AARHUS UNIVERSITY Department of Freshwater Ecology

Biogeochemical processes along the groundwater flow line in a riparian wetland

Carl Christian Hoffmann

Voldby Brook and river valley flooding stage

Based on work by

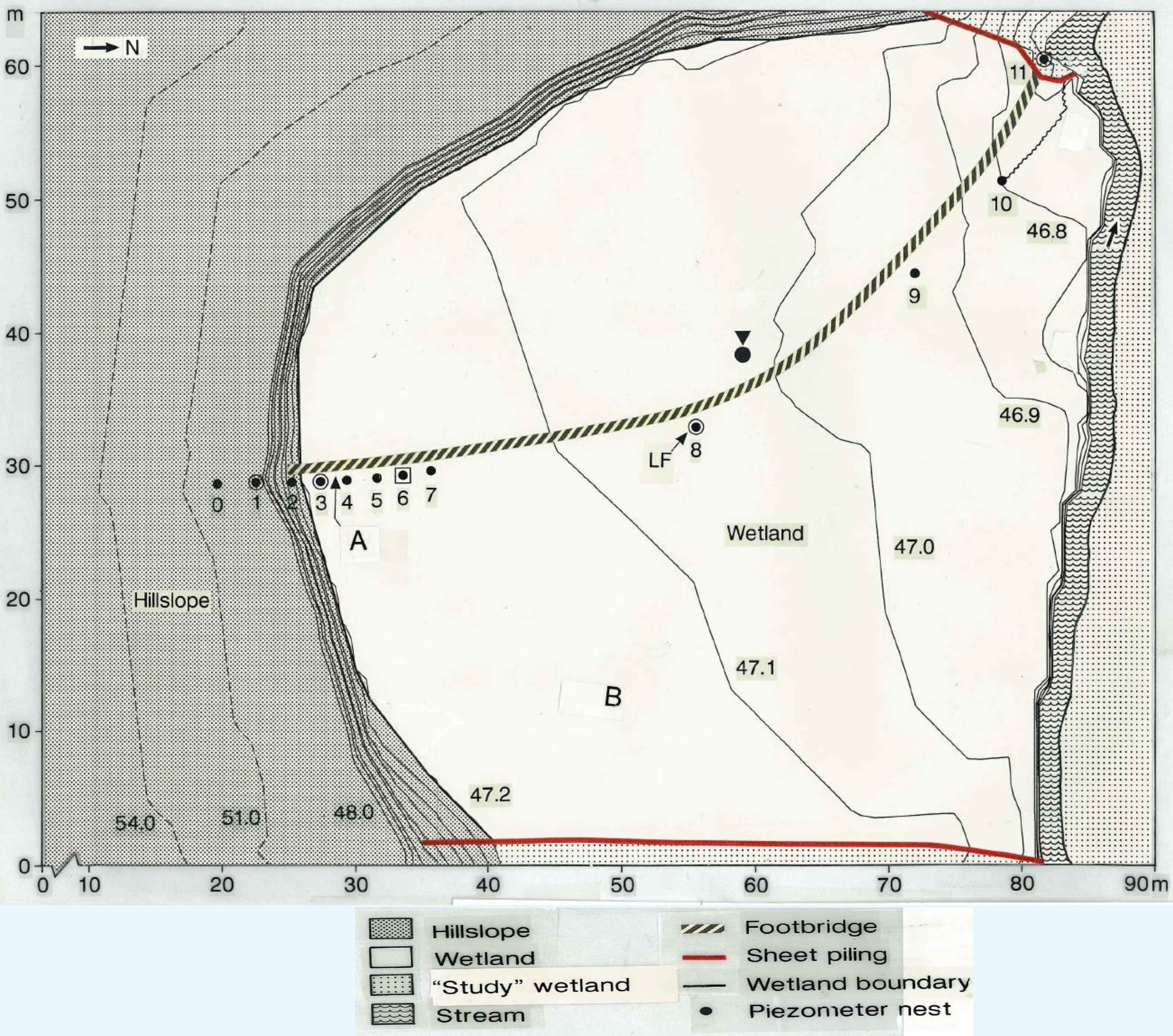
- **Mette Dahl 1995. Flow dynamics and water balance in two freshwater wetlands.** (PhD)
- **Claus Paludan 1995. Phosphorus dynamics in wetland sediments.** (PhD)
- **Gitte Blicher-Mathiesen 1998. Nitrogen removal in riparian areas.** (PhD)
- **Carl Christian Hoffmann 1998. Nutrient retention in wet meadows and fens.** (PhD)
- **Randi Lundshøj Dalgaard 2000. Distribution of iron containg phases in a wet meadow (**master thesis in Danish)

Biogeochemical processes along the groundwater flow line in a riparian wetland

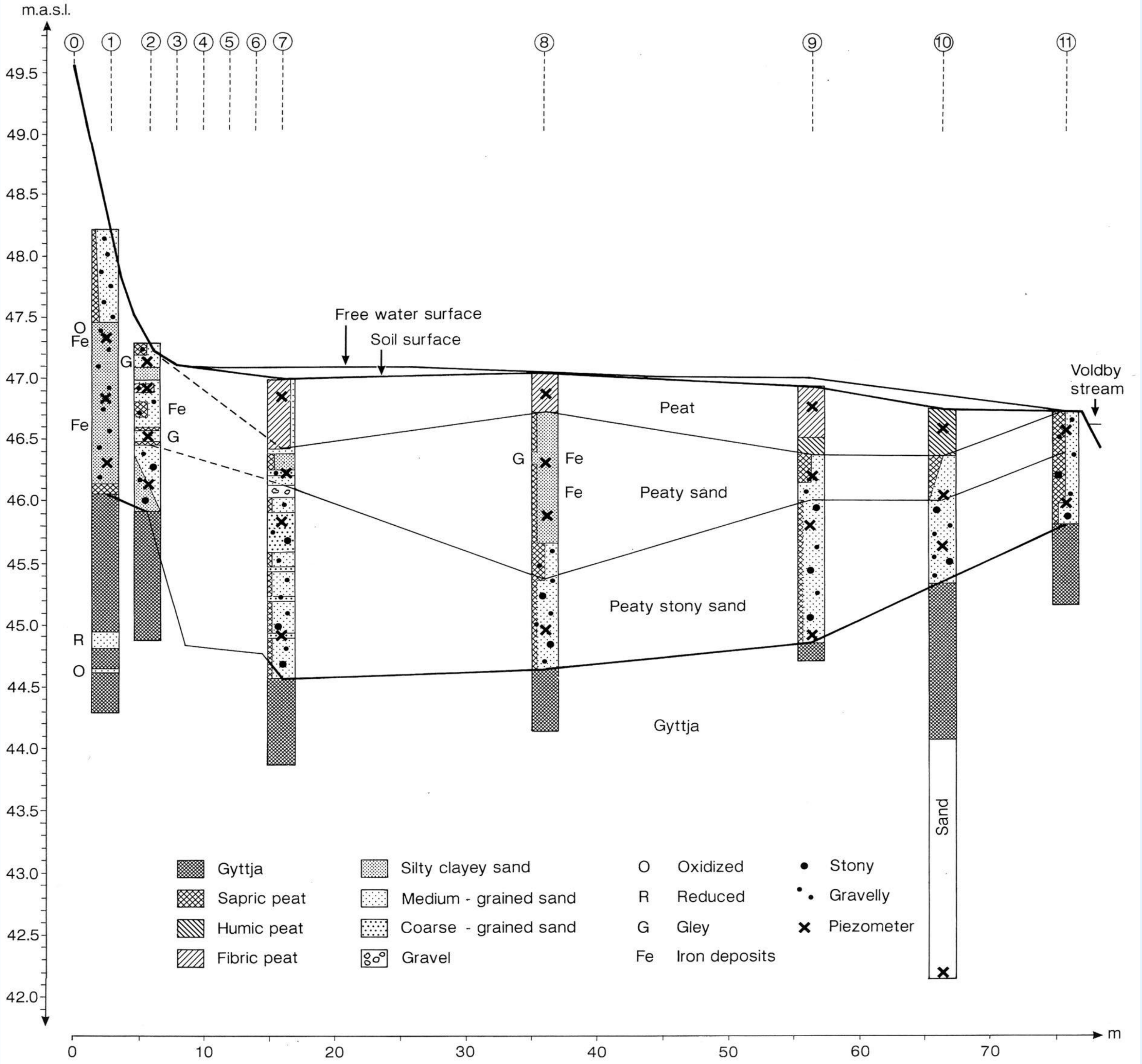
- **Outline**
- **Location, Field set-up, and soil profile**
- **Groundwater – surface water flow in the fen**
- **Redox sequence and consequenses**
- **Mass balances**
- **Denitrification**
- **Green house gases**
- **Iron**
- **Conclusion**

Minerotrophic fen in River Gjern system

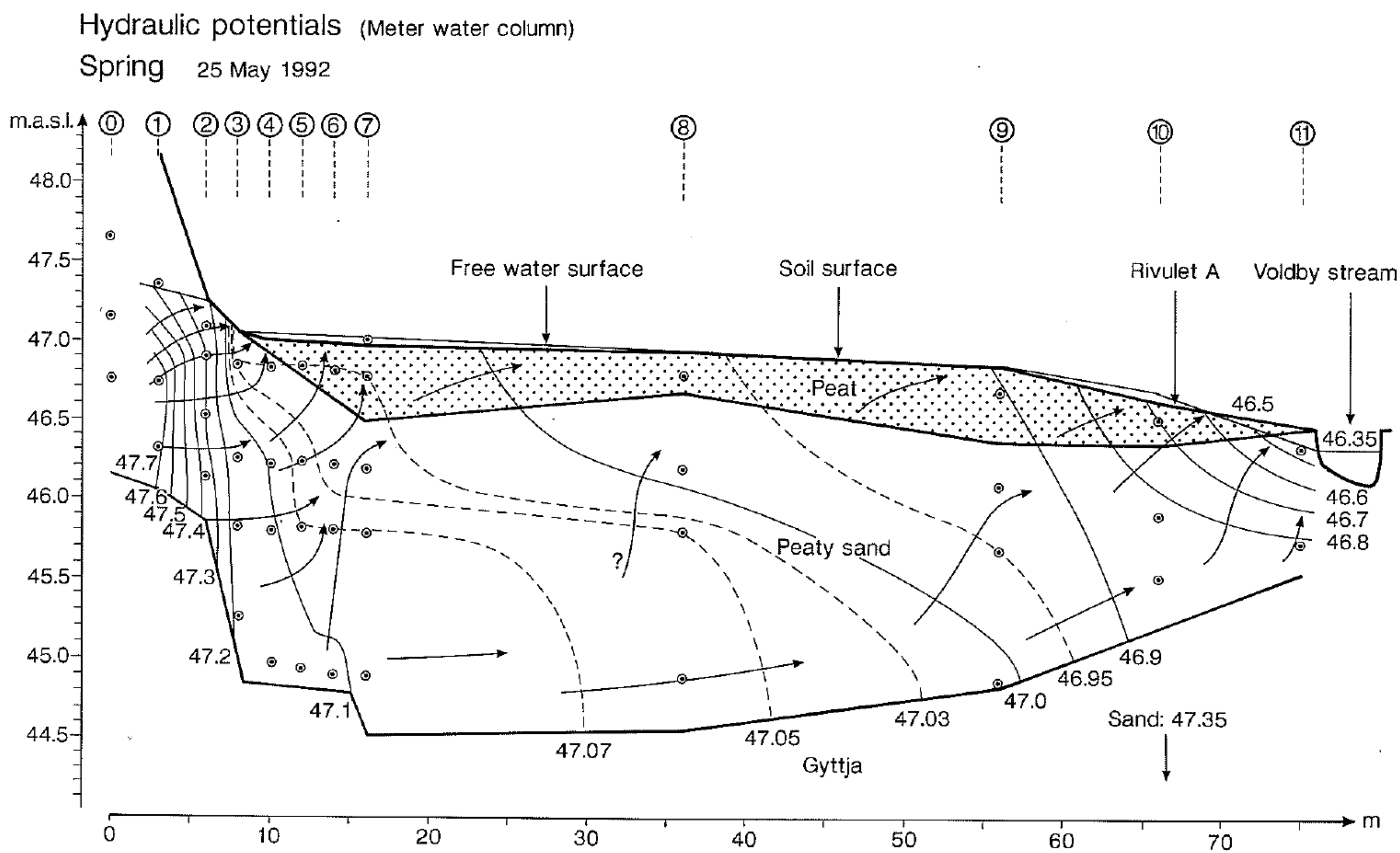
Mølgaarde fen


m
N
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90m
0
1
2
3
4
5
6
7
8
9
10
11
A
B
LF
Hillslope
Wetland
54.0
51.0
48.0
47.2
47.1
47.0
46.9
46.8
Hillslope
Wetland
"Study" wetland
Stream
Footbridge
Sheet piling
Wetland boundary
Piezometer nest

