WCD Thematic Reviews
II.2 Dams and Global Change

Introduction to Global Change

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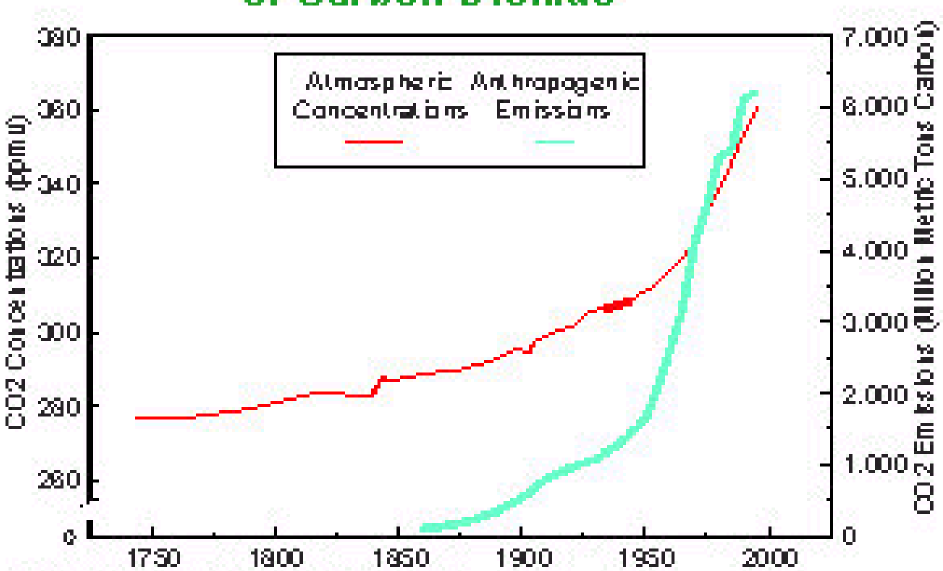
Acronyms

AIJ	Activities Implemented Jointly
CDM	Clean Development Mechanism
COP	Conference of the Parties
ENSO	El Nino Southern Oscillation
GHG	Greenhouse Gas(es)
GWP	Global Warming Potential
IET	International Emissions Trading
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
NGO	Non-governmental Organisation
OECD	Organisation for Economic Co-operation and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCD	World Commission on Dams
WMO	World Meteorological Organisation

1. Introduction

The industrial revolution and the corresponding intensive use of fossil fuels began in Europe in the second half of the 18th 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 20th century" (IPCC, 1995b). The concentration of carbon dioxide, for example, has increased by 30% since pre-industrial time (Figure 1). 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 19th century

Figure 1. Trends in Atmospheric Concentrations and Anthropogenic Emissions of Carbon Dioxide



Source: Oak Ridge National Laboratory.

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 among the main contributors to the greenhouse effect: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Other naturally occurring gases that can have GHG properties are ozone (O_3) 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_4, C_2F_6), and other halogenated compounds (SF_6). 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 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^{o}C by the year 2100 (IPCC 1995a, 1995b, 1995c). In all 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. There is also likely to be an increase in the occurrence of extremely hot days and a decrease in extremely cold days. 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 global climate change will have implications for the operation and design of dams. Therefore, this Thematic Review is composed of two different sections, one that explores the issue of how dams can contribute to decreasing or increasing the rate of global climate change and another one that looks into how this change in climate can affect dams. Section 1 looks into the aspects dams and GHGs emitted or avoided. Section 2 covers the aspects of how a change in global climate can affect rainfall and evaporation and therefore the resource base for dam projects.

