Susann Vogler

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AMBER Annual Meeting

Identification and Quantification of Submarine Groundwater Discharge (SGD) in the Puck Bay/ Poland (WP B.4 and B.5)

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2 Institute of Oceanology of the Polish Academy of Science (IO-PAN), Sopot, Poland
3 Alfred Wegener Institute for Polar and Marine Research (AWI), Marine Geochemistry, Bremerhaven, Germany
4 Naturkundemuseum Berlin, Germany
5 Helmholtz Center for Environmental Research (UFZ), Halle, Germany
6 Max Planck Institute for Marine Microbiology, Bremen, Germany

Outline

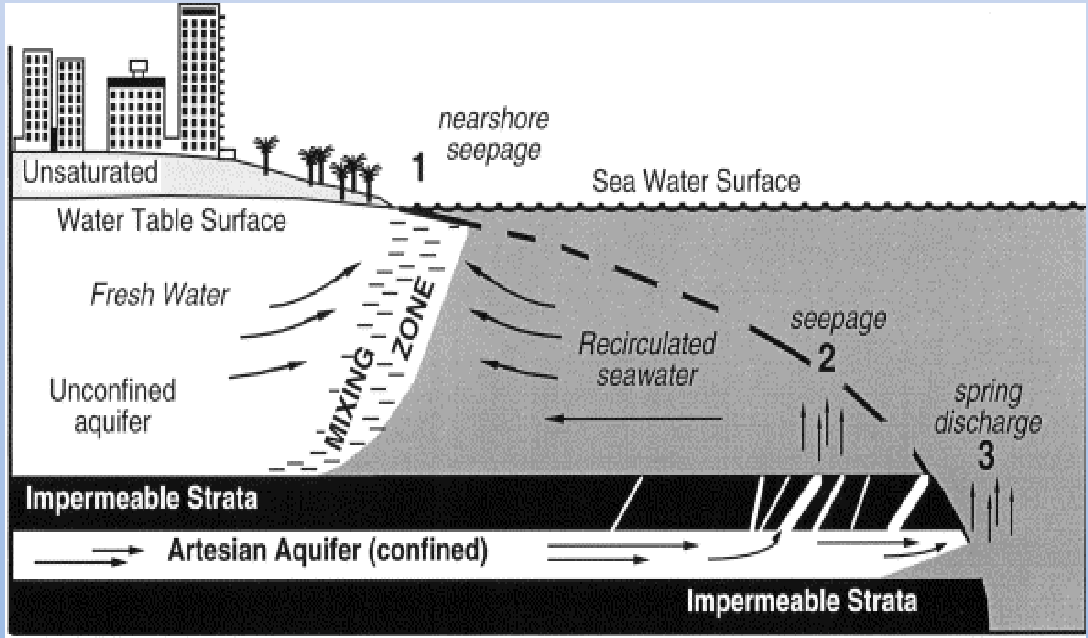
- **Introduction**
  - Submarine Groundwater Discharge
  - Investigation Area
- **Results**
  - Calculation Groundwater Composition
  - Biogeochemical Processes
  - Seepage Rates
- **Conclusions**
- **Outlook**

Introduction

►Submarine Groundwater Discharge (SGD):

SGD = direct groundwater outflow across the ocean- land interface into the ocean (recirculated seawater included)

(Church TM. *Nature*, 1996)



Burnett et al. *Journal of Sea Research* 46, 109-116 (2001)

- **SGD driving forces:**

- convection
- hydraulic head
- tidal pumping

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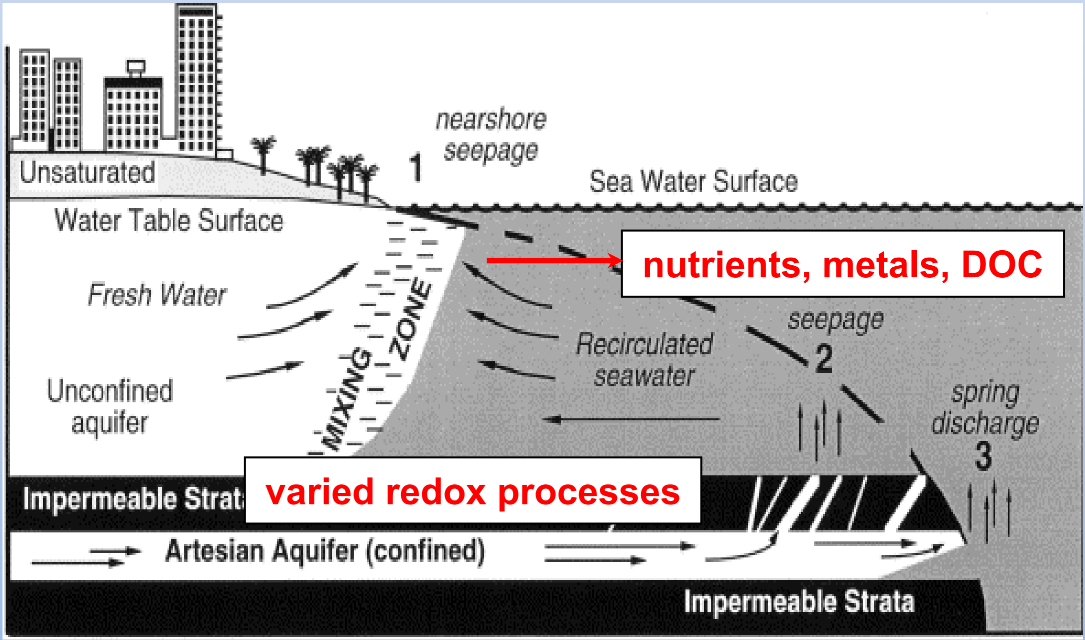

Burnett et al. *Journal of Sea Research* 46, 109-116 (2001)

- **SGD driving forces:**

- convection
- hydraulic head
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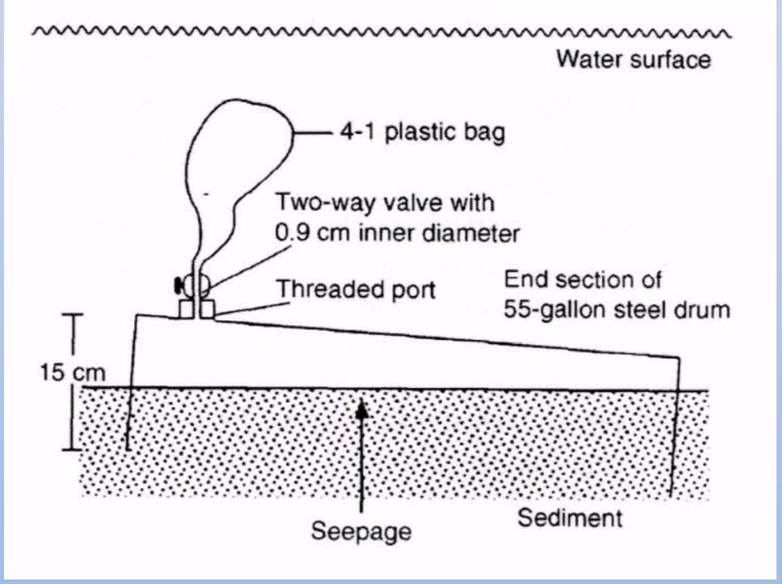
Introduction

► SGD – Identification:

- **Anomalies (salinity, temperature, different biological community)**

- Tracer (CH_4, Ra, Rn)

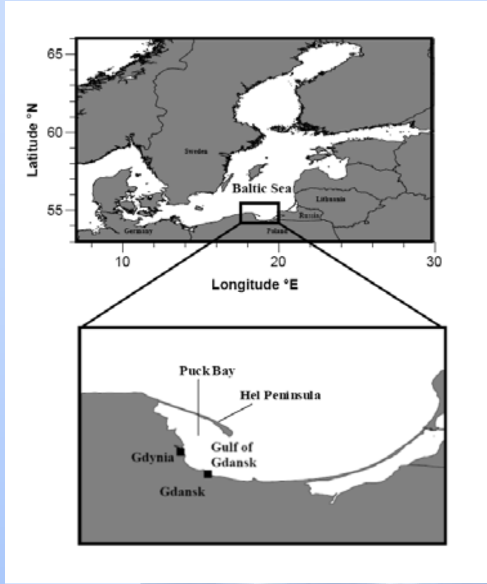


► SGD – Measurement by Seepage Meter:

