GHG Risk Assessment Tool (Beta Version)

USER MANUAL

Derived from:

The UNESCO/IHA Greenhouse Gas Emissions from Freshwater Reservoirs Research Project

August 2012

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United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

Greenhouse Gas Status of Freshwater Reservoirs Project

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The first international UNESCO/IHA GHG workshop on the topic was convened in Paris, France, in 2006. A key reference established through this scientific community is the assessment of the GHG Status of Freshwater Reservoirs – Scoping Paper, which led to the UNESCO/IHA GHG Project. Scientific understanding has since advanced under the UNESCO/IHA GHG Status of Freshwater Reservoirs Research Project (UNESCO/IHA GHG Project), which started in August 2008.

The Project has benefited from the collaboration of numerous research institutions and scientists within its peer-review group. The group was established through a series of international workshops convened over the past four years, and comprises representatives from more than 100 institutions, including universities, research institutes, specialist companies, sponsoring agencies, and others. All documents produced under the Project pass through the peer-review group before being published on the IHA and UNESCO websites.

Further information on the Project's work can be found at: www.hydropower.org

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1. Introduction

1.1 Background

Mitigating climate change is one of the most important goals for strategic sustainable development. There is a clear and pressing need to quantify the greenhouse-gas (GHG) footprint of all human activities. The GHG status of freshwater reservoirs – that is, any change in GHG emissions in a river basin resulting from the creation of such a reservoir – has been discussed in both scientific and policy forums.

The uncertainties and lack of consensus on the assessment of the GHG status of freshwater reservoirs led to consultation between scientists, the International Hydropower Association (IHA) and UNESCO's International Hydrological Programme (UNESCO-IHP), with the subsequent launch of the UNESCO/IHA GHG Research Project - GHG Status of Freshwater Reservoirs. This Project, hosted by the IHA in collaboration with UNESCO-IHP, aims to improve understanding of the impact of reservoirs on natural GHG emissions and of the processes involved, and to help fill knowledge gaps in this area.

The Project has run since August 2008, through a consensus-based, scientific approach, involving collaboration among many institutions and experts, through participation in workshops, development of products/deliverables, and acting as peer review. The resulting deliverables have been reviewed by the Project's peer-review group (the UNESCO/IHA Forum), which comprises more than 200 researchers, scientists and professionals working in this field, from more than 100 institutions, including universities, research institutes, specialist companies and sponsoring agencies.

The original objectives of the Project are to: (1) develop standard guidance for net GHG estimations; (2) promote measurements and calculate net emissions from a representative set of reservoirs, building a database of reliable, comparable data; (3) develop predictive modelling tools; and, (4) develop guidance and assessment tools for mitigation.

The standard guidance for net GHG estimations was achieved with the publication of the GHG Measurement Guidelines (UNESCO/IHA, 2010). These guidelines are being applied to a broad range of sites around the world (more than 20 reservoirs, located in Asia, Europe, South America and North America), with measurements captured in a Project database. The database is an ongoing task during the Project lifetime, to ensure the availability of reliable and comparable data for the development of the other Project products, including predictive modelling and mitigation tools.

The development of the predictive models relies on data from the measurement programmes, which will effectively only be available after application of the GHG Measurement Guidelines to a set of representative reservoirs, during a period of at least two years. While there is not yet enough data available, the Project is making use of existing published data of gross GHG emissions from previous assessments on 169 reservoirs around the world, taking account of the involved uncertainties, to develop an empirical model (GHG Risk Assessment Tool) in order to provide estimation of the level of GHG emissions on proposed or existing freshwater reservoirs.

The development of guidance and assessment tools for mitigation can only be performed after completion of the predictive tools. A framework for an initial mitigation guidance document is under development by the Project to enable hydropower project developers to take advantage of the knowledge created to date within the UNESCO/IHA GHG Research Project.

1.2 Purposes and objectives of the GHG Risk Assessment Tool

The GHG Risk Assessment Tool (the Tool) provides an estimation of the level of gross GHG emissions (existing or future) from a freshwater reservoir, based on limited and available field data, and gives indication of when the assessment of net GHG emissions may be relevant.

The Tool was developed as an empirical model, based on already available published information, for application to proposed sites, or existing freshwater reservoirs.

The Tool responds to needs from industry, financial institutions and decision makers for a product that can be used as a screening tool as well as being able to provide assessment of the level of gross GHG emissions for unmonitored and/or proposed new dam sites.

Emissions from the following GHG species are evaluated by the Tool:

Carbon dioxide (CO_2): 80% of all GHGs released into the atmosphere are CO_2. Freshwater reservoirs do not significantly change natural CO_2 levels – the great majority of CO_2 emissions would naturally occur, even without the reservoir, as part of natural transport processes (conduction, deposition, and emission) in the water bodies at the area affected by the reservoir (upstream catchment, flooded areas, downstream of the reservoir). CO_2 may, however, be released at different times and places because of the existence of a reservoir. High emissions of CO_2 may require the assessment of net GHG emissions to have their sources properly explained.

Methane (CH_4): there is already broad consensus among the scientific community that CH_4 is the main GHG species of concern in freshwater reservoirs. It is important to look at CH_4 emissions because some freshwater reservoirs may create conditions for changes in the natural CH_4 levels in the affected area. Also, according to IPCC (Forster et al., 2007), the global warming potential (GWP) of CH_4 is 25 times stronger than that of CO_2, for a 100-year time horizon. This means that CH_4 has the potential (over a period of 100 years) to produce 25 times the effect of CO_2 on global warming.

This GHG Risk Assessment Tool estimates Gross GHG diffusive fluxes of CH_4 and CO_2 and qualifies the predicted values as LOW, MEDIUM or HIGH potential emissions, compared to the distribution of observed values in the dataset used for calibration of the model. The Tool outputs provide indication of the need for assessment of net GHG emissions.

1.3 Updating the GHG Risk Assessment Tool

The GHG Risk Assessment Tool is being developed as a “living document”. As further data are collected and analysed, its formulation can be revised, and the level of uncertainty can be reduced.

Future versions of the Tool could incorporate other factors such as: soil carbon content, water temperature ranges, hydrodynamics parameters (such as stratification, residence time, and others), primary production, and vegetation. There is a need for further research to obtain the necessary data to properly test and evaluate the importance of these (and other) factors. The possibility of including a three-step decision-tree approach[1] into this model will also be left for future versions. A description of this approach is provided in ANNEX 1.

[1] Three-step decision-tree approach:
STEP ONE: SOURCE (Capacity of the system to provide carbon and nutrients to the reservoir);
STEP TWO: ACCUMULATION (Capacity of the reservoir to create stock);
STEP THREE: RELEASE (Capacity of the reservoir to release the available stock).

2. The concept of Net GHG Emissions

Net GHG emissions (GHG footprint, or GHG status of freshwater reservoirs) represent the change in GHG emissions due to the creation of a reservoir.

All river basins naturally emit greenhouse gases. The introduction of a reservoir may change the way this carbon is distributed in the system, by changing removals (GHG burial in sediments) and emission patterns[2].

The GHG status of freshwater reservoirs is properly assessed only when considering the impact on GHG emissions in a river basin resulting from the creation of such a reservoir, at all portions of the river basin influenced by the reservoir, and subtracting the effects of unrelated anthropogenic and natural sources.

As net GHG emissions cannot be measured directly, their value has to be estimated by assessing total (gross) GHG emissions in the affected area, comparing values for the pre- and post-impoundment conditions, and excluding unrelated anthropogenic sources (UAS).

This approach has been reported by IPCC (2011), which defines net GHG emissions from freshwater reservoirs as those *"excluding unrelated anthropogenic sources and pre-existing natural emissions"*, and asserts that: "*the assessment of man-made net emissions involves: a) appropriate estimation of the natural emissions from the terrestrial ecosystem, wetlands, rivers and lakes that were located in the area before impoundment; and b) abstracting the effect of carbon inflow from the terrestrial ecosystem, both natural and related to human activities, on the net GHG emissions before and after impoundment."*

Several other recent publications also acknowledge the importance of properly assessing the net GHG emissions from freshwater reservoirs, such as: Chanudet et al. (2011), Demarty and Bastien (2011), Goldenfum et al. (2009), Goldenfum (2009, 2010a, 2010b), Tremblay et al. (2010), IHA (2010), and Sikar et al. (2012).

Recently developed knowledge shows that reservoir emissions may be smaller than previously estimated (Barros et al., 2011; Chanudet et al., 2011), and the terrestrial GHG sink may be smaller than currently believed (Bastviken et al., 2011). Also, new studies show evidence that tropical and sub-tropical reservoirs can sometimes behave as carbon sinks (Sikar et al., 2009a, 2009b; Chanudet et al., 2011; Ometto et al., 2010), and that anthropogenic activities contribute to increasing GHG reservoir emissions (Del Sontro et al., 2010).

These research efforts imply that a proper assessment of the GHG emissions from reservoirs must take into account all main processes involved, identifying when there is a need for assessment of net GHG emissions.

This GHG Risk Assessment Tool does not evaluate Net GHG emissions. It predicts Gross GHG diffusive fluxes (of CH_4 and CO_2) and gives indication of when the assessment of Net GHG emissions may be relevant.

[2] It is important to notice that reservoirs do not change the amount of carbon in the hydrosphere-biosphere-atmosphere system (the short-term carbon cycle), as they do not include new carbon in the system. As recalled in Tardieu and Pigeon (2005), it is noteworthy that emissions from artificial reservoirs do not involve returning long-term sequestered carbon into the system.

3. User Guide

3.1 Structure of the Tool

The tool is presented in an Excel™ spreadsheet, divided in three worksheets: "Main", "Simulations" and "Auxiliary". The contents of any of these worksheets can be viewed or printed by the User at any time, but the only cells unlocked for the user are the "Input Values", on worksheet "Main".

A general description of how the input data and results are presented in each of these worksheets is presented below.

- **Worksheet "Main":**
  - includes the cells for allowing the User to provide the values for all input parameters;
  - shows information on the status of the values provided by the User (informing if these values are inside or outside the range of the data used for calibration of the model);
  - shows the results of the simulations:
    - Predicted values of gross GHG fluxes (of CH_4 and CO_2) and its associated 67% confidence intervals;
    - Qualification of the predicted values as LOW, MEDIUM or HIGH emissions, compared to the distribution of observed values in the dataset used for calibration of the model;
    - Indication of the need for assessment of net GHG emissions;
    - Graphs for predicted gross GHG fluxes and their associated 67% confidence intervals.

- **Worksheet "Simulations":**
  - shows all values predicted for gross GHG fluxes and their associated 67% confidence intervals in a table that can be printed by the User.

- **Worksheet "Auxiliary":**
  - Shows auxiliary elements needed by the model:
    - Input parameter values for simulation;
    - Range of the data used for calibration of the model;
    - Atomic mass of the chemical elements involved (N, C, O, H);
    - Molar mass of the main GHG species;
    - Thresholds adopted for qualification of the predicted values as LOW, MEDIUM or HIGH emissions, compared to the distribution of observed values in the dataset used for calibration of the model (see section 3.3.3 for more details).

More detailed descriptions of these elements, as well as of the criteria adopted in the model are provided in sections 3.2 and 3.3. A description of the empirical models developed for this tool is provided in ANNEX 2, and the dataset used for its development is shown in ANNEX 3.

3.2 Use of the Tool spreadsheet

3.2.1 Parameters required to run the model

The values for all input parameters must be provided by the User in the "Input Value" column of the table "INPUT DATA", on the top of the worksheet "Main". The variables in this table are categorised in three groups: input data needed for estimation of both CO_2 and CH_4 fluxes; input data needed for estimation of CO_2 fluxes; input data needed for estimation of CH_4 fluxes.

