**WCD Thematic Reviews**
**II.2 Dams and Global Change**

# Dam Reservoirs and Greenhouse Gases
## Report on the Workshop Held on
## February 24 & 25, 2000; Hydro-Quebec, Montreal

Final Minutes

**DRAFT (NOT FOR CIRCULATION OR CITATION)**

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# 1. Background

This workshop was convened by the World Commission on Dams as part of its Thematic Review process addressing issues related to Dams and Global Climate Change. The initial draft report showed that dam reservoirs are observed to be emitters of greenhouse gases (which for the purposes of this review are mostly carbon dioxide, $CO_2$ and methane, $CH_4$), with large variations between countries and between situations. The natural ecosystem also emits greenhouse gases at different rates through natural carbon fluxes. As with all of the WCD's Thematic Reviews, this paper has gone through an external review process in which professionals in the field have acted as peer reviewers of the work. The review process pointed out differing perspectives in the interpretation of the available science. The workshop therefore brought together invited experts (see Annex I) to build on their experiences by focusing specifically on the aspects that need to be overcome to reach a unified approach on the subject of reservoirs and greenhouse gases (GHGs). While the discussions presented here, and the available research base, are particularly oriented towards hydropower reservoirs due to the explicit link with the thermal generation alternative, it should nevertheless be understood that emissions are not related to reservoir purpose and are also likely to occur in irrigation, water supply, flood control and recreation reservoirs.

Participants were invited based not only on their particular scientific knowledge but also the particular perspective they bring to the table. WCD is committed to bringing together divergent interests from both environmental NGOs and their affiliates, and the industry perspective. The meeting was chaired by Jamie Skinner, WCD Secretariat and was facilitated by Prof Claude Hillaire Marcel of University of Quebec in Montreal (UQAM).

The workshop was held with the financial and logistical support of Hydro-Quebec. Other institutions have also contributed by covering the costs of their participants.

***Workshop Sessions***

The opening day was spent with each presenter introducing their experience and results for 15 minutes to give other participants a feel for their expertise and results (see details in agenda, Annex II). Then the workshop responded to a series of questions concerning the current science base on reservoirs and greenhouse gases.

- What are the areas of agreement and disagreement among experts in the field ?
- What are the major issues that need to be resolved ?
- What steps are needed for a new/existing reservoir to determine its net GHG emissions ?
- How can the major issues be resolved and what future steps should be taken ?

In the discussions that followed it was the WCD objective to find areas of convergence and agreement and to assess the degree to which the science base was strong enough to inform policy development through the work of the Commission. Areas of uncertainty were therefore long debated prior to establishing the agreed list of conclusions that follow in the next sections.

# 2. What are the areas of agreement and disagreement among experts in the field?

Discussions led to general consensus on the text that follows :

"From studies undertaken on about 30 reservoirs mostly in tropical and boreal latitudes, the following conclusions can be drawn :

1. 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.

   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.

   However, the rates of GHG emission measured so far justify consideration of these emissions in:
   (a) evaluating individual future reservoir sites, such as hydro electric dams (most particularly in tropical regions); and
   (b) in global inventories of anthropogenic changes in the sources and sinks for CO2 and CH4

2. Better data are needed on the total surface and flooded area of reservoirs and how they are distributed biogeographically. Measurements are also required in a wider variety of ecosystems to improve our current knowledge of the probable distribution of emission rates from all types of reservoirs.

3. GHG emissions cannot be directly explained by the volume of submerged biomass nor it's carbon content. The sources of the carbon in GHGs emitted from reservoirs include:
   (a) flooded biomass
   (b) carbon in the soil and peat of the reservoir
   (c) emergent biomass (e.g. dead trees)
   (d) Dissolved Organic Carbon/Particulate Organic Carbon and organic debris from the catchment
   (e) decomposition of macrophytes and algae following their death

4. A range of factors directly influence GHG emissions from reservoirs
   (a) Depth
   (b) Water residence time
   (c) Hydrodynamics
   (d) Size and nature of watershed
   (e) Temperature (latitude/altitude)
   (f) Climate and hydrological fluctuations
   (g) Age of reservoir
   (h) Primary production
   (i) Operating regime of dam
   (j) Wind

(k) Size and shape of reservoir (bathymetry)
(l) Anthropogenic activities around the reservoir and in the catchment

5. Emissions of methane and $CO_2$ from water passing through the turbines spillway and downstream may also be a significant source. This is influenced by the depth of the turbine intake.

