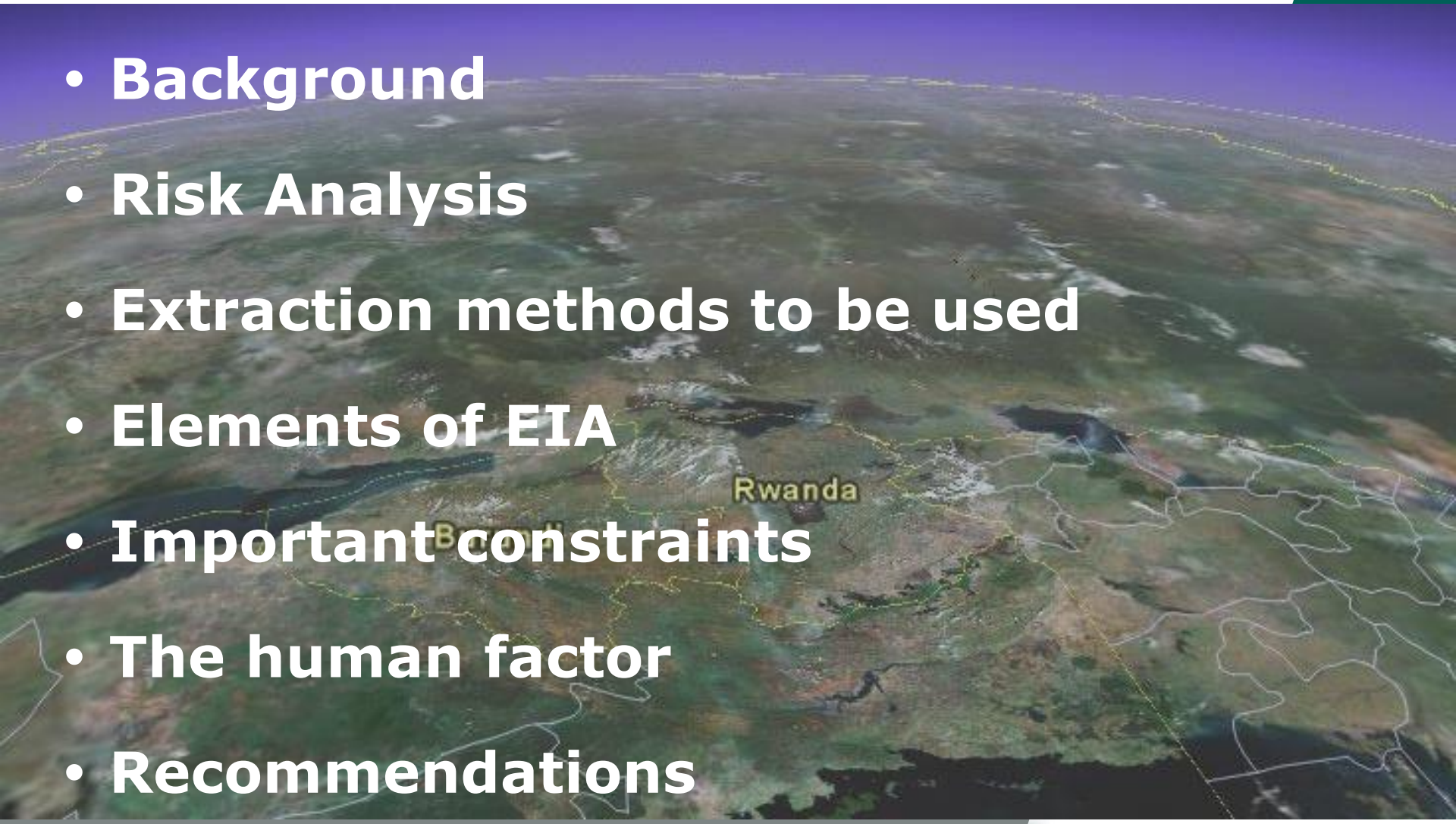
The lake and its safety challenges

Analysis and Recommendations by COWI

Finn Hirslund

COWI A/S, Denmark

Content



- Background
- Risk Analysis
- Extraction methods to be used
- Elements of EIA
- Important constraints
- The human factor
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Background

COWI's background:

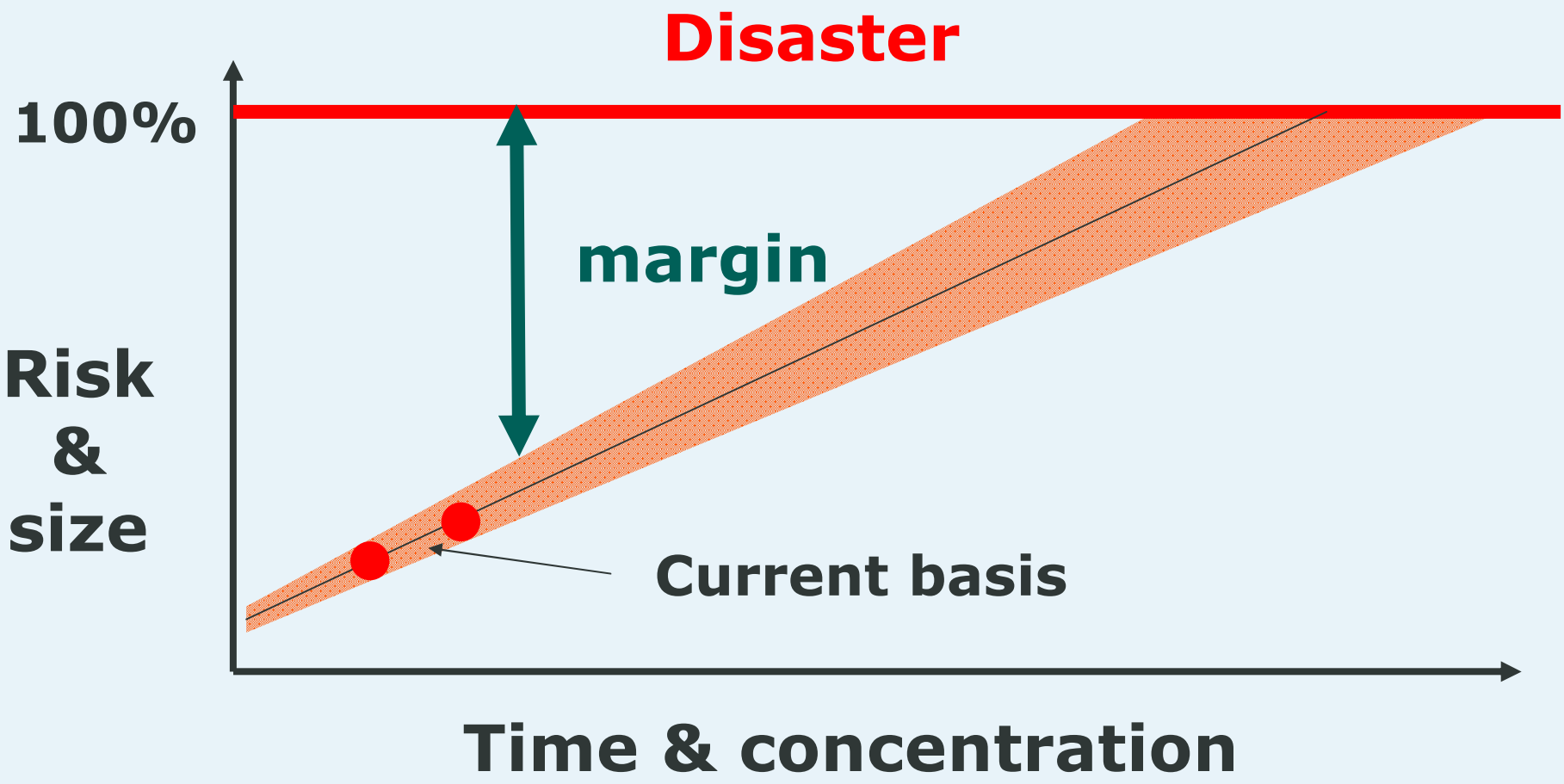
- **Safety review of Ludan design, spring 2006**
- **Lake Kivu gas extraction - report on lake stability, July 2006**
- **Conference in Gisenyi, March 2007**
- **Expert group defining extraction rules**
- **'Methane from Lake Kivu - how to extract the gas and avert the dangers', May 2009**