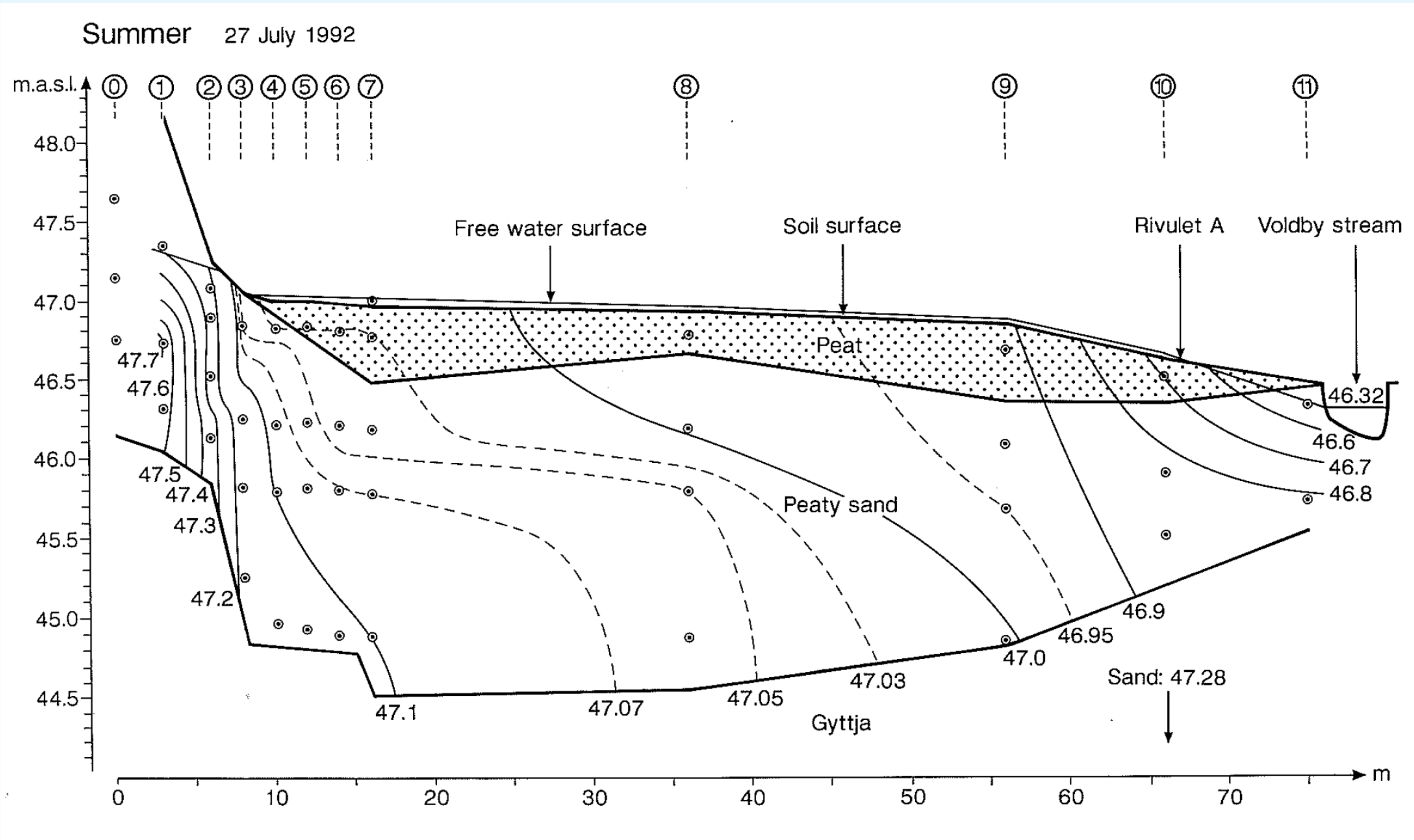
Soil profile



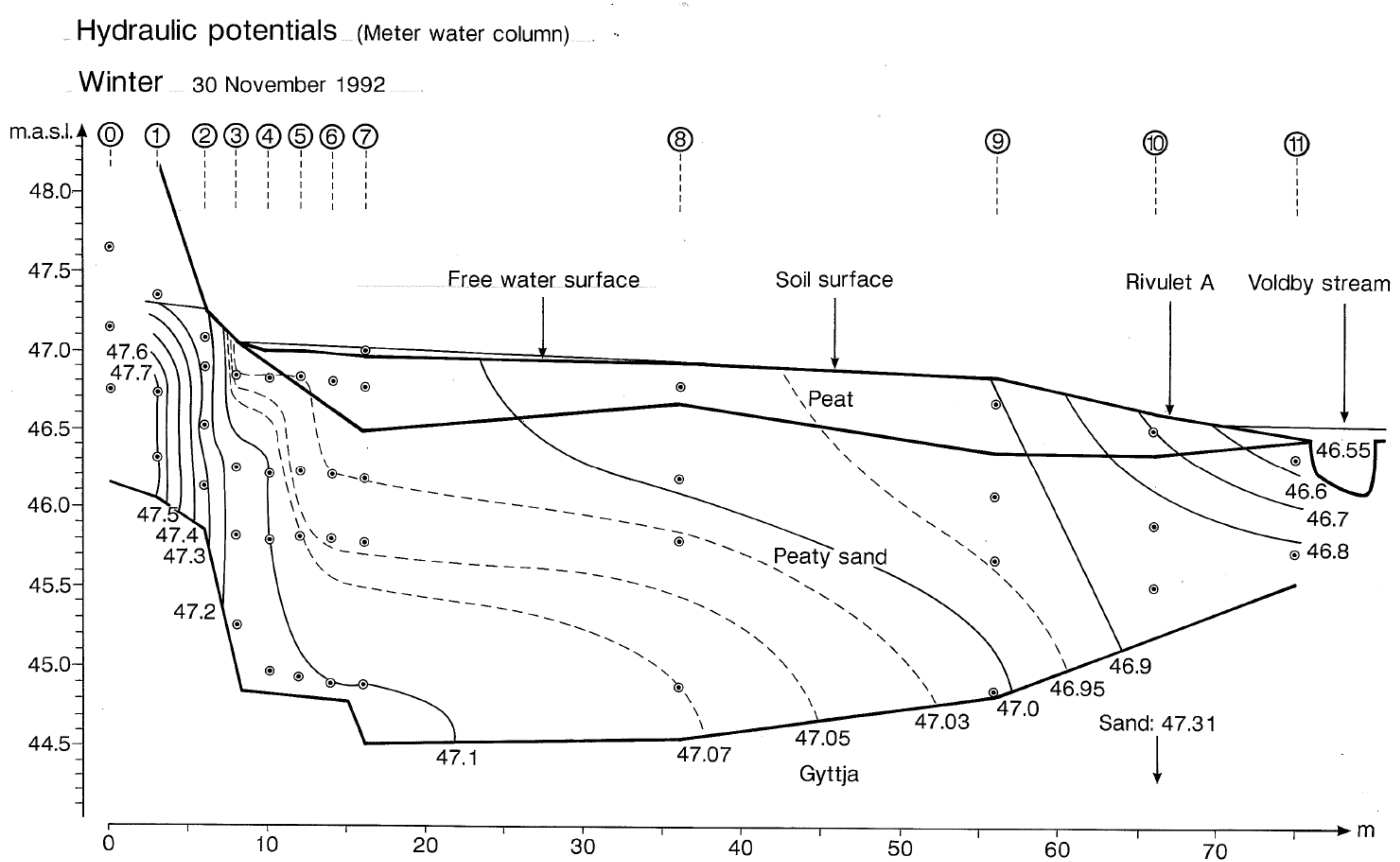
Hydraulic potentials



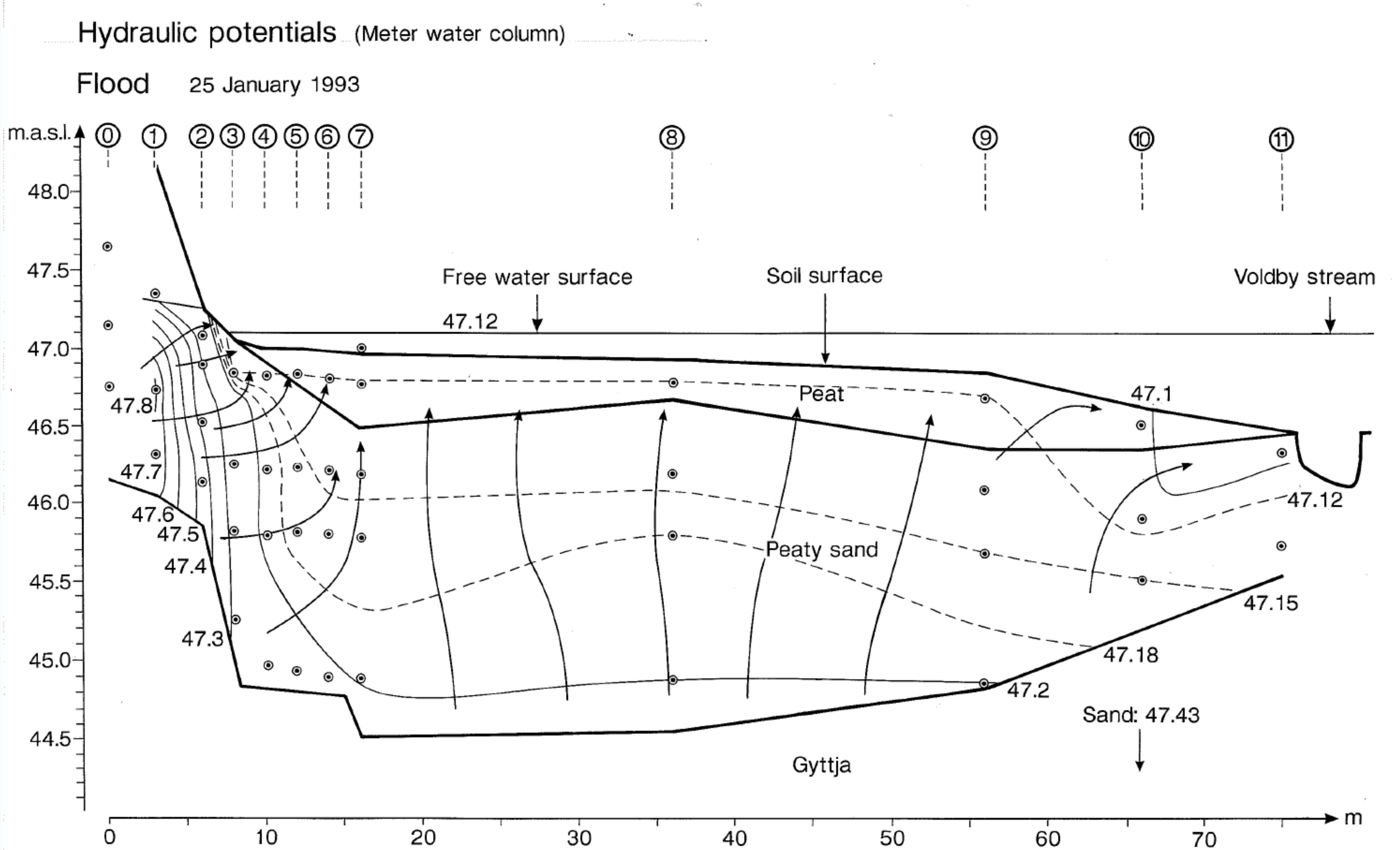
Hydraulic potentials



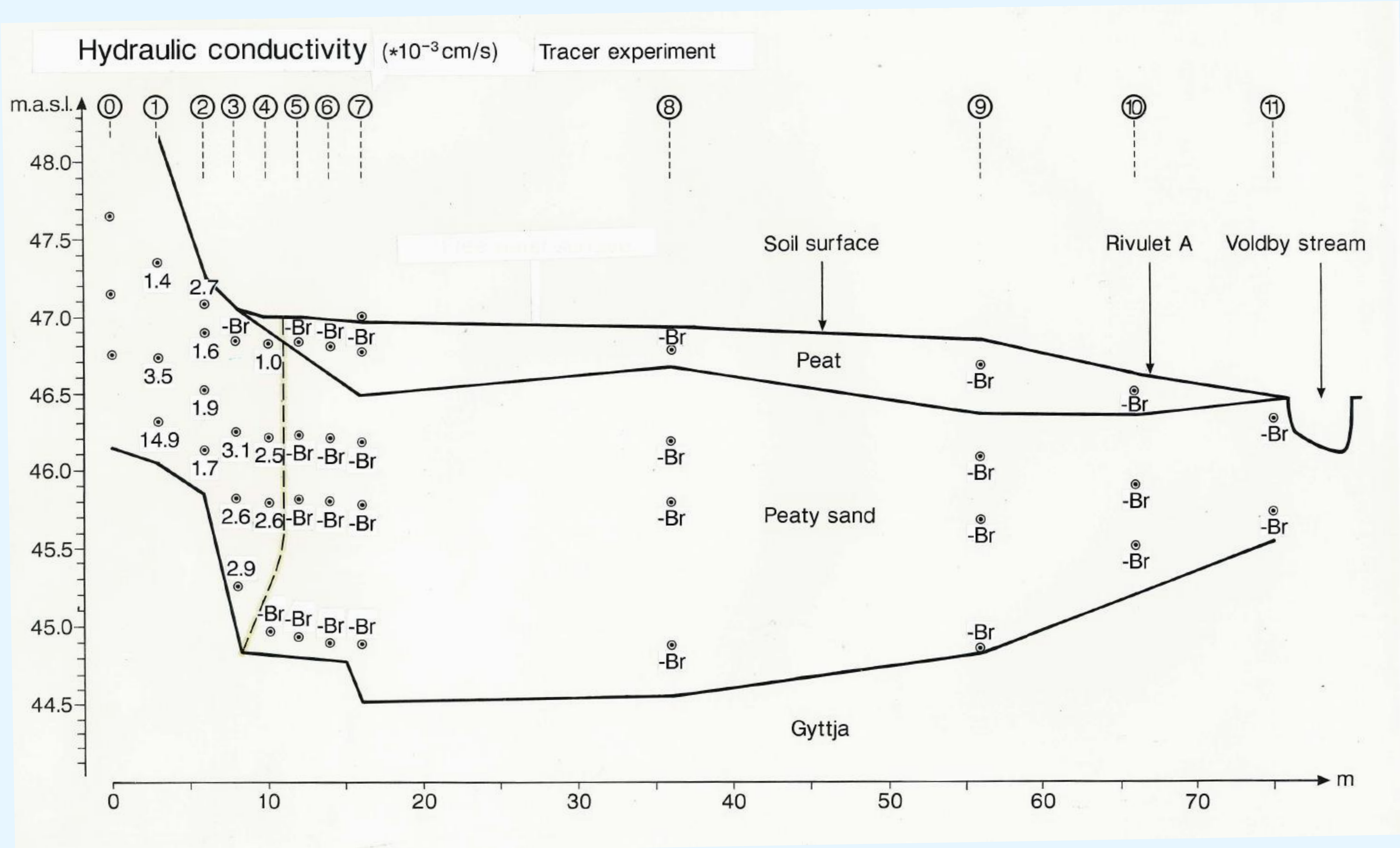
Hydraulic potentials



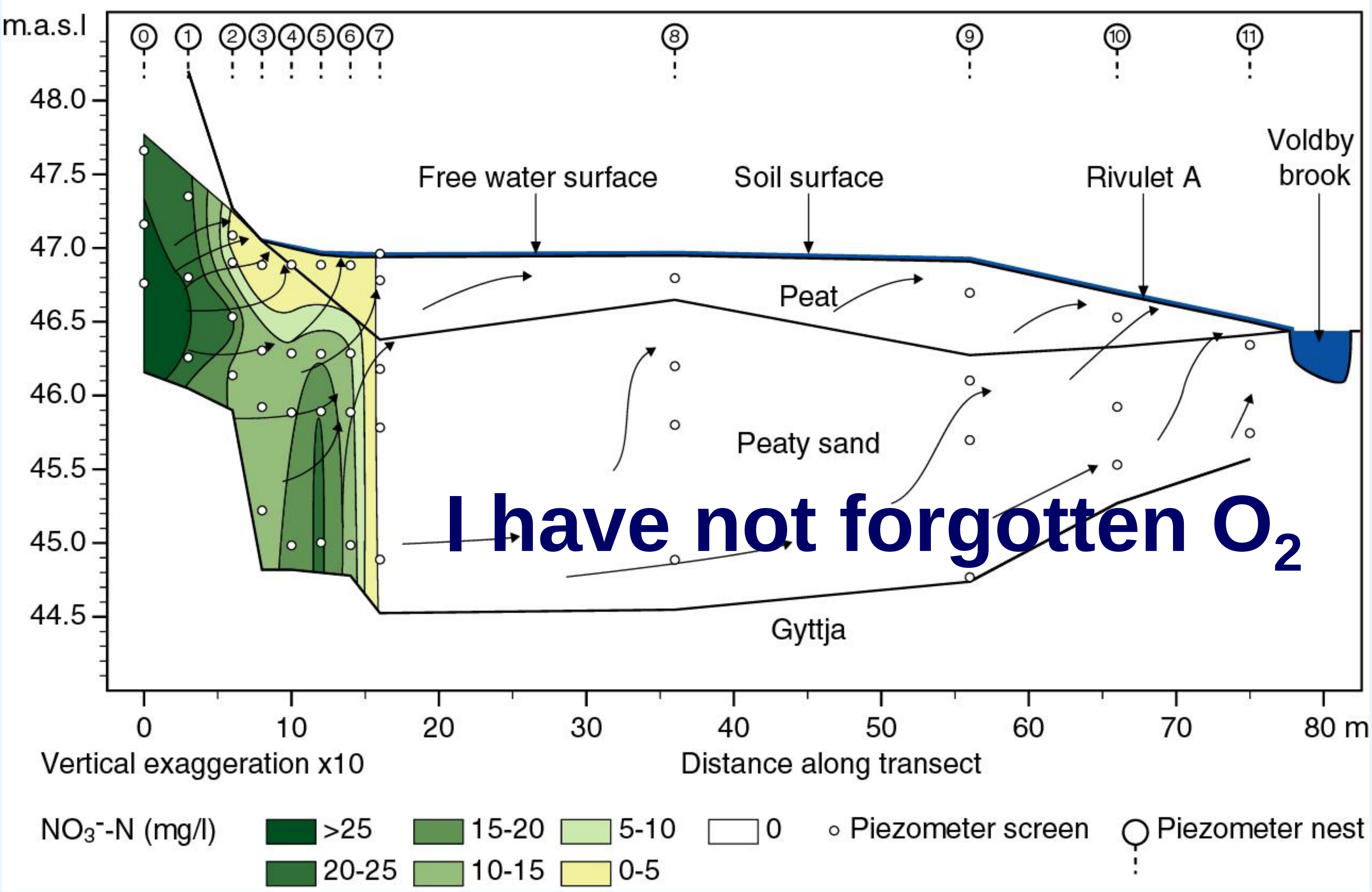
Hydraulic potentials



Tracer experiment with bromide

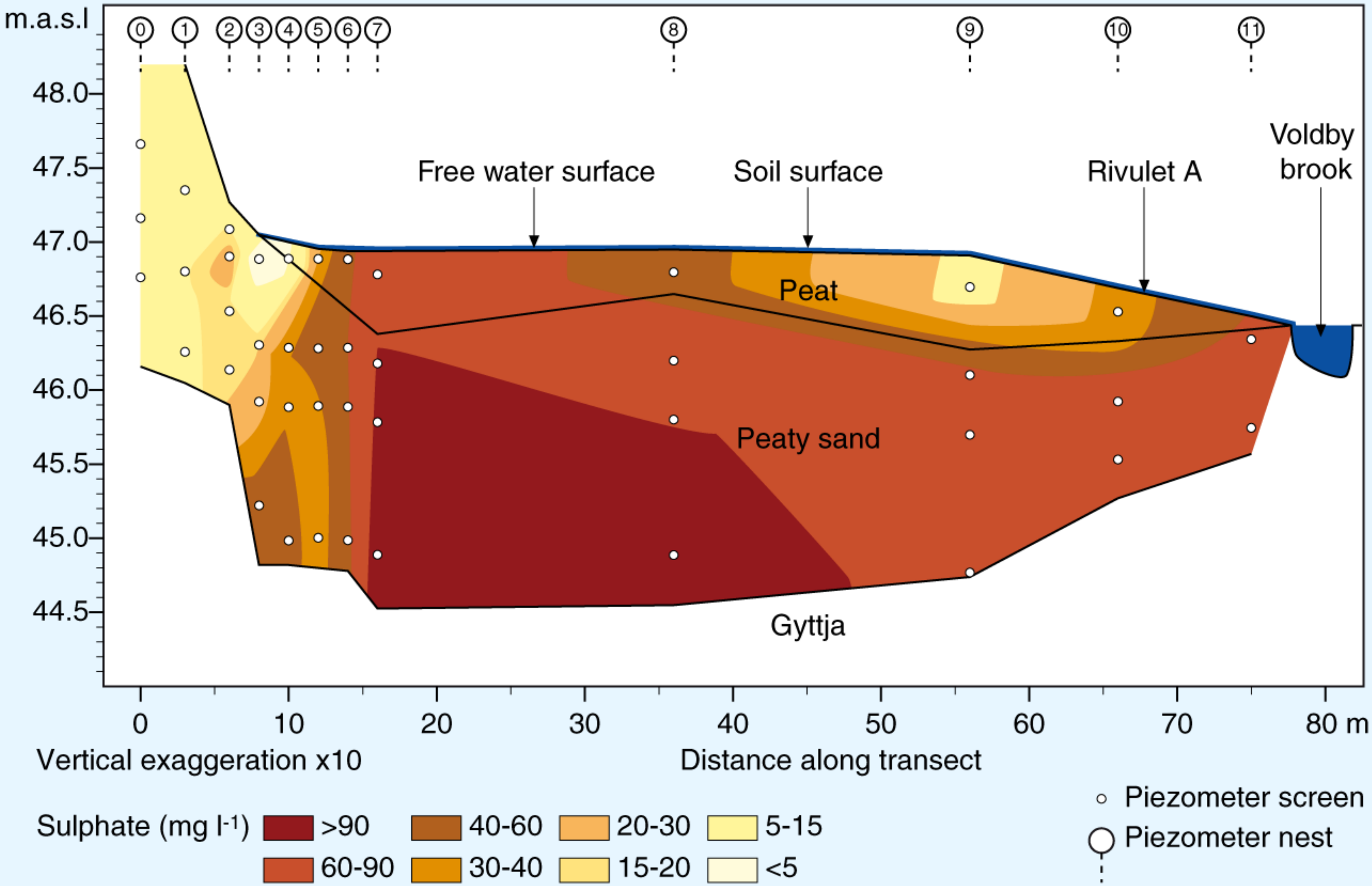


Nitrate reduction



I have not forgotten O_2

Hoffmann, 1998 ; Hoffmann et al., 2000
Blicher-Mathiesen & Hoffmann, 1999



m.a.s.l
48.0
47.5
47.0
46.5
46.0
45.5
45.0
44.5
0
1
2
3
4
5
6
7
8
9
10
11
Free water surface
Soil surface
Rivulet A
Voldby brook
Peat
Peaty sand
Gyttja
0
10
20
30
40
50
60
70
80 m
Vertical exaggeration x10
Distance along transect
Sulphate (mg l-1)
>90
60-90
40-60
30-40
20-30
15-20
5-15
<5
Piezometer screen
Piezometer nest

