국토교통부
Ministry of Land, Infrastructure and Transport

KAIA 국토교통과학기술진흥원

Field & Lab. Experiments on Artificial Recharge in a Saline Confined Aquifer

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Subsurface Reservoir Research Center

SSR 지하저수지 연구단 Subsurface Reservoir Research Center

Contents

I. Objective

Project objective

- Development of a simulation-optimization (SO) model for planning injection and pumping wells in a saline confined aquifer.
- Validation of the SO model against field and laboratory experiments.

I. Objective

Simulation–Optimization(S/O)

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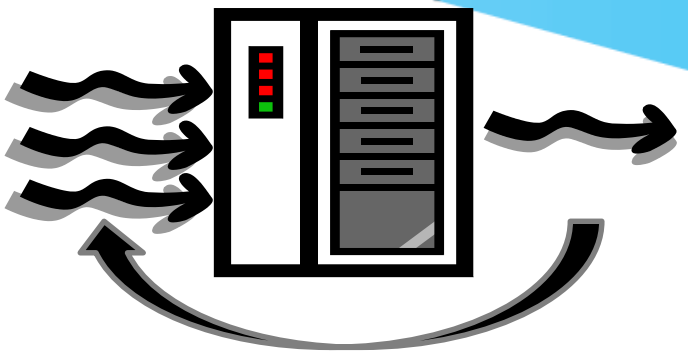
Input parameters

Measure of performance



Optimization function

Simulation-Optimization Model : SIOP

- **Simulation model (Sharp Interface Model)**

  Sharp Interface Governing Equation

$$\nabla \cdot (b_f \mathrm{K}_f \cdot \nabla h_f) = b_f S_{s_f} \frac{\partial h_f}{\partial t} - \theta \frac{\partial \xi}{\partial t} - Q_f$$

$$\nabla \cdot (b_s \mathrm{K}_s \cdot \nabla h_s) = b_s S_{s_s} \frac{\partial h_s}{\partial t} + \theta \frac{\partial \xi}{\partial t} - Q_s$$

- **Optimization method (GA, DE, SCE-UA)**

SIOP

- Sharp Interface Model
- GA (Genetic Algorithm)
  DE (Differential Evolution)

Objective: Maximize the performance of a subsurface reservoir

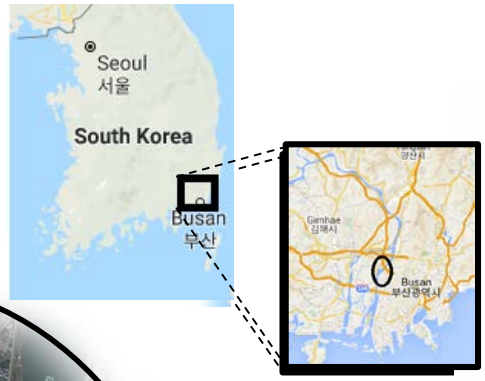
Decision variables: # of wells, locations, operating rates, times

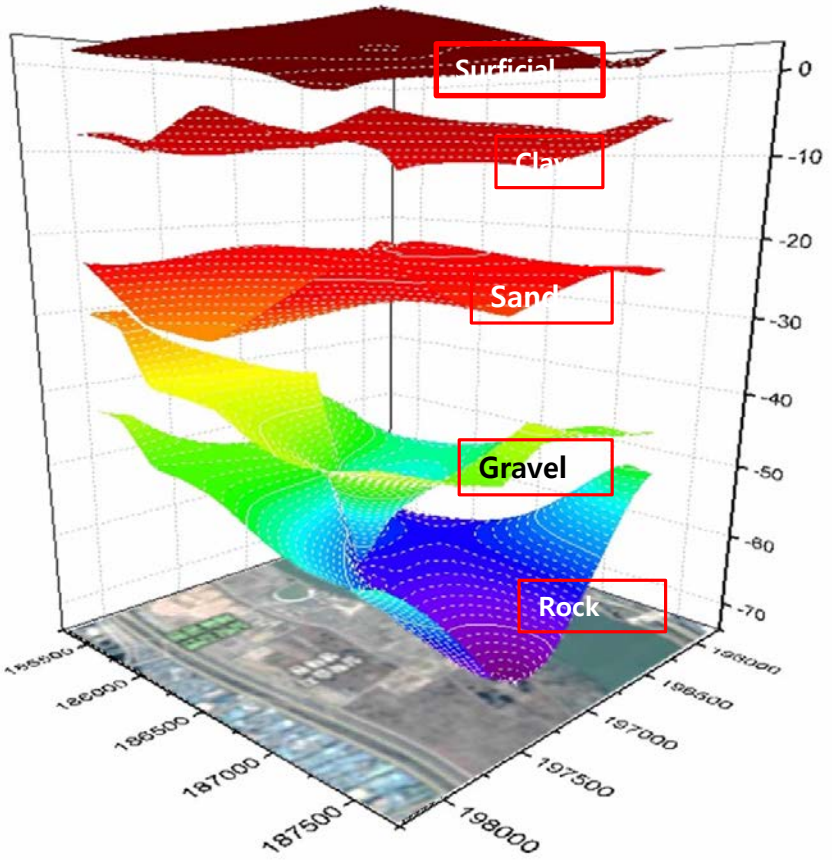
Cluster System
(# of CPUs: 128, OS: Linux)

