Strategies for Greenhouse Gases Mitigation in Hydro-Electrical Water Reservoir

Saeed Karbin[1], Hadi Karbin[2], Hossein Ali Alikhani[1]
1- Department of soil science engineering, University College of Agriculture & Natural Resource, University of Tehran, Karaj, Iran
2- Water Research Institute, Center of Micro-hydro Power Technology Development, Tehran, Iran

Email: saeed.karbin@ut.ac.ir

Abstract

There are many uncertainties for greenhouse gases (GHG) emission in hydro-electrical water reservoirs. GHG sources and sink are different than ponds and lakes and they should be addressed specifically to understand the processes affecting GHG emissions. In many studies, only limited sources and sinks are included in models and it leads to production of unreal GHG budget for water reservoirs. In this study, we discussed different sources and sinks in water reservoirs for calculation of GHG net fluxes. Among the sources, water-level drawdown and turbine degassing effects are specifically for hydro-electrical water reservoirs and molecular diffusion, ebullition, plant-mediated transport and woody material decomposition might happen in ponds or lakes. The water-level drawdown magnitude and timing has a huge effect on ebullition events and it might be the reason for wide variation of GHG fluxes in different studies. Regarding the sinks, proper methods should be selected to measure carbon burial in sediments, net primary production in aqueous environment, vegetation in landscape of coast and CH_4 oxidation in landscape of coast precisely. Methanotrophic activity in the soils around the reservoir induced by alteration in hydrological regimes and land use changes after creation of the reservoir is not included in GHG prediction models yet. Reservoir management, improving green carbon capture in shore lines and afforestation around the reservoir are main strategies for GHG mitigation in water reservoirs.

Keywords: greenhouse gas, reservoir, sources, sinks.

1. INTRODUCTION

It has shown in recent studies that water reservoirs are sources of greenhouse gases (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) for the atmosphere [1, 2]. Inland waters contain large quantities of organic carbon produced by terrestrial primary production [3]. Carbon input is dominated by dissolved organic carbon (DOC) and it can increase microbial production and respiration. Gradually, this addition leads water to be CO_2 supersaturated and act as a source for greenhouse gases (GHG) fluxes [4].

In the first studies, hydroelectric power was considered as a carbon-free source of energy (i.e.[5]). Rudd *et.at.*, for the first time, concluded that the greenhouse gas production per unit of power generated is not zero [6]. Although recent development in GHG flux measurements there are uncertainties in GHG emission in water reservoirs. There are two main reasons for these uncertainties: i) GHG fluxes are measured by different methods (e.g., floating chamber, thin boundary method, eddy covariance tower, acoustic methods and funnels). CO_2 and N_2O are soluble in water (mole fraction solubility of 7.07 × 10–4 and 5.07 × 10–4 respectively at 20°C) and the dominant flux pathway is the air-water interface. In contrast, CH_4 is relatively in soluble in water and often emitted from the sediment in the form of bubbles [7, 8]. Several methods do not capture ebullition events (e.g., air-water gas exchange) or exclude ebullition due to interfere with the linear accumulation of CH_4 in the sampling chamber. ii) Temporal and spatial variation of aquatic GHG fluxes is high. For instance, CH_4 ebullition measured by funnel traps are deployed for relatively short period of time in relatively limited number of locations. However, it is not convenient to estimate both temporal and spatial variability of fluxes[8].

Investigating on GHG sources and sinks in water reservoirs facilitate the process to have a real estimation of GHG budget and manage the existing sinks and sources to mitigate GHG emissions. There are very limited studies that included all GHG sinks and sources in estimation of GHG emissions. However, a guideline for future studies to include the most affecting sources and sinks for GHG emission in water reservoirs is crucial. In below sections, we will discuss briefly GHG sources and sinks. Finally, we will focus on GHG mitigation strategies in water reservoirs for moving to carbon-neutral hydropower production.

2. GREENHOUSE GAS SOURCES

Water reservoirs around the world can affect biogeochemical cycles of elements (e.g., carbon and nitrogen). Although reservoirs are considered as a carbon-neutral sources of energy, there are many studies reported their role as GHG sources. There are very limited studies to include all possible GHG sources and pathways in their investigations. GHG sources in water reservoirs may vary than lakes and ponds and should be addressed specifically.

