Estimate of Greenhouse Gas Emissions caused by the **Glen Canyon and Hoover Dam Facilities** using the All-Res Modeling Tool


Lake Powell with Algae Bloom. Credit: NPS

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Executive Summary

Glen Canyon Dam and Hoover Dam, on the Colorado River, create the two biggest man-made reservoirs in the United States, known as "Lake" Powell and "Lake" Mead, respectively. These dams, reservoirs, and their hydroelectric powerplants (hereafter referred to individually as the Glen Canyon Dam Facility and Hoover Dam Facility) – also cause significant evaporation of Colorado River water, completely regulate the flow of water between and downstream of them, and capture nearly all of the river's sediment. Currently, the U.S. Bureau of Reclamation has launched an Environmental Impact Statement (EIS) process for the management of the reservoirs which warrants this timely investigation of the reservoirs' climate impacts including greenhouse gas emissions.

The hydropower facilities at the dams are often touted as "clean energy" and "carbon-free," which are inaccurate statements addressed in this report. Over the last two decades, knowledge and science about the environmental impacts of dams and reservoirs has increased significantly in the U.S. and across the planet, with a focus on the greenhouse gas (GHG) emissions caused by dams and reservoirs. Recent science has shown that dam, reservoir, and hydropower facilities worldwide cause the emission of hundreds of millions of tons of greenhouse gases including carbon dioxide, methane, and nitrous oxide each year. Methane, an extremely potent climate pollutant, is the largest contributor of climate-heating emissions from these facilities.

In this report, we apply the All-Res Modeling Tool ("All-Res") to estimate the cradle-to-grave, life cycle GHG emissions caused by the Glen Canyon and Hoover Dams facilities over a 100-year life cycle (a common metric in life cycle analysis of dams and reservoirs). All-Res is an advancement over existing modeling tools and frameworks because it is more comprehensive, its use of a 100-year life cycle time window, and it includes all known greenhouse gas emission sources attributed to dam, reservoir, and hydropower systems reported in the scientific literature.

In All-Res, we use the best available data from federal reports and scientific literature. Where there is a lack of data, we utilize alternative estimates from peer-reviewed literature and other sources that are conservative, so that the emissions the tool reports are not overstated.

The **Glen Canyon Dam System** is estimated to cause the emission of

1,780,000

METRIC TONS OF CO_2e/YEAR

The **Glen Canyon Dam System** is estimated to cause the same emissions as

423,600

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

2,000,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

200,000,000

GALLONS OF GASOLINE CONSUMED IN ONE YEAR

The **Hoover Dam System** is estimated to cause the emission of

4,700,000

METRIC TONS OF CO_2e/YEAR

The **Hoover Dam System** is estimated to cause the same emissions as

1,100,000

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

5,100,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

511,000,000

GALLONS OF GASOLINE CONSUMED IN ONE YEAR

*using the U.S. EPA's emissions comparison tool

Together these facilities are estimated to cause the emissions of

6,480,000

METRIC TONS OF CO_2e/YEAR

The **Glen Canyon Dam and Hoover Dam Systems** are estimated to cause the same emissions as

1.7

coal-fired powerplants for one year, or,

17.3

natural gas-fired powerplants for one year

The EPA requires large facilities to report emissions that exceed 25,000 metric tons of CO_2e/year. Over its life, the Glen Canyon Dam System will cause the emission of more than 71 times that threshold annually, and the Hoover Dam System will cause the emission of more than 196 times that threshold annually

Multiple, inaccurate claims have been made about the low environmental and climate impacts of hydroelectricity. The basis for those claims does not take into account that significant amount of climate-heating GHG emissions caused by dams and reservoirs annually and throughout their entire life cycle. We strongly encourage decision-makers and public agencies to consider the GHG emissions caused by these dams in any ongoing or future permitting, funding, and infrastructure decisions.

*using the U.S. EPA's emissions comparison tool

Introduction

Over the last few decades, dam, reservoir, and hydropower projects have come under increasing scientific scrutiny because of the greenhouse gases they emit. Since 1974, more than 770 peer-reviewed scientific studies describe GHGs from dam and reservoir projects, including those generating hydropower. Some projects built primarily for hydropower production can emit even more GHGs than coal-fired powerplants producing an equal amount of electricity.[1,2,3,4]

Further, in 2022 and for the first time in history, the U.S. Environmental Protection Agency (EPA) reported reservoir surface emissions to the United Nations Framework Convention on Climate Change, using guidelines from the Intergovernmental Panel on Climate Change (IPCC), thus setting the precedent for these reports across the U.S. during dam permitting and re-permitting processes[5].

Using readily available emissions models that estimate GHGs from dam, reservoir, and hydropower projects, and using data provided from public sources including reports from the U.S. Bureau of Reclamation, public news articles, the U.S. Fish and Wildlife Service, scientific publications, as well as other sources, we developed and applied the All-Res Modeling Tool[6] to calculate the total carbon footprint over the lifecycle of the Glen Canyon and Hoover Dam Systems.

Glen Canyon Dam, located in northern Arizona, is owned and operated by the U.S. Bureau of Reclamation which oversees all operations of the dam and its hydropower facility. All of Powell Reservoir and its northern shore is owned and managed by the U.S. National Park Service as the "Glen Canyon National Recreation Area." Except for a few miles upstream of the dam, all of the southern shore of Powell Reservoir is owned and managed by the Navajo Nation.

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[1] https://www.climatecentral.org/news/hydropower-as-major-methane-emitter-18246
[2] https://www.washingtonpost.com/news/energy-environment/wp/2016/09/28/scientists-just-found-yet-another-way-that-humans-are-creating-greenhouse-gases/
[3] https://www.latimes.com/science/la-xpm-2013-aug-01-la-dams-greenhouse-gas-hot-spots-20130801-story.html
[4] Scherer, L. and S. Pfister. 2016. Hydropower's Biogenic Carbon Footprint. Plos One. https://doi.org/10.1371/journal.pone.0161947
[5] https://therevelator.org/dam-emissions-reporting/
[6] https://tellthedamtruth.com/all-reservoir-greenhouse-gas-model/

Figure 1:
Vicinity Map, Glen Canyon Dam System

Figure 2: Glen Canyon Dam & Hydropower Facility

Figure 3 (left): Reservoir area 'methane volcanoes'

Figure 4 (right): Reservoir mud & debris

Hoover Dam, located on the Nevada-Arizona border, is also owned and operated by the U.S. Bureau of Reclamation which oversees all operations of the dam and its hydropower facility. All of Mead Reservoir and the entire landscape around it is owned and managed by the U.S. National Park Service as the “Lake Mead National Recreation Area.”

