Sponsored by

Bundesministerium für Bildung und Forschung

INOWAS MAR Junior Research Group

TECHNISCHE UNIVERSITÄT DRESDEN

16th Biennial Symposium on Managed Aquifer Recharge

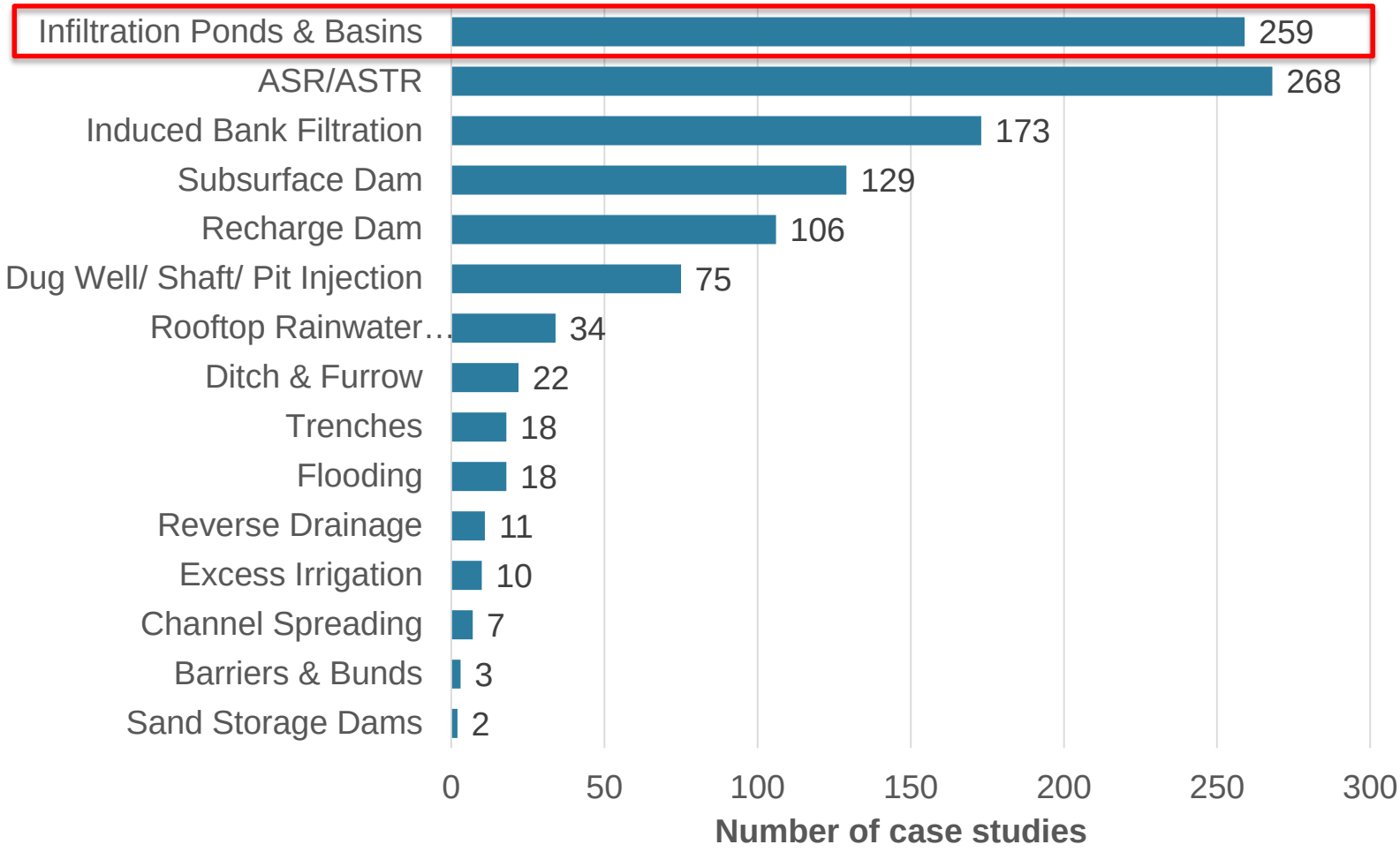
Managed aquifer recharge through surface spreading methods: Optimization of infiltration process by means of physical models

Felix Barquero
Technische Universität Dresden / INOWAS Group
Germany

San Diego, March 2018

Introduction

MAR methods


Infiltration Ponds & Basins
259
ASR/ASTR
268
Induced Bank Filtration
173
Subsurface Dam
129
Recharge Dam
106
Dug Well/ Shaft/ Pit Injection
75
Rooftop Rainwater…
34
Ditch & Furrow
22
Trenches
18
Flooding
18
Reverse Drainage
11
Excess Irrigation
10
Channel Spreading
7
Barriers & Bunds
3
Sand Storage Dams
2
0
50
100
150
200
250
300
Number of case studies

Processes/objectives

Criteria for planning and operation of MAR-systems

Quantity
Maximize infiltration capacity

Quality
Retention and reduction of infiltrated substances (nutrients, tracesubstances such as pharmaceuticals)

clogging processes

soil matrix/ soil pore system

oxygen kinetics

transport of water, substances and nutrients

climate

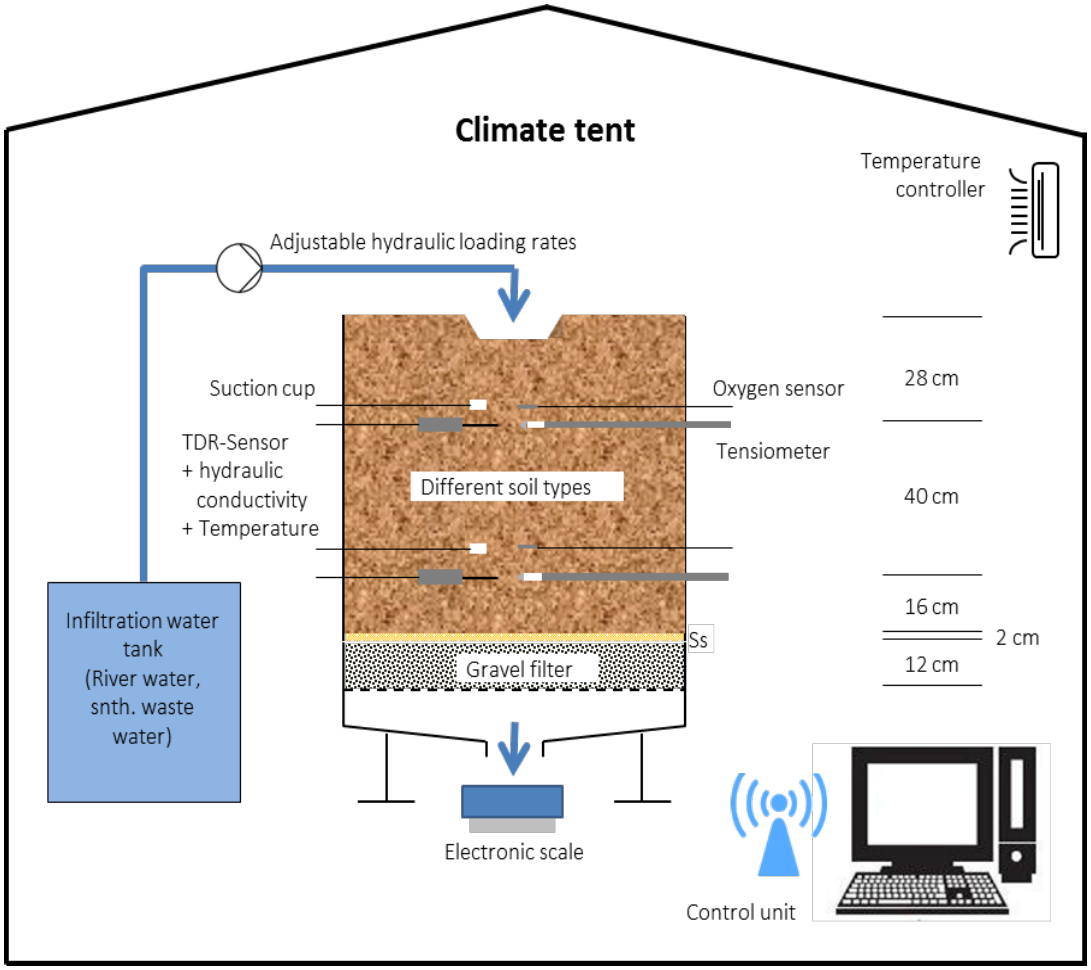
operational conditions

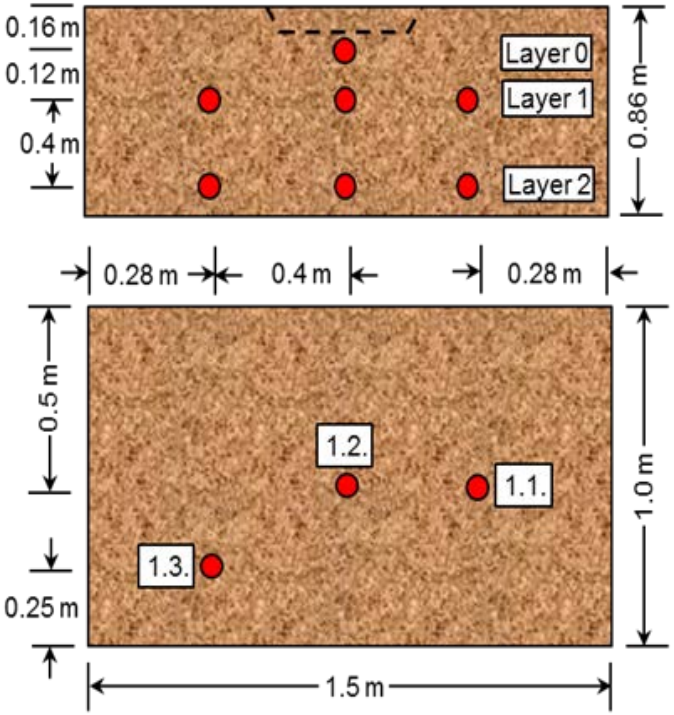
degradation processes

Identifying best conditions for maximizing infiltration capacity while minimizing transfer of undesirable substances into the aquifer

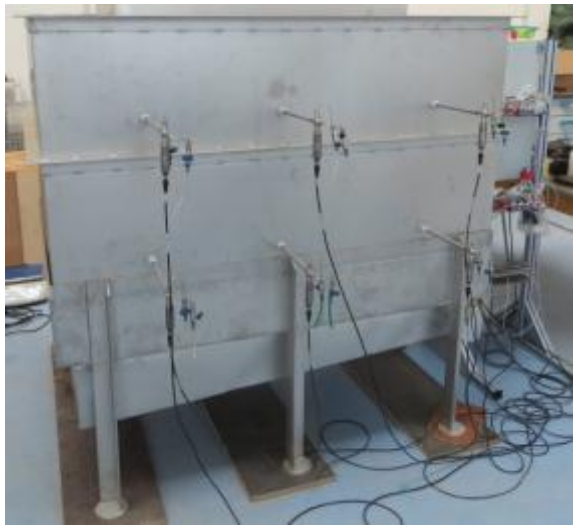
Approaches for identifying boundary conditions influencing clogging the most
-
Lab-scale infiltration scheme

