the country's electrical sector emissions by around 17 percent.

Seventeen of the world's leading researchers on reservoir emissions met in Montreal in February 2000 at a workshop hosted by Hydro-Quebec and sponsored by the World Commission on Dams (see box on page 4). One of the key conclusions from the meeting was that emissions should be considered in assessments of individual reservoirs and in global inventories of greenhouse gas sources and sinks (see box on page 6).

"It's baloney and it's much overblown… Methane is produced quite substantially in the rain forest and no one suggests cutting down the rain forest."

Spokesperson for the US National Hydropower Association responding to reports of greenhouse gas emissions from reservoirs, 1995

SOURCES OF EMISSIONS

Emission levels vary widely among reservoirs depending upon such factors as the area and type of ecosystems flooded, reservoir depth and shape, the local climate, the way in which the dam is operated and the ecological, physical and socio-economic characteristics of the dammed river basin. Emissions can also vary widely among different parts of the same reservoir (largely due to changes in depth, exposure to wind and sun, and growth of aquatic plants), and from year to year, season to season — and even between night and day.

The World Commission on Dams

The World Commission on Dams (WCD) was established by the World Bank and IUCN (The World Conservation Union) in May 1998 in consultation with a wide range of stakeholders. The 12 Commission members came from a variety of backgrounds, representing interests including governments and NGOs, dam operators and grassroots people's movements, corporations and academics, industry associations and consultants.

The WCD undertook by far the most comprehensive and independent review yet done of the world's dams. The Commission's final report *Dams and Development: A New Framework for Decision-Making,* was released by Nelson Mandela at a launch ceremony in London in November 2000.

The WCD concluded that while "dams have made an important and significant contribution to human development, and benefits derived from them have been considerable... in too many cases an unacceptable and often unnecessary price has been paid to secure those benefits, especially in social and environmental terms, by people displaced, by communities downstream, by taxpayers and by the natural environment."

The WCD's final report provides ample evidence that large dams have failed to produce as much electricity, provide as much water or control as much flood damage as their supporters originally predicted. In addition, these projects regularly suffer major cost overruns and time delays. Furthermore, the report found that:

- Large dams have forced 40-80 million people from their homes and lands, with impacts including extreme economic hardship, community disintegration and an increase in mental and physical health problems. Indigenous, tribal and peasant communities have suffered disproportionately. People living downstream of dams have also suffered from waterborne diseases and the loss of natural resources upon which their livelihoods depended.

- Large dams have caused great environmental damage, including the extinction of many fish and other aquatic species, huge losses of forest, wetlands and farmland. Attempts at mitigating these impacts have generally been unsuccessful.

- The benefits of large dams have largely gone to the rich while the poor have borne the costs.

What were the WCD's recommendations?

The Commission provides a new framework for decision-making on water and energy projects based on recognizing the rights of, and assessing the risks to, all stakeholders. Those who would be adversely affected should participate in the planning and decision-making process and have a share in project benefits. The Commission's main recommendations include the following:

- No dam should be built without the "demonstrable acceptance" of the affected people, and without the free, prior and informed consent of affected indigenous and tribal peoples.

- Comprehensive and participatory assessments of people's water and energy needs, and different options for meeting these needs, should be developed before proceeding with any project.

- Priority should be given to maximizing the efficiency of existing water and energy systems before building any new projects.

Specifically on climate-related issues the WCD recommends that comparisons of the costs and benefits of different development options should include assessments of net greenhouse gas emissions from dams. It also recommends that options assessments should take account of the vulnerability of different development paths to potential climate changes (see box on page 17).

The World Bank and many other international agencies, governments and companies have claimed that they will apply the WCD's core values and strategic priorities to their future dam-related activities. The UN Environment Programme has established a Dams and Development Project to disseminate and translate the WCD report and facilitate dialogues on the report.

See the World Commission on Dams at www.dams.org and the Dams and Development Project of UNEP at www.unep-dams.org.