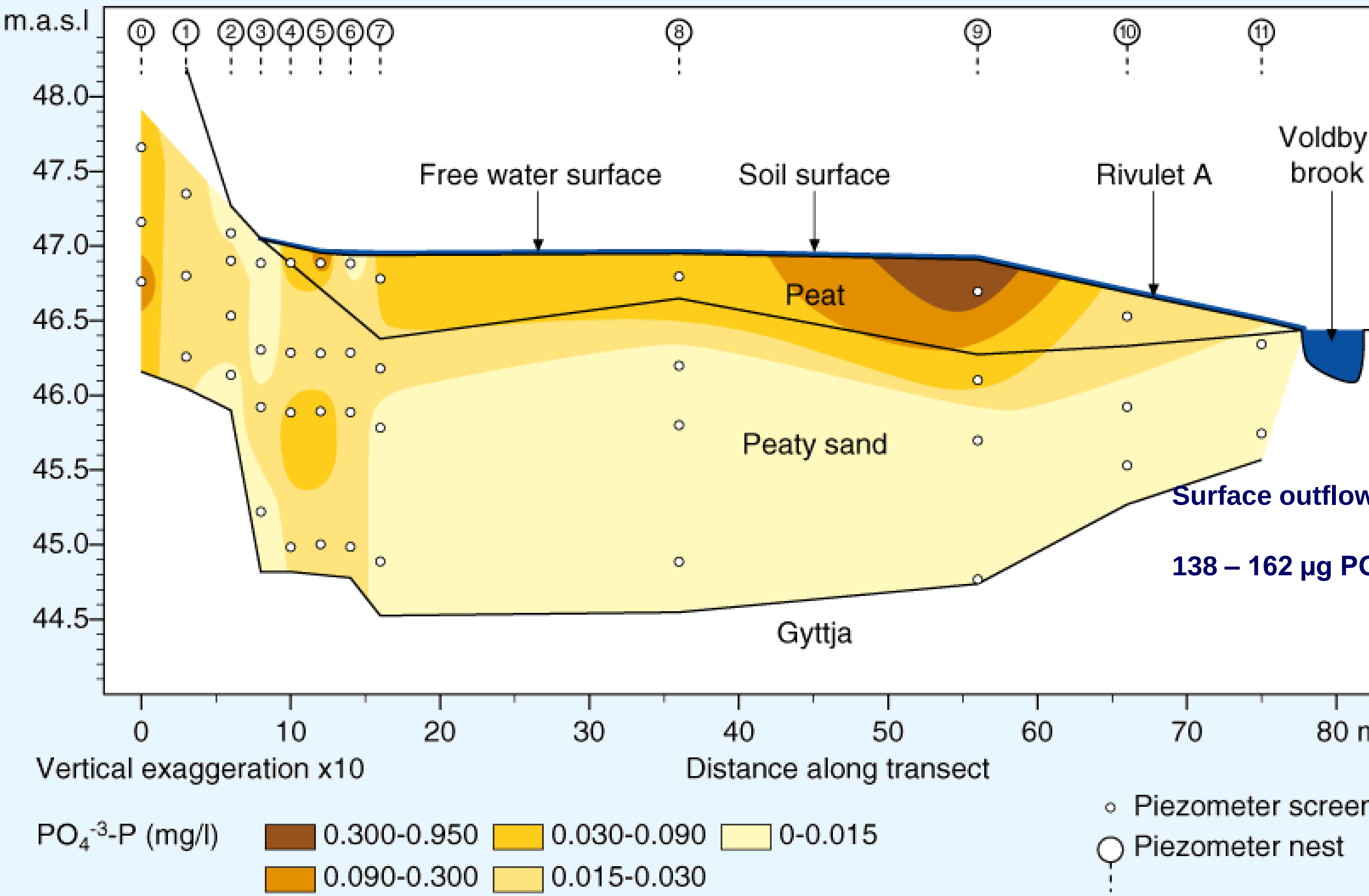
Area with sulphate reduction

Autotrophic and heterotrophic denitrification

$$5(CH_2O) + 4\ NO_3^- + 4\ H^+ \rightarrow 5\ CO_2 + 2\ N_2 + 7\ H_2O$$

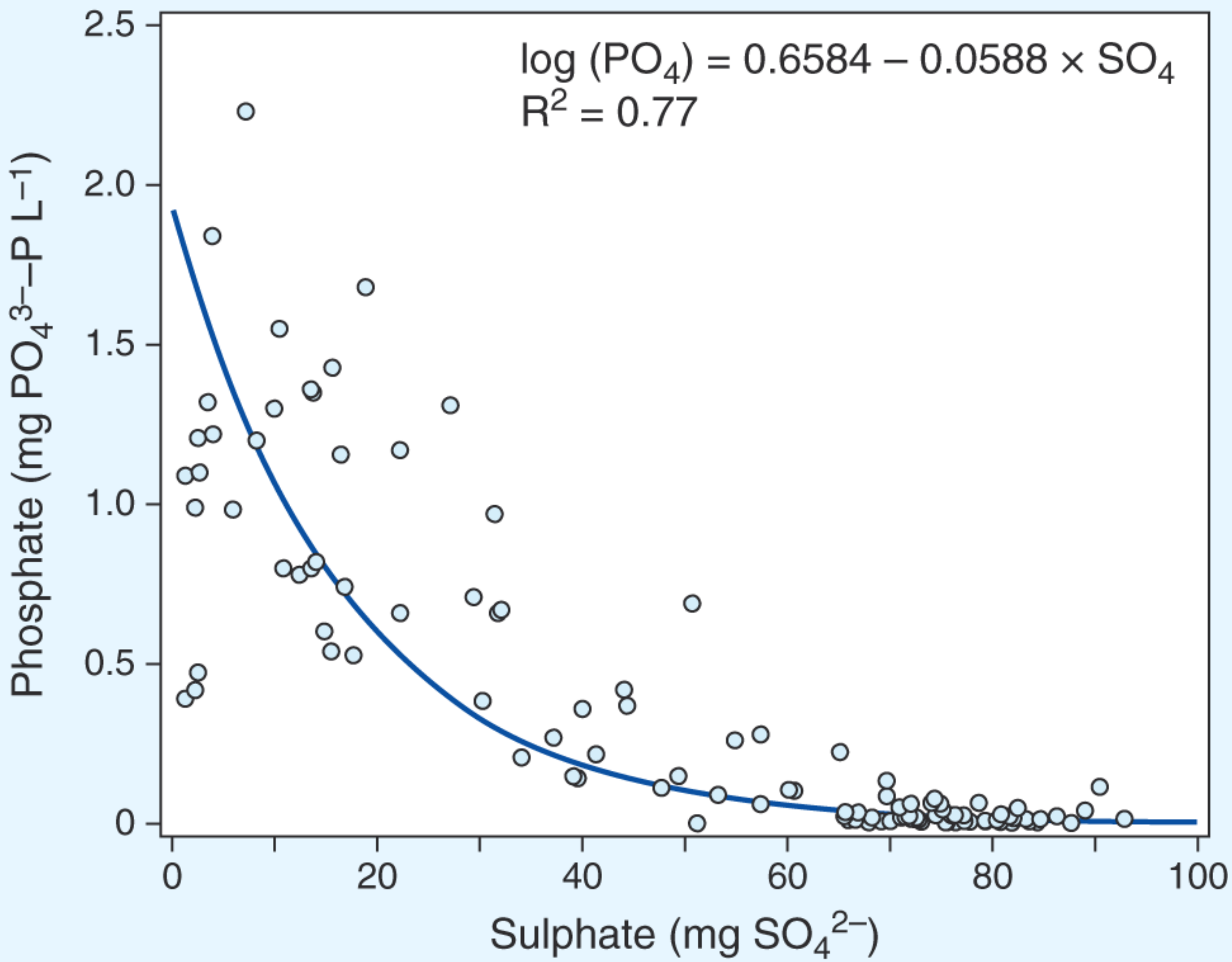
$$5\ FeS_2 + 14\ NO_3^- + 4\ H^+ \rightarrow 7\ N_2 + 10\ SO_4^{2-} + 5\ Fe^{2+} + 2\ H_2O \quad (1)$$

$$5\ Fe^{2+} + NO_3^- + 7\ H_2O \rightarrow 5\ FeOOH + 0.5\ N_2 + 9\ H^+ \quad (2)$$



Surface outflow 1992-95

138 – 162 µg PO_4^{3-}-P l^{-1}



log (PO4) = 0.6584 – 0.0588 × SO4
R2 = 0.77
Phosphate (mg PO43––P L–1)
Sulphate (mg SO42–)
2.5
2.0
1.5
1.0
0.5
0
0
20
40
60
80
100

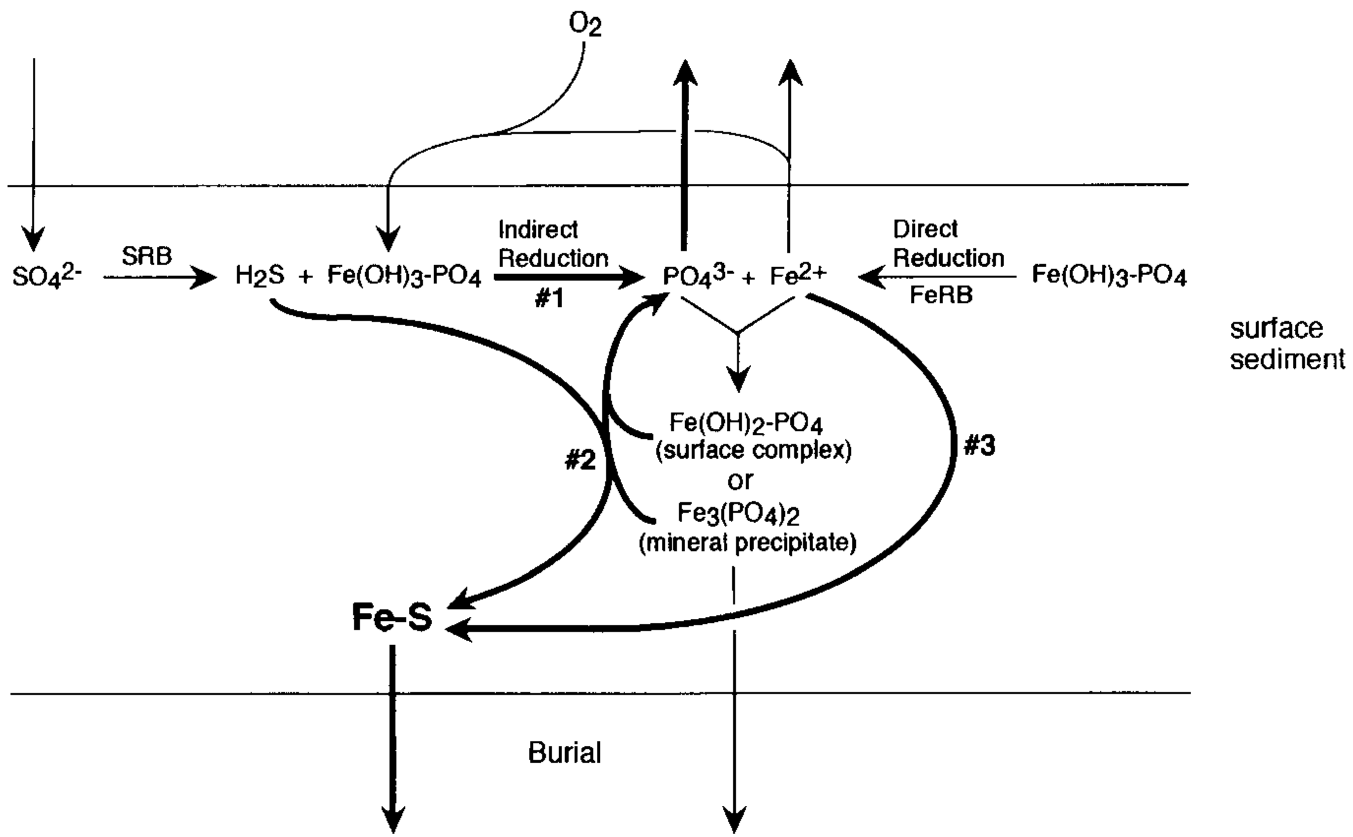


Fig. 11. Conceptual model of Fe-S-P interactions in anaerobic sediments. Thick lines and bolded numbers indicate mechanisms of sulfate reduction-enhanced PO_4^{3-} mobilization (see text). SRB = sulfate-reducing bacteria; FeRB = Fe(III)-reducing bacteria; $Fe(OH)_3$ = amorphous Fe(III) oxide; $Fe(OH)_2$ = Fe(II) hydroxide.

Roden, E.E. and J.W. Edmonds. 1997. Phosphate mobilization in iron-rich anaerobic sediments: microbial Fe(III) oxide reduction vs. iron-sulfide formation. Arch. Hydrobiol. 139:347-378.

Phosphorus pools in the sulphate reduction zone

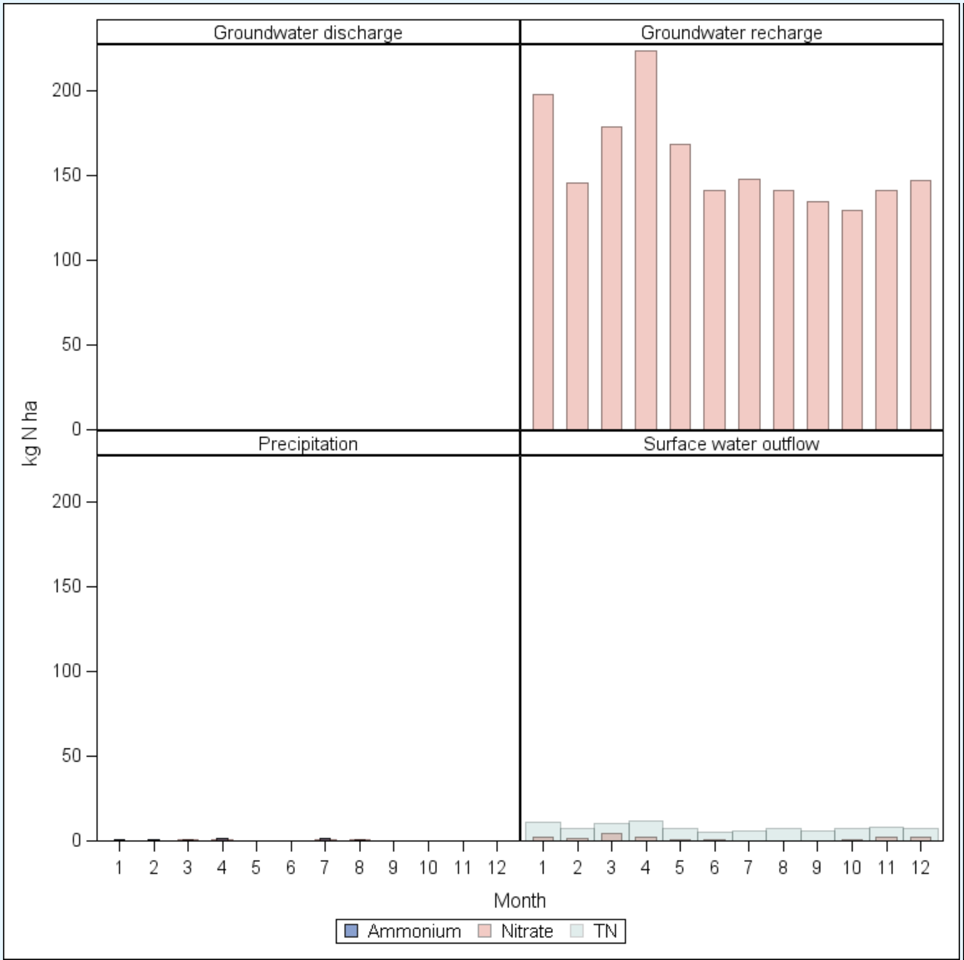
Depth cm	Labile-P	Fe-P	Al-P g P m2	Ca-P	Inorganic-P
0-5	0.18445	11.3817	1.35625	0.26040	13.1936
5-15	0.23250	8.2925	2.01500	1.08500	11.5475
15-25	0.00000	1.5810	1.05400	0.84320	3.5836
25-31	0.00000	1.4396	0.87978	0.31992	2.7193
31-41	0.25730	4.8887	3.85950	1.02920	10.0347
Σ0-41	**0.67425**	**27.5835**	**9.16453**	**3.53772**	**41.0787**