Setup experimental scheme





Setup experimental scheme



Scenarios boundary conditions

Climate: - Temperature 17 ºC

- Humidity 55 – 65 %

Water quality: - DOC 25 mg/l

- TSS 5 – 25 mg/l

Soil type: - nr. 1 $k_f = 2*10^{-4}$ m/s

- nr. 2 $k_f = 7*10^{-5}$ m/s

	Runtime [d]	Soil	Hydraulic loading rate [m/a]	Hydraulic loading cycle [-]
Scenario 1	120	1	146	1:3 (6h/18h)
Scenario 2	116	1	146	1:3 **(24h/72h)**
Scenario 3	75	1	**300**	1:3 (24h/72h)
Scenario 4	43	1	300	1:3 **(6h/18h)**
Scenario 5	34	**2**	300	1:3 (24h/72h)
Scenario 6	20	2	300	**1:1 (168h/168h)**
Scenario 7	27	2	300	**Continuous infiltration**
Scenario 8	30	2	300	**3:1 (72h/24h)**

Quantification methods of clogging

Determination of changing soil moisture:

- Maximum of daily measured matric potential and minimum of daily measured water content at the beginning of next infiltration
- Changing fitting parameters of matric potential and water content profile during complete wet and dry cycles

Determination of changing median flow velocity:

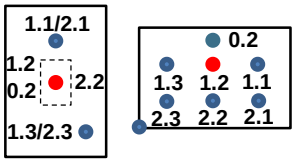
- Time from the beginning of infiltration until registration of water by tensiometers and water content sensor
- Tracer experiments with NaCl
- (Time from the beginning of infiltration until outflow of water at the bottom of the labtank)*****

Determination of changing unsaturated hydraulic conductivity:

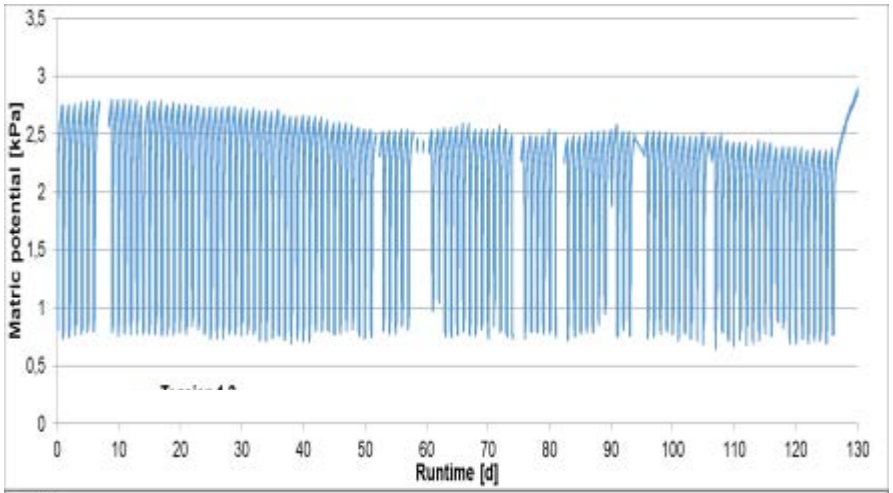
- Method according to Libardi (Libardi et al., 1980)

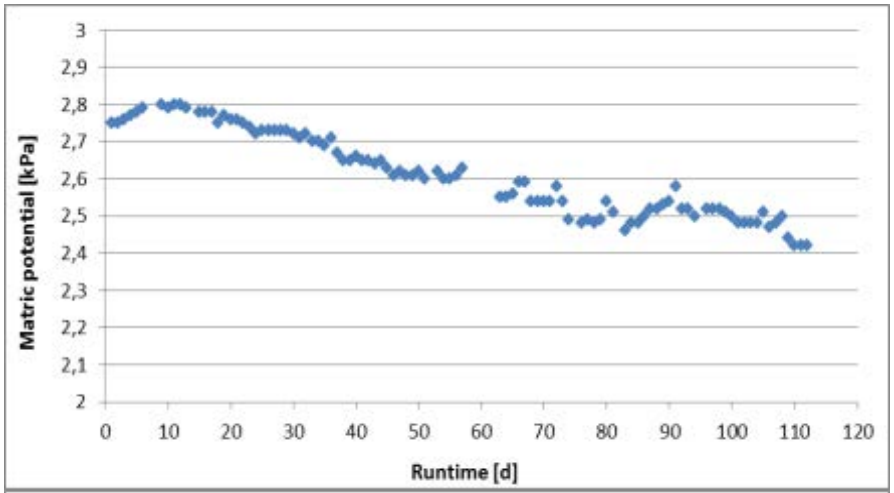
***** only for lab experiment

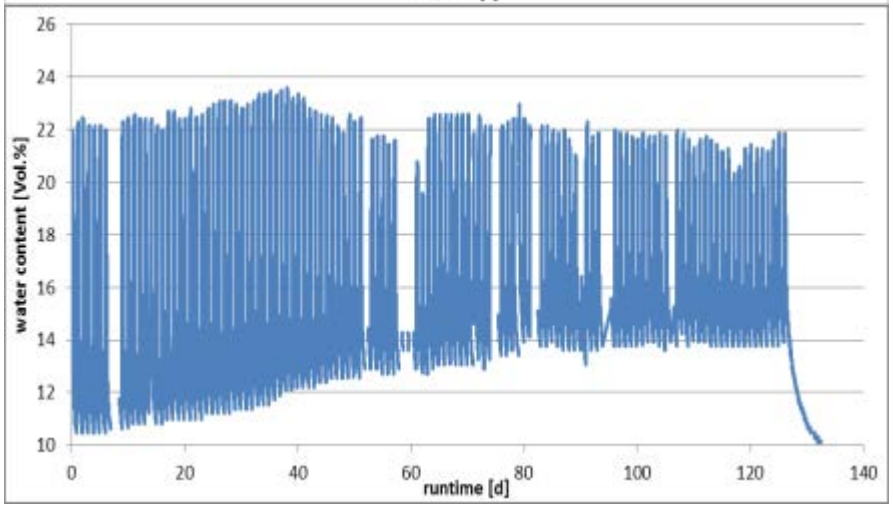
Quantification methods of clogging

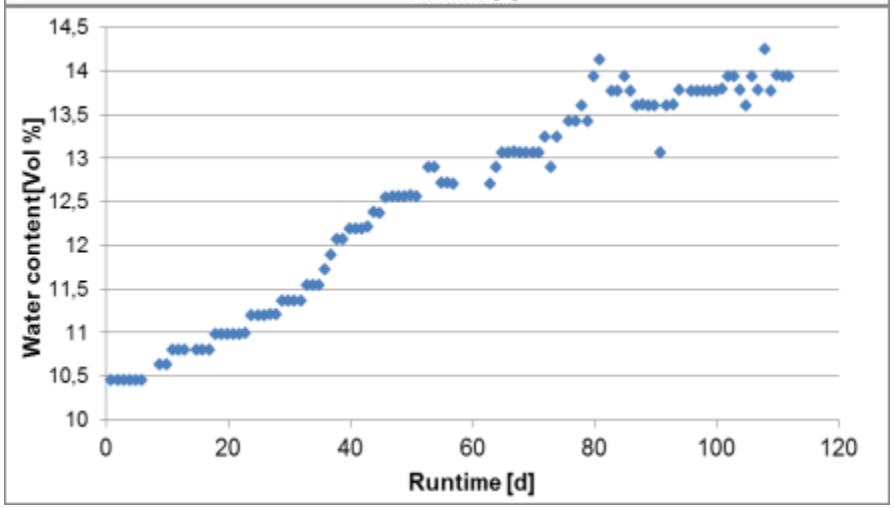


Changing soil moisture - Scenario 1 – HLC 1:3 (6h:18h)

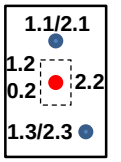


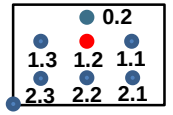




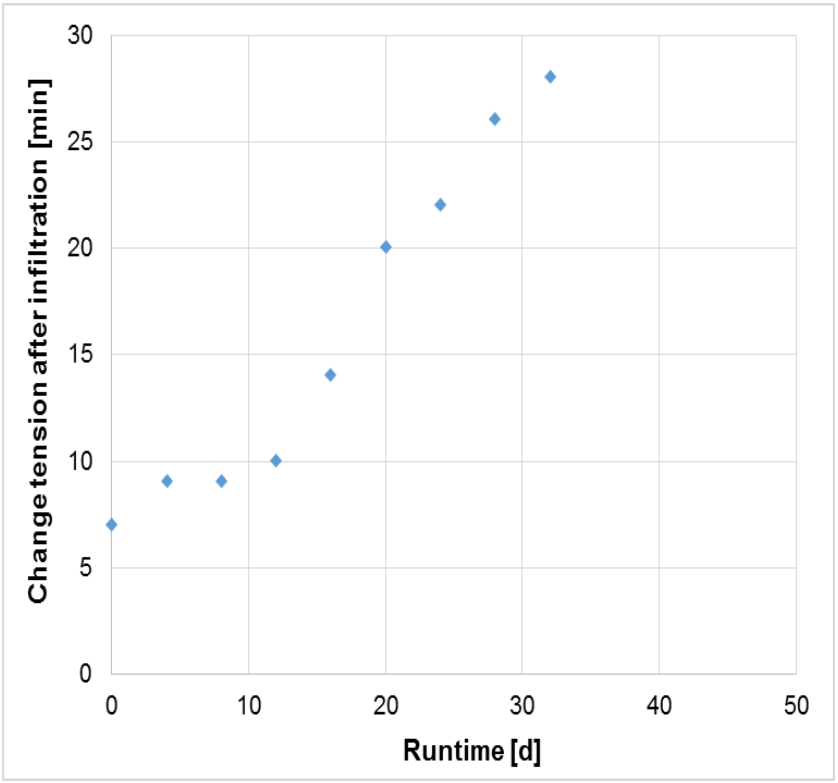


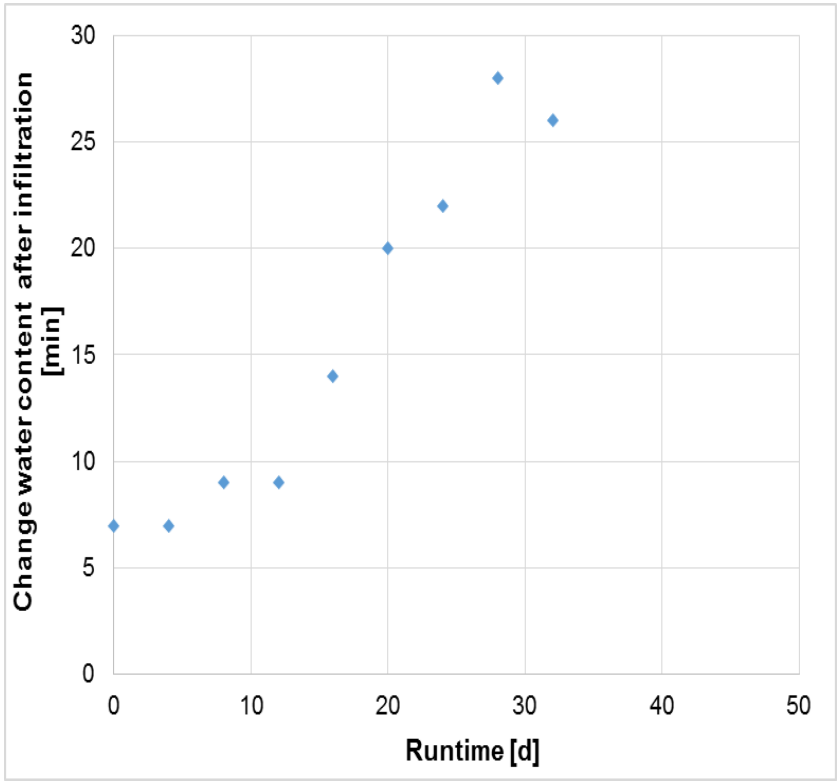
Quantification methods of clogging



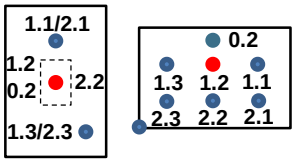


Changing median flow velocity - Scenario 1 – HLC 1:3 (24h:72h)