Research indicates that most of the global warming impact of dams in boreal and temperate regions is from the diffusion of carbon dioxide into the atmosphere from the surfaces of their reservoirs. Diffusive carbon dioxide emissions also appear to contribute most to the climate impact of dams with deep tropical reservoirs. For shallow tropical reservoirs, current research suggests that methane bubbling up from the reservoir bottom contributes most to their climate impact.

Some researchers believe, however, that releases of dissolved methane from water being discharged from the dam may prove to be the largest component of the warming impact of tropical hydropower. A research group led by Corinne Galy-Lacaux of the Observatoire Midi-Pyrénées in Toulouse measured a significant volume of methane being released from water immediately downstream of the Petit Saut Dam in French Guyana. These downstream emissions were much greater than the total volume of methane emitted from Petit Saut's reservoir surface. The degassing occurs because the pressure acting on reservoir water suddenly drops when it is discharged through turbines or over a spillway.

Philip Fearnside of the National Institute for Research in the Amazon has predicted methane emissions at the turbines and spillway of the huge Tucuruí hydropower plant in Brazilian Amazonia. His estimates are based on the Petit Saut measurements together with data on methane concentrations in Tucuruí's reservoir. Fearnside calculates that emissions from degassing at Tucuruí's turbines and spillway in 1990 may have been up to eight times greater than emissions from the surface of the 2,850 square kilometer reservoir (1990, six years after Tucuruí reservoir began filling, is the base year for emissions inventories under the UN climate convention).

The Montreal Statement on Reservoirs and Greenhouse Gases

"Greenhouse gases are emitted for decades from all dam reservoirs in the boreal and tropic regions for which measurements have been made. This is in contrast to the widespread assumption (e.g. IPCC scenarios) that such emissions are negligible." *Montreal Statement.*

The World Commission on Dams convened a workshop on reservoir greenhouse gas emissions in Montreal in February 2000. The workshop, hosted by Hydro-Quebec, brought together 17 of the leading global researchers on the subject, including those funded or employed by the hydro industry.

Although the participants disagreed on a number of important issues they did agree on a consensus statement with the following main points:

- All reservoirs emit greenhouse gases, and continue to do so for, at minimum, decades.

- Analysis of emissions from reservoirs and their alternatives should be undertaken on the basis of net, rather than gross, emissions. This comparison should be done on a life cycle basis.

- The emissions should be considered in:

(a) evaluating future reservoir sites (particularly in tropical regions); and

(b) global inventories of anthropogenic changes in the sources and sinks for carbon dioxide and methane.

- Emissions of methane and CO_2 from water passing through turbines and over spillways may also be a significant source of these gases to the atmosphere.

- The use of the 100-year GWP for methane can significantly underestimate reservoir emissions over the first decades after reservoir filling.

The participants agreed that making informed development choices requires estimating net emissions from planned dams. To do this, it was agreed that the following must be assessed:

- carbon and nitrogen cycles in the pre-impoundment watershed,

- changes to carbon inputs in the watershed from various activities, including deforestation,

- characteristics of proposed reservoir(s) and inundated area(s) that will change the carbon cycle, and

- the cumulative emissions from multiple dams on a watershed basis in cases where a dam and its operations are linked to other dams.

In assessments of emissions from existing reservoirs it is necessary to measure "carbon flux in the whole catchment using long term assessments of the accumulation (in soils, peat, sediments) and export of carbon (to the ocean or to the atmosphere). Studies should take place over around three years…to increase the probability to get average values representative of long term emissions."

Agreement was also reached on the following priorities for future research:

- Measure emissions from a wider range and diversity of reservoirs.

- Measure emissions in a wider range and diversity of natural environments in countries that are currently building dams.

- Improve the understanding of the role of transient carbon in reservoirs and natural lakes.

- Study the role of oceans as repositories of carbon in sediments and how dams affect this.

