

WCD Thematic Reviews  
II.2 Dams and Global Change

# Dams and Global Change

## *Executive Summary*

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Prepared for the WCD by:  
Luiz Pinguelli Rosa & Marco Aurelio dos Santos  
and  
Nigel Arnell & Mike Hulme

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World Commission on Dams Secretariat  
P.O. Box 16002, Vlaeberg, Cape Town 8018, South Africa  
Phone: 27 21 426 4000 Fax: 27 21 426 0036.  
Website: <http://www.dams.org> E-mail: [info@dams.org](mailto:info@dams.org)

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World Commission on Dams  
5<sup>th</sup> Floor, Hycastle House  
58 Loop Street  
PO Box 16002  
Vlaeberg, Cape Town  
8018, SOUTH AFRICA  
Telephone: +27 21 426 4000  
Fax: +27 21 426 0036  
Email: [info@dams.org](mailto:info@dams.org)  
<http://www.dams.org>

## Executive Summary

The industrial revolution and the corresponding intensive use of fossil fuels began in Europe in the second half of the 18<sup>th</sup> century. In 1896, Svante Arrhenius, a Swedish chemist, calculated that a doubling in the atmospheric concentration of carbon dioxide, resulting from the burning of fossil fuels would increase global mean temperature by about 5 °C (Barret, 1999). One hundred years later, in 1995, the Intergovernmental Panel on Climate Change (IPCC) stated that it is clear “that human activities have changed the concentrations and distribution of greenhouse gases and aerosols over the 20<sup>th</sup> century” (IPCC, 1995b). The concentration of carbon dioxide, for example, has increased by 30% since pre-industrial times. Altering the natural concentrations of greenhouse gases (GHGs) is likely to have significant consequences on the global climate. And although Arrhenius’s prediction of a 5 °C increase has not been fulfilled, global mean temperature has increased by 0.3-0.6 °C since the late 19<sup>th</sup> century

Life has evolved on earth as a result of many unique conditions found on the planet; one of which is the greenhouse effect. The greenhouse effect is a natural and vital process where infrared rays from the sun come into Earth’s atmosphere. Gases present in the atmosphere “trap” these rays after they have come in, keeping the Earth warm and maintaining biophysical processes. Therefore, what humans have done is to enhance the natural greenhouse effect by increasing the concentration of GHGs. This has reduced the efficiency with which the earth cools to space.

Three naturally occurring gases are the main contributors to the greenhouse effect: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Other naturally occurring gases that can have GHG properties are ozone (O<sub>3</sub>) and water vapour. Under natural conditions various processes regulate the emission and deposition of naturally occurring gases. Most of the anthropogenic sources of these gases are the combustion of fossil fuels, changes in land use, and some agricultural practices. In addition to natural GHGs there are synthetic GHGs like halocarbons (HFCs, CFCs, HCFCs), perfluorocarbons (PFCs as CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>), and other halogenated compounds (SF<sub>6</sub>). Although only small amounts of halocarbons are released, some of them can persist in the atmosphere for thousands of years. Since some of the synthetic GHGs are the leading cause of ozone depletion (ozone also produces a shield to damaging UV rays), their production has been considerably curtailed and they are regulated by the Montreal Protocol.

Global climate change is of importance because the current projected increase in global mean surface air temperature is of 1-3°C by the year 2100 (IPCC 1995a, 1995b, 1995c). In all future modelling scenarios (low to high) the average rate of warming would probably be greater than any seen in the last 10,000 years. As temperature increases, average sea level is also expected to rise given the thermal expansion of the oceans and the melting of glaciers and ice-sheets. The range of predicted sea level rise from the various scenarios is 15-95 cm by the year 2100. The combined effects of these phenomena can have significant implications for natural ecosystems, agricultural production, and the availability and distribution of water resources.

The purpose of this report is to explore the role dams play in the context of a changing global climate. There are those who argue that dams can be one of the alternatives to mitigate global climate change by substituting fossil-fuel based energy with hydroelectricity (Margolick, 1999). Similarly there are arguments that reservoirs created by dams are a source of natural GHGs and therefore contribute to the enhanced greenhouse effect (Fearnside, 1995). Suggestions have also been made which state that changing rainfall patterns and the increasing potential for extreme storm events will affect water distribution and may have implications for the operation and design

of dams. Therefore, this Thematic Review is composed of two different sections: 1) Certainty and Uncertainty in the Science of Greenhouse Gas Emissions from Hydroelectric Reservoirs and 2) Implications of Climate Change for Large Dams and their Management.

## 1.1 Section 1: Certainty and Uncertainty in the Science of Greenhouse Gas Emissions from Hydroelectric Reservoirs

The report for this section looks at a range of issues related to GHG emissions from reservoirs and their potential impact on global warming. They concern the degree to which different types of reservoirs emit carbon dioxide and methane, how these emissions should best be measured or calculated, how a dam reservoir fits into a complex cycle of carbon within the catchment setting, and the nature of the GWP<sup>1</sup> impact of methane once it reaches the atmosphere.

