Estimate of Greenhouse Gas Emissions for the **Lower Snake River Dams and Reservoirs** using the All-Res Modeling Tool


Lower Granite Dam, Snake River. Credit: EcoFlight

Prepared by Tell The Dam Truth, Inc.

Executive Summary

The four Lower Snake River dams, reservoirs, and their hydropower systems ("LSR dams") – Lower Granite, Little Goose, Lower Monumental, and Ice Harbor – in the state of Washington have been at the center of national controversy in recent months. Because the dams block the passage of native salmon, a decades-long interest has come to a head to promote removing the dams to restore salmon. At the same time, some advocates for keeping the dams in place continue to argue that the dams create "clean energy" and are "carbon-free" sources of electricity. This report seeks to address those claims by shedding light on the greenhouse gas (GHG) emissions caused by the LSR dams and the reservoirs the dams impound.

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 emissions caused by dams and reservoirs. Dam, reservoir, and hydropower systems worldwide emit hundreds of millions of tons of the greenhouse gases carbon dioxide, methane, and nitrous oxide. Methane, an extremely potent climate pollutant, is the largest contributor of climate-heating emissions from these systems.

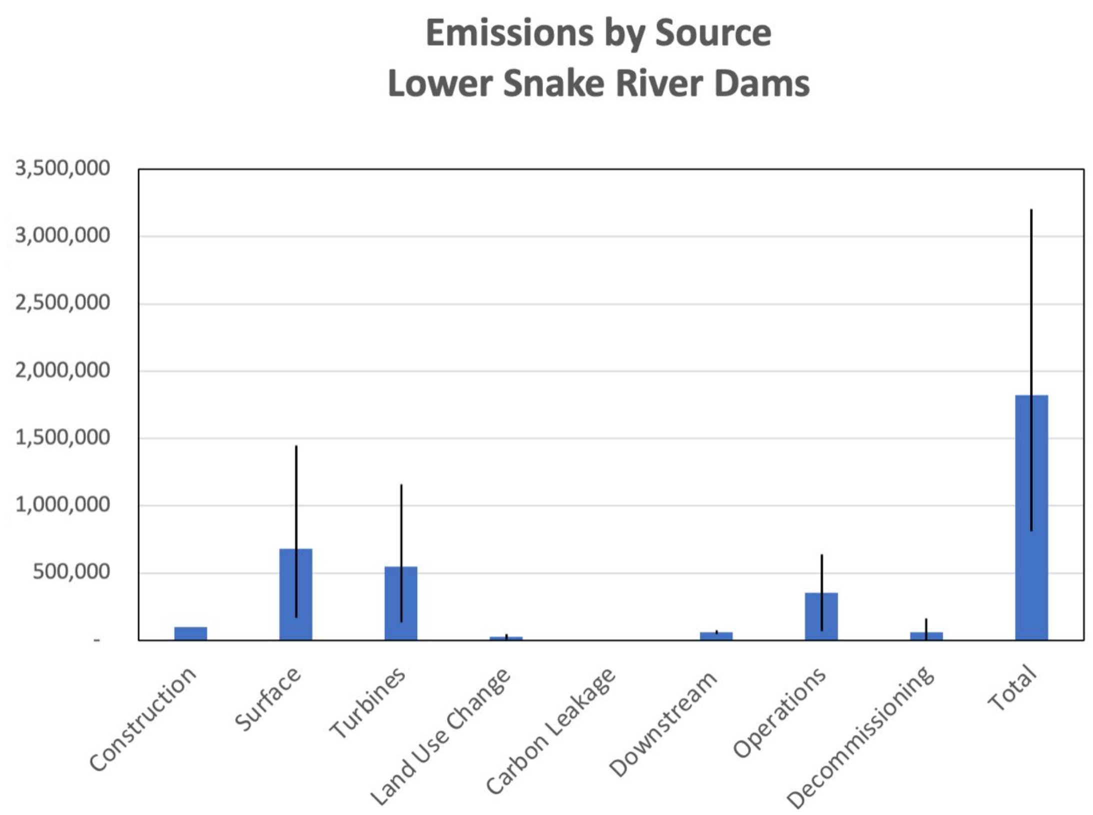
In this report, we apply the All-Res Modeling Tool ("All-Res") to estimate the life cycle GHG emissions from LSR dams, reservoirs, and their hydropower systems. All-Res is an advancement over existing modeling tools and frameworks because it estimates emissions using a cradle-to-grave, life cycle analysis framework, and includes all of the known greenhouse gas emissions attributed to dam, reservoir, and hydropower systems in the scientific literature.