6. There may be an inferred pulse of GHG emission shortly after reservoir filling, although there lacks data except in Petit-Saut, French Guiana.

7. GHG analysis of hydro-electric reservoirs and their alternatives should be undertaken on the basis of net emissions, not gross emissions. This comparison should be done on a life cycle basis. Reservoirs for other purposes should also be assessed with respect to their alternative.

8. Dams on a water course modify particulate and dissolved carbon fluxes by trapping and increasing residence time of the Dissolved Organic Carbon in the freshwater system. They also modify carbon fates after the dam.

9. Generally in a 100 year timescale we can assume that mature forest ecosystems, if preserved, represent a stable carbon stock and when flooded, a portion of that carbon will be decomposed, creating GHG emissions. It is also understood that peatlands act as long-term carbon sinks, and when inundated, the change in ecological processes will prevent it from acting as a sink. The overall assessment of the role of peatland on GHG emissions must however consider the different impacts of $CO_2$ and $CH_4$ input and $CO_2$ and $CH_4$ output.

10. For purposes of converting methane emissions into "equivalent $CO_2$", the currently widespread use of the 100 year GWP (Global Warming Potential [1])for methane can significantly under-estimate the "equivalent $CO_2$" over the first several decades because methane's GWP declines significantly with a longer time horizon. In addition, significant resident timescale uncertainties for methane and $CO_2$ will also affect the "equivalent $CO_2$". Other time-dependent conversion methods (Delmas, Gaffin etc) should be considered.

11. A period of 100 years is appropriate for the initial calculation of the life cycle emissions from reservoirs."

[1] To assist comparisons between the global warming effects of different gases, these are expressed as an index of "global warming potential". The baseline gas is $CO_2$, and the GWP of other gases is expressed as a multiple of this warming potential over a one hundred-year period. The impact of one unit of methane on global warming is equivalent to 21 units of $CO_2$.

# 3. What steps are needed for a new reservoir to determine its net GHG emissions?

This subject is important if the Clean Development Mechanism under the Kyoto Protocol is to provide financial support in the form of carbon credits for hydropower with the purpose of reducing global warming. It is also important considering the current trend towards full life cycle analysis of different energy options prior to decisions being taken on energy supply options. It was clear to all participants that in order to calculate the level of credit to be given to a future hydropower project it is not sufficient to assume that the GHG emissions will be zero. Nor is it enough simply to use current observed levels of emissions from reservoirs in similar areas, as large inter-reservoir variations can be observed. The participants therefore stressed the need to assess the net change in GHG emissions due to the dam and reservoir and laid out the following guidelines for doing so :

"The goal is to predict accurately GHG emissions from reservoirs so as to make the best possible decisions about dams among other development choices. Net emissions from reservoirs above baseline emissions are the appropriate estimates.

To calculate net emissions, one must:

- Assess the carbon and nitrogen cycles ($N_2O$, Nitrous oxide another key GHG that has been so far little studied in connection with reservoirs) in the pre-impoundment watershed context. This involves establishing a carbon budget, including description of flow rates, concentrations, residence time, etc.
- Assess changes to carbon inputs in the watershed from various activities, including deforestation.
- Assess characteristics of proposed reservoir(s) and inundated area(s) that will change the carbon cycle (incl. size, temp, bathymetry, 1º productivity, etc.)
- Assess the cumulative emissions from multiple dams on a watershed basis in cases where a dam and its operations are linked to other dams."