- Study the fate of carbon in an undammed catchment compared to a dammed catchment.

See: World Commission on Dams (2000) "Dam Reservoirs and Greenhouse Gases: Report on the Workshop held on February 24 & 25. Hydro-Quebec, Montreal. Final Minutes," Thematic Review II.2 Dams and Global Change. <http://www.damsreport.org/docs/kbase/thematic/drafts/tr22_workshop.pdf>

Further research is needed to confirm whether such high volumes of methane are regularly emitted from tropical reservoirs. If discharge emissions are confirmed at other sites this could significantly increase estimates of the total global warming impact of dams.

Small quantities of nitrous oxide, a very potent greenhouse gas, have been measured diffusing into the atmosphere at a handful of reservoirs in the boreal and tropical regions. It is not yet known whether nitrous oxide is also emitted through bubbling. Tropical forest soils are a minor source of nitrous oxide so the net impact of tropical reservoirs may be to reduce slightly nitrous oxide emissions from the flooded area.

OTHER DAM-RELATED EMISSIONS

Emissions of greenhouse gases during dam construction due to the use of fossil fuels and the production of materials such as cement have been estimated for a couple of dams. These calculations indicate construction emissions are small in comparison with those released over the lifetime of a reservoir.

Emissions from the human activities that result from building the dam are potentially significant although these have not yet been calculated for any project. These secondary emissions would include deforestation caused by displaced farmers clearing new land, and new access roads built for construction which open areas previously inaccessible to development. Dams with an irrigation component may lead to increased methane emissions from newly watered farmland.

DECLINE AND STABILIZATION

In temperate and boreal zones, carbon dioxide emissions appear to decline by around two percent a year after reservoir filling, and then stabilize around two decades later. After this stabilization occurs, emissions seem to continue at a relatively constant level for many decades. Methane emissions show no clear pattern of decline as reservoirs age, whether in cool or hot climates. Tropical reservoirs, however, appear to emit a massive pulse of methane in the first year after filling. At Petit Saut, an initial pulse was measured which is estimated to represent around a quarter of the methane that would be released over the next 99 years of the reservoir's life.

Emissions continue over the lifetime of the reservoir partly because tree trunks and other woody matter can take an extremely long time to decompose (in some conditions tree trunks may last thousands of years). In addition, organic matter in a reservoir comes not just from flooded vegetation and soils, but also the detritus which is continuously washed in from its catchment, as well as the aquatic plants and algae which grow and die in the reservoir (for the same reasons, natural lakes also tend to be greenhouse gas sources).

Human activities upstream of a reservoir influence the carbon flowing into it and thus its emissions. Increases in deforestation, soil erosion and sewage would mean greater carbon in-flows and thus greater reservoir emissions. Carbon entering the oxygen-poor waters of a reservoir is more likely to produce emissions of methane — which is much more efficient at trapping heat than carbon dioxide — than carbon in a free-flowing river.

NET VS. GROSS EMISSIONS

Ecosystems are a complex mosaic of sources and sinks of carbon dioxide, methane and nitrous oxide. Most forests absorb carbon dioxide and methane while natural lakes are sources of both gases. Northern peatlands are carbon dioxide sinks but important methane sources (see Figure 2). Accurately estimating the impact of a reservoir on climate change therefore requires a calculation of its net emissions — the emissions measured from the reservoir plus the quantity of gases that would have been absorbed by any sinks that it flooded, minus the gases that would have been released from any greenhouse gas sources that it submerged.

net reservoir emissions = emissions from reservoir and discharged water + pre-dam greenhouse gas sinks lost due to dam and reservoir creation - pre-dam sources of greenhouse gases lost

FIGURE 2 Fluxes of Greenhouse Gases from Ecosystems

Ecosystem	Areal flux ($mg/m^2/day$)* CO_2	CH_4
Boreal/temperate forests	2100 ↓	1.0 ↓
Tropical forests	710 ↓	0.2 ↓
Northern peatlands	230 ↓	51 ↑
Lakes (worldwide)	700 ↑	9 ↑
Temperate reservoirs	1500 ↑	20 ↑
Tropical reservoirs	3000 ↑	100 ↑

** Downward arrows indicate net consumption by ecosystem (sinks). Upward arrows indicate net flux to atmosphere (sources).*

Source: V.L. St. Louis *et al.* (2000) "Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate," *BioScience* 50:9.