Manual or "Lee-type" seepage meter

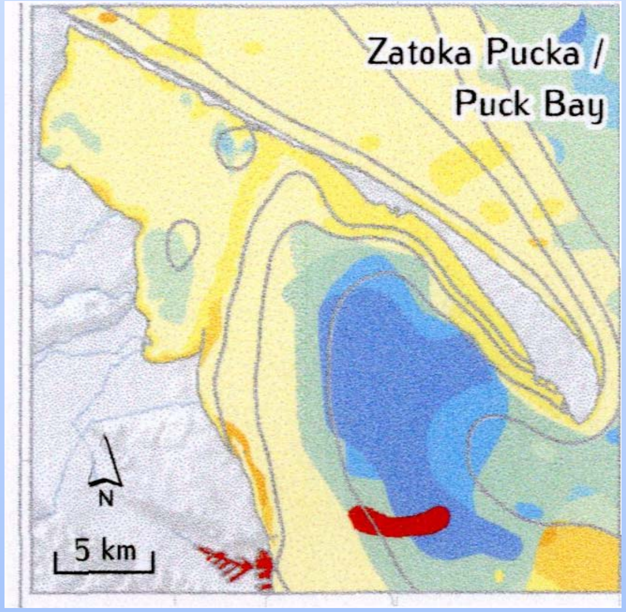
Burnett et al. *Science of the Total Environment* 367 (2006) 498-543

Investigation Area - Puck Bay and Hel Peninsula



Puck Bay and Hel Peninsula/ Poland

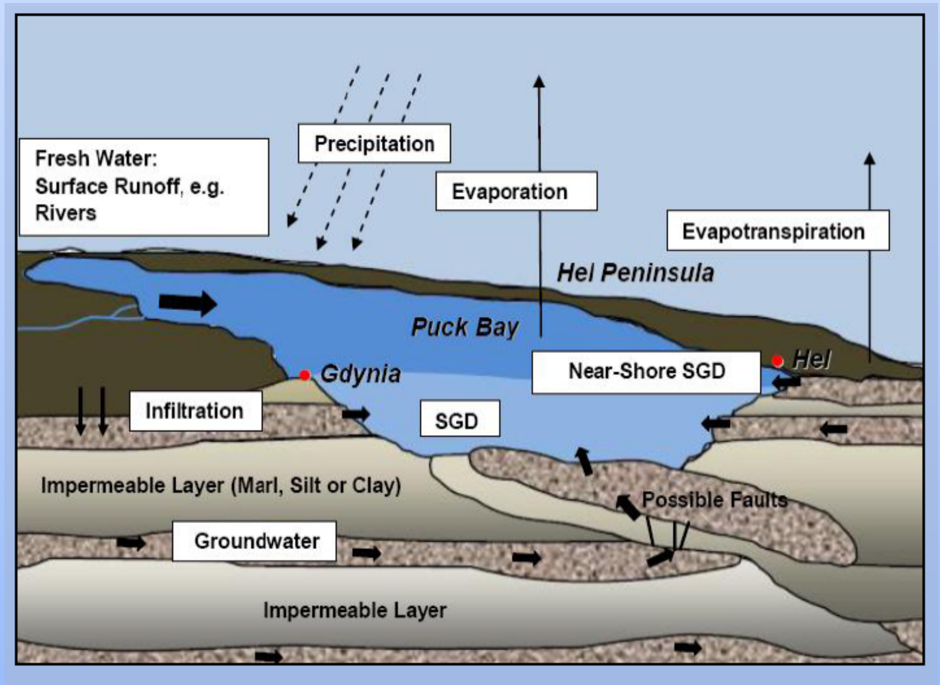
Investigation Area - Puck Bay and Hel Peninsula



Bottom Sediments:

■	clay	■	fine sand
■	sandy clay	■	medium sand
■	anthropogenic	■	coarse sand
□	clayey sand		

Reference: IO-PAN



Hydrological water cycle and hydrogeological layers (modified after Piekarek-Jankowska 1996).

Hel Beach: Investigation with Groundwater Lances

Sampling Site – Salinity Survey and further Investigations October 2010

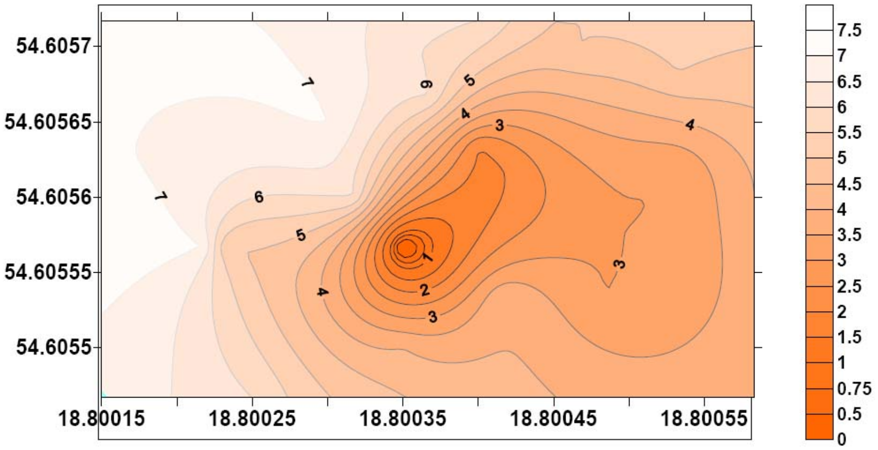
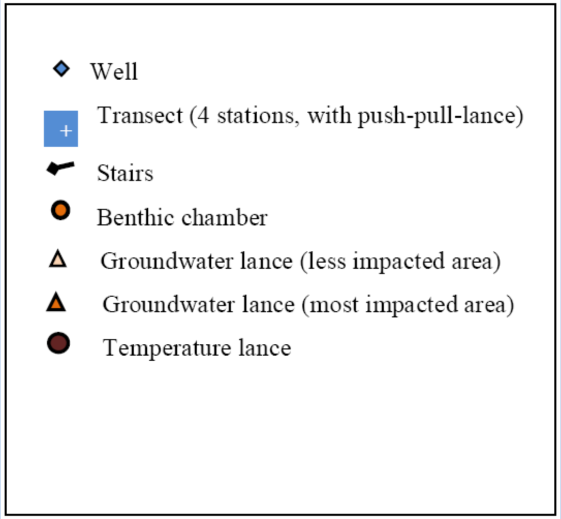


Figure 2: Salinity measurements (in PSU) Hel Beach in an area of 20 x 30 m.



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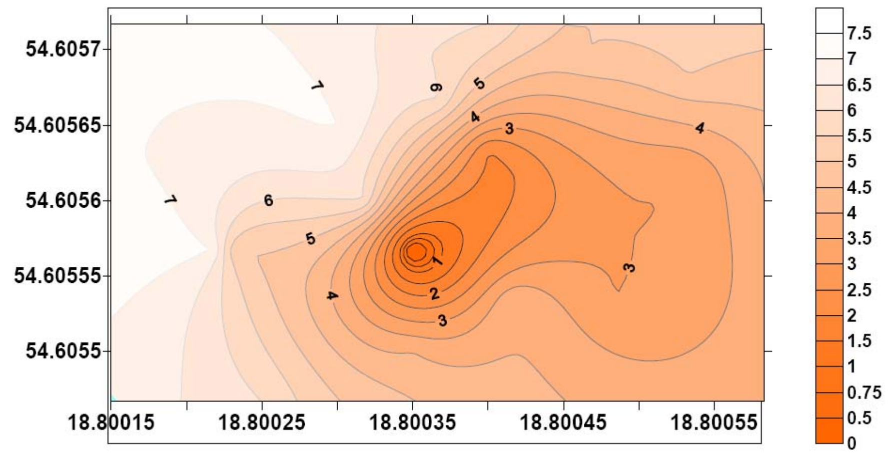