Selected reservoir age (years):
Number of years since impoundment (reservoir filled to full capacity).
This can refer to the present age of the reservoir or to any other year (up to 100) of interest.
This variable is needed for estimation of both CO_2 and CH_4 fluxes.

Mean annual air temperature (Celsius):
Mean annual air temperature at the reservoir area.
This variable is needed for estimation of both CO_2 and CH_4 fluxes.

Mean annual runoff (mm):
Mean annual runoff of the contributing catchment.
This variable is needed for estimation of CO_2 fluxes.

Mean annual precipitation (mm):
Mean annual precipitation on the contributing catchment[3].
This variable is needed for estimation of CH_4 fluxes.

The values for the parameters mean annual temperature (^oC), mean annual precipitation (mm), and mean annual runoff (mm) were, in the development of the model, obtained from datasets available from various open sources (see ANNEX 3).

3.2.2 Results of the simulations

The table with the "results of the simulations" provides information on whether the values entered in the Tool are within the ranges of values of the data used to develop the models. It also shows predicted gross GHG emission values (and approximate 67% confidence intervals) for the selected reservoir age and integrates these values over a defined period. Graphs for predicted gross CO_2 and CH_4 fluxes are also produced.

Section 3.3 gives explanation on how to analyse and interpret the results of the Tool.

[3] obs.: in the lack of the catchment information, a point estimate at the dam site can be adopted.

3.3 Analysis and interpretation of the outputs of the Tool

3.3.1 Table INPUT DATA

The "STATUS" column on the "INPUT DATA" table informs the User if the entered values are within the ranges of values of the data used to develop the models. If an input value falls outside the range of the data used for calibration of the model, it is considered an extrapolation, and the results have to be considered with care (the Tool was developed as an empirical model - so the predicted values are more reliable when there are no extrapolations).

3.3.2 Uncertainty of the estimates

Empirical models were developed to explain the variability of gross CO_2 and CH_4 diffusive fluxes. An intrinsically non-linear approach was adopted, affording flexibility in the shapes of the curve describing the initial decline of GHG emissions following flooding (see ANNEX 2 for more details on the empirical model).

The model for predicting CO_2 diffusive fluxes was able to explain about 45% of the variation observed in the data used for calibration, and had an uncertainty best described on a base-10 logarithmic scale (root mean square error=0.36).

The model for predicting CH_4 diffusive fluxes was able to explain about 42% of the variation observed in the data used for calibration. Its uncertainty is best described by a logarithmic root mean square error of 0.55.

The range of variability of the estimates can be expressed by the confidence interval of the predicted values. The confidence interval for the predictions is obtained as:

$$P[\text{“lower limit”} \leq \text{“GHG flux”} \leq \text{“upper limit”}] = \alpha\%$$

meaning that there is α% of probability that the *“GHG flux”* will be in the interval between the *“lower limit”* and the *“upper limit”*.

The values for *“lower limit”* and *“upper limit”* of the 67% confidence interval for the predictions are provided by the Tool as explained in section 3.3.3.

As already described in sections 1.2 and 1.3, the models were developed based on already available published information. The level of uncertainty will be reduced as new data becomes available, providing conditions for obtaining better fit of the model, as well as allowing the model formulation to be revised, with the possible inclusion of new parameters as input data for the model.

3.3.3 Results of the simulations

Alerts:

Alerts are shown on the table with the "results of the simulations" to indicate that there is need to consider the results with care for cases in which the input values are outside the ranges used for model calibration.

Tables "Predicted gross CO_2 flux" and "Predicted gross CH_4 flux":

The tables "Predicted gross annual CO_2 flux" and "Predicted gross annual CH_4 diffusive flux" show the predicted values of gross GHG fluxes for the selected reservoir age and for the average over an integration period of 100 years (in accordance with IPCC, 2006, the lifecycle assessment period for GHG emissions in freshwater reservoirs is 100 years), as well as the upper and lower limits of their associated 67% confidence intervals.

The uncertainty for the average over the 100 year integration period is smaller than the uncertainty for an individual year. The much narrower confidence intervals of the integrated flux assumes that the uncertainties in the predicted yearly fluxes are independent of one another and therefore average themselves out over the integration period.

It is important to stress that the lower and upper confidence limits are indicative only of the likely precision of the models and of the uncertainty of the results (see section 3.3.2). For the purposes of estimating expected fluxes, the predicted values should be used, not the outer limits.

The predictions are then compared to the distribution of observed values in the dataset used for calibration of the model, divided into three categories, and are given a heuristic qualifier as LOW (first quartile, or, 0-25% of the data), MEDIUM (second+third quartile, or 25-75%) or HIGH (last quartile, or 75-100%) emissions (see ANNEX 3 for more details on the dataset). The column "Action Required" gives indication of when the assessment of NET GHG emissions may be relevant as follows:

LOW or MEDIUM predicted values: No need to assess Net GHG emissions, unless indicated by other predicted values;

HIGH CO_2 predicted values: The assessment of Net GHG emissions should be taken into consideration.
The criteria for requiring this action takes into consideration that high emissions of CO_2 can require the assessment of net GHG emissions to have their sources properly explained.
As stated in section 1.2, although CO_2 may be released at different times and places because of the existence of a reservoir, the majority of the natural CO_2 levels are not significantly changed if the whole affected area (upstream, flooded areas and downstream) is taken into consideration. Consequently, the causes of high CO_2 emissions have to be properly investigated.

HIGH CH_4 predicted values: The assessment of Net GHG emissions is recommended.
This recommendation is based on the importance of CH_4 emissions in reservoirs.
As stated in section 1.2, reservoirs may create the conditions under which CH_4 can be produced and released. As CH_4 has the potential (over a period of 100 years) to produce 25 times the effect of CO_2 on global warming (the Global Warming Potential – GWP), any change in CH_4 emissions has to be properly acknowledged.

Graphs for predicted CO_2 and CH_4 fluxes and associated uncertainty

Graphs for predicted gross CO_2 and CH_4 fluxes and their associated 67% confidence intervals, over a 100 year period, are provided on the worksheet "Main". The predicted values of fluxes and limits for the 67% confidence intervals are also available for printing on worksheet "Simulations". Please note that the predicted gross CO_2 fluxes are provided as "mg C-CO_2 m^{-2} d^{-1}", and predicted gross CH_4 diffusive fluxes are provided as "mg C-CH_4 m^{-2} d^{-1}".

For more details and conversion factors see ANNEX 4.

3.3.4 General but important features

- Predicted fluxes nominally only include diffusive fluxes.
  Due to the lack of reliable information from a sufficient variety of sources, other pathways could not be included in the models. Consequently, the predicted total fluxes do not include some pathways, such as CH_4 bubbling and downstream degassing.
- Predicted fluxes are gross emissions, including emissions from unrelated anthropogenic sources (UAS) and emissions in the area before impoundment. An assessment of the GHG impact of creating a reservoir can only be performed by estimating the NET GHG emissions.
- All fluxes are expressed in mg C m^{-2} d^{-1} – they are noted as "mg C-CO_2" or "mg C-CH_4" to make clear that these "mg of C" refer to Carbon in a CO_2 or in a CH_4 molecule, respectively.
- The integrated fluxes correspond to the cumulative emissions over the integration period (100 years) divided by the total length of the integration period. It thus corresponds to the average emission rate over the 100 year integration period.
- Lower and upper confidence limits are indicative only of the likely precision of the models and of the uncertainty of the results. For the purposes of estimating expected fluxes, the predicted values should be used, not the outer limits.

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ANNEX 1 – THREE-STEP DECISION-TREE APPROACH

ANNEX 1 – THREE-STEP DECISION-TREE APPROACH

The UNESCO/IHA GHG Research Project proposed a technical approach for the risk assessment of the vulnerability of a freshwater reservoir to enhanced GHG emissions, presented as a three-step process. The present version of the GHG Risk Assessment Tool was developed as an empirical model, based on already available published information. As further data becomes available, future versions of the Tool could include the three-step decision-tree approach, as proposed by the UNESCO/IHA GHG Research Project.

STEP ONE: SOURCE (Capacity of the system to provide carbon and nutrients to the reservoir)

If the system (upstream catchment) characteristics imply a low carbon and nutrient stock, or non-labile carbon and nutrients, the introduction of a reservoir is expected to present low vulnerability to an increase in GHG emissions - otherwise, it is necessary to evaluate step two.

Main factors affecting carbon and nutrient supply for reservoirs:

- Carbon and nutrient load
- Rainfall
- Soil type and land use
- Biomass of plants, algae, bacteria and animals in the reservoir and in drawdown zone

STEP TWO: ACCUMULATION (Capacity of the reservoir to create stock)

If the reservoir characteristics imply a low capacity to accumulate GHG stock, the reservoir is expected to present low vulnerability to an increase in GHG emissions, and there is no need to assess net GHG emissions, otherwise it is necessary to evaluate step three.

Main factors affecting GHG accumulation in reservoirs:

- Water temperature
- Residence time
- Stratification of the reservoir body (likelihood)
- Reservoir age
- Drawdown zone exposure (changes in water depth)

STEP THREE: RELEASE (Capacity of the reservoir to release the available stock)

If the reservoir characteristics imply a low capacity to release its GHG stock, the reservoir is expected to present low vulnerability to an increase in GHG emissions, and there is limited need to assess net GHG emissions; if there is a medium to high capacity to release the available GHG stock, the reservoir is expected to present high vulnerability to gross GHG emissions, and it is necessary to measure and assess the net GHG emissions relating to the specific reservoir.

Factors affecting GHG release in reservoirs:

- Wind speed and direction
- Presence of low level outlets;
- Increased turbulence downstream of the dam associated with ancillary structures, e.g. spillways and weirs.
- Reservoir shape (shoreline/surface ratio)
- Average water depth

Figure 1 shows how these steps are interlinked, in a decision tree structure.

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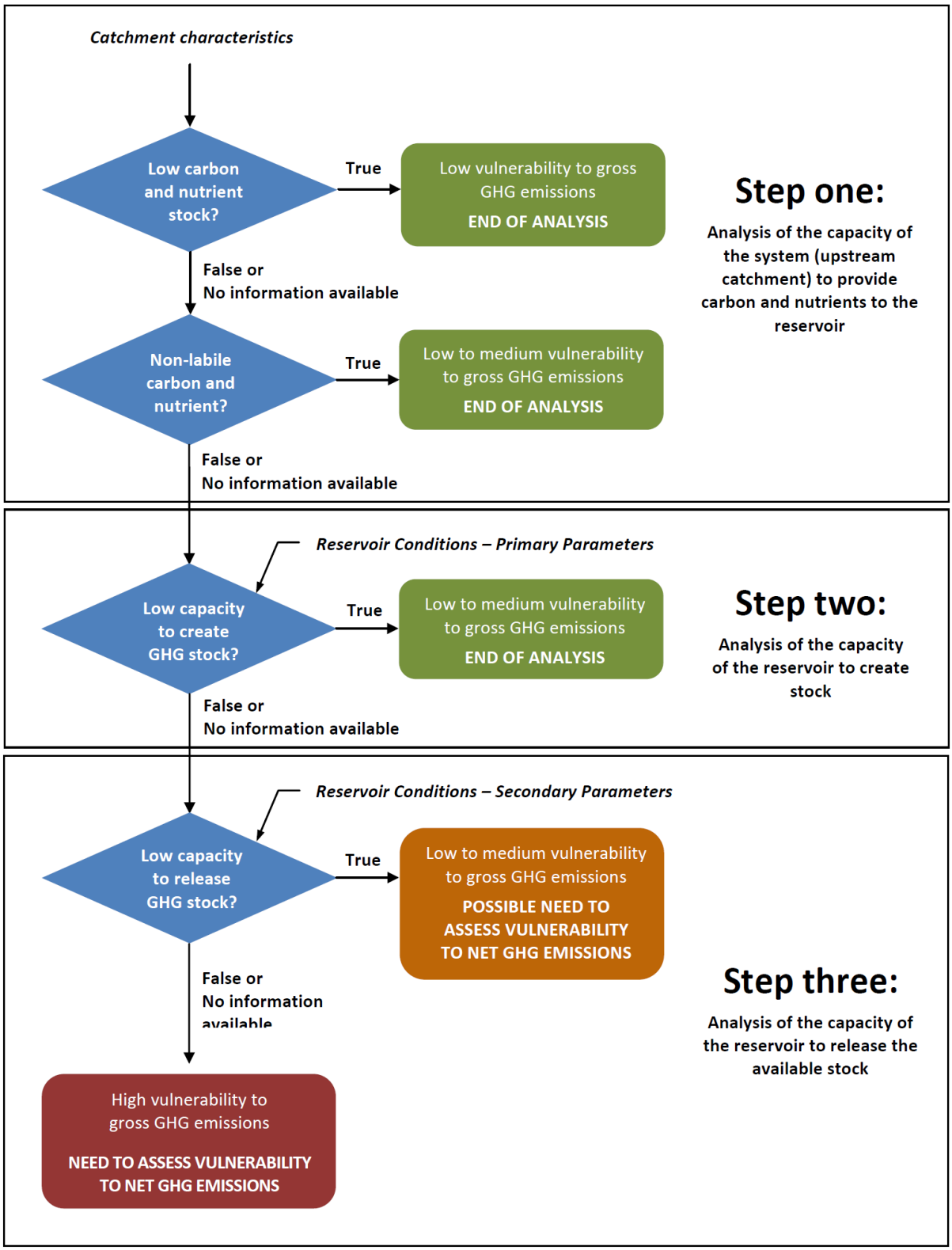