The U.S. Environmental Protection Agency (EPA) requires large facilities to report emissions if their emissions exceed 25,000 metric tons of CO_2e/year. The LSR dams emit more than 70 times that threshold annually. Multiple state, federal, and international initiatives are underway to reduce methane emissions due to their very high impact and potential to warm the climate to dangerous levels in the short term.

In All-Res, we used the best available data from federal reports and scientific literature. Where there was a lack of data about the LSR dams systems – which included the chemical and biological state of the reservoirs and their impacts downstream – we used very conservative estimates such that the emissions reported in this document are likely an underestimate.

We strongly encourage decision-makers and public agencies to consider the GHG emissions caused by the LSR dams in any ongoing or future management, permitting, or decommissioning decisions.

Figure 1: Distribution of predicted emissions of CO_2e/year by emissions pathway for the LSR dams over their 100-year life cycle



The LSR dams **estimated to emit approximately**

1,800,000

METRIC TONS OF CO_2e/YEAR

The LSR dams emit* approximately **the same as**

405,000

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

2,000,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

202,500,000

GALLONS OF GASELINE CONSUMED FOR ONE YEAR

Snake River. Credit: EcoFlight

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

Introduction

Over the last few decades, dam, reservoir, and hydropower facilities have come under increasing scientific scrutiny because of the greenhouse gases they emit. More than 760 peer-reviewed scientific studies since 1974 describe GHGs from dam and reservoir projects, including those generating hydropower. Projects built primarily for hydropower production sometimes can emit even more GHGs than coal-fired power plants producing an equal amount of electricity.[1,2,3,4]

Further, in 2022 and for the first time in history, the 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. Army Corps of Engineers (USACE), the Bonneville Power Administration (BPA), the U.S. Fish and Wildlife Service, public news articles, and other sources, we developed and applied All-Res[6] to calculate the total carbon footprint over the life cycle of the LSR dams.

The U.S. Army Corps of Engineers' Walla Walla District owns and operates the four Lower Snake River dams, all of which are multiple-use facilities. The electricity generated at the dams is marketed and sold to consumers and utilities across the Pacific Northwest by the Bonneville Power Administration which is a nonprofit federal power marketing administration. Figure 2 below is the location of the four LSR dams; Figure 3 depicts where Bonneville markets and sells that electricity.

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 2: Vicinity Map, Lower Snake River dams