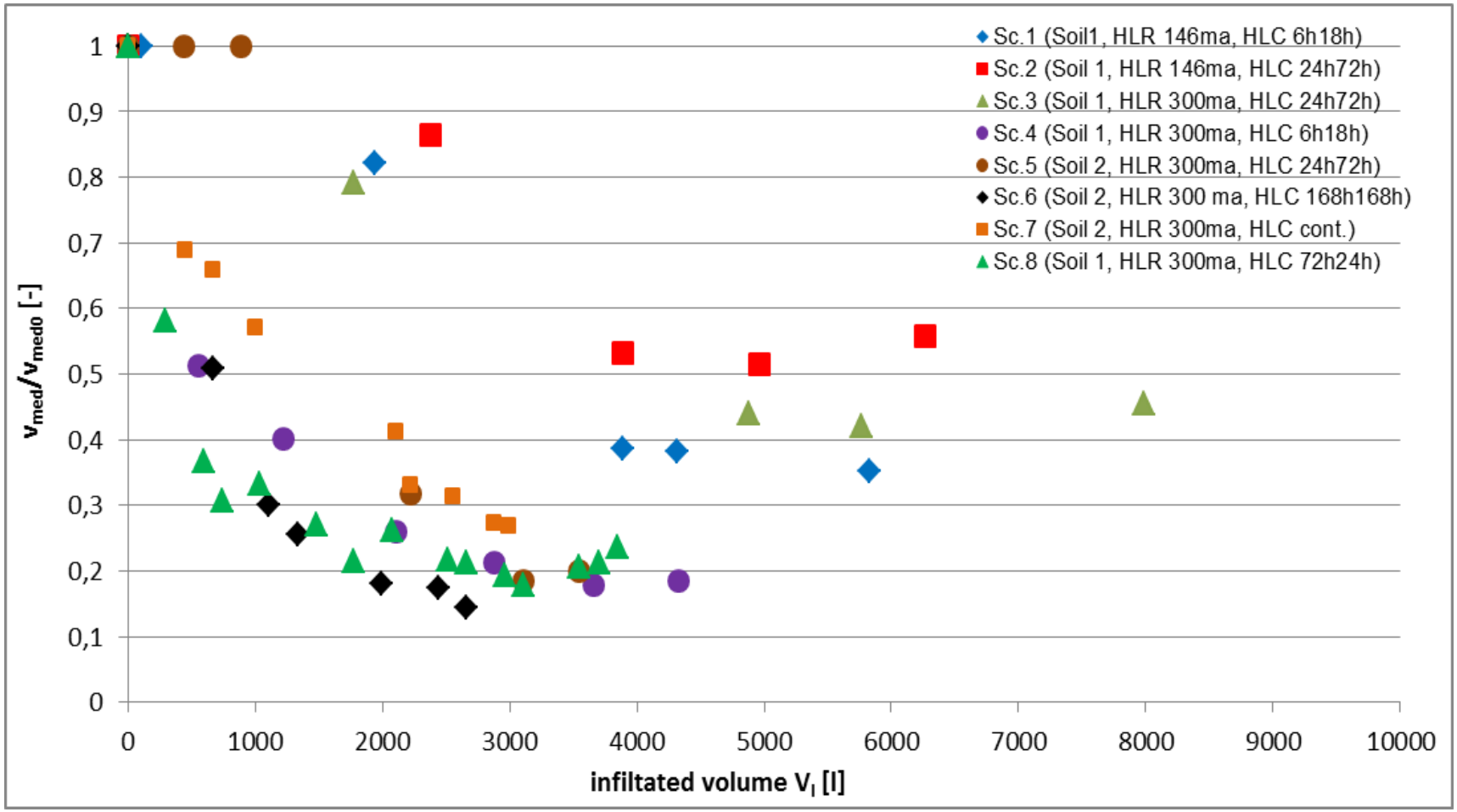




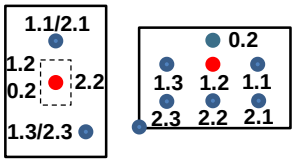
Quantification methods of clogging



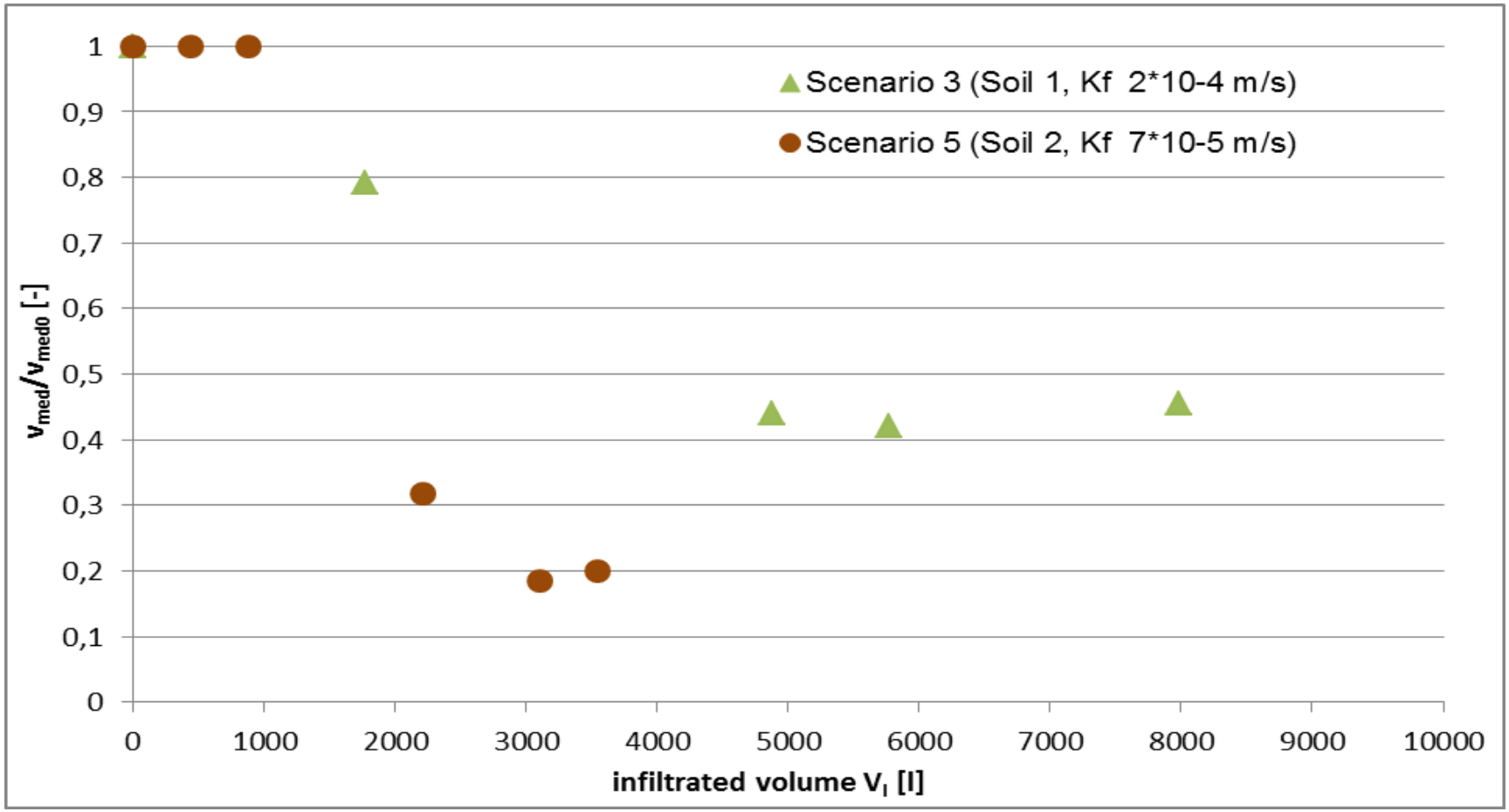
Changing median flow velocity - Scenario 1 to 8



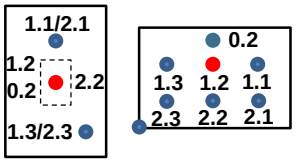
Outcomes



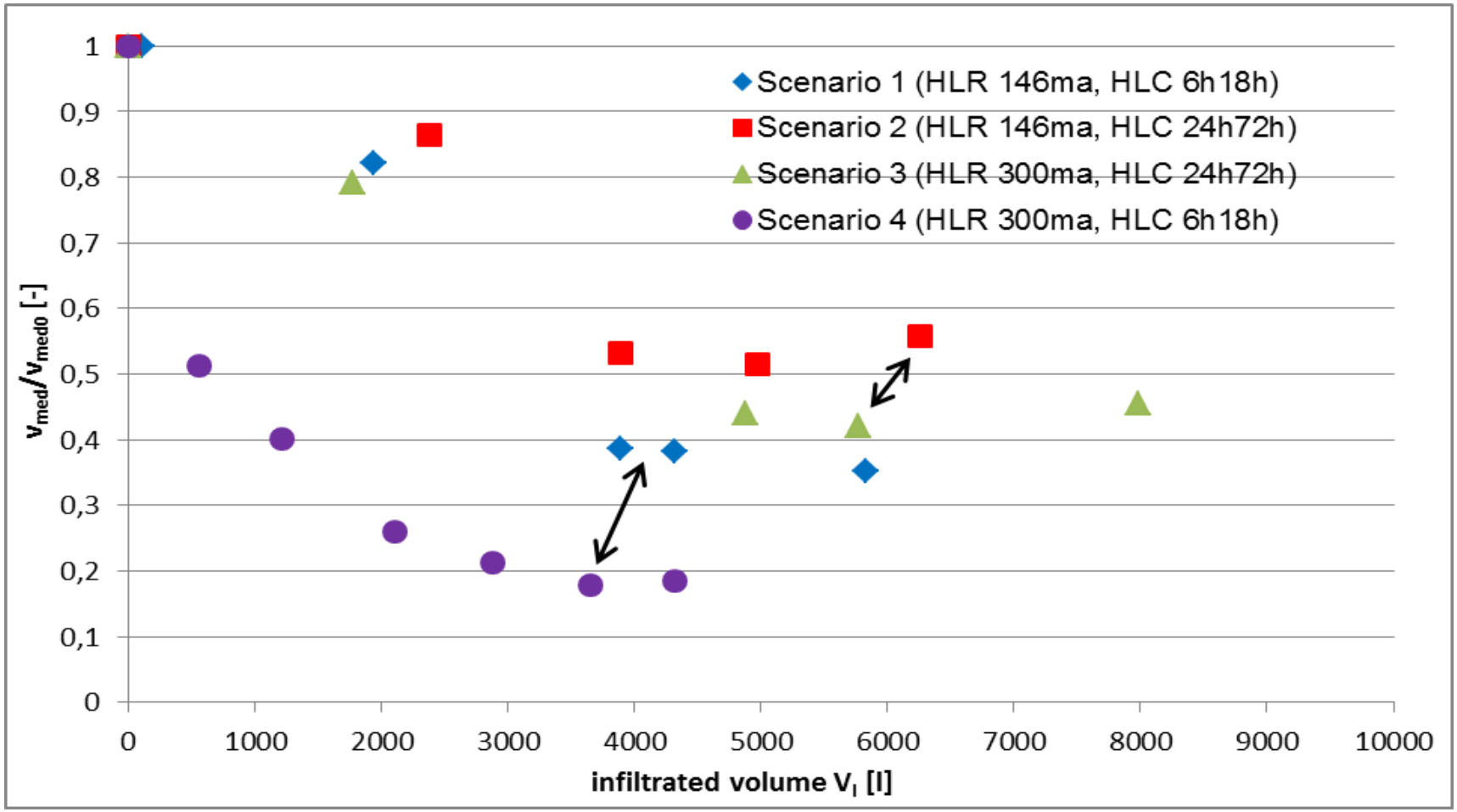
- Lower content of fine particles (higher hydraulic conductivity) causes slower and less strongly clogging



