HYDROPOWER AND THE ENVIRONMENT:

Managing the Carbon Balance in Freshwater Reservoirs

IEA Hydro Technical Report

Guidelines for Quantitative Analysis of Net GHG Emissions from Reservoirs

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Volume 3 – Management, Mitigation and Allocation

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IEA Technology Collaboration Programme on Hydropower:

Annex XII

FINLAND JAPAN NORWAY BRAZIL USA EU CHINA AUSTRALIA

OVERVIEW OF THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

The IEA Technology Collaboration Programme on Hydropower (IEA Hydro) is a working group of International Energy Agency member countries and others that have a common interest in advancing hydropower worldwide. Member governments either participate themselves, or designate an organization in their country to represent them on the Executive Committee (ExCo) and on the Annexes, the task forces through which IEA Hydro's work is carried out. Some activities are collaborative ventures between the IA and other hydropower organizations.

Vision

Through the facilitation of worldwide recognition of hydropower as a well-established and socially desirable energy technology, advance the development of new hydropower and the modernization of existing hydropower

Mission

To encourage through awareness, knowledge, and support the sustainable use of water resources for the development and management of hydropower.

To accomplish its Mission, the Executive Committee has identified the following programme-based strategy to:

- Apply an interdisciplinary approach to the research needed to encourage the public acceptance of hydropower as a feasible, socially desirable form of renewable energy.
- Increase the current wealth of knowledge on a wide array of issues currently associated with hydropower.
- Explore areas of common interest among international organizations in the continued use of hydropower as a socially desirable energy resource.
- Bring a balanced view of hydropower as an environmentally desirable energy technology to the worldwide debate.
- Encourage technology development.

IEA Hydro is keen to promote its work programmes and to encourage increasing involvement of non-participating countries. All OECD and non-OECD countries are eligible to join. Information about membership and research activities can be found on the IEA Hydro website www.ieahydro.org.

THE INTERNATIONAL ENERGY AGENCY

TECHNOLOGY COLLABORATION PROGRAMME

ON HYDROPOWER

Annex XII

Hydropower and the Environment

Task 1: Managing the Carbon Balance in Freshwater Reservoirs

Guidelines for Quantitative Analysis of Net GHG Emissions from Reservoirs

Volume 3

Management, Mitigation and Allocation

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ABSTRACT

Recognizing that the state of knowledge regarding hydropower reservoir GHG emissions contains a large degree of uncertainty and many diverging positions, the IEA Hydro initiated Annex XII in 2009, titled "Managing the Carbon Balance in Freshwater Reservoirs", which developed a comprehensive work program designed to increase knowledge on processes connected to man-made reservoir GHG emissions.

The outcomes of the research are documented as best practice guidelines and have been prepared in three volumes: Volume 1- Measurement Programs and Data Analysis, Volume 2 - Modeling and Volume 3 – Management, Mitigation and Allocation (this document). Volume 3 comprises an executive summary and five chapters.

This Guideline starts with an introduction and the need, objectives and scope of this work, covering the strategic management process for net GHG assessments from reservoirs. This is based on an assessment of the likelihood of significant levels of net GHG emissions (exceeding a threshold value) associated with the reservoir, as determined through a screening process. Where the expected emissions are below acceptable levels, as indicated by the threshold, no further action is required, except under specific circumstances. The Guideline does not recommend a specific threshold value, but rather outlines approaches that are presently considered to have credibility.

The second chapter provides a general description of management strategies where net GHG emission assessments indicate them as required. The third chapter covers mitigation as actions that reduce emissions for projects where screening indicates significant levels of net GHG emissions associated with the reservoir. The Guideline provides management strategies to lessen these emissions wherever practicable through all phases of reservoir planning, design, implementation and operation. The fourth chapter addresses apportioning emissions between the users of the services provided by the reservoir and facilities. The procedures and methodologies identified as best practice will enable the allocation of net GHG emissions in a fair and equitable manner, relative to the services received from the use of the reservoir, and have been developed to allow stakeholders to understand and accept the fundamentals of the process. The fifth chapter covers documenting and reporting of results

Keywords:

Net GHG Emissions, Reservoirs, Management, Mitigation, Allocation.

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Annex XII started with a kickoff meeting in August 2009 at CEPEL's offices in Rio de Janeiro, Brazil, followed by a number of Annex meetings, workshops and sessions at Hydro conferences.

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The names of authors, contributors and independent reviewers are listed below:

Project Manager: Jorge Machado Damazio, Electric Energy Research Center (CEPEL), Brazil. Operating Agent for Annex XII

Principal Author: Niels Nielsen, Secretariat, IEA Hydro

Authors: Jorge Machado Damazio, CEPEL, Brazil; Albert Cordeiro Geber de Melo, CEPEL, Brazil; Marco Aurelio dos Santos, COPPE, Brazil, Li Zhe, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, China. Jukka Alm, Natural Resources Institute, Finland; Vincent Chanudet, Eletricité de France (EDF), France;

Contributors: Maria Elvira Piñeiro Maceira, CEPEL, Brazil; Alexandre Mollica Medeiros, CEPEL, Brazil; Juliano Lucas Souza de Abreu, Electric Energy Research Center (CEPEL), Brazil; Andy Crawford, Hydro Tasmania, Australia; Morten Stickler, Statkraft AS. Norway; Carolyn Maxwell, Hydro Tasmania, Australia; Andrew Scanlon, Consultant, Australia; Géraldine Duvochel, Eletricité de France (EDF), France;

Reviewers: Alain Tremblay, Hydro Québec, Canada; Andrew Scanlon Andrew Scanlon and Associates, Australia; Flavio Miguez de Mello, UFRJ, Brazil; Thomas Schleker, European Commission, Belgium;

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EXECUTIVE SUMMARY

This state-of-the-art Guideline identifies best practices and provides a reference framework for the management, mitigation and allocation of net GHG emissions from freshwater reservoirs. This Guideline is generally applicable for new and existing projects where screening indicates the likelihood of significant levels of net GHG emissions, which are based on exceeding a threshold value. However, these Guidelines do not recommend a specific threshold value, but rather outline approaches that are presently considered to have credibility. Where the expected emissions are within acceptable levels, as indicated by the threshold, no further action is required, except under specific circumstances.

This Guideline provides an introduction to the need, objectives and scope of this work. A roadmap provides guidance to identify projects where the development of a GHG emissions management strategy is appropriate and under what conditions. A general description of the main modules for a management strategy covering net GHG emission assessments is outlined. This includes developing an understanding of GHG emissions, preparing a GHG management plan and addressing governance framework.

Mitigation covers actions to reduce emissions for projects where screening indicates significant levels of net GHG emissions associated with the reservoir. The Guideline identifies potential mitigation options and provides management strategies to lessen these emissions wherever practicable through all phases of the reservoirs life. This includes project planning and design, impoundment, reservoir operation, catchment and downstream management. Of special considerations are ways to approach the mitigation of unrelated anthropogenic sources (UAS). It should be noted that the Guideline does not cover methods of analyzing mitigation options in terms of their feasibility for a specific project.

Where reservoirs and discharge facilities provide or enable multiple services, it is appropriate to allocate emissions between the users of these services. These Guidelines identify procedures and methodologies identified as best practice to estimate fair allocation of net GHG emissions, relative to the services received from the use of the reservoir. These have been developed to allow stakeholders to understand and accept the fundamentals of the process. A special case that is considered covers the allocation of UAS.

Despite recent efforts and progress achieved so far, the present state of knowledge regarding hydropower reservoir GHG emissions still contains uncertainties. To meet this challenge, the IEA Hydro initiated Annex XII, titled "Managing the Carbon Balance in Freshwater Reservoirs", which developed a comprehensive work program designed to increase knowledge on processes connected to man-made reservoir GHG emissions.

The outcomes of the research are documented as best practice guidelines and have been prepared in three volumes. Volume 1, published in 2012 covered measurement programs and data analysis, Volume 2, completed in 2015, addressed the quantitative analysis of net GHG emissions from reservoirs through modeling, with Volume 3 covering management, mitigation and allocation for reservoirs with a likelihood of producing significant levels of net GHG emissions

While this Guideline is written for hydropower reservoirs, or reservoirs that include hydropower as one of their multipurpose services, the processes that have been documented can, in general, be applied to any reservoir and can affect policy for both water and energy services.

1.0 INTRODUCTION TO GUIDELINES

1.1 OVERVIEW

Despite recent efforts and progress achieved so far, the present state of knowledge regarding hydropower reservoir GHG emissions still contains uncertainties. Recognizing this fact, the International Energy Agency Technology Collaboration Programme for Hydropower (IEA Hydro) started an Annex on "Managing the Carbon Balance in Freshwater Reservoirs". The objectives of the Annex are to increase knowledge on processes connected to reservoir GHG emissions, establish best practice guidelines for planning studies on the carbon balance in reservoirs, and standardize GHG flux evaluation methods.

The Guidelines provide best practices to assist the reader in performing measurements, analyzing data, and modeling and, where appropriate, managing net GHG emissions from multipurpose reservoirs. They have been prepared in three volumes:

Volume 1 – Measurement Programs and Data Analysis, contains advice and procedural recommendations for performing measurement campaigns and data analysis, and for obtaining estimates and quantifying uncertainties of net GHG emissions (IEA Hydro 2012). Volume 1 also contains a general introduction to the subject of reservoir emissions.

Volume 2 – Modeling, provides users with a reference framework for performing quantitative analysis and modeling of net GHG emissions and changes in carbon stock. From this framework readers can undertake sufficient analysis and study to understand the process of GHG emissions from an existing or planned reservoir correspondent to long-term horizons.

Volume 3 – Management, Mitigation and Allocation, provides guidance on developing a GHG management strategy for a reservoir where there is a likelihood of significant net emissions, and if so, identifies appropriate mitigation measures to reduce these emissions and allocation approaches between the users of the water services. Volume 3 also provides guidance on reporting management procedures.

The comprehensive and collaborative approach to developing these Guidelines included:

a) Literature Reviews of approaches to the management of GHG emissions from reservoirs
b) Workshops with Annex members and contributing parties in Rio de Janeiro, Brazil (three); Hobart, Australia; Bordeaux, France and Montreux, Switzerland to discuss and draft the Guidelines.

c) Identification of and communication with numerous scientists and engineers with extensive subject knowledge and experience of industry practices
d) The collected knowledge of the authors and other contributors;
e) Peer review from an external group of experts.

1.2 GUIDELINE OBJECTIVES AND SCOPE

Volume 3 of the Guidelines applies primarily to cases where there is likely to be significant levels of net GHG emissions associated with the reservoir, however the Guidelines could be used in any case whenever this would be beneficial. Here, the Guidelines provide a framework for a strategic management approach to mitigate (reduce) GHG emissions as much as possible and thereby lessen negative impacts wherever feasible. Furthermore, they provide guidance on allocating emissions between the services provided by the reservoir in a fair and equitable manner, as well as guidance on management reporting procedures.

Initially, the process should indicate if there are or are likely to be significant levels of net GHG emissions associated with a reservoir, as determined by screening (see Volume 2 of these Guidelines). The indication of significant levels of net GHG emissions[1] would be the primary trigger for developing a strategic management approach. The objectives of developing a GHG emissions management strategy for a reservoir are to:

1. Provide guidance on when it is appropriate to initiate a strategic management process and under what conditions, whereas for many reservoirs, such a management strategy will not be necessary.
2. Outline the framework for the development of a strategic management process and plan.
3. Identify and develop best practices to identify and define mitigation measures that reduce GHG emissions from a reservoir.
4. Identify appropriate approaches for the fair and transparent allocation of GHG emissions from a reservoir between the users of the reservoir water services.
5. Report on the outputs for mitigation and allocation of emissions in the Strategic GHG Management Plan for the reservoir.
6. Facilitate communication of outcomes of the management, mitigation and allocation process in a way that ensures broad uptake and acceptance.

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[1] The indication of significant levels of net GHG emissions for a reservoir relate to exceedance of a threshold value, as addressed in Section 2.2, Best Practice Guideline A.

While this Guideline is written for hydropower reservoirs, or reservoirs that include hydropower as one of their multipurpose services, the management, mitigation and allocation processes that have been documented can, in general, be applied to any reservoir and can affect policy for both water and energy services.

1.3 FORMAT AND USE OF GUIDELINE

The framework for identifying best practices for management, mitigation and allocation of net GHG emissions from reservoirs is set out in this volume, with a format as follows:

Chapter 1: Introduction and Overview - explains the needs, concepts, objectives and scope of this volume. This chapter will provide the user with an understanding of what these Guidelines contain and where it will be applicable to the user's needs.

Chapter 2: Management Strategy for Net GHG Emissions from Reservoirs– covers the conditions under which it is appropriate to develop a management strategy for GHG emissions from reservoirs, the likelihood of significant levels of net GHG emissions associated with the reservoir using a screening process (Volume 2 of these Guidelines) and the development of the modules of a management process.

Chapter 3: Mitigation Measures – covers the overall strategy for managing net GHG emissions from reservoirs in relation to lessening these emissions and hence reducing any negative impacts wherever feasible. The key strategy is to enable the development of mitigation approaches through the planning, design, implementation and operational phases of the reservoir and facilities to meet overall best practices.

Chapter 4: Fair Allocation – addresses apportioning reservoir GHG emissions between the services provided by the reservoir and its facilities. The procedures and methodologies identified as best practice will enable allocation of net GHG emissions in a fair and equitable manner and have been developed to allow stakeholders to understand and accept the fundamentals of the process.