Figure 5: Vicinity Map, Hoover Dam System

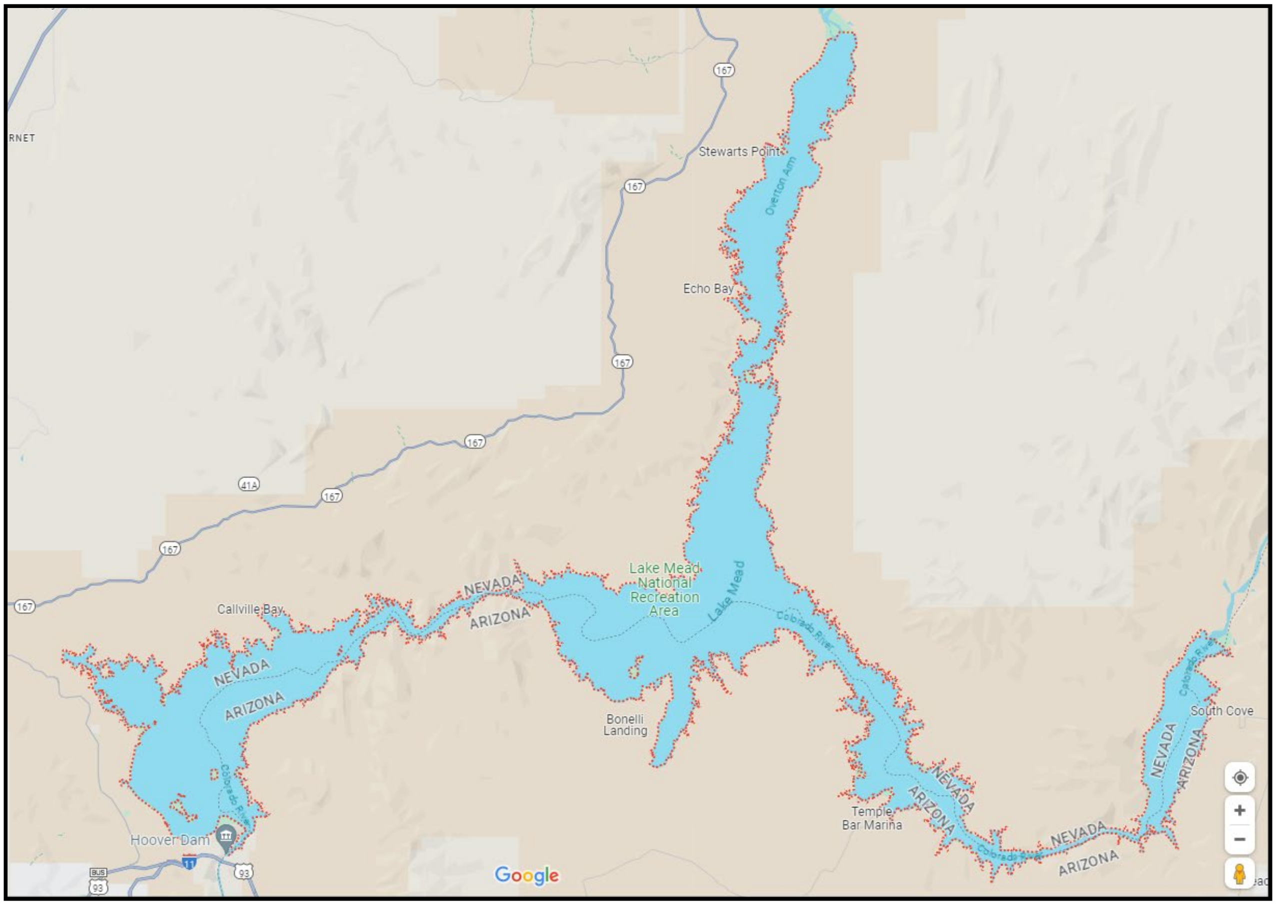

Figure 6:
Hoover Dam

THE ALL-RES MODELING TOOL

We applied the All-Res Modeling Tool to the Glen Canyon and Hoover Dam Systems from their initial construction to their inevitable decommissioning, and compared total greenhouse gas emissions to other emissions sources using the U.S. Environmental Protection Agency's emissions comparison calculator.

All-Res uses a cradle-to-grave, full life cycle inventory approach to estimate the total carbon footprint of the dams, reservoirs and hydropower systems. All-Res uses a 100-year life cycle period, a common metric in greenhouse gas accounting for these facilities.

All-Res is an advancement over existing modeling tools because of its expanded framework, and it includes all known greenhouse gas emissions attributed to dam, reservoir, and hydropower systems that are documented in the peer-reviewed scientific literature. Other existing GHG emissions tools examine only a portion of the life cycle scope and do not include emissions from end-of-life facility decommissioning, downstream emissions due to the impacts on wetland and riparian vegetation, soil and sediment carbon and nitrogen losses caused by the facility, loss of ecosystem function, and the full scope of land-use-change emissions ('carbon leakage').

The following emissions pathways are included in the All-Res modeling tool:

- Construction
- Facility operations and maintenance
- Facility decommissioning
- Reservoir surfaces
- Degassing methane through hydropower turbines and non-hydropower spillways
- Carbon leakage: land use changes away from the reservoir, including deforestation and vegetation changes, to replace inundated farmland, grazing land, and homes.

- Land use changes beneath the reservoir, including loss of carbon sequestration by vegetation that becomes inundated and emissions from anaerobic decay of that vegetation, as well as the lost ecosystem function of future carbon sequestration in the inundated former forest.

- Downstream effects caused by altered river hydrographs and reductions in river flows, including carbon loss from dewatering of wetlands, riparian forests, and estuarian ecosystems.

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 7, below, for a graphical depiction of all emissions sources and pathways.

Per convention as described by the Intergovernmental Panel on Climate Change (IPCC), the tool converts emissions of methane (CH_4) and nitrous oxide (N_2O) emissions into CO_2e (carbon dioxide equivalent) emissions. N_2O emissions are calculated from ecosystem losses downstream, but are not quantified from reservoir surfaces or banks, to avoid the possibility of double-counting emissions already attributed to other emissions sources.

All-Res accounts for the uncertainty of input data and emissions factors by incorporating them into a Monte Carlo simulation to estimate emissions confidence intervals, as recommended by the IPCC.[7]

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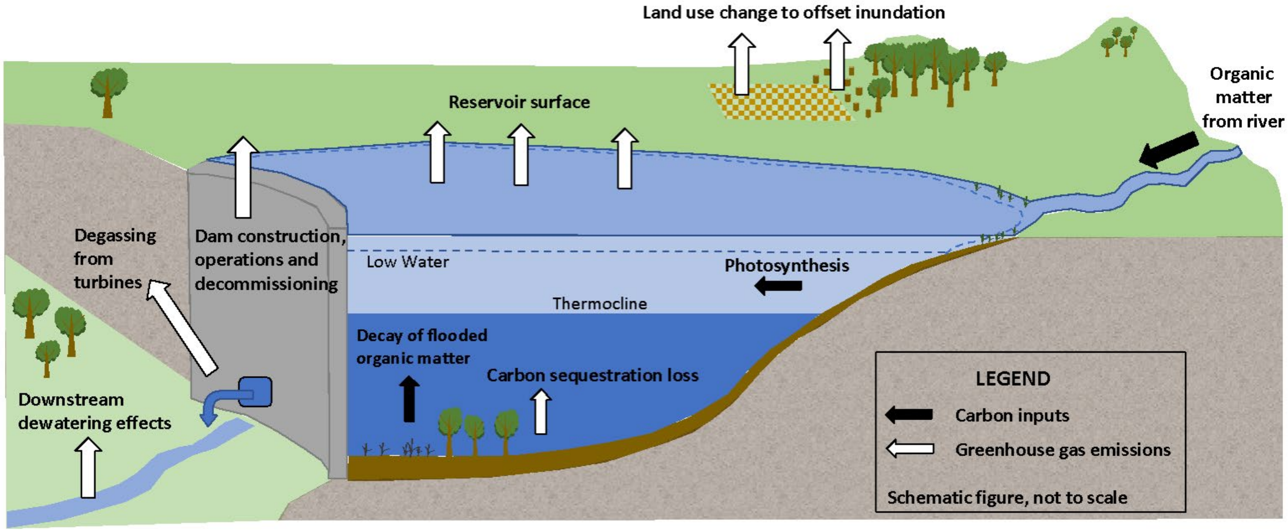
[7] Frey, Christopher, Jim Penman, Lisa Hanle, Suvi Monni, and Stephen Ogle. 2003. Chapter 3: Uncertainties, in 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_3_Ch3_Uncertainties.pdf.

Figure 7:
Emissions pathways in a dam and reservoir facility included in All-Res



EMISSIONS PATHWAYS INCLUDED IN ALL-RES

Construction

Construction is a component of total emissions associated with reservoirs due to the large amount of energy required to manufacture materials such as cement and steel used in construction, as well as the fuel burned by construction equipment on site and to quarry and deliver rock and aggregate used in dam construction.