Risk analysis - the dangers from gas accumulation

Lake Nyos disaster Cameroon 1986:

- ~0.5 km³ CO_2 cloud
- 1746 persons
- >3000 Cattle

Risk analysis - the dangers from gas accumulation



Risk analysis - the dangers from gas accumulation

One end of the scale,
Lake Kivu in 80-100 years:

- **~200 km³ cloud CO_2 + H_2S**
- **Up to ~ 1-2 million persons**

Risk analysis - the dangers from gas accumulation

Lake Kivu today: Small eruptions from intermediate zone, started by gas bubbles Killing maybe a few persons a year

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Risk analysis - the dangers from gas accumulation

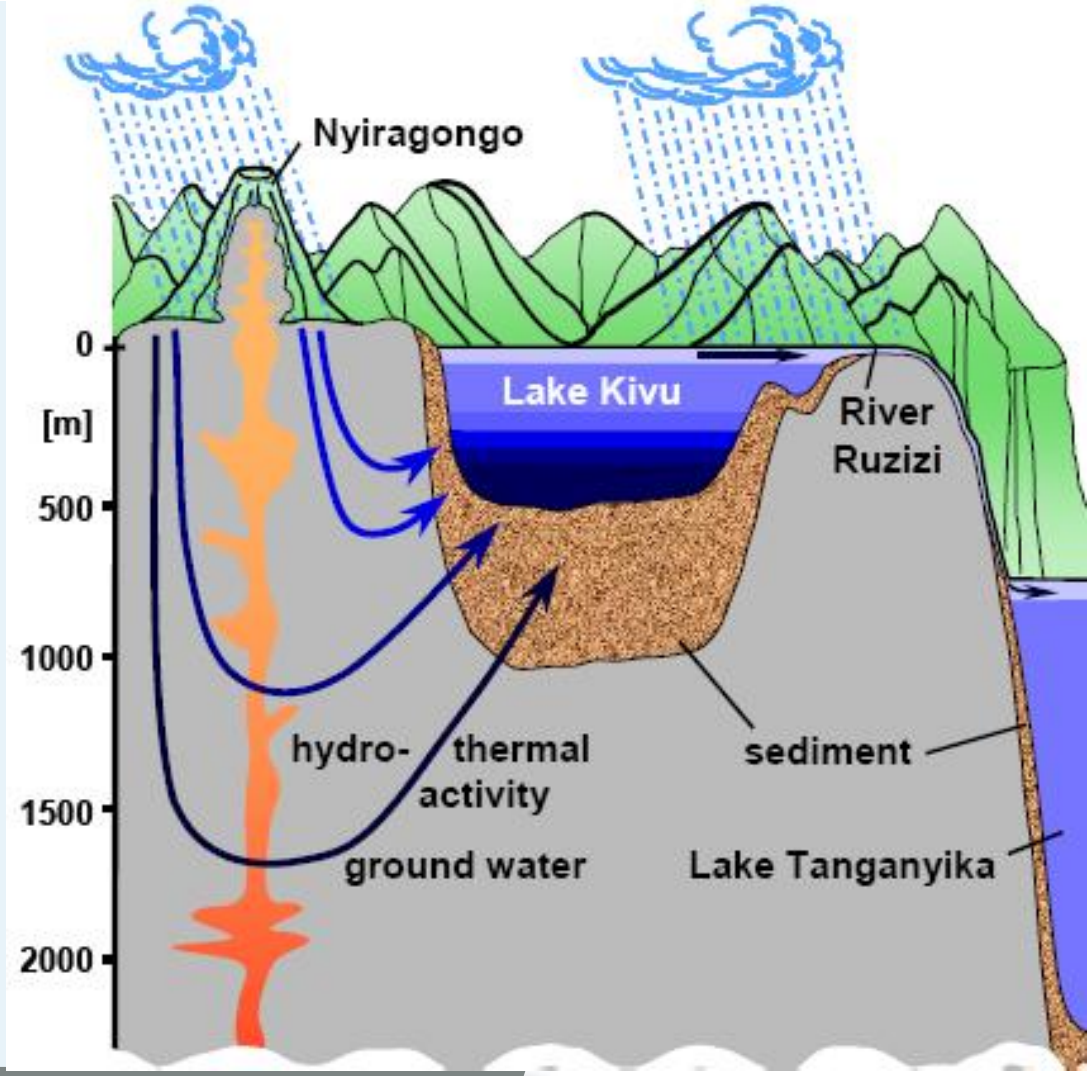
GOAL

- **Start gas extraction at the latest when saturation is a 60 % (in all zones)**
- **Through gas extraction reduce saturation to below 40 % at top of resource zone**
- **Goal for top of potential resource zone not defined yet. Risk study is recommended to define this.**

Risk analysis - general background

Rain water seeps through the lava plains up north.

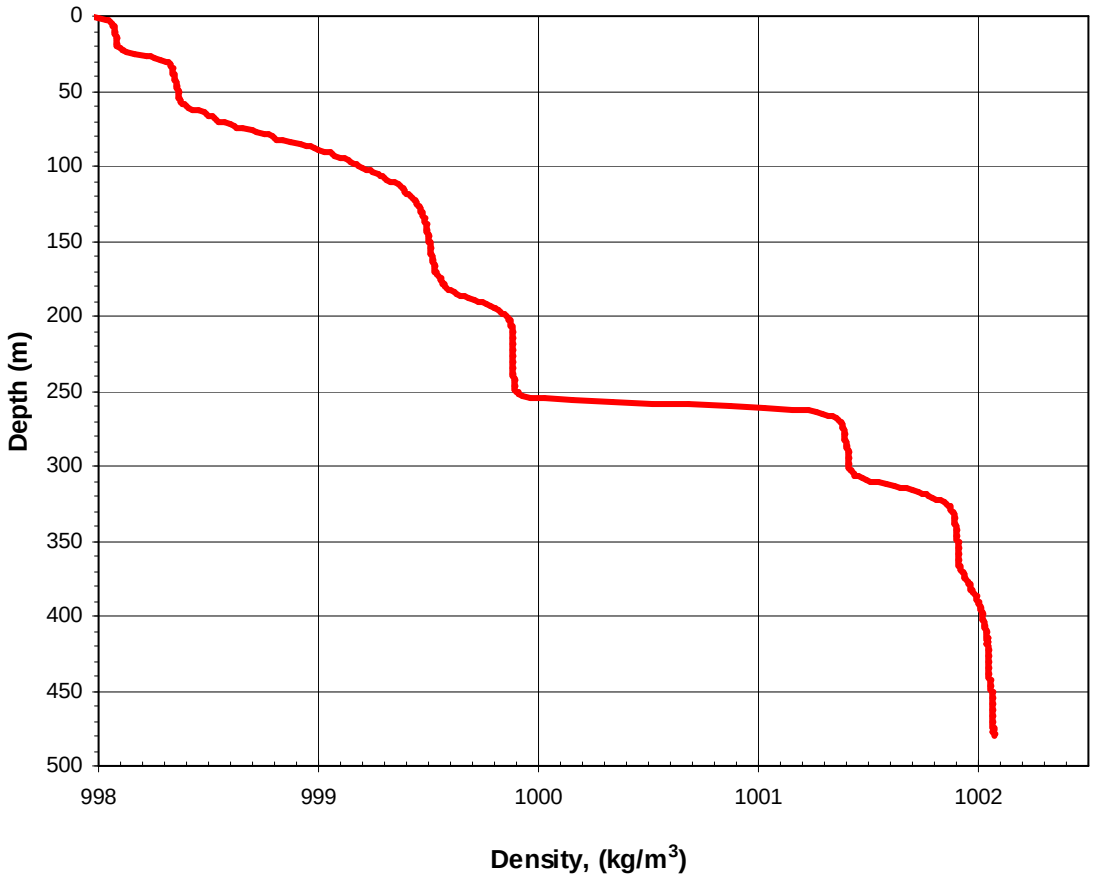
It dissolves salts and carbon dioxide that makes the water heavier and the heavier parts remain near the bottom.



