Definitions and Concepts in Considering GHGs in Water Bodies

Greenhouse Gases (GHG)

- Water Vapor, H_2O
- Carbon Dioxide, CO_2
- **Methane, CH_4**
- Nitrous Oxide, N_2O

Methane Production: Within sediments, methanogens (a microbe) produce methane from the by-products of anaerobic digestion, principally acetic acid and carbon dioxide:

Acetic acid → Methane and Carbon Dioxide

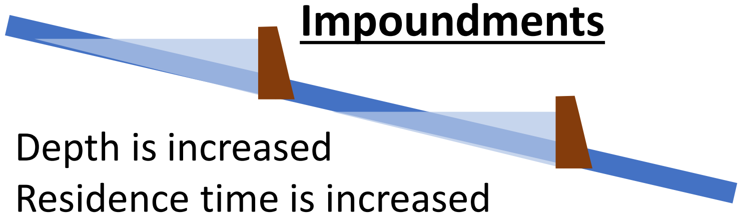
$$CH_3COO^- + H^+ \rightarrow CH_4 + CO_2$$

Carbon Dioxide and Hydrogen → Methane and Water

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$

Not much methane is produced in aqueous environments if an abundance of oxygen is present.

Impoundments



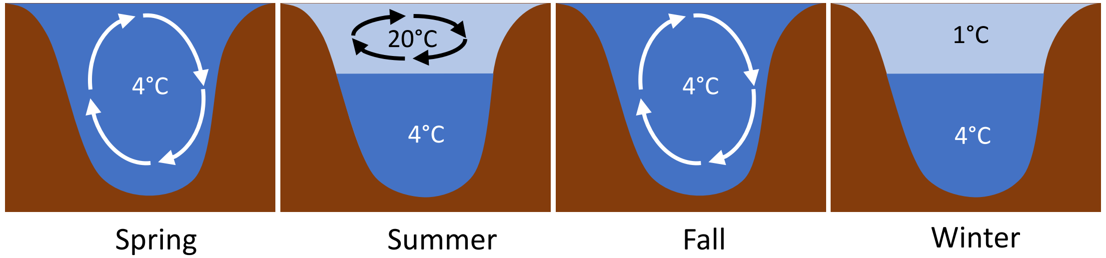
- Depth is increased
- Residence time is increased
- Water velocity and mixing are reduced
- Sediment transport is diminished

$$\textit{Residence Time (days)} = 0.5\,\frac{\textit{Volume (acre-ft)}}{\textit{Inflow (cfs)}}$$

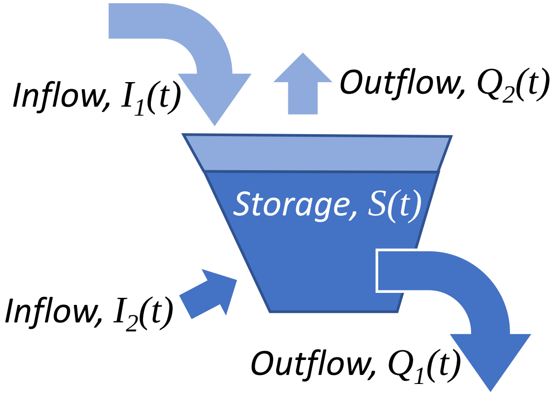
An indication of the amount of time a parcel of water spends in the water body before exiting.

Stratification in lakes and reservoirs

(temperature, dissolved oxygen, and GHGs are linked)



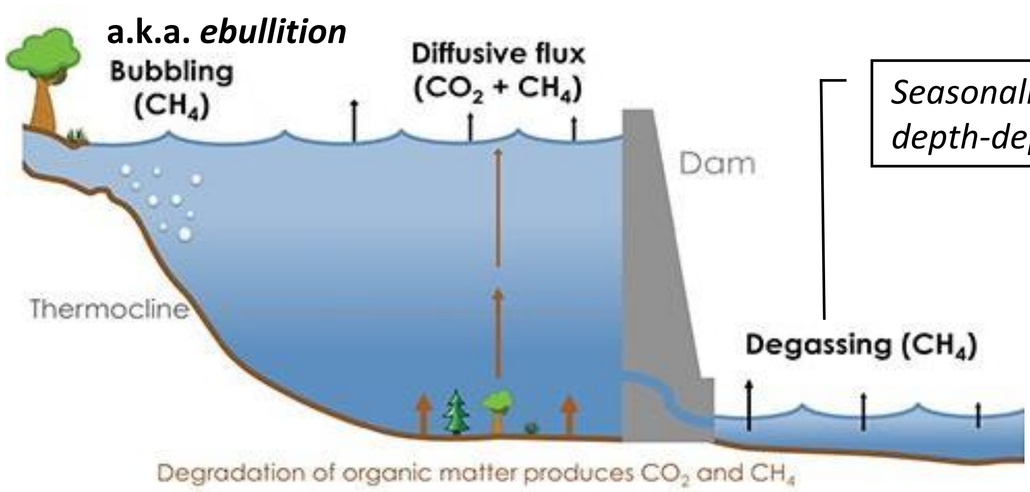
Mass and Energy Balances



- Water balance and storage
- Sediment balance and storage
- Carbon balance and storage
- Energy balance and storage