Contents

II. Field Experiments

Location of the test facility





Geology at the test site

II. Field Experiments

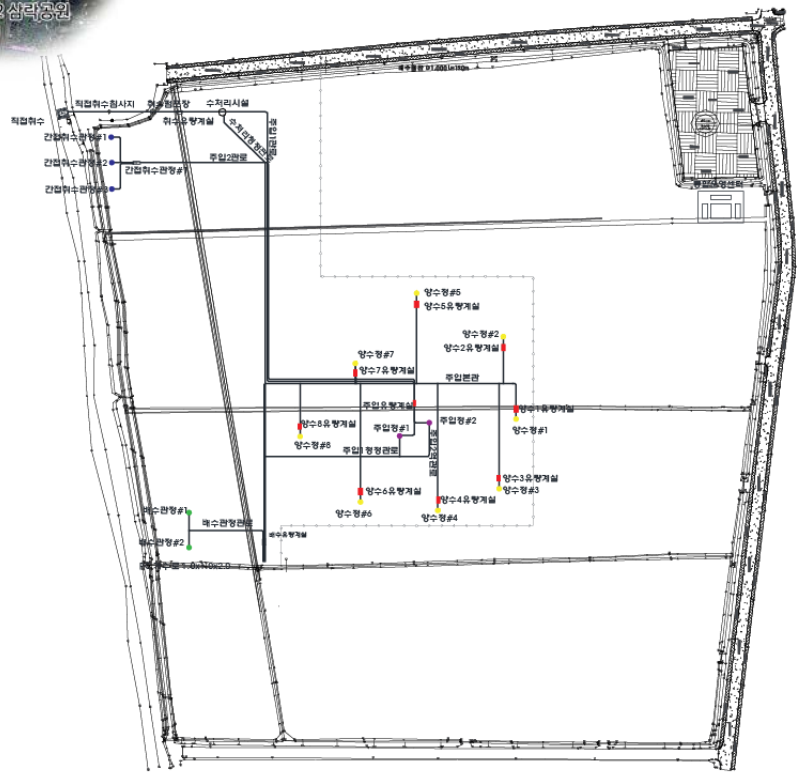
Quality of the native groundwater

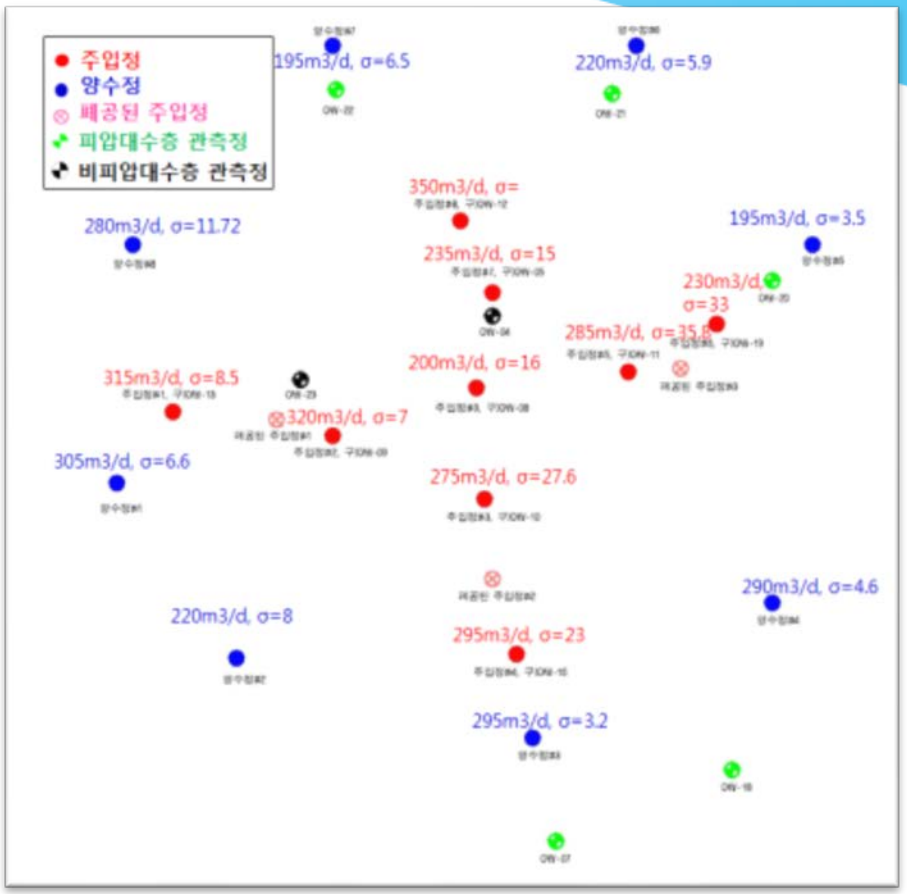
Sampling date: July 14-15, 2014	Confined aquifer					Unconfined aquifer	
	ow1	ow2	ow5	ow6	ow7	ow3	ow4
pH	7.68	7.24	7.16	7.31	7.6	7.76	7.45
Temperature, ^{o}C	18.6	18.48	17.76	18.85	18.1	20.37	17.9
ClO_4^- (mg/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SO_4^{2-} (mg/L)			20.00				
TOC (mg/L)	2.79	2.68	2.92	1.96	2.24	3.12	2.49
Cl^- (mg/L)	17.6	21.2	20.2	21.8	18.1		
NO_3^- (mg/L)			6.40				
TDS (mg/L)	26.43	26.74	26.78	41.63	26.72	0.835	1.319
Conductivity (ms/cm)	40.66	41.14	41.25	41.55	41.12	1.29	2.029
ORP (mV)	-171.50	-104.4	-86.7	-125.8	-138.2	-12.2	81.4
Salinity (psu)	26.12	26.4	26.33	27.6	26.39	0.64	1.04
Zn (mg/L)	0.11	0.04	0.07 (2.14)	0.06	0.08	0.08	0.07
Mn (mg/L)	1.75	2.37	2.26 (0.57)	2.03	1.99	0.26	4.16
Fe (mg/L)	10.89	9.49	7.70 (N.D.)	5.20	7.27	0.65	0.97
B (mg/L)	2.74	2.71	2.91	2.99	2.77	0.42	0.35
Al (mg/L)	0.08	0.08	0.07	0.08	0.14	0.22	0.09
As (mg/L)	N.D.	N.D.	N.D. (0.01)	N.D.	N.D.	N.D.	N.D.
Se (mg/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Cr (mg/L)	N.D.	N.D.	N.D. (N.D.)	N.D.	N.D.	N.D.	N.D.
Cd (mg/L)	N.D.	N.D.	N.D. (N.D.)	N.D.	N.D.	N.D.	N.D.
Pb (mg/L)	N.D.	N.D.	N.D. (N.D.)	N.D.	N.D.	N.D.	N.D.
Cu (mg/L)	N.D.	N.D.	N.D. (N.D.)	N.D.	N.D.	N.D.	N.D.
Dissolved oxygen (mg/L)	0.92	3.54	4.24	0.86	1.54	1.17	3.15

Blue: performed by this team or KBSI. Black: performed by KIST team either on site or in the lab N.D. : Not detected