One working group discussed the pre-dam studies that were needed to establish the baseline situation from which the net change could be measured and proposed the following :

1. "Classification of the catchment
    - Soil types
    - Vegetation types
    - Existing lakes and Rivers down to estuary
    - Hydrology volume and timing

2. Assess the spatial and temporal resolution needed for the field measurements

3. 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 3 years due to the strong interannual variability depicted by the available time series of greenhouse gas emissions in order to increase the probability to get average values representative of long term emissions

4. Is the area to be flooded currently storing or emitting carbon? (include turpenes and biogenics).

> Compare weather during the study period to long term variations and ask whether it is representative."

The workshop therefore felt that there are robust methodologies and sufficient scientific knowledge to provide a preliminary framework for undertaking such assessments on a regular basis if the Clean Development Mechanism does give hydropower carbon credits in future.

As a basis for informing decision-makers on the potential for a new reservoir to emit GHGs the workshop proposed a set of parameters against which at least the possibility of substantial GHG emission can be assessed. Working groups looked at these parameters for tropical and boreal reservoirs (Annex III).

In addition to the GHG emission aspects linked to the CDM, the hydropower option has other social and environmental consequences. As the workshop heard from Brazil, construction of dams in tropical forests may lead to colonisation of forest areas, deforestation, and other local and cumulative impacts.

# 4. Unresolved issues

The meeting held long discussions concerning issues of discounting, that involve some appreciation of the direction and magnitude of future change, the cumulative or interactive effects of dam construction on related global warming inducing activities (e.g. colonisation of areas around Amazonian dams, and increased logging and burning as a result). One proposal for a "conclusion" of the workshop on these issues was made but many participants felt unable to endorse it as it lay outside their area of particular expertise. This proposal is recorded in full below.

**Time horizon and time preference – Dr Philip Fearnside.**

"Decisions on the time scale over which dams and their global warming impacts are assessed, and on the weighing for time (as by discounting) over the course of the time horizon, will have dramatic influence on the choices that are made on energy development options. They will also influence the assessment of the world-wide contribution to global warming made by reservoirs. These policy choices should be made to best represent the interests of society. If long-time horizons are applied without discounting, or other forms of time-preference adjustment within the time horizon, the result would be to give little value to delaying global warming. When global warming is delayed, the impact (including human life and other non-monetary impact) that would have occurred over the course of the delay represent benefits to society. Translating this societal value into the decision-making tools represented by time horizon and discounting will result in giving greater weight to short-term impacts such as the peak of emissions from dam construction and the first few years of impoundment and the short-lived gases such as the methane produced by reservoirs. Choice of 100-year time horizon would be consistent with many dam life cycle analyses and with the global warming potentials currently adopted by the Kyoto Protocol."

# 5. Issues requiring further research

**a) More measurements on a wider range and diversity of reservoirs**

The group agreed that the current limitation of research efforts to tropical reservoirs in Brazil and Guyana, and boreal reservoirs in Canada and Finland was a handicap in trying to deduce globally relevant trends. Research efforts in other countries, especially temperate or semi-arid areas would help complete our general understanding of this issue.

**b) More measurements on a wider range and diversity of natural environments in countries that are currently building dams**.

There is clearly a lack of relevant scientific data on pre-dam carbon flows for countries that envisage building hydropower projects (with the notable exception of Brazil). Research could be organised for catchments where dams are being proposed in order to undertake a pre and post dam assessment. This would be innovative research and give powerful insights into how carbon fluxes change when a dam creates a reservoir.

**c) Improve the understanding of the role of transient carbon in reservoirs and natural lakes**

Research is already underway on this issue within Canada, and perhaps elsewhere. It provides a fundamental understanding of carbon cycles within lakes in peatland areas.

**d) What role do oceans play as repositories of carbon in sediments and how is this role affected by dams?**

This topic is of interest to understanding the global carbon cycle and the role of carbon sinks. Whether dam reservoirs do or do not function as carbon sinks is a key consideration.

