All-Res is a modeling tool that calculates the total carbon footprint over the lifecycle of a dam and reservoir system.

All-Res Executive Summary

https://tellthedamtruth.com/all-reservoir-greenhouse-gas-model/

All-Res is a modeling tool that calculates the total carbon footprint over the lifecycle of a dam and reservoir system. We have developed All-Res for the purpose of making it available to NGOs to use during dam permitting, re-liscensing, and decommissioning processes, as well as educating the media, decision-makers, agencies, and the public.

The All-Res modeling tool is an advancement over existing models used to estimate GHG emissions from reservoir systems because All-Res includes all of the greenhouse gas emission source categories documented in peer-reviewed scientific literature attributable to any dam and reservoir system including hydropower facilities.

Those emissions pathways include:

- emissions associated with construction, operations and maintenance, and decommissioning,
- emissions from the reservoir surface,
- emissions from decay of organic matter on exposed banks of the reservoir,
- emissions through hydropower turbines or spillways/outlets from non-hydropower dams,
- emissions caused by land use changes away from the reservoir, including deforestation and vegetation changes, to replace inundated farmed land (the scientific literature calls this "carbon leakage"),
- land use changes beneath the reservoir, including loss of carbon sequestration by vegetation that becomes inundated and emissions from decay of that vegetation, as well as the opportunity cost of the lost future carbon sequestration in the inundated former forest/grassland,
- downstream effects, including ecosystem carbon loss from dewatering of wetlands, riparian areas, or mangroves, and emission releases from decaying riparian vegetation due to fluctuating river levels, and
- emissions from pumping water.

Each of these are described below, including a summary of the key components and methods used to estimate the emissions from each pathway. See figure 1, below, for a graphical depiction of all emissions sources and pathways.

Per convention, All-Res computes emissions for a 100-year evaluation period, and converts all methane (CH4) and Nitrous oxide (N2O) emissions into CO2e emissions. N2O emissions are calculated from ecosystem losses downstream, but are not quantified from reservoir surfaces or banks due to a lack of a modeling framework to account for those emissions. The All-Res model also takes into account the limited availability of data for most of the emissions pathways, and incorporates that into a Monte Carlo uncertainty analysis to estimate emissions confidence intervals. As more data becomes available and simulation models improve, the uncertainty will likely be improved compared to the current version of the modeling tool.