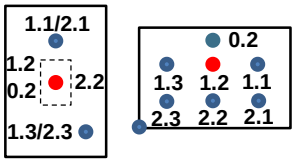
Outcomes



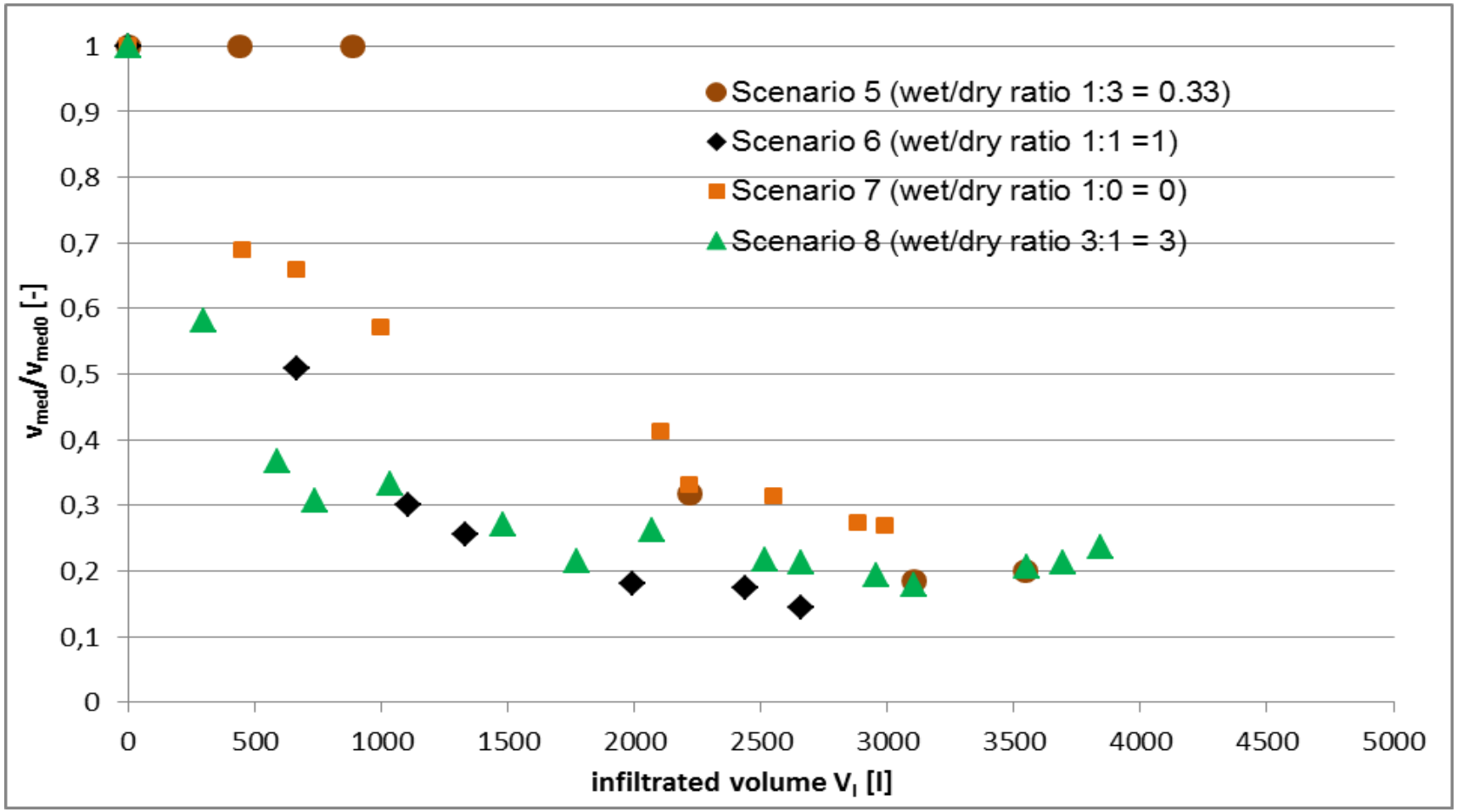
- Lower HLR causes less strongly clogging (halving HLR = halving clogging)



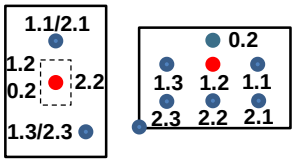
Outcomes



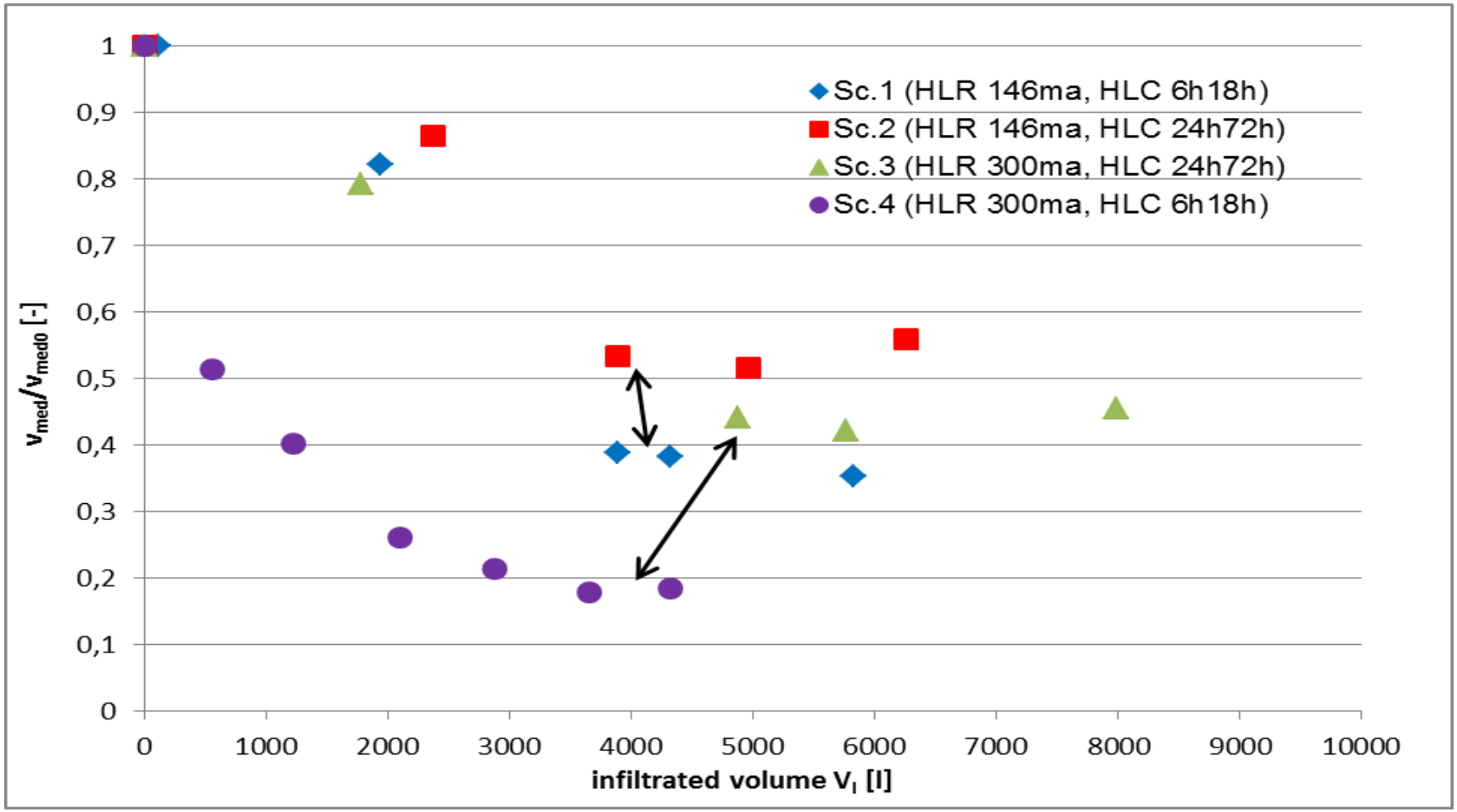
- Lower wet/dry ratio causes not less strongly clogging



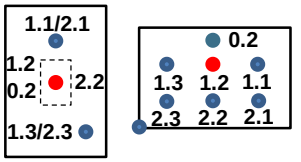
Outcomes



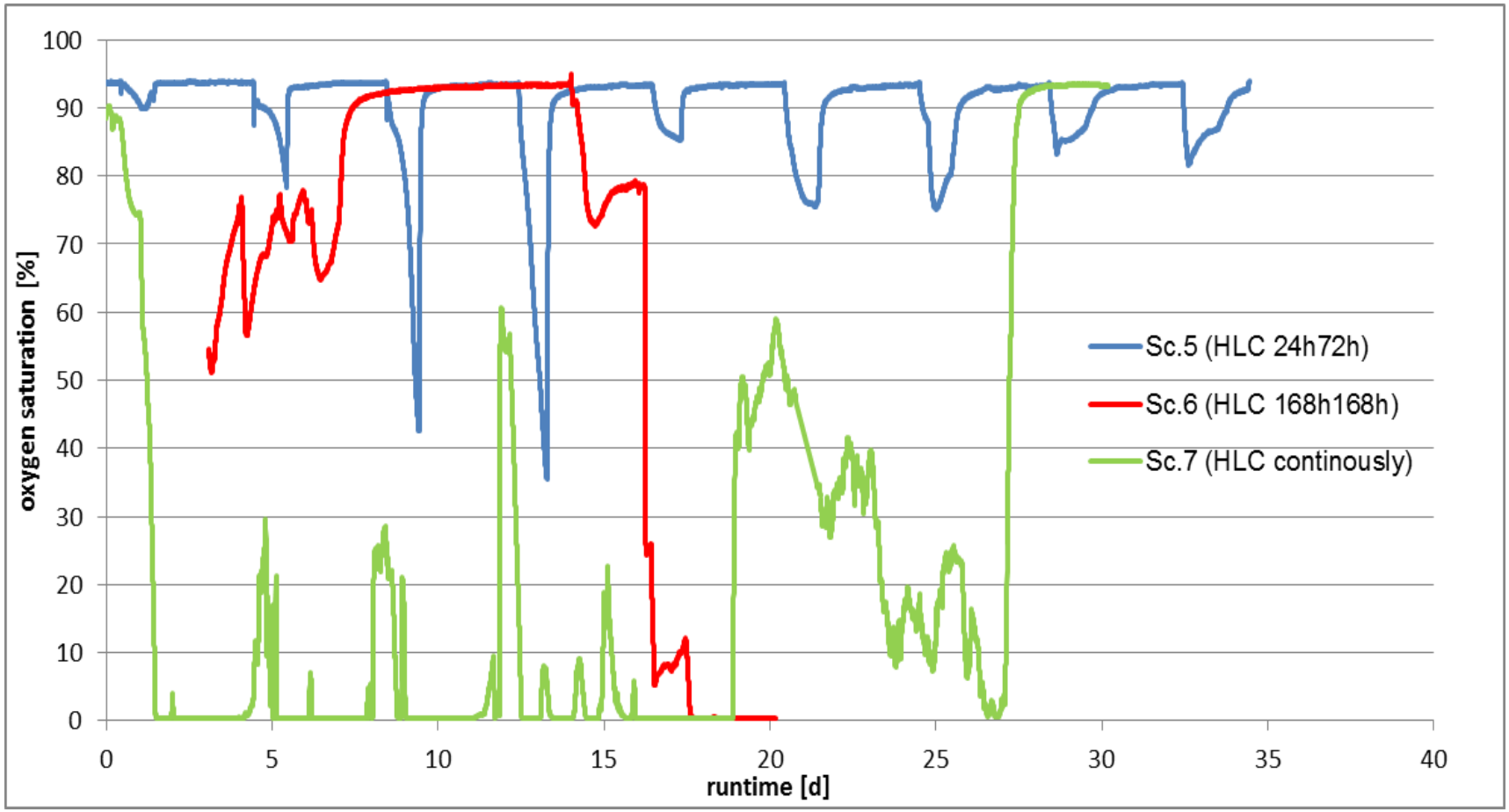
- Longer dry phases causes less strongly clogging