Risk analysis - general background

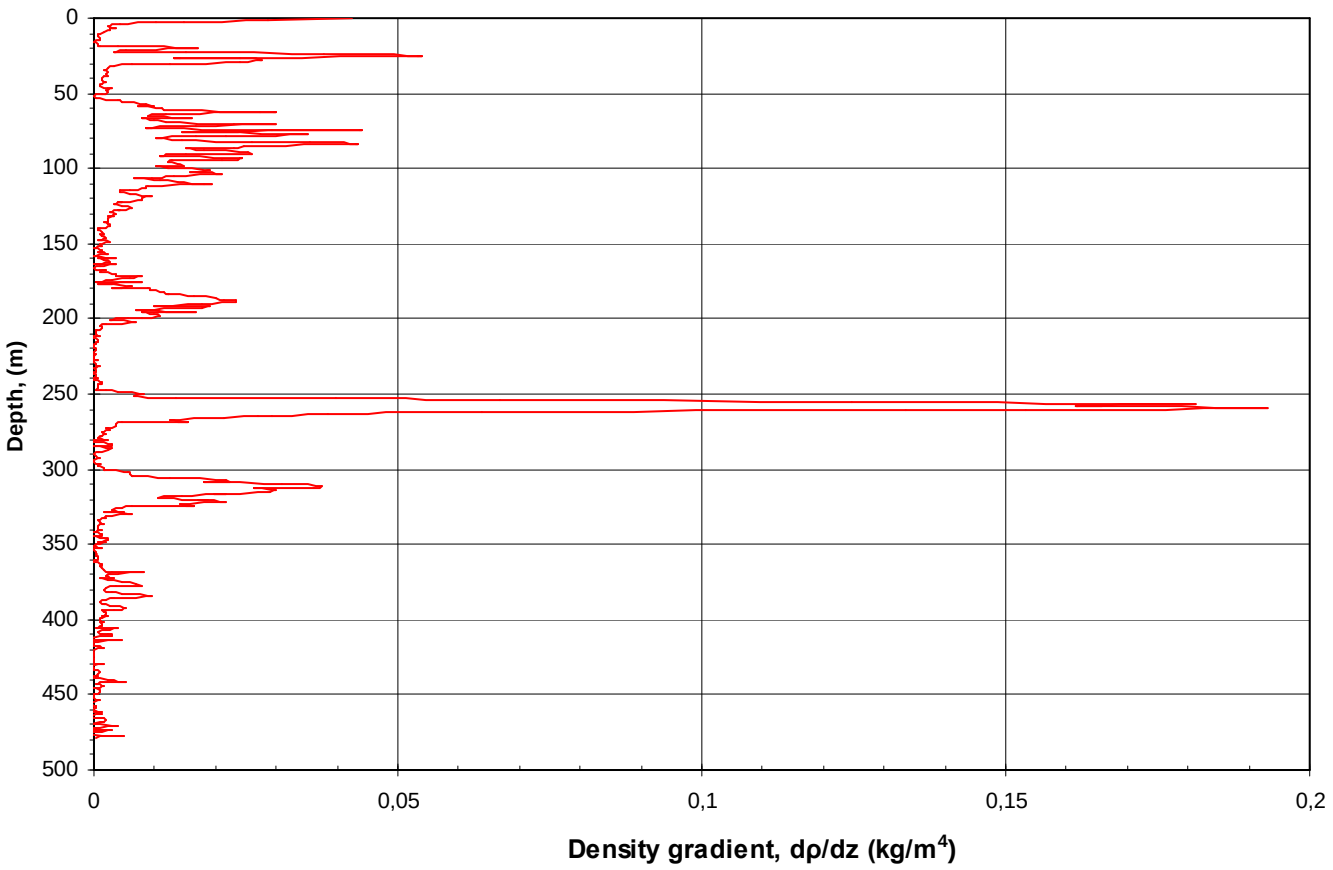
This generates a macro-density structure in the lake with density increasing with depth.

And the heavier inflows to the bottom pushes up the entire structure.



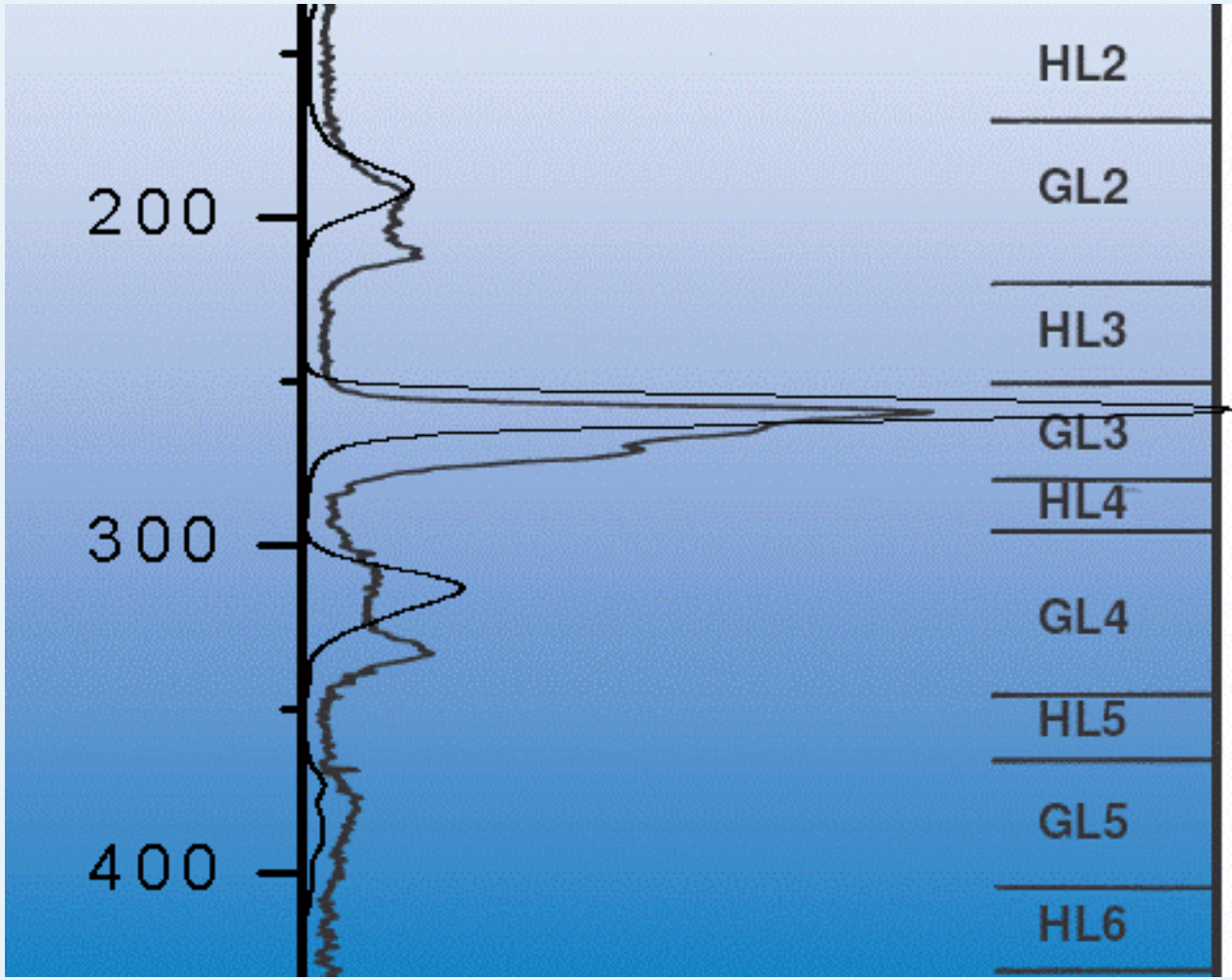
Risk analysis - general background

Taking the derivative of the density graph, we get the density gradients



Risk analysis - general background

And these density gradients are much better suited to illustrate the lifting of gradients as well as the entire density structure