2. The Science of Global Warming

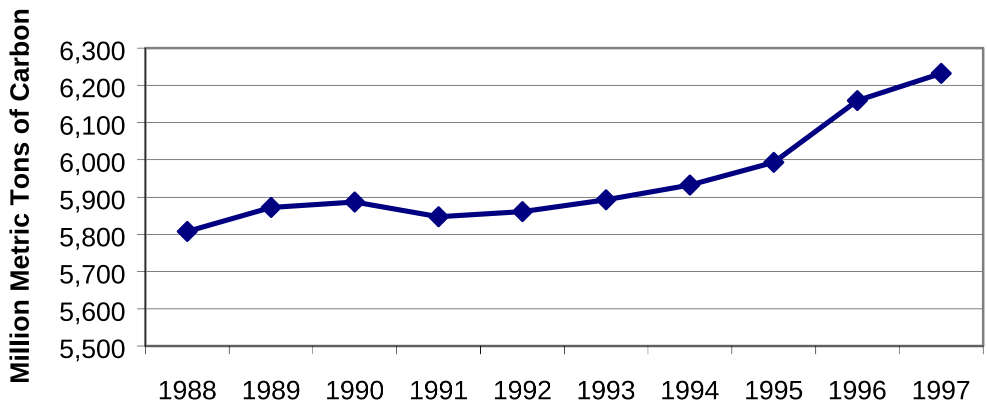
The impact of a GHG on global climate change depends on its physical-chemical properties, its rate of emissions and uptake, as well as the total volume that is emitted and removed from the atmosphere. Two of the major physical-chemical properties of a GHG are its capacity to block outgoing radiation and its atmospheric lifetime.

Different GHGs reflect outgoing radiation at different intensities. For example, a molecule of methane can reflect twenty times more radiation than one molecule of carbon dioxide. At the same time, one molecule of methane has a much shorter residence time in the atmosphere (12 years) before it is transformed chemically if compared with one molecule of carbon dioxide (50-200 years). However, because there is much more carbon dioxide in the atmosphere compared to methane, the overall impact of carbon dioxide is greater than that of methane. This is why the different properties of the various GHGs makes them have a unique impact on the global climate. It is also because of these differences that it is difficult to clearly compare the potential impacts of all GHGs.

In order to compare the differences among the various GHGs, the IPCC developed the Global Warming Potential (GWP) index as a standard measurement. The GWP tries to convert GHGs to a CO_2 equivalent unit of measurement that allows comparing the effects of two chemically and physically different molecules of gas. One of the main shortfalls of the GWP is that it is strongly dependent on the choice of time horizon used, which can give a very different result by using a 20 or a 300 year time horizon. Therefore, when comparing GWP it is necessary to be aware of the explicit timeframe used. These shortcomings of the GWP "are not necessarily sufficiently serious to invalidate the GWP concept" (Skodvin 1999). And further, the GWP is needed to be able to make policy decisions towards mitigating global climate change. This index therefore indicates the global warming potential for each gas expressed in tonnes of carbon equivalent. For a summary of the properties of GHGs see Table 1.

Just as they are involved in different physical processes, GHGs have different sinks and sources. The major sources of carbon dioxide, which remains the most important contributor to anthropogenic forcing of climate change (Figure 2), are the burning of fossil fuels and land use conversion (IPCC 1995a). Being the major raw material for photosynthesis, carbon dioxide is incorporated into the tissues of primary producers and then transferred up to higher trophic levels via the food chain. However, when these organisms die and are decomposed, carbon dioxide is released again into the atmosphere, creating a cycle of emissions and fixation. Therefore, the ultimate sink for carbon is ocean uptake via a biogeochemical process that deposits organic matter, rich in carbon content, in marine sediments. This process is very slow, and it is uncertain if it can adapt to absorb the increased quantities of anthropogenic emissions.

Figure 2. World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, 1988-1997



Source of Data: Energy Information Administration, USA
http://www.eia.doe.gov/emeu/iea/carbon.html

Methane is found in fossil fuel deposits, and is therefore emitted from fossil fuel production and use. It is also a byproduct of bacterial anaerobic decomposition and is emitted from waste disposal, wetlands, agricultural fields, and the digestive tracts of some herbivores. Between 60-80% of current methane emissions are from anthropogenic sources (IPCC 1995b). Another 20% of global methane emissions come from anaerobic decomposition in wetlands. The major sink for methane is its oxidation by OH in the atmosphere, but as more methane is produced and more OH is used up, the rate of methane uptake could slow down. Further, it is believed that if global temperature increases, there will be higher microbial activity and therefore an accelerated rate of methane production from anaerobic decomposition. Such an event could reinforce and accentuate the impacts of methane on global warming (IPCC 1995b). One of the issues addressed