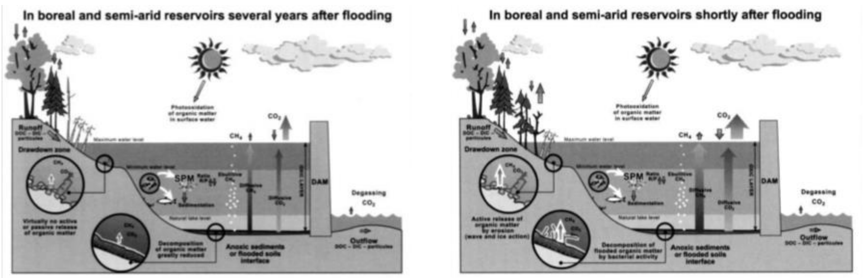
- Spillways typically withdraw from the surface layers of reservoirs.
- Turbines, sluices, and other low-level outlets typically withdraw from the deeper regions of reservoirs.

Biogeochemical Dynamics of GHGs in Reservoirs



Credit: Mercier-Blais (2017). International Hydropower Association

Seasonally- and depth-dependent



Tremblay et al. (2005). Boreal methane emissions increase initially, then decrease to pre-impoundment levels after ~10 years.

	CO_2 Diffusive	CH_4 Diffusive	CH_4 Bubbling	CH_4 Degassing
Age	↓	↓		
Temperature	↑	↑		
Soil C Content	↑			
Phosphorus Concentration	↑			
Reservoir Area	↑			
% Littoral Area		↑	↑	
Cumulative Radiance			↑	
Thermocline / Intake Depth				x
Water Residence Time				↑
Diffusive CH_4 Emissions				↑

Mercier-Blais (2017). International Hydropower Association

Measurement

Into the field with instruments, collect samples, and interpret results to produce data and assess:

- GHG fluxes at the surface
- Presence/rate of ebullition
- WQ profiles in reservoirs
- Soil and sediment samples
- Organic inflows
- Tailwater grab samples

Challenges

- Expensive to achieve adequate coverage in space and time to capture variability
- Very few long-term data exist
- Some measurement techniques are still maturing

Dynamic Modeling

Formulate and solve the mathematical governing equations to resolve dynamics within a water body, calibrating against field measurements:

- Seasonal and long-term hydrologic inputs and water management
- Organic inputs (pollution)
- Fluid dynamics
- Sediment transport
- Stoichiometry of WQ constituents (oxygen, CO_2 and hydrocarbons)
- Heat exchange with atmosphere and streambed

Challenges

- Requires some assumptions
- Requires field data for input and calibration
- WQ models exist, but few have been extended to CO_2, CH_4

Empirical Modeling

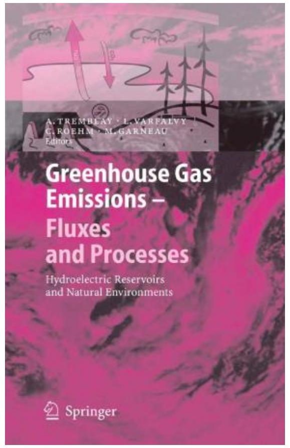
Gather published GHG data and perform multiple statistical regressions to analyze:

- which available parameters most influence GHG fluxes?
- which set of parameters provide "best" predictive capability?
- Predict or extrapolate CO_2 and CH_4 emissions for regional/worldwide sets of reservoirs.
- Predict or extrapolate CO_2 and CH_4 emissions for individual reservoirs

Challenges

- Limited set of static parameters does not characterize dynamics well
- Accuracy and uncertainty estimates are dependent on small samples with limited variability
- Useless if non-modeled parameters dominate