Outcomes



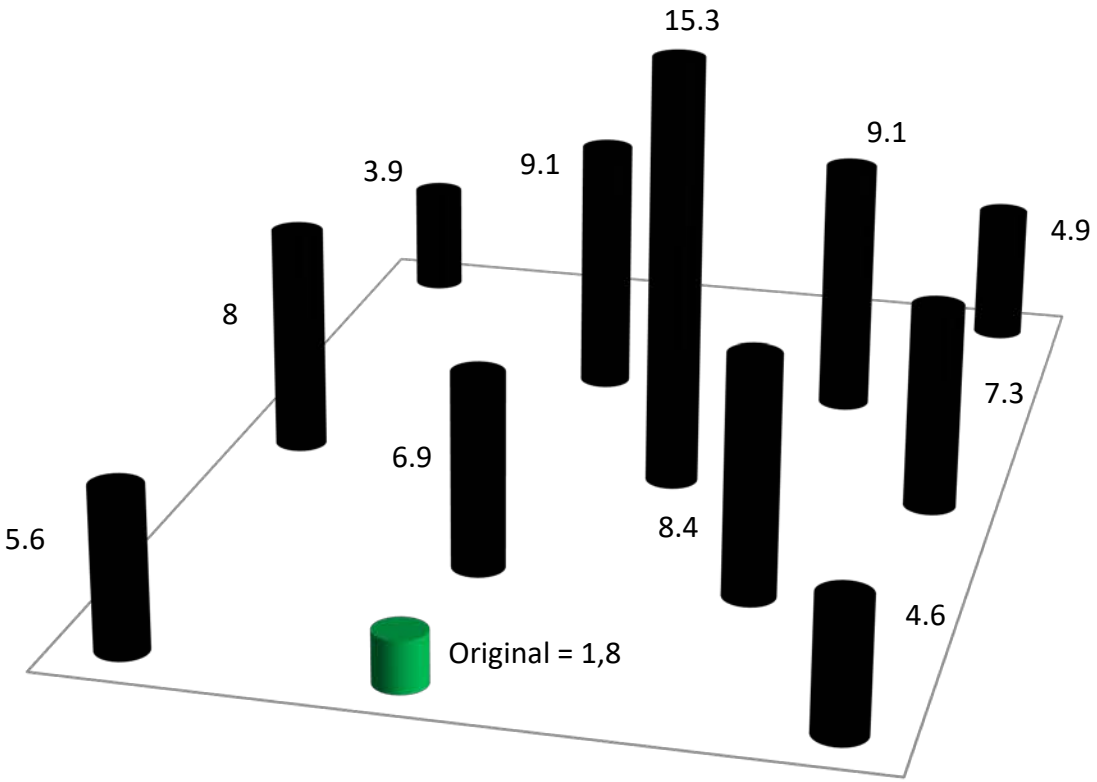
- Oxygen availability is influenced significantly by the HLC – the longer the dry phase the better the oxygen availibility



Outcomes

- Reduction of infiltration capacity by physical clogging happens in the upper layer of the soil (0 – 1 cm deep)

TOC [mg/g] - Surface infiltration basin

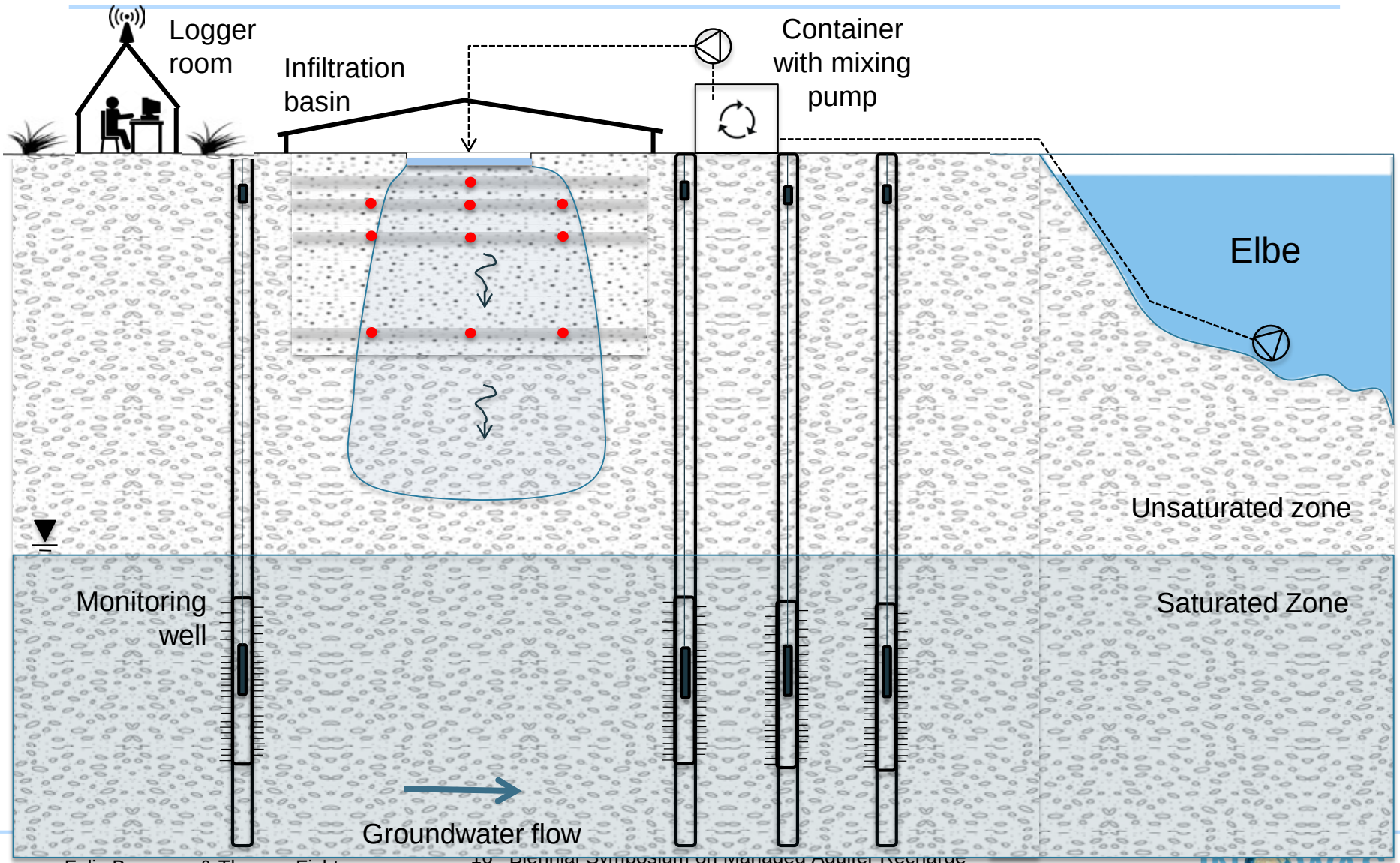


Conclusions

- Most suitable method for determination of infiltration capacity reduction in lab experiments is the measurement of changing median flow velocity by tracer experiments
- Clogging minimization can be reached by following boundary conditions:
    - Low content of fine particles = high hydraulic conductivity
    - Low Hydraulic loading rate
    - Long dry phases
- Reduction of infiltration capacity by physical clogging happens in the upper layer of the soil (0 – 1 cm deep)
- High oxygen availability corresponding with better growth conditions for bacteria, responsible for degradation of infiltrated organic matter as well as biological clogging, can be reached by long dry phases

Approaches for identifying boundary conditions influencing clogging the most
–
Field-scale rapid infiltration scheme

Setup experimental scheme



Setup experimental scheme



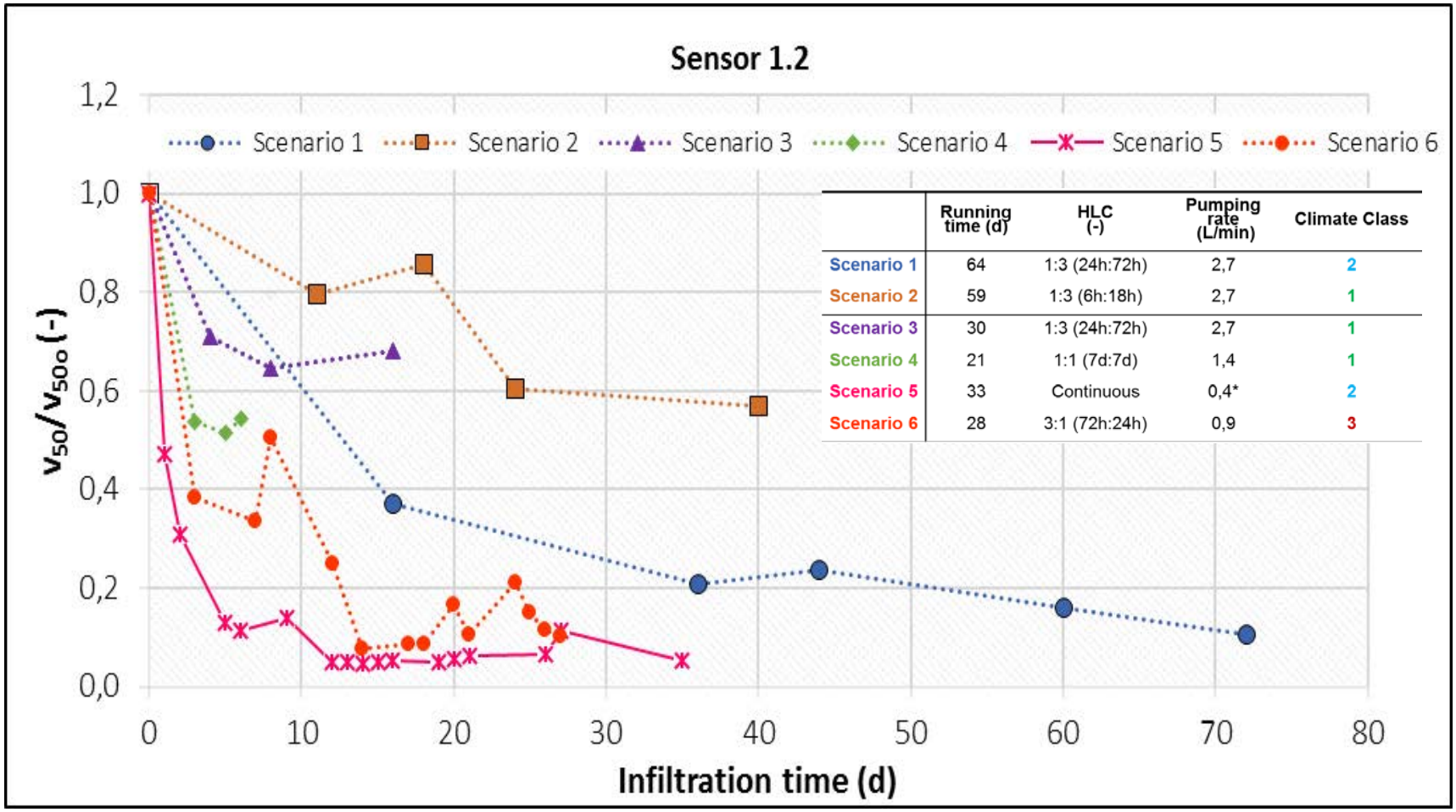



Scenarios boundary conditions

	Running time (d)	HLC (-)	Pumping rate (L/min)	Temperature (ºC) / Humidity (%)	Climate Class
Scenario 1	64	1:3 (24h:72h)	2,7	5 - 30 / 35 - 95	**2**
Scenario 2	59	1:3 (6h:18h)	2,7	-5 - 10 / 86 - 93	**1**
Scenario 3	30	1:3 (24h:72h)	2,7	-3 – 23 / 29 - 86	**1**
Scenario 4	21	1:1 (7d:7d)	1,4	4 – 24 / 40 - 95	**1**
Scenario 5	33	Continuous	0,4*	0 – 20 / 33 – 97	**2**
Scenario 6	28	3:1 (72h:24h)	0,9	6 – 33 / 24 – 97	**3**