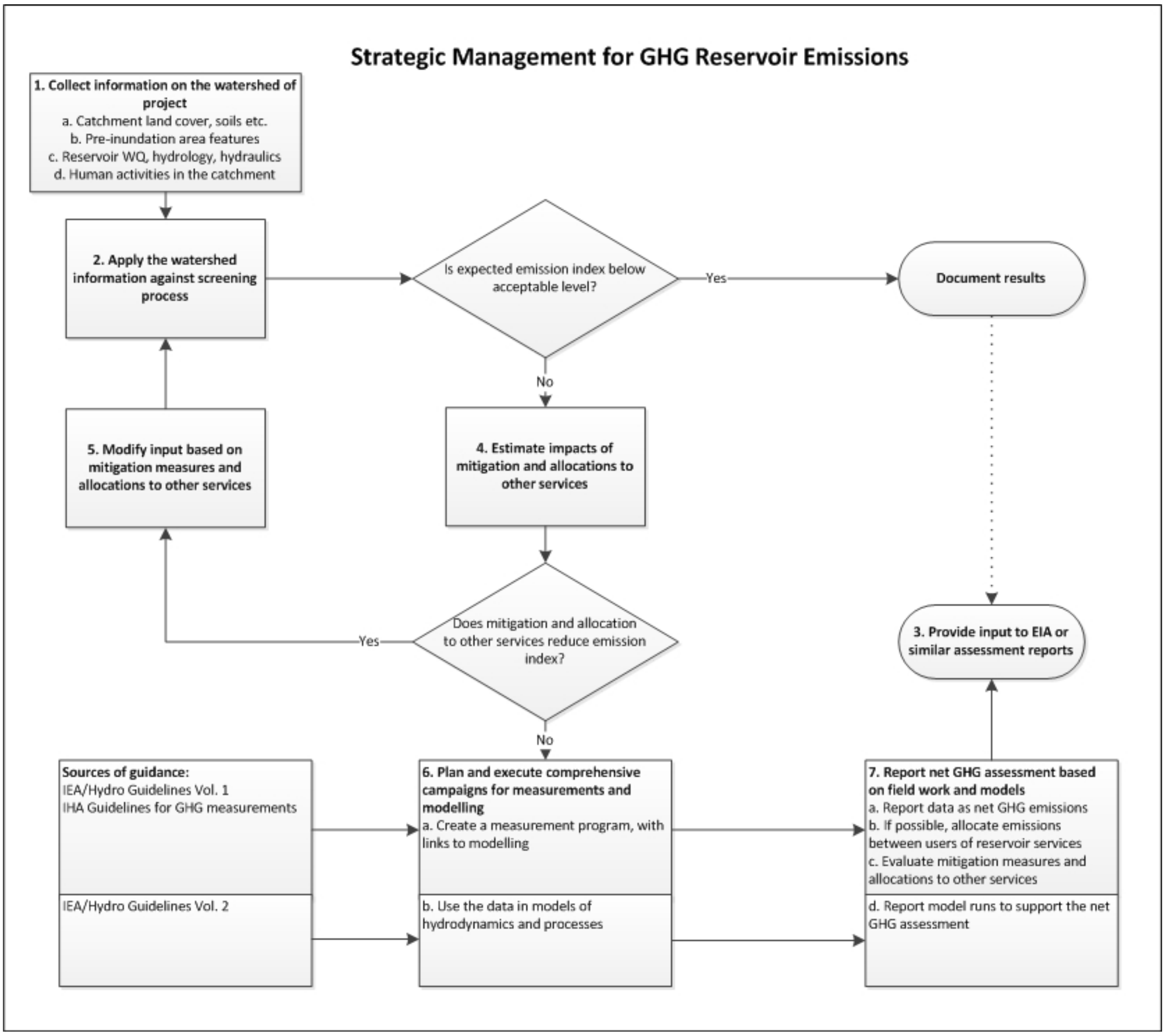
Chapter 5: Reporting of Results– covers the way to report the outcomes of the management, mitigation and allocation processes through comprehensive documentation of methodologies and results.

1.4 ROADMAP FOR MANAGEMENT, MITIGATION AND ALLOCATION

The Roadmap concept was developed in Volume 2 of the Guidelines to assist the user to effectively and efficiently identify best practices for modeling net GHG emissions from reservoirs. This enables a "big picture" view and helps in the selection of the appropriate GHG modeling process for each reservoir or series of reservoirs. Where the screening process indicates that significant GHG emissions are expected from a reservoir, or for other reasons identified in this Guideline (Section 2.2), a management strategy should be developed which identifies appropriate mitigation measures and allocation approaches between the users of the water services.

Figure 1.1 shows a general description of the process for a net GHG emission assessment. This could be used as part of an Environmental Impact Assessment or similar purposes. Following a screening process (Section 2.2) that identifies significant GHG reservoir emissions, Box 4 indicates the process to evaluate the project. If there is potential to change certain features of the project, through modifications to design or operation, for example, which would reduce GHG emissions from the reservoir, these would be considered in detail in Box 5. Following any successful modifications, the amended project would again be screened, and could result in GHG emissions from the reservoir falling below the significant range. As part of this process, appropriate allocation approaches between the users of the water services would be identified.

Figure 1.1. Strategic Management for Net GHG Emissions Assessment.



1.5 GLOSSARY AND ASSUMPTIONS

Term	Definition	Explanation and Assumptions
Application of modeling	All reservoirs, existing, under construction and planned	The application covers all reservoirs, including, but not limited to, hydropower.
Emission index	Criteria used to decide if GHG emissions from projects are significant	These index are used to assess the likelihood of significant levels of net GHG emissions associated with the reservoir using a screening process
Flux	Flow of matter, e.g. a GHG species, passing a boundary such as from water to the atmosphere, per unit time and area.	Called efflux or influx depending on the direction of flux. The flux rate may vary daily or seasonally. Relevant unit times from seconds to years in association with processes of interest.
Gas types under consideration	CO_2, CH_4, N_2O	Volume 1 of this Guideline determines the relevant GHG's for net emissions and removals calculation.
Gross emissions	Total GHG emissions from a reservoir.	These emissions are measured, calculated or postulated from conditions in the reservoir, also referred to as post-impoundment emissions.
Hydropower	A renewable source of power derived from the energy of falling water	Hydropower can be classified as Run-of-river, Storage hydropower and Pumped storage.
Modeling output	Net GHG emissions expressed as CO_2eq g/m^2/year or CO_{2eq}/kWh	These are considered the most useful ways of comparisons between reservoirs and against threshold/performance criteria.
Net GHG emissions	Modification of GHG emissions due to the creation of the reservoir	The contribution of GHG that a reservoir makes to the environment, being the difference between post-impoundment balances of gross GHG emissions and carbon removals, excluding from the gross GHG emissions the UAS emissions , and pre-impoundment balances of gross GHG emissions and carbon removals.
Pre-impoundment emissions	GHG emissions prior to the creation of the reservoir.	These emissions are measured, calculated or postulated from conditions in the natural pre-inundated river basin.
Reservoir	A natural or artificial man-made lake, storage pond, or impoundment from behind a dam which is used to store or divert water	Reservoirs may use their storage and diversion capacity and capability to provide multiple services (multi-purpose reservoirs)
Spatial Coverage	The reservoir footprint, the upstream catchment and the river downstream that is influenced.	The screening process will cover just the reservoir footprint.
Stock	Storage of matter within a body of interest, e.g. sediment, mass per volume.	Carbon stock in sediment or forest trees and soil may be important for fluxes after impoundment-
Time frame for GHG fluxes and changes in Carbon budget	100 years, with the assumption of no change in natural and anthropogenic impacts.	This assumption is not likely in reality, but allows for a comparison considered suitable for the pre- and post-impoundment situation as well as with and without UAS.
Unrelated Anthropogenic Source (UAS)	GHG emissions due to inflow of nutrients and carbon from sources unrelated to the reservoir, e.g. sewage, agricultural run-off, forestry waste etc.	It is important to distinguish between natural background and anthropogenic emissions.

2.0 MANAGEMENT STRATEGY FOR NET GHG EMISSIONS FROM RESERVOIRS

2.1 BACKGROUND

Emissions of carbon dioxide, methane and nitrous oxide are a part of carbon and nitrogen biogeochemical cycling from water bodies in nature. However, local emissions may be changed in areas impacted by reservoir development used for hydroelectricity, flood control, drinking water, irrigation, navigation and other water uses.

GHG emissions comprise mainly methane, carbon dioxide and nitrous oxide and have their source from the breakdown of organic matter inundated by the reservoir and from the biomass growing in the reservoir and entering the reservoir as inflow during its life-cycle. During operation of the reservoir, flows are released through the powerhouse, discharge facilities or other diversion structures. At the same time, GHGs are emitted from the reservoir surface and the discharge/diversion facilities, as well as from flows downstream of the discharge/diversion facilities. In addition, sediments trapped in the reservoir can form a carbon sink

It is generally understood that methane, which is primarily released from the decomposition of organic matter and occurs in higher concentrations closer to the bottom of the reservoir than at the surface, is the GHG of most concern. This can be compounded by the design of dam structures that have intakes for discharge or diversion facilities near the base of the dam.

Significant variations in GHG emissions occur across reservoirs depending on their type and the physical parameters of the reservoir. Types include large and small storage reservoirs and run-of-river schemes. Parameters include a number of variables such as climatic and geochemical conditions of the reservoir, physical differences such as depth, shape and orientation and the selected operating regimes. Human activities in the catchment or within the reservoir may influence the water quality, eutrophication of the water bodies, and thereby promote conditions for enhanced methane formation. Natural factors to consider are major increases in GHG emissions which could occur following extreme precipitation events with inflows carrying large volumes of organic debris. The impacts from these events could last for significant periods of time. General effects from climate change are outside the scope of these Guidelines

In most cases, reservoir emissions peak following the impoundment and filling of the reservoir due to the natural decomposition of organic material in the inundated area, though with time, these emissions will decline. However, temporary peaks will occur due to seasonal 'turn over' events or resulting from catchment inflows carrying large loadings of organic material or contamination from unrelated anthropogenic sources (UAS). These factors need to be well understood for the best management of the reservoir and its catchment as regards its GHG footprint. Depending on the method of decommissioning there may be a secondary emissions event when the carbon sink created when the reservoir is 'dewatered'

The conditions under which it is appropriate to develop a management strategy for GHG emissions from reservoirs and the components of such a strategy are outlined below.

2.2 GHG MANAGEMENT STRATEGY

For those reservoirs that exceed a pre-defined threshold level (see discussion below), reservoir GHG management strategy involves a) actions to identify the magnitude of net emissions, b) understanding the reasons for significant emissions and c) finding measures to reduce them. This approach is generally applicable to projects that have or are likely to have significant levels of net GHG emissions associated with the reservoir and has three main purposes:

1. To identify appropriate mitigation measures to reduce the levels of net GHG emissions.
2. To develop approaches to allocate these emissions between the users of the water services provided by the development and operation of the reservoir.
3. To outline a governance structure for the parties managing the reservoir GHG assessment.

An effective screening process takes into account the prevailing conditions and possible long-term changes of land use in the catchment.

Context

Deciding if the development of a reservoir GHG management strategy is necessary starts with an assessment of the likelihood of significant levels of net GHG emissions associated with the reservoir. The use of a scientifically plausible screening process has been described in Volume 2 of these Guidelines, providing guidance on when it is appropriate to develop such a strategy and under what conditions. For some reservoirs, such a management strategy may not be necessary.

If significant GHG emissions are predicted by the screening process, the objective of the GHG management strategy is to identify means to reduce emissions. If these actions are effective to reduce the emissions below the threshold, no further work is required. If not, an appropriate program for measurement, monitoring and modelling of net GHG emissions should be followed. It is important to note that one function of such a strategy is to promote an understanding of the project including public awareness of the impact of GHG emissions from reservoir creation and operation. It is important to address this issue throughout the life-cycle of a hydro-project.

Best Practice Guideline

A. Assess the likelihood of significant levels of net GHG emissions associated with the reservoir using a screening process
B. Identify projects requiring a GHG emissions management process and under what conditions
C. Consider the principle of strategic adaptive management as a potential management strategy
D. If appropriate develop the modules of a management process

Commentary

A. Assess the likelihood of significant levels of net GHG emissions associated with the reservoir using a screening process

The management strategy for GHG emissions from reservoirs should be based on an assessment of the likelihood of significant levels of net GHG emissions associated with the reservoir. The GHG emissions assessment process starts with the collection of relevant information on the watershed, which is then screened (as noted in Figure 1.1) through the first decision point is "Is expected emission index below acceptable level" The screening process should provide clear guidance in terms of the net GHG emissions risk levels and enable decision-making in terms of two categories:

1. Projects that clearly have minimal risk for significant net GHG emissions, and
2. Projects where there is a risk of significant net GHG emissions, or where the risk is unknown or unclear.

Screening process

It is not the intent of these Guidelines to make specific recommendations as to the use of a particular screening process. Rather it has outlined approaches that are derived from credible organizations.

World Bank

The World Bank has published a Technical Note, Greenhouse Gases from Reservoirs Caused by Biogeochemical Processes (World Bank, 2017) that covers hydropower and other dam infrastructure projects. An initial screening process has been suggested based on compiled data and qualitative assessment to screen out projects likely to cause negligible GHG emissions, and where no further studies are required. It is noted that "due to the extreme variability of GHG from reservoirs, there is no simple threshold that can be used. Instead a number of variables need to be taken into account" A few recommendations are given in the Table 2.1, reproduced with permission from the Technical Note

Guidance for screening Hydropower projects with negligible reservoir GHG emissions
The counterfactuals to hydropower project investments are normally other forms of power generation, or energy demand management programs. The initial screening can therefore focus on the relative difference between potential reservoir emissions and the emission factors of the likely counterfactual. Utilizing the strong relation to power density an early estimate can be made based on the proposed installed capacity and the estimated reservoir surface area. • Irrespective of other factors, if the power density is above 100 W/m2, which would be the case in most run-of-river projects, the global data indicate that reservoir emissions normally are below 1 g CO2/kWh, and even in extreme cases below 10 g CO2/kWh. Compared to most counterfactual for power production this is relatively low (e.g. fossil fuel is in the order of 300-1000 g CO2/kwh), and reservoir emissions can be assumed negligible since they would be within the error margin of the emissions of the counterfactual. . • If factors clearly disfavor high GHG emissions (such as cold climate, low carbon stock, deep reservoir), which would indicate that extreme emissions are unlikely, the upper envelope curve does not need to be considered and a lower power density threshold can

be used to assume negligible reservoir emissions. E.g. a power density of 20 W/m2 indicates a median reservoir emission of about 5 g CO2/kWh. .

