RIO 02
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HYDROELECTRIC RESERVOIRS AND GLOBAL WARMING

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Greenhouse Gas Production in the Hydro Reservoirs

- Carbon dioxide and methane are formed during decomposition of organic matter.

- In reservoirs the source of organic matter can be flooded pre-existing biomass, dissolved and particulate organic carbon (DOC, POC) brought in from the cacthment area, and biomass generated within the reservoir.

- In the oxic layer of water, CO_2 is produced by aerobic decomposition of DOC, POC and methane as it diffuses up from lower strata.

- In the anoxic sediment organic matter is decomposed by methanogenesis, CH_4 and CO_2 result.

- If the initial biomass stock was known and carbon pathways well understood, gas fluxes could be estimated from theory.

- At present, however, trustworthy results can only be obtained by field measurements of gas exchange at the air-water interface.

Case Study

- Brazil has over 400 medium and large hydroelectric reservoirs generating 95% of its electric power.

They are located over a band of geographic latitudes ranging from the equator to about 30°S.

- Of these reservoirs seven were chosen for a greenhouse gas emission study carried out in 1998-1999; partial data from two additional reservoirs are included.

Site description and technical parameters of hydroelectric reservoirs

Name of reservoir	Sampling dates	Year of Dam Closing	Latitude/ Longitude	Surrounding vegetation	Installed power	Reservoir area	Power density
Miranda	04/1998 12/1998	03/1997	18°55'S/ 40°02'W	Cerrado	390 MW	50.6 km^2	7.70 W/m^2
Três Marias	04/1998 03/1999	01/1961	18°10'S/ 45°16'W	Cerrado	387.6 MW	1,040 km^2	0.37 W/m^2
Barra Bonita	04/1998 11/1998	06/1962	20°31's/ 48°33'W	Atlantic Forest	140.80 MW	312 km^2	0.45 W/m^2
Segredo	05/1998 11/1998	06/1992	26°S/ 52°W	Atlantic Forest	1,260 MW	82 km^2	15.3 W/m^2
Xingó	05/1998 03/1999	06/1994	9°35'S/ 37°50'W	Caatinga	3,000 MW	60 km^2	50.00 W/m^2
Samuel	06/1998 06/1999	11/1988	8°45'S/ 63°28'W	Amazon Rainforest	219 MW	559 km^2	0.39 W/m^2
Tucuruí	06/1998 06/1999	09/1984	3°45'S/ 49°40'W	Amazon Rainforest	4,000 MW	2,430 km^2	1.65 W/m^2
Itaipú	12/1998 08/1999	1982	25° 25'S/ 54° 35'W	Atlantic Forest	12,600 MW	1,350 km^2	9.30 W/m^2
Serra da Mesa	11/1997 03/1998	1996	13° 50'S/ 48° 18'W	Cerrado	1,293	1,754 km^2	0.73 W/m^2

Results

- Greenhouse gas emission from the reservoir surface comes from bubbling and diffusive flow.
- Gas fluxes by molecular diffusion are much greater than by bubbling.
- Around 99% of CO_2 is emitted into the atmosphere by diffusive flow. For methane, diffusion into the atmosphere is in the range of 14% to 90% of total flow.
- According to our measurements, flux intensity at reservoirs varies with time, but the fluctuations appear to be modulated by a strong random component.
- The coexistence in the water of sources and sinks of CO_2, as well as of CH_4 , with their activity governed by a complex interplay of internal and external factors results in this apparent randomness and explains the presence of extreme values.
- The large variability is real and not a consequence of faulty analyses because chromatographic analyses are reproducible to better than 4% and thus could not have caused such huge variability.
- These ranged between 7.7 and 88% for methane and between 51 and 902% for CO_2 .
- Methane emission flow rates do not show dependence with latitude.

Table 1. Average gas flow from reservoirs as measured in the first trip.

Dam	gas flux by bubbles mg m^{-2} d^{-1}				gas flux by diffusion mg m^{-2} d^{-1}				sum of ebullitive and diffusive flux			
	CH_4	σ %	CO_2	σ %	CH_4	σ %	CO_2	σ %	CH_4	σ %	CO_2	σ %
Miranda	29.2	64	0.38	55	233	4.6	4,980	4.1	262	11	4,980	4.1
Tres Marias	273	31	5.16	73	55	-	-142	-	328	-	-137	-
Barra Bonita	4.81	24	0.32	43	14	3.7	6,434	1.8	19	9	6,434	1.8
Segredo	2.01	-	0.03	-	8	3.1	4,789	2.4	10	-	4,789	2.4
Xingó	1.85	-	0.02	-	28	3.2	9,837	4.2	30	-	9,837	4.2
Samuel	19.3	95	0.65	36	164	2.6	8,087	1.4	184	12	8,087	1.4
Tucuruí	13.1	59	0.15	51	192	9	10,433	1.9	209	12	10,433	1.9
Itaipu	0.5	-	<1	-	12.4	-	1,205	-	13	-	1,205	-
Serra da Mesa	111	-	1.9	-	10	-	1,316	-	121	-	1,318	-