Some analysts have assumed that net emissions will always be less than gross emissions. But the magnitude and the direction of the difference between net and gross emissions will vary depending on the types of ecosystems flooded: net emissions may be less than gross emissions in some cases, but more than gross emissions in others.

COMPARING GASES

Methane is known to be a much more powerful greenhouse gas than carbon dioxide. But calculating exactly how much more a ton of methane contributes to climate change than a ton of carbon dioxide is complex. While methane is much more efficient at trapping heat than carbon dioxide, methane is much shorter-lived in the atmosphere.

The multiplier commonly used by scientists studying reservoir emissions to convert the impact of methane into "carbon dioxide equivalent" units is known as the 100-year Global Warming Potential (GWP). This represents the cumulative warming impact after 100 years of a one-time pulse into the atmosphere of a ton of methane compared to a ton of carbon dioxide. In its 2001 *Third Assessment Report*, the IPCC gives methane's 100-year GWP as 23, meaning that a ton of methane in the atmosphere should cause 23 times more warming than a ton of carbon dioxide. (The IPCC had previously used a 100-year GWP for methane of 21 — this older figure will be used in calculations of emission inventories in the Kyoto Protocol's first commitment period [2008-2012].)

If methane reservoir emissions were indeed a one-time event resulting from rotting biomass submerged when the reservoir was impounded, this "pulse" approach might be appropriate. Because the emissions are continuous, however, a different methodology is required.

Rivers, Dams and Biogeochemical Cycles

Rivers play an important, although still poorly quantified, role in the global cycles of carbon and nutrients such as nitrogen, iron and silicon. These cycles regulate the concentration of carbon dioxide in the atmosphere. By interrupting these cycles, dams could have a significant climate impact above and beyond that from their reservoir emissions.

Rivers carry downstream carbon and nutrients from eroded soils and dead plants and animals. Much of these are eventually washed out to the oceans. The oceans play a major role in the carbon cycle — there is some 50 times more carbon dioxide stored in the oceans than in the atmosphere.

When a river is dammed, much of the sediments and organic matter that it carries — in many cases more than 90 percent — will be trapped behind the dam wall. Some rivers, including the Nile and Colorado, now only reach the sea during high floods due to diversions for irrigation and municipal water supply. Charles Vörösmarty and Dork Sahagian of the University of New Hampshire estimate that globally dams have reduced sediment discharge to the oceans by 25-30 percent.

The loss of nutrients to inshore waters may have a significant climate impact. These nutrients are important in fertilizing oceanic plankton. Plankton in turn play a major role in absorbing carbon dioxide from the atmosphere. (The IPCC estimates that in the absence of oceanic plankton, atmospheric carbon dioxide concentrations would be 55 percent higher than present levels.)

The nitrates and phosphates trapped in reservoirs are more than compensated for by the run-off into rivers of agricultural fertilizers, sewage and industrial pollution. The same is not true for trapped silicates, which have no significant man-made source. Silicates stimulate the production of silica-shelled plankton known as diatoms. Diatoms are more efficient at carbon sequestration than non-siliceous plankton and, according to Venugopalan Ittekot, director of the Centre for Tropical Marine Ecology in Bremen, "play a crucial role in the biological uptake of carbon dioxide by the ocean."

