eawag aquatic research

Lake Kivu Methane Extraction: Evaluation of Scenarios

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Kongens Lyngby DK, 14 May 2009

Overall conclusions (general)

- **Dilution**

  many disadvantages → **Avoid dilution**
- **Reinjection to Biozone**

  Nutrient pollution → **NOT acceptable**
- **Reinjection below IZ → is acceptable**
- **"Safe" CH_4 extraction → is possible!**

  maintaining stratification / low nutrient

  prize: ~4% of the CH_4 resource

  and 2 withdrawals / reinjections

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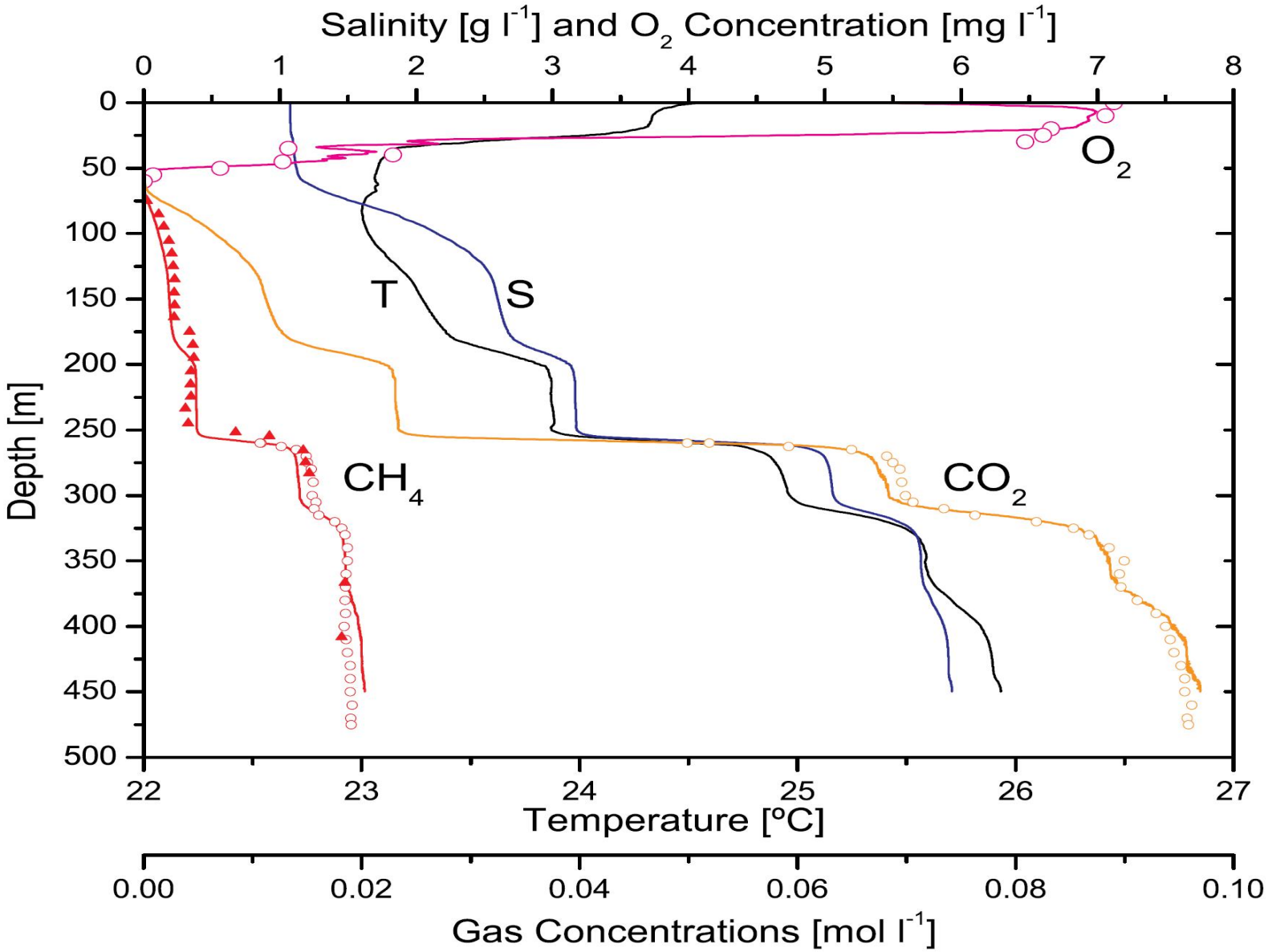
Lake Kivu vertical structure