Table 2. Average gas flow as measured in second trip

Dam	gas flow by bubbles, mg m^{-2}d^{-1}		Diffusive gas flow, mg m^{-2}d^{-1}				sum of ebullitive and diffusive flow	
	CH_4	CO_2	CH_4	σ %	CO_2	σ %	CH_4	CO_2
Miranda	18	0.16	27.4	7.7	3,795	210	45	3,795
Tres Marias	55.8	2.03	9.1	81	2,410	82	65	2,412
Barra Bonita	3.1	0.04	21.1	39	1,348	590	25	1,348
Segredo	2.1	0.07	5.7	49	601	902	7.8	601
Xingó	19.5	0.04	27	88	2,259	281	47	2,259
Samuel	13.6	0.39	10.8	37	5,350	51	24	5,350
Tucuruí	2.4	0.16	12.2	26	6,516	167	15	6,516
Itaipu	0.6	<<1	7.9	-	-864	-	8.5	-864
Serra da Mesa	66.3	1.5	39.2	-	3,972	-	105	3,973

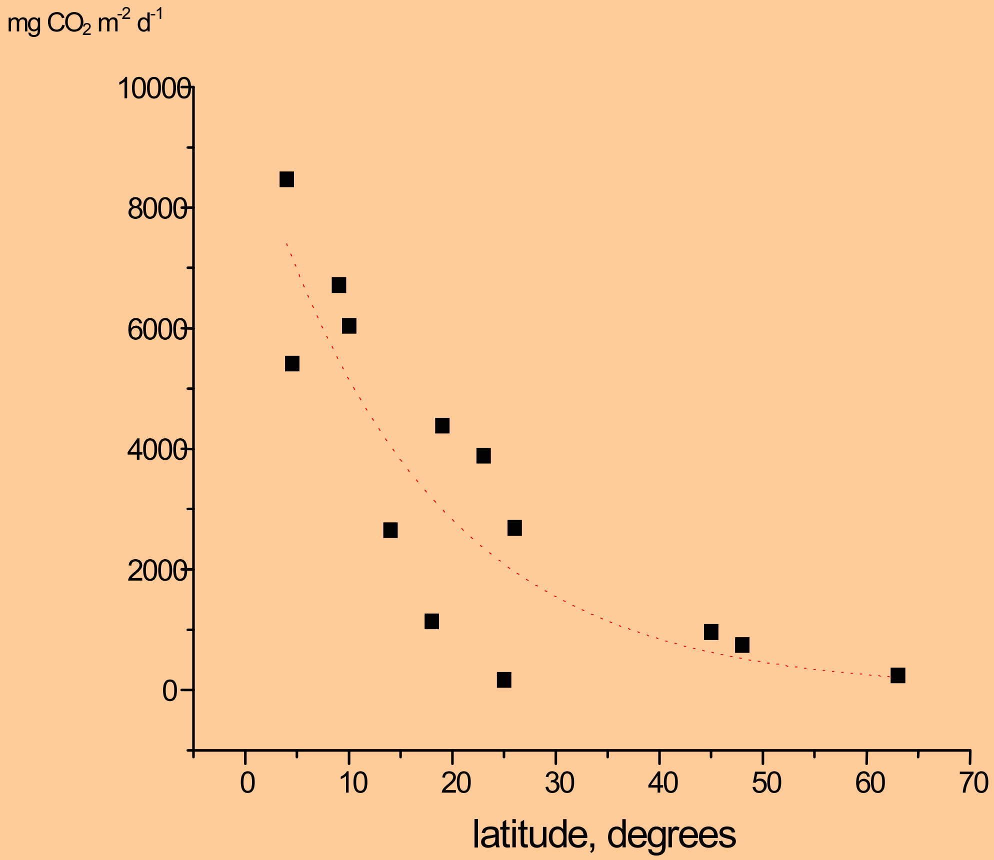


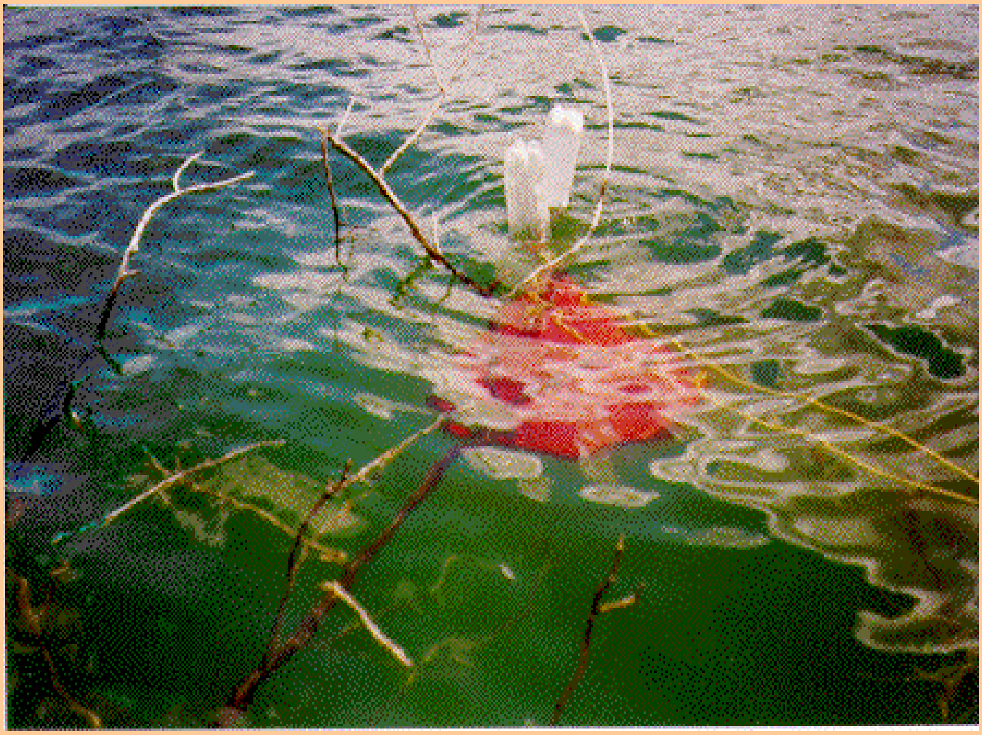
Figure 1. Nine of our flow values, and four values from literature, plotted against latitude. The dotted line is the exponential y = 9408 exp (-x / 16.6).

Nome	N*	Combustível e Tecnologia
Xingó	86,59	carvão mineral (ciclo simples, 35% eficiência)
Xingó	77,85	óleo combustível (ciclo simples, 30% eficiência)
Xingó	77,85	óleo diesel (ciclo simples, 30% eficiência)
Segredo	63,16	carvão mineral (ciclo simples, 35% eficiência)
Segredo	56,79	óleo combustível (ciclo simples, 30% eficiência)
Segredo	56,79	óleo diesel (ciclo simples, 30% eficiência)
Xingó	54,99	gás natural (ciclo combinado, 45% eficiência)
Segredo	40,12	gás natural (ciclo combinado, 45% eficiência)
Miranda	12,02	carvão mineral (ciclo simples, 35% eficiência)
Miranda	10,80	óleo combustível (ciclo simples, 30% eficiência)
