Limnology
Summary + energy from lakes

LéXPLORE platform, 2020

1

Learning objectives

Today you will:

1. **Methane extraction in Lake Kivu**
2. **Review a summary of all chapters with their links**
3. **Interpretation of the vertical profiles (Assignment 11)**
4. **Lake as heat use: Martin Schmid**

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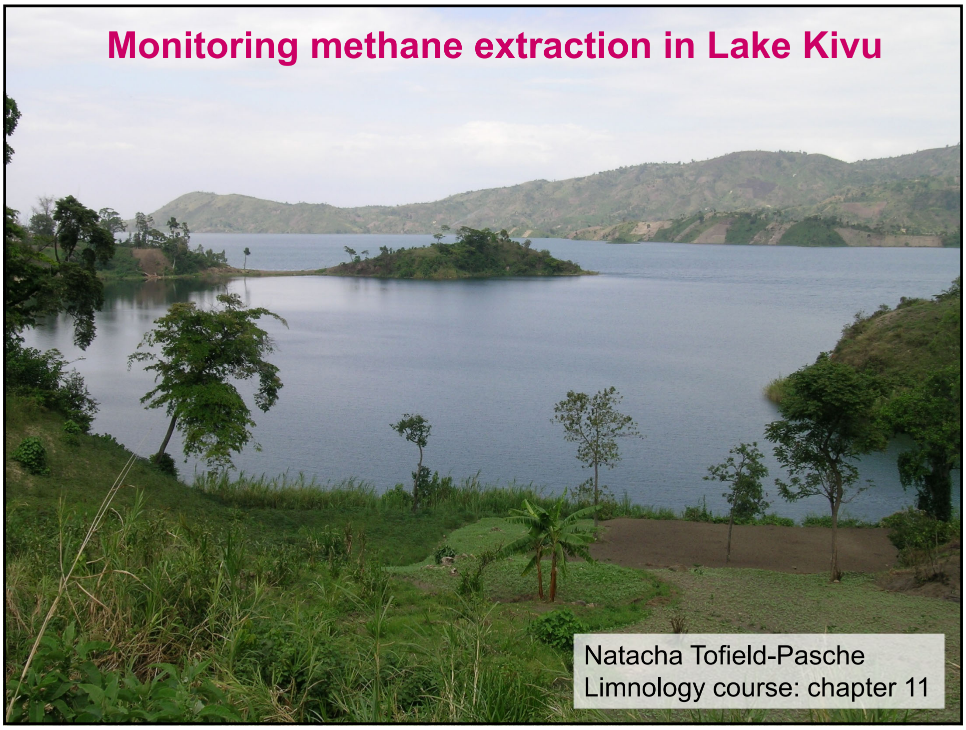
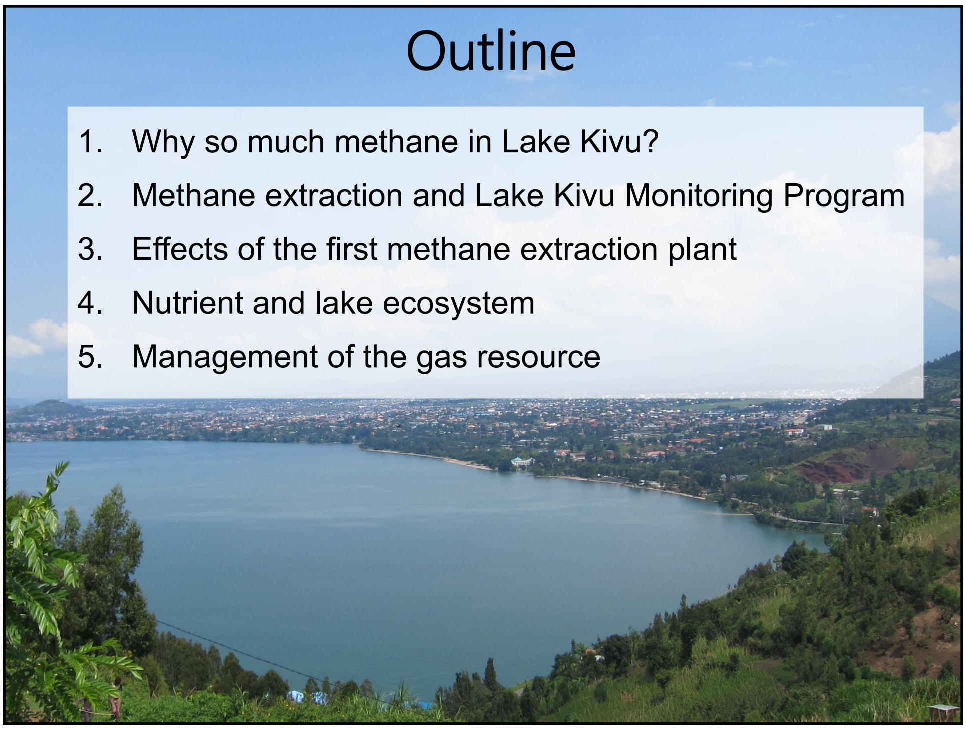
Monitoring methane extraction in Lake Kivu