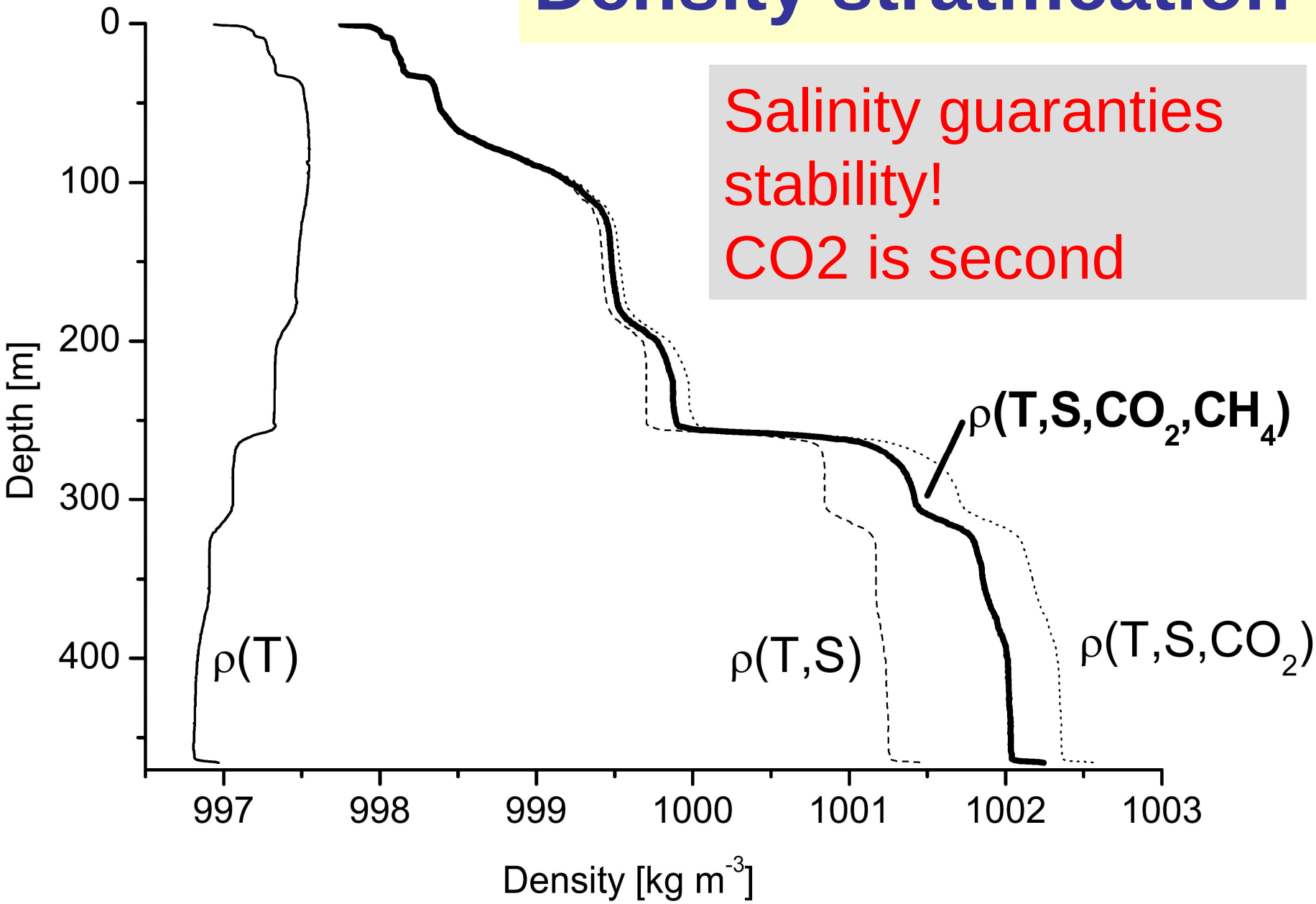


Overall extraction numbers

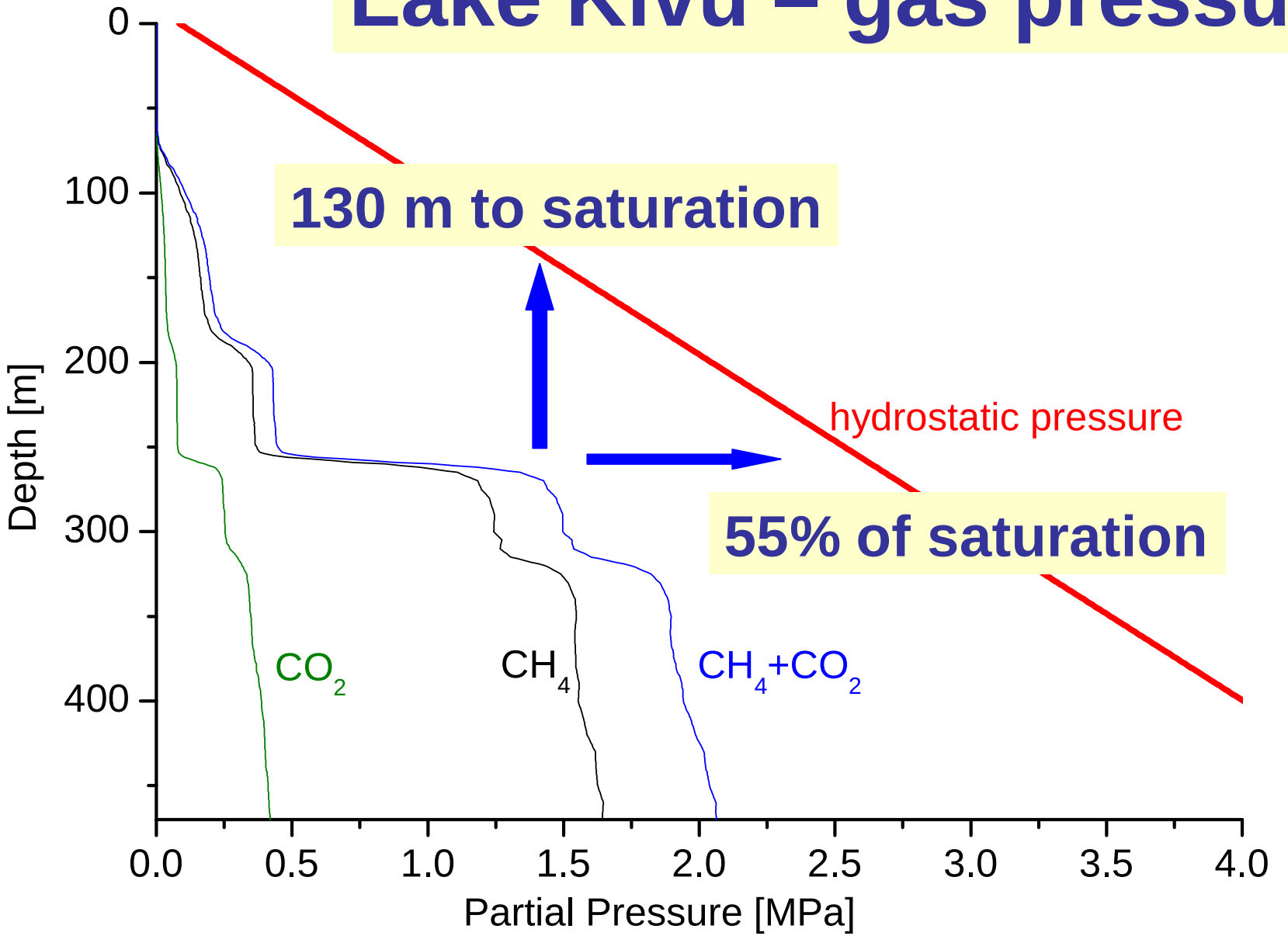
- Total / extractable CH_4 60 / 46 km^3
- Total power 46 x 400 MWyr
- Power (if CH_4 used in 46 yr) 400 MW
- Water flow 100 m^3/s