Miranda	10,80	óleo diesel (ciclo simples, 30% eficiência)
Miranda	7,63	gás natural (ciclo combinado, 45% eficiência)
Tucuruí	1,80	carvão mineral (ciclo simples, 35% eficiência)
Tucuruí	1,62	óleo combustível (ciclo simples, 30% eficiência)
Tucuruí	1,62	óleo diesel (ciclo simples, 30% eficiência)
Barra Bonita	1,23	carvão mineral (ciclo simples, 35% eficiência)
Tucuruí	1,15	gás natural (ciclo combinado, 45% eficiência)
Barra Bonita	1,11	óleo combustível (ciclo simples, 30% eficiência)
Barra Bonita	1,11	óleo diesel (ciclo simples, 30% eficiência)
Três Marias	0,84	carvão mineral (ciclo simples, 35% eficiência)
Barra Bonita	0,78	gás natural (ciclo combinado, 45% eficiência)
Três Marias	0,76	óleo combustível (ciclo simples, 30% eficiência)
Três Marias	0,76	óleo diesel (ciclo simples, 30% eficiência)
Três Marias	0,54	gás natural (ciclo combinado, 45% eficiência)
Samuel	0,52	carvão mineral (ciclo simples, 35% eficiência)
Samuel	0,47	óleo combustível (ciclo simples, 30% eficiência)
Samuel	0,47	óleo diesel (ciclo simples, 30% eficiência)
Samuel	0,33	gás natural (ciclo combinado, 45% eficiência)

$$*N = \frac{\text{Emissão de Carbono de uma Termelétrica Equivalente}}{\text{Emissão de Carbono de uma Hidrelétrica Específica}}$$

View of Submergible Diffusion Chamber

View of Funnel for Bubbling Gas Sampling



- The scientific literature shows that reservoirs can emit methane due to the anaerobic decomposition of biomass and carbon dioxide.