500
501 Figure 1 – Three-step decision-tree approach
502

Summary description of the decision tree (Figure 1):

The first step estimates the potential supply of organic carbon and nutrients, by evaluating the capacity of the contributing areas (upstream catchment and flooded area) to deliver these to the reservoir. This evaluation is done by assessing the carbon and nutrient stock in the catchment (vegetation and soil, including flooded areas), and also by verifying if the available carbon and nutrients are labile. If the stock of carbon and nutrient in the catchment is small, the carbon and nutrient loads will be small, and the site will have a low vulnerability to gross GHG emissions; the risk assessment analysis is then complete. Otherwise, it is necessary to determine if the available carbon and nutrient is labile. If the carbon and nutrient are available in the catchment, but they are not labile, the supply of organic carbon and nutrients to the reservoir will be small. Consequently, the site vulnerability to gross GHG emissions is considered to be low to medium, and the risk assessment analysis is complete. If not, it is necessary to proceed to the second step.

The second step has the objective of evaluating whether the necessary conditions for storing GHG are present. The parameters that modulate the rates of the biological processes creating a stock, were identified by IHA (2010), as Primary parameters. If there is an adequate supply of carbon and nutrients, but the reservoir does not have the conditions needed to convert this supply to GHGs, there can be no GHG emission from the reservoir; consequently, the site is likely to present a low-to-medium vulnerability to gross GHG emissions, and the risk assessment analysis is complete. Otherwise, the GHGs will be available dissolved in the water of the reservoir, and it is necessary to proceed to the third step, to evaluate if the vulnerability to gross GHG emissions is medium or high.

The third step identifies whether the reservoir has the necessary conditions to release the available stock of GHG from the water into the atmosphere. The parameters that modulate gas exchange between the atmosphere and the reservoir or downstream river, allowing the release of GHGs, were identified by IHA (2010), as Secondary parameters. If the GHGs are available in the reservoir, and the reservoir has the capacity to release them, the vulnerability to gross GHG emissions is high, and there is a need to assess the vulnerability to net GHG emissions; otherwise, the site is likely to present medium vulnerability to gross GHG emissions (and there is a possible need to assess the vulnerability to net GHG emissions).

The decision tree also has the option of “no information available” directing the decision in the same direction as “false”, i.e. remaining on the high vulnerability track.

ANNEX 2 – DESCRIPTION OF THE EMPIRICAL MODELS

ANNEX 2 –DESCRIPTION OF THE EMPIRICAL MODELS

C-CO_2 Flux model

The article by Barros et al. (2011) was the initial source for data for the development of this tool. This data was revised and complemented by data from more recently published papers (see ANNEX 3) and by estimates of additional parameters, such as mean annual temperature, mean annual precipitation, and mean annual runoff, obtained from datasets available from various open sources, as described in ANNEX 3.

However, the modelling approach developed by the Project was quite different from that of Barros et al. (2011). It was intrinsically non-linear (and therefore had to be fitted to the data using non-linear algorithms) and more complex, but afforded more flexibility in the shapes of the curve describing the initial decline of CO_2 emissions following flooding. Several alternative formulations were attempted but the following general expression provided both the best empirical fit and a realistic representation of the processes:

$$Flux\ C-CO_2 = \beta 0 + \beta 1 * \mathrm{X1} + (\beta 2 - \beta 3 * \mathrm{X2}) * \mathrm{e}^{-\beta 4 * \mathrm{X3} * \mathrm{Age}} \quad \text{(Eq. 1)}$$

where the βs are the fitted coefficients and the Xs are variables chosen from a suite of potential independent variables (see section 3.2). This particular formulation was chosen because it satisfied four main conditions. First, it allows the model to potentially create a « plateau » to non-zero emissions. Second, the level of GHG emission at this new equilibrium can also be modulated by other factors, such as local climatic conditions (runoff, precipitation, temperature, etc.). Third, the initial decline in GHG emission following flooding was made more flexible that the double-logarithmic model of Barros et al. (2011). In particular, the steepness of this initial decline (the exponential term) was made to potentially interact with other variables. Thus, the shape of this decline could be modulated (i.e. made more or less steep) by the influence of other variables. Lastly, the initial GHG emission (i.e. at Age=1 year) was made to potentially vary according to other variables as well.

After many attempts using different variable combinations, the best model had the following structure:

$$Flux\ C-CO_2 = 186.0 + 0.148 * \mathrm{Runoff} + (944.485 + 1.91 * \mathrm{Temp} + 0.09727 * \mathrm{Temp}^2) * \mathrm{e}^{-0.0044 * \left|52.339 - 0.7033 * \mathrm{Temp} - 0.0358 * \mathrm{Temp}^2\right| * \mathrm{Age}} \quad \text{(Eq.2)}$$

The structure of this model implies that: 1) the maximum CO2 emission occurring immediately after flooding is a positive function of temperature (i.e. maximum for higher temperatures); 2) the new long-term equilibrium emissions (after the initial pulse) is a positive function of runoff (higher in locations with higher runoff); 3) the steepness of the initial decline (the exponential term) is a negative function of temperature (i.e. steeper and faster decline at lower temperatures).

The model explained about 45% of the variation and had an uncertainty best described on a base-10 logarithmic scale (root mean square error=0.36). The range of variability of the estimates can be expressed by the confidence interval of the predicted values, as described in section. 3.3.2.

C-CH_4 Flux model

In the case of methane, the same dataset was used, but a different modelling approach was adopted. While the Project did test the same model structure as for CO_2, little predictive gain was obtained relative to simpler empirical modelling approaches. In the end, the Project used a semi-logarithmic model combined to a regression tree approach, with different empirical models for different segments of the variable space. In particular, we developed a model where CH_4 flux is a function of mean annual temperature, mean annual precipitation and age for reservoirs that are 32 years old or less. For older reservoirs, diffusive methane emissions are constant in time at a level which is determined by temperature and precipitation only. The following models were developed:

For Age<=32 years

$$\mathrm{C-CH4\ Flux} = 10^{(1.46+0.056*\mathrm{Temp}-0.00053*\mathrm{Prec}-0.0186*\mathrm{Age}+0.000288*\mathrm{Age}^2)} \quad \text{(Eq. 3)}$$

For Age>32 years

$$\mathrm{C-CH4\ Flux} = 10^{(1.16+0.056*\mathrm{Temp}-0.00053*\mathrm{Prec})} \quad \text{(Eq. 4)}$$

The combined equations explain about 42% of the observed variation. Its uncertainty is best described by a logarithmic root mean square error of 0.55.

Range of variability of the estimates:

The range of variability of the estimates can be expressed by the confidence interval of the predicted values (see section 3.3.2).

The confidence interval for the predictions is obtained as:

P[*"lower limit"* ≤ *"GHG flux"* ≤ *"upper limit"*] = α% (Eq 5)

The values of *"lower limit"* and the *"upper limit"* can be estimated as a function of the predicted values of gross GHG fluxes (of CH_4 and CO_2) and the mean square errors. Table 1 expresses how to estimate the values of the limits of the 67% confidence interval, for the models adopted in this Tool.

Table 1 - *"lower limit"* and *"upper limit"* of the 67% confidence interval for the models adopted in this Tool

Predicted Value	*"lower limit"*	*"upper limit"*
Gross C-CO_2 Flux	$\frac{1}{2.3}$ * "Predicted Gross C-CO_2 Flux"	2.3 * "Predicted Gross C-CO_2 Flux"
Gross C-CH_4 Flux	$\frac{1}{3.55}$ * "Predicted Gross C-CH_4 Flux"	3.55 * "Predicted Gross C-CH_4 Flux"

Obs.: Both models have uncertainty best described on a base-10 logarithmic scale. Consequently, the factors 2.3 and 3.55 are derived from $10^{0.36}$ and $10^{0.55}$, respectively.

602 # ANNEX 3 – DATASET FOR THE DEVELOPMENT OF THE EMPIRICAL MODELS

ANNEX 3 – DATASET FOR THE DEVELOPMENT OF THE EMPIRICAL MODELS

The initial source for data was obtained from Barros et al. (2011). This data was revised by comparing with the information from the original sources, and complemented by data from more recent papers (see bibliographic references, in the dataset tables, and at the end of this ANNEX) and by estimates of the parameters mean annual temperature, mean annual precipitation, mean annual runoff, bioclimatic factor, net primary productivity, and soil carbon density, obtained from datasets available from various open sources.

The data adopted for the development and calibration of the empirical models of this GHG Risk Assessment Tool were derived from 212 field assessments of gross GHG emissions on 169 reservoirs, as presented in the tables of this ANNEX. The following notes present explanations of aspects of theses tables, to allow a proper understanding of the meaning of some elements, as well as to detail the data sources.

Note 1: q-bathymetric shape

q is the exponent from the bathymetric expression $Az=A0(1-Z:Zmax)^q$ due to Imboden (1973). q accomodates many shapes, from cup-shape (q=1) to almost completely flat with a small deep hole (q=5-6). Integrating this equation, a simple relationship between mean and maximum depths is obtained (Zmean=Zmax/(q+1)), allowing the estimation of the value of q for the reservoirs (from average and maximum depths).

Note 2: Reservoir cross-section and shape categories

The most representative cross-section and shape of the reservoir, using the elements shown in figure 2.

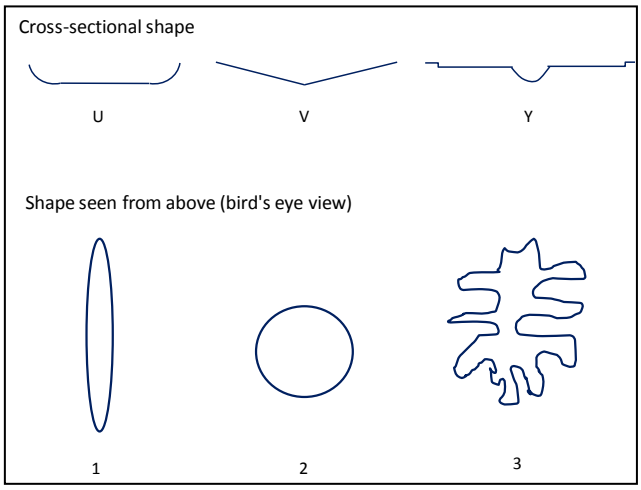

Figure 2 – Typical cross-section and shape of the reservoir (to compute a reservoir shape index)

Note 3: Weighting index

The criteria for weighting the data was based on the level of confidence that the value reported in the data template is an accurate representation of the annual fluxes. The estimation of this level of confidence was assessed with basis on the following criteria:

Level 1: Very few samples in both in time and in space. Possibly frequent and/or severe methodological problems and uncertainties. Overall assessment: Poor confidence that the reported value is an accurate representation of the annual flux. A first cut.