Figure 3: Bonneville Power Transmission System

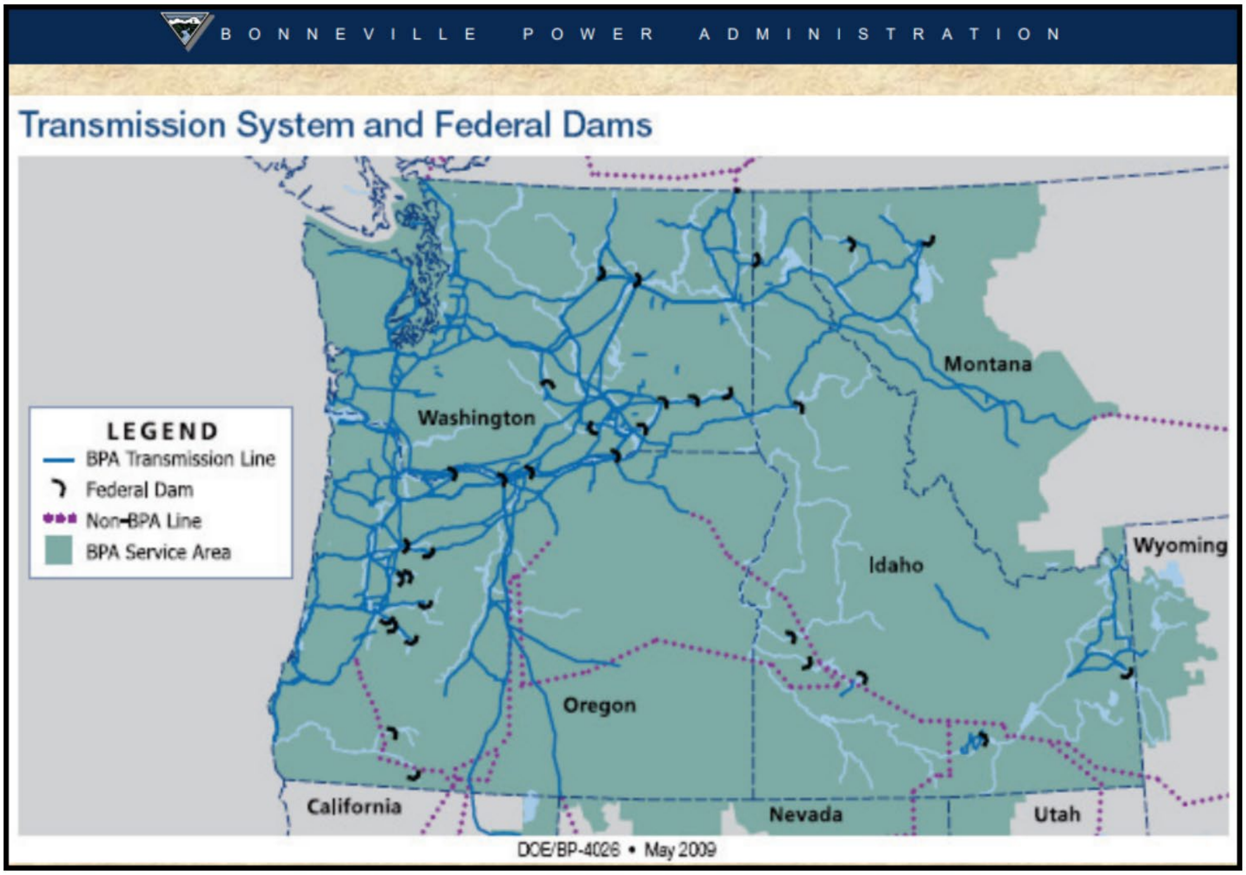


Figure 4: Little Goose Dam

Figure 5: Ice Harbor Dam

Figure 6:
Lower Granite Dam

Figure 7:
Lower Monumental Dam

THE ALL-RES MODELING TOOL

We applied All-Res to the LSR dams from initial construction to inevitable decommissioning and compared total greenhouse gas emissions to other emissions sources using the EPA's emissions comparison calculator.

All-Res uses a cradle-to-grave, 100-year life cycle period — a common metric in greenhouse gas accounting for these facilities — to calculate the total carbon footprint of a dam, reservoir and hydropower facility.

The All-Res modeling tool is an advancement over existing models used to estimate greenhouse gas emissions from reservoir systems because it examines the full, cradle-to-grave scope of the greenhouse gas emissions source categories documented in peer-reviewed scientific literature attributable to a dam and reservoir project. Existing tools examine only a portion of the life cycle scope, leaving out emissions from end-of-life facility decommissioning, downstream biogenic emissions caused by the facility, carbon leakage, loss of ecosystem function, and significant fractions of land-use-change emissions.

The following emissions pathways are included in All-Res:

- 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 fluctuating water levels, altered river hydrographs, and reductions in river flows, including ecosystem carbon loss from dewatering of wetlands, riparian forests, and estuarian ecosystems such as seagrass beds and wetland forests.

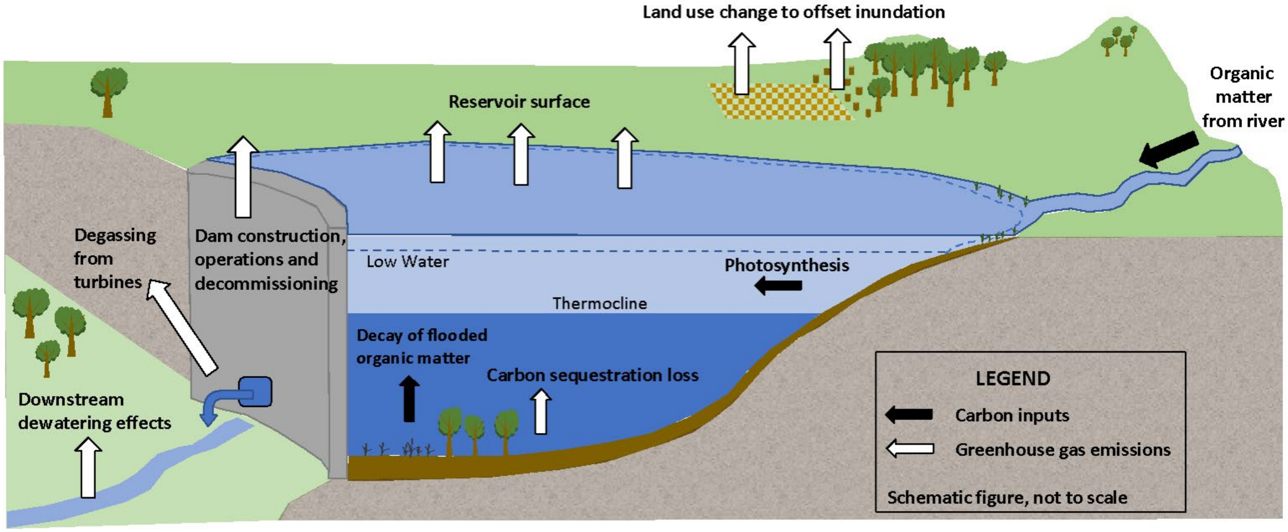
Each of these are described below, including a summary of the key components and methods used to estimate the emissions from each pathway. See figure 8, below, for a graphical depiction of all emissions sources and pathways.