- Should the counterfactual have negligible emissions, and the power density is below 100 W/m2, it is suggested that the threshold is set by the size of the reservoir. Using a threshold of 100,000 metric tons CO2-eqv (or 1,000 mt/year) as is used for other dam infrastructure seems reasonable (see below). An analysis utilizing different installed capacity (from 0.1 to 100 MW) shows that the resulting reservoir area threshold is fairly stable and varies only between 2.5-3.5 km2 during median conditions, and 0.5-0.7 km2 under extremely favorable conditions for high GHG emissions (upper envelope).

UNESCO/IHA

A UNESCO/IHA research project has developed the GHG Reservoir Tool (G-res tool), which builds on the principles of the global carbon cycle and the definition of net reservoir emissions (UNESCO/IHA. 2017). The objective of the tool is to "*quantify the portion of GHG emissions that can be legitimately attributed to the creation of the reservoir over its lifetime*". If potentially significant GHG emissions cannot be discounted through the above initial screening assessment, it is recommended to apply the G-res tool, for which input is derived from secondary data. The G-res tool is available at www.hydropower.org/gres-tool and is free to use. The site includes technical documentation on the scientific basis for the tool and user guide of its step-by-step use

Average pre-impoundment emissions for the inundated area are calculated from land cover, soil and climate. If the area to be inundated works as a carbon sink, the pre-impoundment emissions are negative. Unrelated anthropogenic sources (UAS) are estimated based on land use, population and known point sources in the catchment area.

Annual post-impoundment emissions are estimated through carefully developed statistical models relating GHG emissions to key governing variables such as temperature, age of reservoir, littoral area, solar radiance, phosphorus concentration in the reservoir, and soil carbon content. The statistical models are derived based on the measured gross emissions from over 200 sites

The G-res tool is used through a web-based interface and is available on the internet. The web-based tool is linked to global geographic databases to enable default estimations of variables such as climate zone, land cover, and soil types.

Threshold value assessment approaches

The selection criteria should be based on a threshold value for a GHG emission index, acceptable to regulatory authorities or others who may use this approach, and taking into account the needs of climate policy and development of clean technology systems in the field of renewable energy sources. Choices of units for the emission index are CO_2eq g/m^2/year for inundated areas and CO_2eq g/kWh for hydropower projects.

It is not the intent of these Guidelines to make specific recommendations as to a universally acceptable threshold value. Rather it has outlined approaches that are derived from credible organizations. This also recognizes an ongoing IPCC process that could provide further guidance on setting emissions factors for flooded lands, and which is presently scheduled for reporting in 2019.

OECD/IEA

The IEA has considered hydropower in the context of the overall power sector and has indicated a threshold criteria established on the carbon budget which is required to achieve a low carbon future. Based on a 2° trajectory scenario (2DS) by 2050, modelling suggests that the average direct carbon intensity of the global power sector needs to be at most 90-95% of what it is now, equivalent to 27-54 gCO_2e/kWh. The IEA notes that this 27-54 gCO_2e/kWh range should not be viewed as a target for all low carbon technologies (IEA, 2014). While this may not be practical for setting a hydropower GHG threshold, it nevertheless illustrates the scale of decarburization which is required. This is particularly relevant for long-lived assets like hydropower which are likely to be operational well into the second half of the 21st century and there is a good argument that a hydro threshold should not be as low as these figures indicate, i.e. they are averages. Furthermore, for new-build hydropower capacity, 2020-2040, IEA suggests average emissions intensity should be ~50 gCO_2e/kWh. This was reduced to 40 gCO_2e/kWh in the Energy Technology Perspective 2015 (IEA, 2015).

Another counterfactual approach is to compare thresholds with other low carbon technologies. Two levels are can be considered: *100gCO_2e/kWh – Low carbon renewable benchmark, and 200gCO2e/kWh – Low carbon fossil fuel comparator*.

The majority of low carbon technologies have lifecycle emissions of less than 100gCO_2e/kWh, with this number selected for geothermal criteria. A 100gCO_2e/kWh threshold for lifecycle emissions therefore is considered a reasonable, simple 'ballpark' for low carbon generation technologies. Given the lifecycle figures for hydropower, the literature suggests that a large majority of hydropower projects would pass a 100gCO_2e/kWh threshold, as average lifecycle emissions intensity estimates (24-28 gCO_2e/kWh) tend to be below this figure.

An alternative benchmark for clean electricity could be the cleanest form of commercial fossil-fueled generation (combined-cycle gas turbine at ~490gCO2e/kWh). Based on "pre-commercial" CCS technologies, the lifecycle GHG footprint of fossil-fuels might come down to ~200gCO_2e/kWh and it is possible that these could be supported as 'green' initiatives, on the basis that they are an improvement on business as usual.

B. Identify projects requiring a GHG emissions management process and under what conditions

A GHG emissions management process is deemed appropriate for projects where screening indicates significant levels of net GHG emission index associated with the reservoir. This includes both new developments and existing projects. However, development of a GHG emissions management strategy will generally not be required for reservoirs (planned or existing) that have been screened as likely to produce low or fundamentally no net GHG emissions, as covered in Volume 2 of the Guidelines.

In unusual cases, there may be a reasons to undertake a GHG emissions management process, such as:

- For new developments requiring an Environmental Impact Assessment or similar, which covers managing GHG emissions from the reservoir.
- For projects having regulatory or licensing requirements related to GHG emissions, or projects having such a requirement from developers, customers or lenders

- For projects where 2D or 3D modelling related to net GHG emissions is required or has been undertaken.
- Where high UAS's are expected
- For projects where the developer, customers or lenders require a process to support the allocation of net GHG emissions to users of the reservoir services
- For projects requiring information on GHG emission management that could be related to carbon pricing mechanisms or similar

C. Consider the principle of strategic adaptive management as a potential management strategy

The intrinsic nature of hydropower development suggests a flexible approach to strategic management in relation to net GHG emissions. The principles of strategic adaptive management (SAM) should be considered as a potential management strategy with the objectives to reduce emissions in a cost-efficient manner and, where possible, apportion them to the services provided by the reservoir. SAM is a structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing this uncertainty over time through system monitoring and evaluation. In this way, decision-making simultaneously meets one or more management objectives and, either passively or actively, accrues information needed to improve future management.

While no explicit examples have been found relating to the development and use of the SAM approach to the management of GHG emissions from reservoirs, the approach is considered to be well suited because the natural environment is complex, with many factors influencing the relationships between the different components. Moreover, SAM is a systematic process for improving the effectiveness of natural resource management by learning from experience and utilizing current knowledge to inform decision making. SAM can provide the framework for continuous learning and improvements to management approaches.

The U.S. Department of the Interior has developed practical guidance on SAM (Williams, 2012) using case studies to indicate its use for both management and learning. The Guide presents SAM as a form of structured decision making, with an emphasis on the value of reducing uncertainty over time in order to improve management. Its structure covers the foundations and challenges of SAM, followed by examples that illustrate the components.

Other relevant examples of SAM applications can be found in the following references:

Aquatic ecosystems are connected over large spatial scales, have varied drivers, strong and often conflicting societal interests and interacting management processes. Such complex socio-ecological systems have considerable challenges. A reference report (Kingsford, 2011) suggests that SAM should be implemented as a management framework, irrespective of resourcing, in protected areas of any river system, ranging from heavily managed or regulated through to pristine rivers. The four stages of the SAM process for aquatic protected areas are outlined with three case studies from South Africa and Australia in different stages of SAM implementation. While maturity in SAM is incremental over years or decades, it can and should be applied even if environmental problems are urgent and contentious. The stages of SAM should produce an agreed vision and/or mission among stakeholders, with an appropriate hierarchy of objectives that determines indicators to be measured, allowing ongoing reflection, learning and adaptation. There is no panacea for achieving aquatic conservation, but SAM offers hope with its interlinked processes for navigating complexity and learning.

In a related approach, River Basin Management Planning (RBMP) is a policy that seeks to integrate multiple objectives for water bodies, and is enacted at multiple scales and through the collaboration of multiple stakeholders, using an adaptive management cycle (Blackstock, 2009). Insights from spatial planning and community planning literatures illustrate how many challenges are not particular to RBMP but are fundamental to strategic planning in a modern society.

D. If appropriate develop the modules of a management process

It is important to note that the modules of the management strategy will be selected as appropriate for each project and could vary significantly for the different types of hydropower plant reservoirs, such as large and small storage reservoirs and run-of-river schemes.

If significant levels of net GHG emissions are expected or identified from the reservoir, then:

a) For planned reservoirs a project review process is put in place to identify feasible avoidance or emission reduction opportunities.
b) For existing reservoirs a GHG management plan is developed to identify feasible emission reduction opportunities.

The modules of the GHG management process and plan should include the following considerations, as appropriate:

- Understand the broad scope of GHG emissions, their source and behaviour throughout the life-cycle of the reservoir and catchment area.
- Understand the contributions and projected changes to UAS over the project life-cycle.
- Develop a GHG Management Plan, and include a risk management assessment process, as appropriate to identify and manage key risk issues.
- Actively promote the reduction of GHG emissions.
- Consider and implement feasible conservation and other mitigation measures.
- Plan, design, implement and operate the reservoir and facilities to meet best practices.
- Identify and undertake research needs to improve GHG management approaches.
- Track performance of mitigation measures by applying strategic adaptive management principles.
- Allocate net GHG emissions to the services provided by the reservoir and facilities.
- Report on approaches to GHG emission management and include effective input to policy development.

2.3 UNDERSTANDING GHG EMISSIONS

Context

Prior to the development of any management strategy and the preparation of a management plan, it is necessary to broadly understand the range of net GHG emissions, their source, the processes and behaviour throughout the life-cycle of the planned or existing reservoir. From this, the magnitude of GHG emissions from a specific reservoir can be estimated.

A compounding factor that needs to be addressed is both an understanding of the net approach to GHG emissions and the tools to obtain a realistic estimate of their magnitude over the life-cycle of the reservoir

Best Practice Guideline

A. Understand the source and processes of GHG emissions throughout the life-cycle of the reservoir

B. Determine a realistic estimate of the net GHG emissions from the reservoir, based on the framework contained in Guidelines Volumes 1 and 2.

C. Take into account the additional complexities of cascade reservoir systems

Commentary

A. Understand the source and processes of GHG emissions throughout the life-cycle of the reservoir

Greenhouse gas (GHG) emissions, comprising mainly methane, carbon dioxide and nitrous oxide, originate from the breakdown of detritus and other organic matter that is inundated by the reservoir. During the life-cycle of the reservoir, significant amounts of organic matter can be transported by the river and be deposited as sediments in the reservoir. This organic matter can be broken down and released as GHG into the water column and ultimately emitted to the atmosphere from the reservoir surface.
Furthermore, operation of the reservoir discharge facilities, through the powerhouse, spillways or other structures will release GHGs as well as from flows downstream of the discharge/diversion facilities.

It is generally understood that methane, which is primarily released from detritus and other organic matter at the bottom of the reservoir, is the GHG of most concern. This can be compounded by designs that have intakes for discharge or diversion facilities near the base of the dam, in reservoirs that stratify, and the occurrence of higher concentrations of methane than at the reservoir surface.

Significant variations in GHG emissions occur across the footprint of the reservoir, dependent on a number of factors including reservoir location, depth, shape and orientation as well as wind, precipitation, temperature, vertical gradient (stratification) and hydrodynamics. There can also be major increases in GHG emissions following extreme precipitation events and subsequent inflows carrying large volumes of organic debris, and this can last for significant periods of time.

Care should be taken to understand the issues surrounding the ingress of UAS entering the reservoir as well as the contributions of organic matter in water and sediment releases from upstream hydropower plants and storages in cascade reservoir systems.

The above factors need to be clearly understood in the process to best manage the reservoir GHG emission footprint

B. Determine a realistic estimate of the net GHG emissions from the reservoir, based on the reference framework contained in Guidelines Volumes 1 and 2.

Previous guidelines have been prepared in two volumes: *Volume 1- Measurement Programs and Data Analysis and Volume 2- Modelling.* These provide a reference framework for performing quantitative analyses of net GHG emissions from man-made reservoirs, including advice and recommended procedures for performing in-situ measurements, data analysis and modelling. A realistic estimate of the net GHG emissions from the reservoir needs to include considerations of pre- and post-impoundment emissions as well as emissions from unrelated anthropogenic sources (UAS)

a) Pre-impoundment emissions

Strictly speaking, an estimate of pre-impoundment emissions can only be accurately developed before the reservoir is formed. This points to the importance of monitoring efforts in areas targeted for future reservoirs, as well as comparative studies. The latter can help make reliable estimates of emission (or removal) rates over land under similar soil and vegetation conditions to those prevailing in the area flooded by the reservoir.

A full description of approaches to understand pre-impoundment emissions can be found in the Guidelines Volumes 1 & 2.

b) Post-impoundment emissions

To better understand and manage the post-impoundment emissions of a reservoir following inundation, it is necessary to comprehend several factors including the pre-impoundment conditions, the hydrologic and hydraulic setting and the sources of carbon entering the reservoir.