Density stratification

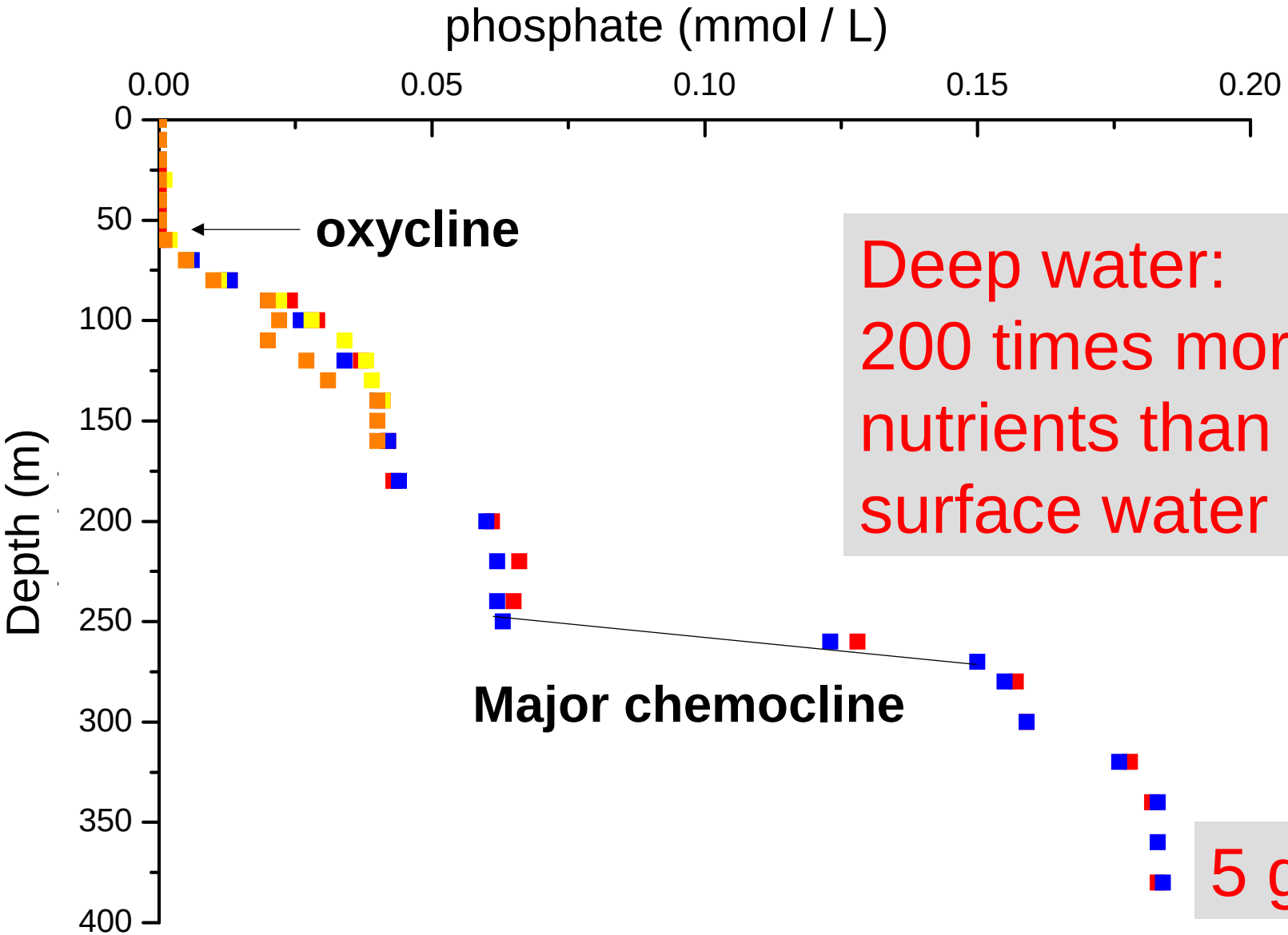
Salinity guaranties stability!
CO2 is second



Lake Kivu – gas pressure



Nutrients: vertical P profile (N same structure)



Deep water: 200 times more nutrients than surface water

5 g/L

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Goal of the scenarios study

- **Find extraction scenario fulfilling the three *Guiding Principles* (constraints)**

First: Reduce risk of eruption

Second: Minimize effect on lake ecology

Third: Maximize methane output

Objectives for Lake Kivu methane harvesting

Priority

First — **Minimize probability of eruption**

→ keep profile stable
→ reduce gas content in lake
→ increase activation energy for bubbles

Second — **Minimize impact on lake ecology**

→ minimize nutrient upward flux to *Biozone*

Third — **Maximize methane harvest**

→ minimize CH_4 loss
→ allow build-up of new deep-water CH_4
→ no dilution of CH_4 resource

Guiding Principles	***Objectives***	***Attributes Quantifying Objectives***
Safety	• Keep stratification • Reduce gas • Reduce risk	**1) Schmidt stability** 2) CO2 Content 3) CH4 Content 4) Bubble forming energy
Lake ecology	• Minimize nutrient input to *Biozone*	**5) P flux to *Biozone*** 6) N flux to *Biozone*
Economic viability	• Minimize CH4 loss • Accumulation of newly formed CH4 • no CH4 dilution	**7) harvested CH4** **8) harvested plus harvestable CH4**

What can be adjusted?