Throughout the paper the focus is on two GHGs: carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). Under natural conditions, the processes of respiration and aerobic decomposition of organic matter release carbon dioxide. When the organic matter decomposes in low-oxygen conditions (anaerobic), methane is released. Therefore emissions of both gases is closely linked to the flux of carbon through the catchment and to the conditions under which it is transported, stored, and transformed.

The scientific basis for drawing conclusions is restricted, and only about 30 field studies have so far been carried out on reservoirs in Brazil, Canada, Finland and French Guyana. The global review of the available knowledge base allows the following conclusions to be drawn concerning areas of certainty and uncertainty on dams and the impact of GHG emissions:

1. The scientific literature shows that reservoirs can emit methane and carbon dioxide due to the decomposition of biomass, and that in some particular circumstances this can be substantial and of a similar order of magnitude as the thermal emissions avoided. Work has been reported on two reservoirs (Balbina and Petit Saut), with particular site conditions, where emissions from reservoirs can be substantial and of a similar order of magnitude to those that would be emitted by an equivalent thermal power plant. The literature also includes studies of reservoirs that contribute significantly less GHGs than those from an equivalent thermal plant (e.g. Tucuruí in Brazil, reservoirs in boreal areas such as Canada and Sweden). However none of these studies have measured in detail the GHG emissions from the pre-project situation and clearly the difference between the pre-project and the post-project emission represents the net GHG output due solely to the reservoir.
2. Shallow tropical reservoirs appear most at risk. Scenarios are calculated showing that in cases where the power generated by the hydroplant is less than 0.1 W per square meter of reservoir area then there is a risk that the GHG emissions may exceed the thermal emissions avoided. Where values exceed 0.5 W per square meter of reservoir the scenarios show that the possibility of reservoir emissions putting at risk the benefits of CO<sub>2</sub> emissions avoided by hydro are reduced.

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<sup>1</sup> The Global Warming Potential (GWP) is a means used by the IPCC to compare the effects that different gases with different properties have on the greenhouse effect.

3. The main scientific controversy on fieldwork centres on the extrapolation of measured emissions per m<sup>2</sup> in selected parts of the reservoir to the whole reservoir area. Emissions almost certainly vary according to depth and the distribution of the submerged biomass. They also vary through time, with a rapid peak occurring shortly after submersion after which they tail off at an unknown rate. Studies have not yet been carried out over long periods of time to characterise the full life-cycle curve of the emissions.
4. IPCC has revised its estimate of GWP of methane on four separate occasions in the last 7 years, with a lowest value of 12.7 times the CO<sub>2</sub> equivalent to a maximum of 22.9 times the CO<sub>2</sub> equivalent. The current value considers that methane has a GWP 20.1 times that of CO<sub>2</sub> over 100 years. If the time response of the climate system is included in GWP calculation its value would be substantially reduced, as the present IPCC definition of GWP does not consider this climate response.
5. Many natural habitats emit methane, especially bogs and other wetlands, or forest habitats in tropical climates. When a dam reservoir floods these habitats, any methane emissions should be counted as net, which requires some measurements of the emissions from the reservoir site prior to impoundment. There is also evidence that the flows of carbon within a system are complex, and carbon may flow into a reservoir from the catchment (and leave it through the spillway and turbines) in a manner that is in some cases analogous to the pre-dam situation.
6. The slow yet steady accumulation of scientific data on methane emissions indicates that, although, in principle, hydroelectric power plants usually emit less than a fossil fuel power plant with the same energy production, there is no justification for claiming that hydro does not contribute significantly to global warming and climate change. This has to be assessed on a case by case basis.
7. Members of the review panel for the report proposed a comprehensive assessment of all GHG emissions from dam and non-dam options. The two main arguments are for using a full Life Cycle Assessment (LCA) approach and to define net GHG emissions as opposed to gross emissions. In doing a full LCA one must consider GHGs other than methane and carbon dioxide (i.e. nitrous oxide) and compare all GHG emissions from pre and post dam situations
8. More research is needed in order to be able to assist in the planning process, and this should focus on the following areas:
  - a) What would be the carbon cycle be with and without the reservoir ?
  - b) How does one account for the stock of carbon by flooding vs growth and decay of forest ?
  - c) How important are the first rapid peaks of methane emission in the total quantity that will be emitted during the life of the reservoir?