Table 1. Basic Properties of the Major GHGs

Greenhouse Gas	Pre-Industrial Concentration	Concentration in 1994	Atmospheric Lifetime (years)	Increase in Concentration since Pre-Industrial Times (ie. ~1750 to 1992)	Direct Radiative Forcing (Wm^{-2})	Source(s)	Sink(s)
CO_2 carbon dioxide	~280,000 ppbv	358,000 ppbv	50-200	30%	1.56	Combustion of fossil fuels, land use change	Forest regrowth, soils, ocean uptake (via biogeocehmical process)
CH_4 methane	~700 ppbv	1720 ppbv	12	145%	0.47	Agriculture, fossil fuel production and use, anaerobic decomposition (waste disposal, wetlands, etc.)	Oxidation by OH in the atmosphere
N_2O nitrous oxide	~275 ppbv	312 ppbv	120	15%	0.14	Many small sources (agriculture, industrial processes)	Photolysis in the stratosphere
CF_4 (a perfluoro-carbon)	Zero	72 pptv	50,000	-	-		
Source	IPCC 1995b	IPCC 1995b	IPCC 1995b	IPCC 1995a	IPCC 1995a		

Radiative forcing is the perturbation to the energy balance of the Earth-atmosphere system, measured in watts per square meter.
ppbv= parts per billion by volume, pptv= parts per trillion by volume.

in this paper is the degree to which a dam reservoir generates an additional net emission of methane or whether such emissions would have occurred naturally anyway.

Nitrous oxide emissions come from many small sources but mainly from natural and agricultural soils and from industrial processes (the production of nitric and adipic acid). In agricultural fields, the main source of N_2O is synthetic nitrogen fertilizers that transform into N_2O and volatilize into the atmosphere. Natural sources are estimated to emit twice as much N_2O than anthropogenic sources (IPCC 1995b). The major sink for N_2O is photolysis in the stratosphere, which is a slow process, giving N_2O a long atmospheric lifetime of approximately 120 years.

The other three GHGs included in the Kyoto Protocol are HFCs, PFCs, and SF_6. These compounds are effective GHGs and occur solely as a result of human activities. Some have very long atmospheric lifetimes, such as SF_6 which can stay in the atmosphere for >1000 years (IPCC 1995b). Although the current impacts of these gases are low, they could be a problem if their concentrations start to increase. Hydrofluorocarbons (HFCs) which are replacing ozone-depleting gases could play a role in global climate change if its emissions increase (IPCC 1995b).

Additional to GHGs that accentuate the greenhouse effect, there are also particles that are believed to reduce the greenhouse effect. The particles scatter and absorb the incoming solar radiation and therefore have a “cooling” effect. These particles are called aerosols and consist of small droplets of chemicals or dust in the atmosphere. Volcanic eruptions and dust storms are among the natural sources of aerosols while the burning of biomass or fossil fuels are anthropogenic sources of aerosols. The radiative forcing due to aerosols depends on the size, shape, and chemical composition of the particles and the spatial distribution of the aerosol (IPCC 1995a). But different from GHGs, aerosols usually have a short life span in the atmosphere as they are removed largely by precipitation. However, aerosols that reach the stratosphere can stay there for months or years. Overall, the combined impacts of increased GHGs emissions from anthropogenic sources is what creates an enhanced greenhouse effect, leading to an increase in global temperature. Aerosols can reduce the rate of increase in climate change, but they are unlikely to counteract the cumulative effects of GHGs with long atmospheric life times.

It is necessary to clarify that any human-induced effect on climate would be superimposed on the background “noise” of natural climate variability which results both from internal fluctuations and from external causes such as solar variability or volcanic eruptions. Therefore the detection and attribution studies carried out by multiple scientists and coordinated through the IPCC have attempted to distinguish between anthropogenic and natural influences. The overall balance of evidence suggests that there is a discernible human influence on global climate (IPCC 1995a).

3. The Observed and Predicted Impacts of Climate Change

Mean global surface temperature has increased by 0.3-0.6 ^{o}C since the late 19th Century, and by 0.2-0.3 ^{o}C over the last forty years (IPCC 1995a). The warming has not been globally uniform and there is a tendency towards a reduced daily temperature range over land since the middle of the 20th century. Projections of future global mean temperature change, considering the long time-scales governing both the accumulation of GHGs in the atmosphere and the response of the climate system, demonstrate that an increase in temperature can have significant worldwide implications such as sea level rise. In fact, global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature which would cause the oceans to expand and glaciers to melt down (IPCC 1995a).

