Methane (CH_4) emissions from a newly flooded subtropical hydroelectric reservoir: Nam Theun 2 case study

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Overview: Hydroelectric reservoirs can contribute to a high part of anthropogenic methane (CH_4) emissions. Global estimates of methane emissions from reservoirs vary i.e. **3 to 69 Tg(CH_4).yr^{-1}** (1,2,3). This high uncertainty range is related to the lack of data from different geographical regions and to the high spatial and temporal variability in the emissions from one reservoir to another.

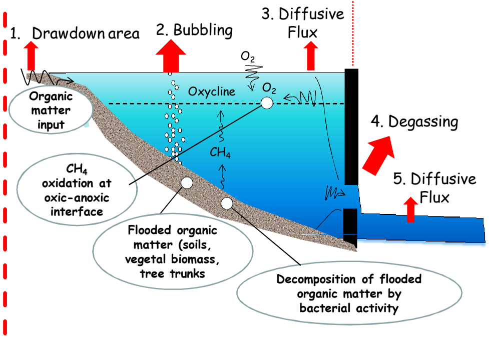
Almost no information is available from the subtropics and specifically from Asia, which is the place of around **68%** of reported dams.

This work quantifies, and describes the seasonal and spatial variation of CH_4 emissions from the 2 year-old subtropical Nam Theun 2 Reservoir (NT2, Lao PDR) system.

References:

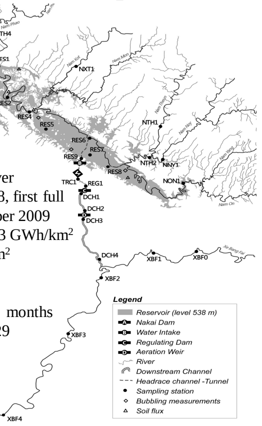
1. Barros, N., Cole, J. J., Tranvik, L. J., Prairie, Y. T., Bastviken, D., Huszar, V. L.M., (2011). Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geosci.*;4(9):593-6.
2. Bastviken, D., Tranvik, L. J., Downing, J. A., Crill, P. M., Enrich-Prast, A., (2011). Freshwater methane emissions offset the continental carbon sink. *Science*. 7; 331(6013):50
3. St.Louis, V.L., Kelly, C.A., Duchemin, E., Rudd, J.W.M., and Rosenberg, D.M., 2000. Reservoirs surfaces as sources of greenhouse gases to the atmosphere: a global estimate. *BioScience* 50:766-775

Methane dynamics in Hydroelectric Reservoir



Upstream
Downstream
1. Drawdown area
2. Bubbling
3. Diffusive Flux
O_2
Oxycline
O_2
Organic matter input
CH_4 oxidation at oxic-anoxic interface
CH_4
4. Degassing
5. Diffusive Flux
Flooded organic matter (soils, vegetal biomass, tree trunks)
Decomposition of flooded organic matter by bacterial activity

Nam Theun 2 (NT2) Reservoir, Laos PDR (Sub-Tropics)



Key features:

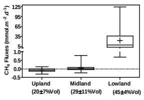
- ✓ Built on the Nam Theun River
- ✓ Flooded started in May 2008, first full impoundment reached in October 2009
- ✓ Annual power density = 13.3 GWh/km²
- ✓ Surface area = 70 to 450 km²
- ✓ Average depth = 8 m
- ✓ Monomictic reservoir
- ✓ Water Residence time = 5-6 months
- ✓ Fortnightly sampling from 29 monitoring sites since flooding

Emissions upstream of the dam

1). Fluxes from drawdown area

- Flux determined by **static chamber**
- Samples analyzed **by** Gas chromatography **with FID detection**
- Fluxes measured at:

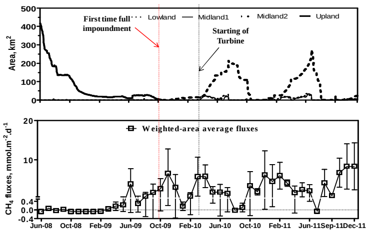
lowland (close to shoreline); **midland** (flooded during high water level); **upland** (never flooded)



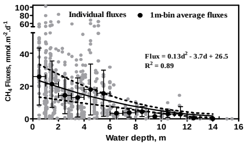
Flux extrapolation on **whole drawdown area** with following considerations

1. **Lowland** (45%) = uncovered from **0** to **20** days
2. **Midland** (29%) = uncovered for more than **20** days
3. **Upland** (20%) = **never** flooded part of drawdown which exists only before **first full impoundment**

Note:*values within bracket are average soil moisture



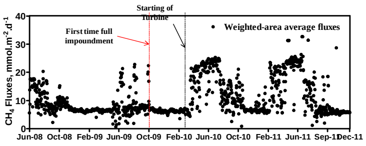
2). Bubbling Fluxes



- Set of **10-24** funnels (**24 hrs**) with water depth ranging from **0.5 to 15** m
- Mixing ratio of methane between **10 and 80%**

Flux extrapolations on the reservoirs scale:

- CH_4 bubbling flux is modelled with **artificial neural network parameterization** using following inputs: water depth, atmospheric pressure, temperature, water level change, rainfall (following methodology in Delon et al., 2007)



References: Delon, C., Serça, D., Boissard, C., Dupont, R., Dutot, A., Laville, P., De Rosnay, P,. and Delmas, R. (2007). "Soil NO emissions modelling using artificial neural network." Tellus B **59** (3): 502-513.