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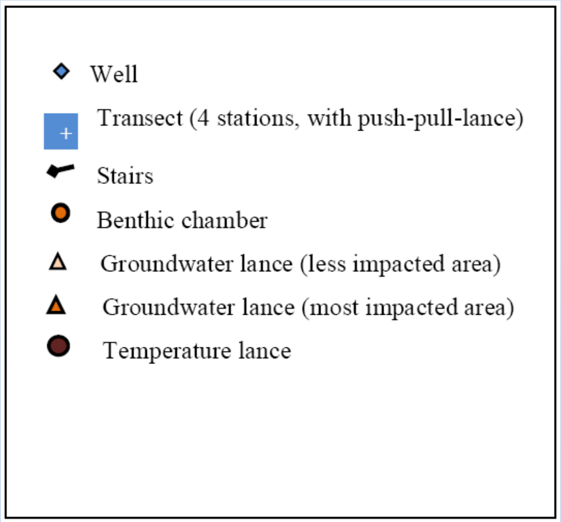


Sampling campaigns:

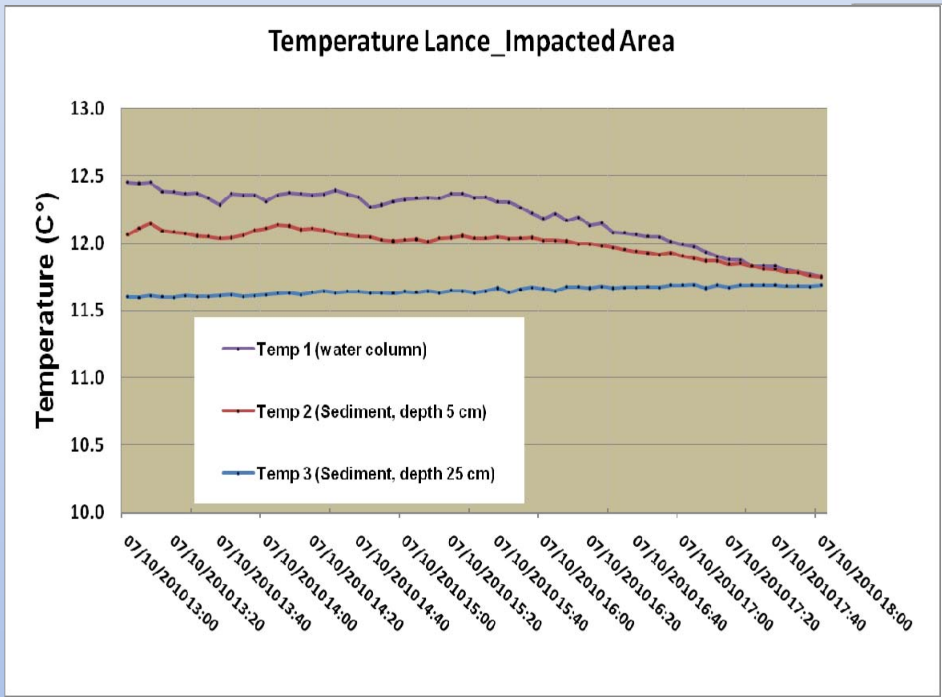
Sept and Nov 09, Feb/March 2010, May 2010, October 2010

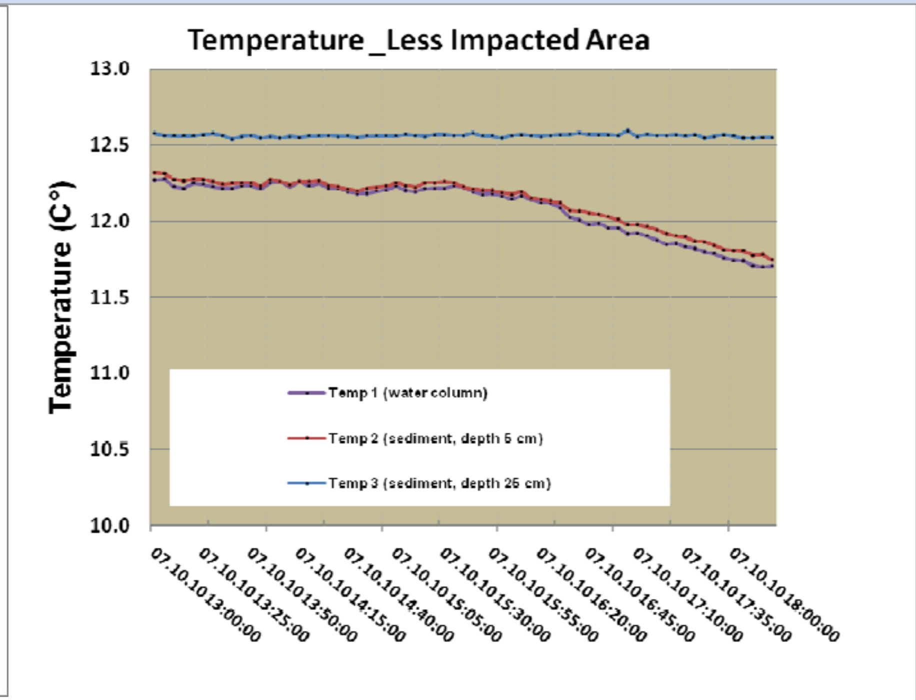
Sampling Site – Salinity Survey and further Investigations

►What is done so far ?:

- Groundwater impact measurable with temperature anomalies
- Groundwater composition
- Spatial, temporal, seasonal variations?
- Groundwater origin (the same like in the well ?)
- Important processes
- Seepage Rates

Hel Beach: Temperature Profiles, Oct 2010





Calculation Groundwater Composition

Two End-Member Mixing-Model:

- groundwater portion x_{GW}
  $= (c_{mix} - x_{Bowa} {}^{*} c_{Bowa})/c_{GW} = (c_{mix} - c_{Bowa})/(c_{GW} - c_{Bowa})$

- theoretical concentration (only dilution) $c_{theoret}$
  $= x_{GW} {}^{*} c_{GW} + x_{Bowa} {}^{*} c_{Bowa}$

