Microbiological Remediation of a CHC Contamination on an Industrial Site in Barcelona using IEG-GCW® and IEG-MIW

- Digital Reconstruction of Sediments -

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- Essentials about Groundwater Circulation Wells (IEG-GCW®)
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Who we are ?

- Founded 1992 with IEG Industrie Engineering GmbH, Reutlingen
- Since 2010 independent, international company
- Business areas: design and implementation of remediation systems and processes via IEG-in-situ technologies, applied R&D

Milestones:

- **1987** First patents for in-situ remediation techniques
- ***1990*** Development of hydraulic models (Uni KA), field tests KA; various projects for US-EPA-Site Program, Large-Scale box models (VEGAS) and testfields (Uni Stuttgart, IfH Karlsruhe.)
- ***1998*** First installations outside Germany (DK, P, NL, B, I, HU)
- ***2005*** Large scale refinery projects in South East Asia
- ***2014*** Increased R&D effort – national and EU – on bio-sensors, oscillating flows, porous media modeling, bioelectric, in-situ bioreactor
- ***2020*** Branch offices in Italy and China

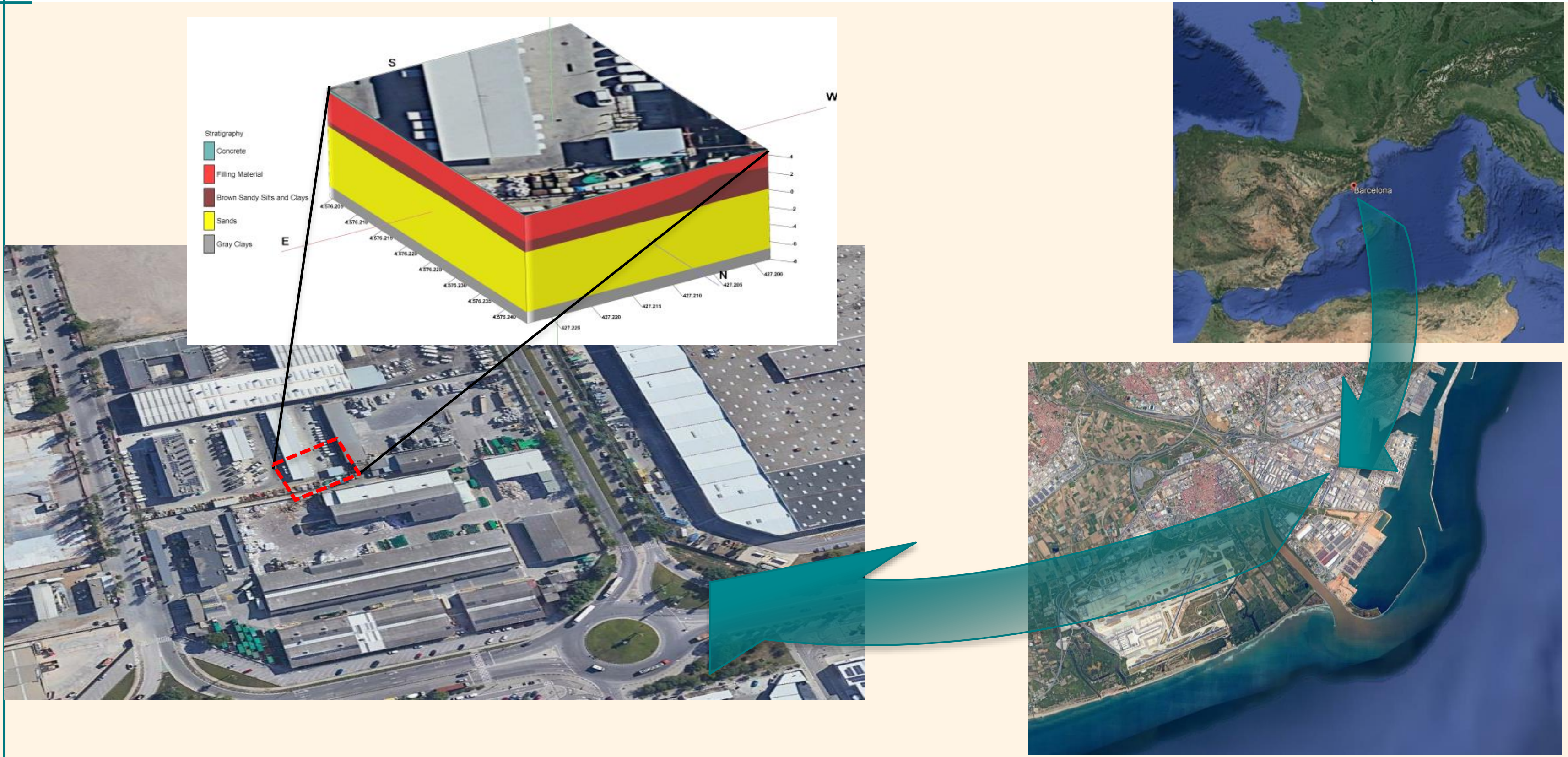
Project Partner

Founded 2001 as Spin-Off from "Battelle Institut Frankfurt/M";
The Main activities are computation services for energy, process and remediation industries.

Founded 1303; the faculties of Geo Sciences and Industrial Chemistry work, among others, on the impact of chemicals on the environment and risk studies regarding the contamination of soil and groundwater

Hochschule Karlsruhe, research and development of new modeling and simulation techniques aimed at virtual design of new materials and the optimization manufacturing