Post-impoundment GHG emissions and removals depend on the situation in aboveground biomass and the carbon stock in the soil of the area to be flooded, as this mobilizes carbon, GHG and nutrients in the soil

Organic matter that was stored on land over decades, centuries and possibly millennia may lead to the release of nutrients and GHG after inundation. Biomass decays aerobically, producing carbon dioxide as well as anaerobically, producing both carbon dioxide and methane.

In general, the construction of a barrier across a river reduces water velocities and increases sedimentation rates, including the deposition of organic matter and carbon. The net emission of GHG requires an estimation of the sources of carbon and keeping track of the change of emission patterns as a consequence of reservoir formation. In many catchments the sources of carbon will come from upstream land use. Prior to inundation, GHG emissions resulting from upstream carbon sources would occur along the river course. Following reservoir inundation similar levels of emission may occur but these may be of a different species, for example methane replacing carbon dioxide.

Factors that could affect post-inundation emissions should also be understood, including physical impacts, such as wind, precipitation and temperature and impacts resulting from changes in the environment setting of the drainage basin.

A fuller description of approaches to understand post-impoundment emissions can be found in the Guidelines Volumes 1 and 2.

c) Emissions from Unrelated Anthropogenic Sources (UAS)

The human-induced release of organic matter, nutrients and other materials impacting directly or indirectly on carbon cycling and GHG fluxes in the reservoir, are referred to as Unrelated Anthropogenic Sources (UAS)

Excessive nutrient loading, when released to the reservoir, enriches the ecosystem and can cause eutrophication, resulting in harmful algal blooms and fish mortality. Examples of activities contributing to loads of nutrients and organic matter are agriculture, animal husbandry, release of inadequately purified wastewater from settlements or industry, mining of minerals or organic deposits, and efficient forest management using fertilizers, drainage or soil amendment. Some nutrients may enter the reservoir directly, e.g. from fish farming.

For management and mitigation of GHG emissions it is desirable to attempt to separate GHG emissions related to UAS from GHG emissions caused directly by the impoundment. While direct measurement of GHG emissions from UAS are generally not possible, the contribution of UAS (nutrients and organic matter) from land use, such as agriculture, animal husbandry, community and industrial sewage, and aquaculture, compared to natural leaching of similar substances from the catchment in its theoretical natural state could be assessed by means of modelling.

Activities in the catchment that increase, or have the potential to increase, the levels of GHG emissions from the reservoir and its downstream reaches are then identified. Management of those activities in ways that effectively suppress the UAS brings evident and mutual benefits to the interest groups using the services of the reservoir for their multiple purposes.

C. Take into account the additional complexities of cascade reservoir systems

The understanding and management of post-impoundment emissions from a cascade of reservoirs provides an additional level of complexity through several added factors, some or all of which could apply. In general, each reservoir would need to be treated independently, even though there would always be some interactions of carbon cycling with other reservoirs in the cascade, located either upstream or downstream. Factors needing consideration include:

- The passage between reservoirs and/or retention of nutrients, organic matter and other factors influencing water quality
- The operational modes of dam and power plant releases
- The type of reservoir, either storage, or run-of-river with no appreciable storage
- Ownership of each reservoir and the approach to sharing information on the reservoirs and their operation
- Jurisdictional issues, such as international or state borders

All the above factors need to be taken into consideration in the allocation process for GHG emissions (see Section 4)

2.4 GHG MANAGEMENT PLAN

Context

For those projects where net GHG emissions from reservoirs are indicated through screening to be above acceptable levels, the appropriate process to identify and manage key issues is through a GHG Management Plan. This plan should include the full life-cycle of the reservoir for new projects and the remaining life of the reservoir for existing projects. (It is noted that GHG emissions associated with construction of the reservoir retaining structures is beyond the scope of all volumes of these Guidelines). Furthermore, it is suggested that for complex projects, a risk management approach be adopted.

Best Practice Guideline

A. For projects where net GHG emissions from the reservoir are indicated through screening to be above acceptable levels, a GHG Management Plan should be prepared to identify and manage key issues.

B. Include a life-cycle assessment of the GHG emissions related to reservoir impoundment and operation in the GHG Management Plan. This should cover the full life of the reservoir for new projects and the remaining life of the reservoir for existing projects.

C. For unusual situations, adopt a risk management approach as the basis of the GHG Management Plan.

Commentary

A. For projects where net GHG emissions from the reservoir are indicated through screening to be above acceptable levels, a GHG Management Plan should be prepared to identify and manage key issues.

In general, major hydropower developments require an Environmental Impact Assessment/Statement and Management Plan. For projects where net GHG emissions from the reservoir are indicated through screening to be above acceptable levels, a specific GHG Management Plan should be prepared. This document should contain guiding environmental principles and procedures that set targets, minimize and reduce the emissions and ensure that environmental impacts are as low as reasonably practicable.

The GHG Management Plan should be prepared during the planning stage for new projects where significant GHG emissions are expected. The potential GHG emissions from the proposed project should be adequately addressed in the planning, design, pre-construction, implementation and operational phases associated with its development. This will also ensure that through the use of best practice, the total net greenhouse emissions are minimized. The GHG Management Plan should incorporate the following measures, as applicable:

- Methodology adopted for the collection of data (see Volume 1 of the Guidelines).
- Procedures used to estimate net GHG emissions from the reservoir and likelihood of significant levels.
- Comparison/benchmarks against other similar reservoirs.
- Mitigation approaches to reduce GHG reservoir emissions
- Methodologies to allocate GHG reservoir emissions to the services provided by the reservoir
- Results from data collection, screening and modelling and management approaches
- Actions for the monitoring and regular reporting of GHG's and mitigation strategies and action plans.

B. Include a life-cycle assessment of the GHG emissions related to reservoir impoundment and operation in the GHG Management Plan. This should cover the full life of the reservoir for new projects and the remaining life of the reservoir for existing projects.

The life-cycle assessment of a project (LCA) should cover the net GHG emissions related to reservoir impoundment, through a process of evaluating its potential effects on the environment over the entire period of its operation. For the purposes of this Guideline, this has been assumed as 100-years for new projects. For existing projects the 100-year period should be assessed from the date of the first impoundment.

A special case can occur where a powerhouse is added to an existing dam/reservoir complex sometime after its original development. In this case it is appropriate to also start the assessment period from the date of first impoundment.

The International Organization for Standardization (ISO) has a process for LCA with a technical framework for life cycle assessment consisting of four components:

- Defining the purpose and scope of the assessment.
- Compiling an inventory and analysis of relevant inputs and outputs for the project.
- Evaluating the potential environmental impacts associated with these inputs and outputs.

- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

C. *For unusual situations, adopt a risk management approach as the basis of the GHG Management Plan.*

Unusual situations can arise that have the potential to produce significant increases in GHG emissions in the reservoir. While the likelihood of occurrence of such events could vary between unlikely to very rare, the impacts or consequences may be significant, Examples of unusual situations include:

- Major flood events in the catchment transporting large amounts of organic debris along the river into the reservoir. The frequency and intensity of these flood events could be aggravated in future climate scenarios
- Large landslides or areas of slope erosion along the reservoir rim carrying organic debris into the reservoir (this could be associated with seismic or flood events)
- Major overflows or breaches in industrial or community waste systems dumping organics into the reservoir.

A risk management approach should be designed to assess the potential risks from these types of events and how this could affect net GHG emissions from the reservoir should the event materialize. The risk management approach should also identify measures to minimize the risk of the event occurring as well as reducing its impact, were the event to occur. There are a number of different approaches to managing risk, with the following components being fundamental:

1. Identify risk issues that have the potential to significantly increase GHG emissions from a reservoir.
2. Classify the likelihood and consequence of each risk issue.
3. Prioritize risks based on seriousness and level of importance.
4. Examine means to reduce or manage potential risks (control measures).
5. Nominate the owner of the risk with responsibility for management.
6. Track the risk and ensure a reporting chain.

2.5 GOVERNANCE

Context

As part of the management strategy for reservoirs having significant levels of net GHG emissions, a governance framework may be incorporated into project governance arrangements. This framework should cover all aspects of the management of the project as it relates to GHG emissions, including:

- Reservoir management.
- Reservoir and catchment mitigation covering the reduction of net GHG emissions.
- Allocation of emissions, including the "external partners" contributing to UAS.

Furthermore, reservoir management, mitigation and allocation of GHG emissions should be covered under consistent governance frameworks.

Best Practice Guideline

A. Establish a Governance Framework for management of GHG emissions

Commentary

A. Establish a Governance Framework for management of GHG emissions

The governance framework should cover all areas of responsibility and authority for managing GHG emissions from a reservoir. Most importantly, the governance framework should be developed and accepted at the earliest possible stages of the project and prior to project approval.

In terms of governance, it should be noted that some stakeholders are private companies, while some beneficiaries may be communities. There is therefore a need for discussion on how community beneficiaries should be represented in the allocation process, such as by State or regional administration.

The governance framework related to the allocation of emissions between parties can be quite complex and needs to be carefully considered. One example is where funding for a project is sourced from external agencies such as International Banks. In these cases, the parties having responsibilities for allocation of emissions needs to be clearly defined. There may be situations (as described in Section 4.4) where it is not possible to either identify ownership of the UAS, or an identified owner of UAS will not accept full responsibility. Such cases should be covered by the framework.

2.6 RESEARCH AND INVESTIGATION NEEDS

It is acknowledged that there are uncertainties surrounding the management of GHG emissions from reservoirs and additional research is needed to better understand the issues.

Context

Focused research and investigations are required to transition the lessons learned from the significant levels of investment in understanding GHG emissions from reservoirs to best practices in managing the associated and complex issues. It is important to prioritize the activities on those that are most important, can be readily achieved, have most impact and can be undertaken at lowest cost

Best Practice Guideline

A. ***Select measures and undertake research and investigations on issues that improve management approaches for GHG emission from reservoirs.***

Commentary

A. ***Select measures and undertake research and investigations on issues that improve management approaches for GHG emission from reservoirs.***

Key research areas that have been identified related to management approaches of GHG emissions from reservoirs include:

a) Further investigations on appropriate threshold values used in the selection criteria defining "Are expected emissions below acceptable levels", to gain consensus on what are significant levels of emissions.
b) While no explicit examples have been found documenting the development and use of, for example, the Strategic Adaptive Management approach to the management of GHG emissions from reservoirs, the approach is considered to be well suited because the natural environment is complex, with many factors influencing the relationships between the different components. Developing an appropriate approach, especially with case histories would be most valuable.
c) Development of in-depth guidance for governance frameworks covering responsibility and authority specific for managing GHG emissions from a reservoir.

d) Further investigation on risk management approaches covering unusual situations where the likelihood of occurrence could increase in the near future due to climate change.

3.0 MITIGATION MEASURES

3.1 PRINCIPLES OF MITIGATION

Mitigation is generally considered to have four main components:

- Avoid; alternatives or technologies that remove impacts.
- Minimize; actions during design/operation that reduce impacts.
- Restore; rehabilitation of the effects of impacts.
- Compensate; offset the remaining effects of impacts.

In regards to greenhouse gases, the IPCC has defined mitigation as “actions to reduce emissions in order to reduce overall climate change” (IPCC, 2007). Other definitions include “an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases” and “actions that limit, stop or reverse the magnitude and/or rate of long-term GHG emissions and reduce their severity (adverse impacts)”.

Many reservoirs may have positive (i.e., from the water body to the atmosphere) net GHG emissions through the water surface and outflow structures and emit varying amounts of greenhouse gases through processes involved in the natural carbon cycle, whereas others may have negative emissions and absorb these gases. It has been noted that gross GHG emissions can be significant from shallow tropical reservoirs while deeper, cooler reservoirs have significantly lower emissions (IPCC, 2008). Natural wetlands and floodplains that were inundated in the establishment of reservoirs may also have been methane emitters, and those wetland emissions may have been substantially reduced by their inundation. On the other hand, drained wetlands may have been net emitters of CO_2 and N_2O. Thus, opportunities for mitigation of GHG emissions may be available in the planning, design and operation of hydropower reservoirs in general. Based on this level of variability and complexity the extent of opportunities for mitigation requires careful assessment.

As noted, the level of GHG emissions from reservoirs can vary significantly and depends on a number of factors, including the type of project, reservoir size, type and amount of flooded vegetation cover, soil type, water depth, local anthropogenic activities and climate in terms of latitude and hydrologic setting and the amount of biomass in the watershed

On this basis, the overall management strategy in relation to net GHG emissions from reservoirs should be to lessen these emissions wherever practicable (mitigation). The objective for GHG emissions mitigation strategy should be to avoid, or reduce GHG emissions from reservoirs to a level which is "as low as is reasonably practicable" (ALARP) to ensure that the potential emissions from proposed projects are adequately addressed in the planning, design, implementation and operation stages. The concept of ALARP is based on one of the fundamental principles of risk management. (HSE, 2014). For the mitigation of GHG emission levels from reservoirs, this covers achieving reductions to the levels of emissions up to a point where it would be significantly more costly and result in little additional benefit to proceed further.

3.2 REDUCING GHG EMISSIONS

Context

Where significant net GHG emissions are expected, the next step in Figure 1.1 is to evaluate the project in terms of net GHG emissions, with the second management decision point being "Is there an opportunity to reduce emissions?" This can be accomplished through mitigation or allocation between the parties benefitting from the multi-purpose reservoir services (see Section 4). Where the opportunity is expected to exist, mitigation approaches should be investigated through the planning, design, implementation and operational phases of the reservoir and facilities. In all cases, mitigation measures should be identified, based on the ALARP principle, and that meet overall best practices.

Recent analysis (Deemer, 2016) of the relationship between reservoir eutrophication and GHG emissions provides a crucial first step in identifying potential management opportunities for the reduction of reservoir GHGs. Specifically, watershed nutrient reduction strategies aimed at preventing reservoir eutrophication may also mitigate both CH_4 and N_2O emissions (specifically through reduction of P and NO_3 loading).