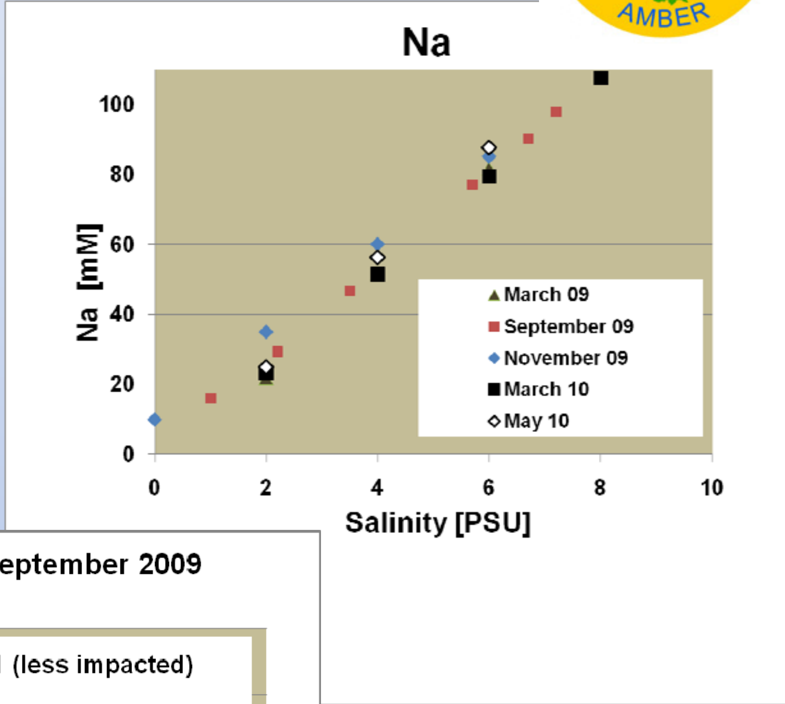
- $x_{Bowa} = 1 - x_{GW}$

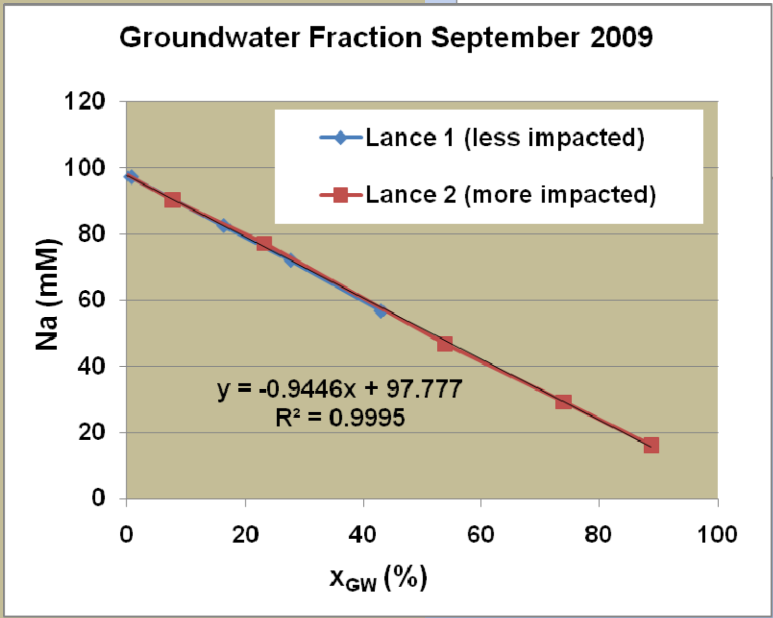
x_{Bowa} portion bottom water

c_{GW} conc. in groundwater

c_{Bowa} conc. in bottom water

c_{mix} conc. mixing water





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x_{Bowa} portion bottom water

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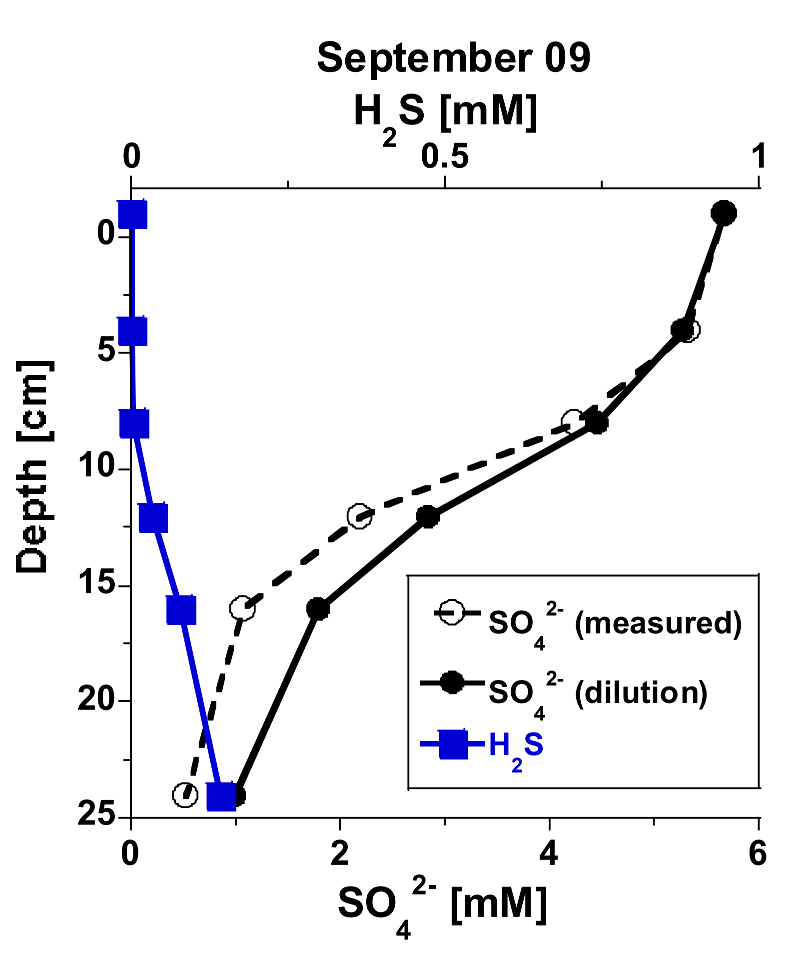
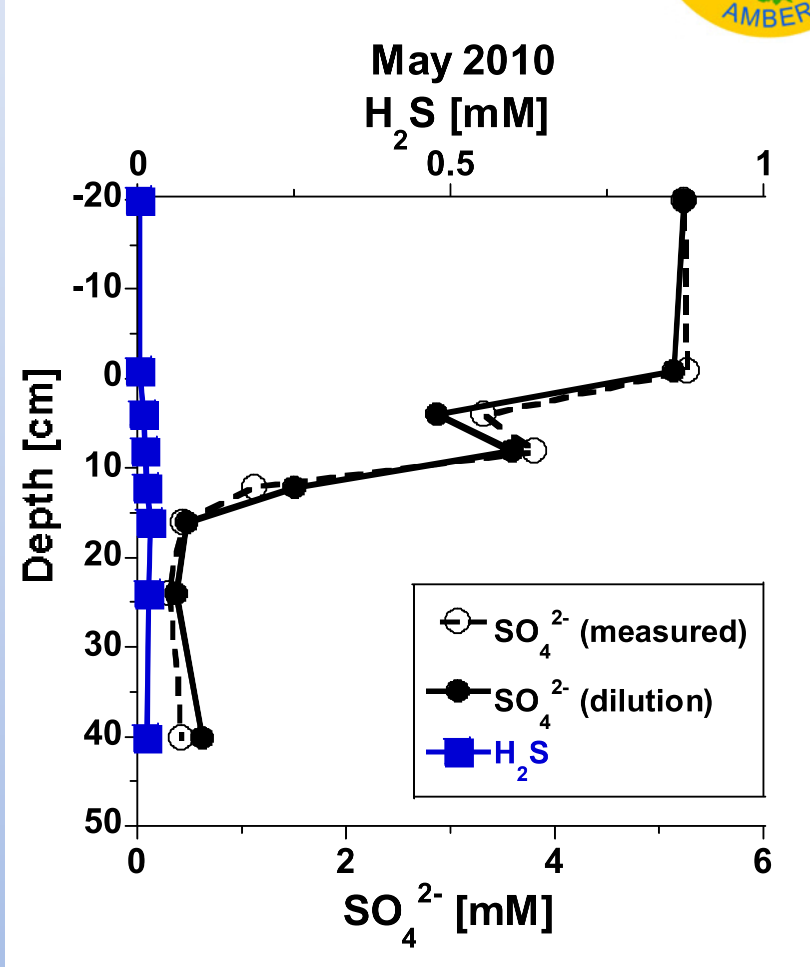
Groundwater end member:

Na =	5.41± 7.44 mM
Mg =	0.84 ± 0.73 mM
K =	0.2 ± 0.07 mM
Fe:	0 - 6 µM
Mn:	2 - 7 µM
S^{2-}:	0 - 2 mM
SO_4^{2-}:	0 - 0.3 mM