**e) What is the fate of carbon in an undammed catchment compared to a dammed catchment ?**

More research is needed on natural carbon fluxes within the catchment, right down to the estuary. This research should identify the factors that affect the ultimate fate of the carbon.

# 6. Interpretation by the WCD Secretariat

Much of the workshop discussion involved sharing the approaches, methods and results of different scientists who have studied GHG emissions for many years. The implications of the agreed texts arising from the workshop, and reported above, may at times be difficult to follow and this section attempts to highlight some of the more important issues that discussions at this workshop point to.

***a) The volume of flooded biomass is not the only factor determining the GHG emissions from a new reservoir.***

This conclusion is an important one as freshwater biologists and limnologists point to the importance of the post-impoundment "nutrient flush" in promoting changes in water quality in reservoirs that have effects on fisheries productivity for example. It is a natural step to assume that significant anaerobic and aerobic decomposition is similarly leading to GHG emissions. Yet the workshop heard that field measurements show it is not possible to directly relate observed GHG emissions to the known flooded biomass.

This in turn infers that there may be no point in deforesting a new reservoir area with the precise objective of reducing GHG emissions in future (there may however be other reasons for doing so).

***b) Carbon inflows from the surrounding catchment in the form of dissolved or particulate organic carbon are important in supplying carbon that is then modified and emitted within the reservoir ecosystem.***

The key issue here is that the dam intervenes in, and modifies, the natural carbon cycle within the catchment. The dam serves to store (however temporarily) this carbon and interrupt its natural flow to the sea or to the atmosphere. As the biochemical processes in reservoirs are likely to be more anaerobic than the natural carbon cycles in the free flowing rivers of the pre-dammed catchment this may prove to be a significant factor in some reservoirs emitting the carbon as methane rather than as $CO_2$ (the workshop pointed out that some dams may not emit methane, but for those that do, especially tropical ones, it may prove true that this represents a first "guesstimate" of the net emission as in the free-flowing state methane would probably normally be absent. This idea needs further work.)

As carbon inflows are a key element in reservoir GHG emissions they are subject to short and long-term fluctuations due to changes in catchment management. Increased sewage inflows, deforestation or changing land use patterns can all affect carbon flows within a catchment upstream of a dam. The dam reservoir becomes a passive receptacle and active processor of carbon that it is not really responsible for generating in the first place. Making predictions about future GHG emissions from reservoirs based on past measurements of carbon inflows may undervalue the estimated GHG emissions if carbon inflows are increasing due to anthropogenic activities such as deforestation. Hence the need for a baseline pre-dam carbon flux survey, for estimates of how such carbon fluxes may change in the future, and for monitoring of emissions from the reservoir to determine the net contribution of the reservoir to the GHG emissions of the catchment. One idea here would be to monitor inflows of carbon to the dam as a matter of routine. Another idea is to ensure that watershed management to control carbon and sediment inputs to the reservoir is implemented, including forest protection.

***c) Carbon flows to the sea may be disrupted***

The storage of organic sediments in dams may disrupt the movement of sediment and its associated carbon to ocean sinks. There is still little evidence of the scale at which this may occur, and the workshop heard about the complexities of biochemical processes in the Amazon leading to partial sinks of carbon and humic acids in the ocean. Some specialists believe that sediments in dams may also constitute a sink for carbon, however the observed emissions suggest that this is not yet clear-cut.

***d) Life cycle analysis and monitoring are essential***

GHG emissions from reservoirs are variable in space, and in some cases also in time. It is essential to look not only at a full life cycle analysis of energy options before selecting the best option, but to ensure that monitoring of emissions takes place.