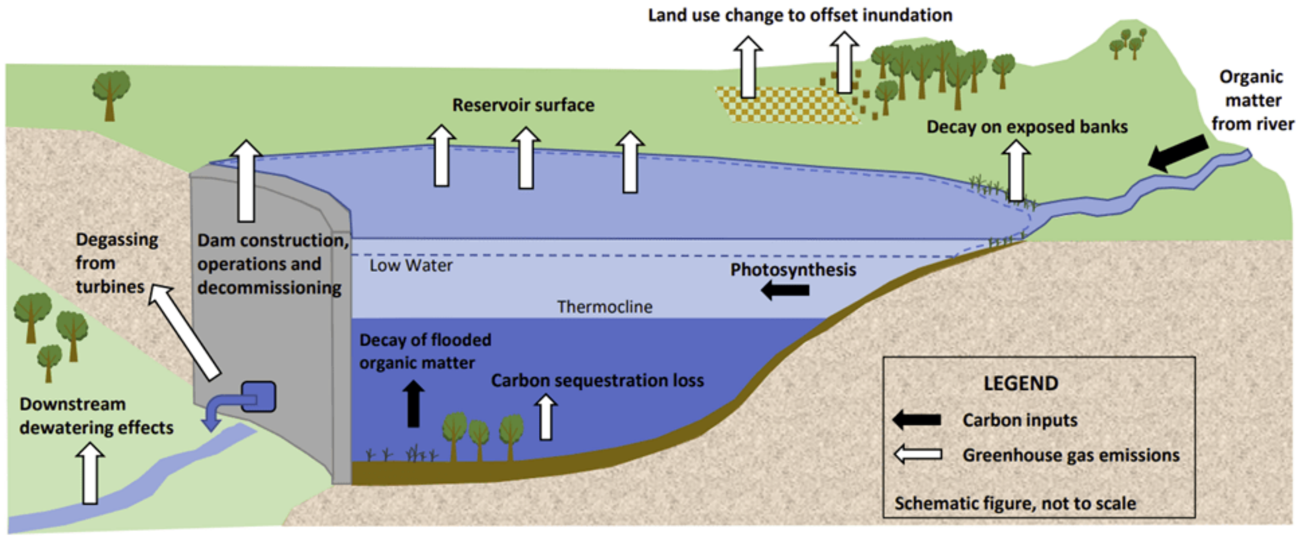

Figure 1: Emissions pathways in a hydropower facility included in All-Res.

Emissions pathways included in the All-Res modeling tool.

Construction

Construction is a component of total emissions associated with reservoirs due to the large amount of energy required to heat limestone, clay, and cement to create the concrete that is used in construction, as well as the fuel burned in construction equipment on site and to quarry and deliver rock and aggregate used in dam construction. CO2 emissions associated with reservoir construction that are in the All-Res modeling tool include those associated with the mass of cement used in construction of the dam, spillway, and associated structures, the mass of mined rock used in the cement, the mass of steel used as concrete reinforcements and in hydropower infrastructure, and the fuel used by equipment involved in the construction. The mass of cement, mined rock, and steel are estimated from the dimensions and shape of the reservoir dam and associated structures. Emission factors for cement, mined rock, steel and diesel fuel are taken from a variety of published sources.

Operations and Maintenance

Emissions from O&M activities are assumed to be related to the hydropower production. Song et al{`1`} provides a range of emissions factors of CO2e per MW-hour and these are used in this modeling tool.

Decommissioning

Decommissioning of a reservoir has the potential to produce a significant amount of both CH4 and CO2 from the mineralization and decomposition of carbon present in exposed lakebed sediments. Pacca{`2`} estimated that emissions associated with decommissioning were an order of magnitude larger than emissions during the life of a large U.S. reservoir. Song et al{`3`} provides a range of emissions factors of CO2e per MW-hour of power production and these are used in this modeling tool.

Reservoir Surface

Greenhouse gases from the reservoir enter the atmosphere from the surface of the water body. These gases come from decomposing organic matter that flows into a reservoir from its watershed, from vegetation and soils that become inundated, and from aquatic plants and algae that produce CH4, CO2, and N2O. Diffusion and bubbling (ebullition) bring the gases that are not oxidized in the reservoir to the reservoir surface. Due to the different processes involved in their production, the All-Res modeling tool conservatively limits surface emissions estimates to CH4. Deemer et al{`4`} provided an estimated CH4 surface flux emissions for 75 reservoirs worldwide.

Exposed Banks

The shorelines (banks) of reservoirs are exposed when water levels fluctuate due to reservoir operations. The periodic exposure and subsequent inundation of the reservoir banks creates conditions that can produce CH4 from vegetation present in this zone. The method described in Prairie et al{`5`} was used to estimate the average width of the affected banks. Deemer et al{`6`} provides an estimate of the CH4 surface emissions per unit area of exposed banks, which is used in this modeling tool.

Turbines/Outlets

Discharge of reservoir water through turbines or outlets, referred to here as the turbines pathway, can be a source of emissions. These emissions are due to degassing of methane-rich water discharged from the oxygen-depleted depths of the reservoir through the turbines. These emissions are released due to the rapid drop in hydrostatic pressure when water exits the turbine into the river downstream. Emissions of CH4 are much higher for outlets that are situated below the thermocline due to the anoxic conditions present in those waters. Delwiche et al{`7`} estimated that CH4 emissions at outlets could be 80 to 95 percent of surface emissions, which is consistent with other publications. A value of 80% of surface emissions is used in the current version of All-Res.