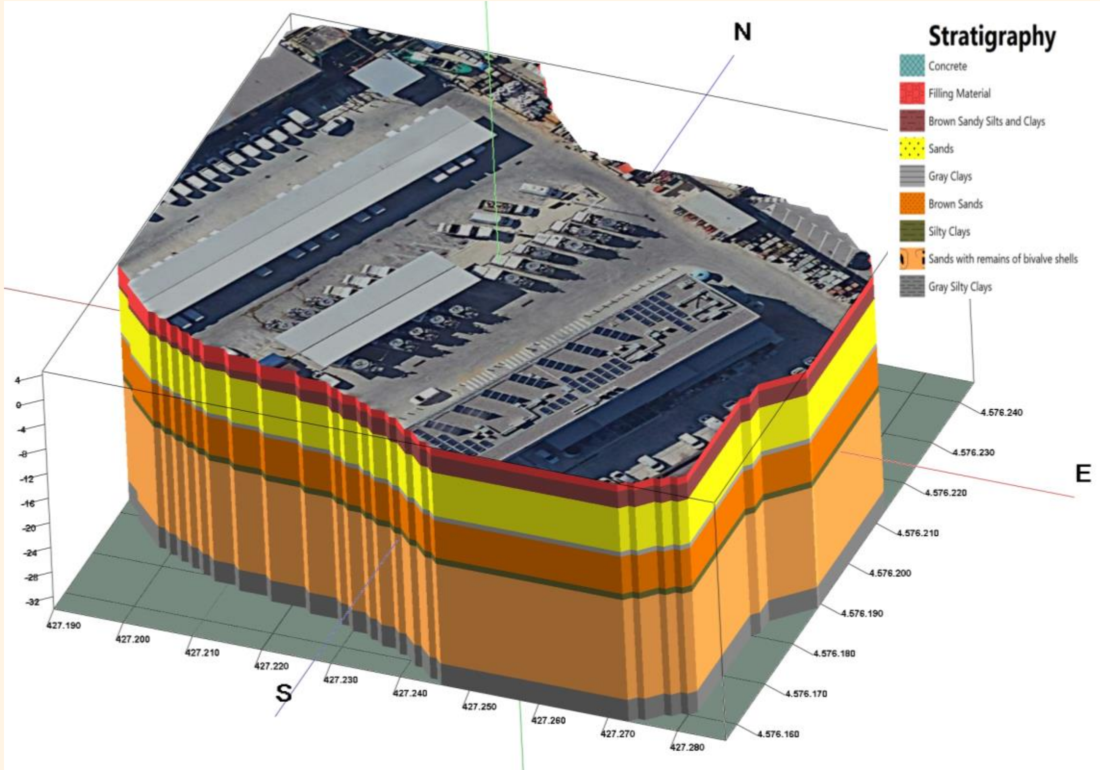
Project Description

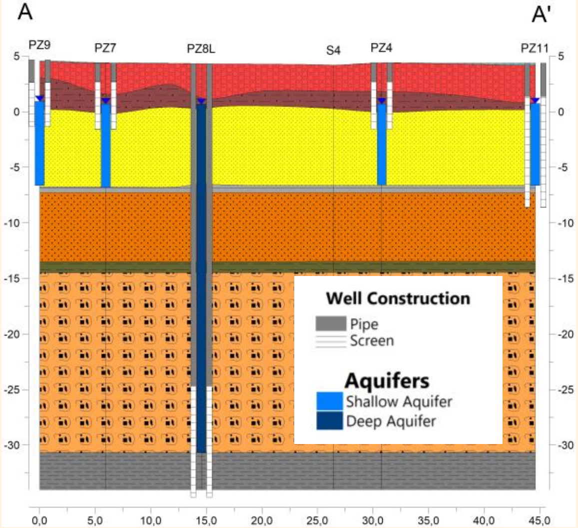


Geology and Contamination

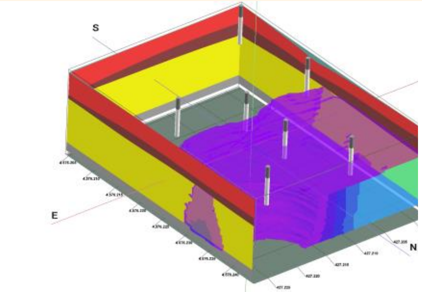
- Intermittent sand layers of varying granulometry
  k_{fh}-value 1,44*10^{-4} – 8,0*10^{-5} m/s, ratio $k_{fh}/k_{fv} \geq 10$
- Aquifer thickness approx. 7,5 m
- Groundwater level - 3,0 m
- Gradient 0,003
- Groundwater velocity ca. 0,25 m/d
- Starting contamination up to 140 mg/l CHC, mainly TCE

Geology und Contamination

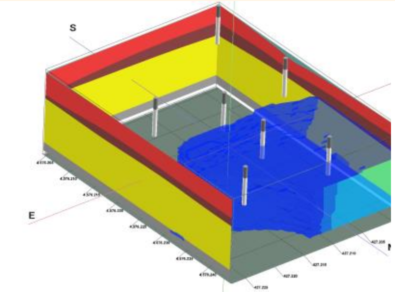




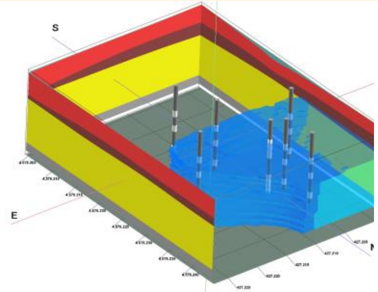
Geology und Contamination



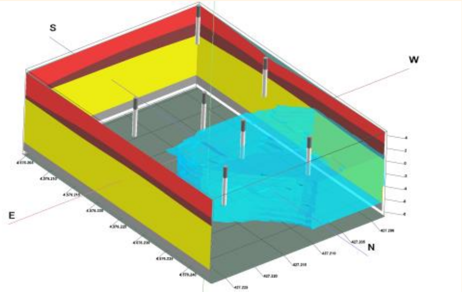
20 mg/L (4.610 m^3)



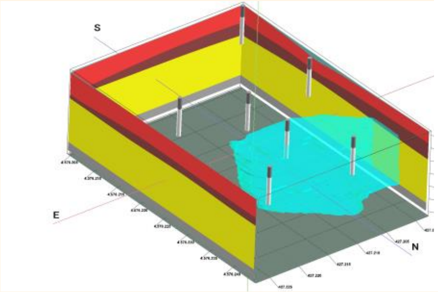
40 mg/L (3.512 m^3)



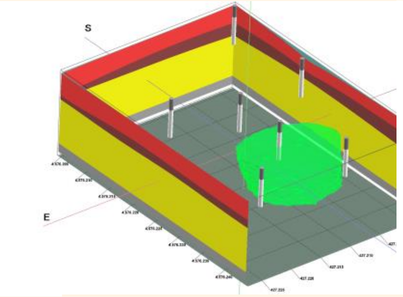
60 mg/L (2.745 m^3)



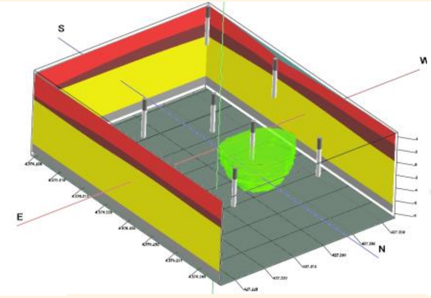
80 mg/L (1.551 m^3)



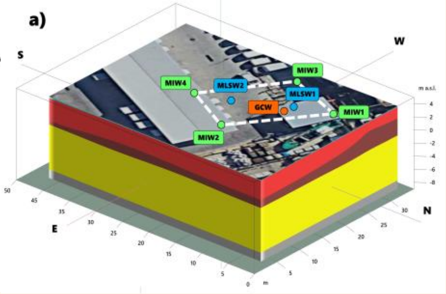
100 mg/L (726 m^3)