Ittekot has found that diatom blooms in the Bay of Bengal occur only during the monsoon months. The diatoms are fertilized by the surge of nutrients entering the Bay from the Ganges-Brahmaputra river system at this time of year. Ittekot believes that the sediments washed into the Bay along with the Ganges-Brahmaputra floodwaters also play an important role by accelerating the rate at which diatoms and the organic carbon they contain fall to the sea floor. The diatoms stick to the sediments which act as tiny ballasts, dragging the diatoms downwards.

See: BioScience *50:9, September 2000. A Special Issue Devoted to Hydrological Alterations.*

The scientists at the World Commission on Dams Montreal workshop on reservoir emissions agreed that using the 100-year GWP "can significantly underestimate the climate change impact of reservoirs over the first several decades." The workshop recommended that "other time-dependent conversion methods such as that developed by Stuart Gaffin should be considered."

Gaffin, an atmospheric chemist at the US organization Environmental Defense, has developed a model for evaluating the warming impact of continuous emissions of methane. Philip Raphals of the Helios Centre in Montreal has used this model to calculate that the cumulative global warming effect after 100 years of a constant methane emitter is 39.4 times greater than that of a constant emitter of an equivalent quantity of carbon dioxide.

Methane, especially in the tropics, is a significant component of reservoir emissions. The value of the methane multiplier used will thus have a large impact on the estimate of a reservoir's total contribution to climate change. Almost all estimates for the warming impact of reservoirs, including those cited above, have been based on the now-outdated methane GWP of 21. Using a larger methane multiplier, such as Gaffin's, would greatly increase the estimated global warming impact of reservoirs.

COMPARING KILOWATTS

Developing effective strategies to curb greenhouse gas emissions requires an understanding of the emissions of different electricity-generating technologies per unit of electricity generated.

A group of Canadian researchers led by Éric Duchemin have calculated hydropower's average global warming impact per kilowatt-hour. They state that average gross emissions from hydro plants in boreal and temperate regions of Canada are equivalent to between 10 and 200 grams of carbon dioxide per kilowatt-hour generated. Average gross emissions from tropical hydro reservoirs range from 200 to 3,000 grams per kilowatt-hour.

By comparison, natural gas-fired combined cycle plants emit around 430-635 grams of CO_2-equivalent per kilowatt-hour (these figures, based on a methane GWP of 21, take into account methane released during gas extraction and transmission, but not the additional efficiencies from using "waste" heat from the power plant for space heating or industrial processes). Life-cycle emissions from wind power — which include emissions from turbine manufacture and installation — are 7-40 grams of CO_2-equivalent per kilowatt-hour.

FIGURE 3 Global Warming Impact of Various Electricity Generating Options

Hydro installation		Electricity generation (TWh/yr)*	Flooded area (km^2)	Emissions (gCO_2eq./kWh)
Canada	Churchill Falls	35	6,705	≤90
	Complexe La Grande	82	13,000	≤75
Tropical	Balbina	1	3,150	30,250
	Curuá-Una	0.1	72	5,700
	Tucuruí	15.7	2,850	3,280
Non-hydro installation				
	Lignite (brown coal)			1,150-1,270
	Coal (modern plant)			790-1,200
	Heavy Oil			690-730
	Diesel			555-880
	Combined-Cycle Natural Gas (550 MW)			460-760
	Natural Gas Cogeneration			300
	Large Fuel Cell (natural gas powered)			290-520
	Photovoltaics			30-210
	Biomass Energy			17-120
	Windpower			7-40
	Nuclear			2-60

Note: Hydro and combined-cycle natural gas emissions calculated using methane multiplier of 39.4.

* *estimated based on an assumed capacity factor of 60% except Balbina and Tucuruí which are based on actual generation. At least for tropical dams capacity factor is likely to be closer to 50% than 60%.*

Sources:

For Canadian emissions, see P. Raphals (2001) "Restructured Rivers: Hydropower in Competitive Energy Markets," Helios Centre/International Rivers Network, Montreal/Berkeley.