Pore Water

Mixing with Groundwater and Biogeochemical Reactions





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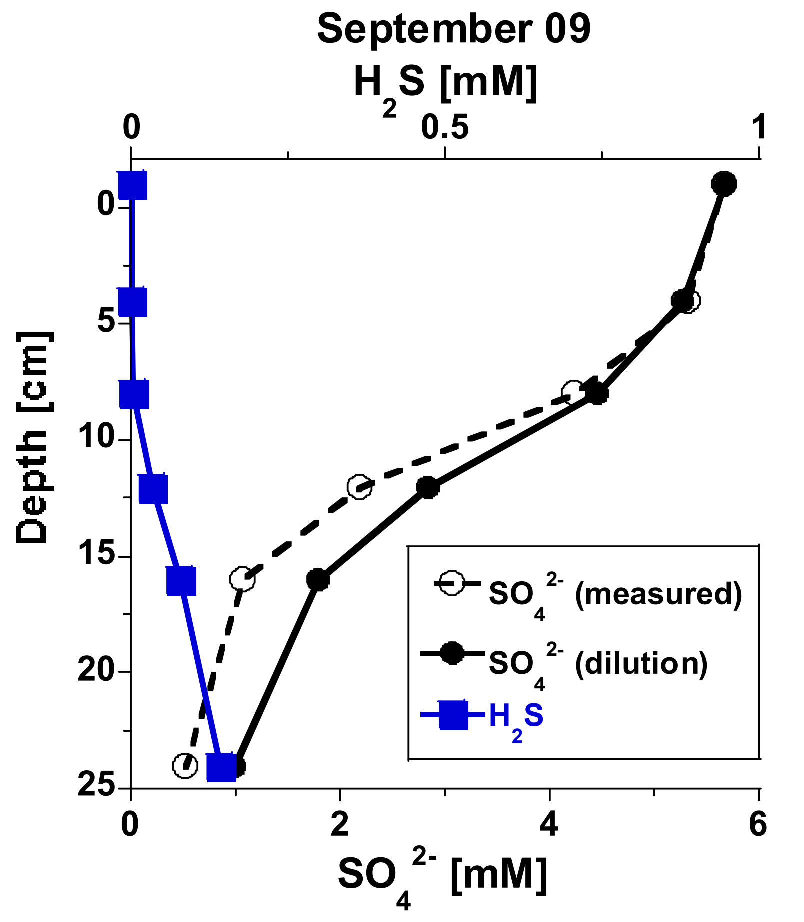
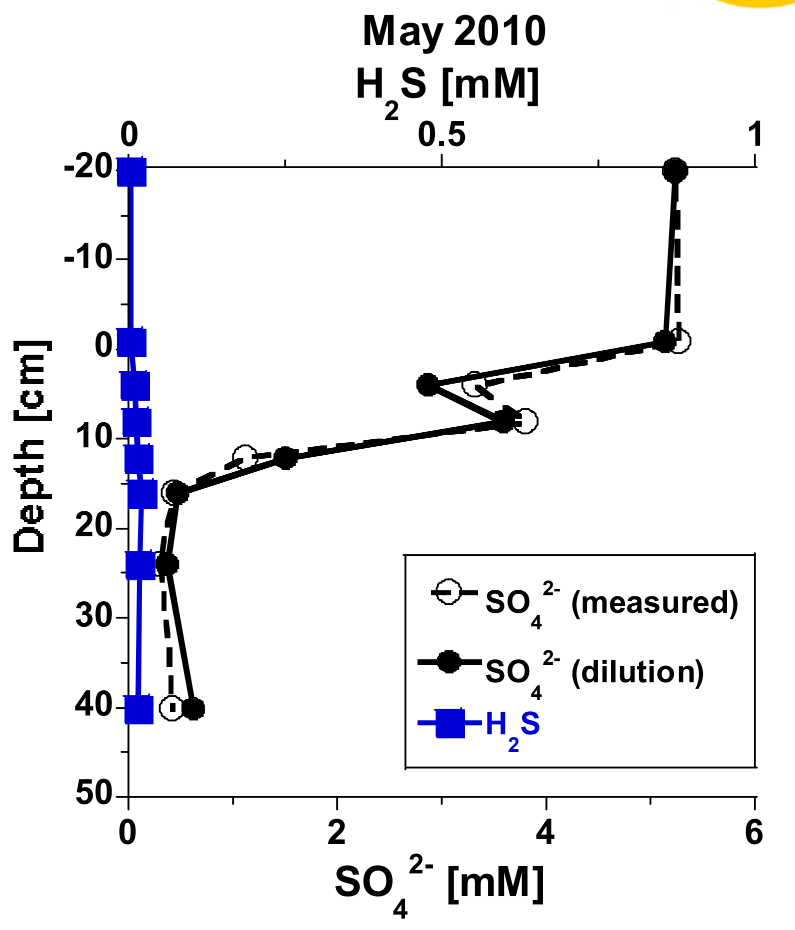