As with all of the WCD's Thematic Reviews, this report went through an external review process in which professionals in the field have acted as peer reviewers of the work. During the specific review process of the component on GHGs and reservoirs, a series of scientific disagreements arose that need to be discussed in order to better understand the relationship between reservoirs and GHG emissions. Therefore a workshop was held during February 2000 in Montreal, to which many of the leading scientists in the field attended. Some of the main conclusions from the workshop were:

- a) Greenhouse gases are emitted for decades from all of the 30 dam reservoirs in the boreal and tropic regions for which measurements have been made. This is in contrast to the widespread

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assumption (e.g. IPCC scenarios) that such emissions are zero. The evaluation of net greenhouse gas emissions from reservoirs following flooding requires comparison to the emissions that existed prior to flooding (i.e the difference between the pre dam emissions from the undammed catchment and the post dam emissions). Quantification of these changes in greenhouse gas emissions, due to flooding, is complex because it requires understanding of the carbon cycle at the level of the whole watershed. The degree to which these emissions are greater than the pre-dam background emission, and their levels when compared to thermal alternatives, is best assessed through a life cycle analysis on a case by case basis. For all boreal reservoirs studied, gross GHG emissions from reservoirs are less than the thermal alternative. This is not, however systematically the case for all tropical reservoirs and the net emissions therefore need to be studied in more detail.

- b) The expert meeting felt that a scientific method for assessing the net emissions from a reservoir is available. Emissions almost certainly vary according to depth and may be unevenly distributed in the reservoir. Some GHGs may also be emitted from water passing through the turbines. In some reservoirs they evolve temporally, with a rapid peak occurring shortly after submersion after which they may tail off over the years at an unknown rate. In others there is no change in emissions over time.
- c) Current understanding of the breakdown processes of methane in the atmosphere remains controversial, and the precise rate at which methane is converted to CO<sub>2</sub> is not generally agreed. The expert meeting recommended that the time period for the GWP should be 100 years, also to fit in with the IPCC calculation of methane GWP.

**Areas of agreement and disagreement in the debate:** Overall there is agreement that GHGs are emitted from reservoirs. Therefore the concept of a reservoir that emits no GHGs is no longer applicable. However, the quantity of each GHG emitted, their spatial and temporal distribution, whether they exceed background levels and the methods to measure these variables are all topics of debate among the few experts in the field. This means that the argument is not about seeking alternatives that emit zero GHGs, but to opt for those with significantly lower GHG emissions on a life cycle basis (see Energy Options paper for life cycle assessments). This is also very much the thrust of the Clean Development Mechanism under the Kyoto Protocol.

## 1.2 Section 2: Implications of Climate Change for Large Dams and their Management

The report for this section summarises the potential implications of climate change for dams due to the enhanced greenhouse effect. It concentrates on dam safety and reservoir reliability (ability to meet design targets), over the planning and design lifetime horizons. It does not consider operational implications.

Climate change is likely to lead to changes in temperature, precipitation and streamflow over dam planning horizons and life times. This can directly affect dam design and feasibility studies that use historical river flows to determine not only project viability but also the dimensions of the dam, the spillway, and other structural components. The relevance of climate change for dam building and operations is that future climatological conditions will not necessarily resemble the past as reflected in the historical records.

Whilst a climate change signal can be seen in global and regional temperature data, it is, however, difficult to detect a trend in streamflow or flood data. The recent apparent spate of extreme flows is in many senses consistent with global warming, but cannot be definitively attributed to it. Floods and droughts occur without global warming, and there have been other periods in the recent past with "unusual" numbers of floods and droughts.

There is an important distinction between two different types of uncertainty in climate projections. Some reflects incomplete scientific knowledge or models, and can in principle be reduced by increased research. Much, however, is due to inherent way in which the world's economy and society will develop over the next few decades, affecting variables like cropping patterns, water use requirements, lifestyles, etc. This uncertainty will always be present, although the shorter the time horizon the less important it is relative to scientific uncertainty. Natural climatic variability adds an additional level of uncertainty to future climatic characteristics.

Virtually all climate change scenarios have so far defined changes in monthly mean climate (generally temperature and precipitation). They have not defined potential changes in year-to-year variability (often important in reservoir reliability analysis), and generally do not include projections of possible changes in extreme rainfall. However, by applying a change in mean climate to a baseline climate time series, it is still possible to estimate not only changes in mean hydrology but also changes in the frequency of extremes. A range of statistical downscaling techniques have been proposed for improving the "accuracy" of catchment-scale scenarios, but these all rely on the quality of the driving GCM scenarios and constructed scenarios are dependent on the details and parameterisation of the downscaling techniques.

Reservoir reliability will be affected by changes in river inflows and lake evaporation. Changes in the volume and timing of inflows are very variable geographically and between scenarios, but increases in lake evaporation (dependent largely on lake thermal characteristics) are likely. Dam safety is affected by changes in the magnitude and/or frequency of extreme precipitation events. These changes are highly uncertain, but from first principles it can be inferred that extreme precipitation events (including PMP) are likely to become larger. One study showed, for example, the discharge of the 50-year flood on the River Severn, UK, would increase by around 20% by the 2050s.

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. This encourages present trends towards more adaptive, flexible water management, which includes the use of scenario analysis in estimating future dam safety and reservoir reliability. Research is needed into techniques for incorporating uncertainty over different possible futures into dam and reservoir assessment.