2.1 MOLECULAR DIFFUSION

CO_2 is highly soluble in water and therefore deep water layer depth contain higher CO_2 concentration. Photosynthesis at surface layers can deplete CO_2 in this layer and lead to an influx of atmospheric CO_2. In water reservoirs where photosynthesis rate is not high at the surface layer, water is over saturated with CO_2 and release CO_2 into the atmosphere. N_2O like CO_2 is soluble in water and diffusive loss is high. In contrast, CH_4 is insoluble in water and consequently rate of diffusive loss to the atmosphere is relatively low. Floating chambers are regularly used to measure diffusive gas flux in aquatic surfaces. Both spatial and temporal variation of gas fluxes can be measured by placing numerous chambers in different location and various time.

2.2 EBULLITION

This is the main gas transportation pathway when an insoluble gas (e.g., CH_4) produced in sediment cannot be dissolve in water and consequently produced bubbles emit into the atmosphere by ebullition[9]. Funnel trap is the most used method to capture ebullition which float beneath the surface of water. In recent years development modified funnel traps can measure bubbles in longer-term by incorporating an air tight tank equipped with a differential pressure sensors or optical bubble size sensors [10]. Acoustic techniques or an echosounder mounted with a boat or a stationary object associated with funnel traps can support higher spatial and temporal resolution for ebullition measurements [8, 11, 12].

2.3 PLANT-MEDIATED TRANSPORT

Plants can transport CH_4 produced in the rhizosphere through the a*erenchyma* tissue into the atmosphere. There are many studies showing that more than half of CH_4 emitted from wetland soils, including rice paddies, was plant-mediated transport [13, 14]. Plants growing along the shore in water reservoirs can transport considerable amount of CH_4 from the anoxic soils. In the majority of studies for water reservoirs, GHG budget measurements vegetation effects, especially for CH_4, are ignored.

2.4. WATER LEVEL DRAWDOWN

Water level management can substantially affect the magnitude and timing of CH_4 fluxes into the atmosphere. Although water-level fluctuation can clearly affect the timing and the magnitude of CH_4 fluxes in reservoirs there have been very limited of this effect in reservoirs. Harrison *et. al.*, showed that water-level fluctuations can increase drastically CH_4 fluxes to the atmosphere [15]. They examined CH_4 emission dynamic in six reservoirs varying in trophic status, morphology and management regime. They reported water-level drawdowns can increase CH_4 emission for more than 90% of annual reservoir CH_4 flux in a period of just few weeks. However, it is possible to reduce CH_4 fluxes in reservoirs by water-level management.

2.5 DEGASSING BY TURBINES

As water undergoes rapidly depressurization or aeration dissolved gases can be emitted. After water passes through the turbines GHG gases can be emitted into the atmosphere or can be absorbed by microbes (e.g., CH_4 oxidation by methanotrophic bacteria). Large degassing emission are expected when GHG content in spilled water is high. Rohem and Trembly [16] reported that the highest quantity of degassing observed in winter and spring when water temperature and CO_2 solubility were low and the buildup of gases due to mineralization of organic matter and the influx from watershed sources due to the springtime melt were high. They concluded that depending on the effluxes occurring at the air-water interface of the main reservoir, degassing can represent a maximum equivalent 16%.

2.6 WOODY MATERIAL DECOMPOSITION

Abril, G., et al reported that standing woody material decomposition constitute a high amount (26-45% of CO2 equivalents in a 100-year period) of total GHG emissions in tropical reservoirs [16]. This GHG source should be investigated in future studies in temperate and arid regions.

3. GREENHOUSE GAS SINKS

After creating a water reservoir carbon can be captured in several pathways. To have a real estimation for GHG budget carbon sink strengths should be investigated and included in real budget calculation. In many studies and investigations for calculation of net GHG emissions, carbon sources are included in models but the capacity of carbon sinks are underestimated or ignored. In below we present the main carbon sinks in water reservoirs.