Level 2: Limited sampling campaigns with significant gaps in the temporal and spatial coverage. Possibly frequent and/or severe methodological problems and uncertainties. Overall assessment: Limited confidence that the reported value is an accurate representation of the annual flux. A coarse approximation.

Level 3 : Several sampling campaigns covering a significant portion of the annual cycle and of the surface area. Some methodological uncertainties and some independent validation of techniques. Good replicability and moderate variability in the results. Overall assessment: Moderate confidence that the reported value is an accurate representation of the annual flux. A good approximation.

Level 4: Multiple sampling campaigns in multiple stations covering most of the reservoir surface. Some extrapolation made to cover periods that were not sampled. No major technical problems or uncertainties and rigorous independent validation of techniques. Overall assessment: High level of confidence that the reported value is an accurate representation of the annual flux. A high quality result.

Level 5: Extensive and detailed sampling regime covering the complete annual cycle. Multiple stations covering the entire surface area. Convergent multiple techniques to estimate flux. Overall assessment: Very high level of confidence that the reported value is an accurate representation of the annual flux. The best data money can buy.

Table 2 summarises these criteria for weighting data in model development

Table 2 – Criteria for weighting data in model development

Resolution/representivity	**Method/uncertainty**		
	Poor	**Good**	**Verified**
Spatial + temporal low	1	2	3
Spatial high + temporal low	2	3	3
Spatial low + temporal high	2	3	4
Spatial + temporal high	3	4	5

Note 4: BioClimatic Factor

The BioClimatic Factor estimates were obtained from WorldCLim, a global climate data GIS data repository. The maps with this data can be downloaded at http://www.worldclim.org/download.

Note 5: Mean annual air temperature, precipitation and runoff

Estimates on mean annual values for air temperature, precipitation and runoff were obtained from Fetke et al. (2000).

Note 6: Net Primary Productivity

Net primary productivity estimates were obtained from the socioeconomic data and applications centre of Columbia University, at http://sedac.ciesin.columbia.edu/es/hanpp.html.

Note 7: Soil Carbon density

Soil Carbon density estimates were obtained from Hiederer and Köchy (2011).

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No	Reservoir Name	Reservoir No	CO_2 flux (from Barros et al.) (mg C m^{-2} d^{-1})	CH_4 flux (from Barros et al.) (mg C m^{-2} d^{-1})	CO_2 flux (REVISED VALUES) (mg C m^{-2} d^{-1})	CH_4 flux (REVISED VALUES) (mg C m^{-2} d^{-1})	Latitude (Degree)	Longitude (Degree)	Age (years)	Age when sampled (years)	q bathymetric shape (see note 1)	Reservoir cross-section category (see note 2)	Reservoir source category (see note 2)	Weighting Index (see note 3)	Mean Depth (m)	Reservoir Surface Area (km2)	Volume (km^3)	Residence Time (days)	Input of TP (mg C m^{-2} d^{-1})	Input of DOC (mg C m^{-2} d^{-1})	Emission Type ('Diffusion' 'D' or 'Bubble 'B')	BioClimatic Factor (see note 4)	Mean Annual Air Temperature (degrees C) (Celsius)	Mean Annual Precipitation (mm) (see note 5)	Altitude (m)	Mean Annual Runoff (mm) (see note 5)	Net Primary Productivity (see note 5) (mg CO_2 m^{-2} d^{-1})	GHG equiv C flux (mg CO_2 m^{-2} d^{-1})	Soil Carbon density (see note 7)	Bibliografic Reference
1	Apache	1			-252.82		33.58	-111.25	74	74	1.4232		1	1.0	30.1	10.39	0.313						194	19.38	440	754	0	185404		21.8696	Therrien et al., 2005
2	Alamo	2			-199.09		34.26	-113.60		33	1.0254		1	0.4	11.8	10.38	0.123				D		199	19.88	214	485	0	171663.9		16.521	Therrien et al., 2005
3	Alouette Lake	3	-111.00		-111.07		49.34	-122.41	74	74			1	2.0		16					D		58	5.83	1509	1198	0	347765		69.8807	Tremblay et al., 2005
4	Angerman	4	30.80		60.00		62.80	17.93	70							854					D		35	3.54	659	29	199	148052		133.025	Bergstrom et al., 2004
5	Annaca	5			11.45		31.53	-111.25		31	1.1375		3	0.2	3.6	0.36	0.00128						165	16.06	502	1235	0	119894		16.521	Therrien et al., 2005
6	Arrow-Lower	6	-281.50	6.60	-281.64	-4.94	49.84	-118.10	33	33			1	2.0	74.2	520	38.6				D		74	7.43	696	483	477	324218	-867.99		Therrillay et al.,2005
7	Arrow-Narrows	7	354.50		354.78		49.43	-123.25	33	22			1	1.0	74.2	520	38.6				D		95	9.48	1281	111	817	433622			Schellhase in StLouis2000
8	Arrow-Narrows	7	-265.10	52.90	-265.27	39.61	50.05	-117.92	33	33			1	2.0	74.2	520	38.6				D		60	6.03	826	699	546	307233	347.52	105.643	Tremblay et al.,2005
9	Arrow-Upper	8	283.40	23.00	283.56	17.22	50.74	-117.95	33	33			1	2.0		520					D		57	5.65	1035	518	1081	204503	1613.69	105.643	Tremblay et al.,2005
10	Baker Dam	9			223.64		37.38	-113.64		51	1.3019		1	0.9	7.3	0.255	0.00185						101	10.11	385	1702	0	155344		34.8513	Kemenes et al., 2007
11	Balbina	10		10.00		47.00	-1.88	-59.47	20	18			3	4.0	7.4	2360	18	365	0.3	68.7	D		273	27.33	2410	42	1536	975488		43.3163	Guerin et al., 2006
12	Balbina	10			912.81	25.22	-1.88	-59.47		17			3	1.0	7.4	1960	17.5	356.85			D		273	27.33	2410	42	1536	975488	4187.73	43.3163	Guerin et al., 2006
13	Barra Bonita	11	1036.40	9.90	955.19	14.97	-22.52	-48.58	42				1	1.0	11.1	312	4	30			D & B		210	21.13	1265	504	69	757051	4001.49	44.163	Rosa et al., 2004
14	Barra Bonita	11	1754.70		1087.55	15.64	-22.52	-48.58	42	35			1	3.0	11.1	312	4	30			D & B		210	21.13	1265	504	69	757051	4509.02	44.163	Santos et al., 2006
15	Bartlett	12			97.91		33.83	-111.63		62	0.9634		1	1.8	27.0	8.15	0.22						191	19.08	433	744	0	141896		16.521	Therrien et al., 2005
16	Baskatong (Mercier)	13	316.60	3.20	316.85	2.40	46.76	-76.00	70	75			3	2.0	6.3	413	2.6	13140	0	2.4	D		30	2.96	947	275	453	292185	1241.64	46.3362	Tremblay et al.,2005
17	Bersimis-1	14	407.70	0.10	405.27	0.07	49.35	-69.78	43	47			3	3.0	2.0	798	1.6				D		-2	-0.19	1000	502	606	232765	1488.50	77.2126	Tremblay et al.,2005
18	Blanco	15		0.00		0.00	46.40	10.02	94	92	2.7857	Y	2	1.0	14.0	2	0.021	150	0.7	252	D		1	0.07	1208	2335	336	157562			Diem et al., 2008
19	Bill Evans	16			86.73		32.86	-108.57		33			2	0.7	0.0	0	0						141	14.08	353	1389	0	107150		21.8696	Therrien et al., 2005
20	Brantley	17			-63.82		32.57	-104.39		21			1	1.4	0.0	16	0						163	16.33	310	999	0	101653		15.4369	Therrien et al., 2005
21	Bunch	18			39.82		34.04	-109.46		72			2	0.0	3.0	0.081	0.000243						58	5.25	679	2704	106	250922		39.6322	Therrien et al., 2005
22	Buntzen	19	384.80		385.08		49.35	-122.86	88	88			2	2.0		2					D		80	8.03	1482	401	808	345635		108.571	Tremblay et al.,2005
23	Caballo	20			141.27		32.93	-103.30		60	1.4070		1	0.8	9.6	45	0.43						152	16.21	389	1174	0	90320.1		52.3478	Tremblay et al.,2005
24	Cabonga	21	381.80	18.00			47.50	-76.68	70				3	3.0	3.0	434	1.3	584	0.1	282	D & B		18	1.83	966	365	562	257957			Duchamin et al., 1995
25	Cabonga	21	376.60	13.90	376.89	10.41	47.30	-76.66	79	74			3	3.0	3.0	434	1.3	584	0.1	28.2	D		20	2.02	963	358	562	257957	1728.82		Tremblay et al.,2005
26	Caniapiscau (Brisay)	22	182.50	9.80	182.58	7.34	54.40	-69.86	19	19			3	2.0	7.9	4318	34.3	803	0.1	54.3	D		-50	-5.04	783	529	660	62971.9	914.02	329.972	Tremblay et al.,2005
27	Cat Arm	23	615.50		615.96		50.05	-56.95	16	18			3	2.0	23.3	43	1				D & B		17	1.74	1123	321	724	158843		154.858	Tremblay et al.,2005
28	Chuffey	24					-31.35	151.13		18	1.4800	V		2.0	11.4	5.42							152	15.18	810	589	0	688899		27.1586	Sherman and Ford, 1997
29	Chipperia Lake	25	106.40	7.00	106.44	5.24	46.20	-80.98	73	73	0.5000	U	2	2.0	2.0	61	0.002				D		38	3.83	829	455	361	322295	564.96	114.243	StLouis, et al., 2000
30	Cochiti	26			432.82		35.64	-106.31		26			1	0.0	0.0	0	0.88						123	12.28	267	1627	0	144473		15.1026	Therrien et al., 2005
31	Conchas	27			358.09		35.38	-104.23		66	3.8563		1	1.3	5.0	38.85	0.196						142	14.16	351	1276	0	812371.3		14.6166	Therrien et al., 2005
32	Corumba	28	294.40		2200.00		-17.98	-48.52	8		3.7661	Y	3	4.0	21.8	55	1.2	40	19.7	1145.5	D		235	23.40	1379	731	592	751162		20.2419	Ometto et al., 2010
33	Corumbá	28	1024.20				-17.98	-48.52	8				3		21.8	55	1.2	40	13.3	927.3	D		235	23.40	1379	731	592	751162		20.2419	Ometto et al., 2010
34	Corumbá	28	724.10				-17.98	-48.52	8				3		21.8	55	1.2	40	9.3	600	D		235	23.40	1379	731	592	751162		20.2419	Ometto et al., 2010
35	Curua-Una	29	790.90	65.00	791.44	48.66	-2.82	-54.28	22	21.5	2.3051	Y	1	1.0	6.9	72	1	29	2.7	538.8	D & B		257	25.68	1850	72	861	1029720	4524.10	51.59	StLouis et al., 2000
36	Dartmouth	30					-37.50	147.50		18				2.0									108	11.16	871	668	0	691539		33.0252	Sherman and Ford, 1997
37	Day Lake	31	190.90	7.00	191.04	5.24	46.18	-90.90	29	29	2.0000	V	2	2.0	2.0	2	0.005				D		39	3.89	831	444	361	322480	875.17	114.243	StLouis et al., 2000
38	Deer Creek	32			-78.82		40.44	-111.50		60	1.6667		1	1.6	15.8	12	0.189						66	6.60	583	1917	244	252755		66.553	Therrien et al., 2005
39	Dillon Lake	33		21.00		16.09	39.62	-106.05	27	27	1.4898	V	3	2.0	24.6	13	0.3	503.7			D		10	1.03	482	2936	295	182459		60.7007	SmithNLewis1992
40	Dix	34		0.00		0.04	46.07	7.40	45	42	1.4409	V	1	1.0	93.3	4	0.4	40	16.6	6217.1	D		13	1.31	1687	2095	728	279727		21.4376	Diem et al., 2008
41	Duncan Lake	35	-220.90	10.00	-221.06	7.49	50.34	-116.93	37	37			1	2.0	30.6	56	1.7				D		34	3.44	825	1087	835	193347	-560.69	105.643	Tremblay et al.,2005
42	Dvorshak	36	-325.90	47.00	-326.13	3.29	46.57	-116.25	31	28	0.7037	U	1	2.0	116.2	37	4.3	1215		172.2	D		81	8.12	747	737	465	359396	-1086.00	69.9114	Soumis et al., 2004
43	Elephant Butte	37			300.00		33.23	-107.17		85	0.8000		1	0.5	15.8	161.67	2.55						156	15.60	233	1351	0	54132.5			Therrien et al., 2005
44	EOL	38	316.60	3.80	316.85	2.84	53.27	-76.66	24	24			3	2.0	20.0	1040					D		-31	-3.15	707	186	453	129489	1256.62	62.7509	Tremblay et al.,2005
45	F. D. Roosevelt	39	-126.00	11.00	-126.09	2.40	47.90	-118.77	62	59	2.2183	Y	1	2.0	37.9	306	11.6	76		1291.5	D		81	8.13	320	691	2	156832	-382.45		Soumis et al., 2004
46	Funil	40	169.40	12.50	-735.66		-22.52	-44.55	39	38	1.2500	V	3	4.0	19.7	27	0.5	55	41.9	1085.4	D		197	20.51	1519	623	734	763618		68.7005	Roland et al., 2010
47	Funil	40	-156.00	3.70			-22.52	-44.55	39				3		19.7	27	0.5	55	23.6	1074.7	D		197	20.51	1519	623	734	763618		68.7005	Roland et al., 2010
48	Funil	40	-163.60	3.50			-22.52	-44.55	40				3		19.7	27	0.5	55	18	3195.4	D		197	20.51	1519	623	734	763618		68.7005	Roland et al., 2010
49	Furnas	41	73.20		126.11		-20.67	-46.25	44	43	4.9333	Y	3	4.0	15.4	1342	20.7	503		58.3	D		203	20.29	1487	837	427	582014		36.8864	Roland et al., 2010
50	Furnas	41	171.90		1400.00		-20.67	-46.25	44	43	1.9436	Y	3	4.0	15.4	1342	20.7	503		49.1	D		203	20.29	1487	837	427	582014		36.8864	Roland et al., 2010
51	Furnas	41	144.10				-20.67	-46.25	45				3		15.4	1342	20.7	503		55.2	D		203	20.29	1487	837	427	582014		36.8864	Roland et al., 2010
52	Furtuna	42	320.50	129.00			9.23	-82.18	18	18			3		17.0	10	0.2	72	3.3	1160.6	D		257	25.71	3205	17		83990			Therrien et al., 2005
53	Gatun Lake	43		537.00			9.23	-79.88	78	74	1.3546	Y	3	3.0	12.1	430	5	365	0.5	198.8	D & B		267	26.68	2710	30	1353	521968		Keller&Stallard1994	
54	Gatun Lake	43	608.50	80.00			9.23	-79.88	90				3		12.1	430	5.2	365	0.5	231.9	D		267	26.68	2710	30	1353	521968			Tremblay et al.,2005
55	Gouin	44	181.40	2.70	181.49	2.02	48.56	-74.57	39	39			3	3.0	47.9	1789	85.7	4124			D		6	0.63	987	405	652	227961	732.83		Tremblay et al.,2005
56	Great Falls	45	1568.30	15.30	1570.33	11.45	50.45	-66.00	86	74			1	2.0		10					D		23	2.32	506	251	44	261704	6139.72	280.935	Tremblay et al.,2005
57	Grimsel	46		0.40		0.27	46.57	8.33	74	73	1.7027	V	1	1.0	37.1	3	0.1	35	7.4	2121.8	D		22	2.16	1677	1816	1349	184609			Diem et al., 2008
58	Gruyere	47	192.80	0.70	267.18	0.11	46.65	7.10	59	58	2.5714	Y	1	1.0	20.8	10	0.2	75	2.5	555.6	D		77	7.71	977	721	1091	421965	983.45	37.9112	Diem et al., 2008