Per convention as described by the IPCC, All-Res estimates 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.[7]

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 8:
Emissions pathways in a dam and reservoir facility included in All-Res



EMISSIONS PATHWAYS INCLUDED IN THE 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 construction of the LSR dams are derived from multiple sources including USACE documentation[8,9,10] and newspaper reports from the time of construction. 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 LSR dams include maintenance activities, use of recreational areas around the reservoir, operation of spillways, turbines, and locks, operating fish hatcheries associated with environmental damage mitigation, and dredging. Data for these activities are derived from the Columbia River Systems Operations Environmental Impact Statement (EIS)[12], the LSR Final Programmatic Sediment Management Plan EIS, and other sources. No information was publicly available on energy used by the dams for operating locks, spillways, and other information, so average emissions from other dam systems as described by Song *et al.* (2018) were applied to the LSR dams[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].

Decommissioning

Decommissioning 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. Pacca[15] estimated significant emissions from sediments during the reservoir decommissioning process. Amani *et al.* (2022)[16] reported large

8. Concrete Pouring Phase is Begun in Lower Granite Dam Construction. Spokane Daily Chronicle, Feb 17, 1971.
9. U.S. Army Corps of Engineers. 1996. Ice Harbor Lock and Dam. Lake (sic) Sacajawea, Washington. Feature Design Memorandum No. 34. Spillway Deflectors. https://apps.dtic.mil/sti/tr/pdf/ADA323414.pdf
10. Barcott, Bruce. 1999. Blow Up. Outside Magazine. https://www.outsideonline.com/outdoor-adventure/environment/blow/
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. Army Corps of Engineers. 2020. Columbia River System Operations Final Environment Impact Statement. https://www.nwd.usace.army.mil/CRSO/Final-EIS/#top
13. Song, CH, KH Gardner, SJW Klein, SP Souza, and WW Mo. “Cradle-to-Grave Greenhouse Gas Emissions from Dams in the United States of America.” RENEWABLE & SUSTAINABLE ENERGY REVIEWS 90 (July 2018): 945–56. https://doi.org/10.1016/j.rser.2018.04.014.
14. U.S. Environmental Protection Agency. 2024. Emissions & Generation Resource Integrated Database (eGRID). https://www.epa.gov/egrid
15. 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
16. 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.

methane and carbon dioxide emissions from sediments after decommissioning. Emissions were estimated using the Pacca (2007) modeling framework based upon the measured sediment accumulation in the four reservoirs and bathymetric maps of the four reservoirs to estimate total sediment load in the reservoirs at the time of decommissioning, along with physical and chemical attributes of the sediment as described in the LSR Programmatic Sediment Management Plan EIS and its appendices[17].