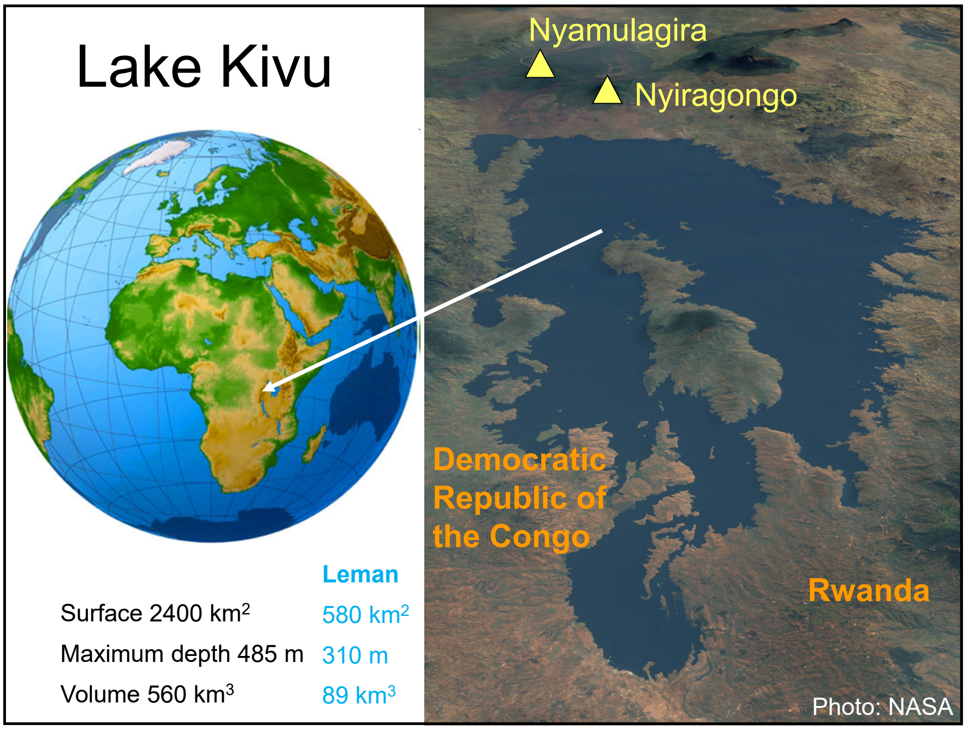


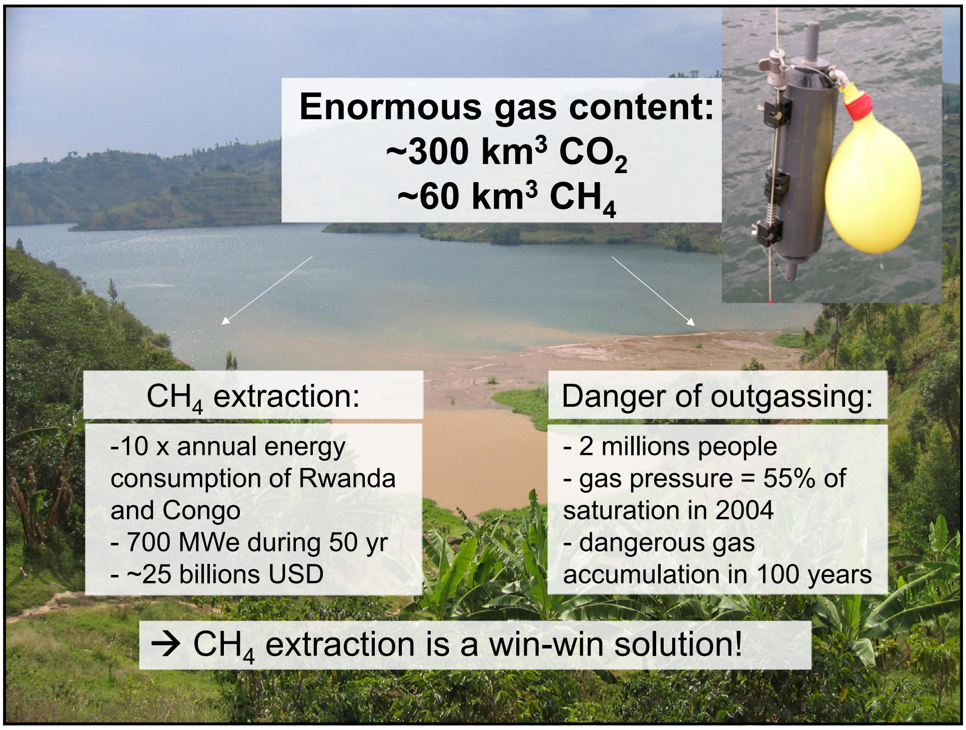
Natacha Tofield-Pasche
Limnology course: chapter 11

Outline

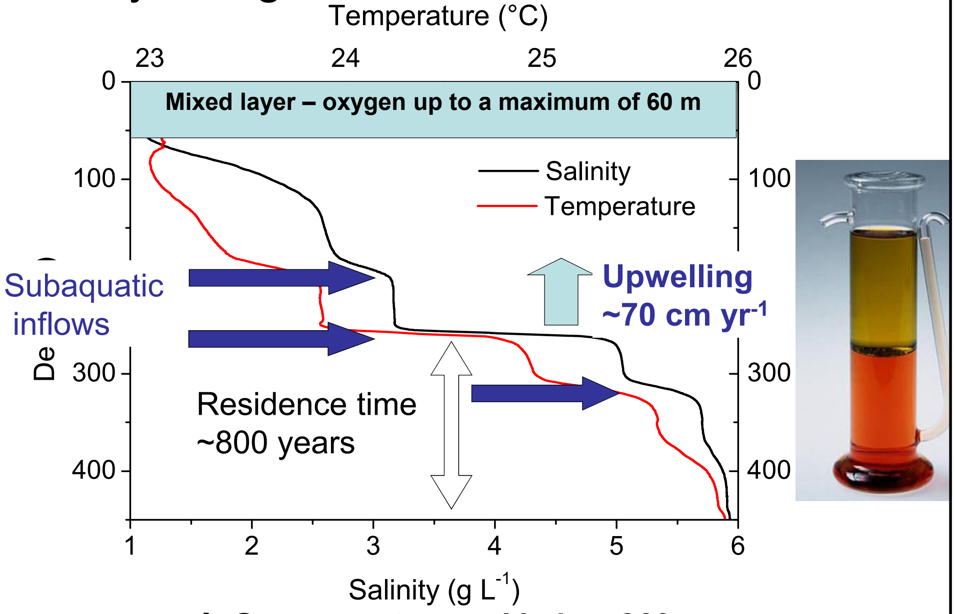


1. Why so much methane in Lake Kivu?
2. Methane extraction and Lake Kivu Monitoring Program
3. Effects of the first methane extraction plant
4. Nutrient and lake ecosystem
5. Management of the gas resource


Lake Kivu
Nyamulagira
Nyiragongo
Democratic Republic of the Congo
Rwanda
Leman
Surface 2400 km²
580 km²
Maximum depth 485 m
310 m
Volume 560 km³
89 km³
Photo: NASA


Enormous gas content:
~300 km³ CO₂
~60 km³ CH₄
CH₄ extraction:
-10 x annual energy consumption of Rwanda and Congo
- 700 MWe during 50 yr
- ~25 billions USD
Danger of outgassing:
- 2 millions people
- gas pressure = 55% of saturation in 2004
- dangerous gas accumulation in 100 years
→ CH₄ extraction is a win-win solution!

Why can gases accumulate in Lake Kivu?