***e) Timescales and atmospheric uncertainties***

The workshop heard that methane breaks down in the troposphere at a particular rate that is one contributing factor to determining its 100 year Global Warming Potential. The IPCC has fixed the GWP of methane at 21 times that of $CO_2$ (over 100 years, but 56 times that of $CO_2$ over 20 years), yet it appears that increases in UV radiation, due to reduction of the ozone layer, may be increasing the density of the hydroxyl radicals that are responsible for breaking methane down into $CO_2$ and water. Observed methane densities are reported by Prof Delmas to be on the decline in recent years. Clearly the period selected for calculating the GWP of methane is critical in assessing its effect on global warming and this may prove variable over time. The workshop recognised that the meeting had focussed on how the carbon moves from the catchment to the atmosphere however there was also recognition of the uncertainties about what exactly happened to it when it reached the atmosphere, and this should clearly be discussed in other fora with atmospheric scientists.

# Annex I- List of Workshop Participants

| **Participant** | **Affiliation** | **Email** |
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# Annex II-Agenda for the Workshop

**Agenda For The Workshop On:**
***RESERVOIRS AND GREENHOUSE GASES***
Hydro-Quebec, Montreal, Canada-February 24 & 25

## *Why the Workshop?*

This workshop has been convened by the World Commission on Dams as part of its Thematic Review process in which it is addressing issues related to Dams and Global Climate Change. As with all of the WCD's Thematic Reviews, this paper has gone 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 have arisen that need to be discussed in order to better understand the relationship between reservoirs and GHG emissions.

The workshop is being held with the financial and logistical support of Hydro-Quebec. Other institutions have also contributed by covering the costs of their participants.

## *Goals of the Workshop*

The present workshop will bring together invited experts to build on their experiences by focusing specifically on the aspects that need to be overcome to reach a unified approach on the subject of reservoirs and greenhouse gases (GHGs). Therefore, although the meeting will need to resolve technical issues, the goal of the workshop is to reach consensus on scientific methodologies in order to use the available information to make policy decisions. One possible supplementary outcome of the meeting would be a joint research agenda that would assist in increasing the certainty surrounding areas of contention, which would be pursued over the next 3-5 years.

## *Details on the Workshop: The Half-Day Sessions*

- In each session, the Chairman will pose the key questions to be answered by the group. These will be asked at the beginning of the session and they will be revisited at the end to answer the response
- The first day will consist of presentations by the participants in the morning with a round table discussion in the afternoon
- The second day will consist of focused discussions aimed at answering particular issues of relevance to the WCD's Work Programme
- All sessions will be chaired by Jamie Skinner and facilitated by a person still to be defined

The report of the workshop will not be a revised version of the Rosa & Dos Santos paper, but a new shorter report on main issues. The outcome of the workshop will be the next step on which the WCD will build for the topic of reservoirs and GHGs.

## *Note to Presenters*

Presenters should note that the afternoon discussion on the first day will be based on the morning presentations. We therefore recommend that presenters try to address the issues to be discussed in the afternoon in order to use the presentations as the base on which to build that discussion.

We suggest that participants bring with them materials they consider can help improve the discussion, particularly visuals and reports for distributing among the experts.

***Thursday February 24***

## ***Morning Session: Presentations by Participants***

✓ Presentations aimed at highlighting the common and different issues that have arisen from the various research groups

**8:30 am Registration, Coffee & Muffins**

**9:00 am Introduction by the WCD**
- Defining the purpose and goals of the workshop
- What is the goal of the WCD?
- Briefly state the purpose and results from the WCD paper on GHGs
- Present the results of the review process for that paper and the issues that have emerged
- Must clarify that the debate is on dam created reservoirs and therefore not only hydropower

**9:20 am-1:00 pm Presentations (titles are based on e-mail correspondence with presenters)**

9:20 am *Marco Aurelio dos Santos*
Presentation of results and issues that have arisen from the paper written by L P Rosa and M A dos Santos for the WCD

9:40 am *Stuart Gaffin*
"Modelling work on CO2 and CH4 relative climate impacts." Presentation of methodology for calculating a 'CO2-equivalent' for the CH4 emissions from dam reservoirs. I will show applications of the model to three tropical dams: Balbina, Tucurui and Petit-Saut. Results will be compared to those using traditional IPCC GWP values.