120 mg/L (320 m^3)



140 mg/L (127 m^3)

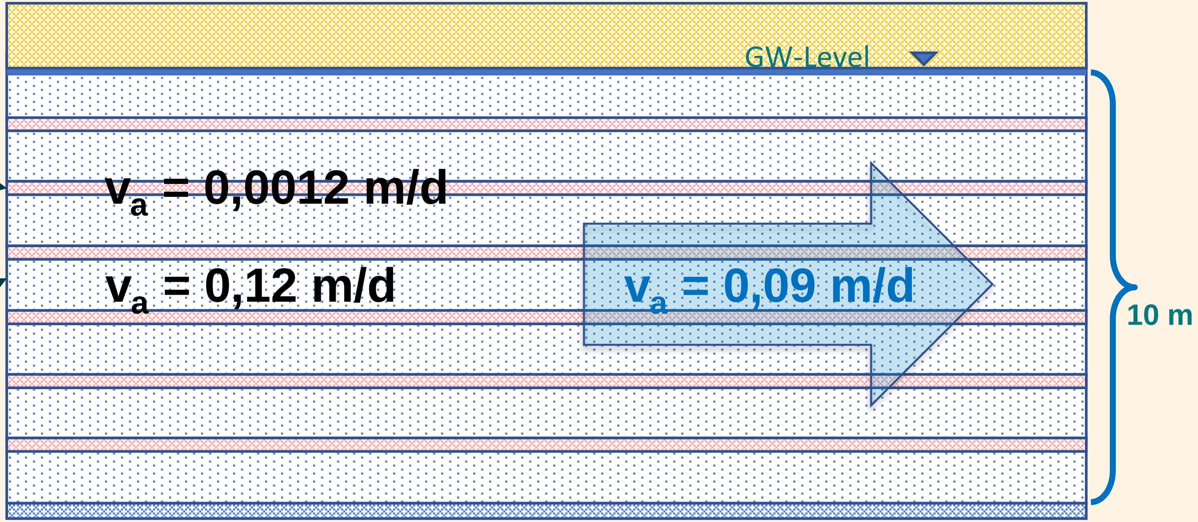


Essentials about IEG-GCW®

Model aquifer constructed with a sequence of medium sands and silty fine sand layers (gradient 0,002, p_0 0,15); contamination with CHC

k_{fh} = 1 * 10^{-6} m/s
(silty fine sand)
Share of aquifer profile
20 %
Heavyly contaminated

k_{fh} = 1 * 10^{-4} m/s
(medium sand)
Share of aquifer profile
80 %
Less contaminated

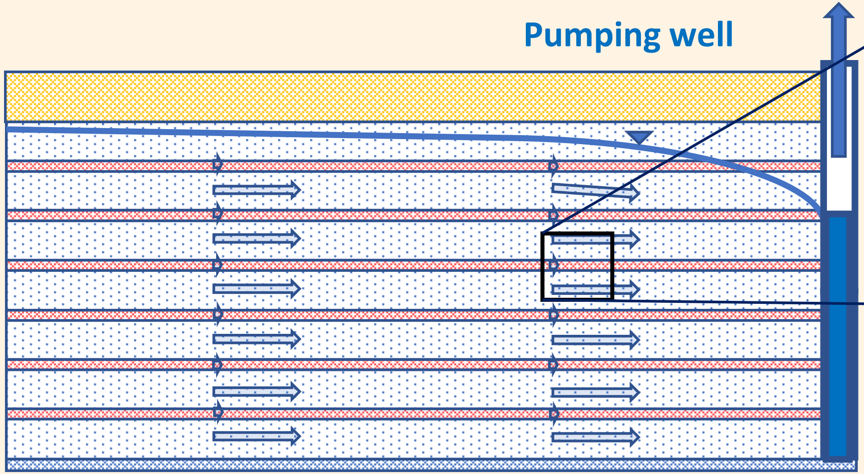


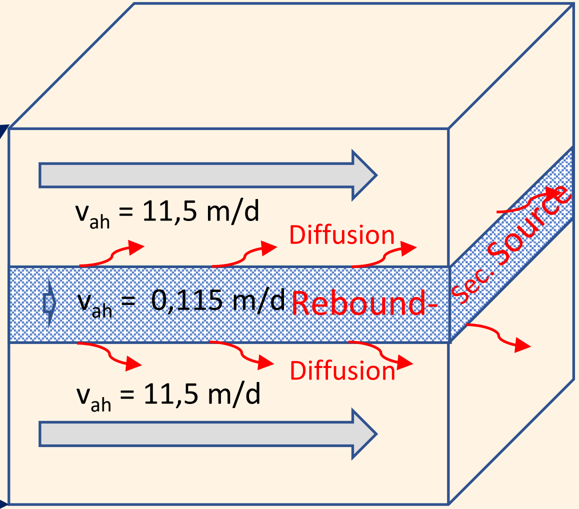
Average horizontal permeability k_{fh} = 8,02 * 10^{-5} m/s
Average vertical permeability k_{fv} = 4,8 * 10^{-6} m/s
Ratio k_{fh} / k_{fv} = 16,7

Essentials about IEG-GCW®

IEG

In the more permeable layers (generally less contaminated) water flows towards a pumping well about 100 times faster than in the more contaminated less permeable intermediate layers.