- In some particular circumstances, this can be substantial and of a similar order of magnitude as the thermal emissions avoided.

- Tropical reservoirs that are shallow and uncleared of biomass appear most at risk.

- Scenarios are calculated showing that in cases where the power capacity 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/m^2 of reservoir the scenarios show that possibility of reservoirs emissions putting at risk the benefits of CO_2 avoided by hydro are reduced.

- The main scientific controversy centres on the extrapolation of measured emissions per m^2 in selected parts of the reservoir to the whole reservoir area.
- Emissions of CH4 almost certainly vary according to depth and the distribution of the submerged biomass.
- Studies have not yet been carried out over long periods to characterize the full life-cycle curve of the emissions.

DAMS AND DEVELOPMENT REPORT - WCD CONCLUSIONS ON DAMS AND GHGs EMISSION

- Reservoirs interrupt the downstream flow of organic carbon, leading to emissions of greenhouse gases such as methane and carbon dioxide that contribute to climate change.

- The emission of greenhouse gases (GHG) from reservoirs due to rotting vegetation and carbon inflows from the catchment is a recently identified ecosystem impact (on climate) of storage dams.

- A first estimate suggests that the gross emissions from reservoirs may account for between 1% and 28% of the global warming potential of GHG emissions.

- All large dams and natural lakes in the boreal and tropical regions that have been measured emit greenhouse gases (carbon dioxide, methane, or sometimes both);

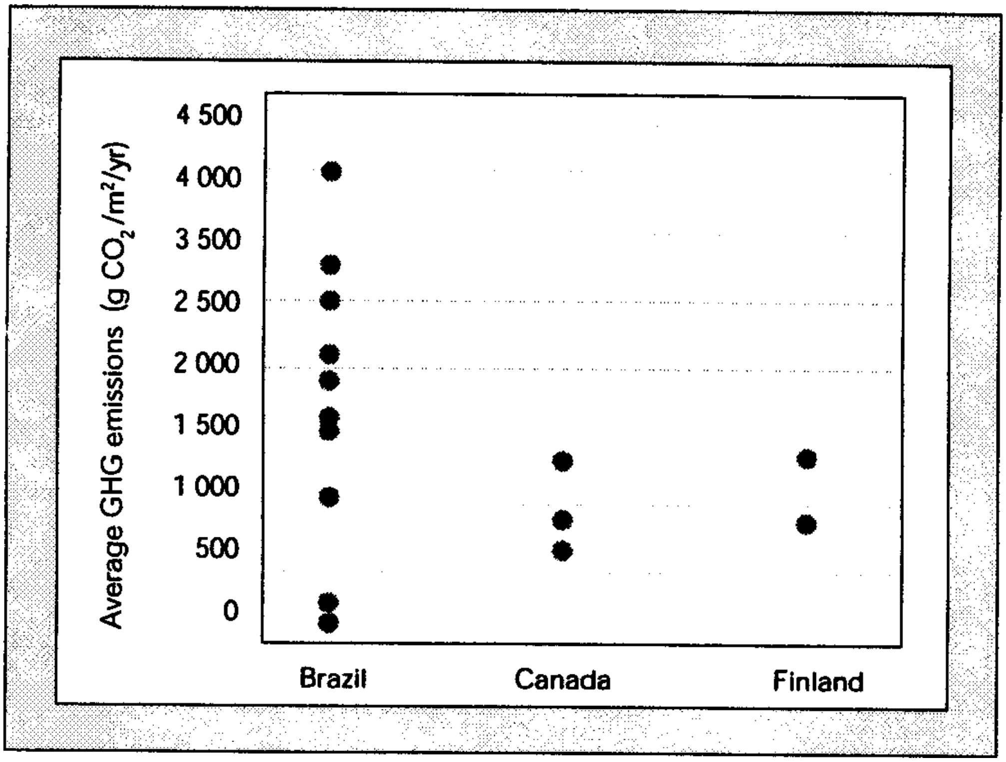
- For example, a floodplain tropical forest in Amazonia may emit methane from soils and, at the same time, absorb carbon dioxide in leaves.

- Some values for gross GHG emissions are extremely low and may be 10 times less than the thermal option. Yet in some circumstances the gross emissions can be considerable, and possibly greater thanthe thermal alternatives.