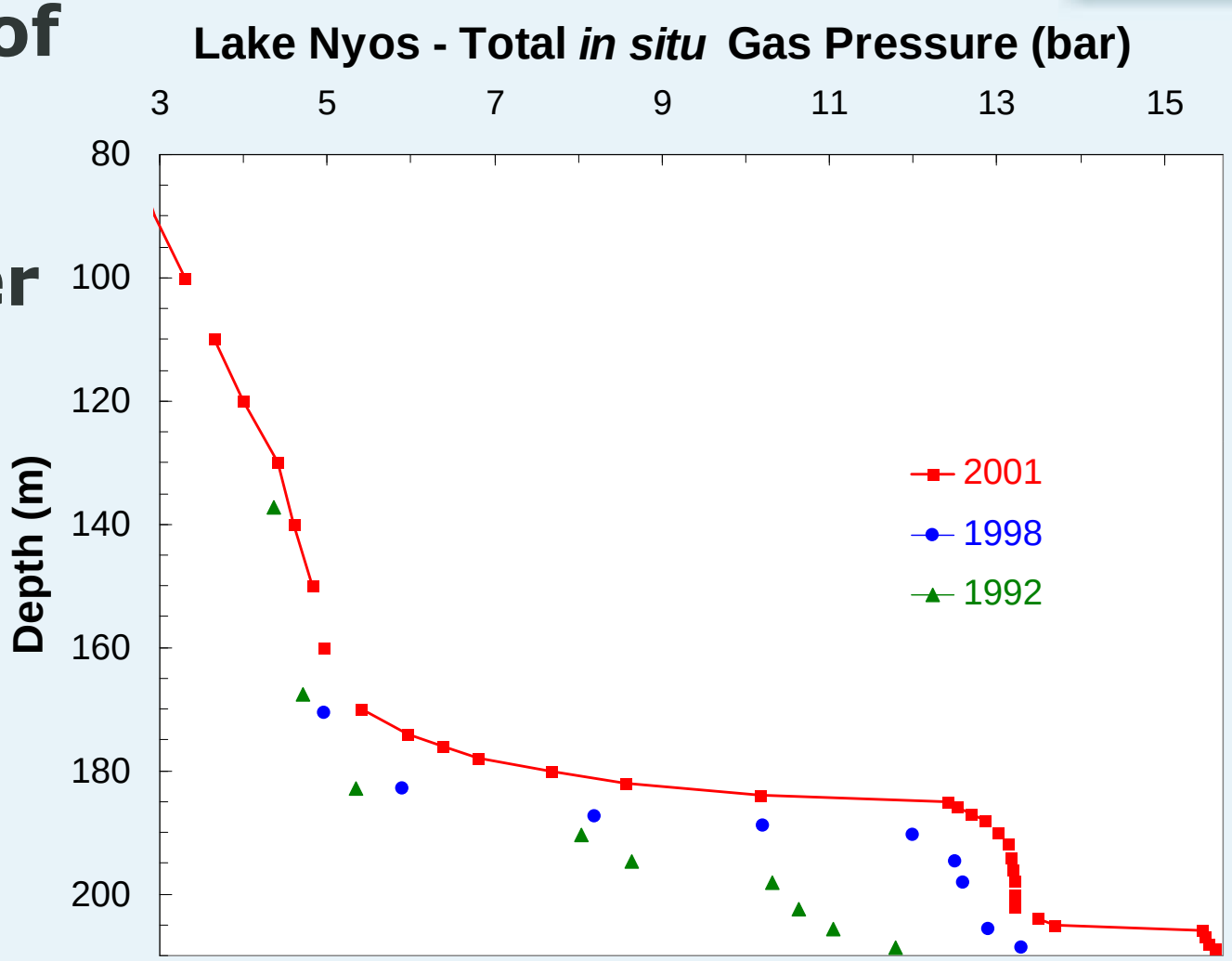
Risk analysis - general background

This lifting of density gradients due to water inflow has been inaccurately measured to:

Location/denomination	Name	$\Delta level_1$ m/year	Q_1, km^3/ years
Below biozone	-85 m	~0	
Below intermediate zone	-190 m	0.35	0.45
Main density gradient	-260 m	0.16	0.17
Lower gradient	-310 m	0.30	0.26

Risk analysis - general background

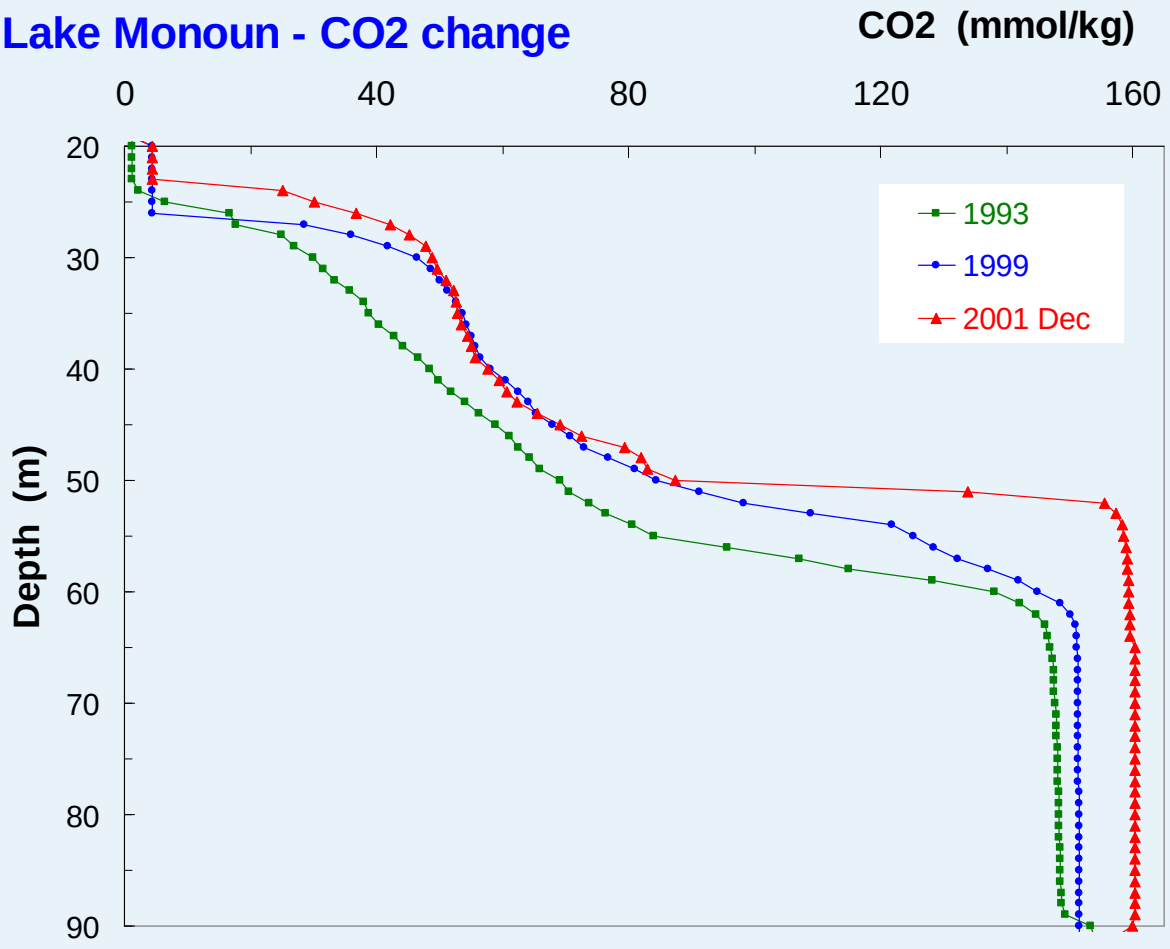
This lifting of density gradients due to water inflow has also been observed in Lake Nyos



Risk analysis - general background

- and in Lake Monoun it happens too

Gradient lifting is thus the second challenge of the killer lakes



Risk analysis - the dangers from gradient lifting

Lifting of the density gradients is the second challenge set by Nature. It results in:

- **Future uncontrollable eruptions of the lake**
- **But much before that (quite soon really), the loss of commercial gas extraction from the PRZ as a means of controlling the danger**

Risk analysis - the dangers from gradient lifting

The lifting rate of the density gradients is not known with sufficient accuracy yet. This must be better monitored.