As global temperature changes, the temporal and spatial distribution of precipitation also changes. This can result in accentuated droughts and floods, exemplified by the 1990 to mid-1995 persistent warm-phase of the El Nino Souther Oscillation event (ENSO), which was unusual in the context of the last 120 years (IPCC 1995a). In addition, both the spatial and temporal distribution of precipitation can alter the geographic distribution of ecosystems and species. An example of this would be the shift in location of deserts or forests. Or within a forest, a more pronounced dry season might shift species composition favouring those with lower moisture requirements. For aquatic ecosystems such as streams and rivers, global warming can accentuate storm and drought events, making conditions more favourable for those species adapted to extreme conditions.

For human beings the critical concerns are changes in water availability, the seasonality of precipitation and runoff, flooding or drought frequencies, and the demand for, and supply of, drinking and irrigation water (Gleick 1991). Climate change could therefore shift the demand for water resources and accentuate tensions over water use. In the specific context of dams, global warming can increase the risk of investment and dam safety by stimulating more erratic rainfall patterns and storm events that are also less predictable.

Finally, another possible consequence of an increase in global temperature is the accelerated rate of decomposition of organic matter deposited in areas like wetlands or the tundra of the northern hemisphere. This phenomenon would reinforce the emissions of GHGs, accentuating the rate of temperature increase. The future and unexpected changes to the climate system are by their nature difficult to predict. This implies that future climate changes may also involve “surprises” in particular those that arise from the non-linear nature of the climate system.

4. The International Response

The United Nations Framework Convention on Climate Change (UNFCCC) was created in 1992 as an attempt to address the enhanced greenhouse effect. Its objective is to restrict the concentration of GHGs in the atmosphere to levels below those that could cause severe climate change. Except for the major oil producers, the Convention was signed by most countries in the Rio de Janeiro Convention in 1992. The UNFCCC entered into force on 21 March 1994 after the receipt of the 50th ratification (by 1999 180 countries have ratified the Convention). Previous to the UNFCCC, there were two World Climate Conferences in 1979 and 1990 that laid out many of the issues addressed by the UNFCCC. In addition, the IPCC was created in 1988 by the WMO and UNEP to assess available scientific information on climate change, evaluate the environmental and socio-economic impacts of such a change, and to formulate response strategies.

Results from the scientific work of IPCC and other researchers show that atmospheric GHG concentration is higher than normal due to anthropogenic activities, which has caused global mean surface temperature to be higher than normal. The consequences of global warming projected by the research so far have led to a consensus response from governments, NGOs, and even the private sector in that global warming must be addressed. After detailing the phenomenon of the greenhouse effect and its complexity, the Climate Convention recognized that the problem concerns all countries, but in distinct ways. This differentiation groups countries into two categories. The first, (Annex 1) includes the industrialized states (developed countries and countries economies in transition), which must bear the greater burden of responsibility for controlling emissions. Countries in the second group are not required to diminish their gas emissions in the short-run, but are responsible for periodically elaborating and publishing reports on gas emissions, among other obligations.

The most recent policy level events regarding climate change have been five annual Conferences of the Parties (COP) in the years 1995-1999 (See Table 2). One of the major results from these international conferences is the Kyoto Protocol, in which industrial nations committed themselves to reduce their GHG emissions by 5.2% from 1990 levels by 2008-2012. In addition, there are three "Kyoto Flexibility Mechanisms" in the Protocol that are intended to help the global reduction of emissions in a joint fashion. In other words, the Kyoto Protocol defines assigned amounts of GHG emissions for Annex B countries (developed countries and countries with transition economies) and authorizes cooperative emission reduction methods under which portions of the assigned amounts may be shared or re-allocated. The Kyoto Mechanisms are international emission trading (IET), Joint Implementation (JI), and the Clean Development Mechanism (CDM).

The rationale behind meeting a reduction in GHG emission jointly is that although the environmental effect of GHG emissions is equal irrespective of where they are emitted, the cost is not (OECD 1999). The pilot phase denominated Activities Implemented Jointly (AIJ) was established at the first Conference of the Parties (COPI) as an experimental mechanism to determine what some of the most cost-effective means of emission mitigation are (OECD 1999). The main difference between AIJ and the Kyoto Mechanisms of JI and CDM is that under the latter investors, will obtain emissions credits that they can then trade or use at home to offset their commitments of GHG emission reduction.