Data used to estimate CO_2 emissions from constructing Glen Canyon Dam are derived from multiple sources, including U.S. Bureau of Reclamation documentation and scientific reports[8,9]. Data used to estimate CO_2 emissions from constructing the Hoover Dam are derived from U.S. Bureau of Reclamation documentation[10].

Emission factors for fuels burned during construction, and construction materials, are derived from the GREET model[11].

Operations and Maintenance

Emissions from Operations and Maintenance (O&M) activities at the Glen Canyon Dam and Hoover Dam Systems include maintenance activities, use of recreational areas around the reservoir, as well as operation of spillways and turbines.

Data for operation of the Glen Canyon Dam system were provided by the U.S. Bureau of Reclamation.[12] Data for operation of the Hoover Dam System was provided by National Park Service.[13]

Energy emission factors were derived from the U.S. EPA EGRID database using information reported for the utility districts from the region of the projects.[14]

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8. U.S. Bureau of Reclamation, Glen Canyon Unit: https://www.usbr.gov/uc/rm/crsp/gc/
9. Pacca, S. and A. Horvath. 2002. Greenhouse Gas Emissions from Building and Operating Electric Power Plants in the Upper Colorado River Basin. Environ. Sci. Technol. 2002, 36:3194-3200.
10. U.S. Bureau of Reclamation, Hoover Unit: https://www.usbr.gov/uc/rm/crsp/gc/
11. Wang, M Q. 1996. "Development and use of the GREET model to estimate fuel-cycle energy use and emissions of various transportation technologies and fuels". United States. https://doi.org/10.2172/230197. https://www.osti.gov/servlets/purl/230197.
12. U.S. Bureau of Reclamation, Upper Basin Unit, personal communication.
13. National Park Service, Climate Friendly Parks (undated). Lake Mead National Recreation Area Action Plan.
14. U.S. Environmental Protection Agency. 2024. Emissions & Generation Resource Integrated Database (eGRID). https://www.epa.gov/egrid

Reservoir Surface

Greenhouse gases can 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 decomposed organic matter in vegetation and soils inundated at the time the reservoir filled, and from organic matter fixed through photosynthesis by aquatic plants and algae in the reservoir. Microbes in the reservoir water column and in reservoir sediments consume the organic matter and release CO_2 in oxygen-rich portions of the reservoir, and produce CH_4 in the oxygen-depleted depths of the reservoir. The gases move to the surface through diffusion and bubbling (ebullition). CH_4 that is not oxidized by CH_4 -consuming organisms in the water column during diffusion and ebullition are emitted from the reservoir surface. CO_2 not taken up by aquatic plants and algae in the water column is also emitted from the reservoir surface.

Due to the different processes involved in the production of various gases, and to avoid double-counting, All-Res conservatively limits surface emissions estimates to CH_4.

Surface Emissions from the Glen Canyon Dam System

We applied emissions factors derived from measurements of surface CH_4 reported by Deemer *et al.* (2021)[15] for littoral and non-littoral regions of Powell Reservoir. "Littoral" is defined as the upper 15m of water, which includes regions near reservoir banks, in river tributary branches, and in the upper reaches of the reservoir where most sediment accumulates, which is where surface CH_4 emissions are correspondingly highest. Emissions from littoral areas were estimated annually as the reported emissions factor multiplied by average annual reservoir surface area classified by the authors as littoral for the period from 1963-2021. Non-littoral (deep water, > 15m) emissions were estimated as the reported emissions factor for non-littoral regions multiplied by the average annual reservoir area classified by the authors as non-littoral for the period 1963-2021.

Areas in littoral and non-littoral portions of the reservoir were reported by Waldo *et al.* (2021)[16] for 1963-2018 and estimated through 2023 using reservoir elevation-

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[15] Deemer, B.R., Waldo, S., and Gushue, T., 2021, Modeled and measured greenhouse gas emissions from Lake Powell and bathymetric analysis of tributary littoral habitat at different water levels: U.S. Geological Survey data release, https://doi.org/10.5066/P9PRW8JX.

[16] Waldo,S., Deemer, B.R., Bair,L.S., and Beaulieu, J.J., 2021. Greenhouse gas emissions from an arid-zone reservoir and their environmental policy significance: Results from existing global models and an exploratory dataset. Environmental Science & Policy 120:53-62, ISSN 1462-9011. https://doi.org/10.1016/j.envsci.2021.02.006.

area-capacity data provided by Root and Jones (2022)[17]. Because All-Res uses a life cycle assessment over a 100-year period as the basis of study, the future areas in littoral and non-littoral portions of the reservoir had to also be estimated. For the period of 2024-2062 we built linear regression models from the year the reservoir filled (1984) to the end of the period of record (2023) and used that regression model to project the relevant areas through the end of the life cycle period[18]. The regression models project downstream delivery requirements to exceed the reservoir's inflow and stored water by the year 2062, meaning the reservoir would no longer continue to store water after that year. It coincides with the 100-year life cycle projection in this study. However, that projection is without consideration of water management strategies that may be implemented in the future.

Surface Emissions from the Hoover Dam System

For estimates of CH_4 surface emissions from the Hoover Dam System, we classified the Mead Reservoir area into littoral (regions with water depth less than 15m (<50 ft), which are near reservoir banks, in river tributary branches, and in the upper reaches of the reservoir where most sediment accumulates, and non-littoral (deep water areas with water depth > 15m with little sedimentation). Multiple studies have shown that littoral regions of reservoirs emit significantly more CH_4 than non-littoral areas, documented in the Colorado River in a study by Deemer *et al.* at the Glen Canyon Dam System, where littoral CH_4 emissions were more than one hundred times greater than emissions in non-littoral regions[19]. CH_4 emissions from littoral regions are dominated by CH_4 ebullition, which are derived largely from organic matter in soils and vegetation inundated by the reservoir and organic matter in sediments that flow into the reservoir from the watershed. Organic matter inputs from algae photosynthesis, which are correlated with *chlorophyll* a concentrations, are not a significant driver of CH_4 emissions from littoral areas. Emissions from littoral regions of the Hoover Dam system were not correlated with *chlorophyll a* measurements[20].

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[17] Root, J.C., and Jones, D,K, 2022. Elevation-Area-Capacity Relationships of Lake Powell in 2018 and Estimated Loss of Storage Capacity Since 1963. U.S. Geological Survey Scientific Investigations Report 2022-5017.

[18] multiple R2 = 0.78-0.83, F=57.9-81.4, p<0.001

[19] Deemer, B.R., Waldo, S., and Gushue, T., 2021, Modeled and measured greenhouse gas emissions from Lake Mead and bathymetric analysis of tributary littoral habitat at different water levels: U.S. Geological Survey data release, https://doi.org/10.5066/P9PRW8JX.

[20] Ibid.

For non-littoral regions we utilized emissions factors derived from remotely-sensed measurements of surface *chlorophyll a* concentrations from the Hoover Dam System for the period 1984-2020, as they have been shown to be highly correlated[21,22].

CH_4 emissions from non-littoral areas were estimated from measured *chlorophyll a* concentrations using a linear regression model developed from data reported by Deemer *et al.* (2021)[23]. Surface CH_4 emissions were calculated for each year as the *chlorophyll a*-derived emission factor for each year multiplied by the non-littoral area in the reservoir for that year. In non-littoral areas for time periods before 1984 and after 2020 we used a mean emission factor of 6.0 mg $CH_4/m^2/hr$ derived from the *chlorophyll a* measurements between 1984-2020.

No measurements of littoral-region surface CH_4 emissions were available for the Hoover Dam system, so for littoral regions we utilized the surface CH_4 emission rate reported by Deemer *et al.* (2021) for littoral regions of the Glen Canyon Dam system (255 mg $CH_4/m^2/hr$).