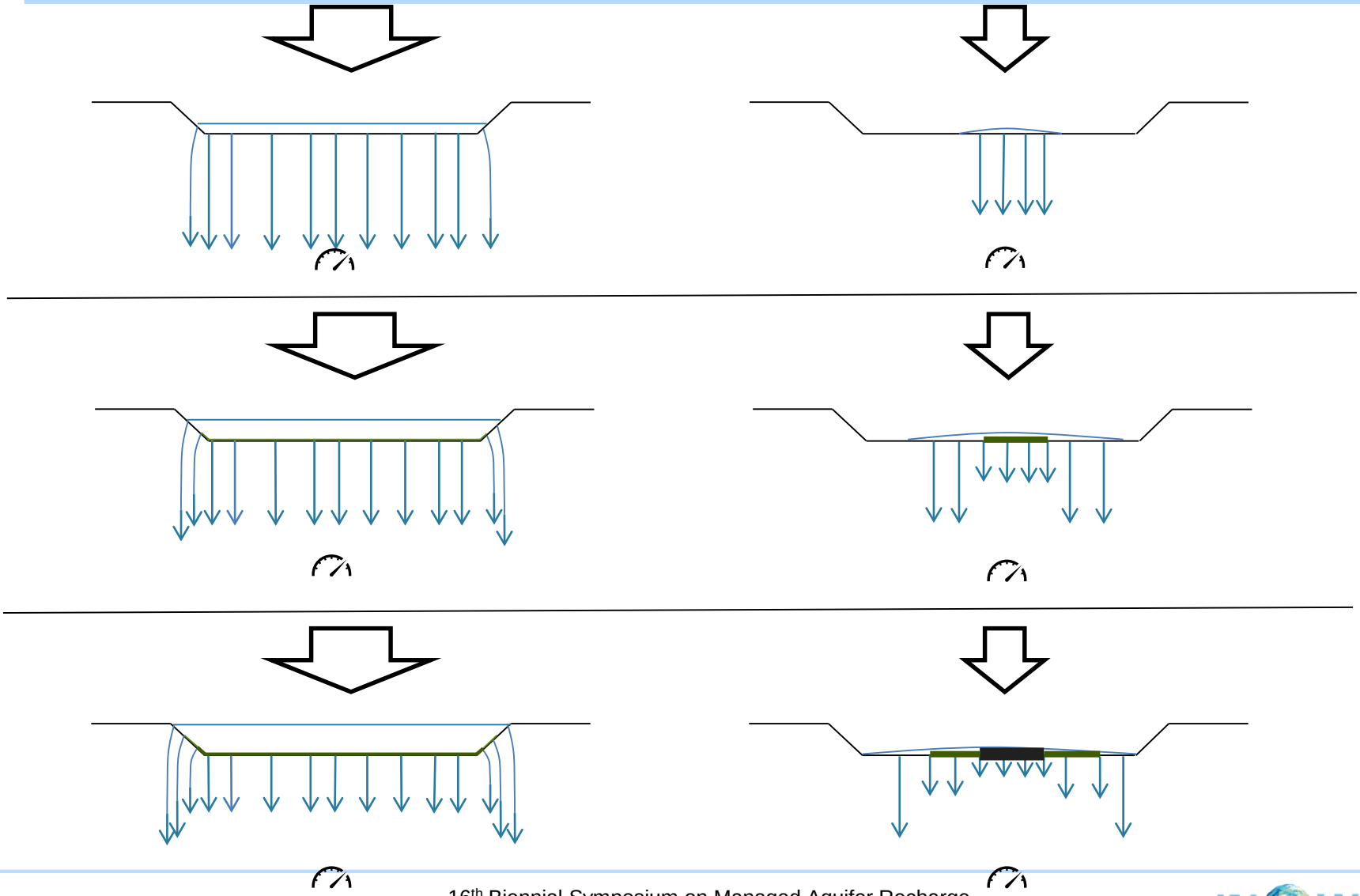
Quantification methods of clogging

Changing median flow velocity



	Running time (d)	HLC (-)	Pumping rate (L/min)	Climate Class
Scenario 1	64	1:3 (24h:72h)	2,7	2
Scenario 2	59	1:3 (6h:18h)	2,7	1
Scenario 3	30	1:3 (24h:72h)	2,7	1
Scenario 4	21	1:1 (7d:7d)	1,4	1
Scenario 5	33	Continuous	0,4*	2
Scenario 6	28	3:1 (72h:24h)	0,9	3