TABLE 2. Chronology of Policy Events Related to Global Climate Change

Year	Event
1896	Svante Arrhenius, a Swedish chemist, calculated that a doubling in the atmospheric concentration of carbon dioxide, brought about by the burning of fossil fuels, would increase global mean temperature by about 5 degrees Celsius
1979	World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) convene First World Climate conference and establish World Climate Program
1988	WMO & UNEP establish the Intergovernmental Panel on Climate Change (IPCC) to assess threat of climate change
1990	IPCC's First Assessment Report affirms scientific basis for climate change
1990	Second World Climate Conference calls for a treaty on climate change
1990	United Nations establishes Intergovernmental Negotiating Committee that ultimately drafts the United Nations Framework Convention on Climate Change (UNFCCC)
1992	UNFCCC opened for signature at the Rio Earth Summit. Developed countries commit to return greenhouse gas emissions to 1990 levels by the year 2000 and to help developing countries respond to climate change through technology transfer and funding
1994	The UFCCC enters into force on 21 March after the receipt of the 50th ratification
1995	First Conference of the Parties (COP1) establishes that initial UNFCCC commitments are inadequate. It issues the "Berlin Mandate" that leads to the Protocol by the Third Conference of the Parties (COP3)
1996	Second Conference of the Parties (COP2). The ministers endorse the IPCC's Second Assessment Report on Climate Change, which states that the balance of evidence "suggests a discernible human influence on global climate"
1997	Third Conference of the Parties (COP3) produces the Kyoto Protocol to the UNFCCC that includes legally binding limits on emissions of six greenhouse gases by 2008-2012
1998	Fourth Conference of the Parties (COP4) in Buenos Aires
1999	Fifth Conference of the Parties (COP5) in Bonn

2000	Sixth Conference of the Parties (COP6) in The Hague. Must define the specific rules and guidelines of the Kyoto Flexibility Mechanisms.
2005	Annex I countries should have made demonstrable progress in meeting commitments of GHG emissions reduction
2008-2012	Compliance period during which reduction targets must be reached

Sources: Barret 1999; Brown 1998.

4.1 Joint Implementation (JI)

JI is a mechanism where a country obtains emissions reductions credits through qualifying investments. Under JI, any country included in Annex I of the UNFCCC can transfer or acquire from any other such country emission reduction units resulting from projects that either reduce anthropogenic emissions or enhances the removal of GHGs by sinks. It is important to note that the countries included in Annex I are only industrialised countries (Europe, the former Soviet block, Canada, USA, Japan, Australia, New Zealand, and Turkey). What JI and other Kyoto Mechanisms do, is allow one country to meet its commitment of GHG reduction by either reducing emissions or increasing the GHG sinks in another country.

4.2 International Emissions Trading (IET)

IET is only allowed between countries included in Annex B of the Kyoto Protocol. Since each country is allowed to emit a certain level of GHGs, and not all the countries emit that ceiling, EIT allows those countries with a GHG credit surplus to transfer the GHG credits to those countries with a GHG credit deficit. IET has been a topic of debate especially because it is perceived that it does not contribute to decrease emissions in real terms. Groups like the European Union believe that GHG emission ceilings for some countries are excessively high, therefore making IET a financial transaction more than a real contribution to mitigate the effect of global warming.

4.3 The Clean Development Mechanism (CDM)

The purpose of the CDM is to assist countries not included in Annex I (developing countries) in achieving sustainable development while also contributing to the ultimate objective of the UNFCCC. It is intended to enable financial transfers from developed to developing countries to cover the incremental cost of choosing options in its process of development that are not least-cost but reduce GHG emissions. In this context it is assumed that actively seeking means of reducing GHG emissions will not be the least-cost option for developing countries, but this is likely to only apply to new projects. Therefore, developed countries can pay developing countries for that marginal cost in exchange for GHG emissions credits that would benefit them by achieving compliance with their quantified emission limitation and reduction commitments. An example of a project under the CDM would be when a developing country chooses to increase their electricity production through a renewable energy project instead of a project based on fossil fuels. In doing so the developing country is entitled to carbon bonds for the prevented emissions, and the bonds are then sold to a developing country that has a cap on GHG emissions. This is central for part of the dams debate because it might allow developing countries to obtain tradable carbon credits if they choose hydropower versus power from fossil fuels. However, this has also opened the discussion of whether or not large hydropower schemes qualify as a clean energy source from the perspective of climate change.