Areas in littoral and non-littoral portions of the Hoover Dam system were estimated from BuRec area-capacity tables[24] and daily pool elevation data from the BuRec HydroData Navigator[25]. As this life cycle assessment uses a 100-year period as the basis of study, the future areas in littoral and non-littoral portions of the reservoir were estimated. For the period of 2024-2034 (with 2034 representing the end of the 100-year life-cycle calculations) we used the average area in littoral and non-littoral portions of the reservoir from the previous eleven years (2013-2023).

Turbines and Bypass Tubes

Discharge of reservoir water through turbines or outlets, referred to here as the turbines and bypass tubes pathway, can be a source of significant CH_4 emissions. These emissions are due to degassing of CH_4 -rich water discharged from the oxygen-depleted depths of reservoirs through turbines and bypass tubes. The bypass tubes lie below the turbine intakes, and are expected to be utilized

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[21] Hanly, Patrick J., Katherine E. Webster, and Patricia A. Soranno. 2024. LAGOS-US LANDSAT: Remotely sensed water quality estimates for U.S. lakes over 4 ha from 1984 to 2020. https://www.biorxiv.org/content/10.1101/2024.05.10.593626v1

[22] Deemer, B. R., Harrison, J.A., Li, Jake J. Beaulieu, Tonya DelSontro, Nathan Barros, José F. Bezerra-Neto, Stephen M. Powers, Marco A. dos Santos, and J. Arie Vonk. "Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis." BioScience 66, no. 11 (November 1, 2016): 949–64. https://doi.org/10.1093/biosci/biw117

[23] Deemer, B.R., Waldo, S., and Gushue, T., 2021, Modeled and measured greenhouse gas emissions from Lake Mead and bathymetric analysis of tributary littoral habitat at different water levels: U.S. Geological Survey data release, https://doi.org/10.5066/P9PRW8JX.

[24] Tighi, Shana, and Russell Callejo. 2011. Lake Mead Area and Capacity Tables. https://www.usbr.gov/lc/region/g4000/LM_AreaCapacityTables2009.pdf

[25] U.S. Bureau of HydroData Navigator. https://www.drought.gov/data-maps-tools/hydrodata

to deliver reservoir water to the river channel downstream after the reservoir elevation drops below power pool. These emissions are released due to the rapid drop in hydrostatic pressure when water exits turbines or bypass tubes into the river downstream. Emissions of CH_4 are much higher for turbine and bypass tube outlets that are situated in the CH_4 -rich hypolimnion, due to the anoxic conditions present in those waters. Delwiche *et al* (2022)[26] estimated that CH_4 emissions at turbine and bypass tube outlets located within the hypolimnion are likely 80 to 95 percent of surface emissions, which is consistent with other publications. A value of 80% of surface emissions was used in All-Res to conservatively estimate CH_4 emissions through the turbine and bypass tubes pathway.

Land Use Change

Inundation of vegetated land beneath a reservoir affects greenhouse gas emissions in two pathways: the loss of ecosystem function as future carbon sequestration (uptake) from the land that was inundated[27]; and the production of CO_2 due to decomposition of organic matter in inundated trees, shrubs, and grasses[28], and in the soil at the reservoir bottom[29].

The equivalent emissions of lost carbon sequestration are quantified using the IPCC greenhouse gas inventory guidance for estimating the total carbon stock and the rate of change of carbon stock at the time of inundation[30,31,32]. Riparian forests are estimated to have covered 20% of the reservoir area in both the Glen Canyon and Hoover Dam systems at the time of inundation[33]. Riparian forest carbon was

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[26] Delwiche et al, 2022. Estimating Drivers and Pathways for Hydroelectric Reservoir Methane Emissions Using a New Mechanistic Model. JGR Biogeosciences, 127, e2022JG006908. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022JG006908

[27] Eve et al, 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity□Scale Inventory. Technical Bulletin Number 1939. U.S. Department of Agriculture, Washington, DC. 606 pages. https://www.usda.gov/sites/default/files/documents/USDATB1939_07072014.pdf

[28] Beaulieu, JJ, S Waldo, DA Balz, W Barnett, A Hall, MC Platz, and KM White. "Methane and Carbon Dioxide Emissions From Reservoirs: Controls and Upscaling." Journal Of Geophysical Research-Biogeosciences 125, no. 12 (December 2020). https://doi.org/10.1029/2019JG005474.

[29] Félix-Faure, J, C Walter, J Balesdent, V Chanudet, JN Avrillier, C Hossann, JM Baudoin, and E Dambrine. "Soils Drowned in Water Impoundments: A New Frontier." Frontiers In Environmental Science 7 (April 24, 2019). https://doi.org/10.3389/fenvs.2019.00053

[30] Penman et al, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme. https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

[31] Lasco et al, 2006. Volume 5 Chapter 5, Cropland. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_05_Ch5_Cropland.pdf

[32] Lovelock et al. 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chater 7: Wetlands. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch07_Wetlands.pdf

[33] Holman, Kathleen & Pearson, Christopher & Jasoni, Richard & Huntington, Justin & Volk, John. (2022). Evaporation from Lake Powell: In-situ Monitoring between 2018 and 2021. DOI: 10.13140/RG.2.2.19477.19684.

derived from studies from a regional dataset[34]. The remaining area is assumed to have been in grassland (10%) and exposed bedrock (65%).

Beaulieu *et al.* (2020)[35] and Deemer *et al* (2016)[36] estimated that 73% and 84% (respectively) of the organic matter in trees and soils under the reservoir at the time of inundation is decomposed into CO_2. The remainder is estimated to be decomposed into CH_4. The CH_4 emissions from inundated organic matter are included in surface emissions and the CO_2 emissions are included in emissions from land use change, to avoid double-counting. All-Res uses the average percentage of decomposable organic matter from the range listed above.

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.

No studies were found for the Glen Canyon Dam System that documented the extent of settlements or use by Indigenous peoples or European settlers, nor the land uses under the reservoir footprint at the time the lands were flooded. For the purposes of this study the land was treated as largely uninhabited and so there are no emissions assumed for this category.

At the Hoover Dam System, the indigenous Moapa band of the Paiute Tribe occupied a reservation of 1,000 acres (405 ha) that was inundated[37], as was the town of St. Thomas[38]. Based on this historic data, 1,000 acres of land were assumed to have been utilized for irrigated agriculture, and 1,000 acres were assumed to have been used for settlements in the inundated area.

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[34] Dybala, Kristen E., Virginia Matzek, Thomas Gardali, and Nathaniel E. Seavy. 2018. Carbon sequestration in riparian forests: A global synthesis and meta-analysis. Global Change Biology. DOI:10.1111/gcb.14475

[35] Beaulieu, JJ, S Waldo, DA Balz, W Barnett, A Hall, MC Platz, and KM White. "Methane and Carbon Dioxide Emissions From Reservoirs: Controls and Upscaling." Journal Of Geophysical Research-Biogeosciences 125, no. 12 (December 2020). https://doi.org/10.1029/2019JG005474

[36] Deemer, B. R., Harrison, J.A., Li, Jake J. Beaulieu, Tonya DelSontro, Nathan Barros, José F. Bezerra-Neto, Stephen M. Powers, Marco A. dos Santos, and J. Arie Vonk. "Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis." BioScience 66, no. 11 (November 1, 2016): 949–64. https://doi.org/10.1093/biosci/biw117

[37] Moapa Bands of the Paiutes, Background. https://www.xeri.com/Moapa/moapa.htm

[38] National Park Service. Town of St. Thomas. https://www.nps.gov/lake/learn/nature/st-thomas-nevada.html

Downstream Effects

A reservoir can affect emissions in downstream areas due to changes in river flow. Reservoirs typically decrease river flow downstream due to evaporation from reservoir surfaces and diversions for irrigation, cities, and other uses, which reduces and dries out wetlands and other riparian vegetation downstream. The organic matter in the plants and soils of those lost wetlands decompose, producing CO_2 and N_2O. In addition, hydropower reservoirs can affect downstream emissions due to fluctuating river levels caused by changes in the hydrologic flow regime. The latter effects may be similar to those for shorelines of reservoirs, with additional emissions produced due to the alternating exposure and subsequent inundation of the riverbanks.