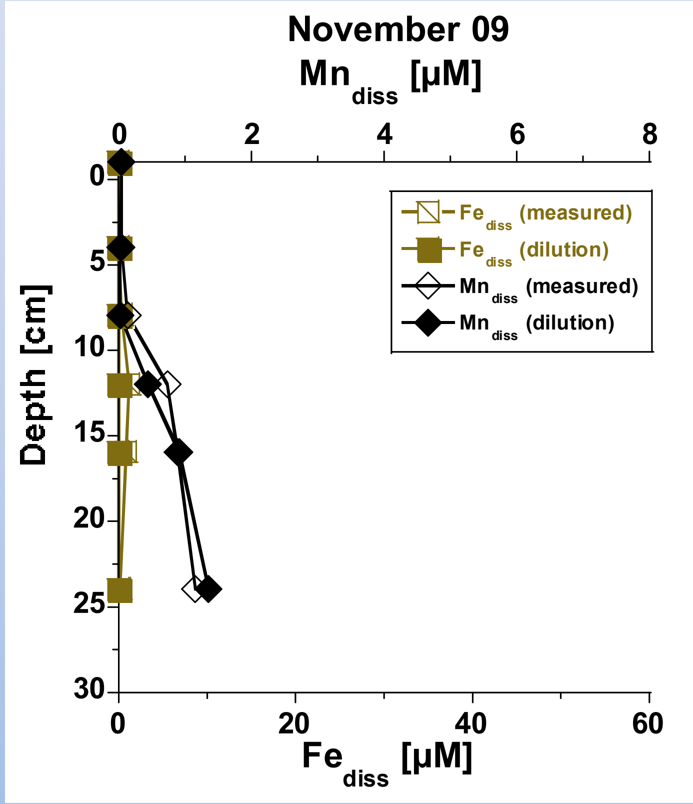


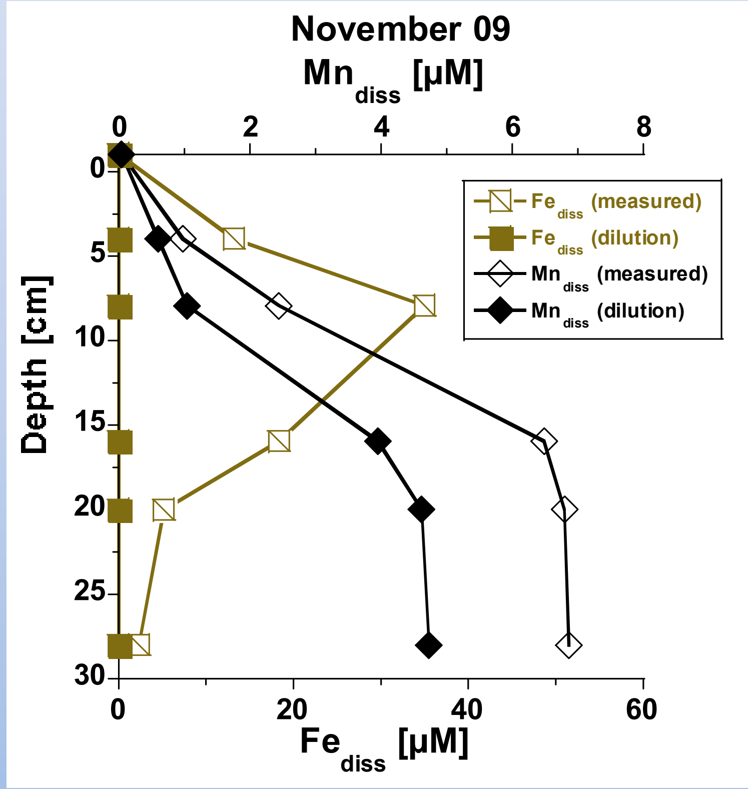
Sulphate Reduction => Release of H_2S

Seasonal Variations

Pore Water

Mixing with Groundwater and Biogeochemical Reactions





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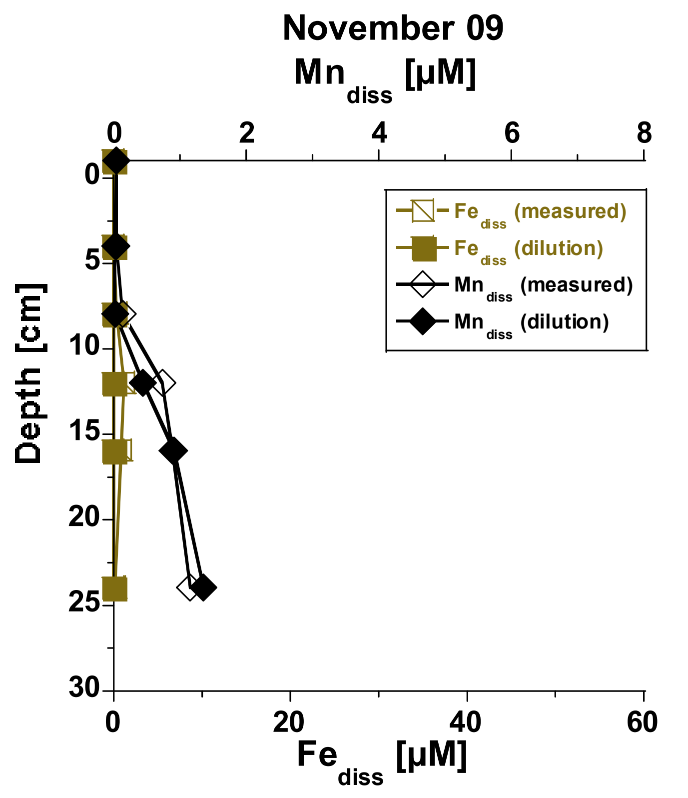
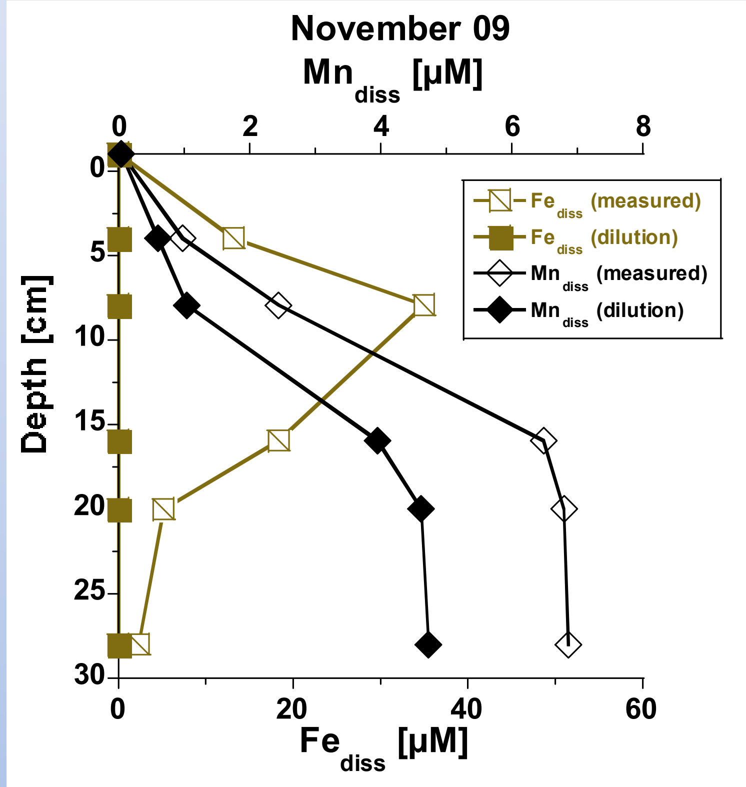
Pore Water

Mixing with Groundwater and Biogeochemical Reactions





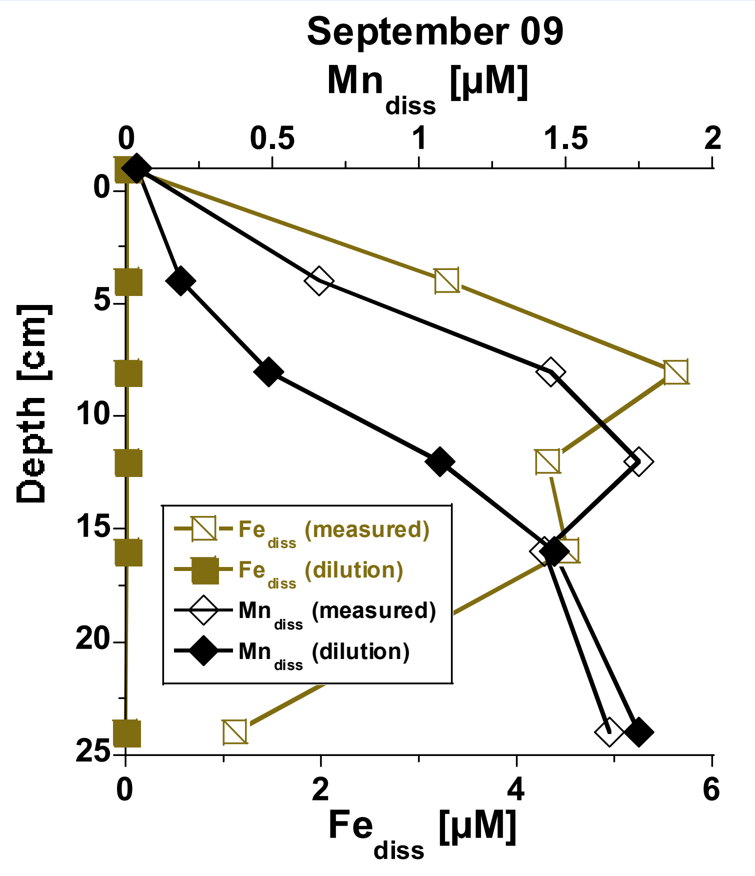
- highly anoxic groundwater

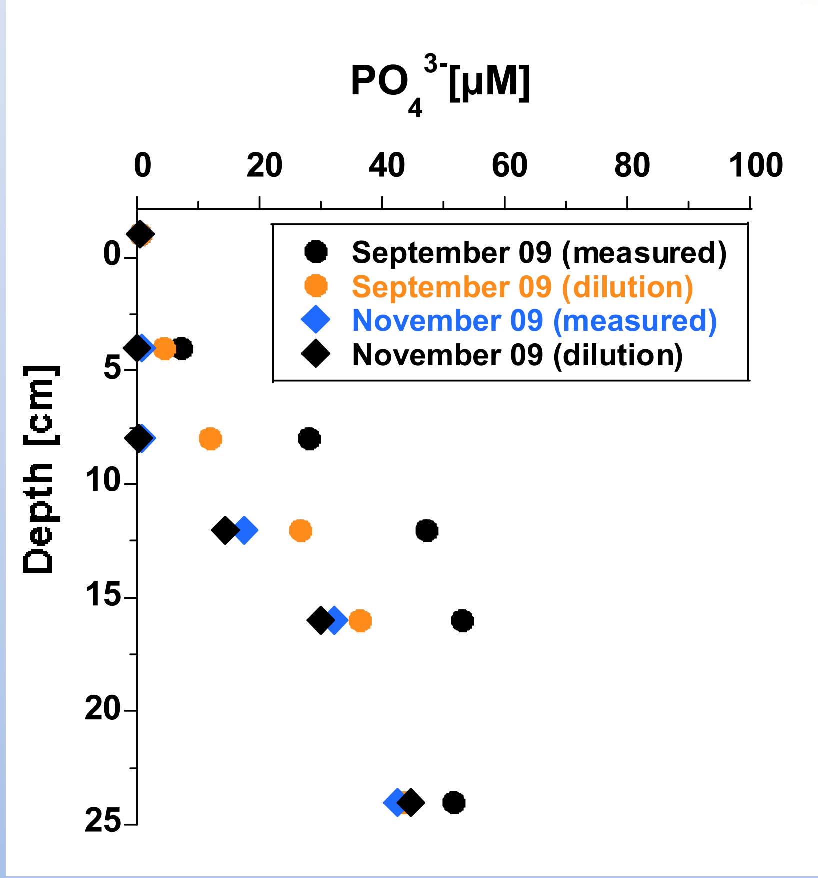
- reduction of Manganese Oxides and Iron-Oxyhydroxides =>
=> Release of Mn^{2+} and Fe^{2+} and in deeper parts formation of FeS