II. Field Experiments

Test facility

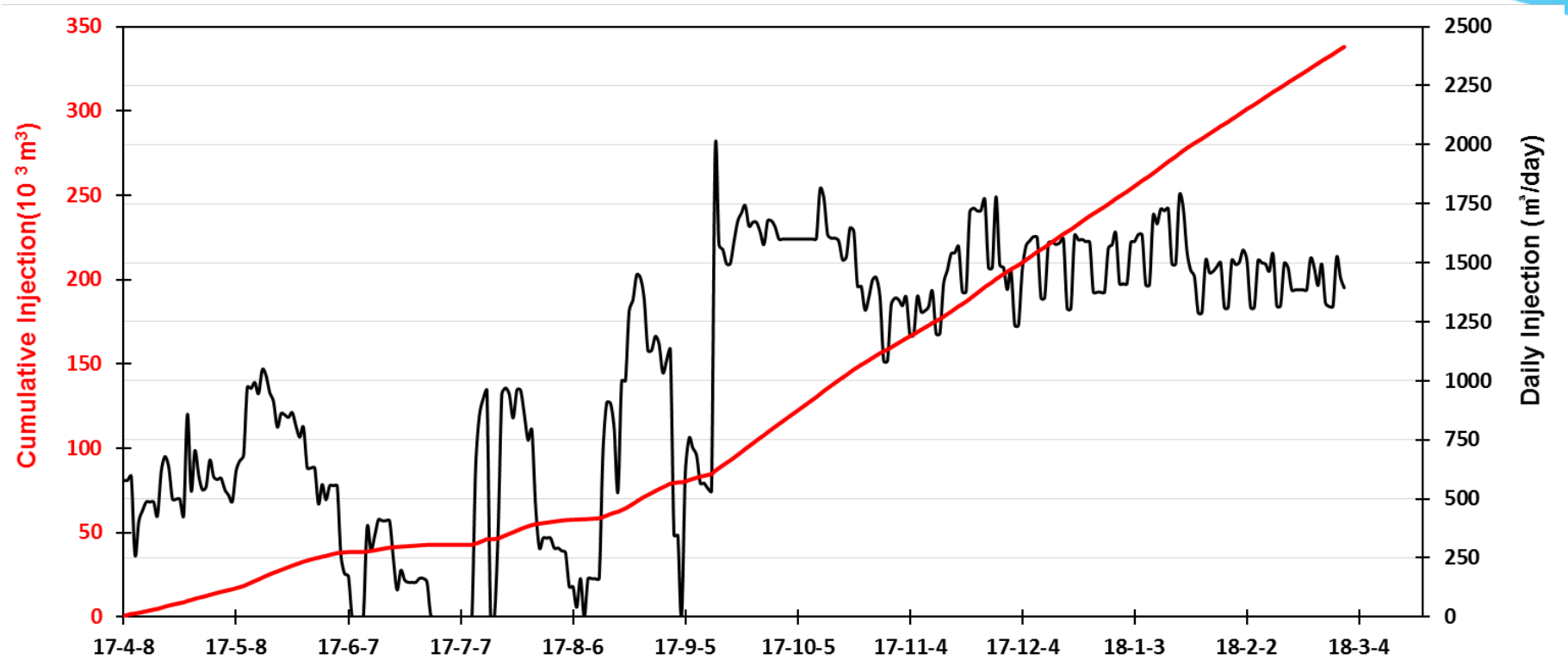




Injection, pumping & monitoring wells

II. Field Experiments

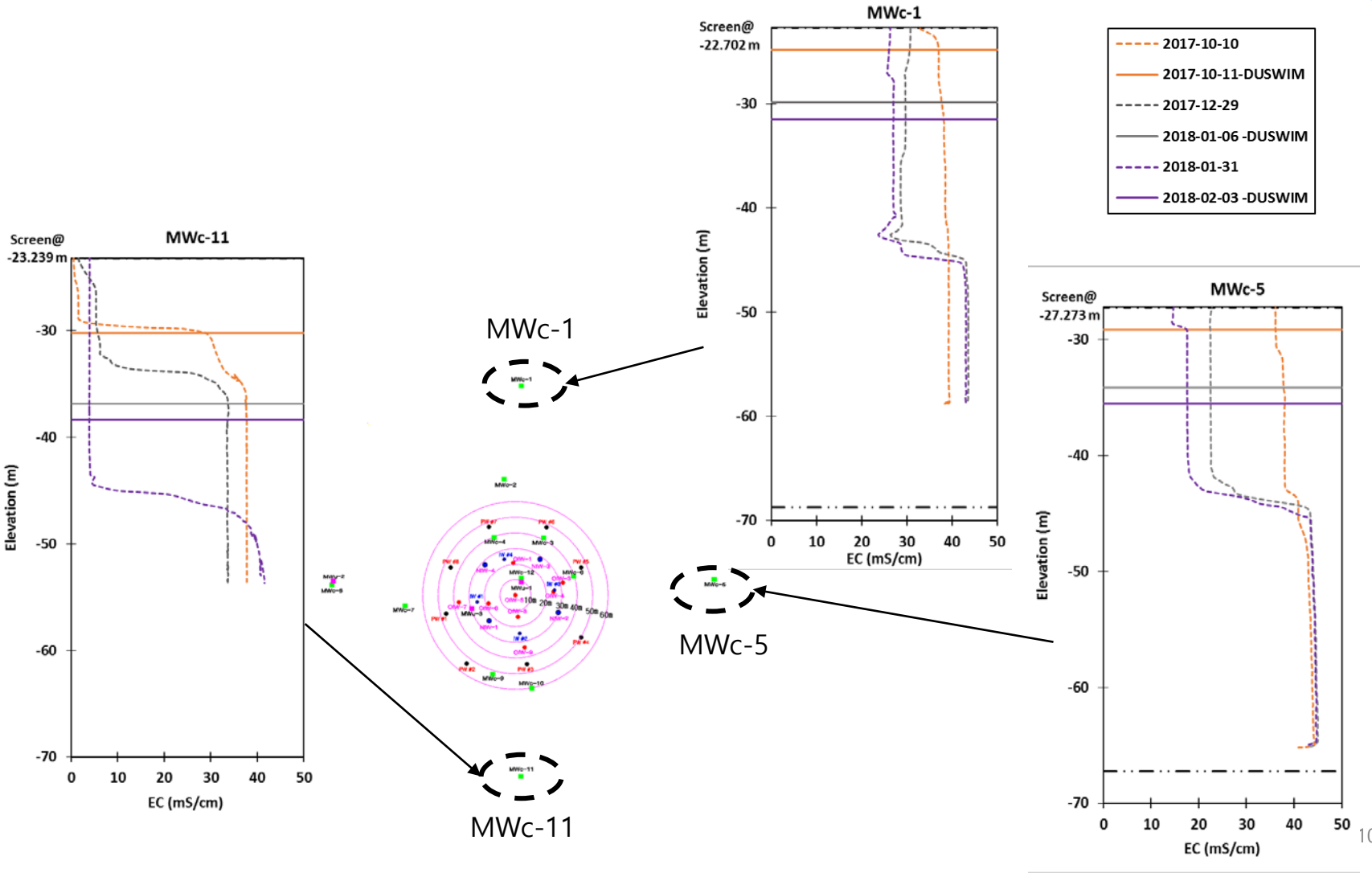
Injection record



Optimum Injection? : Non-optimal

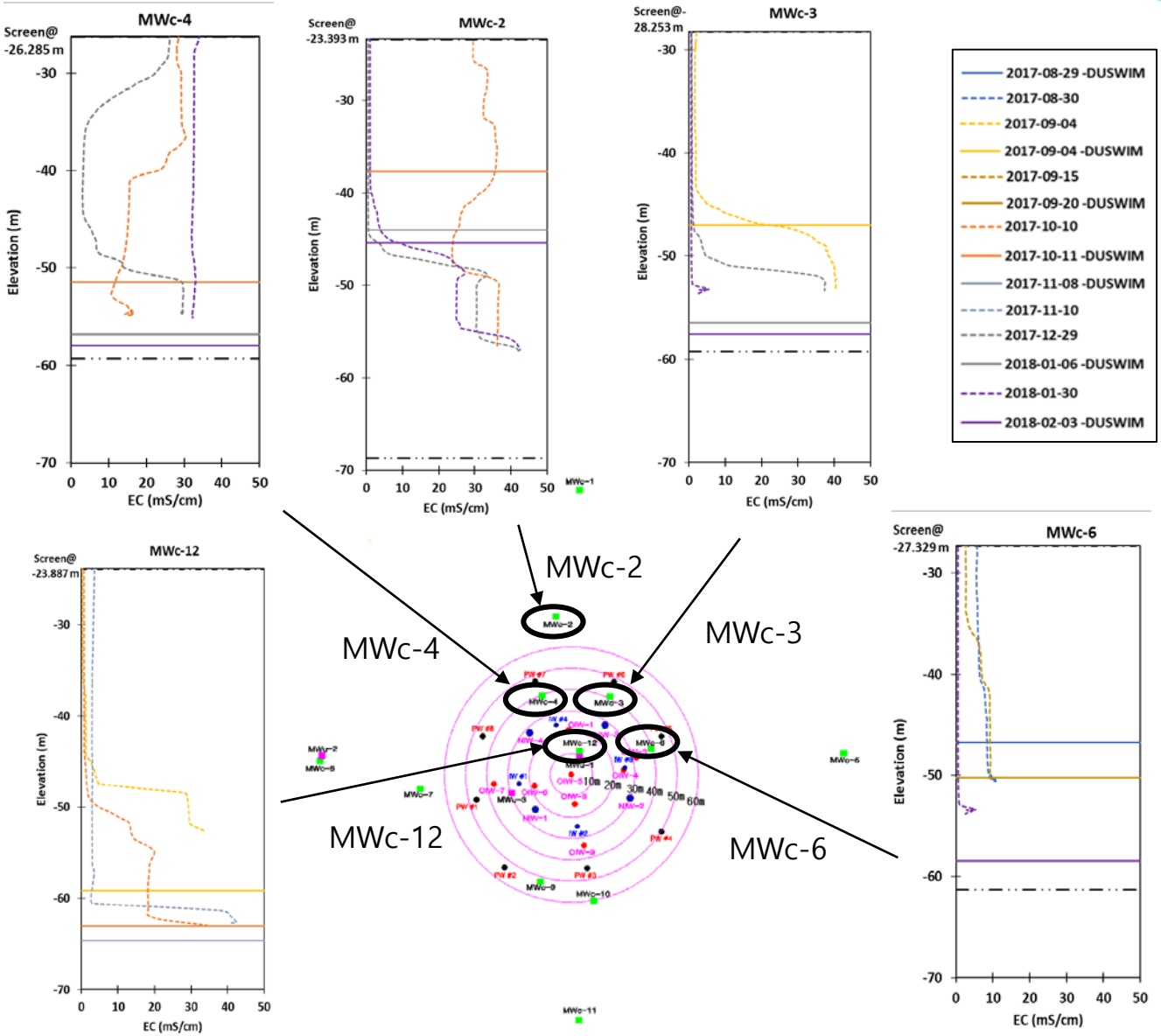
II. Field Experiments

Freshwater body-observed & modeled



II. Field Experiments

Freshwater body-observed & modeled



II. Field Experiments

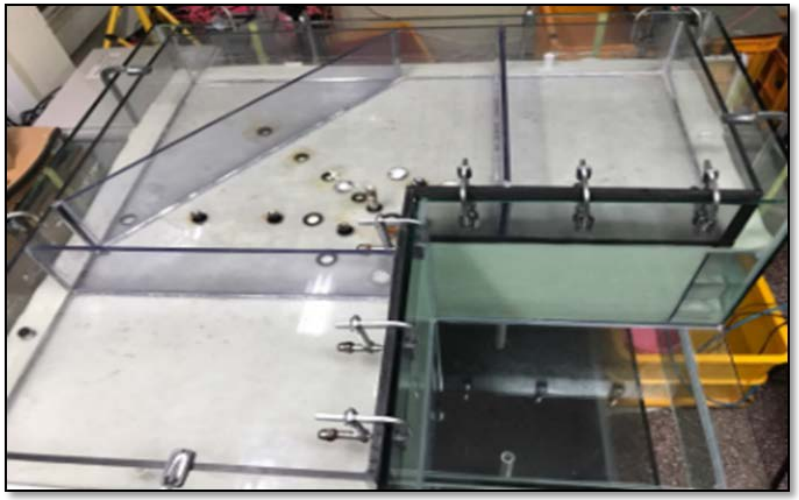
Water quality changes

	River water	MWC-6		PW-6
	21-Feb-18	21-Nov-17	21-Feb-18	21-Feb-18
pH	8.42	7.94	8.09	8.05
DOC (mg/L)	5.98	2.69	2.32	3.22
CODcr (mg/L	22.45	10.80	10.10	14.23
ClO_4^- (mg/L)	0.00	0.00	0.00	0.00
SO_4^{2-} (mg/L)	69.61	39.08	79.96	72.26
Cl^- (mg/L)	0.967	0.614	0.191	1.512
NO_3^- (mg/L)	4.41	0.37	0.90	10.26
NO_2^- (mg/L)	0.00	0.00	0.00	0.00
TDS (mg/L)	1.09	1.27	0.354	1.25
Turbidity (NTU)	1.30	1.23	0.60	1.50
Fe (mg/L)		0.00	0.00	
Cond. (mS/cm)	0.66	1.98	0.65	5.40
Sal. (ppt)	1.30	0.00	0.00	0.90
DO (mg/L)	0.82	0.18	0.66	1.22
ORP (mV)	2.50	-154.87	3.40	43.60
Total heterotrophic cell (CFU/ml)	38100	40066	35600	36740
Total Coliforms (CFU/100 ml)	0	0	0	0