These factors are attributable to the Glen Canyon and Hoover Dam Systems, but many other storage and diversion projects in the Colorado River basin also influenced the downstream wetlands and riparian vegetation.

Interacting ecosystem and hydrologic processes created a dynamic, biodiverse, complex estuary – often called the Colorado River Delta – occupying approximately 2 million acres or 809,372 hectares) where the Colorado River meets the north end of the Gulf of California[39,40]. Early explorers mapped a rich landscape in the region, describing freshwater wetland forests and marshes, sloughs, riparian forests, salt marshes, and tidal flats[41,42]. At present, due to water diversions upstream, 90% of the carbon-rich wetlands of the Colorado River estuary have been lost[43]. The total lost wetland area totals approximately 784,000 hectares (1,940,000 acres)[44].

Leopold (1949) documented the estuary's rich wetland diversity from a journey through the estuary in 1922[45]. Sykes (1926) compiled maps and historic hydrologic records and observations from the estuary, providing important clues as to the vegetation it held[46]. In it, Sykes describes a hydrologically dynamic landscape where river-deposited silt remade the channel through mud flats and the delta in

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39 Alles, David L. (Ed.). 2012. The Delta of the Colorado River. Western Washington University. https://fire.biol.wwu.edu/alles/TheDelta.pdf
40 Schlatter, Karen, Matthew Grabau, and Summer Waters. "The Colorado River Delta: Past and Present." Sustainability of Colorado River Delta Riparian Habitat Under Different Water Management and Climate Change Scenarios. Lincoln Institute of Land Policy, 2015. http://www.jstor.org/stable/resrep18484.4.
41 Sykes, Godfrey. "The Delta and Estuary of the Colorado River." Geographical Review 16, no. 2 (1926): 232–55. https://doi.org/10.2307/208680
42 Kearney, M.S., Court Stevenson, J. (2019). North America, Coastal Ecology. In: Finkl, C.W., Makowski, C. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Sciences Series. Springer, Cham. https://doi.org/10.1007/978-3-319-93806-6_229
43 Alles, David L. (Ed.). 2012. The Delta of the Colorado River. Western Washington University. https://fire.biol.wwu.edu/alles/TheDelta.pdf
44 Voiland, Adam. 2020. Green Lagoons No More. NASA Earth Observatory. https://earthobservatory.nasa.gov/images/146839/green-lagoons-no-more
45 Leopold, aldo. 1949. "The Green Lagoons", in "A Sand County Almanac". Oxford University Press.
46 Sykes, Godfrey. "The Delta and Estuary of the Colorado River." Geographical Review 16, no. 2 (1926): 232–55. https://doi.org/10.2307/208680

the region of tidal influence. Sykes describes how the river channels were regularly constrained in the upper portions of the estuary by thick riparian vegetation. The plant communities described included freshwater wetland forests, freshwater marsh, salt marsh, saltgrass marsh, riparian woodlands, and tidal flats.

In the freshwater region between Yuma and the region of tidal influence, both authors describe a dynamic mosaic of riparian forest, lagoons, and marsh maintained by the river's natural flow regime.

The estuary, once the largest in North America[47], occupied a unique habitat niche for its geology, climate, and relationship to the Gulf of California. No other estuaries appear to be like it. Whereas mangrove forests occupy estuaries further to the south on both sides of the Gulf of California, they exist in a different geologic, climate, and hydrologic context than the Colorado River Estuary. The Colorado River Estuary appears to have been too far north for mangroves to establish. The great tidal swings at the lower end of the estuary (up to 10m) created a large tidal mud flat below where vegetation established, occupying 200,000 ha (494,000 acres) of the estuary.

Because of uncertainties in the areas different ecosystems occupied in the estuary, we partitioned estuary wetlands into the following ecosystem categories and fractions[48,49,50]:

- Tidal flats (Mapped at 23% of former estuary area)
- Freshwater Marsh (15.4% of former estuary)
- Freshwater Forest Marsh (15.4% of former estuary)
- Salt Marsh (15.4% of former estuary)
- Saltgrass Marsh (15.4% of former estuary)
- Riparian Forest (15.4% of former estuary)

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[47] Kearney, M.S., Court Stevenson, J. (2019). North America, Coastal Ecology. In: Finkl, C.W., Makowski, C. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Sciences Series. Springer, Cham. https://doi.org/10.1007/978-3-319-93806-6_229

[48] Kauffman et al. 2020. Total Ecosystem Carbon Stocks of Mangroves across Broad Global Environmental and Physical Gradients. Ecological Monographs 90, no. 2 (May 2020). https://doi.org/10.1002/ecm.1405

[49] Ward et al. 2021. Blue carbon stocks and exchanges along the California coast. https://doi.org/10.5194/bg-18-4717-2021

[50] Second State of the Carbon Cycle Report Chater 15: Tidal Wetlands and Estuaries. https://carbon2018.globalchange.gov/chapter/15/

Estuary tidal and freshwater wetlands are underlain with peat soils that contain some of the highest known soil organic carbon stocks in the world[51]. Without hydrologic support and continued carbon inputs from vegetation, the carbon in these soils is assumed to decompose[52,53,54,55]. In addition to the wetland soils, the tidal mud flats are considered to be a significant carbon sink worldwide, accumulating large carbon stocks fed from organic matter in sediment deposited from the river's yearly influx of organic matter and eroded material from the watershed above[56]. Without regular influx of sediment and organic matter from the river, the tidal flats are degraded by tide and wave action and are no longer supported by an influx of sediment from the river. Under those circumstances, carbon stocks in the tidal flats are assumed to decompose, like the wetland soils.

The total ecosystem organic carbon in the vegetation, soils, and tidal flat sediments in the estuary is estimated to have been 1.1 billion metric tons of CO_2e. Poff (1997) established the concept of the Natural Flow Regime as a surrogate for ecosystem health, noting that alterations in a river's flows, and particularly reductions in flow, directly impact ecosystem function and attributes, including the size of wetlands and riparian corridors supported by river flows[57]. Based on the assumption that the estuary wetlands largely disappeared by the mid-1970s, when no water flowed into the estuary, we make the assumption that the area of the estuary is directly proportional to the amount of water flowing into it. For example, a long-term 10% reduction in total flows would cause a loss of 10% of the estuary's wetlands. The remaining estuary wetlands re-appeared later when saline groundwater was later pumped from beneath cropland upstream in the U.S. to slow the buildup of salt in agricultural soils, as well as treated sewage, was sent downstream. This, combined with occasional small water releases from dams upstream, support the current limited estuary wetland function.

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[51] Ibid.

[52] Rosentreter, Judith, Damien Maher, Dirk Erler, Rachel Murray, and Bradley Eyre. 2018. Methane emissions partially offset "blue carbon" burial in mangroves. Science Advances 4(6). https://doi.org/10.1126/sciadv.aao4985

[53] Huang et al, 2021. Tradeoff of CO2 and CH4 emissions from global peatlands under water-table drawdown. Nature Climate Change 11:618-622. https://www.nature.com/articles/s41558-021-01059-w

[54] Huang et al, 2021. Tradeoff of CO2 and CH4 emissions from global peatlands under water-table drawdown. Nature Climate Change 11:618-622. https://www.nature.com/articles/s41558-021-01059-w

[55] Eve et al, 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. U.S. Department of Agriculture, Washington, DC. 606 pages. https://www.usda.gov/sites/default/files/documents/USDATB1939_07072014.pdf

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[57] Poff, N. LeRoy, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg. "The Natural Flow Regime." BioScience 47, no. 11 (1997): 769–84. https://doi.org/10.2307/1313099.