five “crews”: Design Parameter

- Extraction depth (+ depth range)
- Dilution water (%) (+ intake depth)
- Release depth (+ depth range)
- % CH_4 removed (to turbine)
- % CO_2 removed (to atmosphere)

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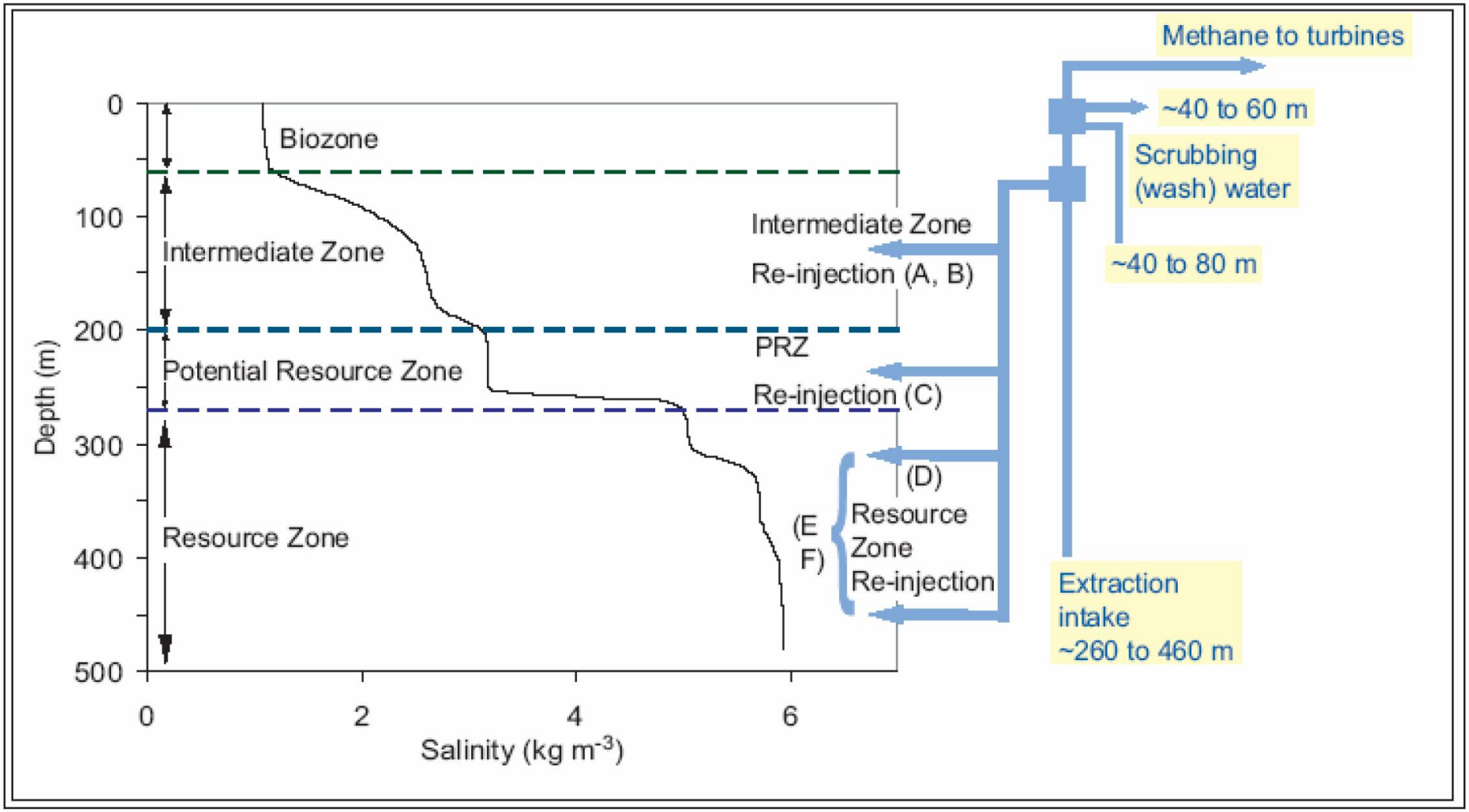
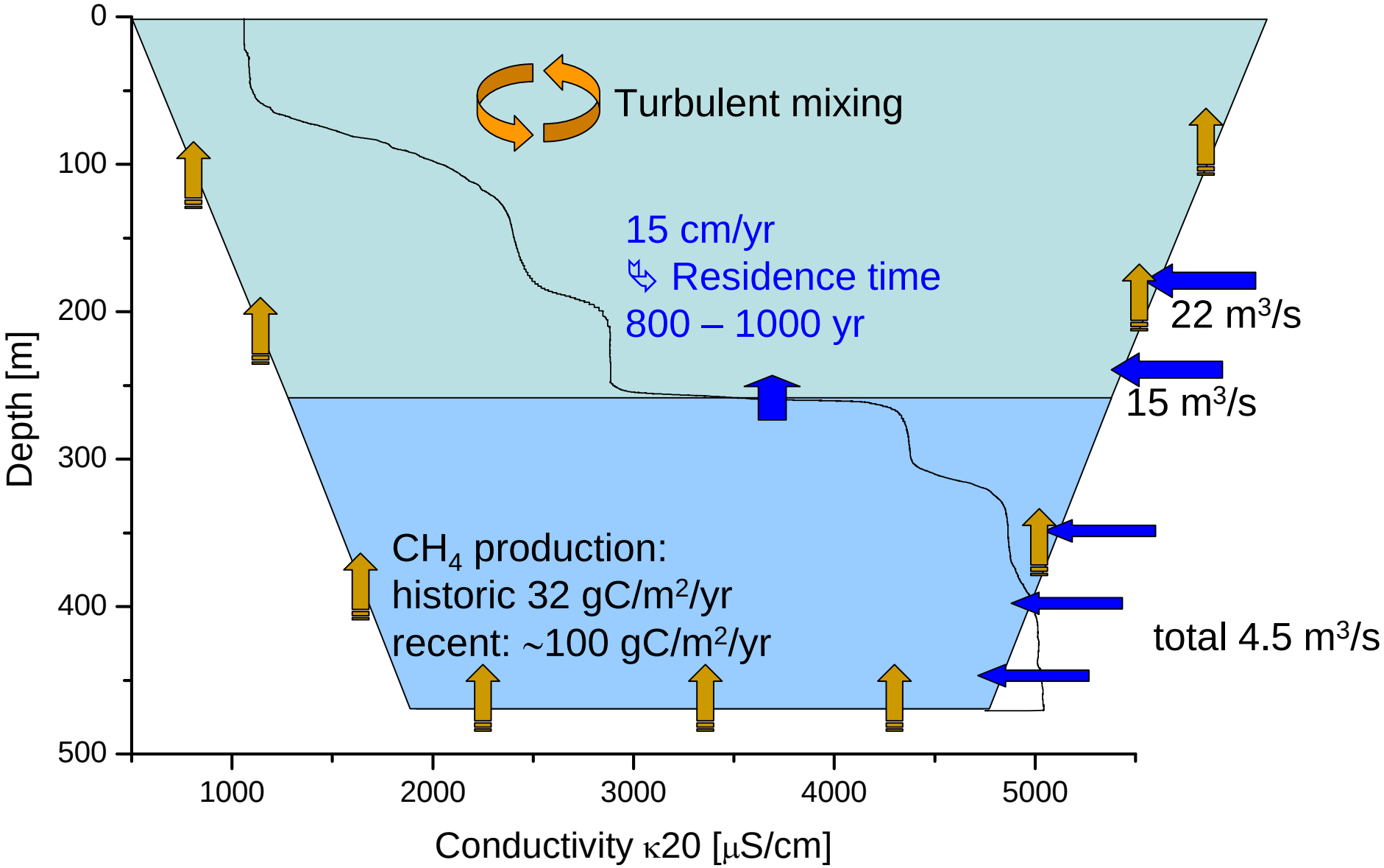
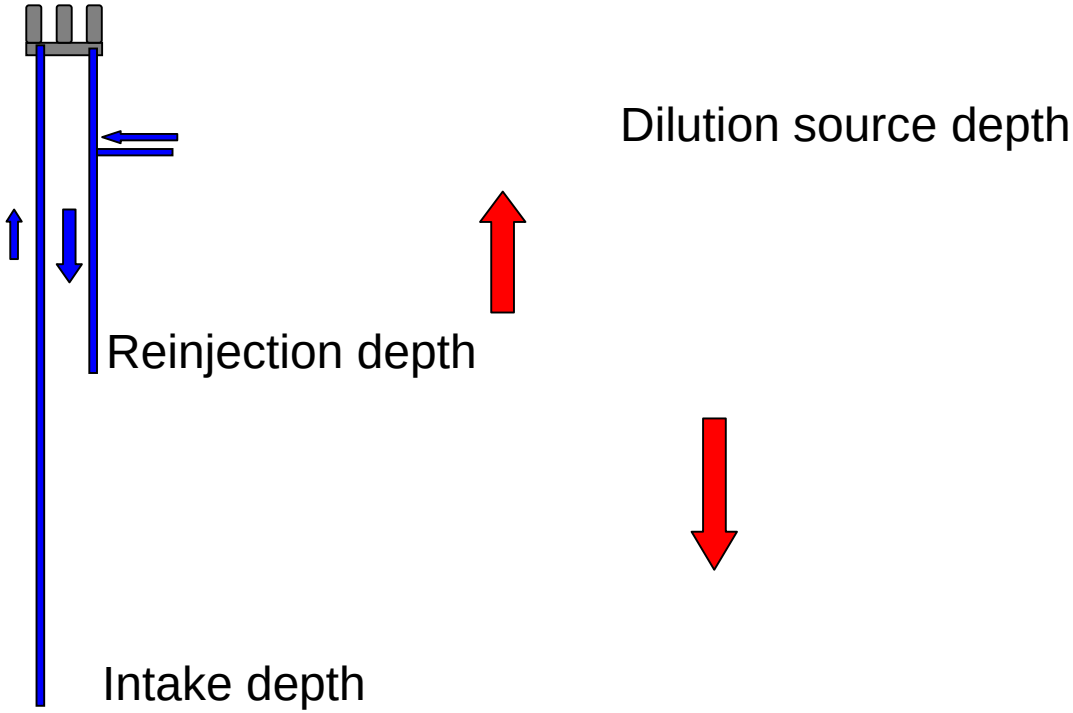
Scenario definitions