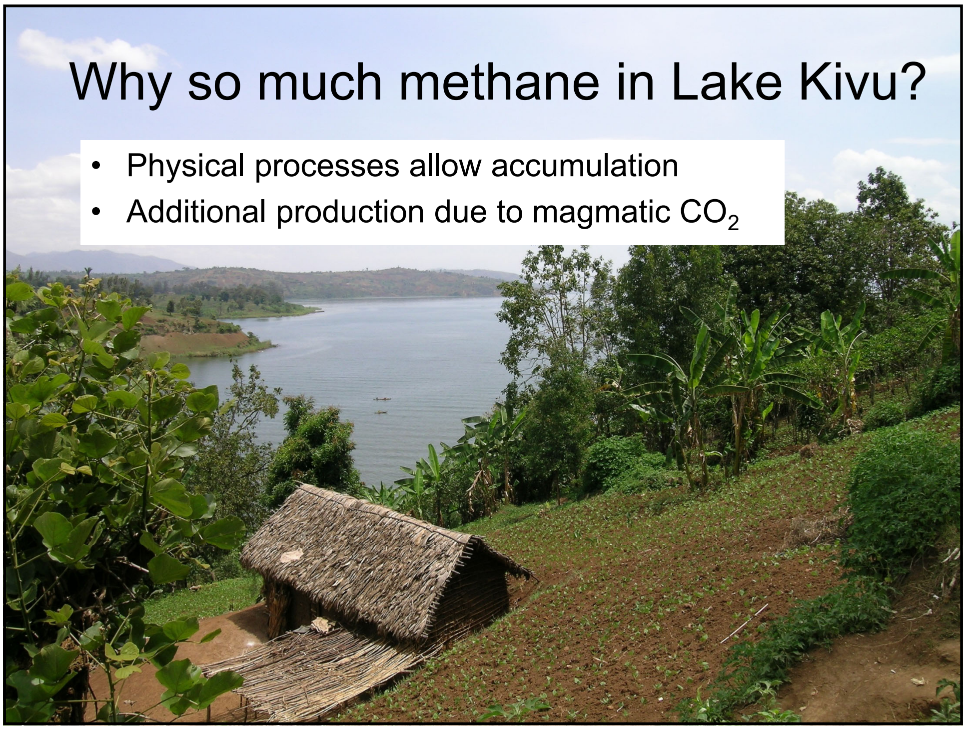


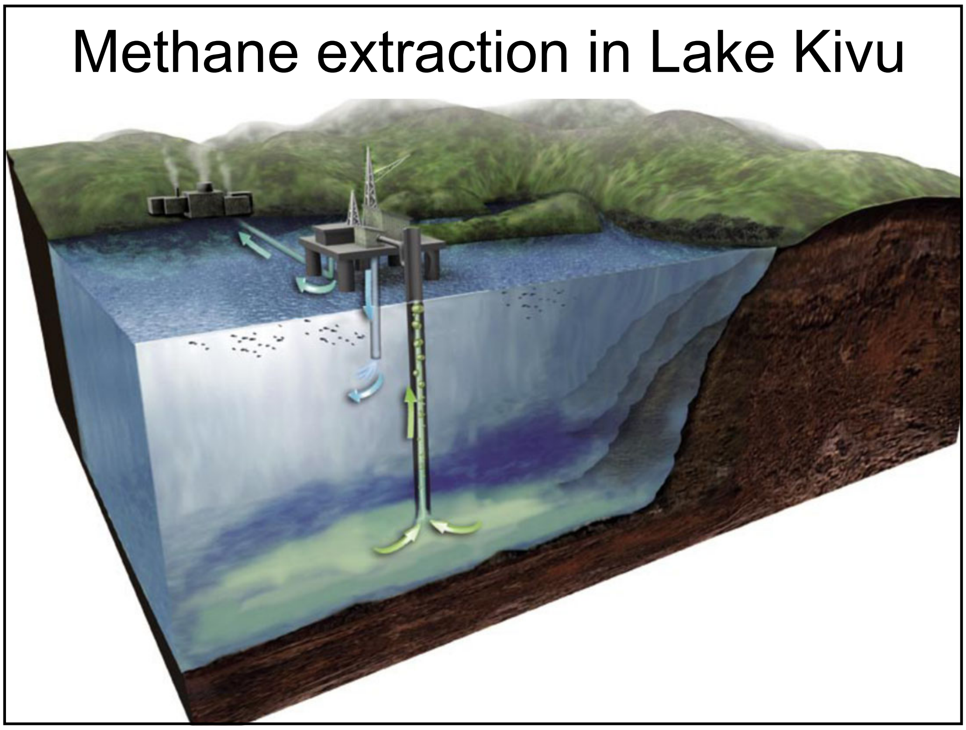
→ **Gases are trapped below 260 m**

Origins of the dissolved gases?

- CO_2 - magmatic origin
- CH_4: two biological processes
  - Decomposition of organic matter = ~ 35%
    - Throughout the water column
    - Common to all lakes
  - Direct reduction of magmatic CO_2 = ~ 65%
    - Only below 260 m
    - Special to Lake Kivu

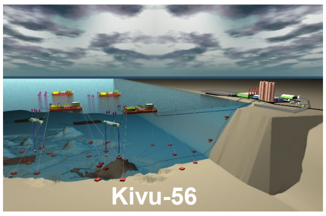
Pasche et al. 2011


Why so much methane in Lake Kivu?
• Physical processes allow accumulation
• Additional production due to magmatic CO_2


Methane extraction in Lake Kivu

History of methane extraction

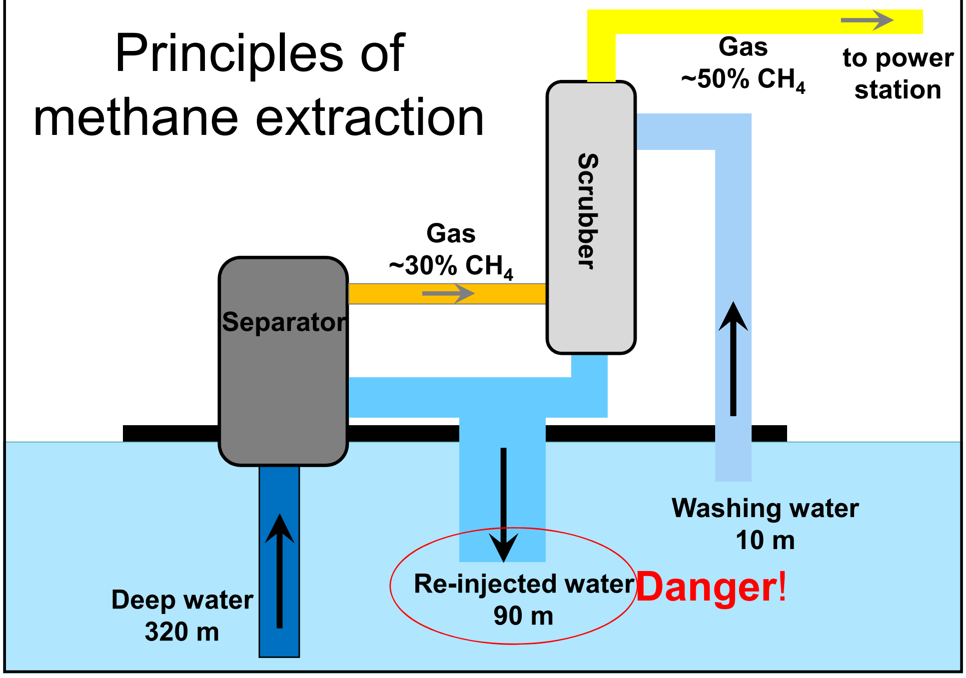
- First extraction by KP1 pilot plant in 2008, 1MW, will be upgraded to 25 MW by Symbion
- Failure of REC pilot plant in 2010
- KivuWatt plant has generated 26 MW since 2016, the phase II plans to add 75 MW
- The Kivu-56 plant will generate 56 MW in 2023