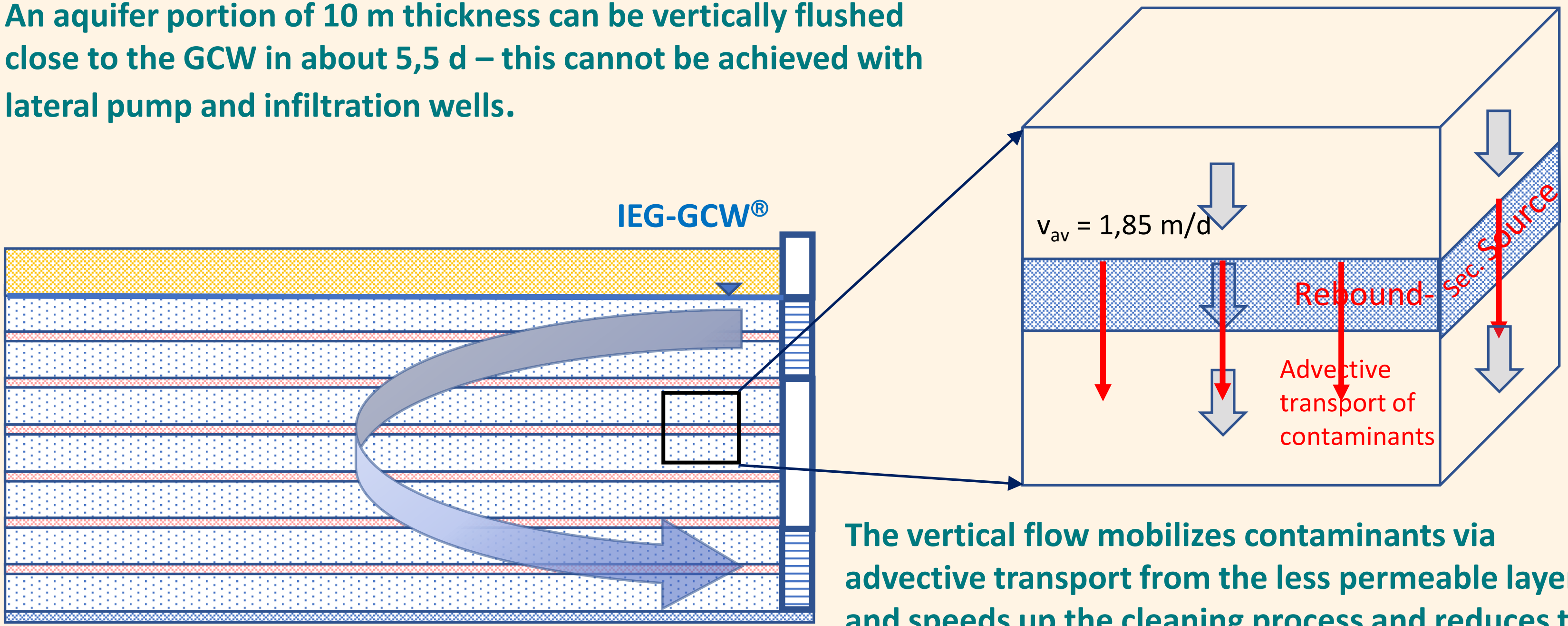
Groundwater gradient close to the well I = 0,2; s = 2 m, Q = 6 m^3/h

Porosity p_o = 0,15

Vertical flushing of the less permeable layers can happen (and only partially) in the immediate vicinity of the pumping well. The continued re-contamination via desorption from the less permeable layers (secondary source - rebound) is the reason for long and costly P&T remediations.

Essentials about IEG-GCW®

An aquifer portion of 10 m thickness can be vertically flushed close to the GCW in about 5,5 d – this cannot be achieved with lateral pump and infiltration wells.



Gradient close to well I = 0,67; k_{fv} = 4,8 * 10^{-6} m/s
porosity p_o = 0,15

The vertical flow mobilizes contaminants via advective transport from the less permeable layers and speeds up the cleaning process and reduces the rebound effect.

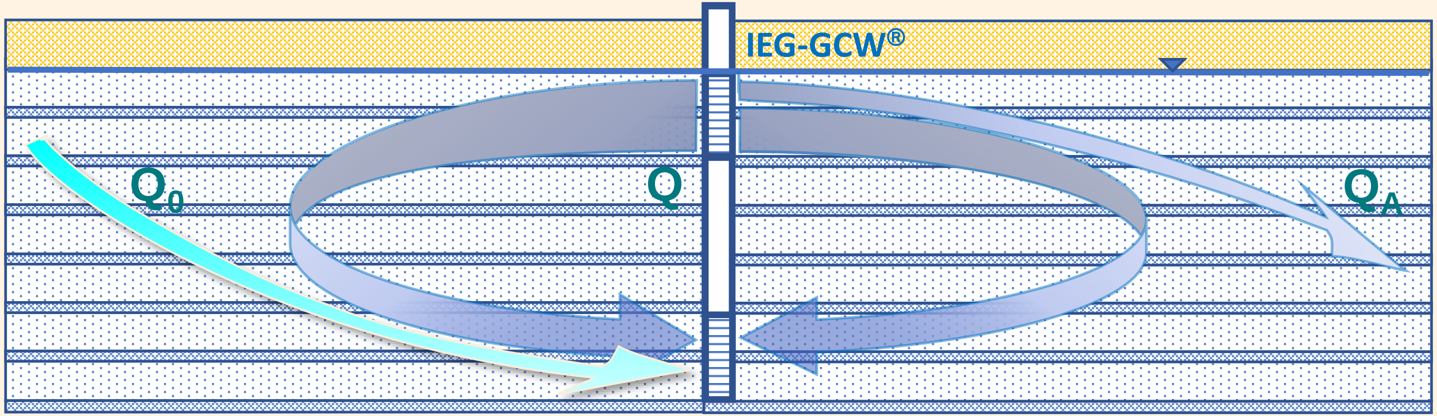
Essentials about IEG-GCW®

Each water particle remains statistically for 10 cycles in the circulation before it is leaving the circulation cell down-gradient.
The vertical circulation cell is a treatment reactor that can be employed to implement a vast variety of treatment approaches.

Share of the upper inflow
Q_0 = 0,6 m³/h

Total circulation
Q = 6 m³/h

Share of outflow down-gradient
$Q_A = Q_0$



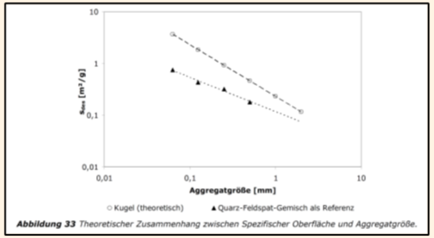
The gradient in the GCW area can be controlled through additional wells up or/and downgradient.

Essentials about IEG-GCW®

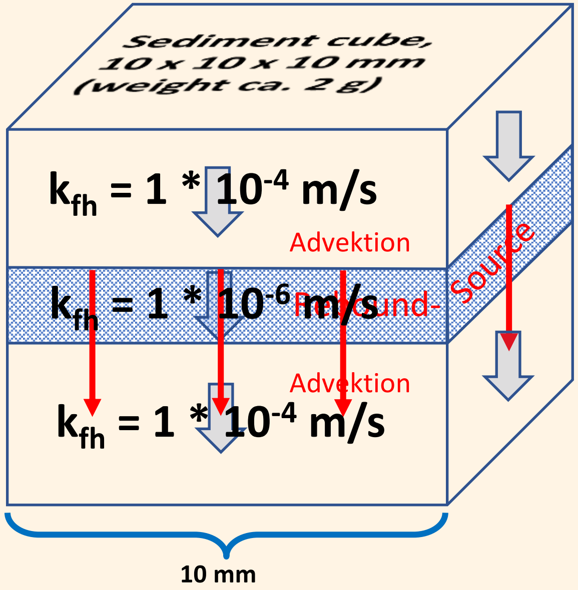
IEG

Through the vertical flow, the inner surface area of the sediments increases from 1,6 to 5,6 m², or from 100 % to 350 % in contrast to only horizontally flowed areas. The enlarged surface area maximizes the dynamics of chemical and physical fluid reactions and increases the bacterial colonization density inside the porous structure.