Downstream Emissions from Ecosystem Losses Caused by the Glen Canyon Dam System

Based on the above, we estimated the minimum fraction of the lost wetland area attributable to filling and operating Powell Reservoir to be 5.3%. We calculated this by averaging two different methods that produced very similar estimates:

- Using the estimated change in average natural annual flows at Lees Ferry, located downstream of Glen Canyon Dam, as a surrogate for the change in estuary area, we estimated the amount of water that evaporated yearly from the reservoir during the period it filled[58,59], and added the fraction of the flows withheld from the watershed required to initially fill the reservoir. This equals 5.3% of the river's flow.

- Using Colorado River flows at the Southern International Boundary (SIB) as a surrogate for estuary area, we estimated the difference between flows at the SIB before and after the reservoir began to fill (late 1963) and the flows at the SIB after the reservoir reached peak storage (in 1984. We estimated this difference to be 5.3% of the river's flows at the SIB.

The above methods do not take into account the additional diversions that the Glen Canyon Dam System makes possible within the complex inter-operations of the states diverting water from the Colorado River's upper and lower basin, in the context of the Colorado River Compact and its treaty with Mexico. Removing the peaks and spreading flows across the hydrograph make additional diversions possible during what previously were low-flow periods. Because of this, we consider this 5.3% fraction to be a very conservative estimate representing the minimum amount attributable to the Glen Canyon Dam System. If we were to take into account diversions that began after the reservoir began filling, and consider whether those diversions would have been possible without the flow regime alterations made possible by Glen Canyon Dam, the amount attributable to the reservoir could be higher.

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[58] Colorado River Basin Natural Flow and Salt Data. 2024. U.S. Bureau of Reclamation. https://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html

[59] Varadharajan, Charuleka, and Harold F. Hemond. "Time‐series Analysis of High‐resolution Ebullition Fluxes from a Stratified, Freshwater Lake." Journal of Geophysical Research: Biogeosciences 117, no. G2 (June 2012): 2011JG001866. https://doi.org/10.1029/2011JG001866.

Downstream Emissions from Ecosystem Losses Caused by the Hoover Dam System

Based on the above, we estimated the minimum fraction of the lost wetland area attributable to filling and operating the Hoover Dam System to be 33.4%. We estimated that 10.3% of the river delta carbon stores were lost due to river flows withheld to fill Mead Reservoir and flows lost to evaporation from the reservoir, and 23% of the river delta carbon stores were lost due to diversions enabled by the presence of the Hoover Dam System. These include the All-American Canal that serves the Imperial and the Coachella Valleys[60]. The proportions of estuary loss attributable to the Hoover Dam System were estimated with the following methods:

- Proportion lost to filling and managing the reservoir = (flows withheld to fill and hold within the reservoir + water evaporated from the reservoir surface) ÷ total natural annual flows at Lees Ferry during the period of 1935-1963)[61,62,63]. This equals 10.3% of the river's flow and hence the corresponding river delta area.

- Proportion lost to diversions enabled by the Hoover Dam System = (flows diverted into the All-American Canal) ÷ (total natural annualized flows at Lees Ferry during the filling period of 1935-1963)[64,65]. This equals 23% of the river's flow and hence the corresponding river delta area.

Decommissioning

Decommissioning of a reservoir has the potential to produce a significant amount of both CH_4 and CO_2 from the mineralization and decomposition of carbon present in exposed sediments. Methane accumulates in sediments and is held in place by the hydrostatic pressure of the water column, until pressure within the sediments is large enough that ebullition (bubbling) events release methane to the reservoir surface. When reservoirs are inevitably decommissioned, and water levels drop to the surface of the sediment, the loss of that hydrostatic pressure releases methane

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[60] https://www.watereducation.org/aquapedia-background/all-american-canal#:~:text=The%20All%2DAmerican%20Canal%20runs,cities%20and%20500%2C000%20agricultural%20acres).

[61] Holman, Kathleen & Pearson, Christopher & Jasoni, Richard & Huntington, Justin & Volk, John. (2022). Evaporation from Lake Mead: In-situ Monitoring between 2018 and 2021. DOI: 10.13140/RG.2.2.19477.19684.

[62] Colorado River Basin Natural Flow and Salt Data. 2024. U.S. Bureau of Reclamation. https://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html

[63] Ibid.

[64] Holman, Kathleen & Pearson, Christopher & Jasoni, Richard & Huntington, Justin & Volk, John. (2022). Evaporation from Lake Mead: In-situ Monitoring between 2018 and 2021. DOI: 10.13140/RG.2.2.19477.19684.

[65] Colorado River Basin Natural Flow and Salt Data. 2024. U.S. Bureau of Reclamation. https://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html

stored in the sediments[66,67]. Additionally, the process of drawing down sediment loads stimulates anoxic microbial activity that causes methane production by methanogenic organisms. Pacca[68] estimated significant emissions from sediments during the reservoir decommissioning process. Amani *et al.* (2022)[69] reported large CH_4 and CO_2 emissions from sediments after decommissioning.

Evidence indicates that the emissions from decommissioning are directly proportional to the amount of sediment captured by the dam. The longer the dam operates, the more sediment accumulates, and the larger the emissions will be at the time of inevitable decommissioning. Emissions for the Glen Canyon and Hoover Dam Facilities were estimated using the Pacca (2007) modeling framework based upon the measured sediment accumulation and bathymetric data to estimate total sediment load in the reservoir at the time of decommissioning, along with physical and chemical attributes of the sediment documented by the U.S. Geological Survey[70,71,72].

Periodic sediment flushes are used in a number of dam facilities to address safety and management problems caused by sediment accumulation[73]. Neither Hoover Dam nor Glen Canyon Dam facilities were designed for periodic flushing, and hence there are no mechanisms to reduce sediment accumulation and therefore the eventual release of methane from the accumulated sediments.

Uncertainty Analyses

The All-Res Modeling Tool includes an uncertainty analysis that utilizes the Monte Carlo processes recommended by the IPCC[74]. The method incorporates published

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[66] Varadharajan, Charuleka, and Harold F. Hemond. “Time-series Analysis of High-resolution Ebullition Fluxes from a Stratified, Freshwater Lake.” Journal of Geophysical Research: Biogeosciences 117, no. G2 (June 2012): 2011JG001866. https://doi.org/10.1029/2011JG001866.

[67] Beaulieu, Jake J., David A. Balz, M. Keith Birchfield, John A. Harrison, Christopher T. Nietch, Michelle C. Platz, William C. Squier, et al. “Effects of an Experimental Water-Level Drawdown on Methane Emissions from a Eutrophic Reservoir.” Ecosystems 21, no. 4 (June 1, 2018): 657–74. https://doi.org/10.1007/s10021-017-0176-2.

[68] Pacca, S., 2007. Impacts from decommissioning of hydroelectric dams: a life cycle perspective. Climatic Change, Vol 84 pp 281-294. https://link.springer.com/article/10.1007/s10584-007-9261-4

[69] Amani, M, D von Schiller, I Suárez, M Atristain, A Elosegi, R Marcé, G García-Baquero, and B Obrador. “The Drawdown Phase of Dam Decommissioning Is a Hot Moment of Gaseous Carbon Emissions from a Temperate Reservoir.” INLAND WATERS 12, no. 4 (October 2, 2022): 451–62. https://doi.org/10.1080/20442041.2022.2096977.