Countries that have already set goals for internal emissions trading to achieve their Kyoto commitments include Denmark, the UK, and New Zealand. Other countries that are currently studying options for emissions trading are Norway, Canada, Russia, Australia, and the US. In addition, private companies like British Petroleum and the Dutch/Shell Group have made voluntary commitments to curtail their overall GHG emissions (Margolick 1999). And although the economic significance of global warming as predicted by models has been questioned (Nordhaus 1991), others believe that if public opinion and perception place a high value on climate change issues, private companies can see it as a business opportunity. This might even make the private sector take the lead to mitigate global warming (Barrett 1991).

5. Areas to be resolved

As of 25 October 1999, 84 UNFCCC Parties have signed the 1997 Kyoto Protocol, but only 16 have ratified it (IISD, 1999). Before the Protocol can enter into force it has to be ratified by 55 countries. It is hoped that the Kyoto Protocol will enter into force in time for the Rio+10 in the year 2002, but before there are various details that need to be resolved with regards to the specifics of how to go about mitigating global climate change.

Although the Kyoto Mechanisms are trying to bring about real, measurable and long-term environmental benefits related to the mitigation of climate change that would have not occurred in the absence of such activities, there are some drawbacks and unresolved issues. For example, one of the drawbacks of alternatives like JI is that a trading system that includes sinks requires greater attention to measurement and verification of reductions than a system regulating only emissions. That verification and monitoring is costly and needs specific methodologies and institutions to carry out the task. Similarly, the rules and guidelines for emissions trading have not been laid out yet.

In the specific case of emissions trading through any of the Kyoto Mechanisms, one key aspect that is not clearly defined yet is how carbon is to be traded. To date there have been several real sales and purchases of carbon, most under the AIJ, but these are all experimental well-intended first steps in developing new environmental markets. Some of the prices at which carbon has been sold range from US$0.01 to US$10 (Table 3). These are just speculative estimates that are likely to vary when guidelines for carbon trading are developed. Actual prices will depend on targets set by governments, the allocation of tradable rights, and subsequent trading. In other words, the assignment of emission rights will first have to create scarcity before the market can start fully pricing emissions.

Table 3. Some projects and prices in which carbon has been traded and there has been a financial transaction as a result.

Project	Country	Year	Buyer	US$ per Ton of CO_2 Equivalent ($/t$CO_2$)	Volume Traded (CO_2 Equivalent, tons)	Project Type
CARE Social Forestry Project	Guatemala	1989	AES Corporation	$0.03/t$CO_2$	70,000,000	Tree planting
Mbaracayu Forest Conservation Project	Paraguay	1990	AES Corporation	$0.04/t$CO_2$	53,000,000	Forest Conservation
AES Corp.-Oxfam	Ecuador, Peru, Bolivia	1992	AES Corporation	$0.01/t$CO_2$	200,000,000	Forest Conservation
Reduced Impact Logging	Malaysia	1993	New England Power Co.	$1.35/t$CO_2$	500,000	Forest Management
Ecoland: Piedras Blancas	Costa Rica	1994	Tenaska	$0.54/t$CO_2$	1,200,000	Forest Conservation

National Park						
Rio Bravo Conservation & Management	Belize	1994	Five US Utility Companies	\$0.54/tCO_2	4,800,000	Forest Conservation/ forest management
Scolel Te	Mexico	1996	Mexican govt & UK ODA	\$2.73/tCO_2	55,000	Tree planting/ forest management
Costa Rica Certified Tradable Offsets	Costa Rica	1997	Norwegian govt & companies, Costa Rica power companies	\$2.73/tCO_2	850,000	Tree planting
Noel Kempff Mercado Climate Action Project	Bolivia	1998	American Electric Power	\$0.20/tCO_2	50,000,000	Forest Conservation
No-Till Farming in Iowa	US/Canada	1999	Coalition of Canadian energy companies	?	2,800,000	No-Till Farming
Methane Capture from Landfills	US/Canada	1999	Ontario Power Generation	\$10/tCO_2	2,500,000	Methane Capture from Landfills