Abhängigkeit der inneren Oberfläche von der Korngröße



Bönsch 2006, p 58



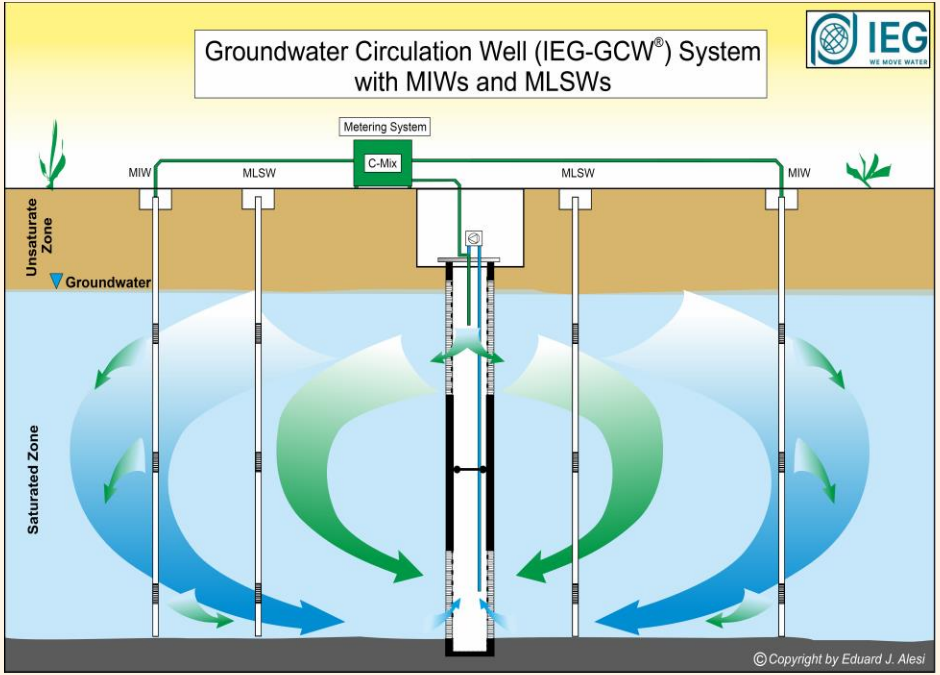
1 g = ca. 1 m² inner surface
4 mm
weight portion 2/5 = 0,8 g = **0,8 m²**

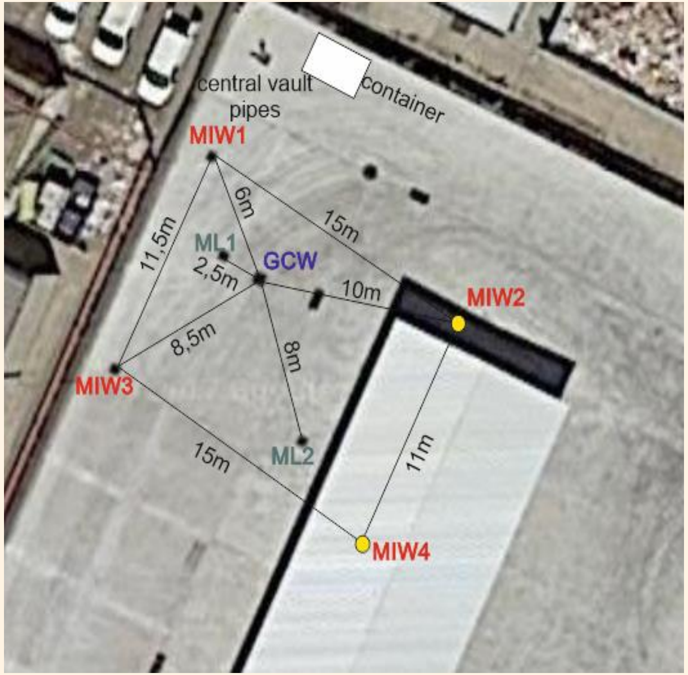
1 g = ca. 10 m² inner surface (c.f. 5 % of clay)
2 mm
weight portion 1/5 = 0,4 g = **4,0 m²**

1 g = ca. 1 m² inner surface
4 mm
weight portion 2/5 = 0,8 g = **0,8 m²**

Compared to P&T or direct push approaches the IEG-GCW® enables the contaminants in the secondary source to be mobilized or addressed otherwise continuously: nutrients, ISCO, ISCR etc., lead to shorter remediation times and lower overall cost.

System Configuration



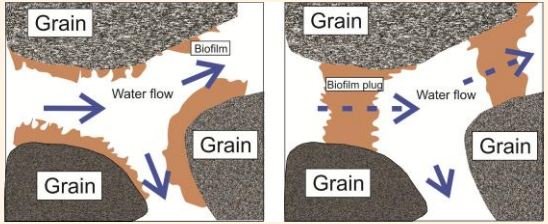


Nutrients are consumed through reactive processes on their horizontal and vertical passage. Additional depth-differentiated MIWs are installed at the peripheral circulation edge for on-demand nutrient dosage

Digital Construction of Sediments

All relevant substance conversions and interactions happen on pore-scale level.

Realistic description of fluid transport, energy flow and transformation processes in the subsurface requires knowledge about the texture and surface properties of sediment particles and their spatial structure with connections, bottlenecks and dead-end pores.