1-D simulation + deep inflows



150 MW plant with intermediate reinjection



Guiding Principles	***Objectives***	***Attributes Quantifying Objectives***
Safety	• Keep stratification • Reduce gas • Reduce risk	**1) Schmidt stability** 2) CO2 Content 3) CH4 Content 4) Safety tolerance
Lake ecology	• Minimize nutrient input to *Biozone*	**5) P flux to *Biozone*** 6) N flux to *Biozone*
Economic viability	• Minimize CH4 loss • Accumulation of newly formed CH4 • no CH4 dilution	**7) harvested CH4** **8) harvested and harvestable CH4**

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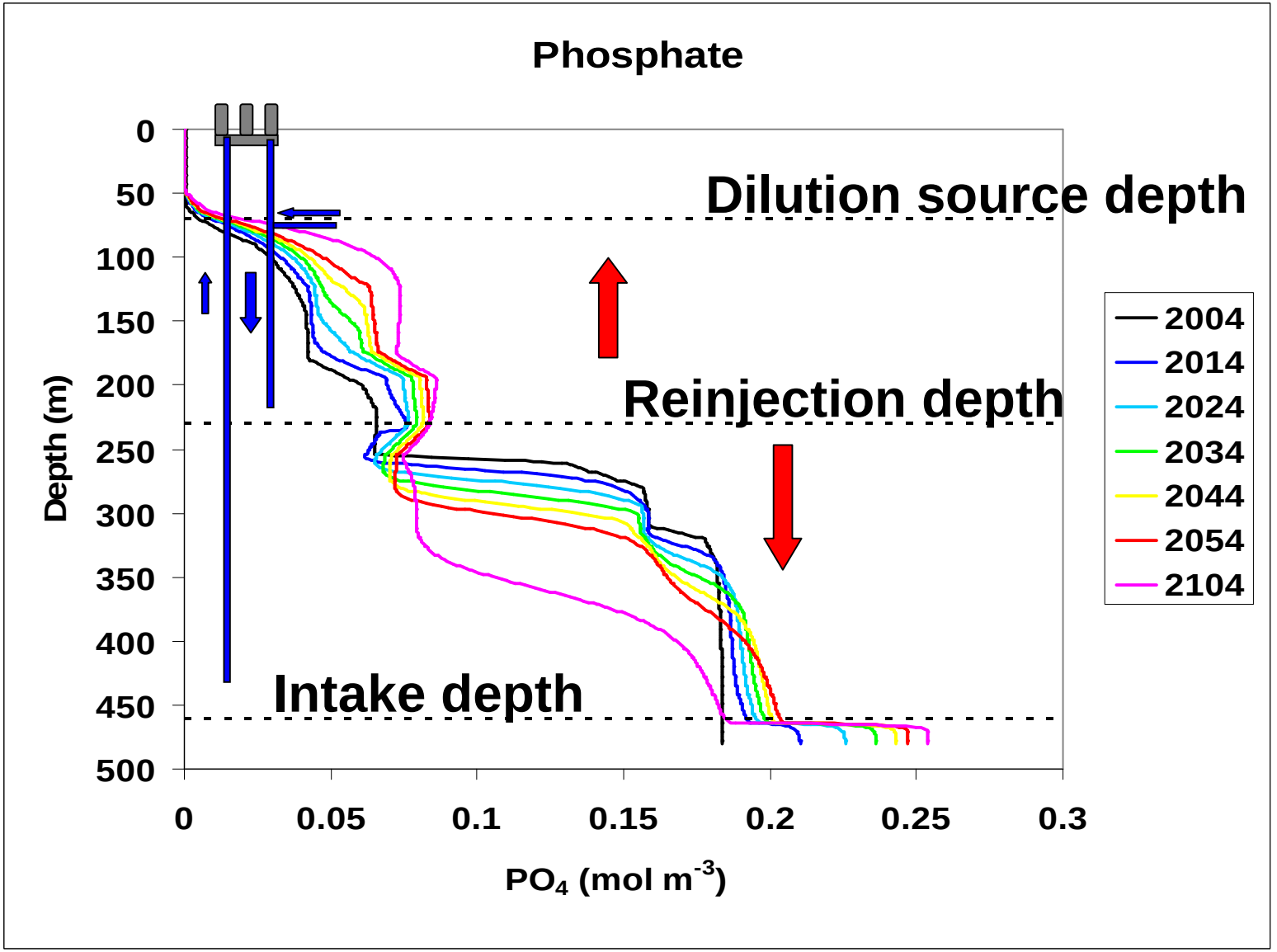
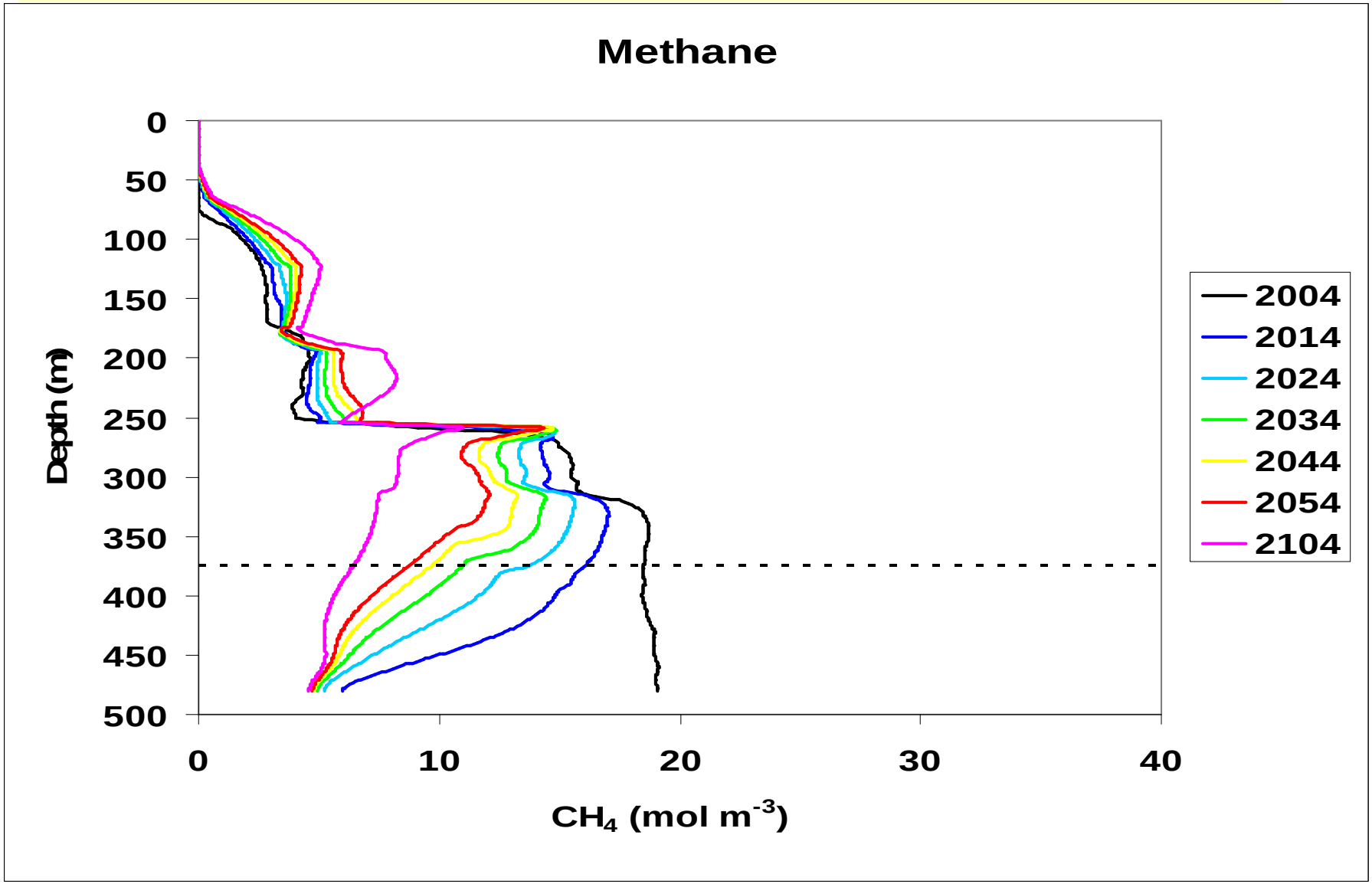
150 MW - intermediate re-injection