High HLR scenario & Low HLR scenario



Quantification methods of clogging

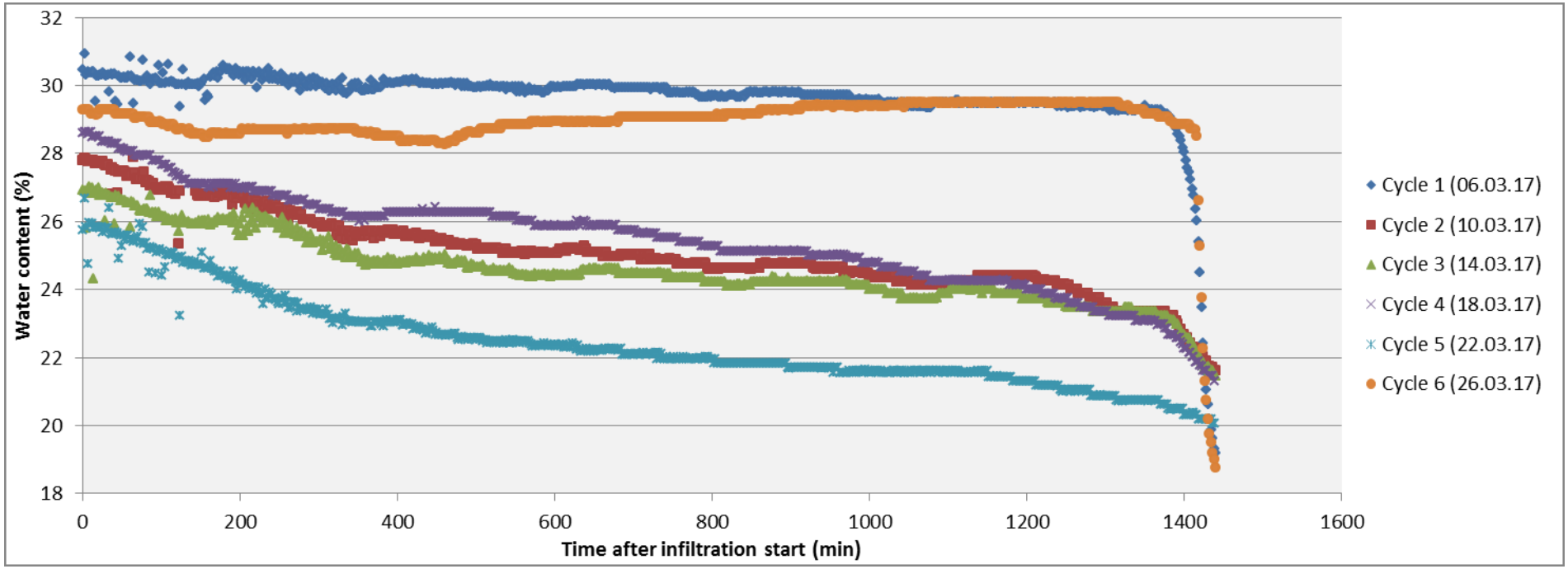
Matric potential & water content data

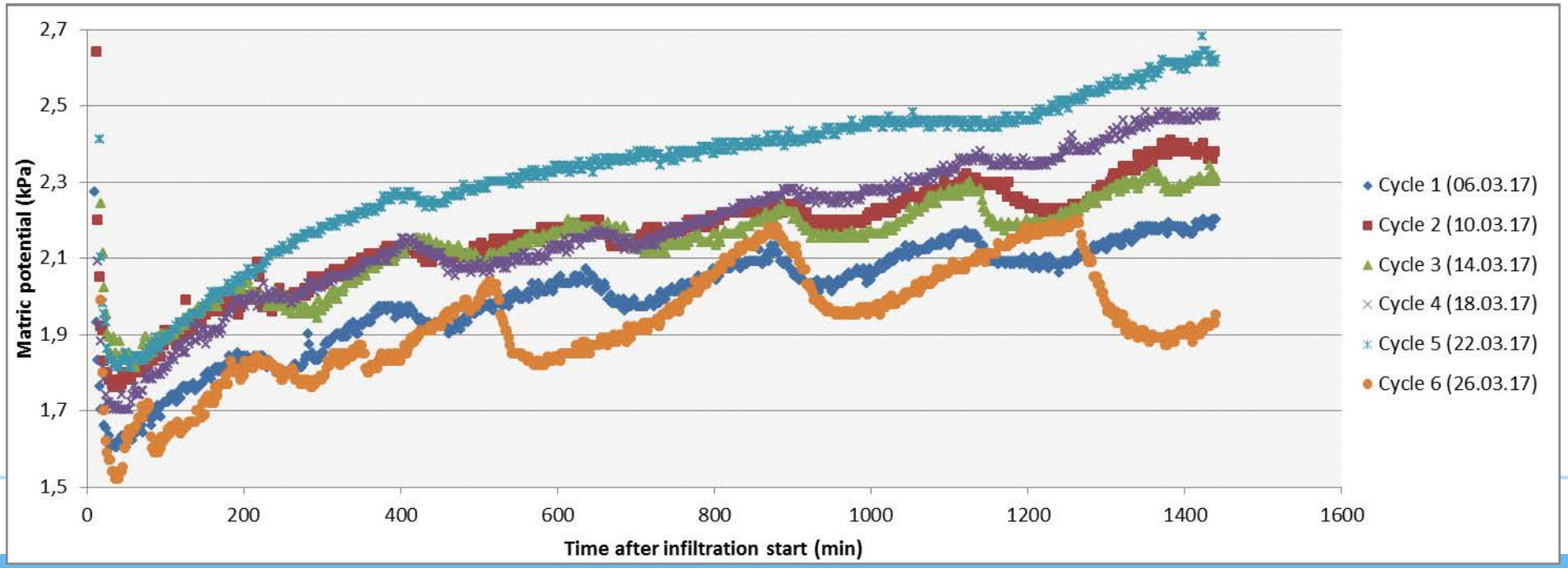
Scenario 3

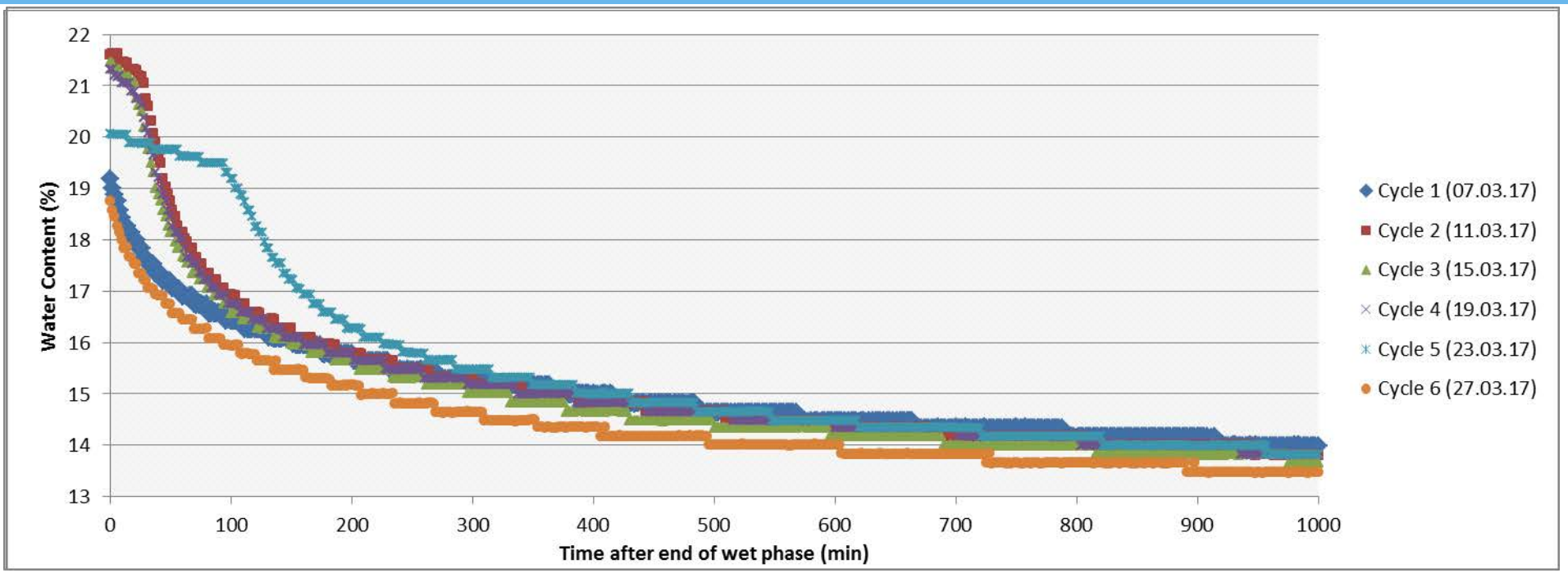
300 m/a 1d:3d

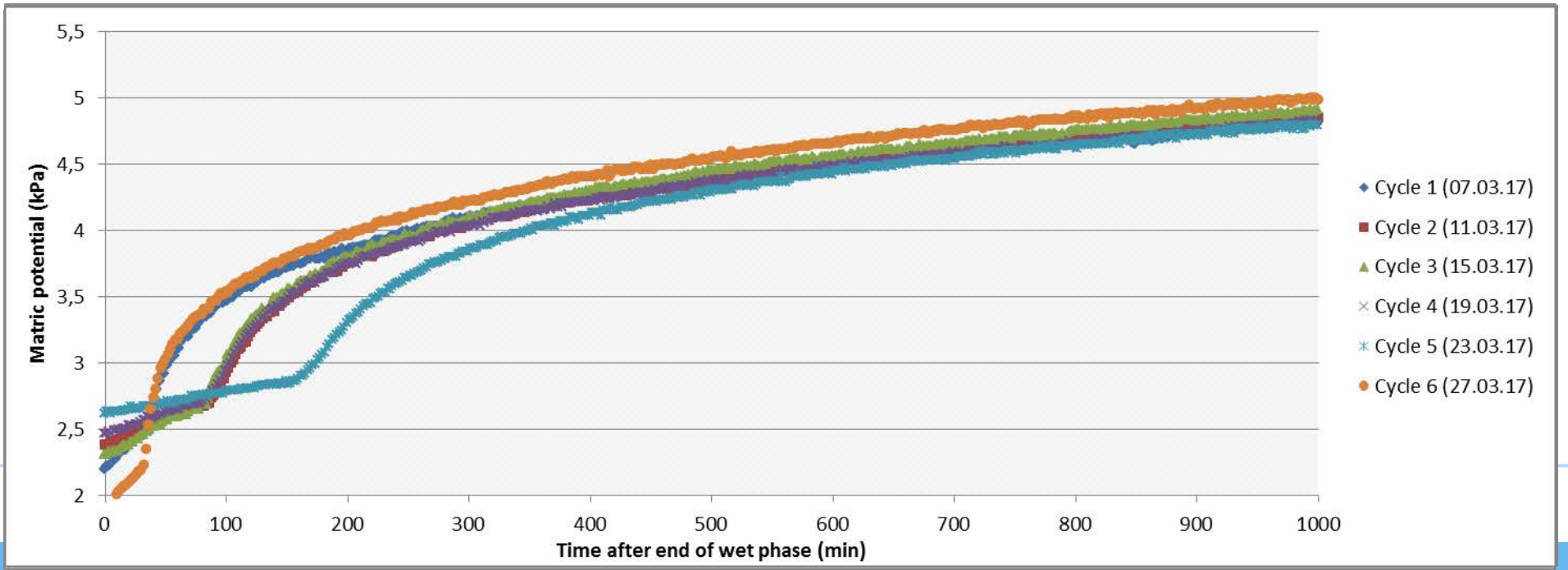
- Graphical analysis of each wet and dry cycle during one scenario gives a better look at the change of the water content and tension.

- This enables a continuous monitoring of the change of the infiltration capacity of the basin, in contrast to tracer experiments that just shows during specific moments.


Water content (%)
32
30
28
26
24
22
20
18
0
200
400
600
800
1000
1200
1400
1600
Time after infiltration start (min)
Cycle 1 (06.03.17)
Cycle 2 (10.03.17)
Cycle 3 (14.03.17)
Cycle 4 (18.03.17)
Cycle 5 (22.03.17)
Cycle 6 (26.03.17)


Matric potential (kPa)
2,7
2,5
2,3
2,1
1,9
1,7
1,5
0
200
400
600
800
1000
1200
1400
1600
Time after infiltration start (min)
Cycle 1 (06.03.17)
Cycle 2 (10.03.17)
Cycle 3 (14.03.17)
Cycle 4 (18.03.17)
Cycle 5 (22.03.17)
Cycle 6 (26.03.17)


Water Content (%)
22
21
20
19
18
17
16
15
14
13
0
100
200
300
400
500
600
700
800
900
1000
Time after end of wet phase (min)
Cycle 1 (07.03.17)
Cycle 2 (11.03.17)
Cycle 3 (15.03.17)
Cycle 4 (19.03.17)
Cycle 5 (23.03.17)
Cycle 6 (27.03.17)


Matric potential (kPa)
5,5
5
4,5
4
3,5
3
2,5
2
0
100
200
300
400
500
600
700
800
900
1000
Time after end of wet phase (min)
Cycle 1 (07.03.17)
Cycle 2 (11.03.17)
Cycle 3 (15.03.17)
Cycle 4 (19.03.17)
Cycle 5 (23.03.17)
Cycle 6 (27.03.17)