Best Practice Guideline

A. ***Reduce the levels of GHG emissions originating from a reservoir to as low as reasonably practicable (ALARP) across the full reservoir life-cycle.***

B. Develop mitigation approaches for the five stages of project development

<u>**Commentary**</u>

A. Reduce the levels of GHG emissions originating from a reservoir to as low as reasonably practicable (ALARP) across the full reservoir life-cycle.

Reductions in GHG emissions from the reservoir can be achieved throughout the life-cycle of the reservoir. This includes the project planning and design stage, implementation (building the dam and managing the inundated area), operation and maintenance, catchment management (e.g. reduction of UAS) and downstream management. However, in most cases the more significant GHG emissions reductions can result from early stage consideration such as project location, concept, planning and design.

B. Develop mitigation approaches for the five stages of project development

The five stages of project development being considered are:

- Project Planning and Design.
- Project Implementation (Construction and Reservoir Impoundment).
- Dam, Power plant and Reservoir Operation, including Contributions of UAS.
- Catchment Management, including Contributions of UAS.
- Downstream Management.

This section outlines some of the approaches to mitigation that should be considered in planning, design, implementation and the overall operations of the reservoir and catchment management.

3.2.1 Project Planning and Design

This stage is critical as in most cases the more significant reductions can be made following appropriate decisions at the earliest stages of project concept and planning. The screening process, as described in Volume 2 of these Guidelines should be used as an initial indicator of GHG reservoir emissions and be a part of the optimization of the design to reduce potential emissions.

The key is to achieve as full an understanding as possible of the expected source, behaviour and magnitude of future GHG emissions from the reservoirs and to put in place effective strategies. These would include, but not be limited to selection and design of the following measures:

- Dam site physical location and design parameters taking into consideration the nature of the area to be flooded/inundated.
- Preparation and management of the area to be inundated by the reservoir, including options for clearing and disposal of organic matter. It should be noted that vegetation can be the main source of carbon in the flooded area and could be difficult or uneconomic to clear. Moreover, organic matter that has been removed to outside the inundated area has the potential to degrade. Therefore these issues have to be managed carefully on a site-specific basis.
- Optimized design of the physical and operational parameters of the dam's discharge facilities, to minimize degassing. Possible design features include a power intake structure drawing water from the reservoir at different levels.
- Special considerations for cascade reservoir systems to consider the symbiotic relationships between various aspects of the projects and their operation.

Examples of mitigation approaches to reduce GHG emissions from a reservoir that can be considered during the earliest stages of project planning and design include.

a) As part of the design considerations for a new reservoir, pre-impoundment vegetation clearance of the reservoir area was considered, with the intent to whenever feasible, reduce the volume and extent of organic matter in the areas to be flooded. In addition, planning considered adjusting reservoir operation and reservoir drawdown to balance hydropower production with regards to GHG reservoir emissions. This approach would require accurate and validated systematic modelling of the carbon dynamics of the reservoir.

b) In some projects the approach to pre-impoundment also removes significant vegetation within the reservoir footprint. This reduces both floating debris after inundation which may create security risks to the dam facilities, and potential toxic pollutants which may cause deterioration in the water quality. Removal of forest and other vegetation cover during pre-impoundment clearances may significantly reduce organic matter that would be inundated and decompose, creating GHGs in the reservoir.

c) Where possible new reservoirs could be economically sited upstream from anthropogenic nutrient sources (Deemer, 2016). With the need for better global water management and the push for expanded global hydropower capacity, careful sitting of new reservoirs, and revising management of existing ones may help balance the positive ecosystem services that reservoirs provide against the GHG emission costs.

3.2.2 Project Implementation (Construction and Reservoir Impoundment)

Some projects have large reservoirs, covering many square kilometers, with the area to be flooded covered in forest or other vegetation. Thus, there is the potential for large amounts of GHG to be released when the reservoir is impounded and the vegetation decomposes. Over time, this vegetation on the floor of the reservoir will continue to decompose in an anoxic setting, resulting in a build-up of dissolved methane. On the other hand, only a fraction of the organic matter flooded will decompose, much of it remains in reservoirs for very long periods of time.

In the majority of projects with reservoirs, the intensity of GHG emissions is highest during impoundment and the first few years of operation. For very large projects with high dams and large storage reservoirs, impoundment can start during construction and continue for more than a year after completion of the structures. Thus the life-cycle for these projects commences with the commencement of inundation.

An example of specific mitigation options to reduce GHG emissions from a reservoir during construction and reservoir impoundment is described in more detail as follows.

Decomposition of organic matter, such as trees, vegetation and general organic debris, in flooded areas may consume oxygen in the water column. This reduction of oxygen in the water column may create hypoxia, i.e. DO$<$4mg/l, with large amounts of methane produced. Therefore, decreasing the possibility of oxygen depletion in the water column can be an effective approach to reducing the negative effects of methane production during reservoir impoundment. From this perspective, extending the duration for reservoir impoundment may reduce the possibility of oxygen depletion in the flooded areas. One approach could be to schedule commencement of reservoir impoundment while the dam structure is being raised.

3.2.3 Operation and Management, including Contributions of UAS

Reservoir operation takes into account a number of requirements, which sometimes conflict, especially for reservoirs that form part of multi-purpose projects. In general, reservoir operation is designed to maximize the value of the water resource for the various services that it provides, including power generation, flood control, irrigation and water supply flows, navigation and recreation. While a full reservoir with a steady level is the theoretical optimum, levels are frequently drawn down to control floods, collect seasonal flows for use in other periods and to generate power or to meet peak demands. On the other hand, navigation, recreation and aquaculture seek more constancy and higher reservoir levels.

Mitigation strategies to reduce GHG emissions during the operational phase can be challenging if the original planning and design prohibits major changes. While most methods are necessarily site and project specific, some options are described in more detail.

The lowering of reservoir levels (drawdown) is a regular feature in the management and operation of many reservoirs, with these drawdowns normally managed to facilitate planned events, such as:

- Powerplant operation for the short term, to meet network services, or for the longer term to provide seasonal or even annual dependability.
- Seasonal storage for water management services, such as domestic and industrial water supply and agricultural irrigation.
- Storage space to retain peak flows and alleviate downstream flooding.
- Drawdowns to maintain environmental flows in the river downstream of the dam.

Where these drawdowns are seasonal and of significant duration, vegetation may grow on the exposed banks of the reservoir, which would decay when flooded. This vegetation will absorb CO2 from the atmosphere, but when decomposing it will be returned for a zero balance (the situation may be different if decomposition includes emissions of CH4). Similarly the seasonal water column 'turnover events' that typically occur in autumn in temperate climatic zones may be a source of GHG emissions.

Drawdowns can also be caused by unplanned events, such as evaporation or leakage, significant reduced inflows, overuse of the previously stored water or general mismanagement.

Reservoir drawdown can be a significant source of GHG emissions and it has been noted that rapid lowering of water levels can enhance methane bubbling fluxes. Moreover, it is difficult to justify changes to drawdowns on the basis of potentially reducing GHG emissions, both due to the uncertainties of the effectiveness of such reductions and to the potential loss of opportunity costs (which could be substantial)

Examples of specific mitigation options to reduce GHG emissions from a reservoir during drawdown are described in more detail as follows.

a) At the Three Gorges Reservoir project in China, areas of the drawdown zone are used for seasonal farming practices. Field measurements of GHG emissions have been undertaken for various crops (Li, 2016). The study found that there were significant differences and clear seasonal variations in GHG emissions between various land uses in the reservoir drawdown areas and unflooded grassland. Reservoir impoundment and drawdown may create a positive net effect on soil-air GHG emissions.

b) At a project in Canada, the reservoir has been drawn down annually for up to six months over a number of years, releasing downstream flows for power and environmental purposes and providing storage to capture winter rains and spring snowmelt. However, the drawdown areas experienced significant erosion and dust storms under high wind situations. This has been managed by plantings of appropriate species, which may in themselves be a source of GHG emissions when submerged.

c) China has a large number of small and very small reservoirs, mostly in mountainous regions and often supplying community drinking water. These reservoirs are periodically (10 years of longer) flushed to clear out deposits of sediment. This both extends the life of the reservoir and removes much of the organic matter embedded in the sediments, which themselves have the potential to reduce emissions of methane.

Discharges from dams can be a source of GHG emissions. This includes flows from power generation, periodic spilling of flood waters across spillways or through sluices or valves and regular discharges to provide or supplement downstream environmental flows in the river. Each type of discharge facility (generation unit, spillway, sluices and valves) can have many different designs and operational modes, and thus different characteristics in terms of degassing of GHG emissions.

An example of specific mitigation options to reduce GHG emissions from a reservoir during discharges through the powerhouse or past the dam is described in more detail as follows.

Fonte Nova, a multi-unit hydropower project in Brazil has been designed both to generate power and deliver flows for the water supply of a major metropolis. To provide the best available water quality, the intake structure was designed with gates at three levels, with water drawn from the highest level providing the best quality. Flows from this highest level intake are diverted through one penstock/unit to initially generate power and subsequently feed the community water supply system through a conduit connected to the draft tube outflows. Flows from the other intakes are diverted through penstocks to the remaining generating units and subsequently released back to the river.

Reservoirs can also be a source of emissions from UAS's. An example of this is the development of fish farms on the reservoir surface. Fish farming is prevalent in reservoirs in some countries, especially in Asia, (though is more prevalent in marine waters in other regions). The issues around operating fish farms in reservoirs are complex and can be quite site specific. There is no conclusive evidence to date on whether operations add to or remove carbon from reservoir water. However, the most potent potential impacts would be the use of fish foods imported from outside the catchment and/or conversion of the food stock biomass into a form more available to methanogenic microorganisms or oxidation to CO_2. This leads to two areas that should be investigated further. One relates to whether the operation of fish farms in reservoirs increases GHG emissions and the second is consideration of best practices to manage and mitigate any impacts.

Another example of users of the services provided by the reservoir that are potential sources of GHG emissions includes the various forms of navigation. This includes haulage of cargo (maybe through multiple reservoirs in a cascade system) as well as commercial usage by ferries, tourist and recreational boats. Some users discharge various wastes into the reservoir, which can be an eventual source of GHG emissions, classified as UAS.

3.2.4 Catchment Management, including Contributions of UAS

Catchment management is a crucial issue with regards to reductions and mitigation of GHG emissions from reservoirs, with two main aspects to consider, periodic floods and UAS.

Periodic floods can carry significant amounts of organic matter from the river and catchment into the reservoir. Sources of this organic matter include the river shoreline and banks as well as any low-lying swampy areas, and can extend over the entire catchment where the natural land cover is susceptible to erosion under intense precipitation. This of course can be compounded by anthropogenic interventions such as forestry and agricultural practices. The organic matter and nutrient loading carried by periodic floods into the reservoir can create both a short-term surge in emissions, especially in shallow zones and a long-term rise throughout the impoundment. However, it is important to note that unusual weather phenomena are just one means to transport UAS-related nutrients into the reservoir. At the same time, the natural loads from unmanaged land may peak. If erosion is significantly due to land cleared earlier for agriculture or grazing land, then the surge may be due to UAS.

Unrelated Anthropogenic Sources can also be a significant source of GHG emissions from reservoirs. It is recognized that it is only possible to make estimates of emissions caused by UAS, as obtaining accurate measurements is not feasible, since the emissions caused by UAS cannot be identified from the overall measurements. These estimates therefore have to be made on the basis of indirect assessment, such as loadings of nutrients and organic matter from identifiable anthropogenic sources. Modelling can play a crucial role, as with the aid of models, it is possible to separate the contribution of UAS to the total emissions.

A fuller description on approaches to understand and model the impact of UAS emissions can be found in the Guidelines Volume 2.

Mitigation strategies to reduce GHG emissions emanating from flood events are primarily related to management practices in the catchment. These include:

- Creating natural forested barriers along susceptible river margins to minimize the ingress of debris and other organics to the river. However, this may only temporally trap nutrients.

- Providing natural vegetation to stabilize areas susceptible to erosion throughout the catchment.
- Land-use change management: Afforestation should be considered where there are significant areas of pasture and arable land that qualify as marginal due to erosion and/or low productivity. These lands could be forested to mitigate emissions without significantly affecting agricultural production.
- Cropland management: In some agricultural areas, planting winter crops could increase carbon storage in the underlying soil. This could also reduce fertilizer requirements as an added benefit.
- Regeneration of areas where the forest has been previously harvested
- Providing upstream storage regulation to moderate flood peaks through dams or diversions.
- Holding back debris during floods using barriers or constraints in the river, and removing for disposal thereafter.
- Capturing and treating waste materials from UAS before they enter the river.

An example of specific mitigation approaches to reduce GHG emissions from a reservoir emanating from the catchment is described below.

a) Fonte Nova, a hydropower plant in Brazil, provides flows for a major community water supply, which requires as higher level of water quality as possible. The catchment had been deforested many decades previously and replaced by coffee plantations. These were more recently removed and replaced by agriculture, mainly cattle grazing. In heavy rain storms, there is significant run-off of organics into the rivers and hence the reservoir. Recognizing the importance of the water quality in the reservoir, a program of re-forestation using the original species is underway. As part of this program, seeds from the remaining native forest are collected and saplings grown in a nursery for eventual plantings. A key will be to provide barriers to run-off by judicious planting such as along river bank margins.

Mitigation strategies to reduce GHG emissions emanating from UAS in most cases need cooperation with the owners of the specific source. Some inclusive or exclusive mitigation strategies include:

- Minimize the nutrient/biomass levels carried into the river and/or reservoir. This could include creating natural forested barriers along susceptible river or reservoir margins to control the ingress of debris and other organics.
- Revegetate areas of the catchment to neutralize areas producing significant levels of nutrient/biomass.
- Provide waste water treatment facilities for domestic and industrial sources.
- Creating constructed wetlands for management of UAS loads from land use or community waste water.