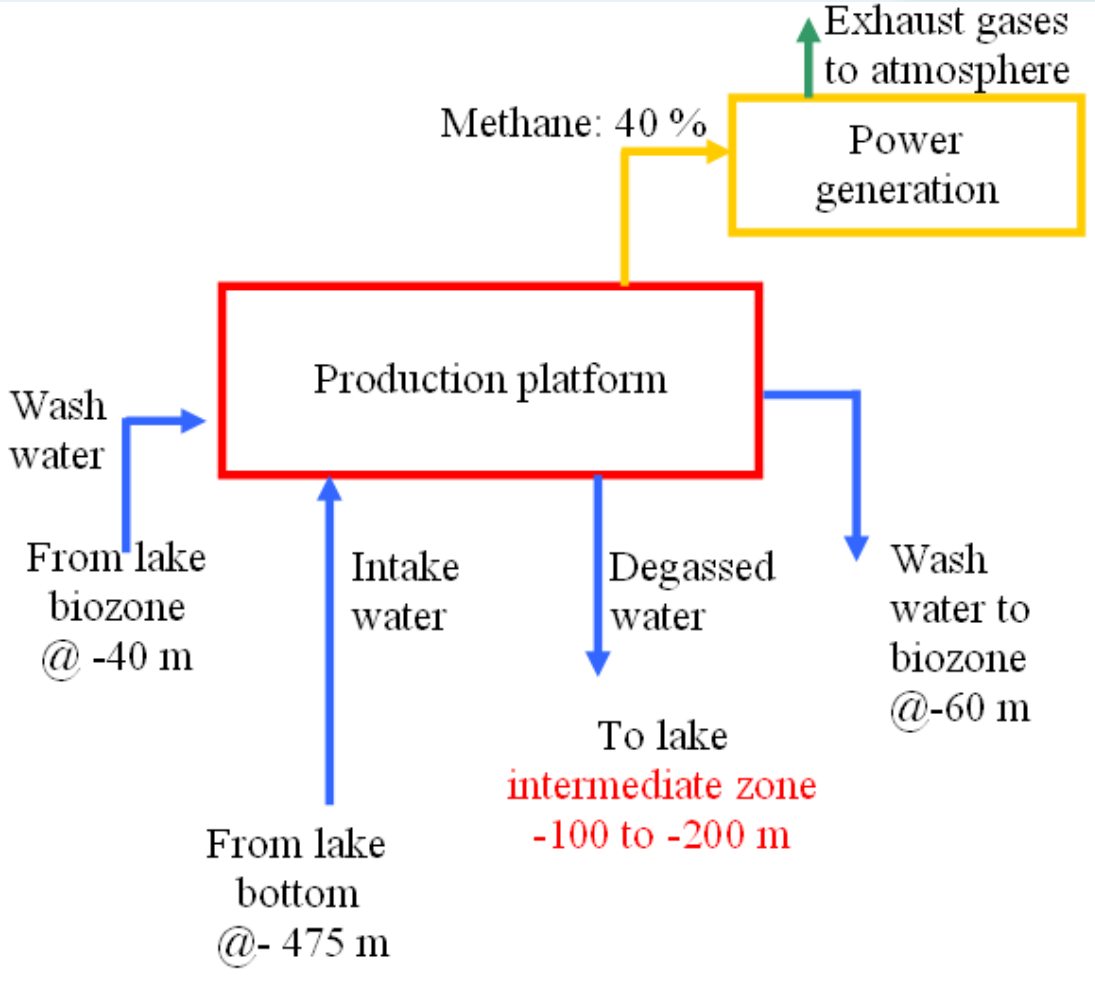
But we must also do something about it, preventing the gradients from lifting in order to maintain controllability

Added benefit: operators need not to adjust pipe lengths on regular basis

Risk analysis - density gradient draw-down extraction method proscribed

This legacy method draws down the gradient structure between suction and reinjection.

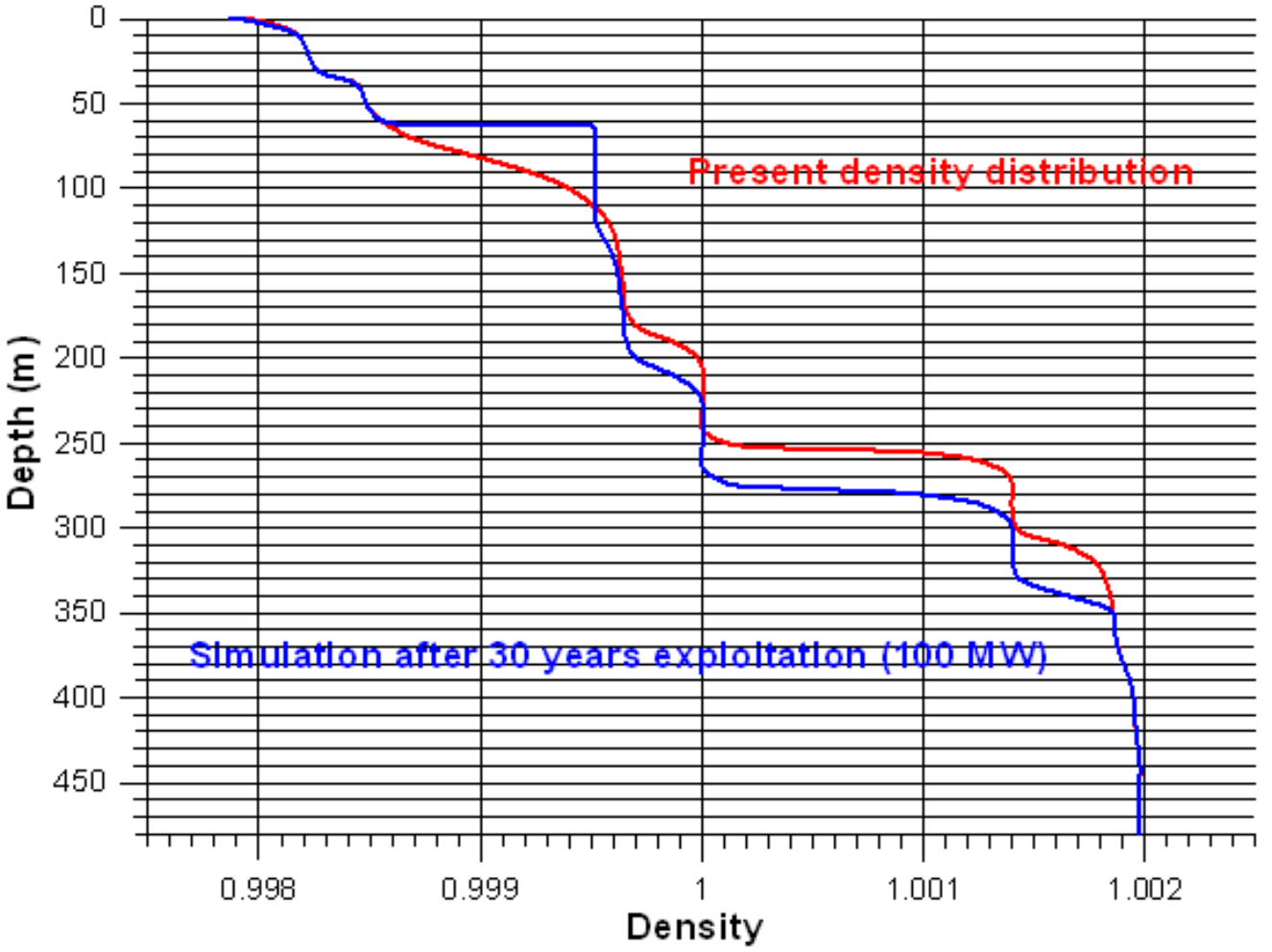
It also injects heavy water at high levels.