Reservoir Surface

Greenhouse gases from reservoirs 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 over the life of the reservoir. Microbes in the reservoir water column and in reservoir sediments consume the organic matter and release carbon dioxide in oxygen-rich portions of the reservoir, and produce methane in the oxygen-depleted depths of the reservoir. The gases move to the surface through diffusion and bubbling (ebullition). Methane that is not oxidized by methane-consuming organisms in the water column during diffusion and ebullition are emitted from the reservoir surface. Carbon dioxide 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. Deemer *et al*.[18] provided an estimated CH_4 surface flux emissions for 267 reservoirs worldwide, and their dataset provides a useful framework for modeling surface methane emissions. The LSR dams are classified as “upper mesotrophic”, “lower eutrophic”, and “eutrophic” by the Columbia River Operations EIS. For the LSR dams we conservatively applied an emissions factor derived from the Deemer *et al*. (2016, 2020) dataset for mesotrophic reservoirs in temperate regions. This emissions factor was applied to the deeper water portions of the reservoir (>6m depth), where *chlorophyll a* measurements indicate mesotrophic conditions. For shallow-water portions of the reservoir (<6m, 39% of Lower Granite surface area

17 Ibid.
18 Deemer, Bridget R., John A. Harrison, Siyue 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.

and 15% of the other 3 reservoirs) where eutrophic conditions dominate, we applied an emissions factor from measurements reported by Miller *et al*. (2020) and which were comparable to *chlorophyll a* measurements reported by Arntzen *et al*. (2013) [19,20].

Turbine

Reservoir water discharge through turbines or outlets, referred to here as the turbine pathway, are a source of significant methane emissions. These emissions are due to degassing of methane-rich water discharged from the oxygen-depleted depths of reservoirs through turbines. These emissions are released due to the rapid drop in hydrostatic pressure when water exits turbines into the river/reservoir/canal downstream. Emissions of CH_4 are much higher for outlets that are situated below the reservoir thermocline, in the hypolimnion, due to the anoxic conditions present in those waters. Delwiche *et al.*[21] estimated that CH_4 emissions at outlets are likely 80 to 95 percent of surface emissions, which is consistent with other publications. A value of 80% of surface emissions has been used in the current version of All-Res to estimate emissions from the turbine pathway.

Land Use Changes Caused by the LSR Reservoirs

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[22]; and the production of CO_2 due to decomposition of organic matter in inundated trees, shrubs, and grasses[23], and in the soil at the reservoir bottom[24].

The equivalent emissions of lost carbon sequestration are quantified using the IPCC greenhouse gas inventory guidance[25,26,27], for estimating the total carbon stock and the rate of change of carbon stock at the time of inundation.

19 Arntzen, Evan V., Benjamin L. Miller, Amanda C. O'Toole, Sara E. Niehus, and Marshall C. Richmond. "Evaluating Greenhouse Gas Emissions from Hydropower Complexes on Large Rivers in Eastern Washington," March 15, 2013. https://doi.org/10.2172/1082603.
20 Miller, BL, EV Arntzen, AE Goldman, and MC Richmond. "Methane Ebullition in Temperate Hydropower Reservoirs and Implications for US Policy on Greenhouse Gas Emissions." ENVIRONMENTAL MANAGEMENT 60, no. 4 (October 2017): 615–29. https://doi.org/10.1007/s00267-017-0909-1.
21 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
22 Ibid.
23 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.
24 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
25 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
26 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
27 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

Riparian forests are estimated to have covered 15% of the reservoir area at the time of inundation. Riparian forest carbon was derived from studies from the state of Washington[28]. The remaining area is assumed to have been in settlements (5%) and grassland.

Beaulieu *et al.* (2020)[29] and Deemer *et al.*[30] estimated that between 73% and 84% of the organic matter in trees and soils under the reservoir at the time of inundation is decomposed into carbon dioxide. The remainder is estimated to be decomposed into methane. The methane emissions from inundated organic matter are included in surface emissions and the carbon dioxide emissions are included in emissions from land use change, to avoid double-counting.

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 by the USACE were found to have documented the extent of settlements by Indigenous peoples or European settlers, nor the land uses under the reservoir footprint at the time the lands were flooded. Hawley (2023)[31] described the experiences of the Palouse, Confederated Tribes of the Colville Reservation, and other Indigenous peoples who were evicted from their lands when the LSR reservoirs were first flooded. Orgill (2022)[32] reconstructed some aspects of historic land uses by Indigenous peoples and European settlers prior to the flooding. From these sources we assume that 5% of the land area under the reservoir footprint was in human settlements, and the remaining 95% was utilized for hunting, gathering, and livestock grazing.

Emissions estimates for carbon stock losses due to replacing these land uses on other lands were estimated from the IPCC guidance (Penman *et al.*[33], Lasco *et al.*[34], and Lovelock *et al.*[35]).