Although UAS are subtracted from gross emission to determine net GHG emissions from a reservoir, reducing UAS is considered good practice as a means to mitigate reservoir eutrophication (a process, natural or anthropogenic, where the reservoir gradually builds up its concentration of plant nutrients). In eutrophic reservoirs, large quantities of methane may be generated at the bottom of the water column and released by diffusion, bubbling and degassing.

3.2.5 Downstream Management

Downstream emissions are directly related to the concentration of GHG in the water being released from the discharge facilities of the dam and powerplant. Where possible, efforts should be concentrated to select designs and operational modes for the water conveyance system at the dam that reduce GHG emissions downstream. This consideration should include the design and operating rules of the intake and diversion structures as well as the water discharge facilities (generating units, spillways, sluices and valves). In general it is good practice to limit the withdrawal of water from the bottom of the reservoir, as this tends to contain the highest accumulations of embedded methane and other greenhouse gases.

However, there can be conflicting outcomes. Aeration weirs, located just downstream of the powerhouse and dam discharge facilities, are sometimes incorporated into the design as a means to re-oxygenate the water (when water from the bottom of the reservoir, depleted in oxygen, is released). The indirect consequence of this process can be the instantaneous degassing of almost 90-95% of the methane. This methane cannot be oxidized into carbon dioxide anymore as might have been the case in the absence of artificial weirs. While this process is beneficial to the aquatic life in the river downstream, it can lead to liberation of methane to the atmosphere.

3.3 EVALUATION AND SELECTION OF MITIGATION MEASURES

Context

Section 3.2 provided guidance on the identification of various mitigation approaches at different stages of project development. This section provides guidance on the evaluation and selection processes. Guidance on design and costing of the selected mitigation approaches should be based on standard engineering methodologies.

Best Practice Guideline

A. *Evaluate and select mitigation approaches, applicable to each phase of project development*

Commentary

A. *Evaluate and select mitigation approaches, applicable to each phase of project development*

The primary objective of any mitigation approach is to reduce the level of net GHG emissions as much as practical and to fall below the threshold level of significant (as defined by the screening process in Section 2.2).

An important step in the process to select appropriate mitigation approaches, is the evaluation of alternatives. While this guideline will not address detailed evaluation methodologies, it is noted that any evaluation should include an understanding of the benefits and costs of the various alternatives, as part of decision-making.

Selection of the appropriate mitigation approach should be based on estimates of reductions that could be achieved, as determined by modeling (*Guidelines, Volume 2 – Modeling)*. The potential GHG emission reductions of each mitigation approach considered, can then be compared and the optimum approach selected.

This selection process should consider the present status of gross GHG emissions, pre-impoundment GHG emissions and UAS. Thus the contributions of different pathways of GHG emissions to reservoir net GHG emissions can be clearly identified and reported, with a ranking based on the importance of these different pathways. This will provide benefits in the evaluation and selection of the mitigation measures for each development phase.

The evaluation and selection process for the suitable mitigation option or the appropriate level of GHG emission reduction for a reservoir is based on one or more of the following considerations:

- Meeting the objectives of the mitigation approach, namely to reduce the level of net GHG emissions much as practical and to below the significant threshold level (as defined by the screening process in Volume 2).
- Reducing net GHG emission levels based on the ALARP principle, being to the point where it would be significantly more costly and result in little additional benefit to proceed further.
- An assessment of the effectiveness and efficiency of implementation of the proposed mitigation approaches.
- An economic evaluation of the costs and benefits of reductions in levels to gain acceptance and approvals from internal and external stakeholders.
- The time to get approvals and financing, and to implement the proposed mitigation approach.
- The technical, economic and environmental/social feasibility of the proposed mitigation approach.
- The level of importance assigned to the proposed mitigation approach by the water service users and other stakeholders.

Following selection of the mitigation measure, designs and costing will follow standard industry practice in the relevant jurisdiction.

3.4 FEEDBACK LOOP

Context

Best practices in the management of mitigation measures for GHG emissions from reservoirs requires the reductions to be measured and tracked. This can be accomplished through management approaches such as the use of SAM, and tracking metrics such as Key Performance Indicators (KPI).

Best Practice Guideline

A. ***Develop performance targets for the mitigation measures adopted to reduce the GHG emissions from the reservoir.***

B. *Track performance of mitigation measures in terms of effectiveness and efficiency in reducing GHG emissions.*

<u>Commentary</u>

A. *Develop performance targets for the mitigation measures adopted to reduce the GHG emissions from the reservoir.*

Section 2.2 covered the basis of the management strategy in relation to net GHG emissions from reservoirs using the principles of strategic adaptive management (SAM). This process facilitates a targeted approach emphasizing monitoring and evaluation as part of a progressive methodology of improvement. With SAM as a systematic process for enhancing the effectiveness of mitigation approaches through continuous learning and improving performance, it can be adapted to include appropriate performance targets.

Performance targets for mitigation approaches should be selected on the basis of the modeling approach contained in the *Guidelines, Volume 2 – Modeling*, which provides a reference framework for performing quantitative analysis and modeling of net GHG emissions and changes in carbon stock. Performance targets for the selected mitigation approach should be based on estimates of reductions that could be achieved, as determined by modeling. The potential GHG emission reductions of each mitigation approach considered, can then be compared. This will provide the basic framework for decision-making on selecting appropriate performance targets. Other references in the selection process include: required time to implement the mitigation measures, technical feasibility, economic investments, benefits and costs for stakeholders, and social impacts.

B. *Track performance of mitigation measures in terms of effectiveness and efficiency in reducing GHG emissions.*

For projects where the screening processes have indicated significant levels of net GHG emissions from the reservoir, it is critical to track the effectiveness and efficiency of the mitigation approaches in place to reduce these emissions. Effectiveness can be measured and tracked in terms of whether the mitigation approach selected is the most appropriate in terms of reducing emissions. Efficiency can be measured and tracked in terms of whether the mitigation approach selected is managed and operated in the optimum way.

Key Performance Indicators (KPI) are an effective approach to tracking the performance of mitigation measures in terms of reductions of GHG emissions. The KPI matrix should be developed prior to the adoption of specific mitigation approaches.

3.5 RESEARCH NEEDS

Despite the recent efforts and progress achieved so far it is acknowledged that there are still uncertainties surrounding GHG emissions from reservoirs and additional research is needed to better understand the issues and improve GHG mitigation approaches.

Context

Focused research is required to transition the knowledge gained from the substantial investment in understanding GHG emissions from reservoirs, to research on mitigation measures that can reduce these GHG levels in a cost effective manner.

It is also important to focus priorities for research activities on those that are most important, can be readily achieved, have most impact and can be undertaken at lowest cost.

Best Practice Guideline

A. Select measures and undertake research on issues that improve mitigation approaches to reducing GHG emission from reservoirs.

Commentary

A. Select measures and undertake research on issues that improve mitigation approaches to reducing GHG emission from reservoirs.

Key research areas that have been identified related to mitigation measures to reduce GHG emissions from reservoirs include:

a) Research on cascade systems, including investigating the impact of high concentrations of carbon moving from upstream projects to the lower dams and the intermediate effects of degassing at each dam in the system. The dependency on the distances between dams, reservoirs and free flowing rivers and their features is also a topic for review.
b) Fish farming is prevalent in some reservoirs but the issues around operating fish farms are complex and can be quite site specific, with no conclusive evidence to date on whether operations add to or remove carbon from reservoir water. Two areas requiring research

cover whether the operation of fish farms increases GHG emissions in reservoirs and the second is consideration of best practices to manage and mitigate any adverse effects.

c) There are places where the reservoir is drawn down for extended periods of time, and the drawdown areas planted. When this vegetation is flooded, this could result in GHG emissions. Research is needed to select vegetation species that are appropriate to the grower and minimize GHG emissions when flooded. Drawdown events also expose aquatic vegetation which decomposes and may become a source of GHG emissions.

d) A greater understanding on the quantification of UAS to various sources and their identification, such as through geochemical signatures and modeling.

e) e) Joint modelling of hydropower plant operation in the mid-term to produce electricity while avoiding drawdowns for extensive periods of time

f) Measurement and modelling of the impact of land use on the reservoir water quality and further to GHG emissions.

g) The impact of opportunistic agricultural practices in the catchment.

h) Impacts of clearing the reservoir inundation area on gross GHG emissions following impoundment. This should include a wide range of vegetation types.

i) Effectiveness of alternate measures to mitigate GHG emissions.

j) Methods of analyzing mitigation options in terms of their feasibility for a specific project

k) Understanding of the impact of sediment transport, settlement and removal in providing mitigation of GHG emissions.

l) Performance of different types of hydropower plants in terms of GHG emissions

m) Impacts on managing GHG emissions based on a reservoir sediment flushing regime

4.0 FAIR ALLOCATION

4.1 PRINCIPLES OF ALLOCATION

Section 3 covered the overall strategy for lessening GHG emissions wherever feasible (mitigation) for projects where screening indicates significant levels of net GHG emissions associated with the reservoir. As a corollary, Section 4 addresses apportioning these emissions between the users of the services provided by the reservoir and facilities (allocation). The procedures and methodologies identified as best practice will enable the allocation of net GHG emissions in a fair and equitable manner, relative to the services received from the use of the reservoir, and have been developed to allow stakeholders to understand and accept the fundamentals of the process.

In another research project by IEA hydro on valuing energy and water management services (IEA Hydro, 2017) it was noted that water allocation is a fundamental component of multi-purpose hydropower developments and with the interdependency of energy and water systems, forms an integral part of the water-energy nexus. A similar process can be followed for the allocation of GHG emission between users of the various services. It is clear that in the development of multipurpose hydropower developments or the management of existing ones, there is no certainty in the future with regards to climate and technology. Multipurpose hydropower developments last for many decades and it is almost certain that over such a long lifetime the optimal allocation of GHG emissions among the various services will change.

Section 4 does not imply that it is always necessary to allocate GHG emissions to the various users of the services; that is the decision of the developer or funder of the overall project. Any need to address allocation issues should be carefully considered for each project assessed, and the reasons to undertake an allocation approach should be reported in the GHG Management Plan. If it is decided that an allocation process is appropriate, this section provides guidance for the process.

The allocation process should follow an integrated approach together with the stakeholders benefiting from the services, with all contributing to the analysis and decision-making. This will allow for acceptance of the process and the project by stakeholders, and present a shared vision of allocation.

4.2 IDENTIFICATION OF SERVICES PROVIDED BY THE RESERVOIR

Multipurpose reservoirs can provide a number of water management services, such as diversions for irrigation, storage capacity for flood or drought control, domestic and industrial water supply, recreation, navigable water ways and others. Most existing hydropower projects were planned and funded by the hydropower owner with other beneficiaries of the multipurpose water services having little planning input and providing a limited financial contribution. For many new projects, this is changing, with multipurpose uses being considered from the outset and more equitable financial contributions provided, as capital and/or operational contributions.

Context

Multi-purpose reservoirs impounded behind hydroelectric dams provide water management services including, but not limited to, as follows:

- Water Quantity Management, including flood control.
- Human Development, including potable water supply and livelihood
- Regional Development, including navigation, irrigation, recreation, industrial water supply and aquaculture
- Water Quality Management, including oxygenation, temperature management and sedimentation control

Best Practice Guideline

A. Identify the services provided by a multi-purpose reservoir and supported by structures and/or facilities, and the stakeholder(s) who receive benefits.

Commentary

A. Identify the services provided by a multi-purpose reservoir and supported by structures and/or facilities, and the stakeholder(s) who receive benefits.

Most reservoirs of significant size (storage, volume and depth) that are impounded behind hydroelectric dams and facilities provide a number of additional services and are considered to be multi-purpose. The water management services include diversions for irrigation, storage capacity for flood or drought control, domestic and industrial water supply, recreation, navigable water ways and others. The construction of the water retaining dam structures can also provide facilities for diversion. The identification, quantification and determining beneficiaries of these water management services provides the basis for the allocation of net GHG emissions from the reservoir.

Table 4.1 lists significant water management services, in addition to hydropower generation, that are provided by the reservoir formation and operation, as well as the general function of the service and the main beneficiaries.

Table 4.1 Water Management Services

Water Management Service	Description of Use	Beneficiary
Flood Control	Dams provide storage to mitigate the severity of flood flows and losses to human and physical resources within a flood basin.	Commercial and Societal
Navigation	Operation of locks in dams facilitate the transportation of passengers and goods via inland waterways.	Commercial and Societal
Recreation	Water bodies (reservoirs or rivers) provide opportunities for recreational activities (boating, fishing, swimming, etc.).	Public and Commercial
Water Supply	Dams provide storage for public and private withdrawals of water used for domestic, municipal and industrial needs.	Public and Commercial
Water Quality	Reservoir storage and releases improves oxygenation and provides temperature management and sedimentation control.	Commercial and Societal
Irrigation	Dams provide diversion facilities for water to provide crop and plant irrigation and enhance growth and production.	Commercial
Aquaculture	Reservoirs provide a stable environment (water level, temperature etc.) for the rearing of fish.	Commercial
Ecosystem	Reservoirs provide aquatic ecosystems that are integral to water quality and habitat.	Environmental

4.3 ALLOCATION OF GHG EMMISSIONS TO SERVICES PROVIDED BY THE RESERVOIR

Multipurpose reservoirs provide a number of water management services and the users of these services receive proportional benefits. It is generally accepted that these services have value to the user, and it is therefore appropriate that the user takes their responsibility for a share of the net GHG emissions having their source from reservoir impoundment and operations.

Context

The various water management services provided by multipurpose hydropower development are closely related to the operations of the reservoir. These include:

1. Drawing down the reservoir to create ability to store inflows
2. Diverting or extracting water from various heights of the reservoir water column
3. Maintaining stable reservoir surface levels

Reservoir operation scenarios for the effective provision of multipurpose water management services, in addition to hydropower generation, are indicated on Table 4.2.