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No	Reservoir Name	Reservoir No	CO_2 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CO_2 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	Latitude (Degree)	Longitude (Degree)	Age (years)	Age when sampled (years)	Hypsometric Integral (from Imboden, 1973) (see note 1)	Basin shape category (see note 2)	Reservoir shape category (see note 3)	Study weight (see note 4)	Mean Depth (m)	Reservoir Surface Area (km2)	Volume (km^3)	Residence Time (days)	Input of TP ($mg\ C\ m^{-2}\ d^{-1}$)	Input of DOC ($mg\ C\ m^{-2}\ d^{-1}$)	Emission Type (Diffusion "D" or Bubble "B")	BioClimatic Factor (see note 6)	Mean Annual Air Temperature (Celsius)	Mean Annual Precipitation (mm)	Altitude (m)	Mean Annual Runoff (mm)	Net Primary Production (see note 8)	GHG equiv C flux ($mg\ CO_2 equiv\ m^{-2}\ d^{-1}$	Carbon density (see note 7)	Bibliografic Reference
59	Gunlock	48			270.82		37.26	-113.77		31	0.4538		2	0.3	24.1	1.08	0.026						125	12.45	311	1361	0	165391			34.8513	Therrien et al., 2005
60	Hinds	49	574.10				48.99	-57.04	23	23				2.0		21					D		27	2.86	1088	312	829	177771			154.858	Tremblay et al.,2005
61	Hinze	50			37.90		-28.05	153.30		34	2.4000		3	2.0	32.0	9.7					D & B		193	19.30	1682	116	711	886475			50.3506	Sherman and Ford, 1997
62	Horseshoe	51		341.18			34.01	-111.73		56	0.9166		1	-0.3	12.3	11.01	0.135						191	19.59	393	692	0	141896			39.8322	Therrien et al., 2005
63	Huntington	52		139.91			39.59	-111.27		35	3.1029		2	2.7	6.8	0.48	0.0069						16	1.62	587	2891	184	242283			66.553	Therrien et al., 2005
64	Indal	53	30.90	60.00			62.57	17.07	70							1176							22	2.23	674	233	238	160480			133.025	Bergstrom et al., 2004
65	Itaipu	54	328.60	46.53	8.01		-25.38	-54.55	14	15			3	2.0	95.6	1549	129	39			D & B		215	21.53	1696	214	673	679935	437.65		39.8464	Santos et al., 2006
66	Itumbiara	55	86.00	800.00			-18.40	-49.05	25	43	7.2811	Y	3	4.0	21.0	719	15.1	146		187	D		244	24.42	1140	478	444	625566			44.163	Ometto et al., 2010
67	Itumbiara	55	258.80				-18.40	-49.05	25				3		21.0	719	15.1	146		201.4	D		244	24.42	1140	478	444	625566			44.163	Ometto et al., 2010
68	Itumbiara	55	227.90				-18.40	-49.05	25				3		21.0	719	15.1	146		129.5	D		244	24.42	1140	478	444	625566			44.163	Ometto et al., 2010
69	Jones Reservoir	56	58.10		-58.13		49.23	-121.61	50	50			2	2.0		5					D		40	3.99	1298	1209	1063	330640			69.8807	Tremblay et al.,2005
70	Jordanelle	57			-41.73		40.61	-111.41		8	1.7024		1	0.0	32.9	13.36	0.44						60	6.04	523	1962	179	223232			67.1829	Therrien et al., 2005
71	Kinbasket	58	144.50		144.64		52.12	-118.42	19	19			1	1.0	34.9	430	15				D		42	4.21	782	756	823	197135			105.643	Schellhase in StLouis2000
72	Koombooloomba	59			932.00	18.00	-17.63	145.60		10			3	2.0	12.9	16		205			D & B		205	20.50	1829	766	1296	964293	4017.33		54.0618	Demarty and Bastien, 2011
73	Kootenay Lake	60	-38.70	23.50	-38.75	17.59	49.75	-116.88	20				1	2.0	94.3	389	36.7	657	1.3	143.6	D		65	6.50	775	640	1261	260040	444.37			Tremblay et al.,2005
74	L.C.B. de Carvalho	61	565.80	23.10	522.47		-20.15	-47.25	38	37	0.8966	U	3	4.0	28.9	45	1.3	18	69.3	2118.5	D		213	21.33	1495	730	422	734873			36.8864	Roland et al., 2010
75	L.C.B. de Carvalho	61	1118.40	38.00	400.00		-20.15	-47.25	38	37	2.9806	V	3	4.0	28.9	45	1.3	18	37.6	2166.7	D		213	21.33	1495	730	422	734873			36.8864	Roland et al., 2010
76	L.C.B. de Carvalho	61	769.30	28.80			-20.15	-47.25	39				3		28.9	45	1.3	18		2439.5	D		213	21.33	1495	730	422	734873			36.8864	Roland et al., 2010
77	La Grande 1	62	454.60	8.80	454.94	6.59	53.73	-78.57	24	24			1	2.0	17.1	70	1.2	1460	0.2		D		-32	-3.17	597	50	237	138874	1887.74		310.246	Tremblay et al.,2005
78	La Grande 2	63	354.50	5.00	631.29	7.41	53.83	-76.00	17	16	5.8182	Y	3	3.0	18.3	2835	52.6	193			D		-39	-3.90	715	264	519	149418	2561.88		62.7509	Duchemin et al., 1995
79	La Grande 3	64	465.50	8.10	465.86	6.06	53.72	-75.68	19	19			3	2.0	24.8	2420	60	4453	0.1	25.1	D		-37	-3.70	716	257	519	19812.4	1910.30		144.747	Tremblay et al.,2005
80	La Grande 4	65	321.30	10.80	321.49	8.09	53.93	-73.33	20	20			3	2.0	28.8	765	22	4015	0.1		D		-42	-4.19	739	372	599	99216	1448.32		144.747	Tremblay et al.,2005
81	LA1	66			243.30		54.23	-72.71	7	7	2.0600	Y	2	3.0	8.5	1074		91.3					-46	-4.65	740	438	602	98955.8			144.747	Tadonleke et al 2011
82	Lac Du Bonnet	67	940.10	23.80	940.73	17.62	50.40	-96.00	47				3	2.0		126					D		23	2.33	506	255	44	261704	4043.28			Tremblay et al.,2005
83	Lac St-Jean	68	403.60		403.91		48.50	-72.00	47	47			2	2.0	11.3	1053	11.9	109.5			D		25	2.62	855	96	525	251694				Tremblay et al.,2005
84	Laforge-1	69	627.30	13.00	635.45	14.65	54.20	-72.58	2	1	3.6667	Y	3	3.0	8.3	960	8	96	0.7	468.8	D		-46	-4.63	739	434	602	98955.8	2818.39		144.747	Duchemin et al., 1995
85	Laforge-1	69	562.40	27.30	562.74	20.44	54.23	-72.71	9	10			3	3.0	6.2	1268	8	96			D		-46	-4.65	740	438	602	98955.8	2744.69		144.747	Tremblay et al.,2005
86	Laforge-2	70	227.20	7.90	227.34	5.62	54.65	-70.80	19	19			3	2.0		260		292			D		-51	-5.10	743	477	615	70047.2	1020.73		58.661	Tremblay et al.,2005
87	LG2	71			386.00		53.83	-76.00		23	7.2000	Y	2	3.0	18.3	2835		204					-39	-3.90	715	264	519	149418			62.7509	Tadonleke et al 2011
88	Little Nerang	72				183.00	-28.14	153.29		49			1	2.0	16.8	0.49	0.0067	232			D & B		193	19.30	1682	116	711	886475			50.3506	Sherman and Ford, 1997
89	Ljungan	73	43.40		84.00		62.52	14.45	70				1			134					D		24	2.70	588	424	185	108421			228.973	Bergstrom et al., 2004
90	Ljusnan/Voxnan	74	69.20		132.00		62.05	15.12	70				1			210					D		30	3.01	608	296	132	124523			169.974	Bergstrom et al., 2004
91	Loiska	75	545.50	79.00	545.82	59.15	67.82	27.73	28	28	1.0000	U	2	1.0	4.9	417	2.1	559	0.1	35.4	D & B		-14	-1.43	486	266	349	8387.92	3972.88		293.489	Heikkeri in StLouis2000
92	Loiska	75	288.00		415.26	103.40	67.82	27.73	28	28	1.0000	U	2	3.0	4.9	417	2.1	559	0.1	35.4	D & B		-14	-1.43	486	266	349	8387.92	4969.31		293.489	Huttunen et al., 2002
93	Lower Charrette	76			252.55		36.18	-104.80		71	0.0000		2	1.0	0.0	1.2	0						89	8.86	413	2035	0	153119			49.9483	Therrien et al., 2005
94	Lower Enterprise	77			89.73		37.52	-113.65		81			2	2.4	0.0	0.32	0						90	8.48	365	1646	0	165391			34.8513	Therrien et al., 2005
95	Lule	78	12.30		24.00		65.83	21.67	70				1			574					D		12	1.19	490	15	106	94256.5			163.967	Bergstrom et al., 2004
96	Lungern	79	96.30	0.10	66.18	0.10	46.80	8.17	86	86	1.1250	V	1	2.0	31.0	2	0.1	150	2.3	825.4	D		61	6.05	1362	1091	1349	355540	246.00		21.4376	Diem et al., 2008
97	Luzzone	80	686.20	0.10	522.49	0.10	46.57	8.97	46	42	1.9672	V	2	1.0	61.1	1	0.1	230	1.9	797.1	D		-13	-1.30	1870	2455	1046	259693	1919.06		21.4376	Diem et al., 2008
98	Lyman	81			203.73		34.36	-109.36					1	0.0	0.0	0	0						108	10.79	314	1625	0	50860.3			17.6027	Therrien et al., 2005
99	M5	82			634.60		51.20	-68.69		35	4.7800	Y	2	3.0	60.8	1950		2338					-23	-2.33	999	487	629	202609			77.2126	Tadonleke et al 2011
100	MacAllister	83			331.36		35.52	-105.18		41	0.7714		2	2.3	2.7	0.62	0.00168						92	9.20	404	1955	0	144000			29.4169	Therrien et al., 2005
101	Manic 1	84	832.90	11.30	833.47	8.46	49.21	-68.35	52	52			1	3.0		12					D		13	1.31	960	93	649	23830	3339.07		208.798	Tremblay et al.,2005
102	Manic 2	85	231.30	6.00	231.43	4.49	49.46	-68.38	34	34			1	2.0	9.7	124	1.2				D		8	0.65	973	137	649	272280	998.31		77.2126	Tremblay et al.,2005
103	Manic 3	86	83.50	1.10	83.51	0.82	50.14	-68.62	28	28			1	2.0	44.1	236	10.4				D		-13	-1.33	1017	458	647	222334	333.66		77.2126	Tremblay et al.,2005
104	Manic 5	87	383.70	6.10	383.99	4.57	51.20	-68.69	38	39			3	3.0	60.8	1973	120.1	2920	0.2		D		-23	-2.33	999	487	629	202609	1560.18		77.2126	Tremblay et al.,2005
105	Manso	88	-81.00		-367.09	74.86	-14.87	-55.77	3	4			3	1.0	15.7	357	5.6	430	0.6	65.7	D		244	24.38	1488	325	95	627985	1149.37		32.6558	Silkar et al., 2005
106	Manso	88	139.20		2600.00		-14.87	-55.77	4		2.6731	Y	3	4.0	15.7	357	5.6	430	0.6	65.7	D		244	24.38	1488	325	95	627985			32.6558	Ometto et al., 2010
107	Manso	88	138.90		3600.00		-14.87	-55.77	4		3.8414	Y	3	4.0	15.7	357	5.6	430	1	69.3	D		244	24.38	1488	325	95	627985			32.6558	Ometto et al., 2010
108	Manso	88	866.20	31.20	654.58		-14.87	-55.77	7	7	1.1053	V	3	4.0	15.7	357	5.6	430	1.9	76.6	D		244	24.38	1488	325	95	627985			32.6558	Roland et al., 2010
109	Manso	88	1265.40	42.00			-14.87	-55.77	7				3		15.7	357	5.6	430	0.6	116.4	D		244	24.38	1488	325	95	627985			32.6558	Roland et al., 2010
110	Mascarenhar.de Moraes	89			306.27		-20.27	-47.05		49	1.8667	V	3	4.0	15.0	250	3.8	51.1		736.9761 76	D		203	20.30	1492	881	422	714408			36.8864	Roland et al., 2010
111	Mead	90			314.73		36.14	-114.42		199	1.9582		3	0.6	50.4	640	32.236				D		210	20.95	111	388	0	415093.3				Therrien et al., 2005
112	Meelpaeg	91	375.30		375.53		48.21	-66.63	33				2	2.0		328					D		37	3.66	1340	188	883	160285				Tremblay et al.,2005
113	Meelpaeg (Granite Lake)	92	889.90		890.51		48.20	-66.96	31				1	2.0		80					D		31	3.05	1369	317	883	210240			154.858	Tremblay et al.,2005
114	Millaste	93			520.36		39.10	-111.19		27	1.4800		2	1.2	12.5	1.76	0.022						76	7.63	243	1961	171	103066			25.1026	Therrien et al., 2005
115	Minersville	94			49.91		38.23	-112.82		87	0.6242		1	2.4	8.3	4	0.033						75	7.45	345	1964	0	175280			34.8513	Therrien et al., 2005