28 Glenn A. Christensen, Andrew N. Gray, Olaf Kuegler, & Dan Siemann. 2018. Washington Forest Ecosystem Carbon Inventory: 2002-2016. https://www.dnr.wa.gov/publications/em_wa_carbon_inventory_final_111220.pdf
29 Ibid.
30 Ibid.
31 Hawley, Steven. 2023. Cracked: The Future of Dams in a Hot, Chaotic World. Patagonia Works.
32 Orgill, Lexi. June 22, 2022. Beneath the Lower Snake River: Looking to the river's past to re-imagine the resources that could once again become part of its future. National Parks Conservation Association. https://storymaps.arcgis.com/stories/fe619c445c32456dba42f89f101cf7a1.
33 Ibid 13.
34 Ibid 14.
35 Ibid 15.

These emissions estimates do not include the greenhouse gas emissions from establishing and operating aquaculture operations to replace the renewable resource of millions of pounds of salmon produced annually by the Snake River system prior to inundation. This consequence of land use change is an additional significant driver of carbon leakage from this system.

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 wetlands and other riparian vegetation, causing a loss of ecosystem carbon and nitrogen through decomposition of dead plants and loss of soil organic carbon and nitrogen. This decomposition process produces CH_4, 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. 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 river banks.

Most of the native wetlands and riparian forests present in the Snake and Columbia River systems above the Bonneville Dam were inundated under reservoirs within the Snake River watershed and downstream[36]. The Columbia River EIS does not clearly quantify the extent of wetlands affected by the inundation, nor does it quantify impacted wetlands downstream of Bonneville Dam into the river's region where ocean tidal influence increasingly affects the hydrologic cycle.

According to Brophy *et al.* (2022), 74% of the tidal wetlands in the Columbia River estuary have been lost due to disrupted hydrologic processes and post-reservoir land use change in the region, totaling 30,640 hectares (75,680 acres)[37]. For this report we partitioned those lost estuary wetlands evenly into saltmarsh and forested wetlands. These wetlands are typically underlain with peat soils that are no longer supported by the native hydrologic regime of the Columbia River and the previous vegetations. The peat in these soils is assumed to decompose in the same ways that peat soils drained for agricultural production would decompose[38,39]. The

36 Ibid.
37 Brophy LS, Greene CM, Hare VC, Holycross B, Lanier A, Heady WN, et al. (2019) Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PLoS ONE 14(8): e0218558. https://doi.org/10.1371/journal.pone.021855.

impacted area was estimated as 3.15%, by equating the disrupted wetland area to the fraction of reservoir storage volume of the LSR dams, to the total reservoir storage volume in the Columbia River watershed.

The Columbia River EIS describes mitigation projects in the region, however none of the projects are clearly described as "additional" or designed to compensate for ecosystem carbon and nitrogen losses from the systems. The projects were implemented by various state, federal, and local agencies to meet varying purposes and needs. For projects to be classified as "additional" – meaning they would offset carbon emissions from loss of wetlands and ecosystem function within the LSR system boundary – they would have to be planned and implemented as a direct result of the LSR dams.

Uncertainty Analyses

All-Res includes an uncertainty analysis that utilizes the Monte Carlo processes recommended by the IPCC[40]. The method incorporates published 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 Construction, Operations, nor Maintenance pathways since data from which those emissions were derived from data in USACE documentation and news reports that provided no confidence intervals.