Real grain topology

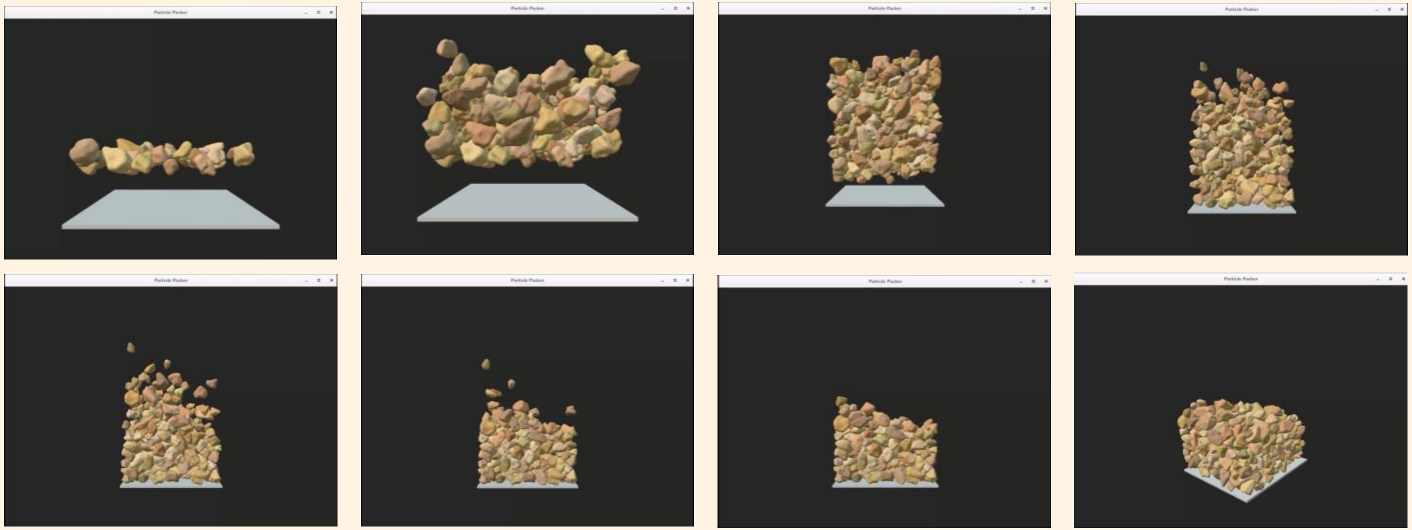
Virtual sand grains
(sediment libraries)

Sand grain accumulation

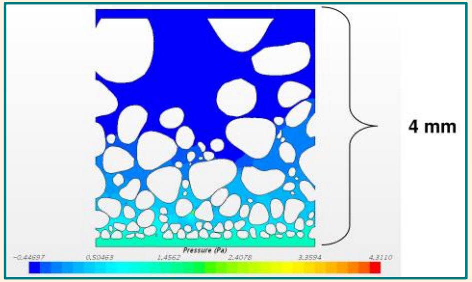
Digital Construction of Sediments

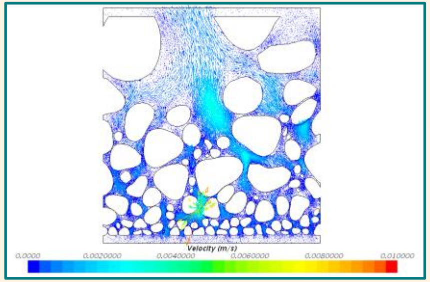
Digital sediment twins

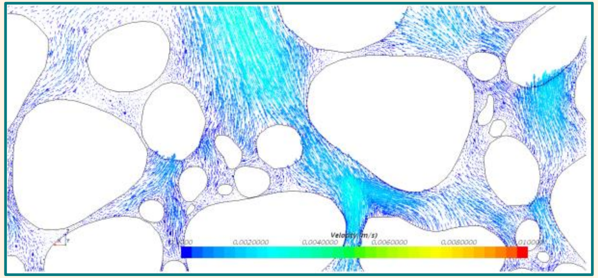
..can be used to visualize 3D sedimentation processes, to derive hydraulic parameters and to predict and simulate the behavior of materials from a chemical, physical and biological point of view.



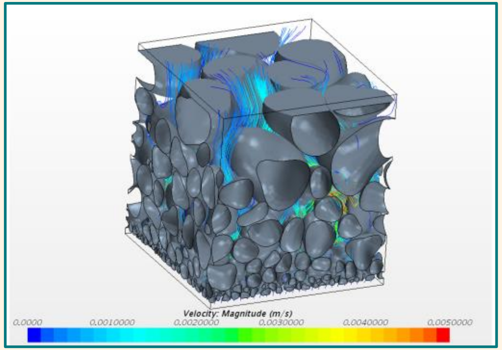
Digital Construction of Sediments





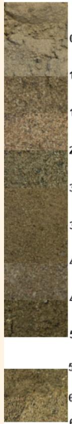


resolved sand structures



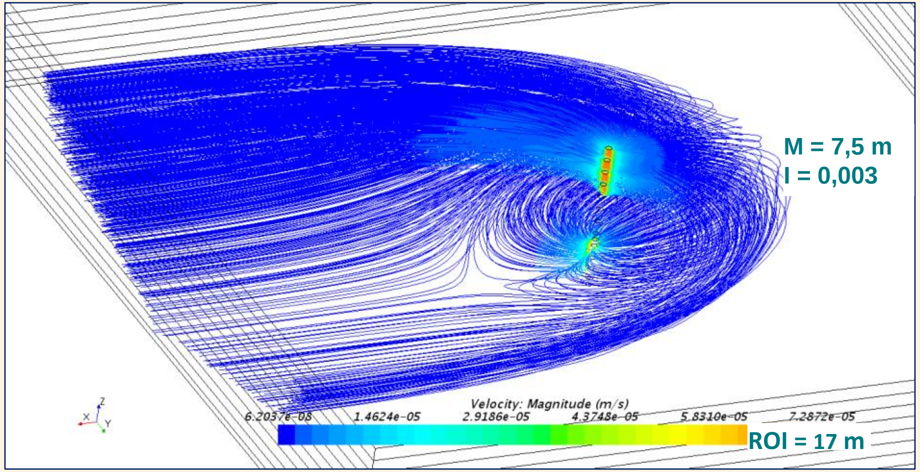
1. Flows through digital sediment twins and determination of their hydraulic properties.