Depth cm	Humic-P	ΣDNRP	Res-P g P m2	Org-P	P-Microbial
0-5	0.8463	1.9747	0.9765	3.7975	1.9639
5-15	5.1150	9.2225	5.8125	20.2275	5.3475
15-25	2.8458	4.0052	2.6350	9.4860	1.3702
25-31	2.9593	3.3592	2.2394	8.4779	0.7198
31-41	4.3741	3.8595	3.0876	11.0639	1.2865
Σ0-41	**16.1405**	**22.4211**	**14.7510**	**53.0528**	**10.6879**

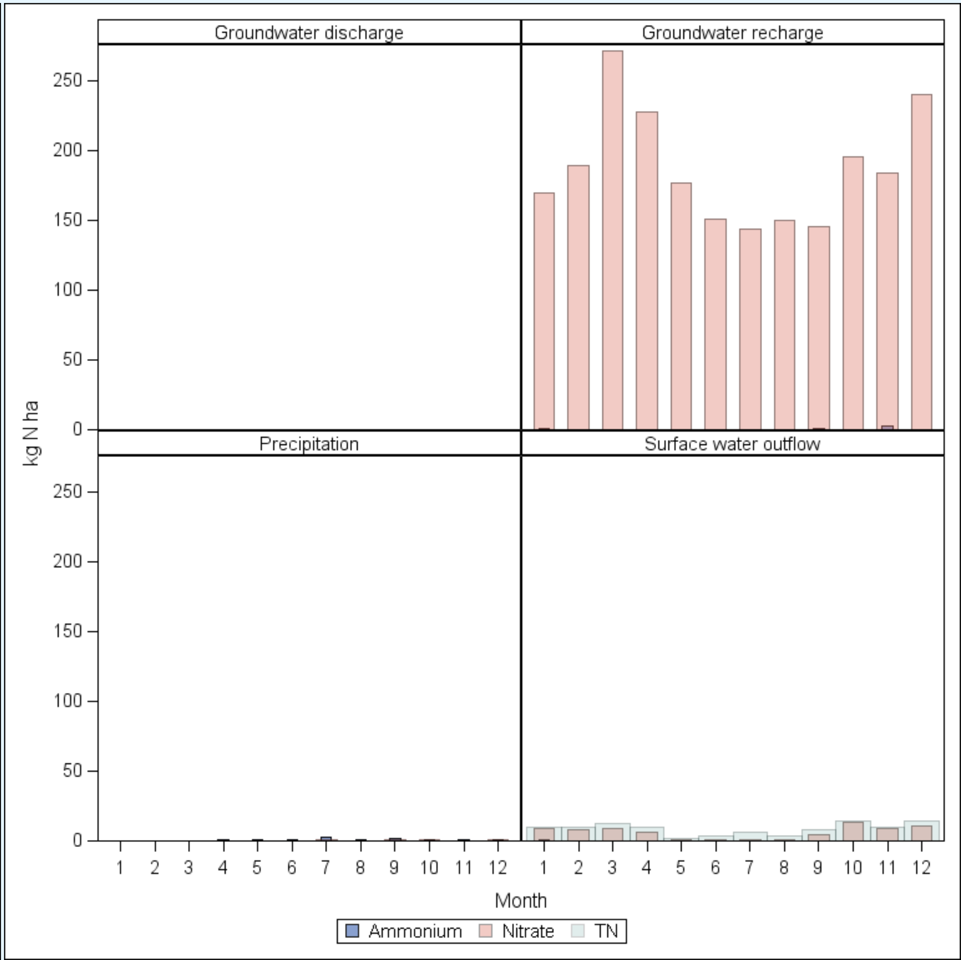
Mass balances

Nitrogen

1992



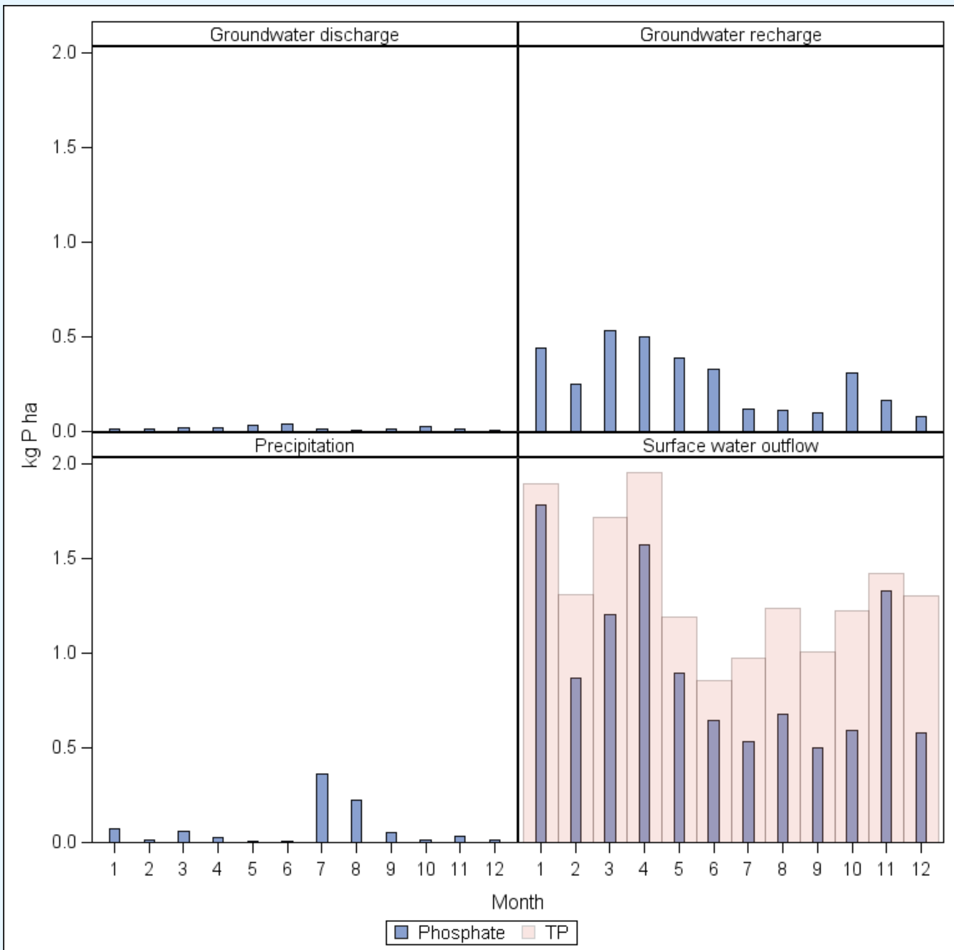
1993

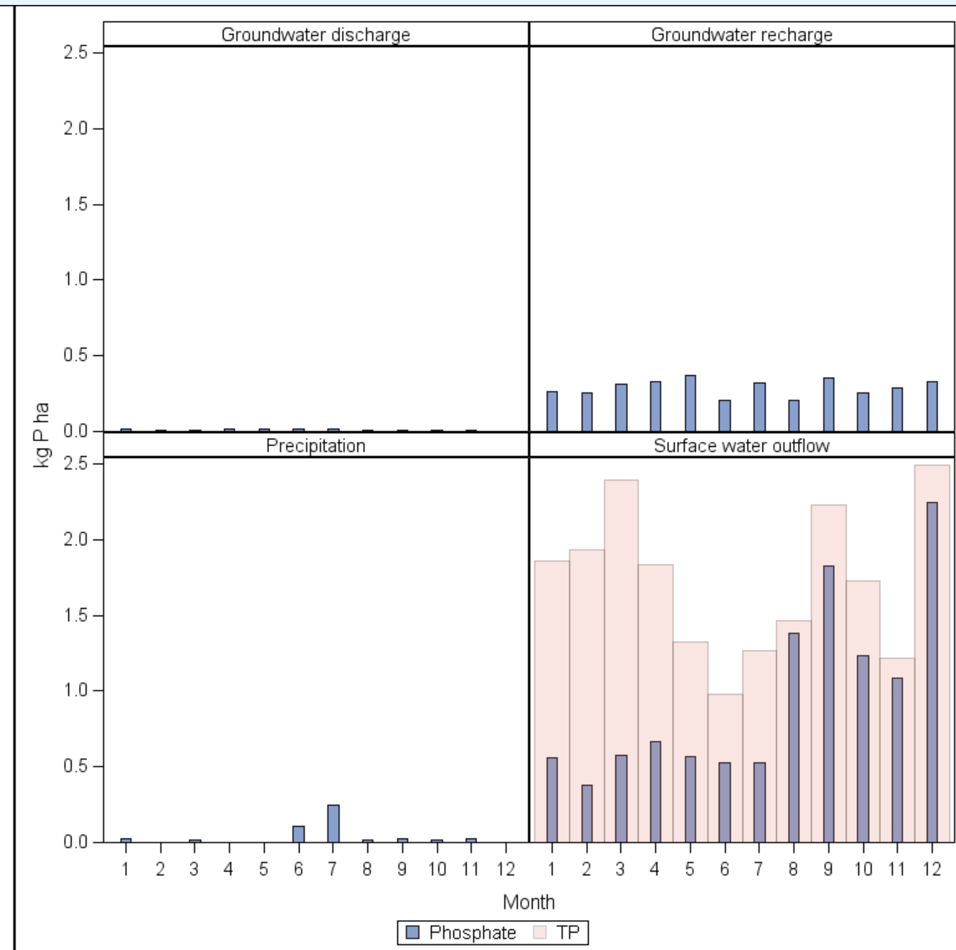


Phosphorus

1992

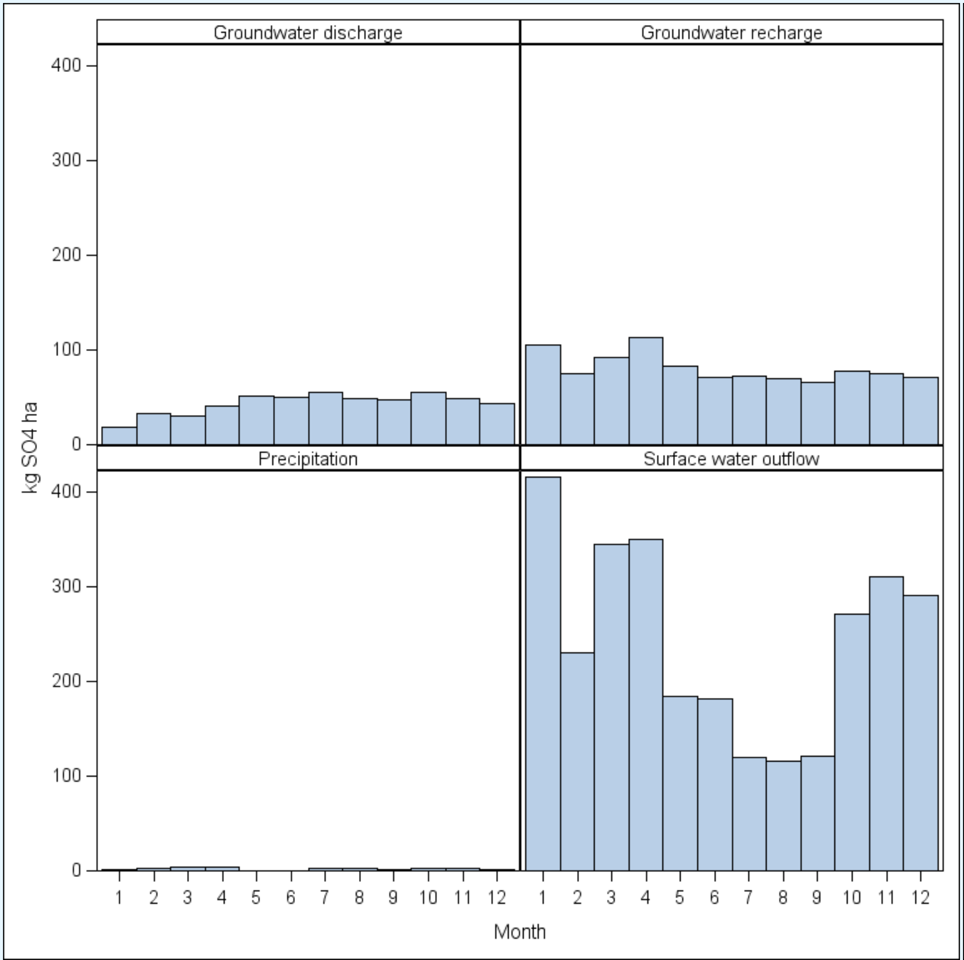
1993



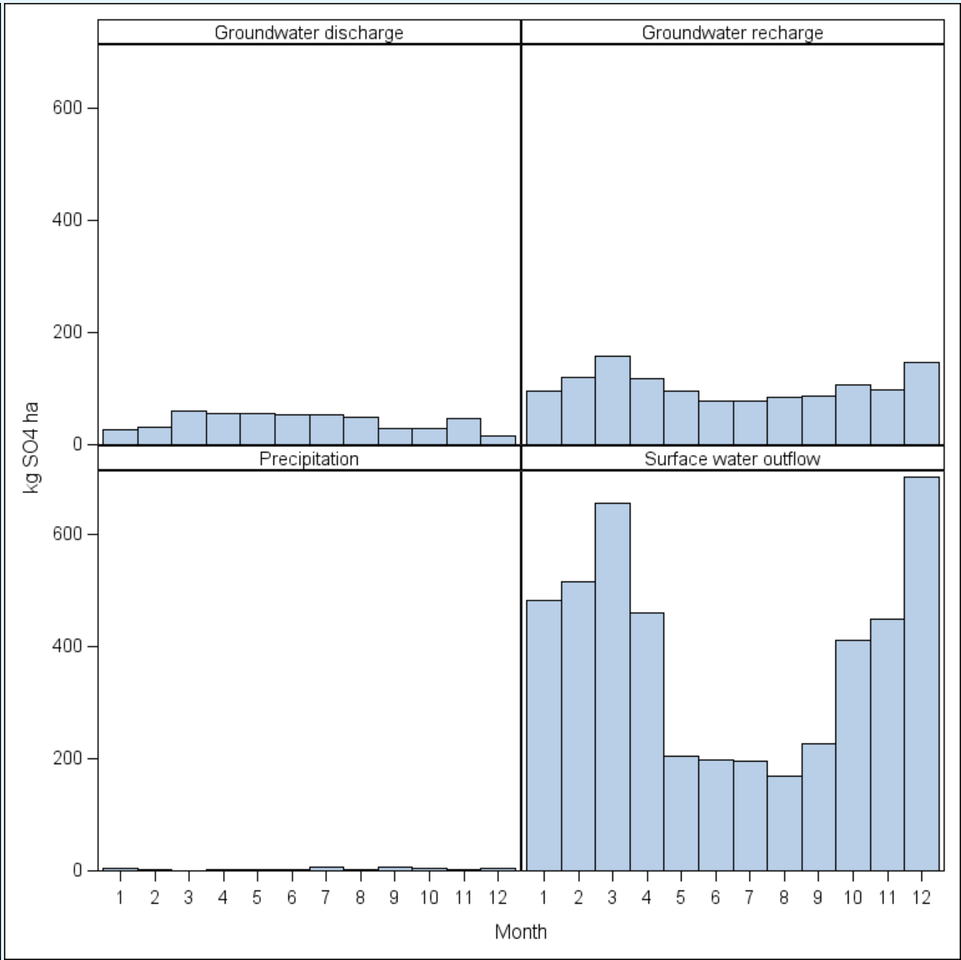


Sulphate

1992



1993



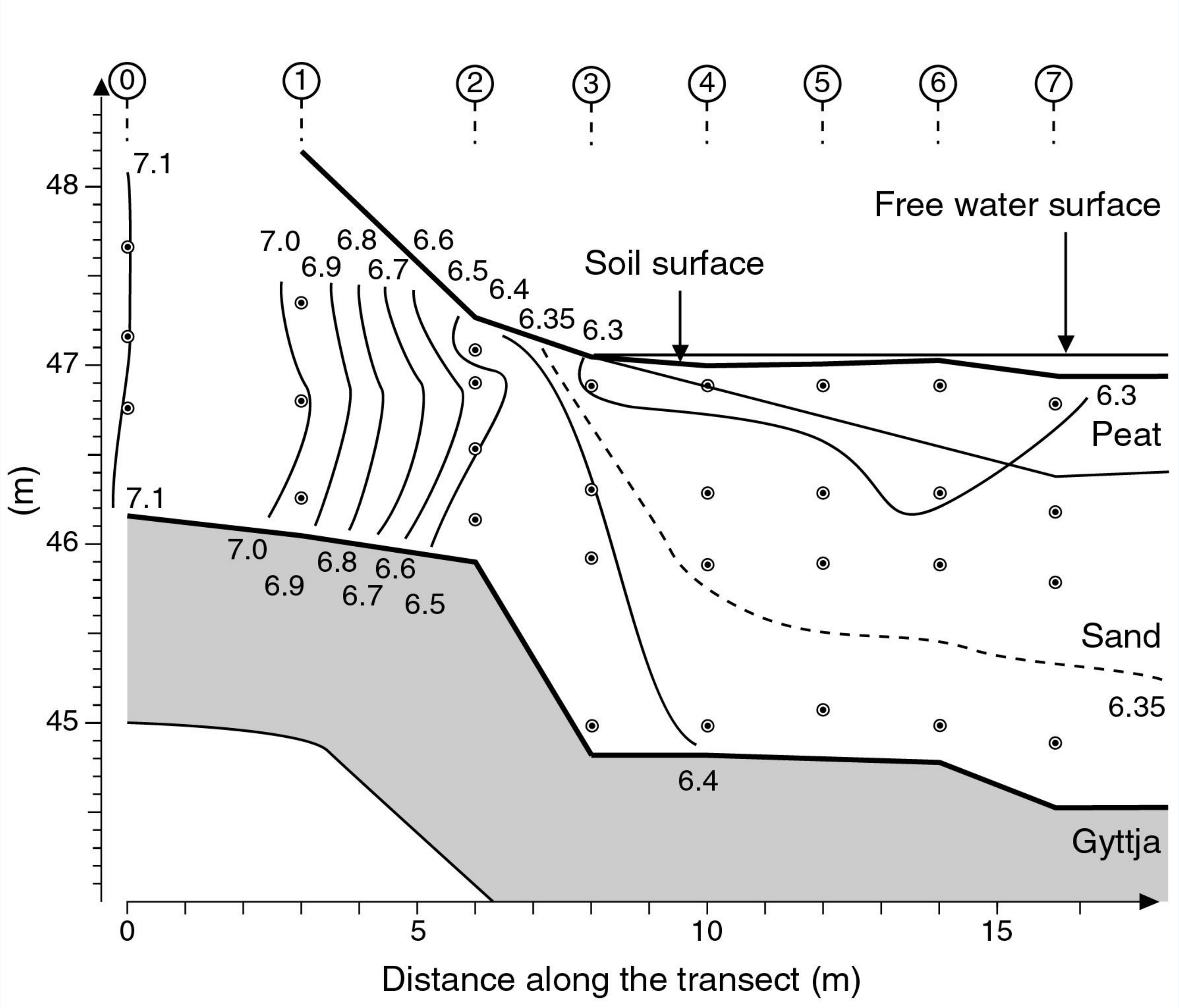