Table 4.2 Reservoir Operation Scenarios and Multipurpose Water Management Services

Water Management Service	**Reservoir Drawdown**	**Reservoir Diversion or Extraction**	**Stable Reservoir Levels**
Flood Control	✓ Storage space reduces magnitude of flood		
Navigation			✓ High and stable water levels provide safer and efficient transportation
Recreation			✓ Stable water levels enhance range of recreation opportunities
Water Supply	✓ Storage provides reliability of supply in low flow periods	✓ Extraction normally from intakes to provide hydraulic head	
Water Quality		✓ Releases improves oxygenation and provides temperature management	
Irrigation	✓ Storage provides temporal availability of supply	✓ Diversion normally from reservoir surface to maximize spatial coverage	
Aquaculture			✓ High and stable water levels provide most efficient production
Ecosystems			✓ Stable water levels enable most effective management of the ecosystem

Storage and diversion of river flows in a reservoir normally serve a number of functions, often for the benefit of different stakeholders. It is therefore appropriate that both the GHG emissions from the reservoir and any costs associated with managing the GHG emissions be shared in a fair and equitable manner amongst all beneficiaries of the services provided.

Best Practice Guideline

- ***A. Follow the allocation process initially during the screening process and subsequently (if required) as input to the net GHG assessment of field work and modeling.***
- ***B. Allocate GHG emissions from reservoirs proportionally to the services provided by the reservoir, in a fair and equitable manner.***
- ***C. Allocate costs associated from managing and mitigating GHG emissions from reservoirs proportionally to the services provided by the reservoir, in a fair and equitable manner.***

Commentary

A. Follow the allocation process initially during the screening process and subsequently (if required) as input to the net GHG assessment of field work and modelling

The allocation process should be applied initially at the screening process stage, as shown as Steps 4 & 5 on Figure 1.1. This application should be at a level commensurate with that of the overall screening process.

If mitigation measures and allocation to other services do not reduce the emission index to below the required threshold, then a full scale allocation assessment should be undertaken as part of the additional field work and modelling. This application should be at a level commensurate with that of the overall modelling process.

B. Allocate net GHG emissions from reservoirs proportionally to the services provided by the reservoir, in a fair and equitable manner

There are a number of key areas for consideration in the allocation of net GHG emissions from reservoirs between the beneficiaries of the water services.

1. All allocation processes involve an iterative approach to building consensus with and between the stakeholders.
2. It is understood that the methodologies to determine net GHG emissions from reservoirs will provide generally accepted outcomes.
3. GHG emissions from the reservoir will cover the life-cycle of the project from first filling of the reservoir to the end of life, and this will be the basis of allocation.

4. A number of alternate methodologies to estimate allocations between the services are identified in Section 4.5. The selection of the most appropriate should be based on fundamental principles and agreed among the stakeholders.
5. The acceptance of a fair and equitable outcome should be the basis of discussions and negotiations, with mediation to cover any challenging aspects
6. In cases where a user of the reservoir water services, such as for aquaculture (fish farming) or navigation (commercial or recreational boating), adds to the GHG emissions, those user would first be allocated the total of what they produce. These allocated GHG emissions should be subtracted from the total reservoir net emissions and the result apportioned between all users of reservoir services proportionally.

Specific examples of approaches to allocate GHG emissions between users of the water services are described in more detail as follows.

a. In general, hydropower production and flood control are directly related to the management of the reservoir through its operating rules, e.g. variations in water level and controls of reservoir outflow. Other services, such as navigation, irrigation and water supply depend mainly on the intensity of human activity in the surrounding communities. Taking, for example, the case of two reservoirs with the same reservoir operating scheme, installed capacity and having the same net GHG emissions, they provide similar functions of flood control and hydropower generation. However, if they have a different population density in the adjacent region, this may result in different human activity on the reservoir, e.g. different uses of navigation, irrigation and water supply services. In this example, allocation of GHG emissions to the various services could be quite different and changes to the provision of navigation, water supply and irrigation services could affect the GHG emissions allocated to the two hydropower projects, even though their hydropower output was similar.
b. Some hydropower projects in China, including those having very large installed capacity were justified based on a number of important water management services in addition to hydroelectric generation. Two examples are noted in Table 4.3.

Table 4.3 Reservoirs in China showing Primary and Secondary Water Management Services

Reservoir	Installed Capacity(GW)	Primary Services	Secondary Services	Other Beneficial Services
Three Gorges	22.5	Flood control	Hydropower production. Navigation	Sediment management Downstream drought control Water supply Recreation
Xiangjiaba	6.4	Hydropower production	Flood control. Navigation	Sediment management Irrigation Recreation

While in principle the total net GHG emissions should be allocated to all users in a fair and equitable manner, there may be situations where it is not possible. This could be as a result of:

- Negotiations are not successful in allocations being accepted.
- A beneficial user of some of the services may not be identifiable. Examples could include flood protection and UAS (Section 4.4).

In these cases, these emissions shall be considered as unallocated and apportioned between all reservoir users. A framework covering these situations is discussed in Section 2.5.

C. Allocate costs associated from managing and mitigating GHG emissions from reservoirs proportionally to the services provided by the reservoir, in a fair and equitable manner

There are a number of key areas for consideration in the allocation of the costs associated with managing and mitigating net GHG emissions from reservoirs between the beneficiaries of the use of the water services.

1. All involve an iterative approach to building consensus with and between the stakeholders.
2. Any costs associated with managing and mitigating the GHG emissions be shared in a fair and equitable manner amongst all beneficiaries of the water service.
3. Costs include expenditures on measurement, monitoring, modelling and design and implementation of any mitigation works for reducing GHG emissions.
4. Any costs should be allocated in the same ratios as the GHG emissions.

4.4 ALLOCATION OF UNRELATED ANTHROPOGENIC SOURCES (UAS)

Organic matter, nutrients and other material, released to the reservoir through leaching from areas under land use or from sewage management, may enhance carbon and nitrogen cycling and thereby the GHG fluxes from the reservoir. This impact was considered not to be caused due to the impoundment, but was referred to as Unrelated Anthropogenic Sources (UAS) by the IPCC in the Special Report of Renewable Energy Sources (SRREN 2012). Volume 1 and 2 of these Guidelines contain a full description of UAS. This section discusses how UAS mediated GHG fluxes should be considered when allocating the GHG emission burden to relevant beneficiaries of the reservoir.

Context

Direct measurements and identification of UAS-related nutrient and organic matter loads could be available for reservoir managers in developed areas, where e.g. community sewage and industrial sewage loads are monitored, and the fate of nutrients used in fertilization of croplands is known from regionally relevant studies. The areas of active land use in the catchment can be resolved from survey maps or interpreted with the help of remote sensing.

If detailed data of loads caused by agriculture or other activities are not available, or have poor relevance to the catchment in question, conservative central estimates from literature could be used. Community sewage can also be estimated on the basis of population equivalent (pe) nutrient loads, where phosphorus is used as a proxy for the nutrient load. Since water bodies in natural conditions typically emit GHG's such as CH4, the impact generated by UAS should be viewed as the difference above the natural background emissions, respectively. Screening of the possible UAS impact can be done with specialized models such as the International Hydropower Associations' (IHA) G-res tool (UNESCO/IHA. 2017).

A complicated question is how much the UAS-related load actually affects the emissions of GHG's beyond the natural background levels, as the emissions measured from water surface carry no unanimous signatures of their origins. Estimates of UAS-related GHG emissions can thus only be based on circumstantial evidence, such as loads of nutrients and organic matter from identifiable sources caused by human activities. This clearly challenges the goal of distinguishing the share of UAS from total GHG emissions and to identify those directly caused by the reservoir impoundment. However, even when the rightful allocation of emission burden between the actors behind the UAS impact and the reservoir builders and managers appears difficult, assessment of UAS should be done in order to identify the potential to reduce GHG emissions from the reservoir, e.g. by means of improved management of catchment activities or aquaculture.

Best Practice Guideline

A. ***Identify the potential sources of UAS contributing organic loadings to the reservoir***
B. ***Assess the significance of the impact of UAS on the GHG emissions from the reservoir***
C. ***If tractable, allocate the share of GHG emissions from reservoirs caused by UAS to the sources of the organic and nutrient loadings.***
D. ***Allocate costs associated from managing and mitigating GHG emissions from reservoirs caused by UAS to the source of the organic loadings.***

Commentary

A. ***Identify the potential sources of UAS contributing organic loadings to the reservoir***

Activities in the catchment contributing to UAS can include agriculture, animal husbandry, release of inadequately treated wastewater from urban or rural communities, industrial waste production, mining of minerals or organic deposits, and forest management using fertilizers and drainage. The land use related activities can be interpreted from remote sensing imagery, but sewage loads need either monitored statistics or knowledge of population inhabiting the catchment.

Some rationalities of reservoir construction may create impacts similar to UAS, and these need to be considered in the assessment and allocation of net GHG emissions. Many existing and new multi-purpose reservoirs provide water management services beyond hydropower, such as irrigated agriculture, water supply, navigation and recreational activities. These can elicit significant anthropogenic activity in the watershed, along the reservoir rim and downstream of the project and create a significant increase in external organic loadings into the reservoir.

Some loadings may enter the reservoir directly. Where the reservoir supports significant levels of aquaculture, the organic loading is primarily in the form of unused food and waste. In the case of tourism by boat, the source is refuse and waste discharged into the reservoir. With high usage and limited controls, both sources can have significant impacts. While these sources may be directly related to the planned activities of the reservoir, they may in certain cases be considered as UAS. Those could include unexpected new opportunities of reservoir usage.

While these activities can be considered to be directly related to reservoir management, the responsibility should be allocated accordingly. This needs to be considered in project planning, development and operations, as well as a determination on whether these external loadings are the direct consequence of reservoir impoundment, or can be considered to be derived from UAS.

B. ***Assess the significance of the impact of UAS on the GHG emissions from the reservoir***

Direct measurement of the impact of UAS on the background GHG emissions from activities in the reservoir catchment or the impact due to impoundment may be very difficult to achieve, and modeling may provide the best means to assess this impact, as noted in Volume 2 of these Guidelines. The impact of UAS should be determined for both the pre-impoundment and post-impoundment stages of development. Pollution by pre-impoundment land use activities or sewage loads may have enriched the sediment of the water body, especially if there was a lake. The historical pollution may reflect in the post-impoundment GHG emissions through internal nutrient cycling established by long-term hyper-eutrophic conditions. While the assessment of pre-impoundment conditions may be useful in identifying the reference conditions for post-impoundment, the activities behind the impact will likely have been different to modern day UAS.

Levels of nutrient and organic loading from a reservoir catchment often increase dramatically during and following high precipitation events, as a component of surface run-off. In many catchments, high precipitation events can be the most significant contributor to GHG emissions from both natural sources and UAS. A clear separation needs to be made between these natural and UAS contributions. The natural variability of factors affecting the net GHG emissions should be considered as part of the normal reservoir management.

Some existing reservoirs may be in catchments where UAS loadings have changed dramatically since the inundation and may be expected to continue to change, due to an overall increase in development or through extreme levels of variability. A life-cycle approach to estimating UAS can be used to address this issue.

UAS activities in the catchment that exist, or might in the future increase their contribution to GHG emissions from the reservoir and its downstream reaches, should be identified. Management and mitigation of those activities in ways that effectively reduce UAS loadings are beneficial to all stakeholders using the water services provided by the reservoir.

C. If tractable, allocate the share of GHG emissions from reservoirs caused by UAS to the sources of the organic and nutrient loadings.

If sources of nutrients and organic matter are tractable to activities not directly associated to reservoir impoundment or management (UAS), the distinction of responsibilities should be attempted. There are a number of key areas for consideration in the allocation of net GHG emissions from reservoirs associated with UAS.

1. The organizations who have responsibility for discharging nutrients and organics from UAS into the reservoir should be willing to accept responsibility for their GHG contribution.
2. Any GHG emissions emanating from UAS should be allocated to the responsible organizations.
3. All discussions and negotiations relating to allocations of UAS should involve a cooperative approach with the organizations responsible for the UAS.
4. It is understood that the methodologies to determine the net GHG emissions from UAS will provide generally accepted outcomes.
5. GHG emissions from UAS should cover the life-cycle of the project from first filling of the reservoir to the end of life, and this should be the basis of allocation.
6. The acceptance of a fair and equitable outcome should be the basis of discussions and negotiations, with mediation to cover any challenging aspects.

Where it is not possible to either identify ownership of the UAS, or if an identified owner of UAS will not accept responsibility, the applicable GHG emissions shall be considered as unallocated, and included in the net GHG emissions of the normal reservoir operation, to be apportioned between the reservoir users. A framework covering these situations is discussed in Section 2.5.

D. Allocate costs associated from managing and mitigating GHG emissions from reservoirs caused by UAS to the source of the organic loadings.

There are a number of key areas for consideration in the allocation of costs associated with UAS.

1. The organizations who have responsibility for discharging nutrients and organics from UAS into the reservoir should be willing to accept responsibility for costs.
2. All discussions and negotiations relating to allocations of UAS should involve a cooperative approach with the organizations responsible for the UAS.
3. Any costs associated with managing and mitigating the GHG emissions from UAS should be allocated to the organizations responsible for the UAS.
4. Costs include expenditures on measurement, monitoring, modelling and design and implementation of any mitigation works for reducing GHG emissions.

4.5 METHODOLOGIES TO ESTIMATE FAIR ALLOCATION

Stakeholders whose activities contribute to reservoir net GHG emissions and benefit from the services provided, should be involved in the allocation process. This should involve an iterative approach with all contributing to the analysis and decision-making.