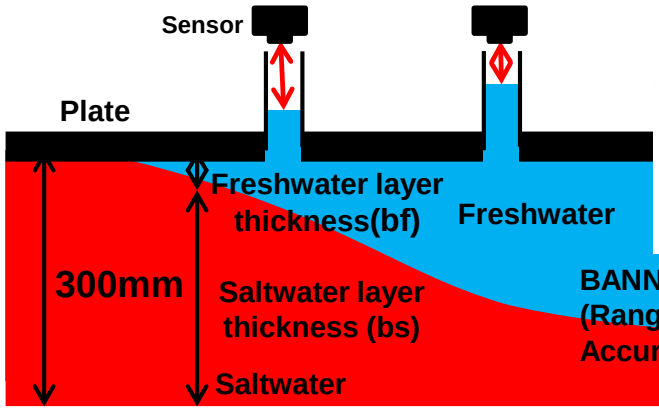
Contents

III. Lab. Experiments

Sand tank



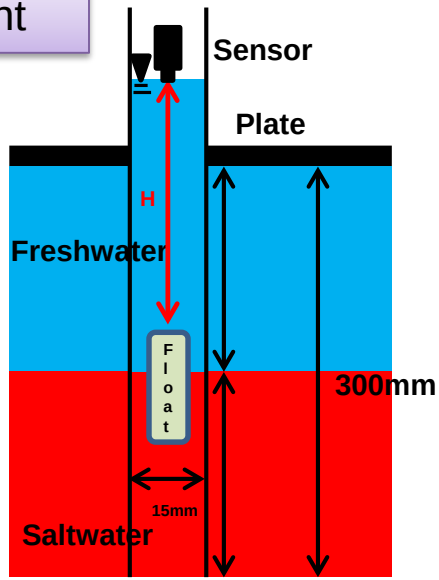
Water level measurement



BANNER Q4XTULAF100-Q8
(Range : 25mm~100mm,
Accuracy : ±1%)

Interface measurement

BANNER Q4XTULAF300-Q8
(range : 25mm~300mm,
Accuracy : ±3%)



Electrical conductivity measurement

METTLER TOLEDO Cond Sen. ISM
3/4 NPT.1C Ti 2
(range : 0.02~50,000us/cm,
Accuracy : ±1%, Repeatability :
±0.25%)

METTLER TOLEDO M300
ISM Transmitter

Measures directly in the injection and pumping process using a contact-type conductivity measurement sensor

III. Lab. Experiments

Preliminary experiment

Hydrological properties

Coefficient of Permeability (K) : 110 m/d

Aquifer Thickness: 0.3 m

Specific Storage(Ss):0.004 m^{-1}

Specific gravity of saltwater :1.025

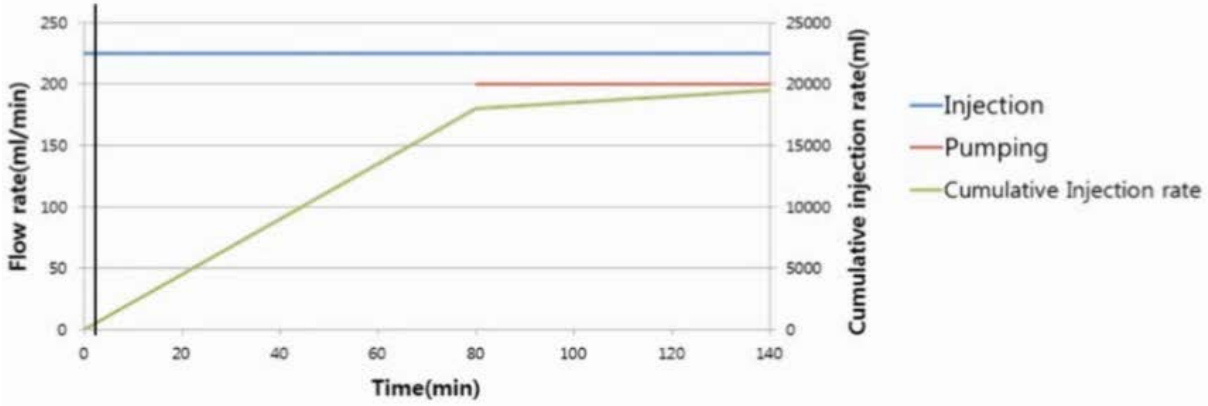
Porosity: 0.4

Operational Scenario

	Injection, Pumping			Time
Injection	225 ml/min			140 min
Pumping	200 ml/min	Pumping Well 1	16.67 ml/min	After 80 minutes of injection Start pumping (1 hour)
		Pumping Well 2	33.33 ml/min	
		Pumping Well 3	33.33 ml/min	
		Pumping Well 4	33.33 ml/min	
		Pumping Well 5	33.33 ml/min	
		Pumping Well 6	33.33 ml/min	
		Pumping Well 7	16.67 ml/min	