Mass balance 1992

	NH_4^+-N	NO_3^--N	TN	PO_4^{3-}-P	TP	SO_4^{2-}
	Kg ha^{-1} $year^{-1}$					
Gw input	1.52	1897.30	-	3.33	-	972
Precipitation	6.13	4.31	-	0.89		26
Gw discharge	0.22	0.03	-	0.22	-	523
Surface outflow	1.95	18.24	94.41	11.17	16.08	2937
Retention	5.48	1883.34	1807.20	-7.17	-12.08	-2462

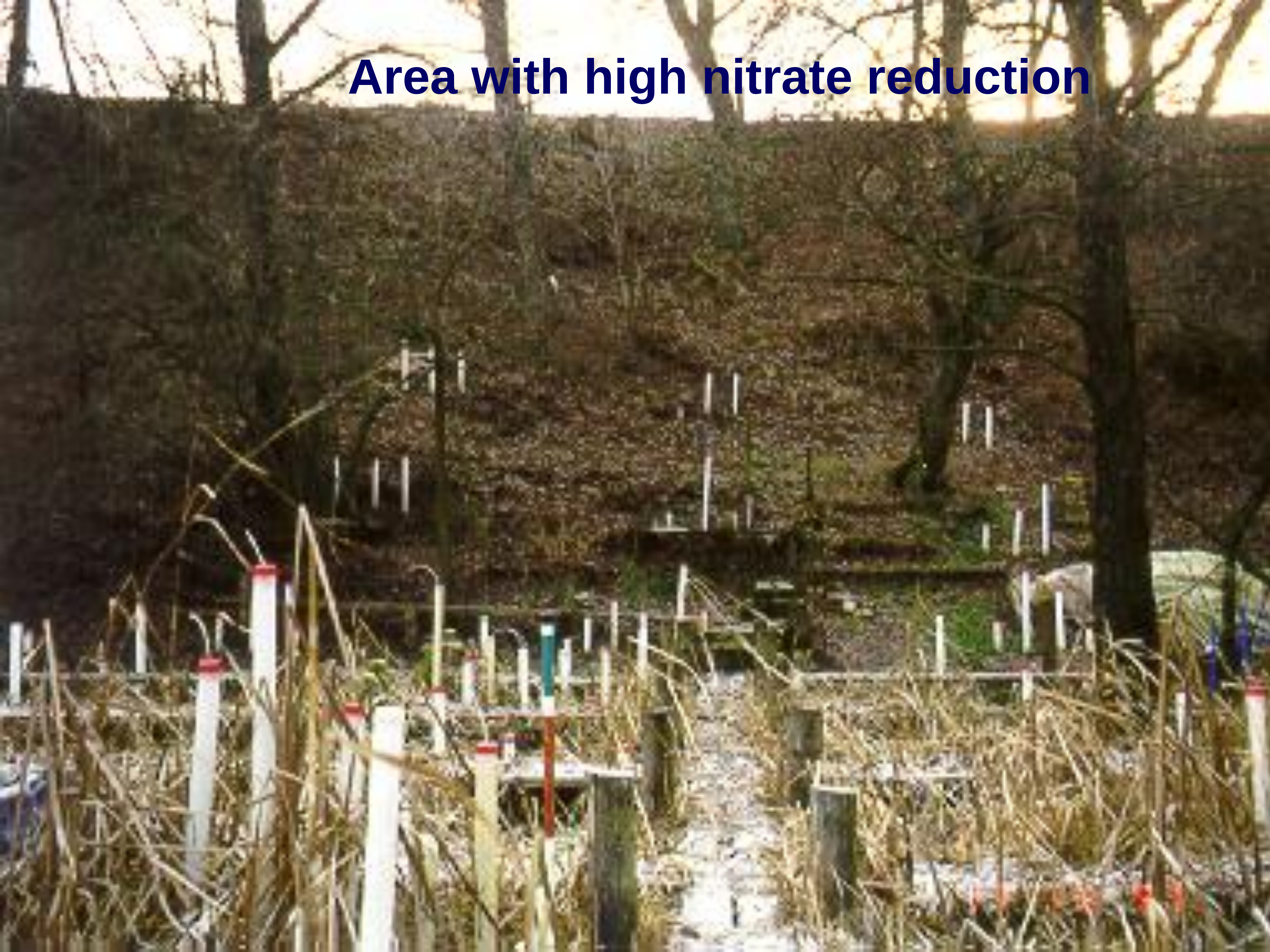
Mass balance 1993

	NH_4^+-N	NO_3^--N	TN	PO_4^{3-}-P	TP	SO_4^{2-}	Fe
	Kg ha^{-1} year^{-1}						
Gw input	4.94	2245.73	-	3.48	-	1265	
Precipitation	9.11	4.47	-	0.48		36	
Gw discharge	0.08	0.17	-	0.12	-	505	18.40
Surface outflow	2.45	71.94	105	11.57	20.70	4662	16.69
Retention	11.52	2178.09	2159	-7.73	-16.86	-3866	