Balbina emissions were calculated from data in P.M. Fearnside (1995) "Hydroelectric Dams in the Brazilian Amazon as Sources of Greenhouse Gases," *Environmental Conservation* 22:1.

Tucuruí emissions recalculated from P.M. Fearnside (2000) "Environmental Lessons of Brazil's Tucuruí Dam: Unlearned Lessons for Hydroelectric Development in Amazonia," *Environmental Management* 26:2. Tucuruí energy production (average 1984-1998) calculated from E.L. La Rovere *et al.* (1999) "Estudos de Caso da Commisão Mundial de Barragens: Usina Hidrelétrica de Tucuruí (Brasil): Relatório Preliminar," World Commission on Dams.

Natural gas emissions data were recalculated from P.L. Spath and M.K. Mann (2000) "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System," National Renewable Energy Laboratory, Colorado.

Nuclear emissions information is from M. Rizau *et al.* (1998) "Clean Electricity Supply With Low Climate Impact and No Nuclear Power," Greenpeace Germany, Hamburg.

For emissions from all other sources, see International Energy Agency Implementing Agreement For Hydropower Technologies And Programmes (2000) "Hydropower And The Environment: Present Context And Guidelines For Future Action, Volume I: Summary and Recommendations."

Reservoirs Emissions are Forever?

Environmental concerns and the depletion of oil and natural gas supplies will drive the research, development and implementation of sustainable energy technologies. In many places wind power is already competitive with fossil fuel-fired power. Within a few decades decentralized grids based on wind, solar and biomass generation and hydrogen fuel cells may well be the basis of our energy systems.

It is relatively easy to turn off a coal or gas power plant and so end its emissions. It is also easy to take hydropower turbines off-line. But just turning off a hydropower plant will not halt the emissions from its reservoir. While it may be relatively straightforward to drain the reservoir behind a relatively low, barrage-type dam, it will be difficult and expensive to decommission a reservoir behind a high dam without bottom outlets.

Filling a hydropower reservoir behind a high dam thus commits society either to the potentially huge costs of dam decommissioning, or to creating a source of greenhouse gas emissions for the indefinite future regardless of what advances may occur in the development of cleaner power sources.

At the same time, where the dam design makes it feasible, draining a highly polluting tropical reservoir and replacing its generation with cleaner sources may be a highly cost-effective greenhouse gas mitigation measure. Such dam decommissioning options could be considered for carbon credits under instruments such as the Clean Development Mechanism.

Duchemin's estimates of average reservoir emissions are calculated using the methane global warming potential of 21. The results of calculating the warming impact of reservoirs and a gas combined-cycle plant using Gaffin's methane multiplier of 39.4 are given in Figure 3 (methane is a small part of the total emissions for most electricity generation technologies so changing the methane multiplier would have little impact on estimates for their emissions). These figures suggest that the warming impact of a boreal reservoir is much less than that of a modern gas plant. Yet a tropical reservoir can have a warming impact at least four times greater than that of a gas plant.

Duchemin's figures for average reservoir emissions are based on gross rather than net emissions. They do not include the potentially major emissions of methane from the degassing of water discharged from tropical reservoirs. They also exclude secondary impacts such as project-related deforestation and the disruption of oceanic carbon uptake (see box on page 10).

The averages are also likely conservative as they assume that hydroplants have an average "plant factor" of 60 percent. This means that in a typical year they should generate 60 percent of the electricity they would generate if their turbines ran constantly at full

The Vilm Workshop on Climate and Biodiversity

A group of 32 experts, mainly from European Union governments, met on the German island of Vilm in December 2001 to discuss possible conflicts and synergies between the UN conventions on climate and biodiversity.

The workshop concluded that because of the negative biodiversity and climate impacts of reservoirs, large dams should be excluded from climate change mitigation measures such as the Kyoto Protocol's Clean Development Mechanism (CDM). The participants also recommended that any small hydropower plants built for climate mitigation purposes should comply with the recommendations of the World Commission on Dams.