38 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

39 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

40 Ibid.

LOWER SNAKE RIVER DAMS AND RESERVOIRS RESULTS

The LSR dams **estimated to emit approximately**

180,000,000

METRIC TONS OF CO_2e /YEAR **OVER 100 YEAR LIFE CYCLE, OR**

1,800,000

METRIC TONS OF CO_2e **A YEAR**

The **most significant emissions**, in decreasing order

1,200,000

METRIC TONS CO_2e /YR FROM **METHANE FROM THE RESERVOIR SURFACE AND TURBINES**

355,000

METRIC TONS CO_2e/YR FROM **RESERVOIR OPERATIONS**

99,000

METRIC TONS CO_2e/YR FROM **DAM CONSTRUCTION**

59,000

METRIC TONS CO_2e/YR FROM **LOST ECOSYSTEM CARBON FROM DOWNSTREAM WETLANDS AND RIPARIAN FORESTS**

57,000

METRIC TONS CO_2e/YR FROM **DAM DECOMMISSIONING**

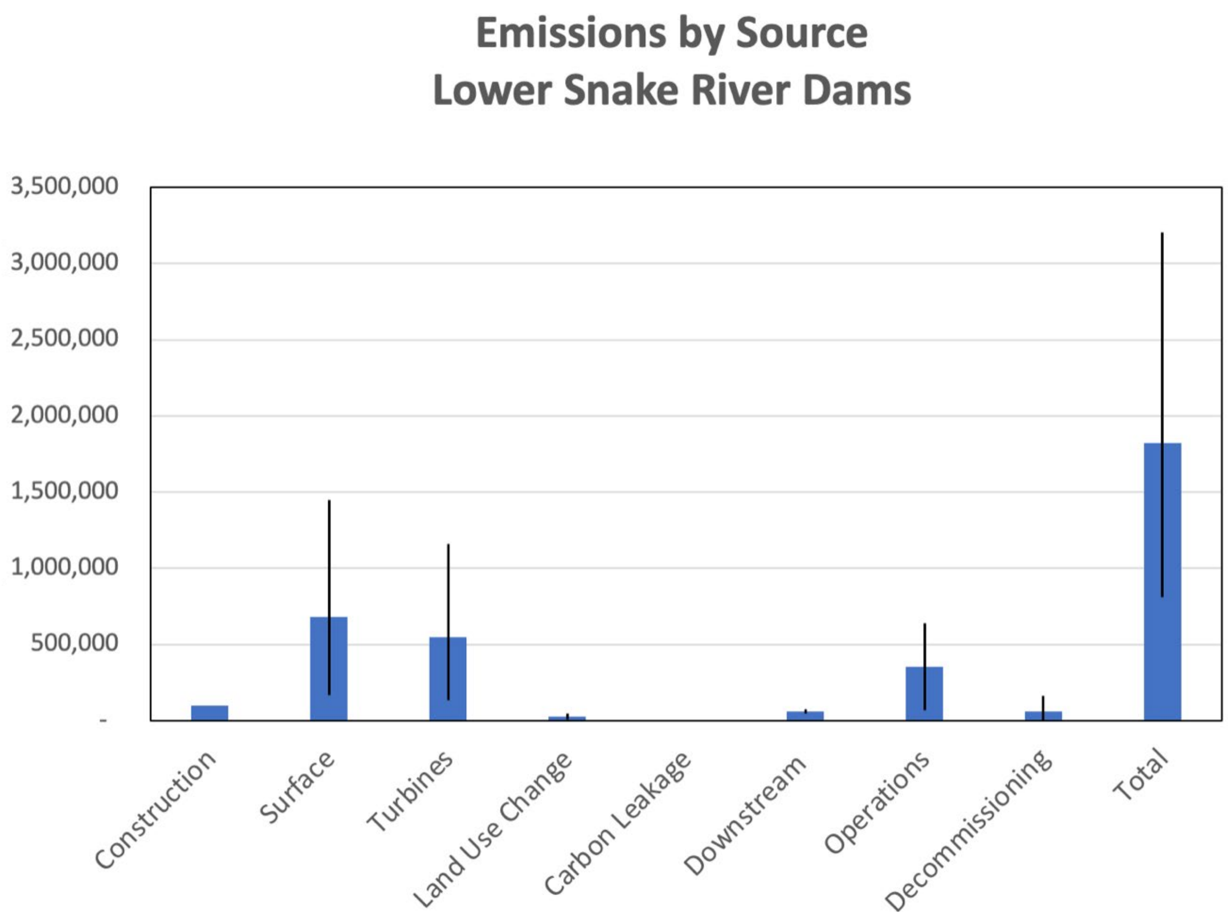
25,000

METRIC TONS CO_2e/YR FROM **LAND USE CHANGE & LLST CARBON SEQUESTRATION**

500

METRIC TONS CO_2e/YR FROM **CARBON LEAKAGE**

Figure 9: Distribution of predicted emissions of CO_2e/year by emissions pathway for the LSR dams over their 100-year life cycle



For comparison, using the EPA's GHG emissions calculator[41], the amount of yearly emissions from LSR dams is approximately equivalent to:

Equivalent emissions for **1.8 million** metric tons of CO_2

400,000

GAS-POWERED AUTOMOBILES DRIVEN FOR ONE YEAR, OR,

4,600,000,000

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

202,500,000

GALLONS OF GAS CONSUMED FOR ONE YEAR, OR,

176,000,000

GALLONS OF DIESEL CONSUME DFOR ONE YEAR, OR,

2,000,000,000

POUNDS OF COAL BURNED IN ONE YEAR, OR,

23,000

TANKER TRUCKS' WORTH OF GASOLINE

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

For further comparison, the EPA's Greenhouse Gas Reporting Program requires that certain large emitters in the U.S. report if their emissions equal or exceed 25,000 metric tons of CO_2e/year[42]. The LSR dams estimated emissions are over 70 times greater than the EPA's reporting threshold.