History of monitoring

- Lake Kivu Monitoring Program in 2008
  - 2008-2009: 4 members – 1 CTD
  - 2009-2013: expert in limnology, 10 members
    - laboratory to analyse nutrients, gases and planktons since 2012
    - Capacity building of 5 local technicians
  - 2013-2016: reinforcement of LKMP
    - Two experts, 15 members
    - Develop the institutional framework

Principles of methane extraction



Risks of methane extraction

- Modify the permanent stratification

  → destabilize the lake
- Increase the nutrients inputs

  → deteriorate the ecosystem
- Waste the gas resource

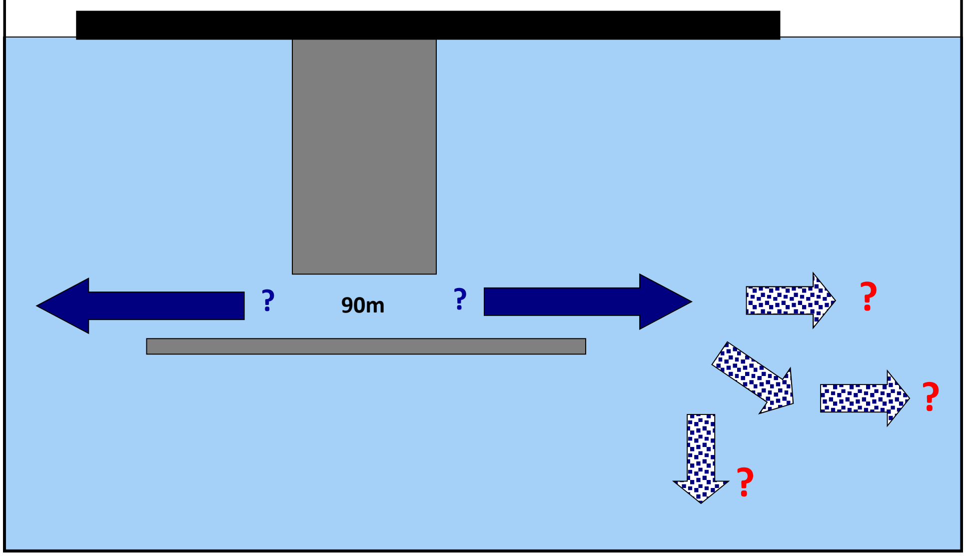
  → optimize the technology

KP1 pilot plant

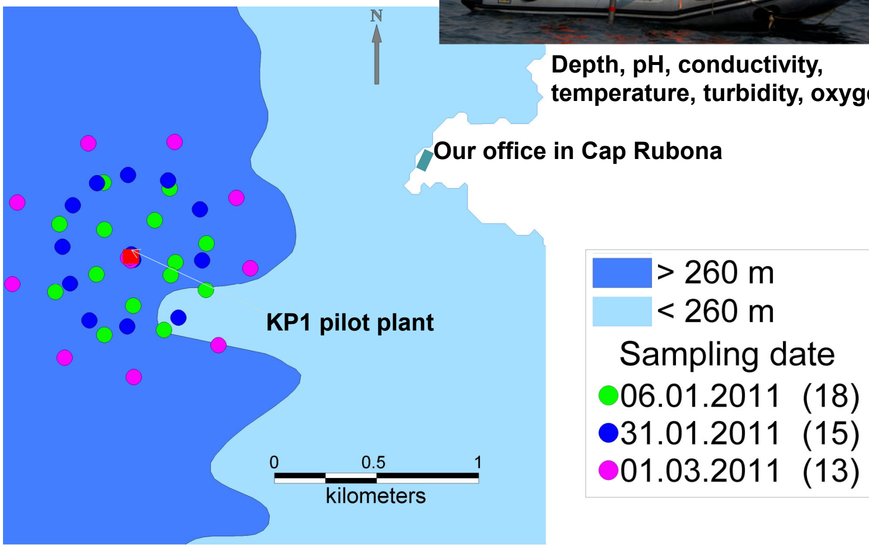
Three levels of monitoring

- On-plant inspections:
  - Detect leaks and maximise the efficiency
  - Assure a safe extraction and minimize pollution
- Near-plant monitoring → re-injected water:
  - Check for lake stability
  - Nutrient inputs
- Lake-wide long-term monitoring:
  - Maintain the lake stratification
  - Assure ecosystem integrity
  - Follow gas resources

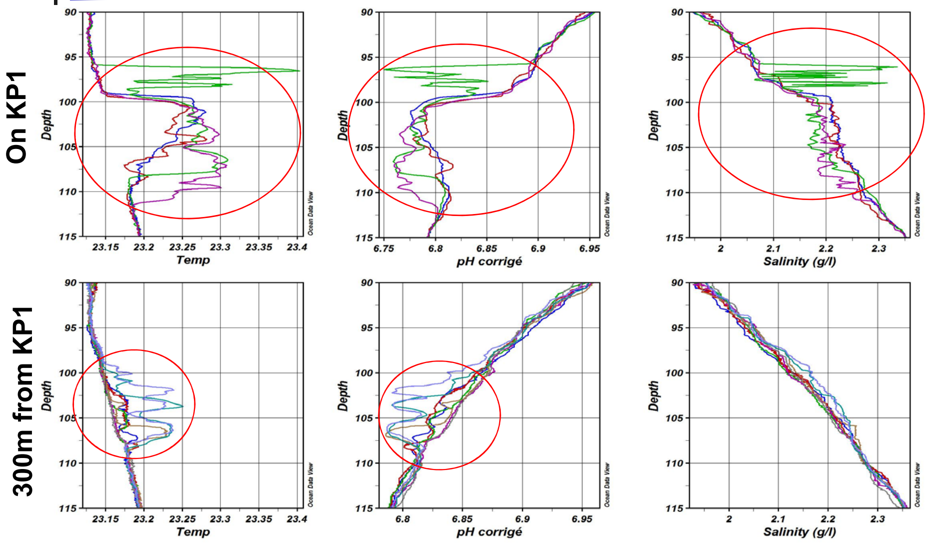
Near-plant monitoring: what happen to the reinjected water?