See: European Expert Workshop (2001) "Climate Protection and Conservation of Biodiversity: How to solve possible conflicts and find win-win solutions," Organized by the German Federal Environmental Agency and the German Federal Agency for Nature Conservation, December 9-11, 2001. <http://www.biodiv-chm.de/pdf/vilm_conclusions.pdf>

capacity. Hydropower plant factors vary widely but on average appear to be well under 60 percent: average hydropower plant factor in the US is 46 percent; in developing countries, according to the World Bank, it is 49 percent. Lower plant factors mean less electricity generation which would in turn mean higher emissions per kilowatt-hour.

Some tropical reservoirs have an impact many times greater than even the dirtiest fossil-fuel equivalent. Emissions from the 250-megawatt Balbina Dam in the middle of Amazonia are exceptionally high, some 25-38 times higher than a modern coal plant of similar capacity (calculated using Gaffin's methane multiplier). Balbina's reservoir is shallow and submerged a huge area to generate a relatively small amount of electricity.

Tucuruí generates almost 20 times more electricity with a reservoir 300 square kilometers smaller than Balbina's. But Tucuruí's global warming impact is still much greater than that of a gas plant producing a similar amount of power.

At present five large hydropower plants have been completed or are near completion in the forest of the Brazilian Amazon. Plans exist to build more than 70 additional plants, flooding a total area of 100,000 square kilometers. These planned hydroplants would on average flood around 60 percent more land per kilowatt generated than Tucuruí, implying that their emissions per kilowatt-hour would also be significantly greater than those from Tucuruí.

CONCLUSION

Dams and reservoirs are important, yet largely overlooked, global sources of greenhouse gas emissions. There are a number of reasons why even policy makers and scientists involved in the climate issue are not more aware of the issue: the science is still relatively young, only a handful of researchers are working on the issue, little has been published on it in peer-reviewed journals and numerous uncertainties about net emissions levels remain to be resolved.

Dams and reservoirs are important, yet largely overlooked, global sources of greenhouse gas emissions.

Governments and electrical utilities have not provided sufficient funding for the large-scale research programs necessary for a comprehensive understanding of reservoir emissions. Hydropower interests have little incentive to encourage the publication of research findings that may harm their industry. The lack of awareness of the importance of reservoir emissions is also likely in part just a matter of perception: because reservoirs have no soot-belching chimneys and hydropower has long been promoted as "clean" energy (ignoring its impact on rivers — see box on page 16), many people find it difficult to accept the concept that reservoirs could be major contributors to global warming.

Despite the complexities and need for further research, there is already a preponderance of evidence showing that the IPCC's scientists should incorporate dams and reservoirs into their analysis of global sources of greenhouse gases. Likewise the climate convention's Subsidiary Body for Scientific and Technical Advice should include reservoir emissions in its guidelines for how countries report their sources of greenhouse gases. Estimates of greenhouse gas emissions from proposed dam projects should be required by regulatory agencies and funders as part of the project approval process, as recommended by the World Commission on Dams.

Climate Change, Dams and Ecosystems

The world's rivers and the life they support have been seriously impacted by dams. Climate change will further stress these already degraded ecosystems. According to the World Commission on Dams, 60 percent of the world's large river basins have been highly or moderately affected by dams and water diversions. Dams are the main reason why freshwaters have more endangered species than any other major ecosystem type. The World Conservation Union estimates that around a third of the world's 12,600 freshwater fish species are extinct, endangered or vulnerable.

Reservoirs have flooded vast areas. Canadian reservoir emission researchers estimate that globally 1.5 million square kilometers, one percent of the world's land surface, have been inundated behind dams. The area turned into reservoirs is an even greater loss in ecological terms than the raw statistic implies as rivers and floodplain forests and marshes tend to be the most biologically diverse of all ecosystems.