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No	Reservoir Name	Reservoir No	CO_2 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CO_2 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	Latitude (Degree)	Longitude (Degree)	Age (years)	Age when sampled (years)	q-bathymetric slope (from Irrgolden, 1973) (see note 1)	Basin shape category (see note 2)	Reservoir shape category (see note 3)	Study weight (see note 4)	Mean Depth (m)	Reservoir Surface Area (km^2)	Volume (km^3)	Residence Time (days)	Input of TP ($mg\ C\ m^{-2}\ d^{-1}$)	Input of DOC ($mg\ C\ m^{-2}\ d^{-1}$)	Emission Type (Diffusion "D" or Bubble "B")	BioClimatic Factor (see note 6)	Mean Annual Air Temperature (Celcius)	Mean Annual Precipitation (mm)	Altitude (m)	Mean Annual Runoff (mm)	Net Primary Production (see note 6) ($mg\ CO_2 equiv\ m^{-2}\ d^{-1}$)	GHG equiv C flux	Carbon density (see note 7)	Bibliografic Reference
116	Miranda	95	1090.90	328.00	1091.65	112.30	-18.82	0.00	10				1	1.0	158.1	51	8	420	9.4	752.9	D & B	205	20.45	1499	1014	525	727745	7746.11	48.5075	Rosa et al., 2004
117	Miranda	96	1358.20	183.00	1197.54	115.41	-18.82	0.00	10	1			1	3.0	158.1	51	8	420	9.4	752.9	D & B	205	20.45	1499	1014	525	727745	8237.94	48.5075	Santos et al., 2006
118	Mosser Lake	96	354.50	3.00	354.78	2.25	46.02	-91.97	73	73	1.6250	V	1	2.0	2.3	7	0.016	266	49.7	15295.4	D	40	4.03	819	427	304	322147	1378.75	98.3221	StLouis et al., 2000
119	Morphy	97			-93.00		35.94	-105.40		62			2	0.0	5.0	0.1	0.0005					56	5.58	573	2678	0	380289		51.2461	Therrien et al., 2005
120	Nam Leuk	98			116.90	60.00	18.45	102.95		10			1	3.0	14.0	13	0.19	128		168.6		239	23.43	2434	479	1662	689565	2428.63	40.6334	Chanudet et al., 2011
121	Nam Ngum	99			-187.90	3.50	18.53	103.55		38			2	3.0	19.0	350	7	274		110		247	25.23	3056	283	2273	591463	-572.30	35.425	Chanudet et al., 2011
122	Navajo	100			205.36		36.80	-107.61		38			2	0.3	0.0	60.7	0					95	9.48	336	1877	0	103739		43.5485	Therrien et al., 2005
123	Nelson Lake	101	193.60	6.00	193.77	4.49	46.08	-91.50	61	61	2.3333	Y	2	2.0	3.0	25	0.03				D	43	4.32	777	390	306	323312	860.22	114.243	StLouis et al., 2000
124	New Melones	102	-323.50	34.00	-323.67	5.32	37.98	-120.52	25	22	0.7200	U	3	2.0	100.0	38	3.8	793		178.5	D	150	15.02	706	403	256	298155	-1009.61	28.5362	Soumis et al., 2004
125	Oberaar	103		0.30		0.21	46.55	8.27	63	52	1.1429	Y	2	1.0	41.8	1	0.1	45	6.5	2506.8	D	22	2.16	1677	1816	1349	184609			Diem et al., 2008
126	Opinaca	104	514.10		514.44		52.47	-76.37	23	23			3	2.0	9.0	947	8.5	1460	0.1		D	-27	-2.52	749	249	601	158644		310.246	Tremblay et al., 2005
127	Opinica (pre-Eastmain)	105	940.90	8.00	773.25	4.37	52.78	-76.62	13	13			3	1.0	7.0	600	4.2	1460	0.1		D	-28	-2.81	732	208	449	148664	2660.82	310.246	Kelly et al., 1994
128	Oroville	106	279.80	75.00	280.01	3.14	39.55	-121.43	36	33	0.6382	U	3	2.0	129.4	34	4.4	1337		87.1	D	140	13.99	1386	594	912	623480	1131.51	57.765	Soumis et al., 2004
129	Otter Creek	107			339.82		38.20	-111.99		86	0.7262		1	1.1	6.4	10.2	0.065					74	7.39	242	1996	0	122266		66.553	Therrien et al., 2005
130	Outaouais	108	349.60		349.87		45.56	-74.40	41	41			1	2.0		11					D	98	5.82	932	44	578	308589		47.8507	Therrien et al., 2005
131	Outardes 3	109	23.20	0.10	23.20	0.07	49.57	-68.81	30	30			1	2.0		19					D	-1	-0.14	984	348	701	233528	87.55	77.2126	Tremblay et al., 2005
132	Outardes 4	110		0.90	596.86	0.67	49.77	-68.97	32	35			3	3.0	28.0	625	17.5	7843	0		D	-3	-0.34	965	348	701	245935	2210.94	77.2126	Tremblay et al., 2005
133	Parker Canyon	111			190.09		31.43	-110.45		75			2	-0.4	25.0	0.51	0.01275					149	14.89	520	1600	0	191610		20.3688	Therrien et al., 2005
134	Patagonia	112			611.73		31.49	-110.86		33			1	-0.3	0.0	1.01	0					162	16.50	430	1257	0	119608		29.4169	Therrien et al., 2005
135	Pena Blanca	113			41.45		31.40	-111.09		43			1	-0.1	20.0	0.18	0.0036					160	16.04	488	1280	0	130111		16.521	Therrien et al., 2005
136	Peribonka	114	682.90		683.37		49.50	-71.17					1	2.0		19					D	7	0.68	976	259	881	236037		77.2126	Tremblay et al., 2005
137	Petit Saut	115	1216.40	1140.00	1217.19	853.50	5.05	-53.03	3	1.5			3	1.0	9.6	300	3.5	180	1.1	274.9	D & B	257	25.68	2944	70	1389	916361	329 12.93	46.7628	Galy-Lacaux in StLouis2000
138	Petit Saut	115	1224.30	160.00	1408.25	33.63	5.05	-53.03	11	10			3	3.0	9.6	300	3.5	180	1.1	274.9	D	257	25.68	2944	70	1389	916361	6294.60	46.7628	Guerin et al., 2006
139	Petit Saut	115	1296.30	180.00	1297.16	34.83	5.05	-53.03	9	9	2.3854	Y	3	3.0	9.6	300	3.5	180	1.1	274.9	D	257	25.68	2944	70	1389	916361	5917.27	46.7628	Abril et al., 2005
140	Petit Saut	115	1245.30	20.00			5.05	-53.03	11				3		9.6	300	3.5	180	1.1	274.9	D	257	25.68	2944	70	1389	916361		46.7628	Therrien et al., 2005
141	Pine Falls	116	928.40	0.10	928.99	-3.74	50.57	-96.20	60	50			1	2.0		9					D	21	2.08	515	235	75	264973	3281.52	280.935	Tremblay et al., 2005
142	Pote	117			141.00		38.29	-112.21		86	1.2621		1	1.0	8.7	10.2	0.089					77	7.70	258	1930	0	152297		34.5513	Therrien et al., 2005
143	Pleasant	118			-139.09		33.88	-112.28		28			3	1.3	21.0	30	0.63					204	20.44	318	551	0	72929.9		16.521	Therrien et al., 2005
144	Pointe du Bois	119	846.00		846.57		50.30	-95.53	35				3	2.0		593					D	19	1.89	545	313	69	250084		29.5191	Tremblay et al., 2005
145	Portispahta	120	572.70	13.00	573.11	9.73	68.00	26.75	25	25	4.4762	Y	1	1.0	6.3	214	1.4	310	0.1	101.7	D & B	-18	-1.78	478	260	328	59977.7	2425.85	166.182	Hellsten in StLouis2000
146	Portispahta	120	420.00	6.00	419.19	3.18	68.00	26.75	25	25	4.4762	Y	1	2.0	6.3	214	1.4	310	0.1	101.7	D & B	-18	-1.78	478	260	328	59977.7	1643.10	166.182	Huttunen et al., 2002
147	Powell bullfrog basin	121			156.82		37.00	-111.48		38	2.7500		3	2.0	40.0	658	26.32					154	15.45	120	1146	0	57772.1		22.8791	Therrien et al., 2005
148	Powell Wahweap	122			224.45		37.05	-111.32		38	3.4744		3	0.7	38.0	658	25					146	14.59	106	1243	0	48173.9		22.8791	Therrien et al., 2005
149	Quail	123			103.64		37.19	-113.39		16	1.8290		2	1.6	20.5	184	2.39	0.049				157	15.72	256	948	0	108496		22.8791	Therrien et al., 2005
150	Red Indian	124	208.40		208.50		48.78	-56.65	93				1	2.0		184					D	32	3.21	1083	206	829	187165		154.858	Tremblay et al., 2005
151	Revelstoke	125	600.00		600.41		-51.00	-118.20	8	8			1	1.0	44.2	120	6.3				D	43	6.64	1022	886	2648	266534		105.643	Schelhaas in StLouis2000
152	Ribeirão das Lages	126	22.10				-22.70	-43.88	95				3		15.0	30	0.5	279	0.8	96.8	D & B	208	20.84	1379	452	500	850062		43.6318	Santos et al., 2003
153	Robert	127			186.82		33.03	-108.16		38			2	0.0	0.0	0.28	0					108	9.16	493	1939	0	244873		39.6322	Therrien et al., 2005
154	Robert-Bourassa (La Grande 2)	128	409.10	13.00	620.67	11.42	53.67	-77.00	15	13			3	1.0	21.9	2815	61.7	207			D	-34	-3.45	686	170	468	18109.3	2657.12	144.747	Kelly et al., 1994
155	Robert-Bourassa (La Grande 2)	128	465.30	7.90	465.59	5.91	53.68	-77.07	20	24			3	4.0	21.8	2835	61.7	207			D	-34	-3.45	683	169	451	18109.3	1904.31	144.747	Tremblay et al., 2005
156	Robertson	129	384.00	6.10	384.26	4.57	51.00	-59.10	7	9			3	3.0		73					D	10	1.06	1125	33	990	23891	1561.18	62.7509	Tremblay et al., 2005
157	Rockport	130			421.09		40.77	-111.40		44			1	1.4	19.3	4.81	0.093					63	6.34	453	1852	179	220329		67.1829	Therrien et al., 2005
158	Roosevelt	131			-304.36		33.68	-111.12		90			1	1.1	23.4	86.98	2.039					198	19.76	398	642	0	133956		21.8696	Therrien et al., 2005
159	Sainte-Marguerite 2	132	410.70	4.10	411.00	3.07	50.31	-66.84					1	3.0		19.5					D	-3	-0.30	1144	337	791	240040	1609.34	208.798	Tremblay et al., 2005
160	Sainte-Marguerite 3	133	1495.60	2.70	1496.85	2.02	51.40	-67.02	4	5			1	3.0	47.0	253	11.9				D	-21	-2.06	1000	447	898	144463	5555.09	77.2126	Tremblay et al., 2005
161	Samuel	134	1171.50	100.00	1172.40	60.05	-8.80	-63.42	15	16			1 or 2	1.0	8.9	559	5	105	1.7	340.7	D	260	26.02	2267	84	1903	921984	6300.58	51.59	Guerin et al., 2006
162	Samuel	134			262.00		50.87	-8.80	-63.42	12	11.7		1 or 2	2.0	8.9	559	5	105	1.7	340.7	D	260	26.02	2267	84	1903	921984		51.59	Lima et al., 2005
163	Samuel	134	1909.10	13.00	1910.38	74.87	-8.80	-63.42	12				1 or 2	1.0	8.9	559	5	105	1.7	340.7	D	260	26.02	2267	84	1903	921984	9500.34	51.59	Rosa et al., 2004
164	Samuel	134	2205.50		2032.65	77.88	-8.80	-63.42	10	10			1 or 2	3.0	8.9	559	5	105	1.7	340.7	D & B	260	26.02	2267	84	1903	921984	10048.96	51.59	Santos et al., 2006
165	Sandy	135	684.50		685.01		49.25	-97.03	39	78			2	2.0	5.4	508	2.7				D	35	3.47	1030	124	694	245722			Tremblay et al., 2005
166	Santa Maria	136		0.20		0.24	46.57	8.80	38	37	0.5088	U	2	1.0	57.3	1	0.1	150	2.7	916.2	D	6	0.56	1749	2111	1168	259693		84.6213	Diem et al., 2008
167	Segredo	137	600.00	29.90	682.28	7.49	-25.78	-52.12	13	13			1	1.0	36.6	62	3	47	10.8	3113.6	D & B	176	17.59	1809	732	692	826534	2751.25	46.5995	Rosa et al., 2004
168	Segredo	137	1306.10	5.00	735.50	6.58	-25.78	-52.12	13	7			1	3.0	36.6	62	3	47	10.8	3892.1	D & B	176	17.59	1809	732	692	826534	2916.18	46.5995	Santos et al., 2006
169	Serra da Mesa	138	1090.90	80.00	1091.65	59.89	-13.85	-48.33	1	1			3	1.0	30.5	1784	54.4	770	0.5	51.5	D & B	250	25.03	1798	524	382	759043	5999.19	20.7767	StLouis et al., 2000
170	Serra da Mesa	138	358.90		721.58	84.60	-13.85	-48.33	1	1			3	2.0	60.8	1784	54.4	770	0.9	102.3	D & B	250	25.03	1798	524	382	759043	5465.82	20.7767	Santos et al., 2006
171	Serra da Mesa	138	175.10		330.17	6.39	-13.85	-48.33	5	6			3	1.0	30.5	948	54.4	770	0.5	51.5	D	250	25.03	1798	524	382	759043	1423.70	20.7767	Silker et al., 2005
172	Serra da Mesa	138	652.60				-13.85	-48.33	6				3		27.1	898	24.3	770	0.4	45.7	D	250	25.03	1798	524	382	759043		20.7767	Ometto et al., 2010
173	Serra da Mesa	138	719.90				-13.85	-48.33	6				3		27.1	898	24.3	770	0.5	101.9	D	250	25.03	1798	524	382	759043		20.7767	Ometto et al., 2010
174	Seven Mile	139	-199.40	109.50	-199.50	81.98	55.97	-120.40	23	23			1	2.0		4					D	13	1.63	477	714	184	212961	2001.20	75.4983	Tremblay et al., 2005