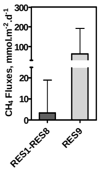
3). Diffusive Fluxes from Lake

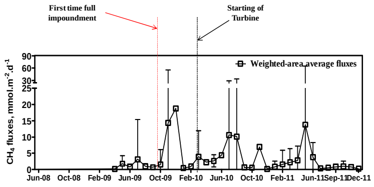
- **Floating chamber (FC)** method used during **5 field campaigns**
- **Gas transfer velocities** were calculated from fluxes measured with **FC**

Flux extrapolation from boundary layer equation with average gas transfer velocities applied on **fortnightly** surface concentrations dataset.

$$\mathbf{Flux = k_{g,T} * \Delta C}$$

- Surface concentrations were measured at **9 sampling station** (RES1-RES9) on the reservoir from **May 2009 to December 2011**.
- Statistically, station **RES9** behaved differently from all other sampling stations (Kruskal-Wallis, $p < 0.05$ at 95% confidence interval)





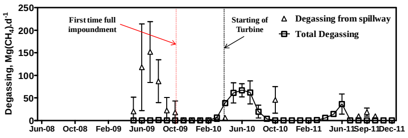
Downstream Emissions

4). Degassing

$$\mathbf{Emission = \Delta C * Discharge}$$

- In the NT2 system, degassing occurs at **five** sites

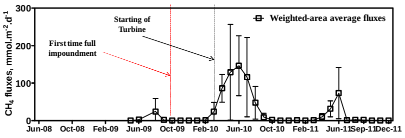
Continuous:	**A.** from downstream of the Nakai dam (ecological flow) **B**. below the turbines **C**. below the regulating pond dam **D**. from aeration weir
Occasionally:	**A**. from the spillway



5). Diffusive fluxes from downstream

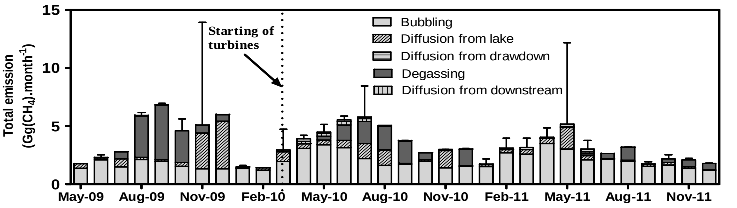
$$\mathbf{Flux = k_{g,T} * \Delta C}$$

- **Constant** k_{600} (= 10) were used
- Downstream has been divided into **five sections**
  - **Section1:** area covers tailrace channel (TRC) and regulating pond (
  - **Section2:** area between DCH1 and DCH2
  - **Section3:** area between DCH3 and DCH4
  - **Section4:** area between DCH4 and XBF4
  - **Section5:** area between Nakai dam and NTH7
- Fluxes **decrease** with **distance** from the turbines



Summary and conclusions

1. Changes in total monthly emission from the whole NT2 system (From May 2009 to December 2011)



2. Annual gross CH_4 Budget for Year 2010 and 2011(Gg(CH_4).y^{-1})

	Upstream emission			Downstream emission		Total Emission
	Bubbling (water depth < 13m)	Diffusive fluxes from reservoir surface	Diffusive fluxes from drawdown Area	Degassing	Diffusive fluxes from downstream	
Year 2010	24 (57%)	6.9 ± 5.6 (16%)	0.7 ± 0.8 (1%)	9.7 ± 8.8 (23%)	1.2 ± 1.1 (3%)	**43.2 ± 16.3**
Year 2011	25 (75%)	4.2 ± 6.3 (12%)	0.9 ± 0.6 (1%)	3.2 ± 2.5 (9%)	0.2 ± 0.2 (1%)	**33.9 ± 9.8**

3. Concluding remarks

1. Relative **importance of pathways** and **temporal variation**
   - **a)** **Bubbling emissions** from the reservoir surface is the most important contributor to total CH_4 emission
   - **b)** **Minor** emissions from **downstream and drawdown diffusion**
   - c) Estimates of **gross and net emissions** for year 2010 and 2011 confirms a **decrease** in emissions with time

2. Upstream emissions vs. downstream emissions
   - a) **Monomictic** nature of NT2 Reservoir **significantly reduces** downstream emission during wet and cold dry seasons
   - b) Structural design of **water intake of turbines** in NT2 Reservoir allows a mixing of CH_4-poor epilimnion and CH_4-rich hypolimnion, causing a significantly lowering of CH_4 degassing from turbined water.

3. The sum of the quantified CH_4 emission pathways proved NT2 reservoir to be a significant CH_4 emitter, about **two order** of magnitude higher than pre-impoundment emissions (**0.3** Gg (CH_4).yr^{-1}), leading to a net emission equal to **42.9±16.0** and **33.6 ± 9.6** Gg (CH_4).yr^{-1} for year 2010 and 2011, respectively.

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