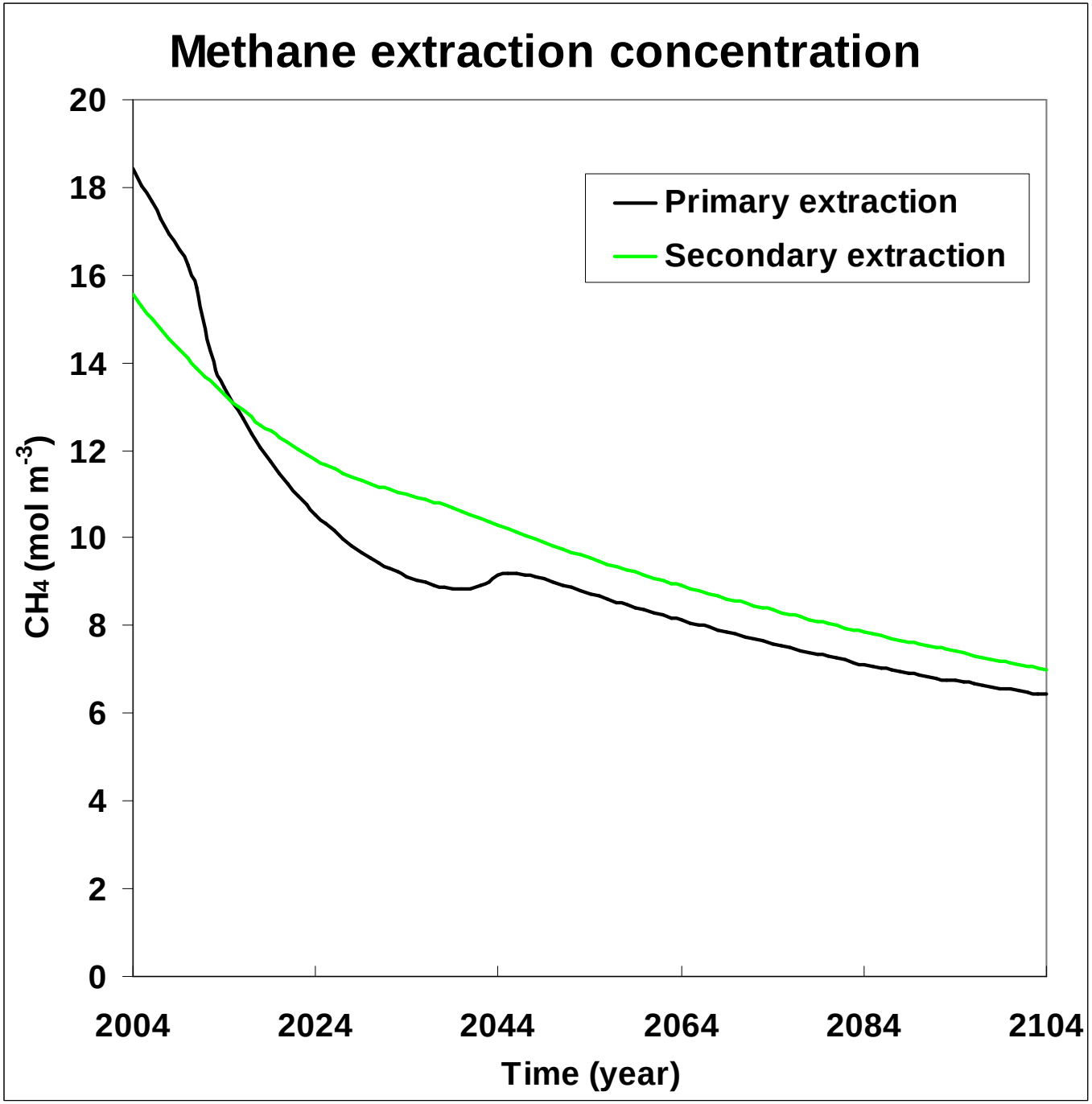


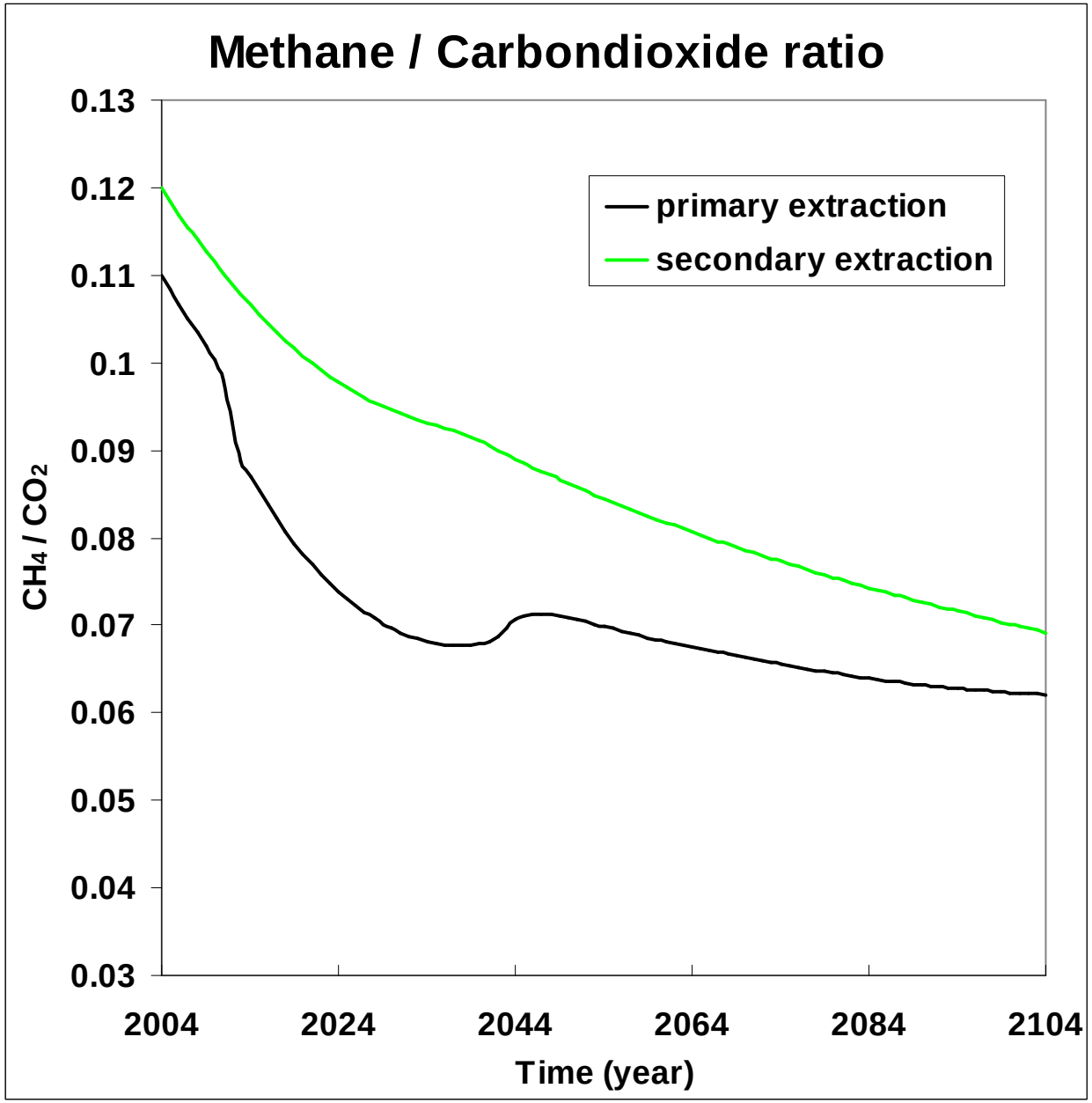
Problems related to intermediate re-injection

Sce-nario	Objective "Safety"	Objective "Ecology"	Objective "Economic benefit"	Objective "Economic benefit"	Decision
KP1	61% of max. after 100 yr	1.6-fold of natural after 50 yr	92 % of maximum	84 % of maximum	failed on Obj "Ecology" and "Economic benefit"
KP2	82% of max. after 100 yr	1.2-fold of natural after 100 yr	93 % of maximum	83 % of maximum	weak on two Obj., hence not recommended
MH	48% of max. after 100 yr	2.6-fold of natural after 50 yr	96 % of maximum	89 % of maximum	failed on Obj. "Safety" and on Obj "Ecology"

Resource Zone intake / reinjection (Ext = Re-in = 375 +/- 105 m)




Methane extraction concentration
Primary extraction
Secondary extraction
CH4 (mol m-3)
20
18
16
14
12
10
8
6
4
2
0
2004
2024
2044
2064
2084
2104
Time (year)


Methane / Carbondioxide ratio
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
CH4 / CO2
primary extraction
secondary extraction
2004
2024
2044
2064
2084
2104
Time (year)

Advantages of Resource Zone / reinjection

Sce-nario	Objective "Safety"	Objective "Ecology"	Objective "Economic benefit"	Objective "Economic benefit"	Decision
B	48% of max. after 100 yr,	2.0-fold of natural after 50 yr	100 % of maximum	100 % of maximum	failed on Obj. "Safety" and on Obj "Ecology"
C	81% of max. after 100 yr	natural	97 % of maximum	92 % of maximum	option
D	100% of max. after 100 yr	natural	97 % of maximum	90 % of maximum	option