Methodology

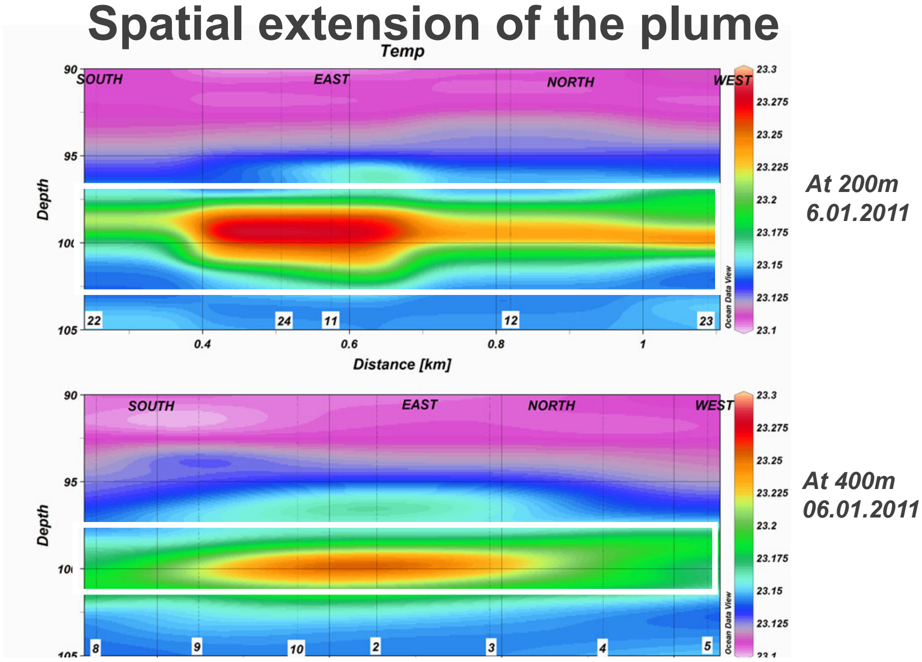


Effects of the re-injected water on the lake



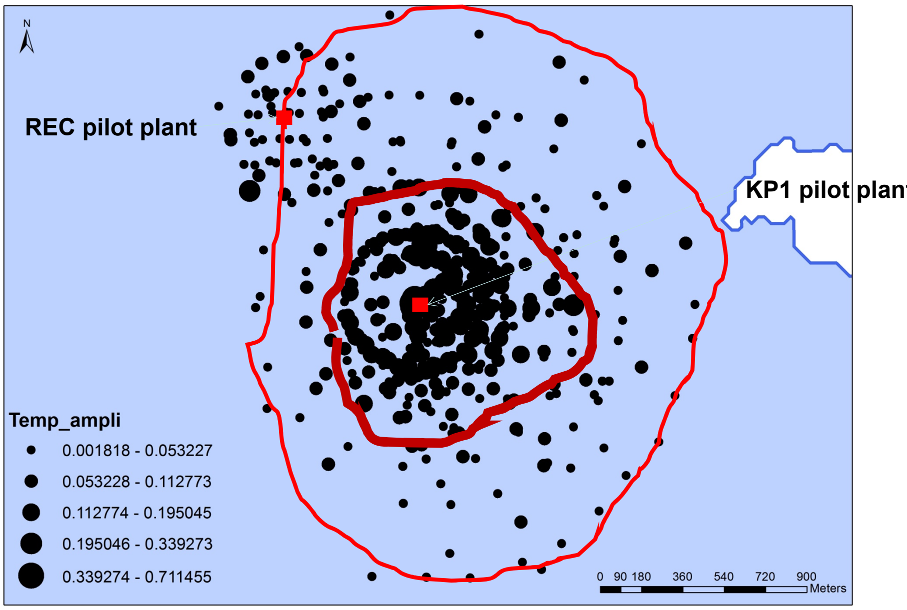
Temperature increase pH decrease salinity slightly increase

Spatial extension of the plume



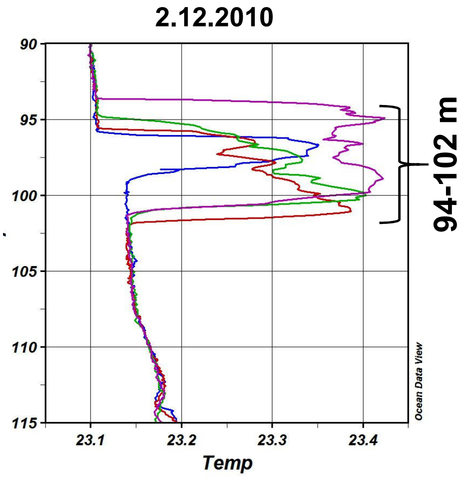
Intensity decrease with distance, observed up to 1,2 km

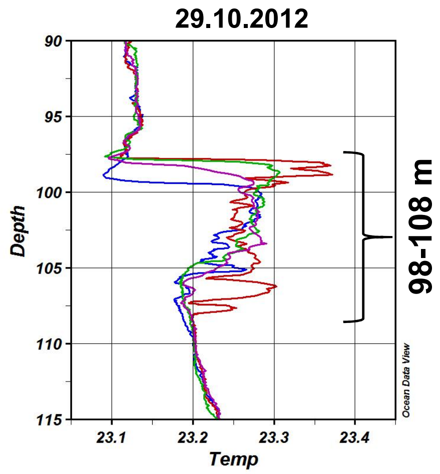
Localisation of the re-injected water plume



The re-stratification depth at KP1

Dilution factor = washing water / deepwater flows





Re-stratifying depth from 92 to 112 m: sinking of 2 to 22 m

Why does the plume stabilize at 100m?

- Re-injected water :
  - Dilution factor 1.17
  - Temperature = 24.619 °C
  - Salinity = 3.32 g/l