The most important consideration in selecting the appropriate methodology for allocation is to fully understand the relationship between the reservoir services provided and the GHG emissions that are attributable to them. A number of alternate methodologies to estimate allocations between the services are identified in this section. The selection of the most appropriate should be based on fundamental principles and agreed among the stakeholders.

Context

Following the identification of the GHG emissions emanating from the reservoir and the services that the multi-purpose reservoir supports, it is appropriate to develop the proportional relationship between them. In this way, the stakeholder(s) who receive benefits from these services can understand and manage the emissions that are applicable to that service and are their responsibility.

Best Practice Guideline

A. ***Consider the proportional relationship between the reservoir GHG emissions and the water management services provided as the basis of a fair allocation.***
B. ***Identify methodologies to allocate net GHG emissions from the reservoir for each of the water services provided.***

Commentary

A. ***Consider the proportional relationship between the reservoir GHG emissions and the water management services provided as the basis of a fair allocation***

Multipurpose reservoirs can provide a number of water management services, such as diversions for irrigation, storage capacity for flood or drought control, domestic and industrial water supply, recreation, navigable waterways and others. Each of these services can receive significant benefits from the impoundments created by the reservoir. These can include reservoir storage and drawdown capability, raising water levels to provide hydraulic head and building dam structure to provide facilities for divert flows.

While multipurpose reservoirs can provide a number of water management services, the physical relationship between the GHG emissions that emanate from the reservoir and these services can vary considerably and be quite complex to estimate.

B. ***Identify methodologies to allocate net GHG emissions from the reservoir for each of the water services provided.***

The most important consideration in selecting the appropriate methodology for allocation of GHG emissions is to understand the relationship with the reservoir water services. Subsections below outline some of the alternative methodologies that have been identified as suitable for the allocating GHG emissions to the various water management services provided. However, not all methods are applicable to any one water management service

There is need to undertake a normalized approach to apportion GHG emissions between the different services provided by the reservoir. This could include 1) a physical allocation, such as water footprint; 2) an economic approach, such as an evaluation of economic costs and benefits; or 3) a scientific approach, where the GHG emissions are dependent on either use of the reservoir or method of water extraction.

4.5.1 Proportional to water consumption, water-use or water footprint

Where the reservoir GHG emissions are primarily proportional to water consumption, water-use or water footprint, allocation methodologies are generally considered as directly proportion to the use of the reservoir for each or combinations of specific services:

a) For water consumption, (where the water is not eventually returned to the river) this includes water supply for domestic or industrial use and water diverted for irrigation use.

b) For water-use, (where the water is returned to the river), this includes reservoir drawdown to provide flood control and power generation. It also includes water drawdown to provide room for storage of seasonal rainfall and snow melt.

c) For incremental changes in water footprint covering reservoir drawdown to provide storage for flood retention. This is based on the difference in area between the full reservoir and when it is drawn down.

4.5.2 Actual cost of service provided

Where the reservoir GHG emissions are primarily proportional to the actual costs of the service provided, allocation methodologies are generally considered as directly proportion to the use of the reservoir for each or combinations of specific services. This is dependent on the ability to assign a cost to those services.

a) For this analysis, the costs of common facilities, such as the dam, would be divided proportionally between all applicable water services

b) The cost of each service is considered as the NPV of the cost of implementation and the on-going operational costs.

c) Applicable services include power generation, water supply for domestic or industrial use and water diverted for irrigation use,

4.5.3 Commercial value of service provided

Where the reservoir GHG emissions are primarily proportional to the commercial value of the service provided, allocation methodologies are generally considered as directly proportion to the use of the reservoir for each or combinations of specific services. This is dependent on the ability to assign a commercial value to those services.

a) The commercial value of each service is considered as the average annual value of net revenue from the sale of the products of the water services.

b) Applicable services that have commercial value include power generation, water supply for domestic or industrial use and water diverted for irrigation use.

4.5.4 Related to method of water extraction

Where the GHG emissions have a dependency on the method of extraction from the reservoir, methodologies are generally considered based on the method and location of water extraction, as

GHG emissions can vary dependent on the location and depth of extraction, as well as at different seasons of the year:

a) For irrigation flows, it is usual to divert water from structures adjoining or near the dam and extracted from the upper layers of the water column directly into water conveyances.
b) For domestic and industrial water supply, the method of depth of extraction varies between surface level diversion structures and intakes at various levels of the water column.
c) For power generation, power intakes at the dam can be located at varying levels in the water column, selected to ensure adequate submergence under all conditions. Many hydro plants divert water from the upper levels through tunnels, conduits and pipelines to power stations remote from the dam.

4.5.5 Related to the operation mode of the reservoir

Some reservoirs are drawn down to a significant extent during their lifetime. The operating modes could be planned or unforeseen and could include:

- Annual drawdowns to retain seasonally high flows and/or snowmelt, used to minimize spill and enhance power generation. This can also enhance other services, such as irrigation and water supply.
- Seasonal drawdowns to capture and retain flood flows and avoid flooding and damage to downstream communities and infrastructure.
- Periodic drawdowns due to overuse of the retained water and lower than usual or predicted inflows.

In some of these reservoir operating modes, the advantages to the primary water management service, such as flood control, could be a disadvantage to other users in terms of increased GHG emissions. Examples include:

a) Reservoirs having large drawdowns for flood water retention. These can expose large areas of the reservoir bottom on a regular basis and over an extended period of time and be a significant emitter of GHG. However, other users such as power generation, water use etc., would be required to extract water from the remaining inundated zones closer to the reservoir bottom. This extracted water would likely be the source of higher emissions than if the reservoir were full.

In these cases, the incremental increase in GHG emissions, due the reservoir operating mode, should be estimated and allocated to the primary beneficiary of the water management services.

Many reservoirs were developed to provide for one or a relatively small number of water management services, but over the years have had other water service users take advantage of the water storage and hydraulic head attributes that are provided. This includes adding generating capacity to non-powered dams as well as diversions or extractions for various uses. In other cases, the use of a water service could be withdrawn or curtailed.

Allocations between water service users should be regularly reviewed and updated over the project life–cycle.

4.5.6 Related to temporal variations in GHG emissions over the life-cycle

Where the reservoir GHG emissions have a dependency on the temporal variations in emissions over the reservoir life-cycle, methodologies are generally considered based on these variations. GHG emissions can vary dependent on the seasons of the year or over many years, based on floods or droughts or significant changes in operation.

a) Allocation of reservoir net GHG emissions should consider these potential temporal variations rather than averaging across the life-cycle of the project.

b) Contributions of net GHG emissions may not be evenly distributed from the perspective of reservoir life-cycle. Studies have regularly indicated that for many reservoirs, the inundation phase and the first few years of operation produce higher levels of emissions.

c) Significant flood/inflow events and the potential release of reservoir sediment can also provide significant peaks in reservoir GHG emissions.

It should also be carefully noted that although the GHG management plan considers the reservoir life-cycle as a nominal 100 years, the allocation of reservoir services should reflect the life-span for each specific service. For example, irrigation and water supply offtakes may have a limited life, based on the longevity of the water diversion and conveyance facilities. On the other hand, flood protection, provided by reservoir operating rules, would be required for as long as the reservoir was in existence.

Changes in the provision of reservoir services due to an increase in reservoir life expectancy should be taken into account in determining allocations. For example, an ageing reservoir, whose development and primary, or only, service was originally hydropower production, may be slated for decommissioning. This could be based on the large amount of accumulated sedimentation or the dramatic increased costs for powerplant maintenance. However, rather than removing the project, other water services, such as recreation, irrigation and water supply may wish to use the water resource. In this case, ongoing costs should be allocated between them.

4.5.7 Production of GHG emissions by reservoir water users

Where users of the water resource are shown to be direct producers of GHG emissions from the reservoir, the allocation should be directly related to that production. Some examples include:

a) Developers and operators of aquaculture facilities, such as fish farming.
b) Owners and operators of commercial and/or recreational vessels that dump waste into the reservoir or spill fuel or oil.

4.6 FAIR ALLOCATION QUOTIENT ACROSS MULTIPLE SERVICES

Section 4.5 covers acceptable methodologies to estimate fair allocation across the various water management services provided by a multi-purpose reservoir. Table 4.3 provides a summary of applicable methodologies for each water management service.

Where all the water management services for a specific multi-purpose hydro power project can be covered by one allocation methodology, an allocation quotient should be determined for each. If the services can be covered by more than one allocation methodology, they should all be apportioned and the final quotient negotiated and agreed between the water management service users.

There will be projects where there is no apparent commonality between all the water management services and one allocation methodology. In these cases, an allocation quotient should be determined between each of the combinations of the various common methodologies, with the final quotient negotiated and agreed between the water management service users.

Table 4.3 Methodologies to Estimate Allocation of GHG Emissions from Reservoirs

Allocation Methodologies	Hydro power	Flood Control	Navigation	Recreation	Water Supply	Irrigation	Aquaculture
Water consumption, water-use or water footprint	✓	✓			✓	✓	
Actual cost of service provided	✓				✓	✓	
Commercial value of service provided	✓		✓	✓	✓	✓	✓
Method of water extraction	✓				✓	✓	
Temporal variations over reservoir life-cycle	✓	✓					
GHG emission production by reservoir water users	✓		✓	✓			✓

4.7 ALLOCATION APPROACHES FOR RESERVOIR CASCADE SYSTEMS

In general, the water allocation methodologies outlined in Section 4.5 should be followed. However, the details of the processes may be complicated by the numbers of reservoirs in the cascade system, especially if the operations are not coordinated, such as through different ownership or covering diverse jurisdictions.

In general, the development of a reservoir cascade system has distinct advantages for the coordination and optimization of the water management services. An effective operation and management strategy for the cascade can ensure hydropower dispatch is balanced with the importance, economic framework and risk profiles of the other services, such as flood routing and irrigation offtakes.

Allocation of net reservoir GHG emissions across a cascade system starts with identifying the general operation strategy for water movement down the river and any distribution or diversion requirements. This will create a baseline for each reservoir in the cascade, as to how much water moves down the river and how much is used for other services. Through the methodology for water consumption or water footprint, a proportional matrix in the reservoir cascade system can be developed to allocate reservoir services on a proportional basis. This can be considered as the first phase in the allocation process. If required, further stages in the allocation process can be developed based on the approaches covered in Sections 4.5 and 4.6.

In the development of the GHG management plan covering cascade reservoir systems, participation of water users and other stakeholder is important. Taking an iterative approach to building consensus will be beneficial to all stakeholders.

4.8 RESEARCH NEEDS

It is acknowledged that there are many options surrounding the allocation of GHG emissions from reservoirs to the various users of the water services. Targeted research would be valuable to better understand the issues surrounding the determination of appropriate levels of GHG emissions to each beneficial service

Context

Focused research is required to transition the lessons learned from the significant levels of investment in understanding GHG emissions from reservoirs to research on fair levels of allocation to the beneficiaries of the water services provided by that reservoir.

It is also important to focus priorities for research activities on those that are most important, can be readily achieved, have most impact and can be undertaken at lowest cost

Best Practice Guideline

A. ***Select measures and undertake research on issues that improve measures for allocation of GHG emission from reservoirs to the users of the water management services provided by the reservoir.***

Commentary

A. ***Select measures and undertake research on issues that improve measures for allocation of GHG emission from reservoirs to the users of the water management services provided by the reservoir.***

Net GHG emission comprising the difference of post-impoundment and pre-impoundment landscape GHG exchange in itself needs scientific studies to become a generally acceptable principle for expressing the true impact of reservoirs to atmospheric GHG composition. Case studies showing how the net GHG emissions from reservoirs can be evaluated, and how the possible contribution of UAS could be distinguished would be imperative. In absence of such illustrative examples the allocation questions would remain theoretical.

Other key research areas that have been identified related to allocations of GHG emissions from reservoirs to beneficial water users include:

a) A greater understanding on the allocation of UAS to various sources, such as through geochemical signatures and other methods
b) Methodology development to identify services in reservoir cascade system and allocate reservoir net GHG emissions proportionally in a fair and equitable manner.
c) A framework to select an appropriate allocation process between the various alternatives available.

5.0 REPORTING OF RESULTS

5.1 INTRODUCTION

The initial activity of the reporting phase is to document the outcomes of the original screening process and the decision to undertake a strategic management process covering GHG emissions from the reservoir. The balance of reporting should cover, in a transparent manner, the methodologies, decisions and outcomes of each step in the GHG reservoir emission management process.

5.2 REPORTING REQUIREMENTS

Context

The *Guidelines - Volume 3* describes a road map for best practices in the management of net GHG emissions from reservoirs through the process of mitigation and allocation. This includes development of a management strategy, identification of the need for a GHG Management Plan and the components of that plan. Irrespective of the outcome, a comprehensive reporting of the inputs, methodology and results is essential.

Best Practice Guidelines:

A. ***The GHG Management Plan should describe all relevant input and methodology used to identify the strategy and outputs for mitigation and allocation of GHG emissions from reservoirs in a transparent manner.***

Commentary

B. ***The GHG Management Plan should describe all relevant input and methodology used to identify the strategy and outputs for mitigation and allocation of GHG emissions from reservoirs in a transparent manner.***

The GHG Management Plan will cover the identification and management of key issues associated with GHG emissions from reservoirs. This plan will include the full life-cycle of the project for new projects and the remaining life for existing projects. Embedded in the Plan will be the strategy and outputs for mitigation and allocation.

At present, most countries do not include GHG emissions from reservoirs in their national inventories of GHG emissions.

5.3 INPUT TO POLICY DEVELOPMENT

The report on approaches to GHG emission management should include effective input to policy development. Some aspects to be considered include:

- A coordinated approach to mitigation and allocation policies.
- Consistency and long-term approaches to required emissions reduction programs and carbon pricing statutes
- Provision of incentives for low-cost strategies to reduce impacts.

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