While the flooding of land by a reservoir is the most obvious ecological impact of a dam, the most damaging impact is probably the disruption of the flow patterns of water, sediment and nutrients. Ecosystems in and along rivers, and in their estuaries and the coastal zones they influence, have co-evolved with the rivers' annual rise and fall. Dams trap sediments and nutrients, reduce normal peak flows and increase low flows and change river temperature and chemistry. The result is invariably a reduction in the diversity of river habitats and species.

Dams also reduce diversity by fragmenting riverine ecosystems, isolating populations of species living up and downstream of the reservoir, and cutting off migrations and other species movements across the river valley.

Climate change will likely exacerbate the existing stresses faced by river ecosystems. River water will become warmer, making it difficult for cold water fishes, invertebrates and other organisms to survive in their current habitats. Organisms attempting to migrate to cooler climates will often be blocked by dams, diversions and other human interventions.

Changes in the quantity and timing of rainfall and snowmelt will alter streamflow patterns. Both floods and droughts are expected to increase in frequency and severity. In areas where river flow is dominated by high spring flows from melting snow, climate change would mean floods come earlier in the year if precipitation falls as rain rather than being stored through the winter in the form of snow. Many aquatic and floodplain species are likely to have difficulty surviving under these new conditions.

Further Reading:

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Climate Change Impacts on Hydropower

"The major implications of climate change for dams and reservoirs are firstly that the future can no longer be assumed to be like the past, and secondly that the future is uncertain."
N. Arnell and M. Hume.

Global warming is rendering obsolete one of the key assumptions used in dam planning and design — that the hydrological past is a reliable guide to the hydrological future. Changes in global climate are likely to reduce hydropower production and the amounts of water stored in reservoirs. They will also increase risks to people downstream of dams because of increased possibilities of dam collapses and because dam operators will be more likely to be forced to make sudden releases of large quantities of water.

The IPCC's 2001 assessment predicts that the world will warm by 1.4-5.8 degrees Celsius by 2100. For every degree Celsius warming, global precipitation is expected to increase by 2-4 percent. The resulting changes in regional weather patterns will vary widely but there is widespread agreement that in many parts of the world the frequency and severity of both floods and droughts will increase.

Changes in regional weather will have various implications for hydropower. Increased droughts and greater evaporation from reservoirs due to higher temperatures would reduce hydro generation (conversely more rainfall would not substantially increase power production as dam operators would have to spill high flows beyond those the dam was designed to handle). Increased uncertainty in hydropower production would require electricity system operators to arrange additional back-up supplies.

An acceleration in the loss of reservoir capacity to sedimentation is also expected. Most sediments enter reservoirs during and soon after major rainstorms. The predicted increases in the duration, intensity and frequency of storms would thus increase reservoir sedimentation.

Dam spillways are generally designed to pass the maximum flood considered probable in their catchments. If the capacity of a spillway is exceeded, water may flow over the top of its dam, potentially causing the dam to collapse — "overtopping" is the single most important reason for dam failures. The maximum flood estimates used in dam design have not allowed for a changing climate and many dam spillways may thus be unable to cope with future floods.

Dam collapses can have catastrophic consequences, but thankfully are rare events. A much more frequent cause of damage are floods caused by dam operation. Dam operators are sometimes forced to quickly release large volumes of water as a preemptive measure against overtopping during major storms. Such dam-induced floods are likely to increase as the intensity and unpredictability of storms increases.

The World Commission on Dams report expresses concern over the adequacy of existing spillways given the likelihood of increased flood intensities. It also recommends that planning and monitoring of dams should account for the impact of potential climate changes on both dam safety and performance.

See: N. Arnell and M. Hume (2000) "Implications of Climate Change for Large Dams and their Management," World Commission on Dams, Thematic Review II.2 Dams and Global Change. <http://www.dams.org/docs/kbase/thematic/tr22pt4.pdf>

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International Rivers Network

Linking Human Rights and Environmental Protection