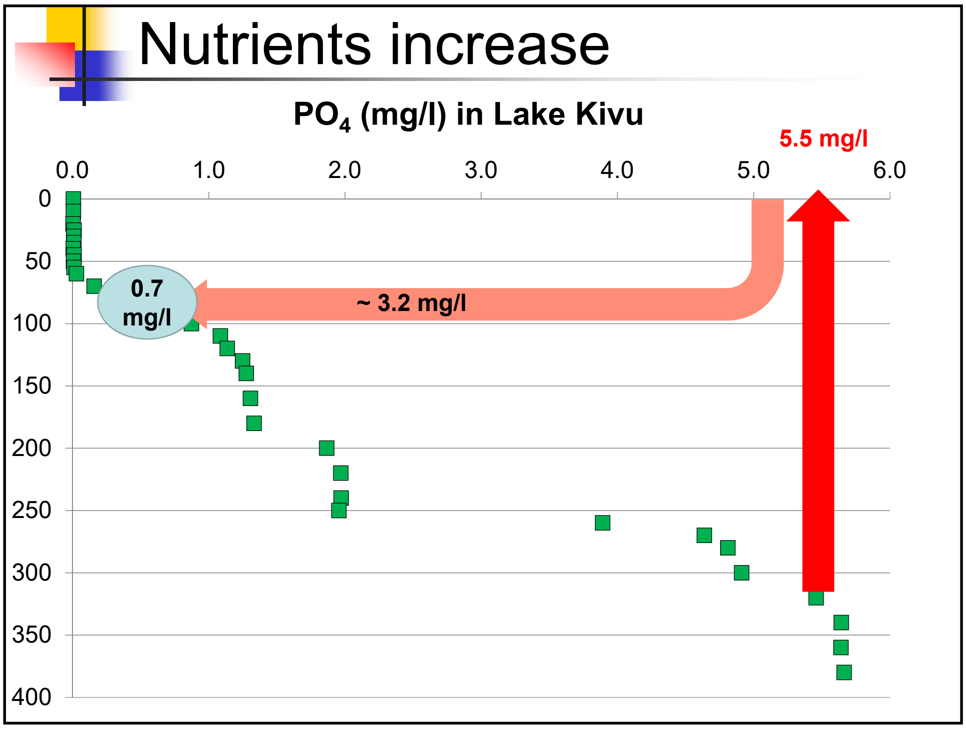
→ Same density as 250m

Dilution with local water by a factor 10

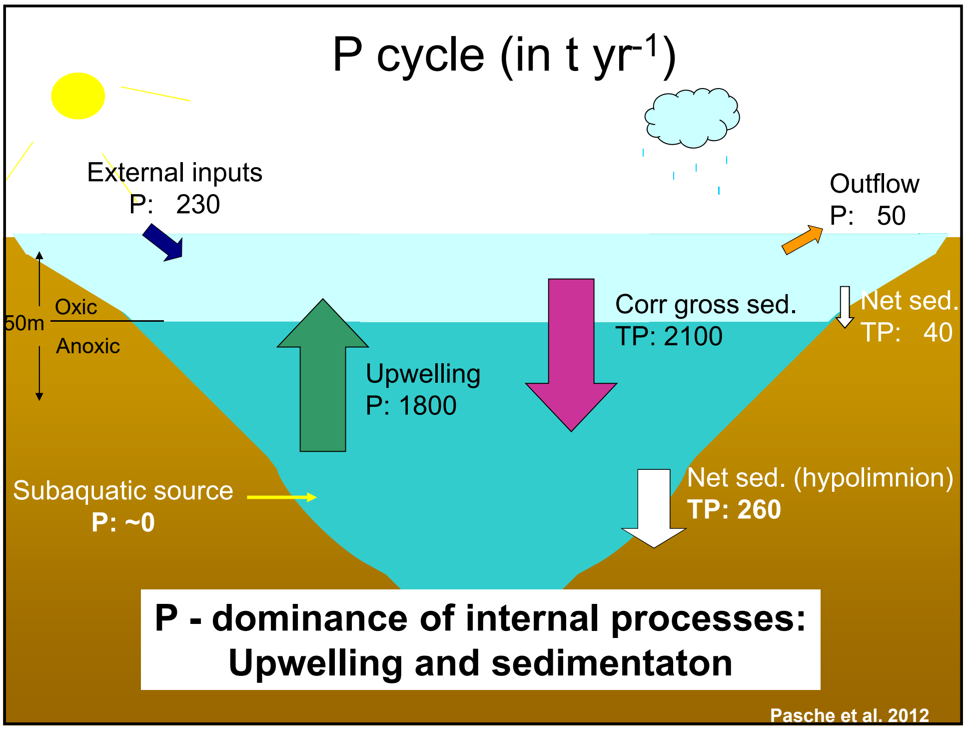
- Plume water
  - Temperature = 23.308 °C
  - Salinity = 2.22 g/l

→ Same density as 100m

→ Dilution with local water prevents any destabilization



Nutrients increase
PO4 (mg/l) in Lake Kivu
5.5 mg/l
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
50
100
150
200
250
300
350
400
0.7 mg/l
~ 3.2 mg/l



P cycle (in t yr-1)
External inputs
P: 230
Outflow
P: 50
Oxic
50m
Anoxic
Corr gross sed.
TP: 2100
Net sed.
TP: 40
Upwelling
P: 1800
Subaquatic source
P: ~0
Net sed. (hypolimnion)
TP: 260
P - dominance of internal processes:
Upwelling and sedimentaton
Pasche et al. 2012

Enhanced nutrients input

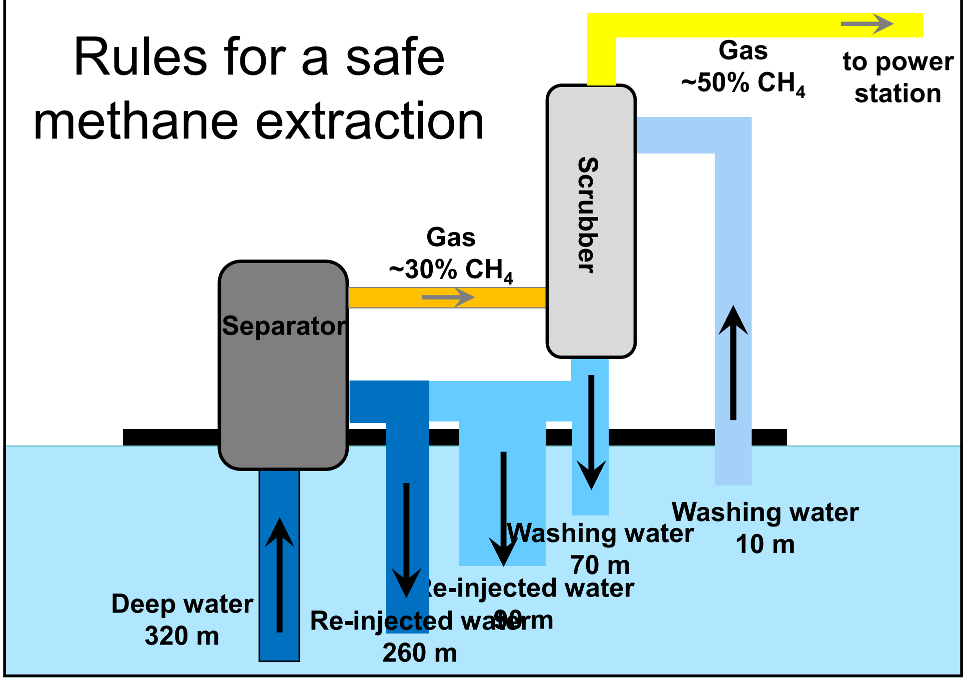
Nutrients released by KP1 compared to natural inputs:

	N-NH_4 (t)	P-PO_4 (t)	Si-SiO_2 (t)
Annual Load from KP1	**413**	**42**	**320**
% external nutrients	15.9	18.5	1.3
% upward fluxes	2.2	2.4	1.1
% total nutrient	2.0	2.1	0.6

Relatively small impacts due to the limited power production.

Reinjection at 90 m will not be tolerated for the future industrial plants.