The Broader Context for Considering GHGs in Water Bodies

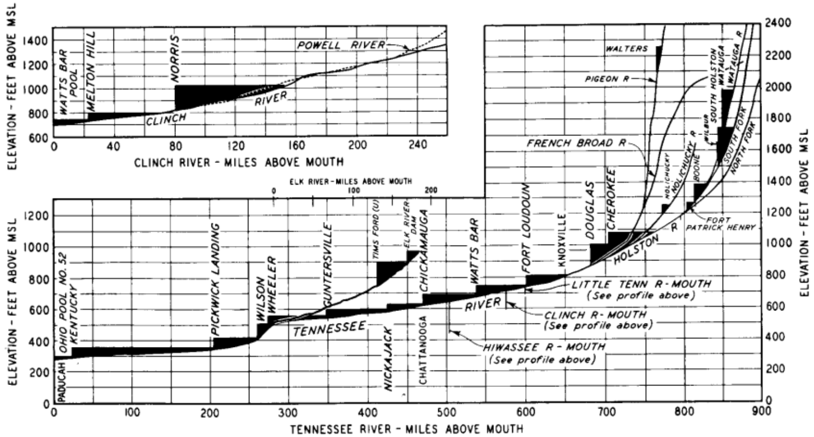


This monograph and other studies suggest that natural lakes and rivers are substantial emitters of CO_2 and CH_4, while estuaries and terrestrial ecosystems can be either sources or sinks of GHGs according to the stage of their succession. Moreover, the results in this monograph demonstrate that the creation of reservoirs has a direct impact on the increased production of GHG during the first years after impoundment. Therefore, to correctly estimate net GHG emissions from reservoirs, it would be essential to determine the emissions from the various ecosystems in the watersheds, prior to and following the creation of the reservoir. However, quantification of the changes in GHG emissions due to flooding is very complex, time-consuming, and quite costly, since it requires an understanding of the carbon cycle at the drainage basin level. This includes the downstream river portion from the dam to the estuary. Because of this complexity, such quantifications are rarely undertaken.

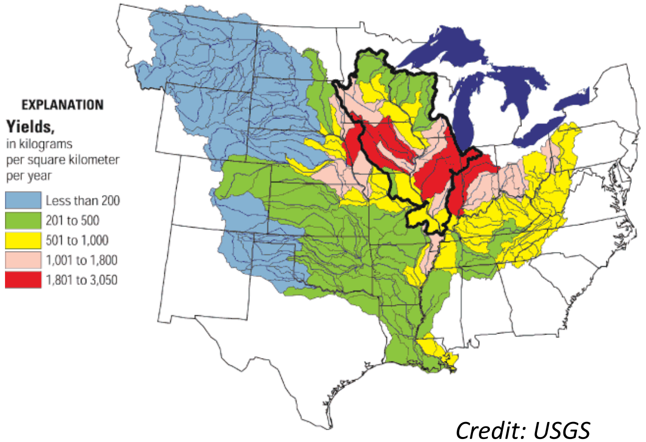
Tremblay, A., L. Varfalvy, C. Roehm, M. Garneau editors. *Greenhouse Gas Emissions - Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments*. Springer-Verla: Berlin-Heidelberg, 2005. https://doi.org/10.1007/978-3-540-26643-3

"at the drainage basin level" … "in the watersheds" … "from the dam to the estuary"

Credit: USGS



Credit: TVA



Credit: USGS

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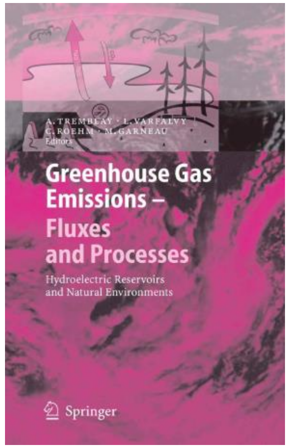

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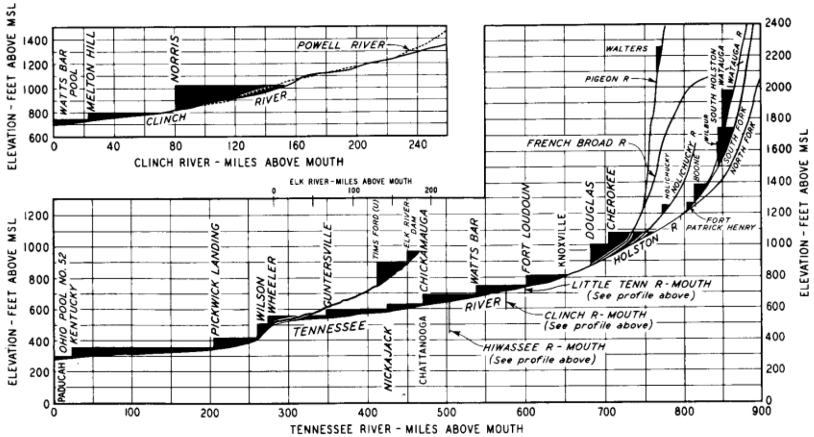

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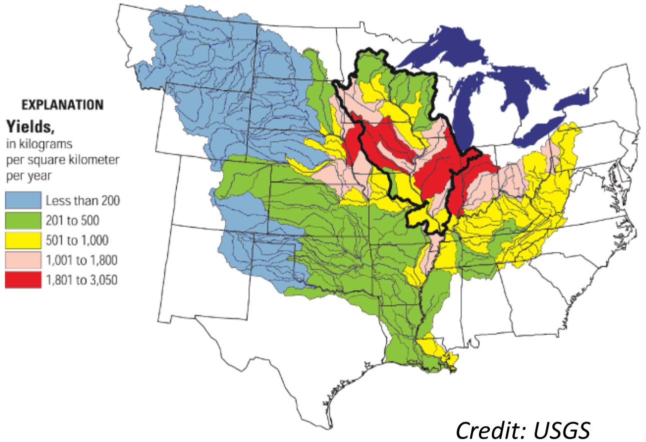

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