10:00 am *Robert Delmas*
Comparison of emission from Petit Saut compared to thermal alternatives

10:20 am *Bohdan Matvienko*
Techniques of measurements for GHGs from hydro reservoirs.

10:40 am *Philip Fearnside*
"Greenhouse gas emissions from hydropower in tropical forest areas: Brazil's Tucuruí Dam as an example of unresolved issues in assessing energy options"

11:00 am *Don Addams*
GHG fluxes at the sediment-water interface.

11:20 am *Coffee Break*

11:40 am *Vincent St. Louis & Carol Kelly*
"Reservoir surfaces as sources of greenhouse gases to the atmosphere: a global estimate." A summary of the state of knowledge on GHG fluxes from reservoirs, on a global basis. It includes data from 22 reservoirs and also an analysis of how well the global area is known

12:00 pm *Luc Gagnon*

Comparing hydropower with other options and the issue of representative reservoirs

12:20 pm *Marc Lucotte*

The State of research on reservoirs in Quebec. Considers the intensity of last summer's research program, with four different measurement techniques on reservoirs and natural lakes

**12:40 pm-1:40 pm Lunch**

*1:40 pm* Bill Hamlin

"Manitoba Hydro's reservoir emission model," a model based on the research results from experimental lakes.

2:00 pm *Louis Varfalvy*

Research concerning isotope analysis, measurements with laser, and assessment of carbon and N2O emissions from ecosystems in the watershed.

2:20 pm *Jamie Skinner*

Wrap up of presentations

## ***Afternoon Session*: Round Table Discussion Based on the Presentations from the Morning Session**

- ✓ What are the areas of agreement and disagreement among experts in the field?
- ✓ What are the major issues that need to be resolved?

**2:30-6:30 pm What are the commonalties and differences from our research?**

a) What are the observed trends of CO2 or CH4 emissions from reservoirs over time? A reduction or an increase?
b) How do GHG emissions, per square meter, from *tropical* ecosystems, compare with *boreal* ecosystems? More? Less? Which GHG is more significant in each ecosystem?
c) Does the flooded biomass at the bottom of reservoirs explain the level of emissions that is measured?
d) How quickly does the flooded biomass decompose in a reservoir?
e) Does organic or/and inorganic carbon flowing through a natural river create emissions somewhere in the river basin (in natural lakes or delta)? Or when a reservoir is created, are there specific conditions that change the fate of this carbon? Would that carbon have been eventually stored in the depths of the ocean?
f) Is there a need to have a common measurement protocol for measuring and quantifying GHG emissions from reservoirs?
g) Do we agree on life span of 100 years for the dam life cycle assessment? And a GWP over 100 years for methane?

**4:00-4:20 pm Coffee Break**

**7:30 pm Dinner**

***Friday February 25***

## ***Morning Session: Focused Discussion***

- ✓ What steps are needed for a new/existing reservoir to determine its net GHG emissions?

**8:30 am Coffee & Muffins**

9:00 am-1:00 pm How can we address the issue of GHG emissions in pre vs. post impoundment condition (Net versus Gross emissions)?

a) How do we measure the pre-impoundment GHG emissions? How do we measure the carbon flux in the catchment?
b) How can we compare pre vs. post impoundment GHG emissions?
c) Is it necessary to also consider N2O emissions?
d) Do the current methodologies allow for extrapolation? How should the sampling be organized to ensure it is representative enough? How do we prevent only looking at a small portion of the picture?
e) How can current practices be modified as to minimize net GHG emissions? For example, should the vegetation be cleared before impoundment?

**11:00 am Coffee Break**

**1:00 pm-2:00 pm Lunch**

## ***Afternoon Session: Final Wrap-Up Discussion and Conclusions***

- ✓ Have we moved forward?
- ✓ How can the major issues be resolved and what future steps should be taken?