2. Transmission of resolved sand structures to regions of porous sediment layers with variable properties.



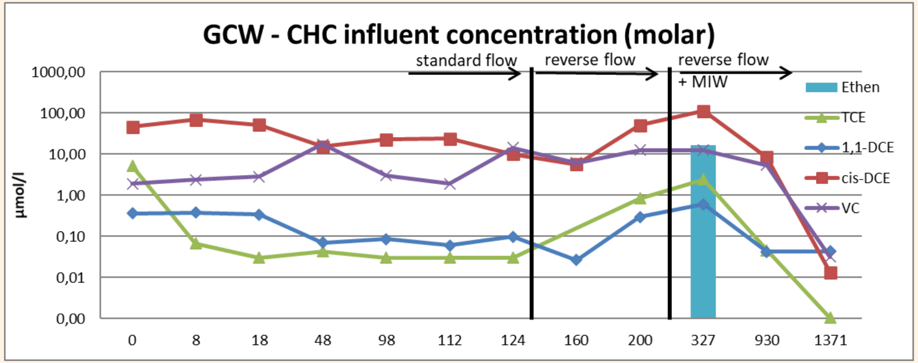
	Gravas limosas y arenoas de cantos angulosos de pizara y calizos			
	Ton	A0		
0 – 0,6	**60% Feinsand**, 20% Schluff/Ton, 15% Mittelsand, 5% Grobsand	A1	S1	Kf: 1,44E-5
0,6 – 1,2	**55% Feinsand**, 25% Mittelsand, 15% Schluff, 5% Grobsand		S2	Kf: 2,23E-5
1,2 – 1,8	**70% Mittelsand,** 15% Feinsand, 10% Grobsand, 5% Schluff,	A2	S3	Kf: 1,66E-4
1,8 – 2,4	**55% Mittelsand,** 25% Feinsand, 10% Grobsand, 5% Grobkies, 5% Schluff		S4	Kf: 1,67E-4
2,4 – 3,0	**55% Feinsand**, 27% Mittelsand, 15% Schluff, 3% Grobsand	A3	S5	Kf: 4,67E-5
3,0 – 3,5	**48% Feinsand**, 40% Mittelsand, 12% Schluff / Ton,		S6	Kf: 8,25E-5
3,5 – 4,2	**55% Mittelsand,** 25% Feinsand, 5% Schluff / Ton, 5% Grobsand, 5% Feinkies, 5% Mittelkies	A4	S7	Kf: 1,37E-4
4,2 – 4,8	**62% Mittelsand,** 30% Feinsand, 5% Schluff / Ton, 3% Grobsand		S8	Kf: 1,72E-4
4,8 – 5,4	**58% Mittelsand,** 25% Feinsand, 11% Grobsand 5% Schluff / Ton, 1% Kies		S9	Kf: 1,67E-4
5,4 – 5,9	Schluff, sandig	A5-1		
	Schluff, tonig	A5-2		
5,9 – 6,4	**50% Mittelsand,** 25% Grobsand, 20% Feinsand, 5% Schluff / Ton	A6	S10	Kf: 1,86E-4
6,4 – 6,7	**60% Mittelsand,** 20% Grobsand, 20% Feinsand, 5% Schluff / Ton		S11	Kf: 1,9E-4
6,7 –	Ton, schluffiger Sand Ton			

Test Configuration



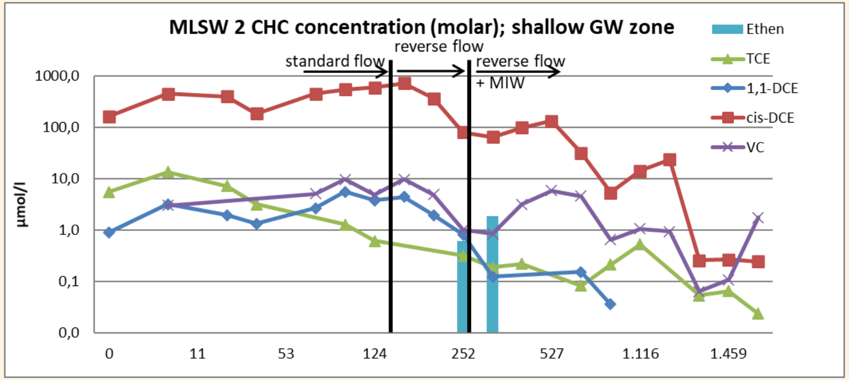
Model of GCW flowlines using resolved sediment structures

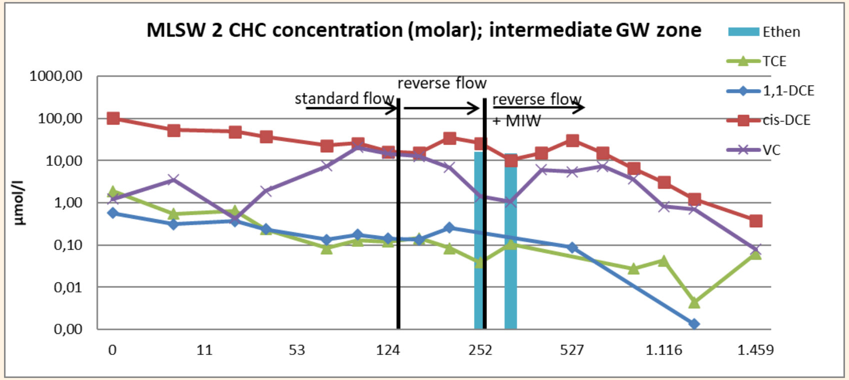
Results

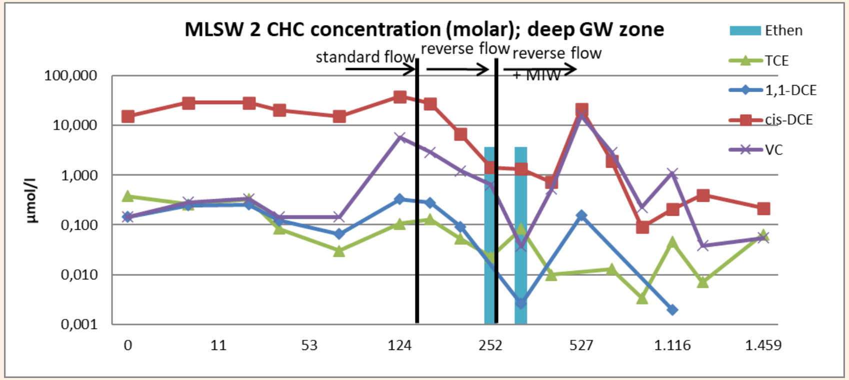


- Dosing of approx. 140 liter nutrient solution until day 140
- Thereafter switch GCW to reverse flow mode
- From day 250 nutrient dosage in MIW 1-4
- Total quantity of nutrient solution employed until day 1.523: approx. 10.800 l

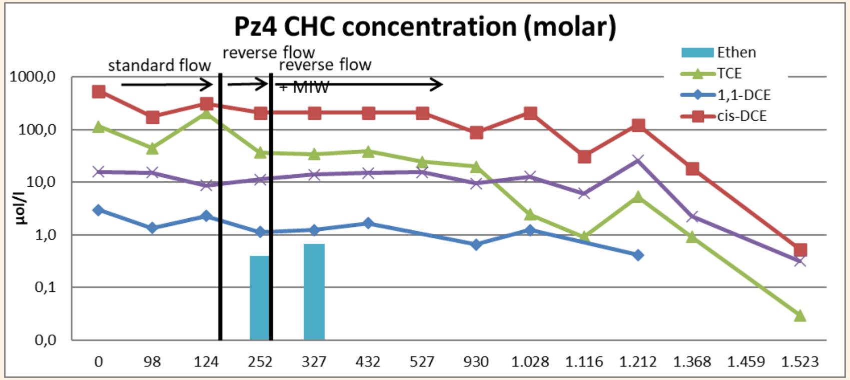
Results


MLSW 2 CHC concentration (molar); shallow GW zone
standard flow
reverse flow
reverse flow
+ MIW
µmol/l
1000,0
100,0
10,0
1,0
0,1
0,0
0
11
53
124
252
527
1.116
1.459
Ethen
TCE
1,1-DCE
cis-DCE
VC