III. Lab. Experiments

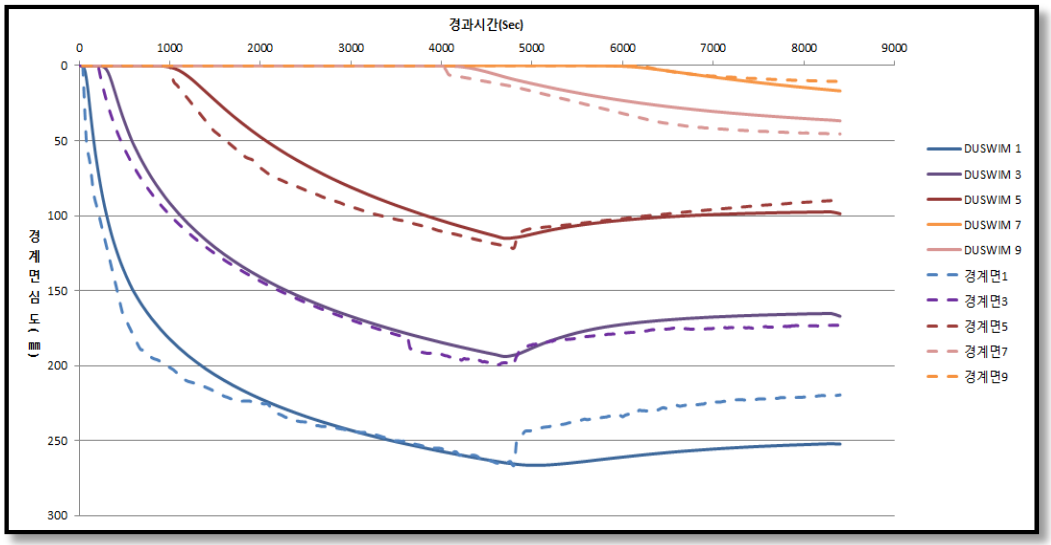
Preliminary experiment



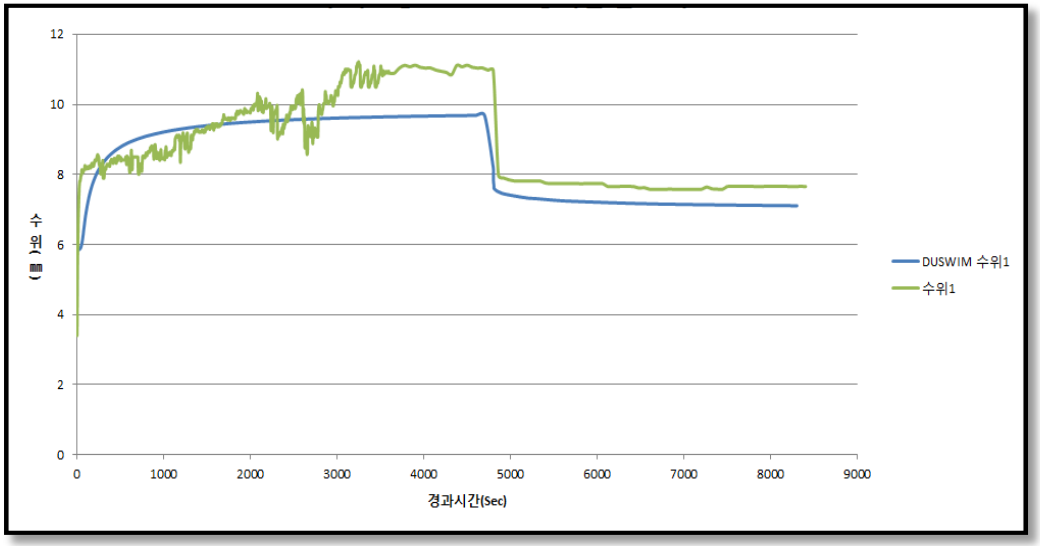
III. Lab. Experiments

Preliminary experiment

Depths to Interface



Water level



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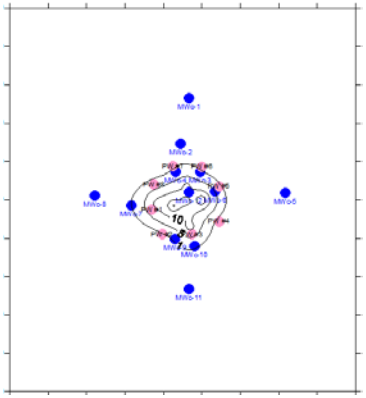
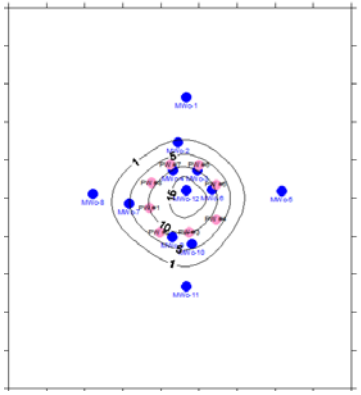
IV. Next Step

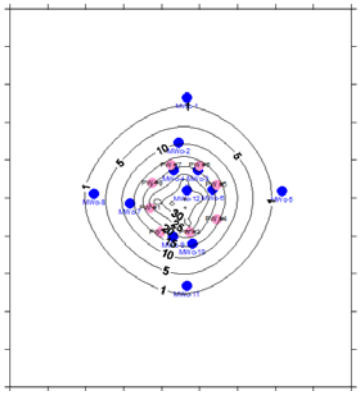
Pumping



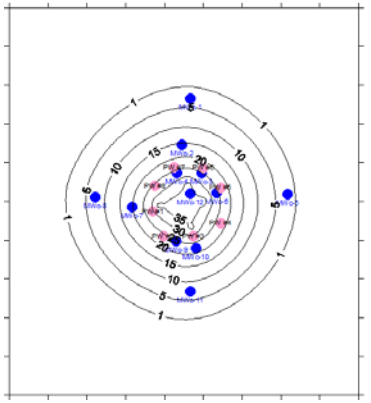
2017-05-01(28 days)



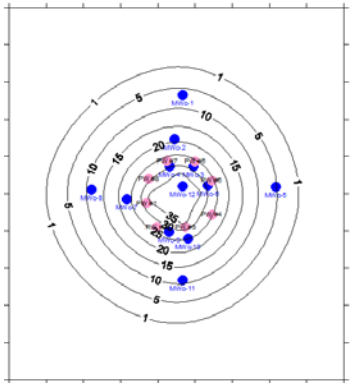
2017-06-16(72 days)



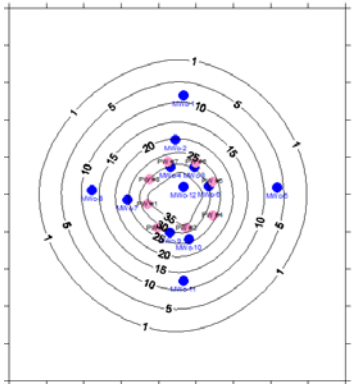
2017-09-04(155 days)