Risk analysis - density gradient draw-down extraction method proscribed

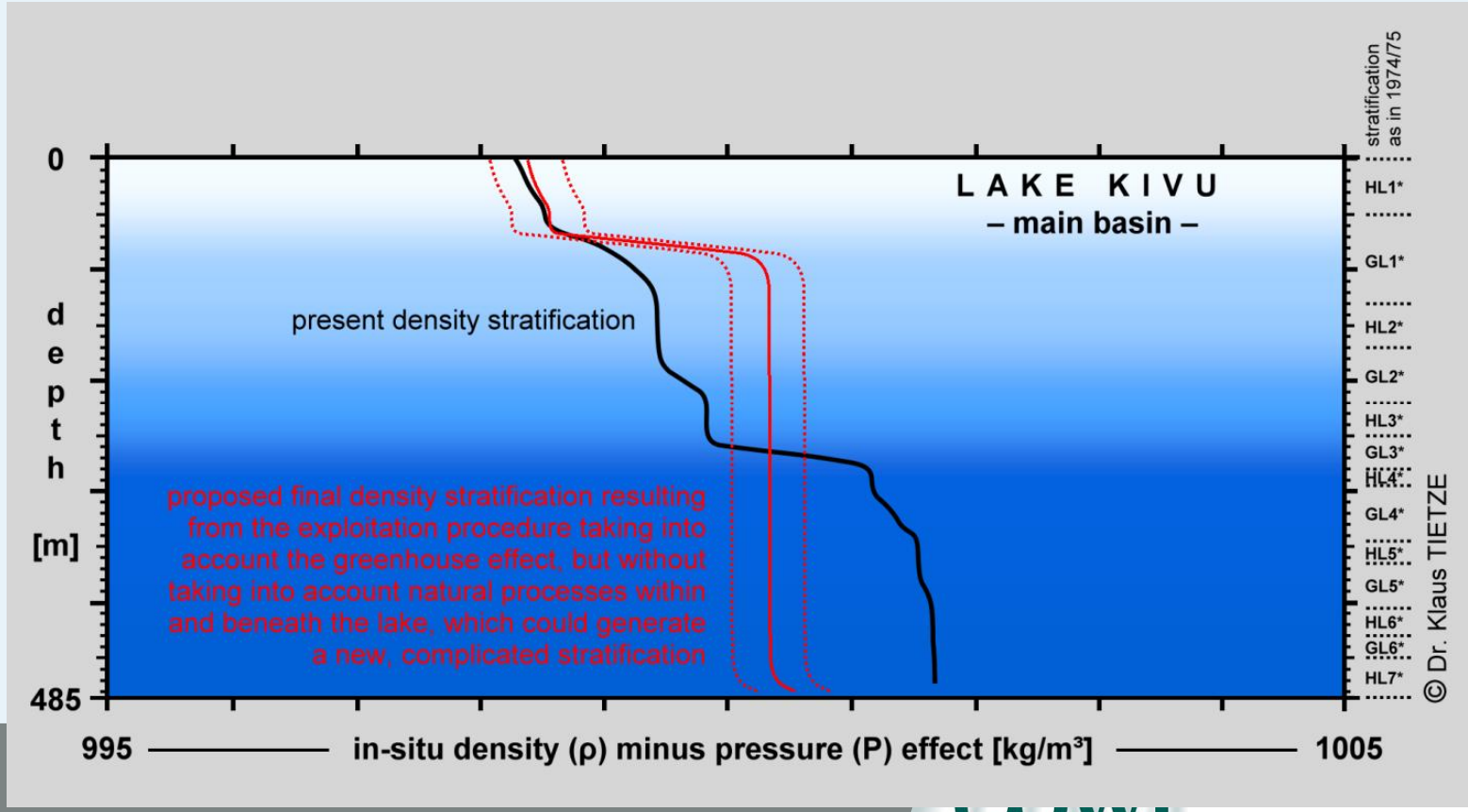
At the beginning it might look harmless, but it is not …

Increased nutrient transport to biozone



Risk analysis - density gradient draw-down extraction method proscribed

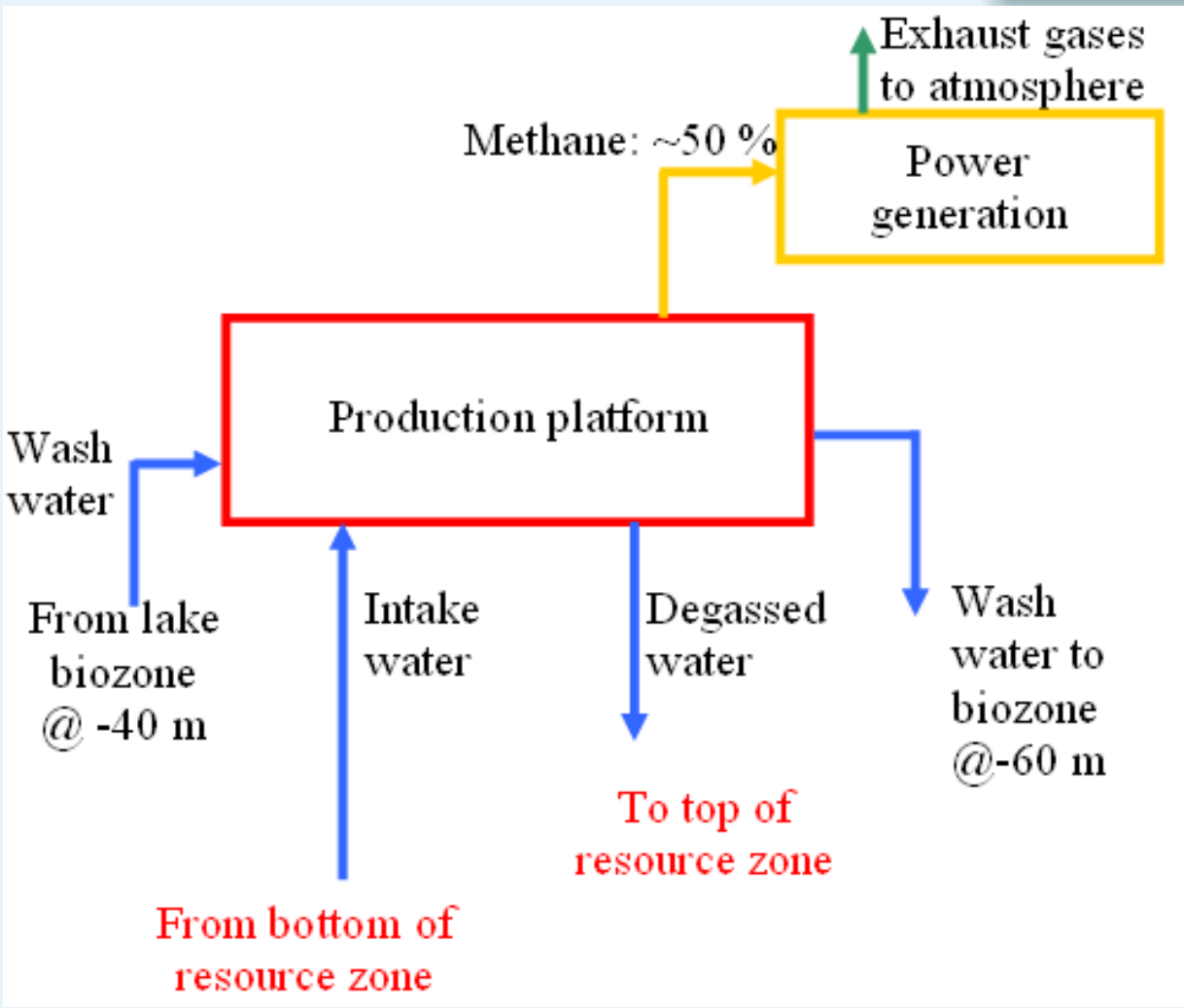
And through destruction of the gradient structure, gases get access to high levels and future eruptions is the result.



Extraction methods to be used

Sustainable control of the gas pressure through the zone preservation method

It preserves the lake's gradient structure.