- not ideal redox zonation (advective transport through permeable sediment)

Pore Water

Mixing with Groundwater and Biogeochemical Reactions

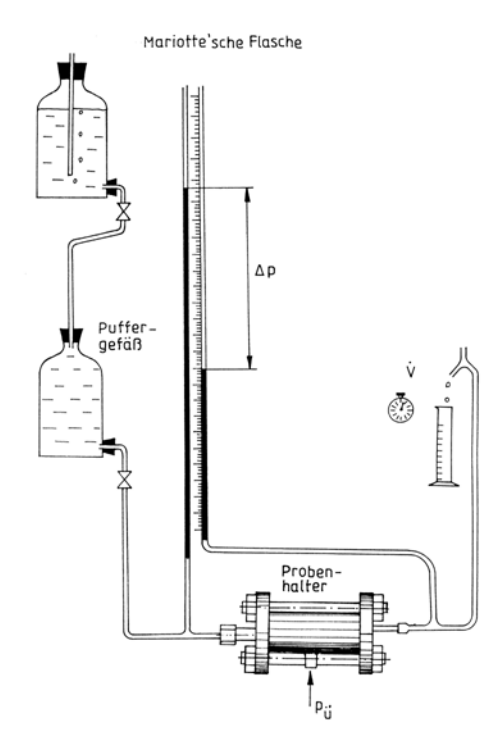




- Dissolution of iron oxyhydroxides = release of phosphate

Permeability

Hel Sediments:

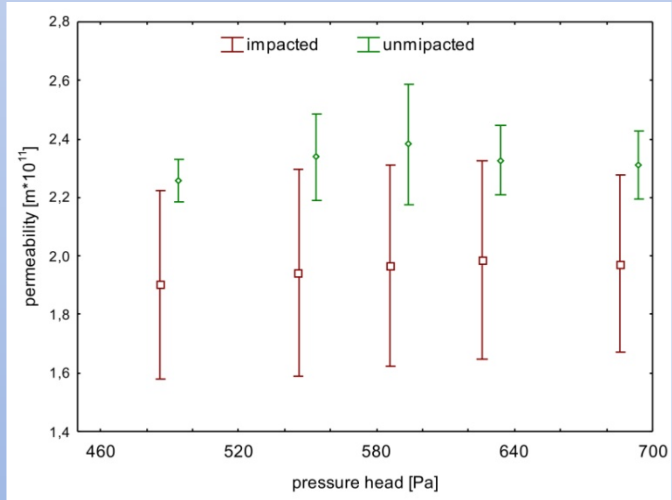


Permeability Measurement
(Häfner et al. 2009)

Tab. 1. Basic descriptive statistics for impacted and unimpacted sediments

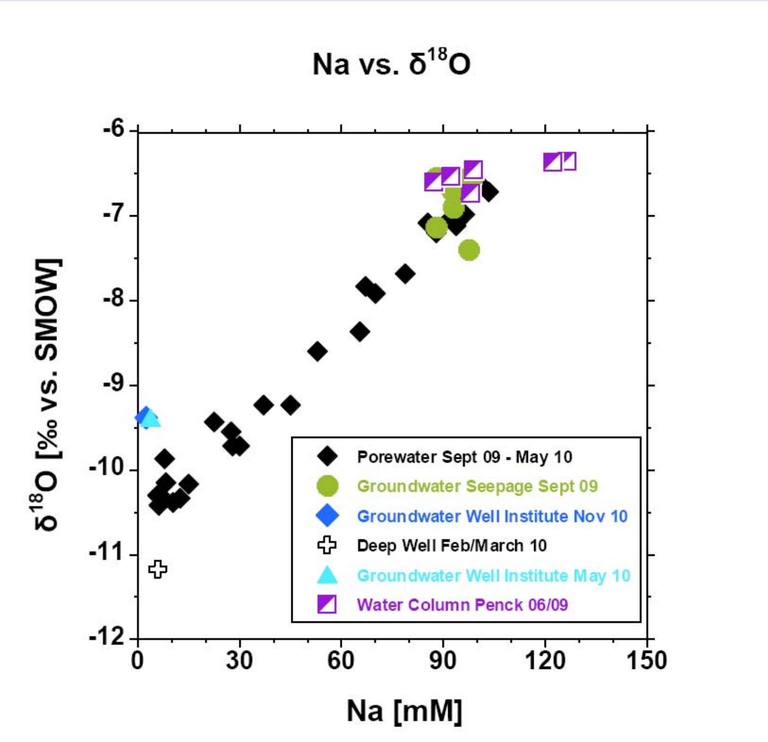
STATISTICS	*PERMEABILITY [m²] BASIC STATISTICS*	
	IMPACTED	UNIMPACTED
VALID N	150	150
MEAN	1.95×10^{-11}	2.32×10^{-11}
MINIMUM	1.43×10^{-11}	2.06×10^{-11}
MAXIMUM	2.32×10^{-11}	2.87×10^{-11}
ST.DEV.	0.33×10^{-11}	0.14×10^{-11}

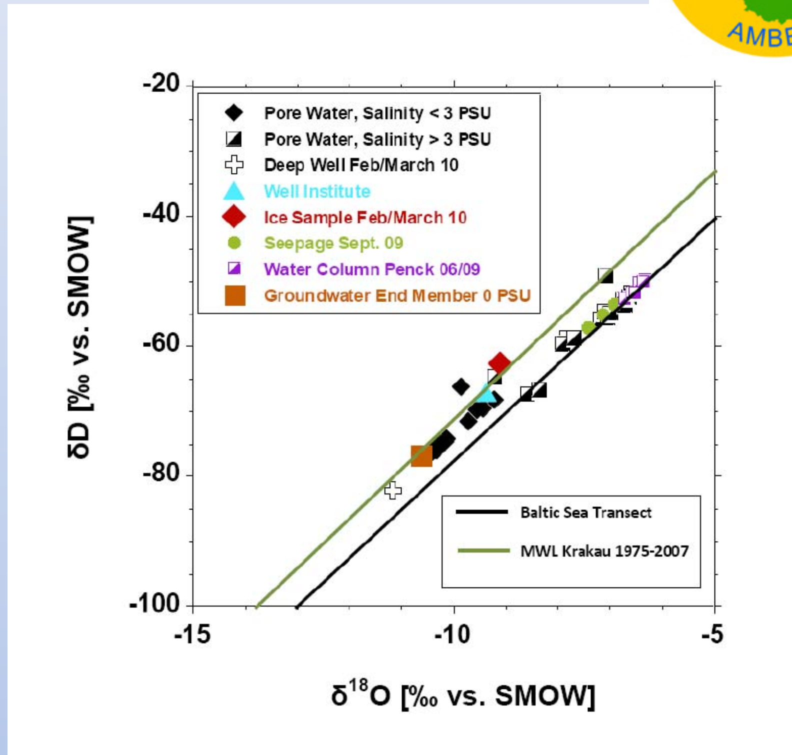
$K_f = 10^{-11}$ m/s
⇒ less permeable
???