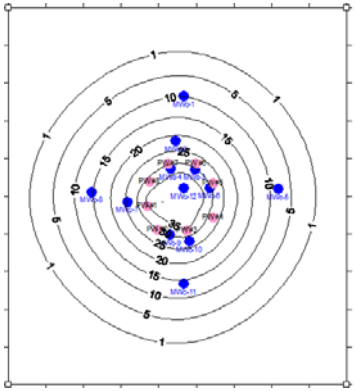
2017-10-25(206 days)



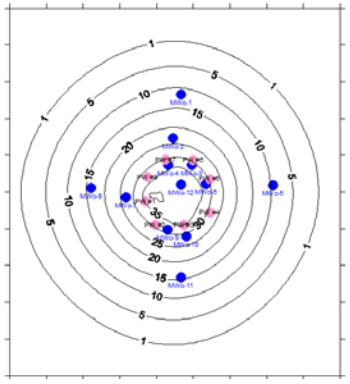
2017-12-13(253 days)



2018-01-06(275 days)



2018-02-03(302 days)

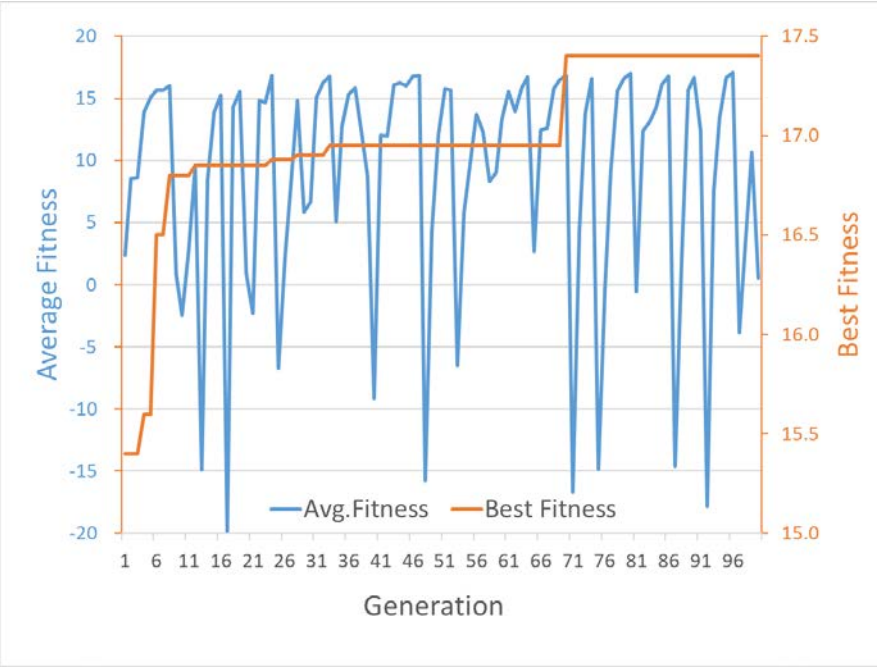


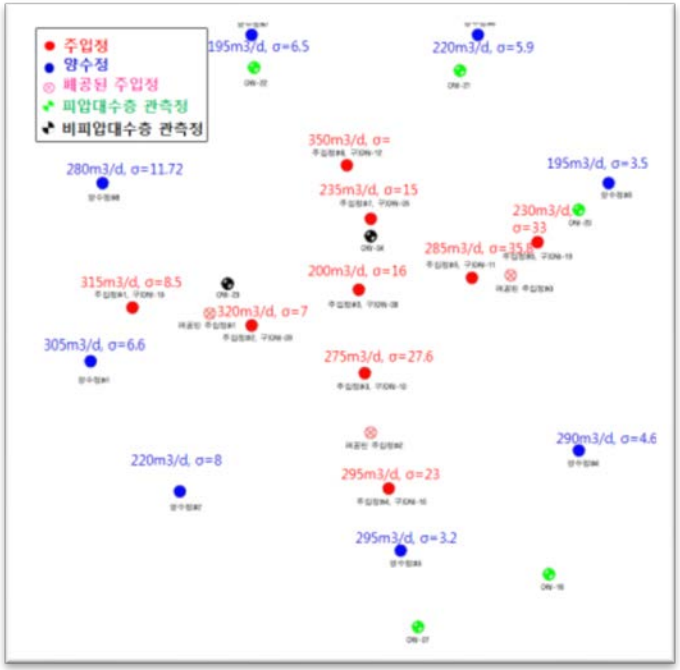
2018-03-03 (335 days)

IV. Next Step

Pumping

Objective: Avoid pumping salt water for three months
Decision variables: pumping rates





Identified Pumping Rates (m^3/d) – Optimal?

Pumping Well ID	1	2	3	4	5	6	7	8	Total
Qopt (m3/d)	251	242	233	181	164	147	130	156	1503