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No	Reservoir Name	Reservoir No	CO_2 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (from Barros et al.) ($mg\ C\ m^{-2}\ d^{-1}$)	CO_2 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	CH_4 flux (REVISED VALUES) ($mg\ C\ m^{-2}\ d^{-1}$)	Latitude (Degree)	Longitude (Degree)	Age (years)	Age when sampled (years)	q-bathymetric shape (from Introcen. et al., 2003) (see note 1)	Basin shape category (see note 2)	Reservoir shape category (see note 3)	Study weight (see note 4)	Mean Depth (m)	Reservoir Surface Area (km^2)	Volume (km^3)	Residence Time (days)	Input of TP ($mg\ C\ m^{-2}\ d^{-1}$)	Input of DOC ($mg\ C\ m^{-2}\ d^{-1}$)	Emission Type (Diffusion "D" or Bubble "B")	BioClimatic Factor (see note 5)	Mean Annual Air Temperature (Celsius)	Mean Annual Precipitation (mm)	Altitude (m)	Mean Annual Runoff (mm)	Net Primary Production (see note 6)	GHG equiv C flux ($mg\ CO_2 equiv\ m^{-2}\ d^{-1}$)	Carbon density (see note 7)	Bibliografic Reference
175	Seven Sisters Falls	140	1357.90		1358.83		50.12	-98.00	71	71			2	2.0		21					D	22	2.22	517	272	44	261977		48.3777	Tremblay et al., 2005
176	Shasta	141	340.10	47.00	340.32	7.11	40.85	122.38	60	57	1.0976	V	3	2.0	75.3	77	5.8	372		384.9	D	90	9.04	668	2	32	222348	1484.93	19.129	Soumis et al., 2004
177	Shi	142	125.50	0.20	300.38	0.16	47.13	8.80	70	69	1.5556	V	1	1.0	8.9	11	0.1	140	0.4	95.3	D	66	6.60	1336	1014	893	413445	1108.60	59.5247	Diem et al., 2008
178	Skeleffe	143	24.50		48.00		64.50	20.68	70							817					D	18	1.66	581	85	210	106874		159.867	Bergstrom et al., 2004
179	Skinnmuddseket	144	15.00	298.80	298.84		64.03	18.32	15	12	2.0769	Y	1	2.0	6.5	27	170	110		555.952381	D	10	1.20	603	292	231	135537		133.025	Aberg et al., 2004
180	Slave Falls	145	280.40		637.52	84.60	50.22	-95.57	35				1	2.0		7					D	21	2.11	529	283	44	253908	5157.61	29.5191	Tremblay et al., 2005
181	SM3	146			1828.00		51.40	-67.02		1	2.0800	Y	1	3.0	47.0	246	12.5	876				-21	-2.06	1000	447	898	144463		77.2126	Tadonleke et al 2011
182	Slave Lake	147	164.20		164.29		49.33	-122.30	91	91			1	2.0	0.3	1170	0.4	150	0	6.2	D	93	9.31	1910	120	1198	347765			Tremblay et al., 2005
183	Tigercat Lake	148	60.00	11.00	60.04	8.24	46.03	-91.25	60	60	2.3750	Y	3	2.0	2.7	3	2.375				D	42	4.30	815	410	304	321746	494.67	98.3221	StLouis et al., 2000
184	Toulnoustouc	149	379.90	0.10	380.17	0.07	50.06	-67.83	46	46			1 or 3	3.0		235					D	-7	-0.69	1040	357	793	232747	1396.44	77.2126	Tremblay et al., 2005
185	Tres Marias	150	-38.70	205.00	304.84	146.95	-18.23	-45.25	45	38			3	2.0	20.2	1040	21	120			D & B	231	23.13	1253	611	303	522655	6016.13	38.82	Santos et al., 2006
186	Tres Marias	150	272.70	19.00	272.91	142.25	-18.23	-45.25	45	45			3	1.0	20.2	1040	21	120			D & B	231	23.13	1253	611	303	522655	5742.39	38.82	Rosa et al., 2004
187	Tucurui	151		75.00		56.15	-3.92	-49.60	13	13	2.8100		1	1.0	18.9	2430	46	51			D	272	27.20	2398	75	1096	903670		54.1118	StLouis et al., 2000
188	Tucurui	151		40.00		51.00	-3.92	-49.60	22	22	2.8100		1	1.0	18.9	2430	46	51			D & B	272	27.20	2398	75	1096	903670		54.1118	Lima et al., 1998
189	Tucurui	151		98.00		11.60	-3.92	-49.60	15	16.7	2.8100		1	2.0	18.9	2430	46	51			D	272	27.20	2398	75	1096	903670		54.1118	Lima et al., 2005
190	Tucurui	151	2181.80	12.70	2183.29	82.36	-3.92	-49.60	15	15	2.8100		1	1.0	18.9	2430	46	51			D	272	27.20	2398	75	1096	903670	10750.57	54.1118	Rosa et al., 2004
191	Tucurui	151	2845.40		2312.93	81.88	-3.92	-49.60	22	15	2.8100		1	2.0	18.9	2430	46	51			D & B	272	27.20	2398	75	1096	903670	11209.92	54.1118	Santos et al., 2006
192	Ume	152	12.30		24.00		63.82	20.12	70	70				1.0		360					D	24	2.36	584	86	220	113374		133.025	Bergstrom et al., 2004
193	Upper Chanrelle	153			252.82		36.17	-104.82		71			2	0.0	0.0	0.45	0					89	8.86	413	2035	0	153119		49.8483	Therrien et al., 2005
194	Upper Enterprise	154			-5.45		37.52	-113.87		89	0.6407		3	1.8	11.2	1.07	0.012					90	8.48	385	1846	0	165391		34.8513	Therrien et al., 2005
195	Upper Salmon (Cold Spring Pond)	155	524.50		524.81		48.18	-56.30	20	20			1	2.0		130					D	34	3.42	1401	264	865	222292		154.858	Therrien et al., 2005
196	Upper Salmon (Long Pond)	156	519.80		520.17		47.95	-55.90	33	36			3	2.0		130					D	41	4.06	1547	163	1048	250782		154.858	Tremblay et al., 2005
197	Upperlake Mary	157			846.55		35.06	-111.48		61			1	0.1	12.0	2.4	0.0288					80	8.03	531	2145	0	246209		44.569	Therrien et al., 2005
198	Ute	158			191.18		35.35	-103.90		38	0.9741		1	1.6	11.8	28.59	0.336					144	14.40	372	1187	0	101162		21.5358	Therrien et al., 2005
199	Wallace	159			664.36		35.04	-104.68		81			1	0.3	0.0	0.4	0					134	13.58	359	1475	0	72344.7		14.6166	Therrien et al., 2005
200	Wallula	160	-95.20	84.00	-95.25	6.74	45.92	-119.17	50	47	1.2563	V	1	2.0	1.5	157	0.2	1		1882.2	D	119	11.92	231	140	0	218549	-124.63	22.8459	Soumis et al., 2004
201	Waneta	161	-127.90	38.80	-128.00	29.05	49.01	-117.55	20	20			1	2.0							D	78	6.98	690	553	512	364977	498.98	40.7364	Tremblay et al., 2005
202	Whatshan	162	182.70		182.85		49.08	-116.10	40	40			1	1.0		15					D	37	3.71	757	1318	403	307495		146.153	Schelhaas in StLouis2000
203	Whatshan	162	-1.40	5.80	-1.38	4.34	49.08	-116.10	51	51			1	2.0		15					D	37	3.71	757	1318	403	307495	139.74	146.153	Tremblay et al., 2005
204	Williston-Finlay	163	192.00		192.13		56.09	-124.02	41	41			1	2.0	42.3	1660	70.3		0.3		D	0	0.02	543	1026	388	191039		89.453	Tremblay et al., 2005
205	Williston-Parsnip	164	479.50		479.78		55.49	-123.36	33	33			1	2.0	39.5	1779	70.3	803	0.3	49.2	D	21	1.76	620	681	96	235255		89.453	Tremblay et al., 2005
206	Williston-Peace	165	250.90		251.08		56.07	-122.79	23	23			1	2.0	42.3	1660	70.3				D	14	1.38	601	812	329	211070		32.2284	Tremblay et al., 2005
207	Wohlen	166	297.20	1.80	262.63	1.15	49.97	7.32	86	85	1.8571	V	1	2.0	6.8	4	0.025	3	18.3	2968	D	78	7.93	739	448	336	315653	1001.16	60.2128	Diem et al., 2008
208	Wohlen	166				117.00	46.96	7.32		88	1.0455		1	4.0	8.8	2.5	0.022	2				80	8.27	966	657	1091	437935		37.991	Del Sontro et al., 2010
209	Xingó	167	1636.40	121.00	1637.47	22.46	-9.62	-37.78	10		1.0526		3	1.0	63.3	60	3.8	22		18030.3	D & B	255	25.48	513	155	134	454869	6752.74	23.9529	Rosa et al., 2004
210	Xingó	167	2682.80		1675.13	30.01	-9.62	-37.78	10	5	1.0526		3	3.0	63.3	60	3.8	22		2121.2	D & B	255	25.48	513	155	134	454869	7142.64	23.9529	Santos et al., 2006
211	Yuba	168			379.09		39.27	-109.90		87	2.4615		1	1.8	6.5	44.13	0.286845					58	5.84	379	2384	0	145343		66.553	Therrien et al., 2005
212	Zeuzier	169		0.10		0.05	-3.90	-49.60	49	48	1.3333	V	2	1.0	60.0	1	0.1	120	4	1250	D	272	27.20	2398	75	1096	903670		54.1118	Diem et al., 2008