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

- The WCD Case Studies only provide data on carbon dioxide and methane emissions from the Tucurui reservoir .

Figure 3.1 Gross greenhouse gas emissions from reservoirs



Box 3.2 Greenhouse gas emissions at Tucurui, Brazil

Recent monitoring in the 2 600 km^2 reservoir of Tucurui show that greenhouse gas emissions are substantial and highly variable from year to year. Values in 1998 exceeded those measured in 1999 by more than a factor of 10 for methane and by 65% for carbon dioxide (see table below).[15]

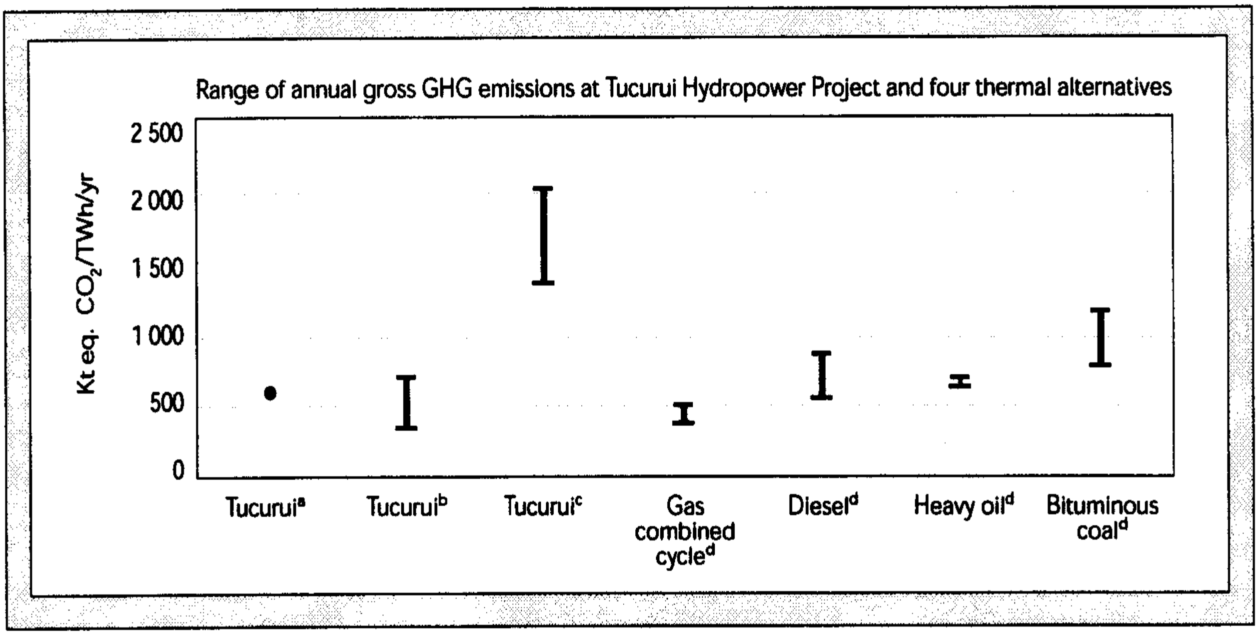
Total Gross Emissions (tons/km^2/ year)

Year	**Methane**	**Carbon dioxide**
1998	76.36	3 808
1999	5.33	2 378

Modelling taking into account emissions from water passing through the turbines or over the spillway leads to higher estimates of total emissions.[16] The figure below compares these gross emissions to those of alternative technologies for large-scale power generation.[17] Background emissions from natural pre-impoundment habitats have not yet been measured for Tucurui, so true comparisons of net emissions with alternatives remain elusive.

The alternative technology for large-scale electricity generation required for aluminium smelting (the main consumer of electricity) was thermal power employing diesel fuel when the project was built in the 1970s. Today the alternative would be gas combined cycle plants.

Source: WCD Tucurui Case Study.



Sources: [a]Fearnside, 1995; [b]Rosa et al, 1999; [c]Fearnside, 2000; [d]IEA, 2000.

- Current understanding of emissions suggests that shallow, warm tropical dams are more likely to be major GHG emitters than deep cold boreal dams.

- In the case of hydropower dams, tropical dams that have low installed capacity and large shallow reservoirs are more likely to have gross emissions that approach those of comparable thermal alternatives than those with small, deep reservoirs and high in-stalled capacity.

- No experience exists with minimising, mitigating, or compensating these impacts.

- Pre-inundation removal of vegetation is one alternative, but the net effects of such an activity are not well understood.

- The outcome of global negotiations on climate change may bear on future penalties and incentives for net GHG emissions from dams.