[70] Sedimentation in Lake Powell. 2021. Recent USGS Utah Water Science Center activities. https://www.epa.gov/system/files/documents/2022-04/usgs_november-1-2021_508.pdf

[71] Johnson, Cari L., Jonathan Casey Root, Scott A. Hynek, and John (Jack) C. Schmidt. 2022. Sedimentary record of annual-decadal timescale reservoir dynamics: Anthropogenic stratigraphy of Lake Powell, Utah, U.S.A. doi: 10.2110/sedred.2022.1.3, https://thesedimentaryrecord.scholasticahq.com/article/33914-sedimentary-record-of-annual-decadal-timescale-reservoir-dynamics-anthropogenic-stratigraphy-of-lake-powell-utah-u-s-a

[72] Ferrari (U.S. Bureau of Reclamation). 2008. 2001 Lake Mead Sedimentation Survey

[73] Morris, Gregory L. Travis A. Dahl, Marielys Ramos-Villanueva, Jamres R. Leech, and Meg M. Jonas. 2023. Sustainable Sediment Management at US Army Corps of Engineers Reservoirs. U.S. Army Corps of Engineers ERDC Report ERDC/CHL TR-23-2. https://apps.dtic.mil/sti/trecms/pdf/AD1193098.pdf

[74] Eve et al, 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. U.S. Department of Agriculture, Washington, DC. 606 pages.
https://www.usda.gov/sites/default/files/documents/USDATB1939_07072014.pdf

probability distributions of emissions factors, carbon stocks, construction materials, and activity data, based on published means, ranges, and standard deviations. Using a 1000-iteration approach, the resulting emissions are described by their mean and percentile distributions. The uncertainty analysis was not applied to emissions associated with the Operations and Maintenance pathways since data from which those emissions were derived from data in Bureau of Reclamation documentation and scientific reports that provided no confidence intervals[75,76].

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[75] U.S. Bureau of Reclamation, Glen Canyon Unit: https://www.usbr.gov/uc/rm/crsp/gc/

[76] Pacca, Sergio and Arpad Horvath. 2002. Greenhous Gas Emissions from Guiding and Operating Electric Power Plants in the Upper Colorado River Basin. Environmental Science and Technology (36):3194-3200

GLEN CANYON DAM SYSTEM RESULTS

The Glen Canyon Dam System is estimated to cause the emissions of approximately 178 million metric tons of CO_2e over a 100-year lifecycle projection, or approximately 1.78 million metric tons of CO_2e/year. These emissions are comparable to the total estimated emissions from the four Lower Snake River Dams[77]. The most significant emissions are, in decreasing order (see Table 1 and Figure 8 below):

Table 1:
Estimated Greenhouse Gas Emissions From Known Life Cycle Emissions Sources caused by **Glen Canyon Dam System.**

METRIC TONS OF CO_2e A YEAR	
503,400	Lost ecosystem carbon and nitrogen from downstream wetlands and riparian forests
484,000	CH_4 from the reservoir surface, turbines, and bypass tubes
465,000	Decommissioning
234,000	Land Use Change & Lost Carbon Sequestration
91,600	Dam Construction
2,082	Reservoir Operations

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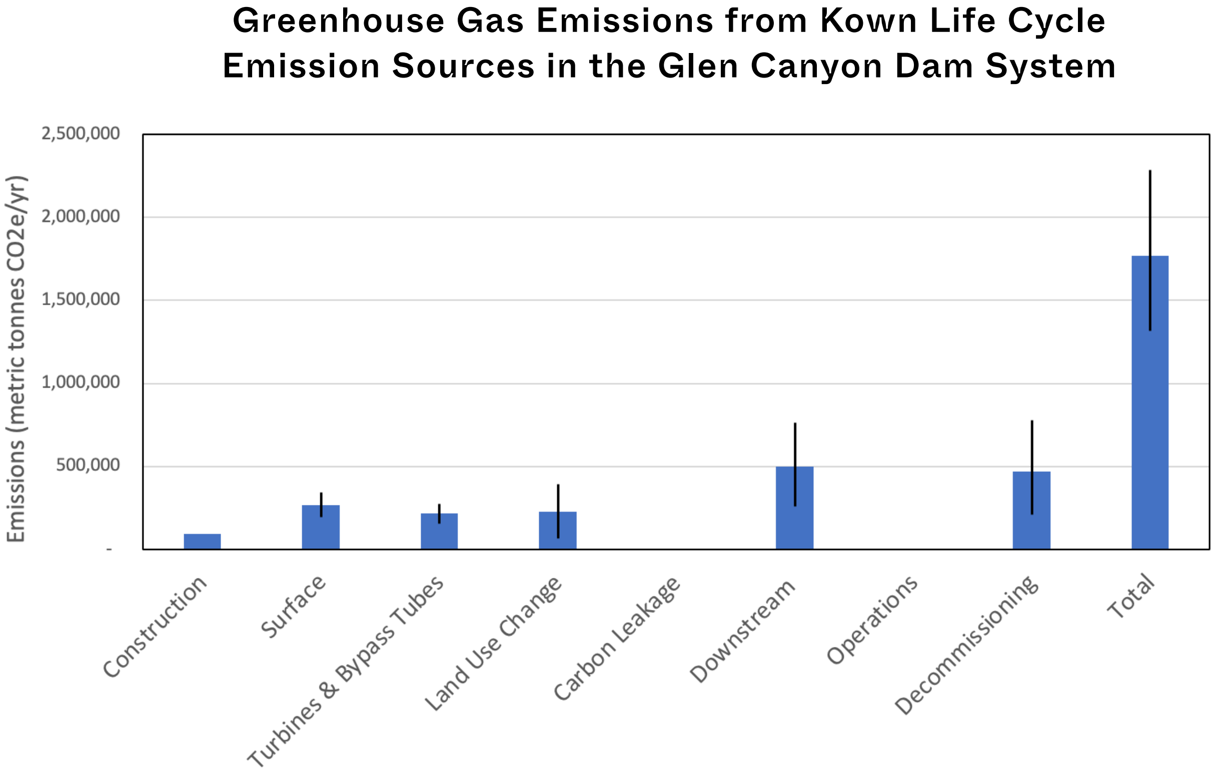
[77] Wockner, Gary, Mark Easter, and Gordon McCurry. 2024. Estimate of Greenhouse Gas Emissions for the Lower Snake River Dams and Reservoirs using the All-Res Modeling Tool. https://tellthedamtruth.com/wp-content/uploads/2024/03/LSR-Dam-Reservoir-Estimated-GHG-Emissions-Final.pdf

Figure 8: Distribution of estimated emissions of CO_2e/year by emissions sources for the Glen Canyon Dam System. The blue bars show the mean emissions +/- 95% confidence interval.



For comparison, using the EPA's GHG emissions calculator[78], this amount of yearly emissions is equivalent to the emissions described in Figure 9 below.

For further comparison, the U.S. Environmental Protection Agency requires that certain large emitters in the U.S. report under the EPA's Greenhouse Gas Reporting Program if their emissions equal or exceed 25,000 metric tons of CO_2e/year[79]. The Glen Canyon Dam System's estimated yearly emissions are 71 times greater than the EPA's reporting threshold.