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Thank You

Acknowledgement
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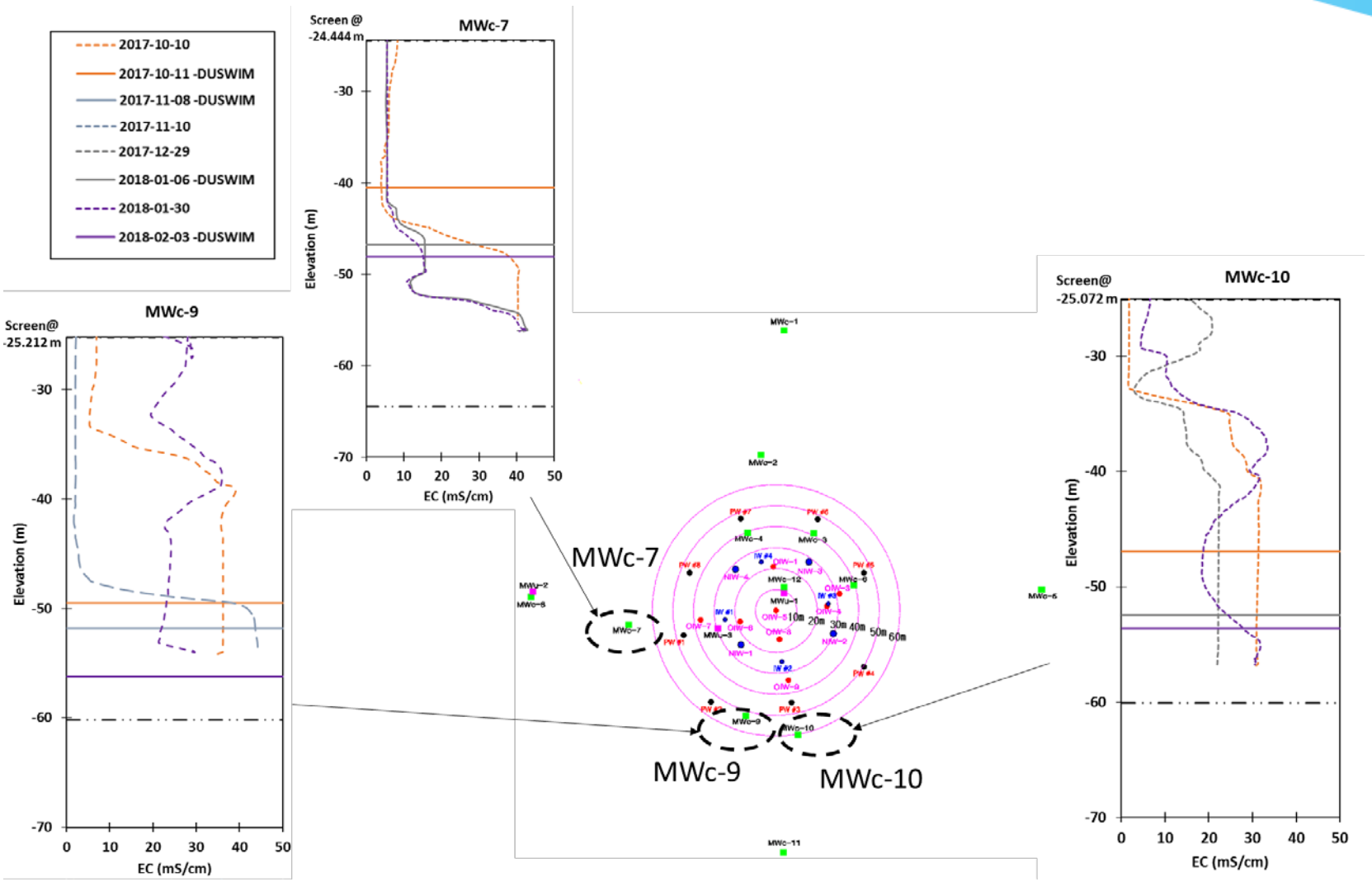
II. Field Experiments

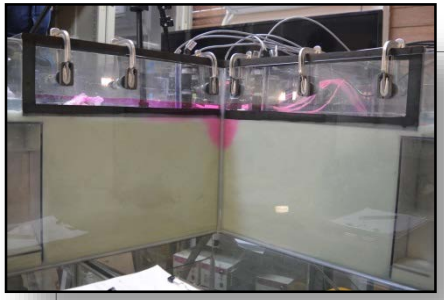
Freshwater body-observed & modeled



III. Lab. Experiments

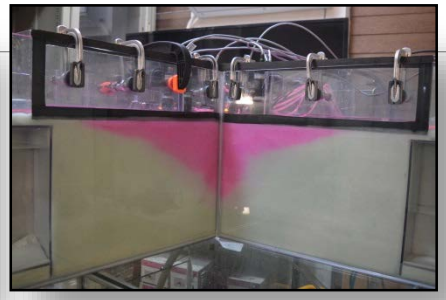
III.5 Hydraulic experiment results..

Emergency water supply capacity - Hydraulic model results



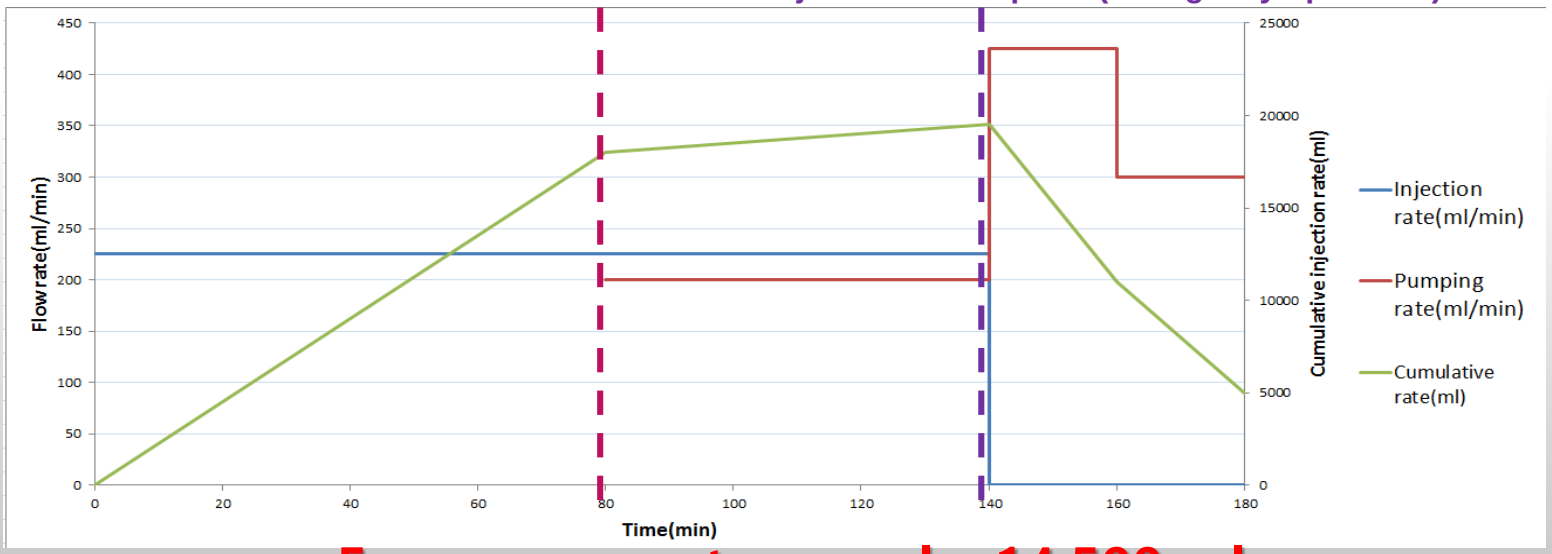
Begin Injection

Begin Pumping



Injection interruption (emergency operation)

End of experiment



Emergency water supply: 14,500 ml