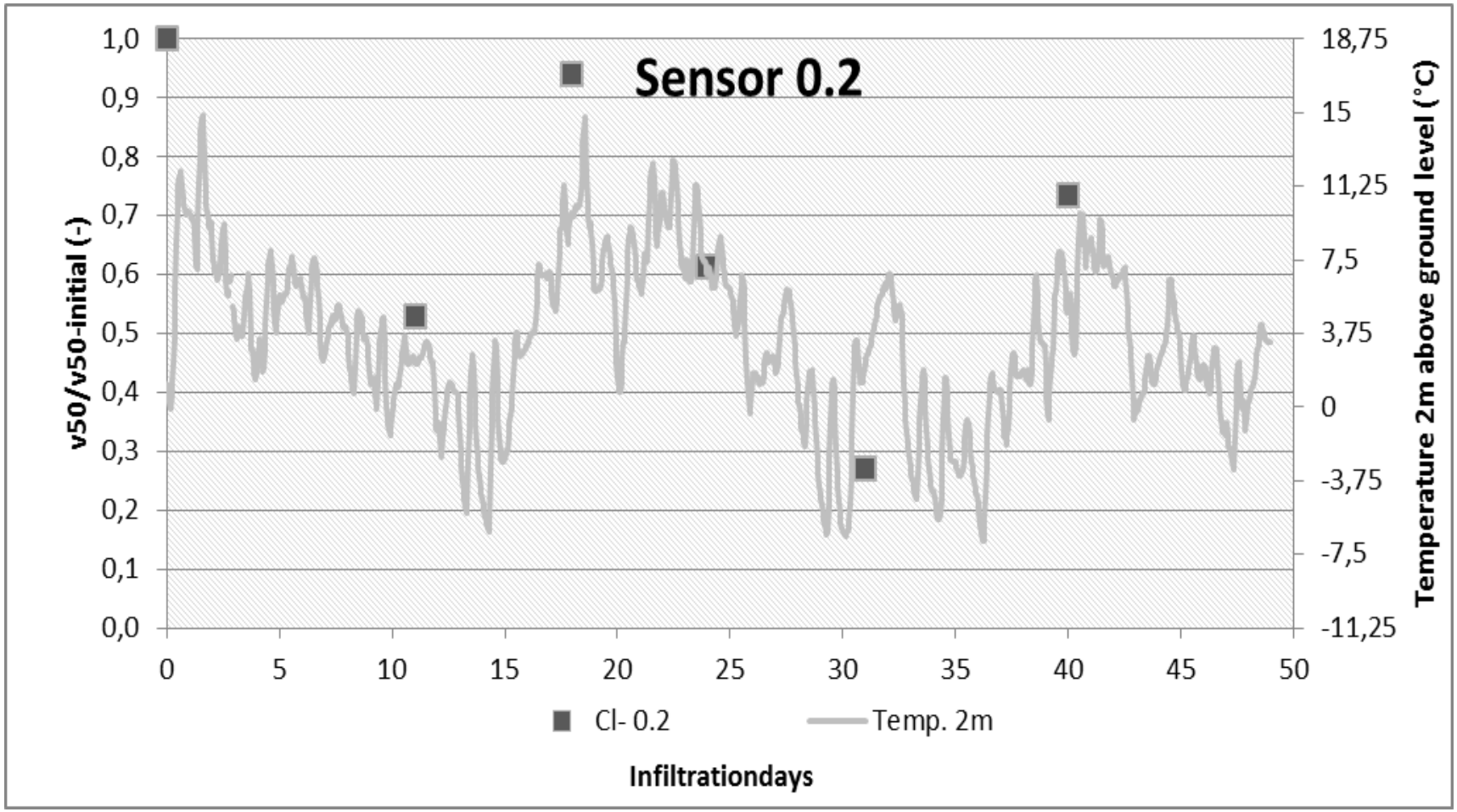
Outcomes

- Change of K in the basin is very heterogenous



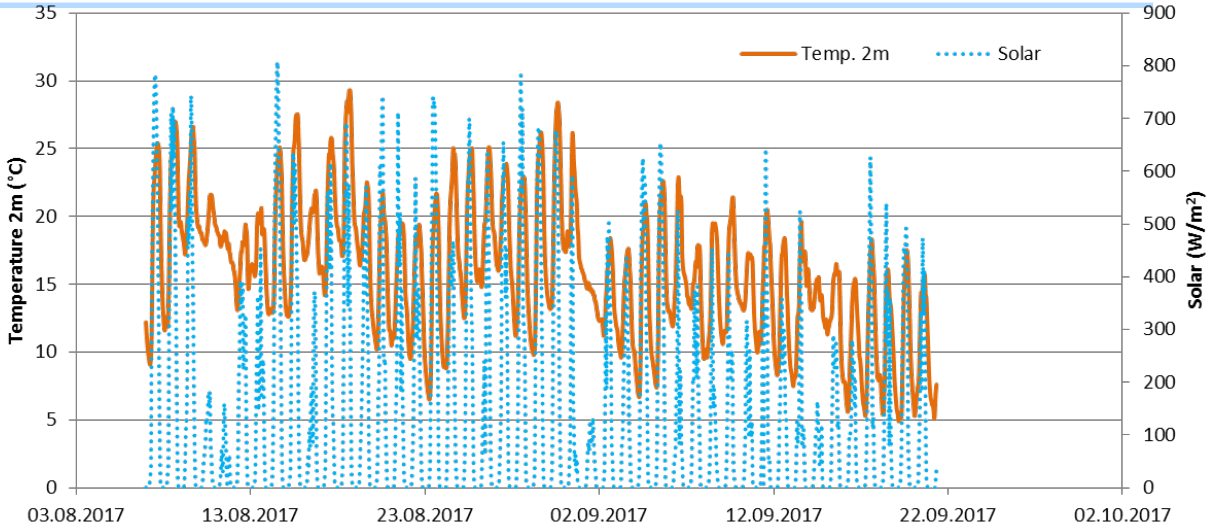
Outcomes

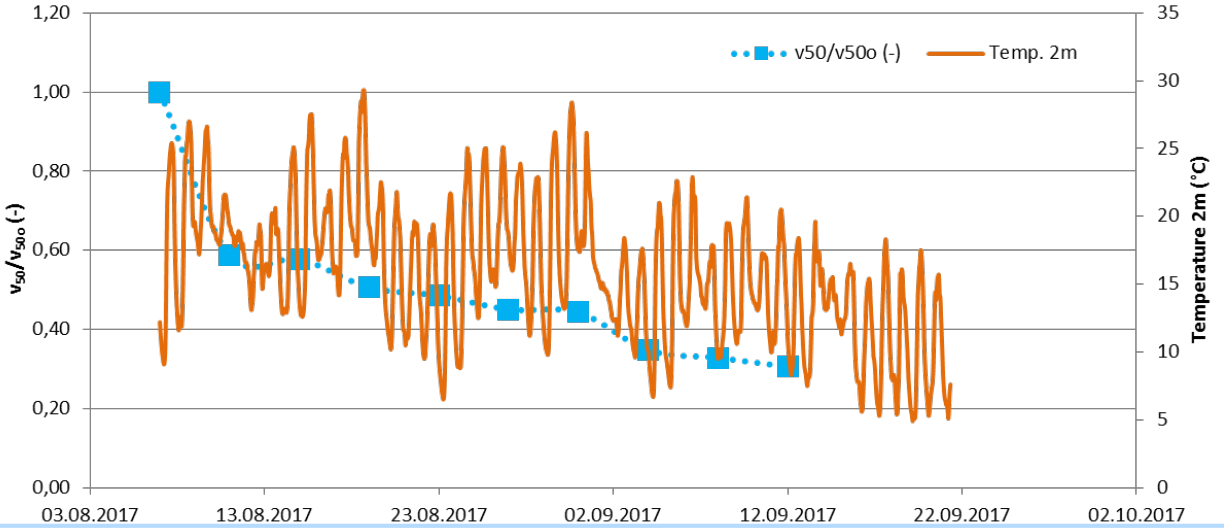
- Flow of water is strongly influenced by the temperature of medium and fluid.



Outcomes

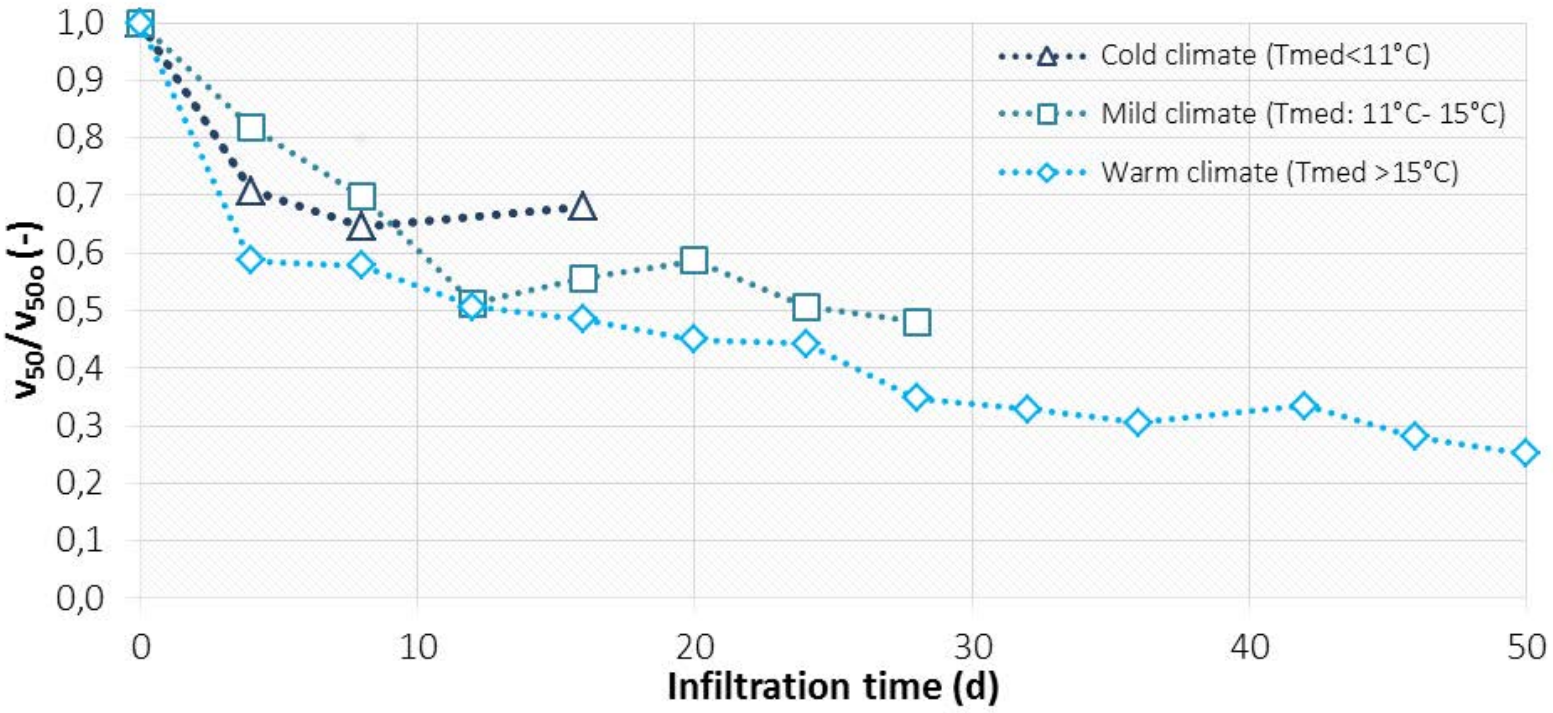
- Flow of water is strongly influenced by the temperature of medium and fluid.





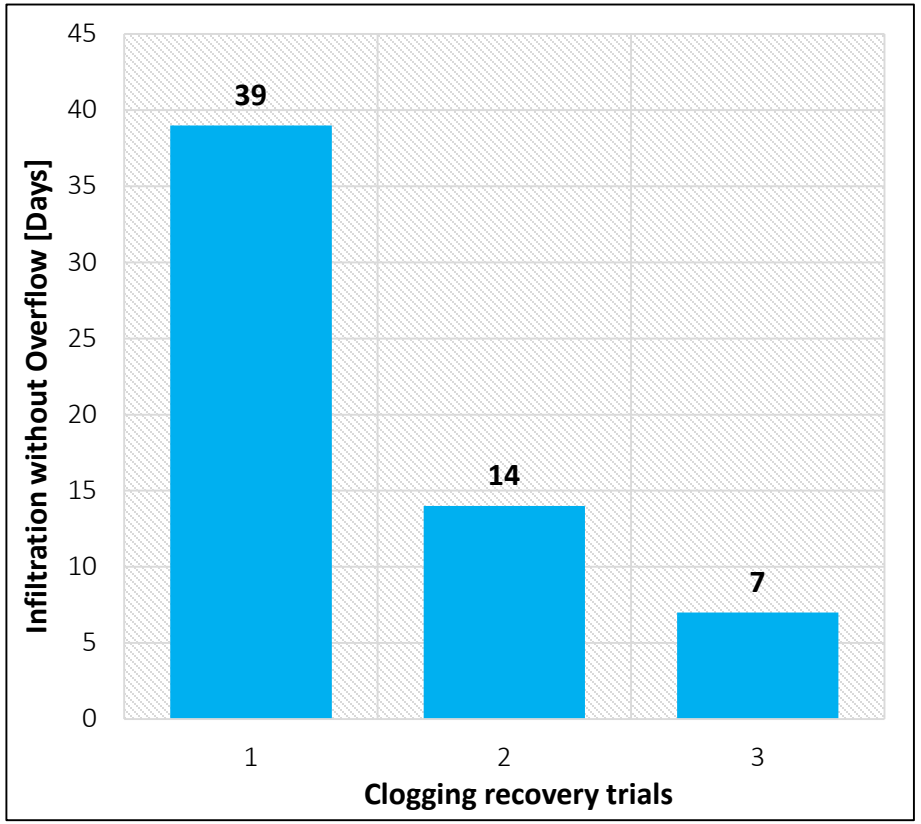
Outcomes

- Infiltration capacity is reduced the most during the warmer conditions. Nevertheless the scenario lasts longer before the overflow of the basin occurs.
- Overflow happens faster in a colder environment, where the influence of the biological clogging can be neglected..



Outcomes

- Restoration of infiltration capacity can be reached by scratching procedure. Nevertheless, initial conditions are not obtained.



Conclusions

- Water content and matric potential overlapping of the different cycles of the infiltration scenario might give a good sign of hydraulic conductivity reduction. This method features the continuous monitoring in time of this reduction.
- The infiltration capacity reduction happens heterogenously through the basin floor area.
- Winter conditions affect the flow dynamic in the basin, causing interferfences in tracer breakthrough curves.
- Clogging layer developes in the upper few cm of the basin floor.
- Scrapping procedure improves the infiltration capacity of the basin, but clogging developes faster.

Contact

TECHNISCHE UNIVERSITÄT DRESDEN

INOWAS
MAR Junior Research Group

ADDRESS

Technische Universität Dresden
Institute of Waste Management
and Circular Economy
Pratzschwitzer Str. 15
01796 Pirna
GERMANY

Felix Barquero
Thomas Fichtner

Phone: +49 351 463 441 68
Fax: +49 351 463 441 22
Email: felix.barquero@mailbox.tu-dresden.de
thomas.fichtner@tu-dresden.de

http://tu-dresden.de/uw/inowas