Rules for a safe methane extraction

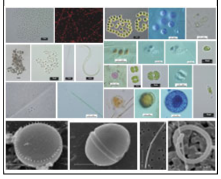


Ecosystem of Lake Kivu

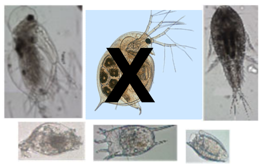
Nutrients
NH_4, NO_3, PO_4, SiO_2 + light

An eutrophication might deteriorate the ecosystem

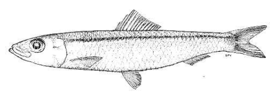
Phytoplankton



Zooplankton



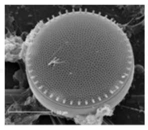
Limnothrissa miodon



introduced in 1960s

Preserve fisheries → an important source of protein

Biological baseline project

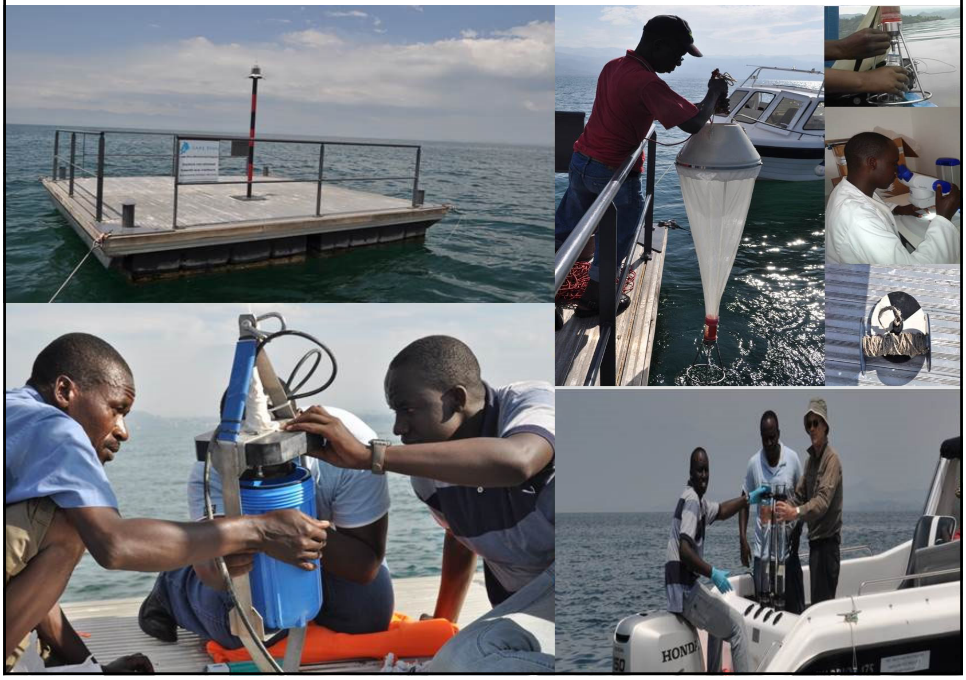


Three components from 2012-2014

- Actual fish stock
  - 4 Hydro-acoustics surveys per year
- Phytoplankton and zooplankton composition:
  - Monthly sampling 0-60 m
  - In-situ continuous measure of primary production
- Sedimentation of particulate organic matter:
  - Mooring with sediment trap at 100 m

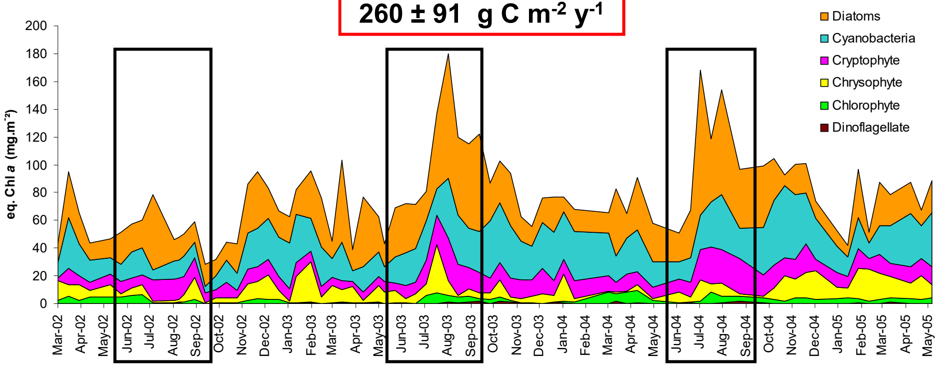
→Baseline before large-scale exploitation

LKMP baseline platform and monthly sampling



Primary production in Lake Kivu

PP in Lake Kivu:
260 ± 91 g C m^{-2} y^{-1}

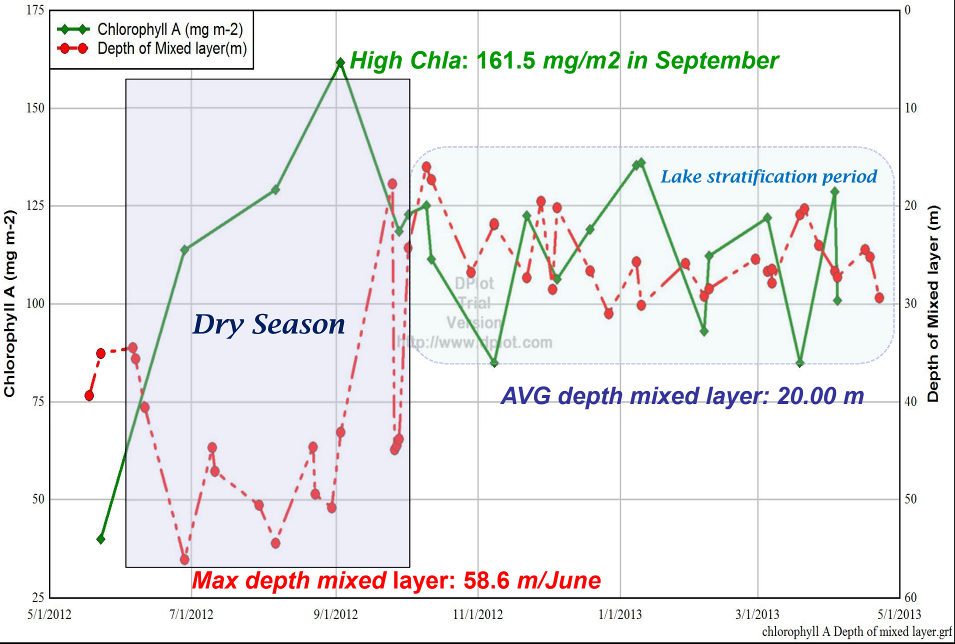


Phytoplankton peak during annual mixing

High inter-annual variability

Sarmento et al. 2006

Depth of mixed layer and Chla concentration



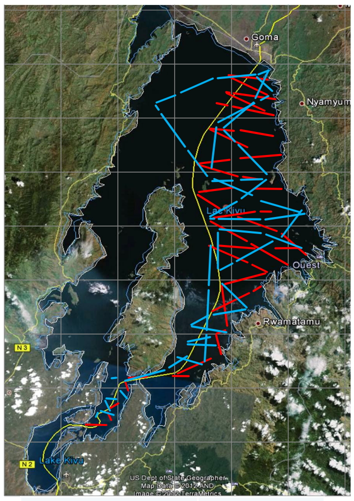
Fish biodiversity and biomass

Previously 27 species (Snoeks et al. 2012)
This study 42 species, new haplochromis