3.1 CARBON BURIAL IN SEDIMENT

Inland water reservoirs can accumulate carbon more than natural lakes because of higher sedimentation rate (three to four times higher, [17]). The real carbon accumulation rate in water reservoirs is not well-investigated yet. The potential of water reservoirs in carbon sequestration depends on organic carbon deposition rate, efficiency of organic carbon preservation process and the life-span of system. In more productive and smaller systems organic carbon deposition rate and organic carbon burial are high. Organic carbon preservation efficiency depends on sediment source, oxygen exposure and temperature [18-20]. There are few studies on organic carbon burial assessment in artificial reservoirs and applying a precise method for estimation of sediment deposition rates, organic carbon content and sediment density measurements remain challenging. Mendonça *et al.,* (2014) determined the organic carbon burial rate and the total organic carbon stock accumulated in the sediments of a tropical reservoir by combining sediment sample analyses and a seismic survey. They estimated organic carbon burial in two tropical reservoirs was about 2.5 times lower than emission in one reservoirs and about 2.5 times higher in the other one. The main two important factor for this variations were the trophic state and the sediment load.

3.2 NET PRIMARY PRODUCTION IN AQUEOUS ENVIRONMENT

Primary production is the synthesis of organic compounds from atmospheric or aqueous CO_2. This process occurs by photosynthesis which uses the light as a source of energy. Gross primary production (GPP) is the amount of chemical energy as biomass that primary producers produce in given time. Some fraction of this energy is used by primary producers as cellular respiration and maintenance of tissue. The remaining fixed energy is referred as net primary production (NPP). The main primary producers in aquatic environments are planktonic algae (phytoplankton), periphytic algae (periphyton) and macrophytes (aquatic plants). The relative contribution of these main primary producers to total primary production depends on basin morphology, water clarity, substrate suitability and extent of water level fluctuations. Phytoplankton productivity is higher in reservoirs than natural lakes. Reservoirs are located in fertile regions and however, the natural trophic equilibrium level is higher than most of natural lakes [21]. Primary production is influenced by water size of reservoir, latitude, insolation and nutrient availability [22].

In addition, aquatic vegetation in water reservoir has the high potential to capture carbon. For example, it has been shown that over 10 years after dam construction the most rapid changes in soil cover was the area of aquatic vegetation [23]. These plants sequester atmospheric CO_2 and however act as a carbon sink in reservoir environment. Bini *et. al.,* [24] showed that floating macrophyte assemblage in water reservoirs has a direct relation with nutrient concentration in both sediment and water and light penetration was the strongest predictor of submerged species occurrence. Perera *et. al.*, [25] showed that vegetation in coastal water can be functionally as sink for atmospheric CO_2 and this was contrary with previous studies considering near-shore ecosystems as a source of CO_2. The key factor for determining whether or not coastal ecosystems directly decrease the concentration of atmospheric CO_2 may be net ecosystem production.

3.3 VEGETATION OF LANDSCAPES OF COASTS

Soil hydrological regime changes can affect land cover, wildlife, and micro-climatic conditions. Increased water table depth induced by water reservoir leads to changes in soil physio-chemical properties and soil cover. Creating a reservoir can change plant species richness and plant community structure in the coastal regions and the places where soil hydrological regime is affected. This effect can be more obvious in arid and semi-arid regions where water is the main limiting factor for the region.

Many studies demonstrate that, on shore of reservoirs, several years after the construction the changes in ecological conditions promote the growth of tree vegetation. The magnitude of these changes depends on geographic position of reservoir and local geological-geomorphological condition of the coast. Novikova and Nazarenko [26] reported that the soil vegetation cover and the species number tend to increase in the direction away from the coast in water reservoirs. They concluded that this is the results of diversity of conditions in the biotope and a decrease in the externality of factors. They added that the typical vegetation after creating the reservoirs for steppe zones includes 115 species of higher vascular plants from 29 families. The leading families were *Asteraceae*, *Poaceae, Fabaceae*, *Chenopodiaceae*, *Labiatae*, and *Polygonaceae*. Lange *et. at.,* [27] showed that in diverse plant communities soil carbon storage and soil microbial communities are higher than in soils with low species number. However, creating water reservoir can increase carbon sequestration rate by increasing vegetation growth and plant diversity in landscape of coasts.

However, creating water reservoir can change soil vegetation and through this process atmospheric CO_2 can be captured. In most of recent biogeochemical models for GHG emissions, this effect is ignored.