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ANNEX 4 – CONVERSION FACTORS

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1. Conversion from moles to grams

In chemistry, a mole is considered to be Avogadro's number (6.02×10^{23}) of molecules (or anything) of a substance - so depending on the density of the substance, the mass of that amount of the substance could vary widely.

To convert from moles to grams you must first find the molar mass of the element or compound. Use the periodic table to read off the atomic mass from an element. If it is a compound, you must know the molecular formula, and then you find the total molar mass of the compound by adding up the atomic masses of each atom in the compound. The unit of the molar mass will be in grams per moles (g/mole).

Once you have the molar mass, you can easily convert from grams to moles, and also from moles to grams.

Number of moles = (# of grams) ÷ (molar mass)

Number of grams = (# of moles) × (molar mass)

For carbon dioxide and methane (most common GHG species in reservoirs):

Element	Atomic mass (g/mol)
C	12
O	16
H	1

GHG	Molar mass (g/mol)
CO_2	44
CH_4	16

2. CO_2 equivalents (CO_2eq or CO_2equiv)

The international practice is to express GHG in CO_2 equivalents (CO_2eq or CO_2equiv). Emissions of gases other than CO_2 are translated into CO_2eq by multiplying by the respective global warming potential (GWP). From the 2007 IPCC report:

GWP relative to CO_2 at different time horizon for carbon dioxide and methane

Gas name	Chemical formula	Global warming potential (GWP) for given time horizon		
		20-yr	100-yr	500-yr
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	72	25	7.6

Source: 2007 IPCC Fourth Assessment Report (AR4)

The IPCC considers the GWP of GHGs in a 100-year time frame.

It is important to note that care must be taken on the use of GWP as the conversion factor for calculation of gases' warming potential equivalences, as the IPCC GWP is not widely accepted to correctly represent the relative weight of the gases on the change in global temperature.

3. Conversion from "g of GHG" to "g of Carbon"

The conversion between "g of GHG" and "g of Carbon" is directly related to the ratio of the atomic mass of a GHG molecule to the atomic mass of a carbon atom. Essentially, this practice accounts for the carbon in the GHG molecule, as opposed to counting the entire molecule.

For carbon dioxide, the ratio of the atomic mass of a CO_2 molecule to the mass of a carbon atom is 44:12.

- To convert from "g of C" to "g of CO_2", multiply by 44/12
- To convert from "g of CO_2" to "g of C", multiply by 12/44
- Sometimes you find this noted as gC-CO_2 or tC-CO_2 (to make clear that these "g of C" refer to Carbon in a CO_2 molecule).

For methane, the ratio of the atomic mass of a CH_4 molecule to the atomic mass of a carbon atom is 16:12.

- To convert from "g of C" to "g of CH_4", multiply by 16/12
- To convert from "g of CH_4" to "g of C", multiply by 12/16
- It is important to make clear that these "g of C" refer to Carbon in a CH_4 molecule (i.e., NOT CO_2eq – not taking into account GWP). It is common to use gC-CH_4 or tC-CH_4

4. Conversion from "g of Carbon" to "g of CO_2eq"

With the use of CO_2 equivalents (CO_2eq or CO_2equiv) it is possible to express emissions/removals of different GHG species on the same units of mass (g of CO_2eq), allowing then to compare and to combine (add or subtract) these emissions.

To convert from "g of Carbon" to "g of CO_2eq" it is necessary to:

- first convert from "g of C" to "g of GHG" (see item 3),
- and then multiply by the respective global warming potential (GWP) in order to obtain the "g of CO_2eq".

For CO_2, as the GWP is 1, it is only necessary to convert from "g of C" to "g of CO_2", multiplying by 44/12.

For methane:

- first convert from "g of C-CH_4" to "g of CH_4", multiplying by 16/12
- and then, adopting the IPCC GWP for a 100-yr time-horizon, multiply by 25 in order to obtain the "g of CO_2eq".

After converting the unit "g of Carbon" from the different GHG species in analysis to the unit "g of CO_2eq", it is possible to compare the emissions or to add/subtract all values and then to obtain a total estimated emission expressed as "g of CO_2eq".

It is also possible to express these values as "g of C-CO_2eq" (grams of Carbon in the CO_2eq), by multiplying the "g of CO_2eq" by 12/44.

5. Carbon dioxide equivalents vs. carbon equivalents

While the international standard is to express emissions in CO_2 equivalents (CO_2eq), many U.S.A. sources have expressed emissions data in terms of carbon equivalents (CE) in the past. In particular, the United States Environmental Protection Agency (USEPA) has used the carbon equivalent metric in the past for budget documents.

For the purposes of national greenhouse gas inventories, emissions are expressed as teragrams of CO_2 equivalent (Tg CO_2eq). One teragram is equal to 10^{12} grams, or one million metric tons.

- To convert from CE to CO_2eq, multiply by 44/12
- To convert from CO_2eq to CE, multiply by 12/44