E	100% of max. after 100 yr	natural	98 % of maximum	96 % of maximum	option
F	87% of max. after 100 yr	natural	98 % of maximum	96 % of maximum	option
G	91% of max. after 100 yr	natural	98 % of maximum	88 % of maximum	option
H	85% of max. after 100 yr	natural	98 % of maximum	89 % of maximum	option
GH	87% of max. after 100 yr	natural	98 % of maximum	88 % of maximum	option

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- **Reinjection to Biozone**

  Nutrient pollution → **NOT acceptable**
- **Reinjection below IZ → is acceptable**
- **"Safe" CH_4 extraction → is possible!**

  maintaining stratification / low nutrient

  prize: ~4% of the CH_4 resource

  and 2 withdrawals / reinjections

Specific conclusions (scenarios)

- **Intermediate Zone reinjection (< 200 m) (Scenario A,B, KP1, MH)**
  drives huge P, N fluxes
  increase CH_4 loss
  reduce stability → **NO OPTION**

- **PRZ re-injection (Scenario C)**
  little change to nutrients and stability
  "dilutes" PRZ → loss of 3 to 8 % (If Extraction works ideal)
  → **Simple for panning, no short-circuiting**

- **Deep re-injection (stacking) (Scenario D)**
  minimum change to the lake functioning
  → **Simple for panning, no short-circuiting, up to 10% loss**

- **Deep re-injection (homogenizing) (Scenario E,F,GH)**
  minimum change to the lake functioning
  → **more complex, short-circuiting(?) , ony 4% loss**

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