Figure 9: Emissions Comparisons From EPA's Greenhouse Gas Equivalencies Calculator

Equivalent emissions for **1.78 million** metric tons of CO_2

424,000

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

4,550,000,000

MILES DRIVEN BY AVERAGE GAS POWERED VEHICLE FOR ONE YEAR, OR,

200,300,000

GALLONS OF GAS CONSUMED FOR ONE YEAR, OR,

175,000,000

GALLONS OF DIESEL CONSUMED FOR ONE YEAR, OR,

2,000,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

24,000

TANKER TRUCKS' WORTH OF GASOLINE

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[78] U.S. EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[79] U.S. EPA Greenhouse Gas Reporting Program. https://www.epa.gov/ghgreporting

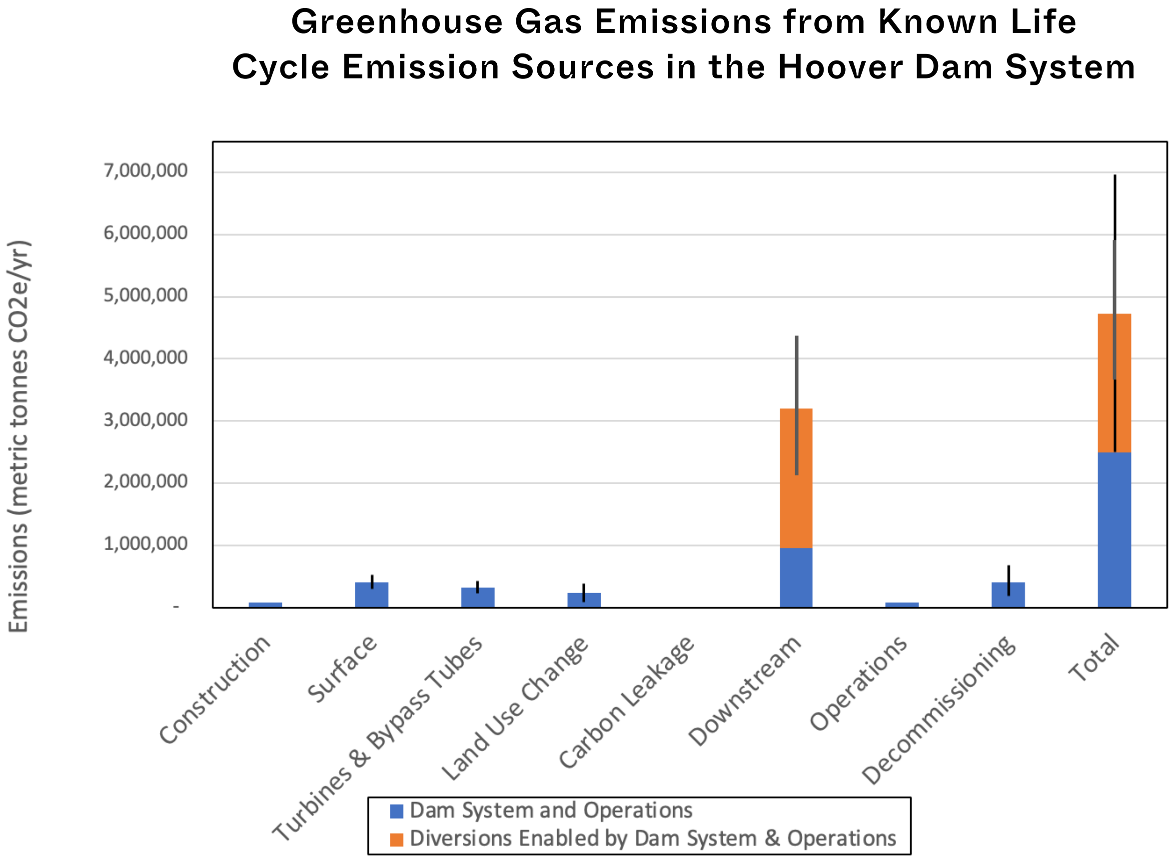
HOOVER DAM SYSTEM RESULTS

The Hoover Dam System is estimated to emit approximately 470 million metric tons of CO_2e over a 100-year life cycle projection, or approximately 4.7 million metric tons of CO_2e/year. For reference, the total life cycle emissions are more than three times greater than those from the Glen Canyon Dam system. The most significant emissions are, in decreasing order (See Table 2 and Figure 10 below)

Table 2: Estimated Greenhouse Gas Emissions From Known Life Cycle Emissions Sources caused by **Hoover Dam System.**

METRIC TONS OF CO_2e A YEAR	
3,200,000	Lost ecosystem carbon and nitrogen from downstream wetlands and riparian forests ("Dam System and Operations" + "Diversions Enabled by the Dam System and Operations")
732,000	CH_4 from the reservoir surface, turbines, and bypass tubes
407,000	Decommissioning
236,000	Land Use Change & Lost Carbon Sequestration
81,000	Dam Construction
74,000	Reservoir Operations

Figure 10: Distribution of estimated emissions of CO_2e/year by emissions sources for the Hoover Dam System. The blue bars show the mean emissions +/- 95% confidence interval.



For comparison, using the EPA's GHG emissions calculator[80], this amount of yearly emissions is equivalent to the emissions described in Figure 11 below:

For further comparison, the U.S. Environmental Protection Agency requires that certain large emitters in the U.S. report under the EPA's Greenhouse Gas Reporting Program if their emissions equal or exceed 25,000 metric tons of CO_2e/year[81]. The Hoover Dam System estimated yearly emissions are 188 times greater than the EPA's reporting threshold.

Figure 11: Emissions Comparisons From EPA's Greenhouse Gas Equivalencies Calculator

Equivalent emissions for **4.7 million** metric tons of CO_2

1,119,000

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

12,021,000,000

MILES DRIVEN BY AVERAGE GAS POWERED VEHICLE FOR ONE YEAR, OR,

528,900,000

GALLONS OF GAS CONSUMED FOR ONE YEAR, OR,

461,700,000

GALLONS OF DIESEL CONSUMED FOR ONE YEAR, OR,

5,180,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

62,200

TANKER TRUCKS' WORTH OF GASOLINE

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[80] U.S. EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[81] U.S. EPA Greenhouse Gas Reporting Program. https://www.epa.gov/ghgreporting

Notes Regarding Conservative Emissions Estimates

The emissions estimated in this report are likely a conservative under-estimate of the actual emissions from the Glen Canyon and Hoover Dam Systems, for the following reasons:

- The carbon stock losses due to dewatering of the Colorado River estuary are likely a conservative underestimate. The authors of the studies that report carbon stocks in estuary soils report that due to limitations in the equipment available, measurements of carbon stocks had to be limited to only 1 meter in depth. The studies note that the carbon-rich soil layers underlying these ecosystems are likely significantly deeper than 1 meter, with greater carbon stocks than scientists were able to measure.

- Tidal estuary ecosystems, including marshes, forests, and mud flats, have been shown to be net carbon sinks. The former Colorado River Delta was likely to be steadily accumulating carbon in its soils and sediments before upstream diversions forced its disappearance. Losing that net carbon sink is a significant opportunity cost of lost carbon sequestration, which could not be accounted for in this study due to a lack of historical data on carbon accumulation rates.

- Since the Hoover Dam System is likely to exist beyond the year 2034, which is the end of the 100-year life-cycle assessment time period used in this analysis, GHG emissions from the Surface, Turbine, O&M, and decommissioning emissions categories would be larger than calculated.

- The assumption that turbine emissions are 80% of surface emissions is estimated as the lower end of the emissions range reported by Delwiche.

THE
AUTHORS

Tell The Dam Truth (TTDT) fights the climate crisis by advocating for the protection and restoration of native river ecosystem biodiversity and carbon sequestration. TTDT works to include all of the impacts of dams in all public decision-making around dam permitting, re-licensing, and decommissioning.

TELLTHEDAMTRUTH.COM

Gary Wockner, PhD, is an award-winning environmental activist and author who directs Tell The Dam Truth. Gary has over two decades of experience protecting rivers in Colorado, the Southwest U.S., and across the world. He has written and lectured extensively for public audiences and the media about the greenhouse gas emissions caused by dams and reservoirs.

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Gordon McCurry, PhD, is a hydrologist with more than 35 years of experience with quantitative analyses and modeling of groundwater and surface water systems. He has been involved in evaluating the hydrologic effects of climate change for several decades, focusing on how changes in precipitation and temperature affect both water supply and water demand, and how water management practices need to adapt to our new hydrology. Gordon is a TTDT consultant.