Land Use Changes Under The Reservoir

Inundation of vegetated land beneath a reservoir affects greenhouse gas emissions in two pathways: the loss of future carbon sequestration (uptake) from the vegetation had the reservoir not inundated the site, and the production of CO2 due to decomposition of that inundated vegetation. These gasses are released through the reservoir surface and turbines but are included in this emissions pathway due to uncertainties in the release pathway to the atmosphere. The

IPCC greenhouse gas inventory guidance (Penman et al{`8`}, Lasco et al{`9`}, and Lovelock et al{`10`}) for estimating the carbon stock (mass), the changes in carbon stock, and the greenhouse gas emissions and removals associated with changes in land use are used for this pathway. Estimated inundation areas of oak and poplar-willow forests, settlements and farmland were provided by interested parties.

Land Use Changes Away From The Reservoir (Carbon Leakage)

"Carbon leakage" describes the change in CO_2 emissions that occur due to a land use change away from a reservoir to replace land uses in areas that were inundated. The most common example is the need to replace inundated farmland to match the food production prior to the loss of farmland due to inundation. IPCC guidance (Penman et al{`11`}, Lasco et al{`12`}, and Lovelock et al{`13`}) for estimating the changes in carbon stock due to changes in land use were used for this pathway. Estimated inundation areas of oak and poplar-willow forests, settlements and farmland were provided by interested parties.

Downstream Effects

A reservoir can affect emissions in downstream areas due to changes in river flow. Reservoirs typically decrease river flow downstream, which can have the effect of reducing and drying out of wetland and other riparian vegetation, causing a loss of carbon sequestration and also causing plants to die and stored carbon and nitrogen in the plants to decompose to CH_4, CO_2 and N_2O. In addition, hydropower reservoirs can affect downstream emissions due to fluctuating river levels caused by changes in flow. The latter effects may be similar to those for shorelines of reservoirs, with additional gasses produced due to the periodic exposure and subsequent inundation of the river banks.

Pumping of Water

Some dam/reservoir systems pump water out of rivers up into, or upstream into, an off-channel reservoir. This pumping will always caused some kind of greenhouse gas emissions because the pumping uses either fossil-fuel driven electricity or uses fossil fuels to operate local pumps. In addition, it's rare, but some hydropower facilities also pump water back up into reservoirs, which will likewise cause GHG emissions.

Uncertainty Analyses

To account for uncertainty in the emissions models, the All-Res modeling tool includes an uncertainty analysis. The analysis uses a Monte-Carlo process that utilizes the published probability distributions of emissions factors, carbon stocks, and quantities of steel, based on published ranges and standard deviations, where provided. Using a 1000-iteration approach, the resulting emissions are described by their mean and percentile distributions which are presented in the model output.

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{`1`} Song et al, 2018. Cradle-to-Grave Greenhouse Gas Emissions from Dams in the United States of America. Science, Elsevier. www.sciencedirect.com/science/article/pii/S1364032118302235

{`2`} Pacca, S., 2007. Impacts from decommissioning of hydroelectric dams: a life cycle perspective. Climatic Change, Vol 84 pp 281-294.

{`3`} Id. at 5.

{`4`} Deemer et al, 2016. Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis: Supplementary Information. Bioscience, Vol 16 No 11, pp 949-964.

{`5`} Prairie et al, 2021. The GHG Reservoir Tool (G-res) GHG status of freshwater reservoirs Technical documentation. Updated version 3.0 (2021-10-27). Joint publication of the UNESCO Chair in Global Environmental Change and the International Hydropower Association.

{`6`} Id. at 8.

{`7`} Delwiche et al, 2022. Estimating Drivers and Pathways for Hydroelectric Reservoir Methane Emissions Using a New Mechanistic Model. JGR Biogeosciences, 127, e2022JG006908.

{`8`} Penman et al, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme.

{`9`} Lasco et al, 2006. Volume 5 Chapter 5, Cropland. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

{`10`} National Greenhouse Gas Inventories.

{`11`} Id. at 13.

{`12`} Id. at 14.

{`13`} Id. at 15.