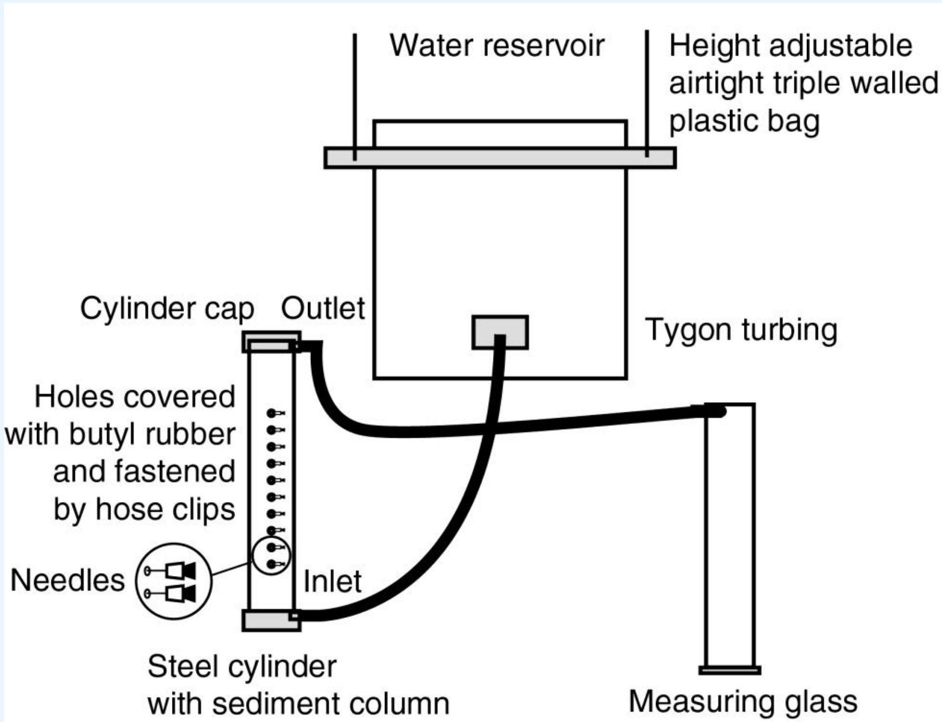
Denitrification



Area with high nitrate reduction



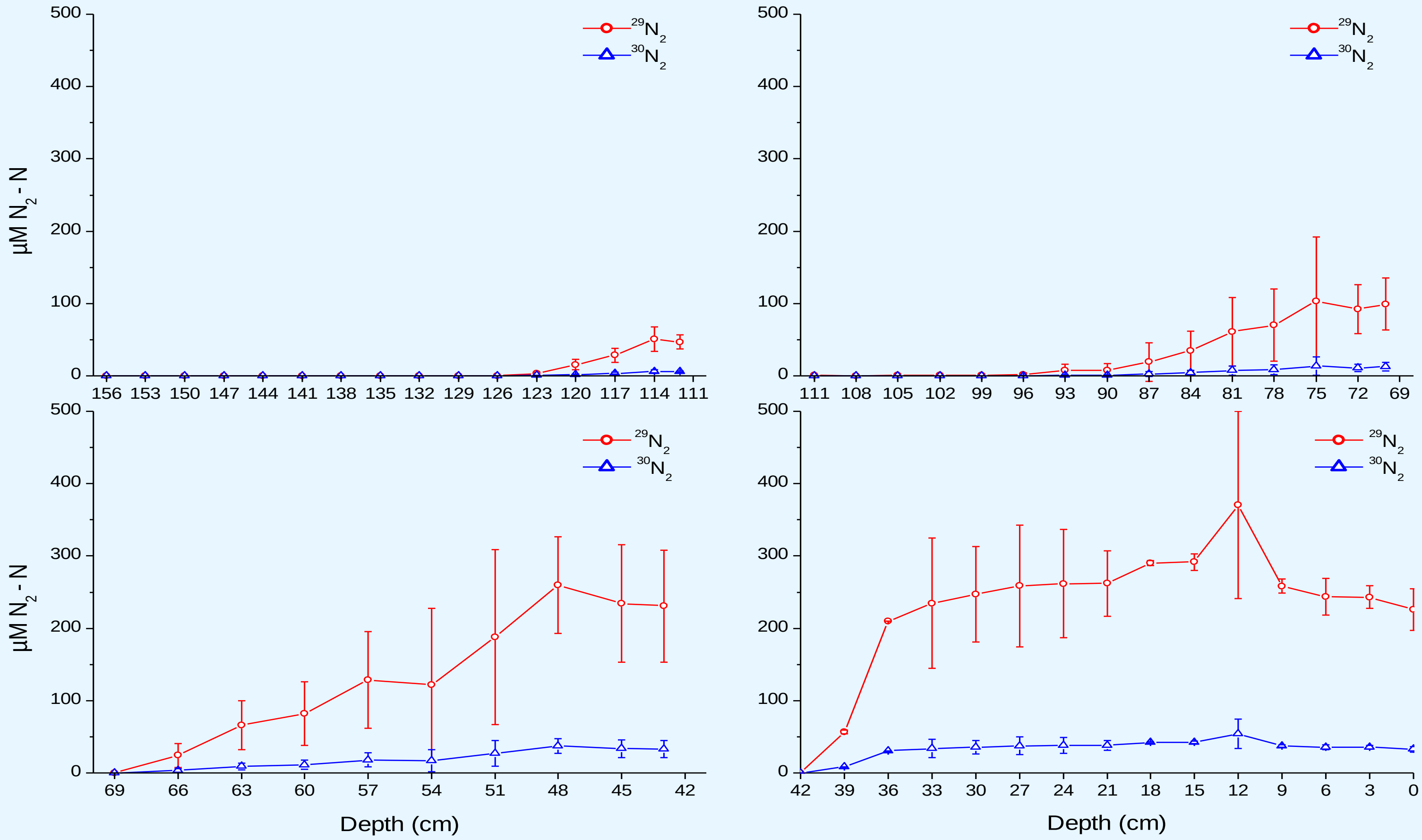
Denitrification experimental setup



Core/Depth cm	Flow rate ± S.E. ml cm^{-2} d^{-1}
1: 0-42	11.5 ± 2.1
2: 42-69	12.1 ± 1.9
3: 69-111	16.5 ± 1.9
4: 111-159	14.2 ± 1.6

Flow direction

^{15}N measurements of denitrification



Hoffmann et al., 2000

Denitrification rates

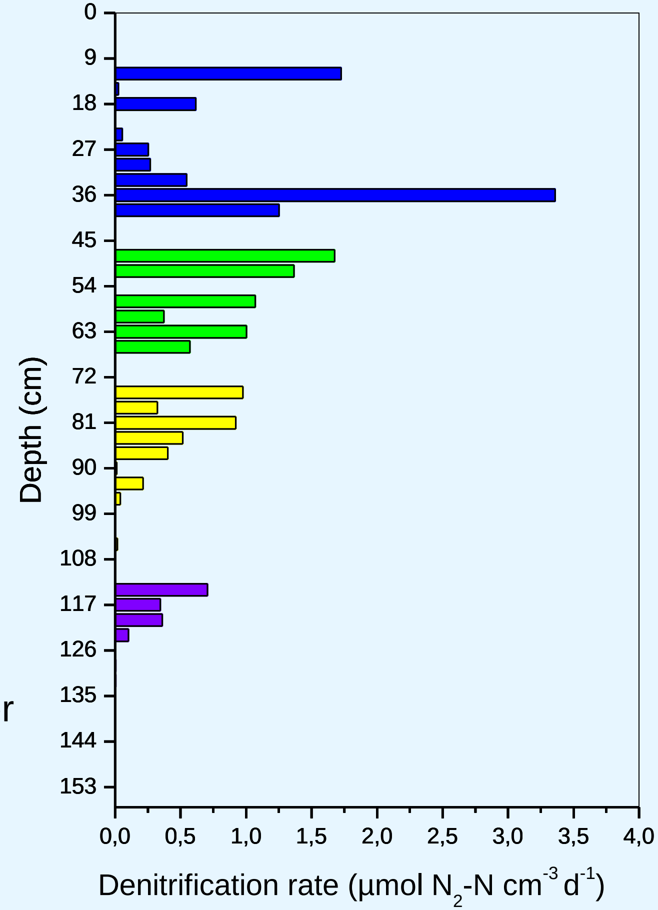
Column no. Depth in cm	^{15}N-method Mmol m^{-2}d^{-1}	(g)	Standard method Mmol m^{-2}d^{-1}	(g)
1: 0-42	243.0	(3.4)	212.6	(3.0)
2: 42-69	181.7	(2.5)	216.8	(3.0)
3: 69-111	102.7	(1.4)	136.7	(1.9)
4: 111-156	45.7	(0.6)	32.9	(0.5)
	573.1	(7.9)	599.0	(8.4)

Hoffmann et al., 2000

Denitrification rates (Mølgårde)

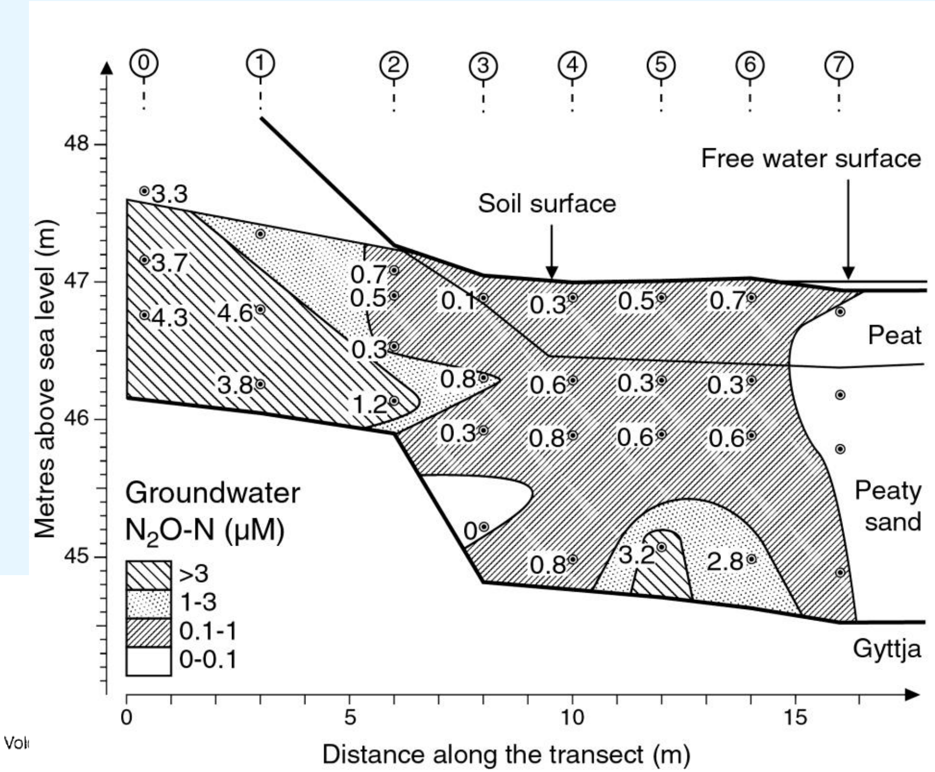
Depth	Loss of ignition
cm	%
0-10	68.4
10-30	18.5
30-68	11.3
68-78	12.0
78-88	13.0
88-98	3.0
98-112	1.6
112-122	9.2
122-132	0.5
132-142	0.6