The latest event at the policy level with regards to climate change is the fifth meeting of the Conference of the Parties (COP 5) to the United Nations Framework Convention on Climate Change (UNFCCC). COP 5 met in Bonn, Germany, from 25 October to 5 November 1999. During its last two days, COP 5 adopted 32 draft decisions and conclusions including issues relating to the implementation of commitments and other UNFCCC provisions and preparations for the first session of the COP serving as the Meeting of the Parties to the Kyoto Protocol (COP/MOP 1). Delegates completed their work ahead of schedule and generated an "unexpected mood of optimism" in the lead-up to COP 6. The process recovered vital momentum and began to gather determination and support for a self-imposed deadline for entry into force of the Kyoto Protocol by 2002. It is expected that many of the unresolved issues, including the rules and guidelines to the Kyoto Mechanisms, will be defined by the sixth Conference of the Parties in November 2000 at The Hague.

6. The link between dams and global change

Within the context of global climate change and the dams debate, there are two very different ways in which dams and alternative options to dams can play a role. One is as a means of increasing or decreasing the emissions of GHGs. The other way to look at dams and global change is to try and determine how would a change in climate affect the dams and reservoirs themselves. In other words, there are two questions that can be asked: "How can dams and their alternatives affect (positively or negatively) the global climate?" and "How do changes in the global climate affect dams and their alternatives?"

6.1 How can Dams and their Alternatives Affect (Positively or Negatively) the Global Climate?: Section 1 of the Report

Some groups argue that hydropower is a clean source of electricity because it does not emit GHGs. In this sense, it could serve as a means to mitigate global warming by reducing overall emissions. Hydropower is defined as a clean energy source when compared to electricity produced by burning fossil fuels, namely coal, gas, and oil, which aggravates the enhanced greenhouse effect. However, there is evidence that in particular circumstances large reservoirs may also emit GHGs from the decomposing matter submerged by the flooding of the reservoir (Fearnside 1995). The two major GHGs emitted from reservoirs are carbon dioxide and methane.

At this stage it is accepted that reservoirs emit GHGs, although significant differences stem from the quantification of these emissions, whether they represent a genuine net additional emission over and above background gas releases, and how they compare to those from thermal power. The IPCC has not created a separate category for GHG emissions from hydroelectric schemes. And it appears unlikely that they will since it is believed to be a "minor source of methane emissions compared to other energy sector or agricultural activities" therefore it will probably be computed as part of a broader category of other emissions (SRES Draft April 1999, Not For Quotation). Some of the unresolved issues with regards to GHG emissions from reservoirs are how to measure and extrapolate emissions from large reservoirs and how do post-flooding emissions compare to pre-flooding conditions (how much additional GHG is emitted).

Other aspects that make it difficult to compare hydropower to thermal power is that the pattern of GHG emissions from a hydroelectric reservoir is different from the pattern of emissions from a thermal plant. While CO_2 emissions from the combustion of fossil fuels in a thermal plant are released uniformly over the entire period of operation of the plant, part of the production of CH_4 and CO_2 from the bacterial decomposition of organic matter in the reservoir can be concentrated in time and can decay over a period much shorter than the lifespan of the reservoir. Similarly, the time horizon used for the comparison can influence the outcome since methane breaks down to carbon dioxide in the atmosphere after a period of 15-20 years, and because methane has a GWP 20 times higher than carbon dioxide. The focus of Section 1 of this report is therefore to specifically investigate this issue and to report on areas of agreement and disagreement from the scientific studies undertaken so far.

6.2 How do Changes in the Global Climate Affect Dams and their Alternatives? Section 2 of the Report

The IPCC has concluded that human activities are having a discernible effect on climate. This is likely to lead to changes in temperature, precipitation and streamflow over dam planning horizons and life times. 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.

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 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 probable maximum precipitation) are likely to become larger.

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. Section 2 of this report therefore summarises the potential implications of climate change due to the enhanced greenhouse effect for dams. It concentrates on dam safety and reservoir reliability (ability to meet design targets), over the planning and design life time horizons.

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