The total emissions from this report are likely a conservative underestimate of the actual emissions, for the following reasons:

- Hydropower was reported by the Northwest Power Pool (NWPP) to have zero emissions in their energy mix, which is demonstrably false as evidenced in this report and numerous scientific studies[43,44,45]. Were the actual emissions from hydropower included in the NWPP emissions estimate, the emissions per megawatt-hour would be significantly higher, and the corresponding emissions from dam operations due to electricity use would be correspondingly higher.

- The surface emissions reported here likely underestimate the total surface emissions from the LSR dams. High *chlorophyll a* concentrations and high methane emissions are unlikely to be restricted to shallow portions of the reservoirs, as reports document widespread algal blooms (which are linked to high methane emissions[46,47,48]) in the LSR reservoirs[49]. Reservoir surface methane emissions

42 U.S. EPA Greenhouse Gas Reporting Program. https://www.epa.gov/ghgreporting
43 Rosentreter, JA, AV Borges, BR Deemer, MA Holgerson, SD Liu, CL Song, J Melack, et al. "Half of Global Methane Emissions Come from Highly Variable Aquatic Ecosystem Sources." NATURE GEOSCIENCE 14, no. 4 (April 2021): 225-+. https://doi.org/10.1038/s41561-021-00715-2.
44 Deemer, BR, JA Harrison, SY Li, JJ Beaulieu, T Delsontro, N Barros, JF Bezerra-Neto, SM Powers, MA dos Santos, and JA Vonk. "Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis." BIOSCIENCE 66, no. 11 (November 2016): 949–64. https://doi.org/10.1093/biosci/biw117.
45 Song, CH, KH Gardner, SJW Klein, SP Souza, and WW Mo. "Cradle-to-Grave Greenhouse Gas Emissions from Dams in the United States of America." RENEWABLE & SUSTAINABLE ENERGY REVIEWS 90 (July 2018): 945–56. https://doi.org/10.1016/j.rser.2018.04.014.
46 Deemer, BR, and MA Holgerson. "Drivers of Methane Flux Differ Between Lakes and Reservoirs, Complicating Global Upscaling Efforts." JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES 126, no. 4 (April 2021). https://doi.org/10.1029/2019JG005600.
47 Ibid.
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are reported to be increasing over time[50], and climate-induced variability in reservoir surface levels due to watershed-level hydrologic instability are increasingly likely, driving additional increases in reservoir emissions[51]. The *chlorophyll a* samples reported in the Columbia River EIS were not a spatially-derived representative sample set that describes the entire reservoir surface area. Samples taken to show gradations in *chlorophyll a* between shallow and deep water portions of the reservoir would likely show a significantly higher concentration of *chlorophyll a*, and thus higher surface methane emissions.

It's also important to recognize that surface emissions from reservoirs increase with their sediment loads[52], and the sediment loads in the LSR dams have been reduced by upstream reservoirs. A disproportionate amount of the total sediment load in the Snake River is captured by reservoirs upstream of the LSR dams but which do not produce hydropower. Their flows are intricately linked to the LSR system and other parts of the Snake River watershed through water use and flow agreements as well as state and federal law (Columbia River EIS)[53]. If reservoirs upstream did not exist, or their sediment loads were managed to more evenly distribute the sediment throughout the watershed, the sediment load (and therefore surface methane emissions) from the LSR dams would likely be significantly higher.

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THE AUTHORS

Tell The Dam Truth (TTDT) fights the climate crisis by advocating for the protection and restoration of 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 TTDT. 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.

Mark Easter is an ecologist, retired from Colorado State University, where he worked for over two decades developing and implementing ecosystem greenhouse gas accounting methods and decision support systems for agriculture, forestry, wetlands, and other land uses. He has authored or co-authored more than fifty publications and contributed to multiple others in the field of ecosystem GHG accounting. Mark has a popular science book on the carbon footprint of food titled *The Blue Plate: A Food Lover's Guide to Climate Chaos* in production, scheduled to be released in the Autumn of 2024. Mark is a TTDT consultant.

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.