3.4. CH_4 UPTAKE IN LANDSCAPE OF COAST

Methanotrophic bacteria have the ability to utilize CH_4 as their energy source [28] and have been found in many terrestrial ecosystems. Soil moisture is the main driver of methanotrophic activity. In the other hand, water stress can restrict the activity of methanotrophic bacteria. The optimal range of water content depends on land use. In grassland soils, maximum CH_4 oxidation occurred in a range from 18 to 33% of gravimetric moisture content and in forest soils, optimal soil moisture was between 30 and 51% [29]. Creating water reservoir can alter soil moisture in the landscape of the coast and optimise methanotrophic activity in the oxic soils. In many studies effects of water reservoirs on methanotrophic activity in the coastal soil are ignored and it should be investigated in future studies. In addition, land use changes in the coastal landscapes can improve soil CH_4 oxidation. Karbin *et. al.,* [30] showed that CH_4 oxidation in grassland soils is less than forests and it increases as the forest stand age increases. However, the forest soils around the reservoirs has the potential to increase soil CH_4 oxidation and decrease the net CH_4 emission.

4. GHG MITIGATION STRATEGIES IN WATER RESERVOIRS

Renewable energy sources such as hydropower contribute significantly to the GHG emission reduction. Comparing with conventional coal power plants hydropower reduce CO_2 emission about 3 GT annually or about 9% global annual CO_2 emission [31]. Over last decade there has been many investigations on methodologies of GHG budget in hydropower reservoirs and in some cases, unreal data in GHG emission has challenged hydropower development. As an instance, in some studies in early 2000 estimated hydropower emissions as high as 7% of global emissions. High level of GHG emission estimations were due to studies at sites with very unfavorable conditions. In the recent synthesis by Deemer *et.al.,* [8] CO_2 and N_2O fluxes in reservoirs are lower than anthropogenic or natural sources as reported by the IPCC and CH_4 emissions are similar to rice paddies.

GHG mitigation and adaptation programs in water reservoirs are important and should be considered in reservoir management. Mitigation refers to reduce the source or enhance the sinks for GHG and adaptation assign for adjustment in natural or human systems in response to actual or expected effects of global warming conditions which moderate negative effects or exploits beneficial opportunities.

Reservoir management can mitigate GHG fluxes in reservoirs by affecting CH_4 ebullition events. Demmer *et. al.,* [8] demonstrated that water level drawdown events affects timing and the magnitude of CH_4 ebullition substantially in water reservoirs. Decreasing the number and the magnitude of drawdowns could decrease CH_4 emissions but there is a potential trade-off between power generation and GHG fluxes.

In addition, it is possible to reduce CH_4 emission by changing drawdown timing from the end of the stratified summer to a period when waters are better mixed. This allows rapid methanotrophy at the sediment-water interface.

Moreover, in recent studies “Blue Carbon” refers for the carbon captured by aquatic living organisms and has been recently highlighted as a new method for climate change mitigation strategy. For instance, carbon sink capacity of seagrass meadow in water reservoirs could be used to support strategies to mitigate climate change. Carbon accumulation rate for seagrass meadow is reported between 83 and 133 g C m^{-2} y^{-1} and about 50% of this organic matter is driven from seagrass tissue. However, between 41 and 66 g C m^{-2} y^{-1} of the organic matter produced by seagrasses become buried in the sediments [32].

In addition, methanotrophic bacteria in upland soils can oxidize atmospheric CH_4 and act as a sink for emitted CH_4 from reservoirs. Forest soils pose the highest ability in CH_4 oxidation comparing to other different land uses (e.g., grasslands, agricultural fields). However, afforestation and land use changes (i.e., altering rangeland to forest) rooted from microclimatic effects of water reservoirs can increase CH_4 sink strength.

5. CONCLUSIONS

There are many uncertainties in GHG flux estimation for hydro-electrical water reservoirs. Some of these uncertainties are results of selecting improper sampling methods to collect data with clear spatial and temporal resolution. Including data for all sinks and sources strengths in biogeochemical models is the next challenge for estimation of GHG budget in water reservoirs. This is due to very limited studies with proper data collection for all available sinks and sources water reservoirs. To mitigate GHG fluxes in water reservoir the strengths of the sinks and sources should be determined first and the proper method should be selected in next step. Water-level management has a huge effect on CH_4 ebullition events and should be done when water is not stratified and is better mixed. Methanotrophic activity in soils in the landscape of the coast and “Blue Carbon” capture by aquatic vegetation in the shore line are important GHG sinks and should be included in biogeochemical models for water reservoirs.

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