Extraction methods to be used

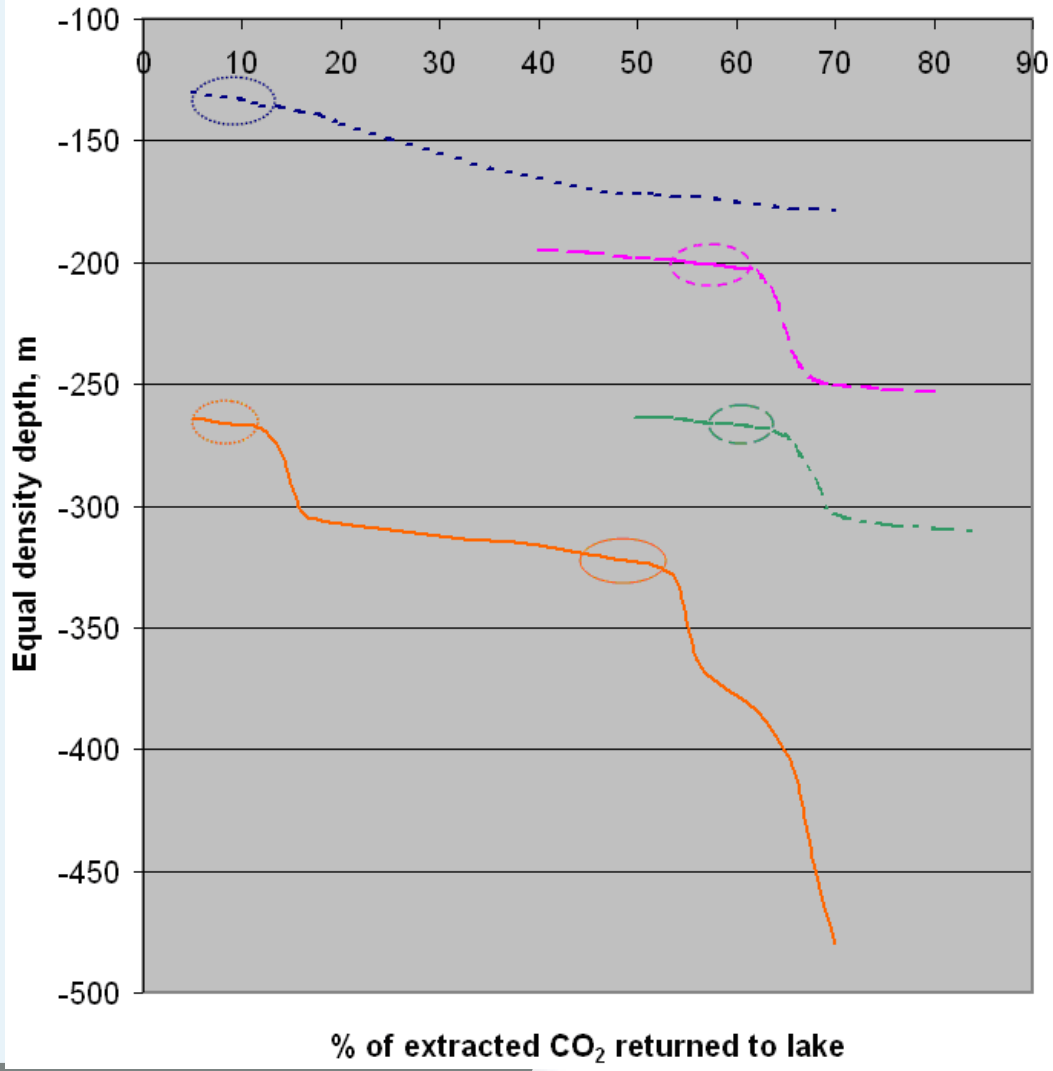
Zone preservation method in detail:

- **Draw up: Unsafe, not acceptable**
- **Mixed production: not safe enough and short-circuiting is guaranteed**
- **Draw down: Safest solution, makes prolonged sustainable production possible**

Extraction methods to be used

Density control through CO_2 removal

- **PRZ: ~40-45 %**
- **RZ: Not possible**
- **URZ: ~40 %**
- **LRZ: ~50 %**
- **IZ: Not possible.**



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Extraction methods to be used

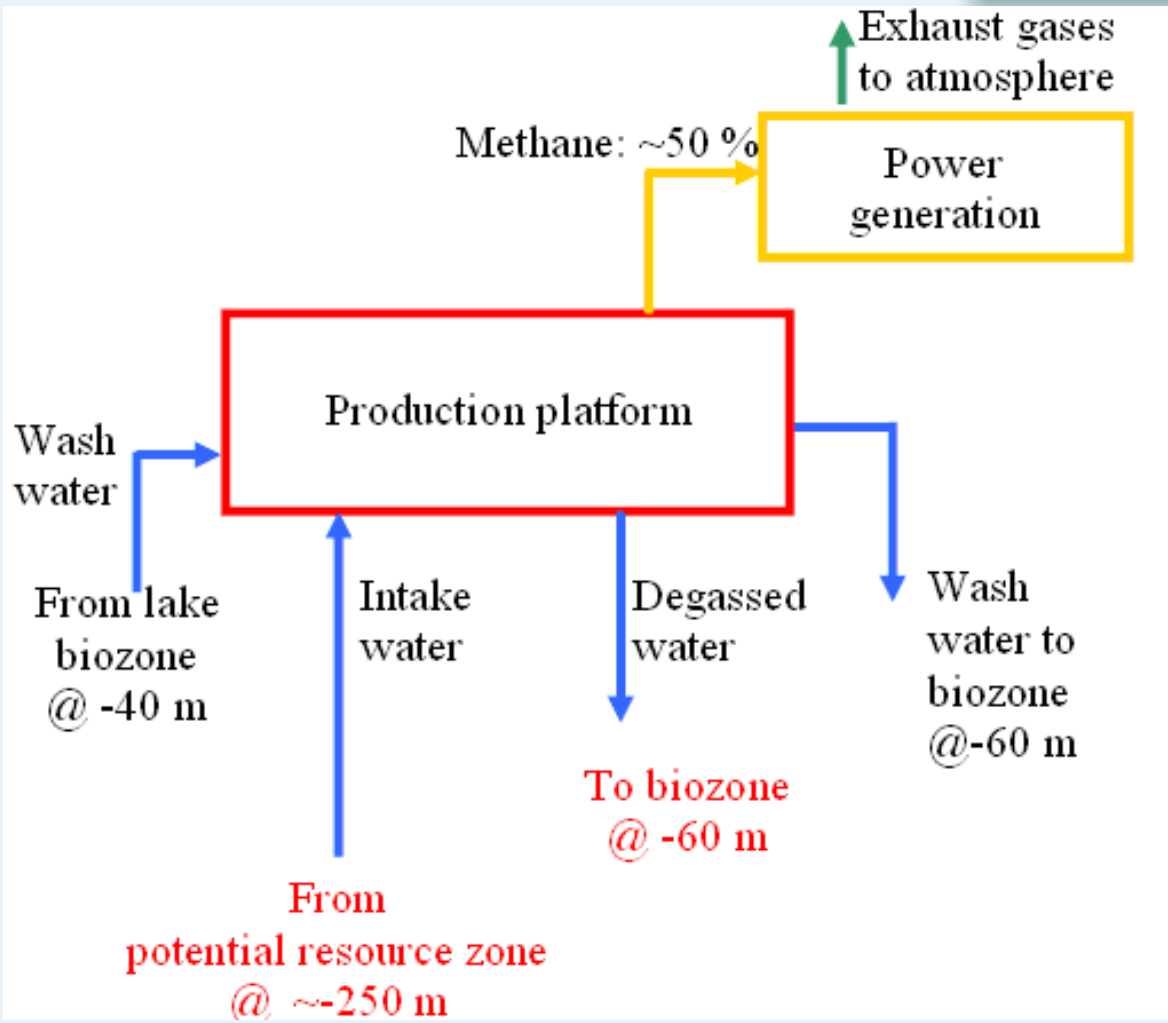
Zone preservation method:

- **It is safer in the long run,**
- **It gives the same gas production, and**
- **It makes transition to long-term sustainable production possible so as to allow continuous management of public safety**

Extraction methods to be used

The gradient preservation method is required to prevent gradient lifting

It preserves the lake's gradient structure.



Extraction methods to be used

Gradient preservation method requires:

- **Maybe ~0.2-0.3 km^3/year from RZ**
- **Maybe ~0.2 km^3/year from PRZ**
  (400 MW ≈ 2,5 km^3/year)