Limnothrissa Miodon: 34%

Lamprichthys Tanganicanus: 23%

32 species of Haplochromis: 42%



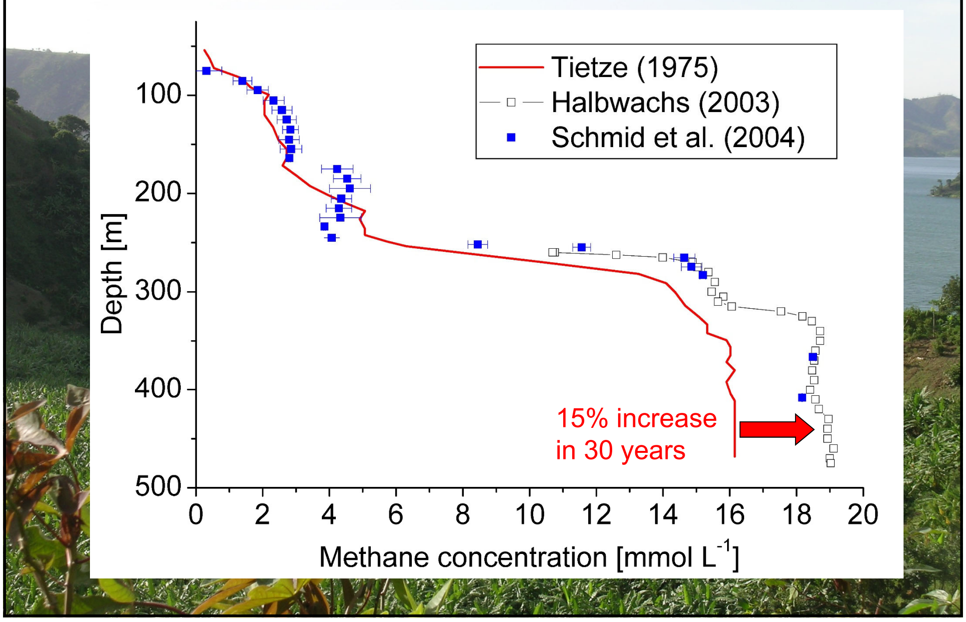
	tons
July 2012	1362
January 2013	3925

Manage the gas resource

1. Extract the current resource
   – 700 MW over 50 years
2. Exploit the annual production
   – a renewable source of energy
   – 80 MW per year

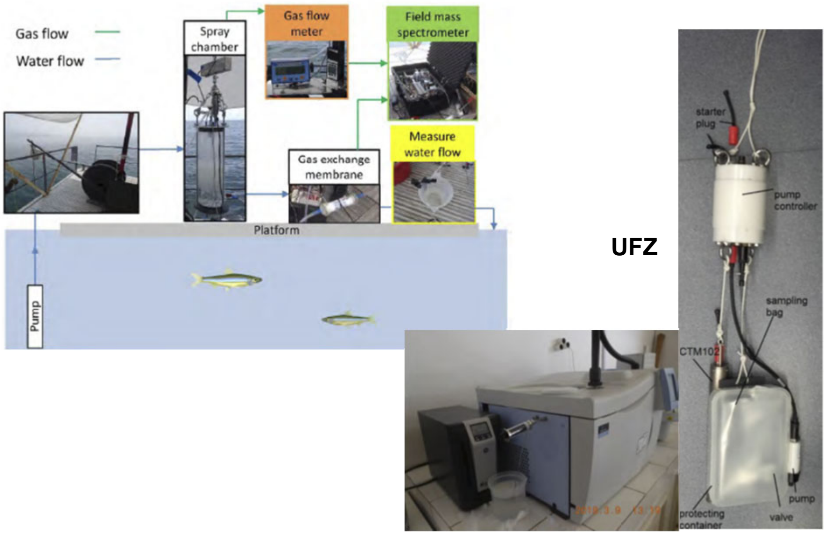
- Challenges
  – Measure the dissolved gases in the lake and in the extraction plants
  – Determine the annual production of methane

Recent increase in CH_4 concentrations



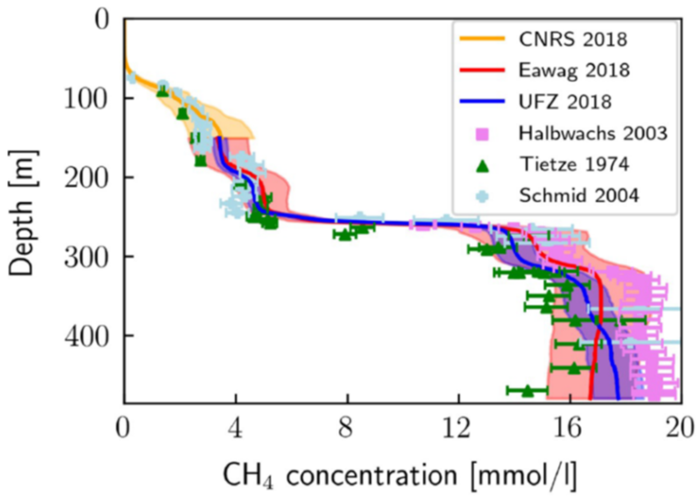
Intercalibration campaign in 2018

Eawag



(Bärenbold et al. 2020

Intercalibration campaign in 2018



→ Within uncertainies, constant CH_4 and CO_2 concentrations over 45 years
→ The production of CH_4 is similar to the loss through upwelling
→ **Not a renewable source of energy**

(Bärenbold et al. 2020)

Capacity building strategy

Build a strong **local** monitoring team:

1. improve skills of employees
2. reinforce organization within the team
3. develop local infrastructure
4. build up a strong institutional framework

→ **Capacity building projects**
- International expert
- courses

Conclusion

- Is methane extraction changing the lake?
  - Local effects on temperature, pH and salinity
  - Increase nutrients inputs
- The stability is not disturbed
  - Reinjected water sinks by 2-22m
  - Important dilution with local lakewater
- Lake Kivu Monitoring Program
  - Equipment available and capacity building
  - Collected a large dataset
  - Long-term data to account for high inter-annual variability

In class exercice:

1) What is different (except for the methane) in Lake Kivu than in the Swiss lakes?
2) What are the potential impacts of methane extraction on the lake?
3) What are the main challenges to monitor methane extraction?