**2:00 pm What are the future research needs**

**f)** There will be two 10-minute presentations on the future research needs by two of the participants
**g)** More measurements on a wider range and diversity of reservoirs?
**h)** More measurements on a wider range and diversity of natural environments, to be able to make better comparisons?
**i)** Improve the understanding of human interventions such as forest exploitation and its effect on emissions from watersheds?
**j)** Improve the understanding of effects of forest fires?
**k)** Improve the understanding of the role of transient carbon in reservoirs and natural lakes?
**l)** What contribution should we expect from new research tools, such as lasers to measure emissions in a continuous mode?
**m)** What role do oceans play and how is it affected by dams? (the role of oceans as repositories of carbon in sediments)

**3:40-4:00 pm Coffee Break**

4:00-5:30 pm What's next?

a) Is the science clear enough to make conclusions and use the evidence from research? Can scientists provide answers to practitioners making decisions on dam building, planning, operations, and decommissioning?
b) How can all the accumulated knowledge base from the research be used in practice?
c) Should we choose a dam under construction and do a thorough study to compare pre and post impoundment GHG emissions? i.e. Nam Theun 2?

5:30-6:00 pm Closing Remarks

# Annex III- Working Groups: Parameters Influencing GHG Emissions from Tropical and Boreal Reservoirs.

**Working Group 1: Parameters Influencing GHGs Emissions from Tropical Reservoirs**. (XXX indicates more emission mg/m²/y; OOO indicates more emissions mg/KWh)

| **Parameter** | **Parameters Influencing GHGs Emissions from Tropical Reservoirs** | |
|---|---|---|
| | ***High*** | ***Low*** |
| 1) Power density V/m² inundated | X | XXX |
| 2) Installed capacity<br>generation efficiency | O<br>O | OOO<br>OOO |
| 3) Depth | X | XXX |
| 4) Labile biomass density | XXX | X |
| 5) Shape of reservoir | XXX<br>very dendritic | X<br>Canyon like |
| 6) Water residence time in reservoir | XXX | X |
| 7) Size of catchment area | XXX | X |
| 8) Temperature | XXX | X |
| 9) Nutrient and Carbon input | XXX | X |
| 10) Macrophytes/ algae? | XXX<br>? | X<br>? |
| 11) Emergent trees | XXX | X |
| 12) Drawdown areas and frequency | XXX | X |
| 13) Slope stability | X | XXX |

**Working group 2 : Parameters Influencing GHG Emissions from Boreal Reservoirs**

| **Parameter** | **Parameters Influencing GHG Emissions from Boreal Reservoirs** | |
|---|---|---|
| | ***Low GHG emissions*** | ***High GHG emissions*** |
| 1) Depth | Deep | Shallow |
| 2) Residence Time | - | - |
| 3) Hydro Dynamics | - | - |
| 4) Size of Reservoir | High energy to flooding ratio | - |
| 5) Size of Reservoir / Drainage Basin | - | - |
| 6) Physiography | Steep and deep | - |
| 7) Temperature | Cold | Warm |
| 8) Climate and Hydrological fluctuations | Long Ice Cover | - |
| 9) Operating (Fluctuations) | - | - |
| 10) Flooded Carbon soil including peat | Site dependant but potentially a source of GHGs | |
| 11) Emergent flooded biomass | | Minor |
| 12) Dissolved organic carbon/Particulate organic carbon | Unknown but a significant factor | |
| 13) Photosynthesis from Macrophytes | Not significant | - |
| 14) Algae | Absent | Extensive |
| 15) Oxygen | - | - |

| | | |
|---|---|---|
| 16) Nutrient Availability | - | High |
| 17) Ratio Size Res / Drainage | - | - |
| 18) Dam Network | Maximise energy production per flooded area | - |
| 19) Diversion | Site specific consideration, notably the ratio [$CH_4$ + $CO_2$] emissions from turbines – downstream vs. emissions in the reservoir | - |

The working group laid out the parameters but did not have time to revisit them all. Some parameters were considered important but variable from site to site. No clear trends therefore emerged.