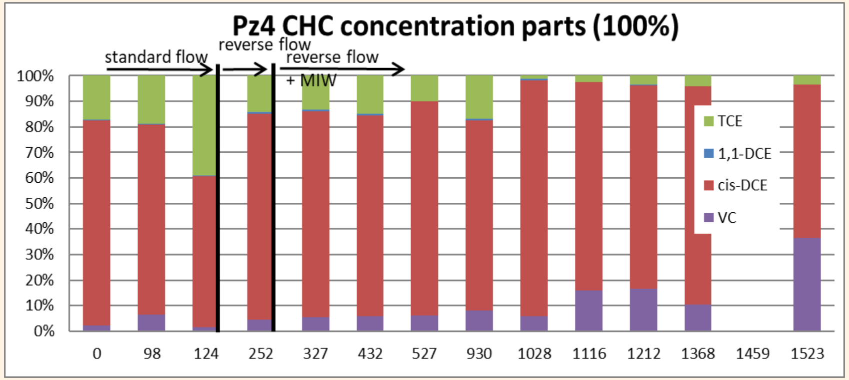

MLSW 2 CHC concentration (molar); intermediate GW zone
standard flow
reverse flow
reverse flow
+ MIW
µmol/l
1000,00
100,00
10,00
1,00
0,10
0,01
0,00
0
11
53
124
252
527
1.116
1.459
Ethen
TCE
1,1-DCE
cis-DCE
VC


MLSW 2 CHC concentration (molar); deep GW zone
standard flow
reverse flow
reverse flow
+ MIW
µmol/l
100,000
10,000
1,000
0,100
0,010
0,001
0
11
53
124
252
527
1.116
1.459
Ethen
TCE
1,1-DCE
cis-DCE
VC

Results



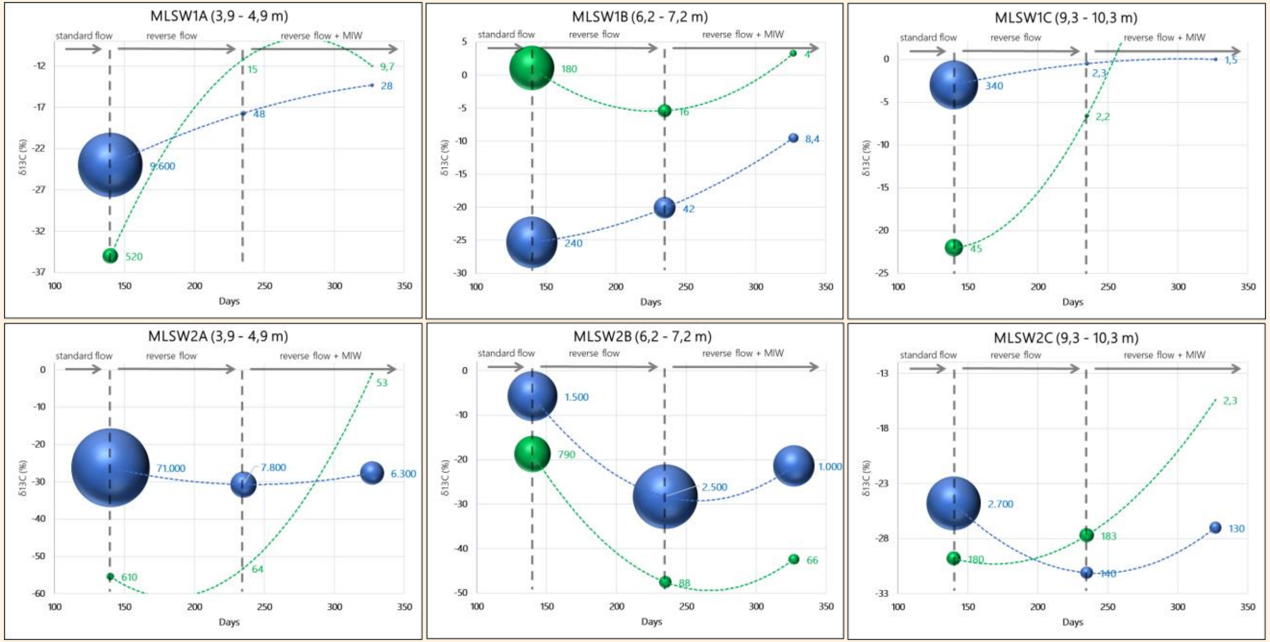
Pz4 CHC concentration (molar)
standard flow
reverse flow
reverse flow
+ MIW
Ethen
TCE
1,1-DCE
cis-DCE
µmol/l
1000,0
100,0
10,0
1,0
0,1
0,0
0
98
124
252
327
432
527
930
1.028
1.116
1.212
1.368
1.459
1.523

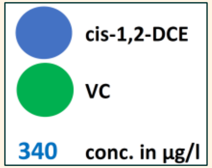


Pz4 CHC concentration parts (100%)
standard flow
reverse flow
reverse flow
+ MIW
TCE
1,1-DCE
cis-DCE
VC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
98
124
252
327
432
527
930
1028
1116
1212
1368
1459
1523

Results

In sampling point MLSW 1 close to the GCW it was observed after 90 days an obvious increase of heavy ^{13}C-Isotopes for cDCE and VC, particularly after the start of dosing via MIW.
MLSW 2 shows a retarded reaction.





Hence the reduction of contaminants can be linked back to biological degradation processes.

Conclusions

The combination of IEG-GCW® and MIW for nutrient distribution can be employed to achieve effective and efficient contaminant (CHC) degradation.

The process enables a vertically differentiated infiltration of nutrients or reagents and their uniform distribution. This has an enormous practical relevance since contaminants are irregularly distributed mainly in low permeable areas.

The possibility to control infiltration via variable quantities in a laterally and vertically differentiated mode enables an adaptive remediation process management (monitoring via MLSW).

Digital sediment construction enables a more precise description of flow conditions and contaminant transport phenomena than traditional modeling tools.

IEG
WE MOVE WATER

"A new scientific truth does not generally triumph by persuading its opponents and getting them to admit their errors, but rather by its opponents gradually dying out and giving way to a new generation that is raised on it."

(Max Planck, Scientific Autobiography 1948)

Thanks for Your attention – Help us move water!