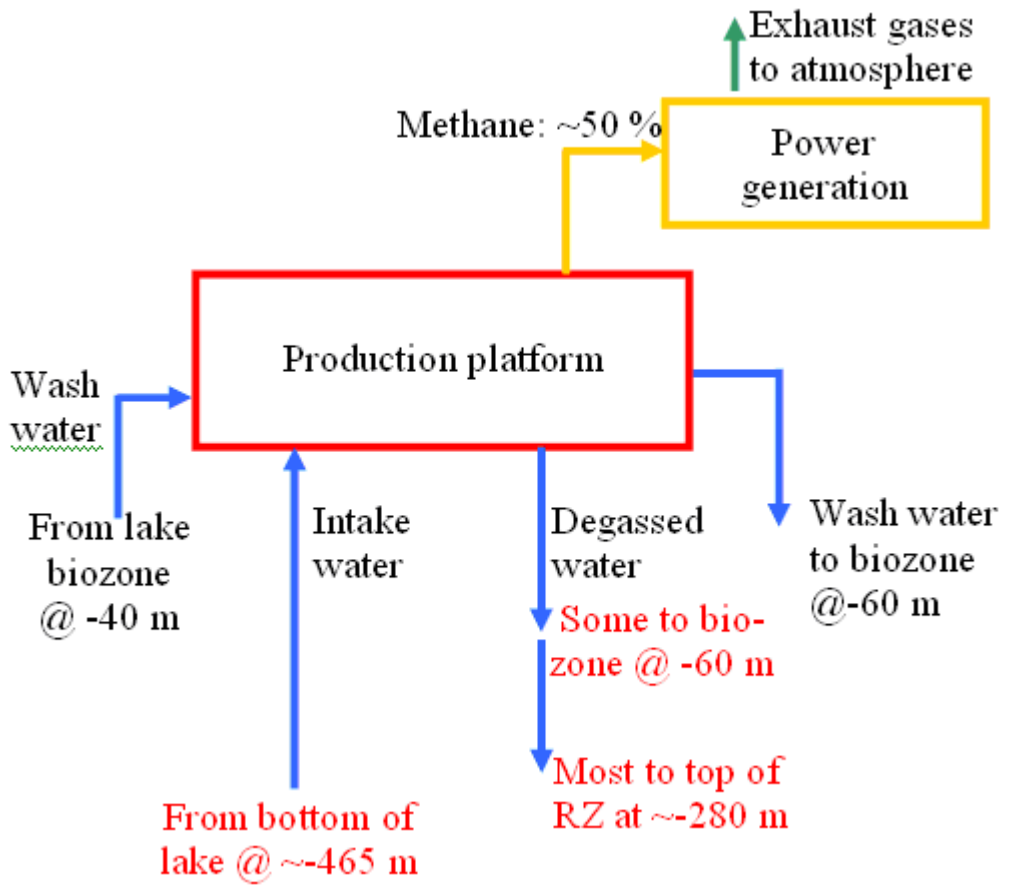
Risk of eutrophication of biozone. Possible mitigating measures to be tested in smaller scale first:

- **Injection over deep part of lake**
- **Injection high up in biozone**

Extraction methods to be used

So, some facilities must be able to switch from zone preservation to gradient preservation.

The 'combined preservation method' is easy if included in design from the start



Elements of EIA

WATER EXTRACTION METHODS:

Risk of eruption to present and future generations has first priority.

Environmental impact comes second.

REST OF GAS EXTRACTION FACILITIES:

Traditional requirements.

Elements of EIA

Best Available Technology with No Excessive Extra Costs (BATNEEC) for water extraction:

1. **Gas extraction advantages: Eruptions prevented, substitution of fuel, methane converted to carbon dioxide (21 time less potent greenhouse gas)**
2. **As much as possivble degassed water returned to zone of origin**

Elements of EIA

BATNEEC continued:

3 **All Nature's accumulation of CO_2 must come out - in an orderly way**

4 **Gradient lifting must be prevented**

5 **Washing water to biozone, but sparingly - minimize use (technology, biogas engines)**

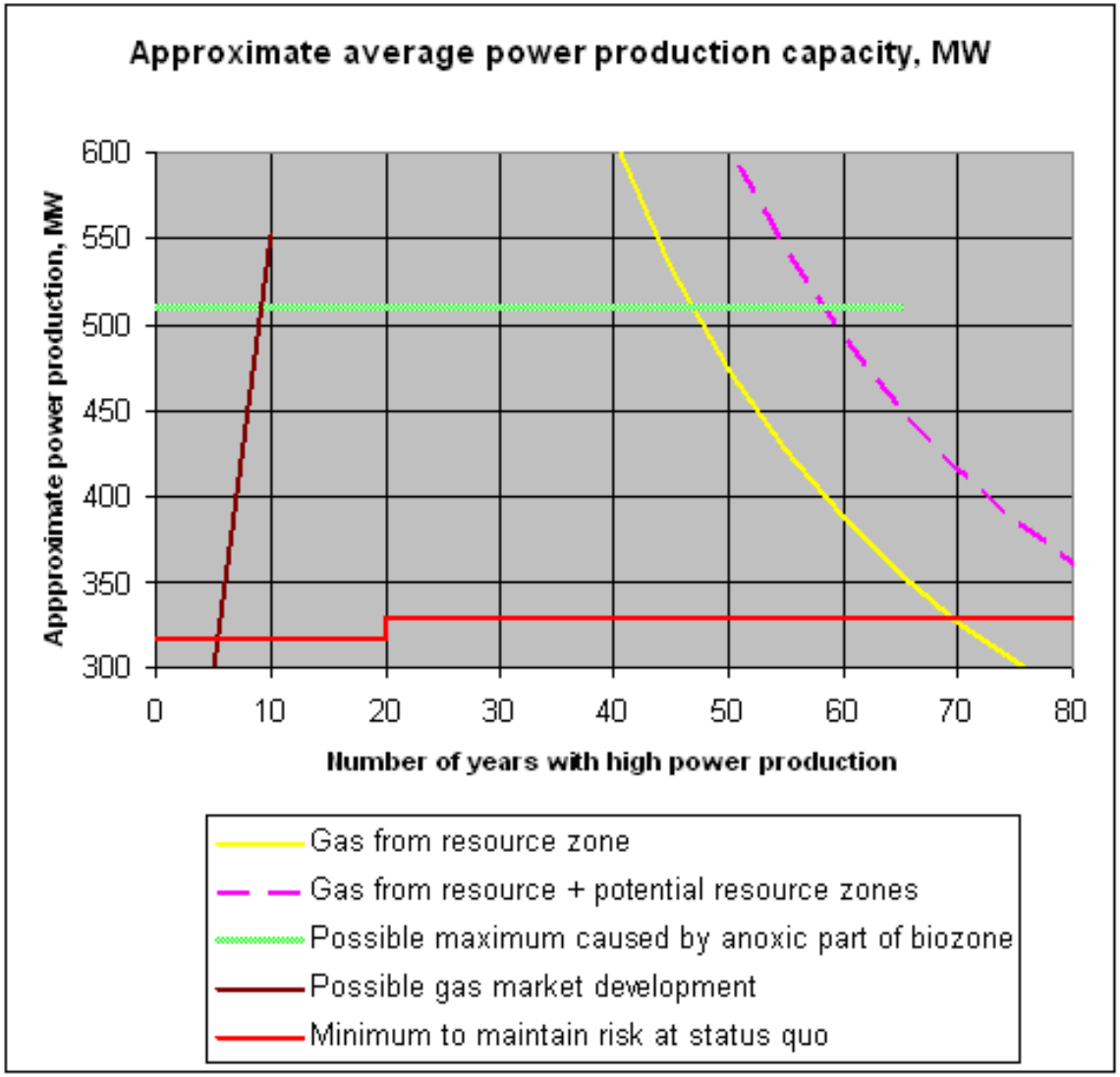
6 **Solution for IZ missing, expected to be problematic**

Important constraints

Minimum extraction rate to be achieved soon

Feasibility of PRZ

Market build-up



Important constraints

Gas harvesting plan:

- **Safeguarding public safety: harvesting zone by zone, starting with 2/3 URZ and 1/3 LRZ (Kibuye + up north)**
- **When URZ depleted, continue with plan B: entire RZ (practically only up north)**
- **At the same time control of gradient lifting**
- **Later, when economically feasible: PRZ**

The human factor

These were the main technical conclusions, that started with a risk an overall risk assessment of the lake.

But more is required before we can claim success: Unconditional co-operation among all parties involved. This is probably the single biggest challenge of them all.

The human factor

Need for unconventional thinking (1):

- **High degree of regulation required for water extraction**
- **Role of EIA conditioned by risk assessment**
- **Bilateral delegation of power to common institute**
- **Scientists to make public all raw data**

The human factor

Need for unconventional thinking (2):

- **When soliciting advice, go for quality, not cost**
- **Advice on rules must be by group of experts, not by single persons**
- **Monitoring to be defined by master list. Financers to check with this list, not financing individual initiatives.**

The human factor

Need for unconventional thinking (3):

- **A lake Kivu expert must master all the issues exposed in the M.O.**
- **Technical limitations on concessioning options**
- **Tight co-ordination between two governments**
- **Etc.**

Recommendations

Save the lake by producing gas

Implementation of rules

Formation of <u>one</u> Bilateral Authority with sufficient powers, assisted by <u>one</u> group of foreign experts