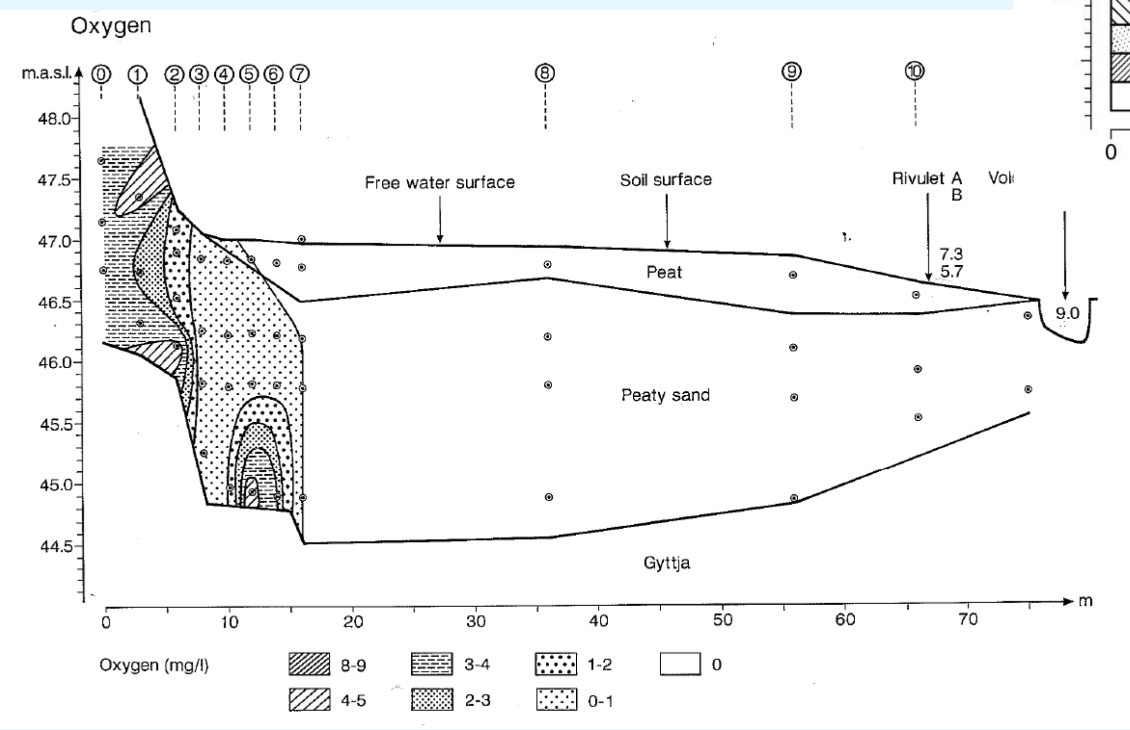
Min 3 % organic matter



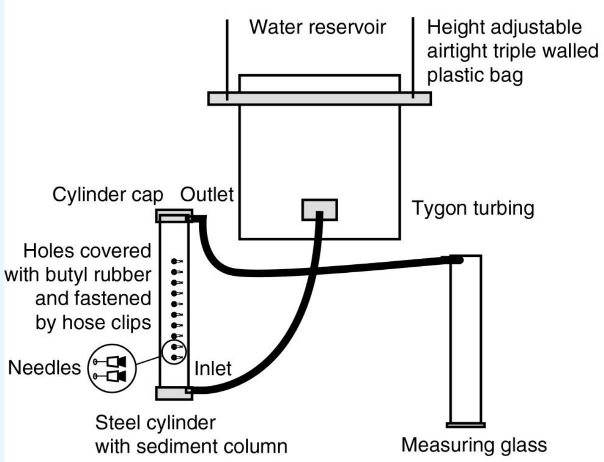
Hoffmann et al., 2000

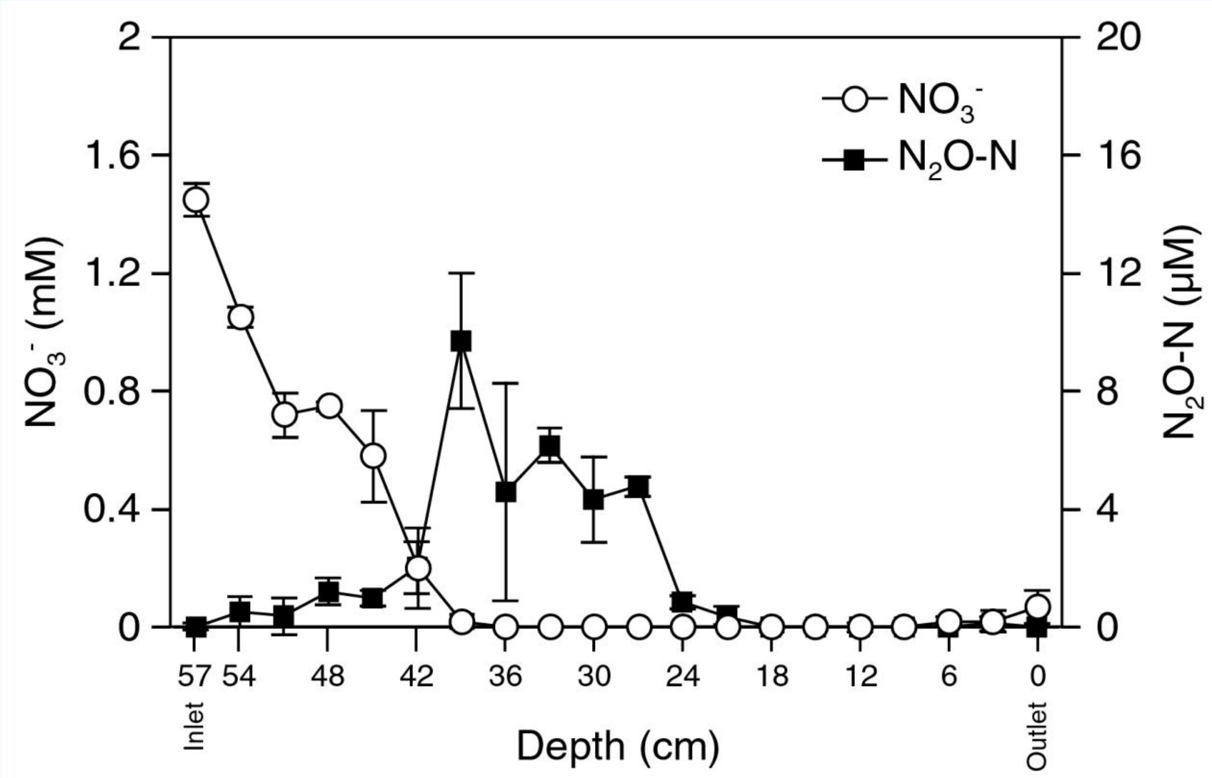
Nitrous oxide



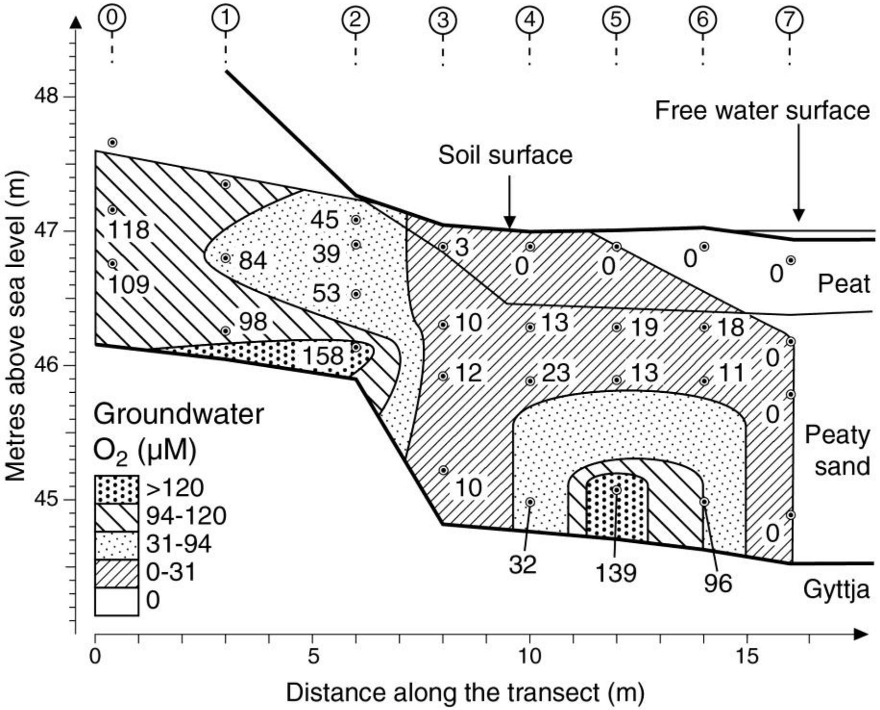


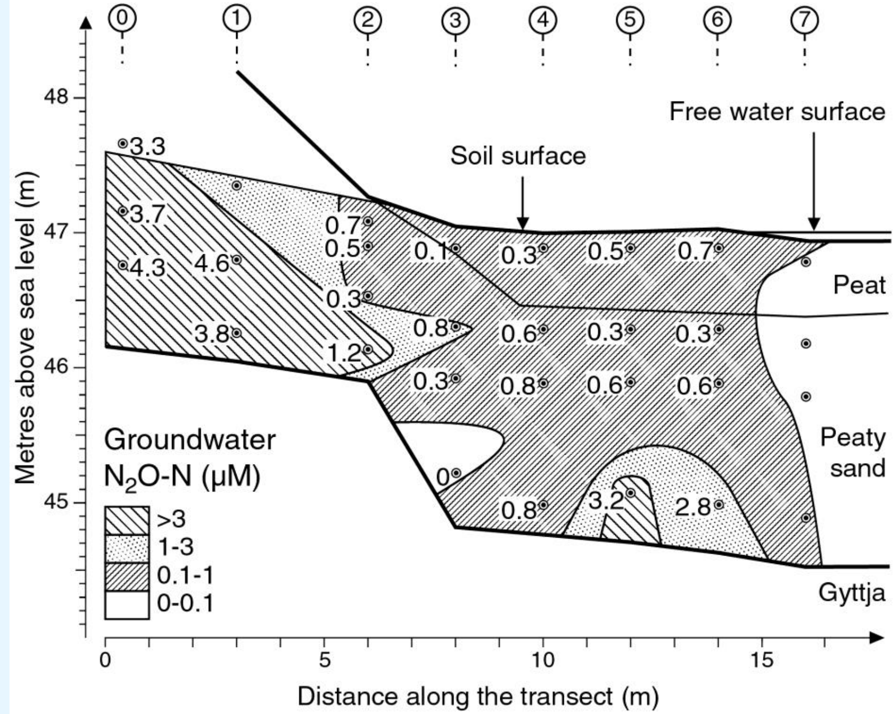
Nitrous oxide





Blicher-Mathiesen & Hoffmann et al., 1999



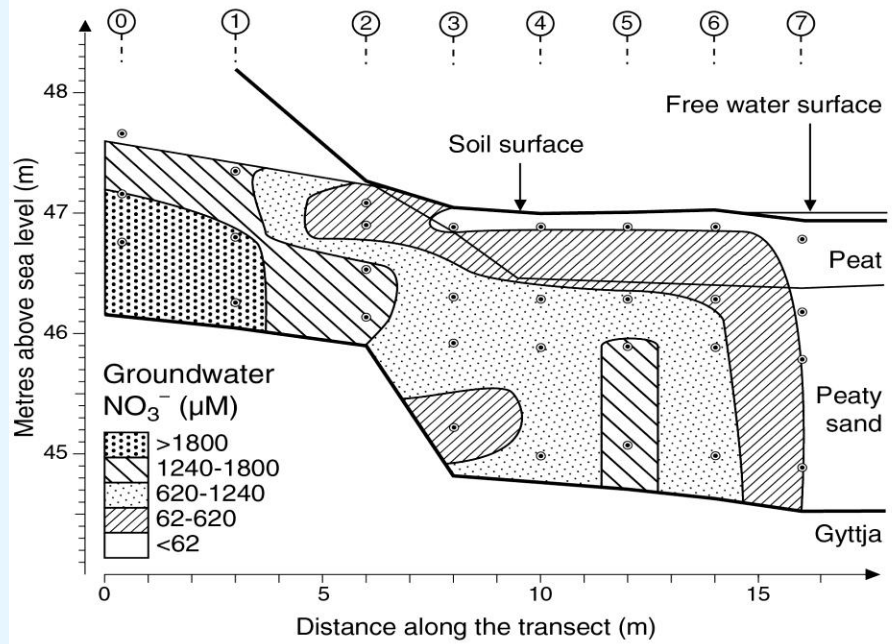


N$_2$O-N in groundwater:

56 μg l^{-1}

N$_2$O emission:

5.9 % of N$_2$O in recharging gw



Ecosystem stability

- e-donor for denitrification
- leaching/discharge of nutrients e.g phosphate

Phosphorus pools in the sulphate reduction zone

Depth cm	Labile-P	Fe-P	Al-P g P m2	Ca-P	Inorganic-P
0-5	0.18445	11.3817	1.35625	0.26040	13.1936
5-15	0.23250	8.2925	2.01500	1.08500	11.5475
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25-31	2.9593	3.3592	2.2394	8.4779	0.7198
31-41	4.3741	3.8595	3.0876	11.0639	1.2865
Σ0-41	**16.1405**	**22.4211**	**14.7510**	**53.0528**	**10.6879**

Surface runoff DRP g P m-2 y-1	Surface runoff DNRP	Turnover of Fe-P	Turnover of Microbial pool
0.769	**0.886**	**35.9 years**	**12.1 years**

What happened to Iron

	NH_4^+-N	NO_3^--N	TN	PO_4^{3-}-P	TP	SO_4^{2-}	Fe
	Kg ha^{-1} year^{-1}						
Gw input	4.94	2245.73	-	3.48	-	1265	
Precipitation	9.11	4.47	-	0.48		36	
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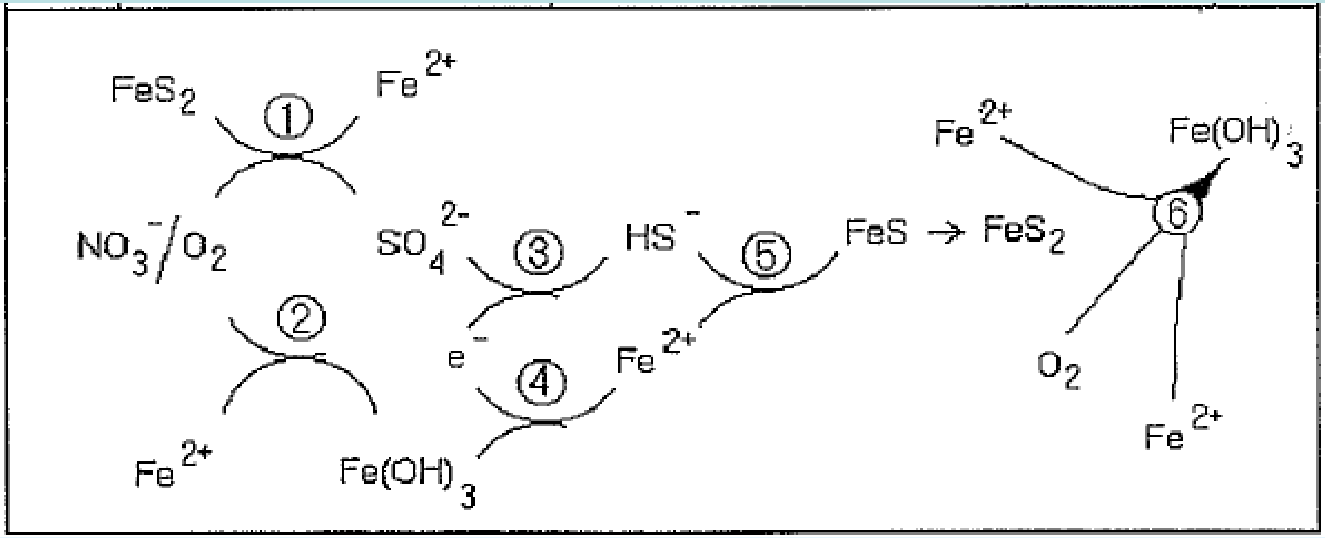
Surface outflow	2.45	71.94	105	11.57	20.70	4662	16.69
Retention	11.52	2178.09	2159	-7.73	-16.86	-3866	

Mølgårde surface outflow

Iron

hill slope| 4 – 16 m | 16 – 60 m | 60 - 75| 75 - brook



Conclusions

- Redoxcline identified tracing the groundwater flow line
- Biogeochemical processes linked together by hydrogeological processes
- Zone of enhanced denitrification with both autotrophic and heterotrophic denitrification
- N_2O production in wetland but also consumption of N_2O coming from upland agricultural areas $\rightarrow$ overall the wetland act as a sink maybe due to electron acceptor limitation and pH increase (1 pH unit) thereby suspending inhibition of N_2O reductase
- Longterm stability of fen threatened by external NO_3^- load $\rightarrow$ P-release and probably P exhaustion

Thank You for your attentiom