Lech Kotwicki (IOPAN)

Hel Beach: Isotopic Analyses





Isotope Data measured by Ulrich Struck/
Museum für Naturkunde Berlin

Holocene meteoric waters (D´Obyrn et al. 1997):
$\delta^{18}O$ = -10.09 ‰
δD = - 69.45 ‰

Groundwater End-Member:
$\delta^{18}O$ = -10.63 ‰
δD = - 76.70‰
^{3}H (groundwater endmember) = 2.4 TU
^{3}H (sea water) = 9.1 TU

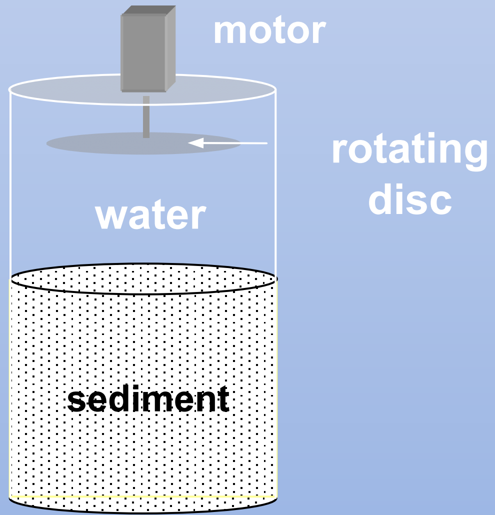
Hel Beach: Seepage Rates May 2010

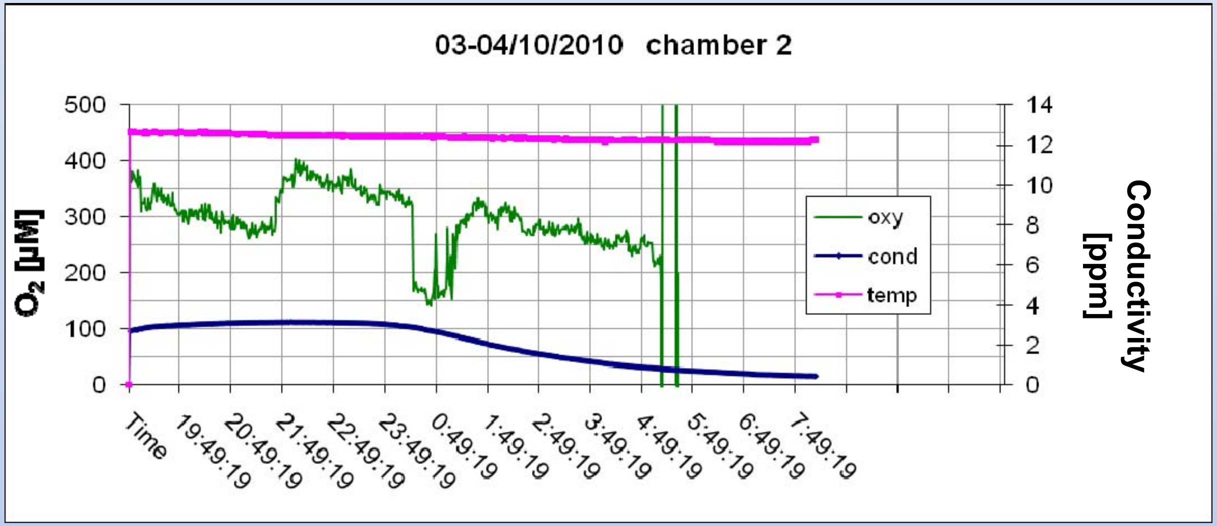
Measured by Lee-type-seepage meter:

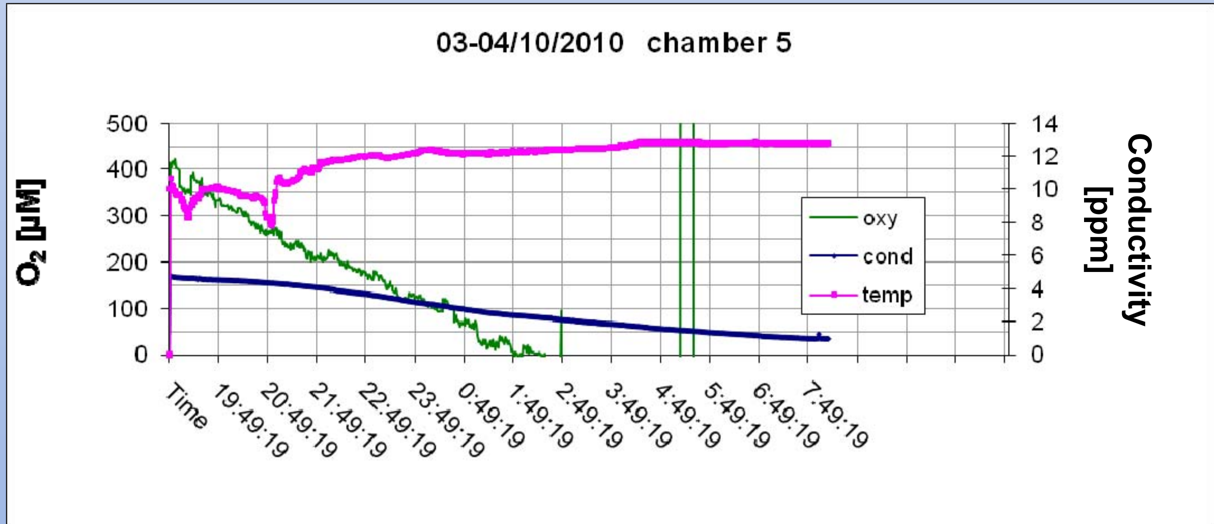
Benthic Chamber	1	2	3	4	5
Station	1	1	2	2	2
Size (cm)	30 x 30 x 14	20 x 20 x 13	30 x 30 x 13	20 x 20 x 13	27 x 33 x 10
Salinity (PSU)	5.5	3.7	6.5	/	5.9
Volume in Bags (mL/h)	210	240	890	70	630
Seepage Rate ($mL\ m^{-2} min^{-1}$)	39	100	162	29	119
Seepage Rate ($L\ m^{-2} d^{-1}$)	56	144	233	42	172

Hel Beach: Seepage Rates October 2010

Measured by automated benthic chambers:





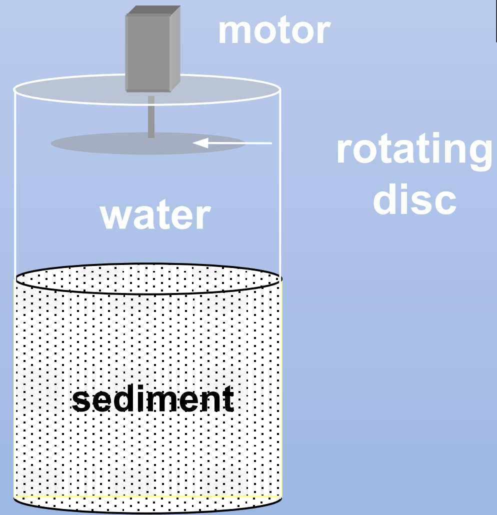


Source: MPI

Hel Beach: Seepage Rates October 2010

Measured by automated benthic chambers:

3.- 4.10.10	Seepage rate (L/m² d)					
Chamber	**1**	**2**	**3**	**4**	**5**	**6**
	24	*32*				
7.10.2010						
	79	*76*	*28*	*25*	*113*	*13*



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Conclusions

- no saisonal variability in groundwater composition (conservative elements)
- temporal and spatial variability of seepage
- advective transport of groundwater and sea water through permeable sediments
- biogeochemical reactions in the mixing zone => anoxic groundwater
- methane and precepitation products in groundwater may decrease permeability in sediment

=> also responsible for high spatial variability of element contents

Outlook

- further field campaigns in Hel Peninsula (sampling of rivers and wells) and near Kühlungsborn
  - radium measurements (modeling)
  - further measurement of seepage rates
- Isotopic analyses (^{13}C (DIC, DOC, CH_4), ^{34}S (SO_4^{2-}, H_2S))

Planed Publications

- Composition of anoxic groundwater escaping from coastal sands to the Puck Bay (Poland)/ in Estuarine, Coastal and Shelf Sciences (in preparation)
- paper about geobiochemical processes leading to this groundwater (modeling)
- paper about quantification of SGD (cooperation with AWI, comparison of different techniques)

Relevance of Results

- process of SGD important to consider in coastal areas

- important to know quality and quantity of seepage water

⇒ danger of eutrophication

- quantification: uniform definition of SGD (recirculated seawater included)

- important to know source and age of groundwater =>
  affected by climate change and change in land use
  (spring of aquifer may be affected kilometres away from coast
  e.g. by agriculture)

Thank you !