Using thermal tracer tests and numerical model to evaluate the layered flow characteristic in a coastal aquifer system

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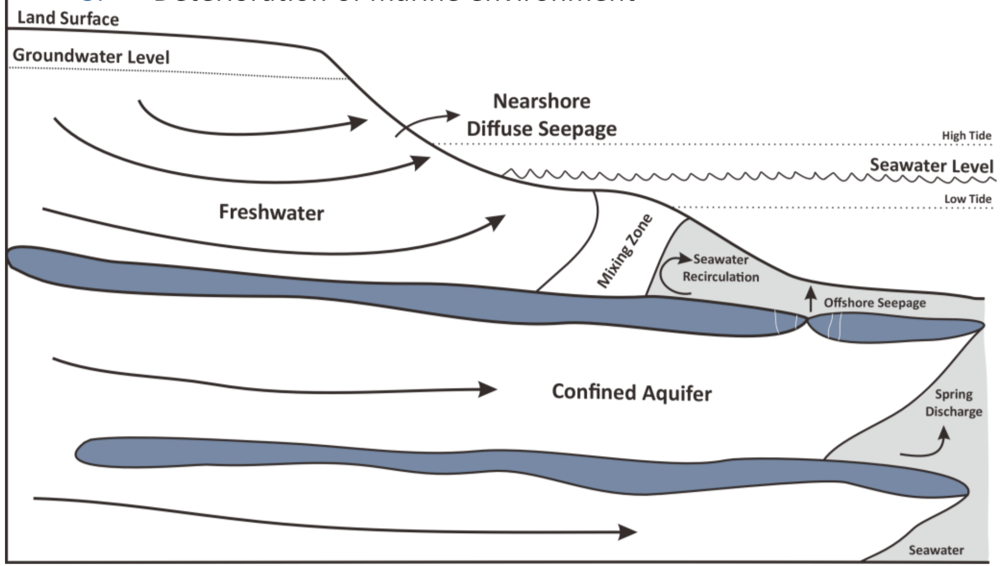
Introduction

Coastal aquifer

- With the social and economic development in coastal areas, various problems arise

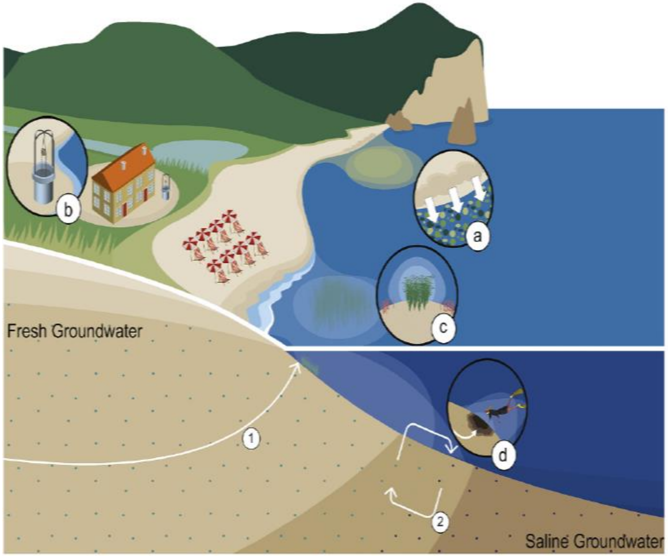
    1. Seawater intrusion
    2. Stability of coastal structures
    3. Deterioration of marine environment

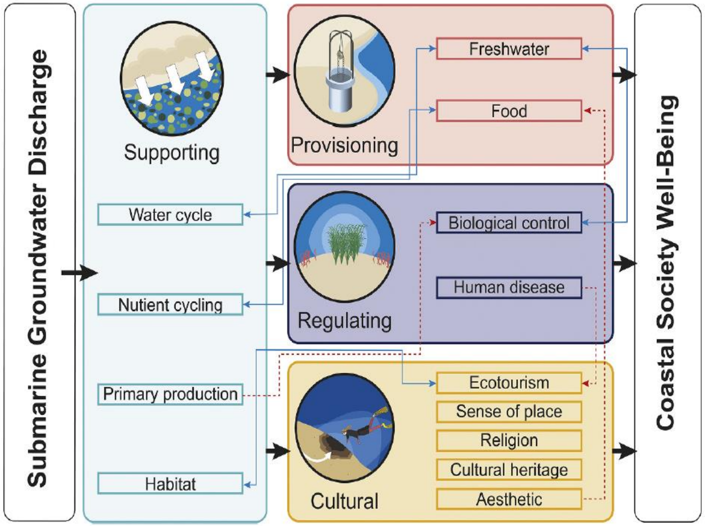
(Hailong Li et al., 2002)



SGD

- **S**ubmarine **G**roundwater **D**ischarge (SGD) is recognized as a fundamental hydrological process that supports many coastal biogeochemical cycles and social-ecological systems
- Important land-to-sea material transport pipeline, such as nutrient salts

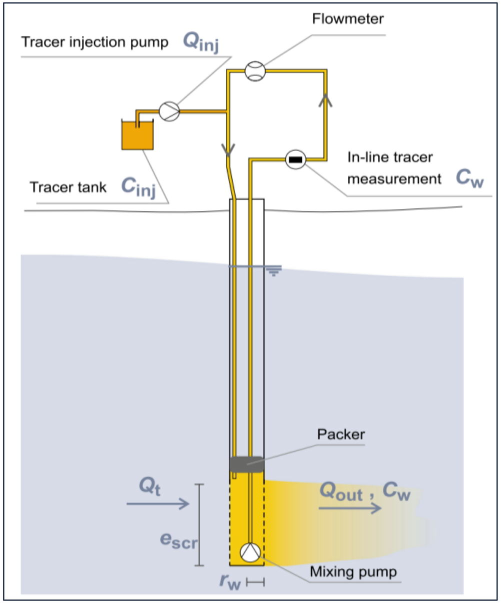




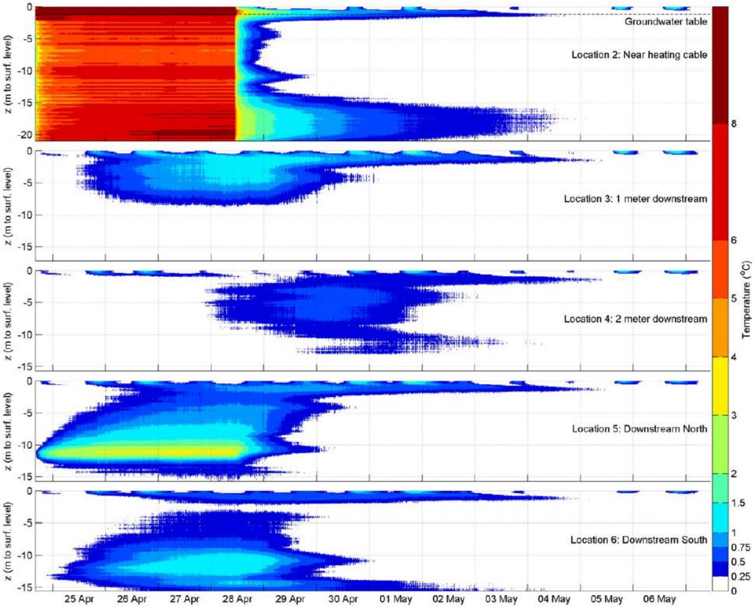
(Aaron et al., 2021)

Tracer

- The heat source can be regarded as solute transported with groundwater (Lin et al.,2021)
- The advantage of using heat as a tracer over other geochemical tracers
  - Low environmental pollution / High spatial resolution (Bense et al., 2016)

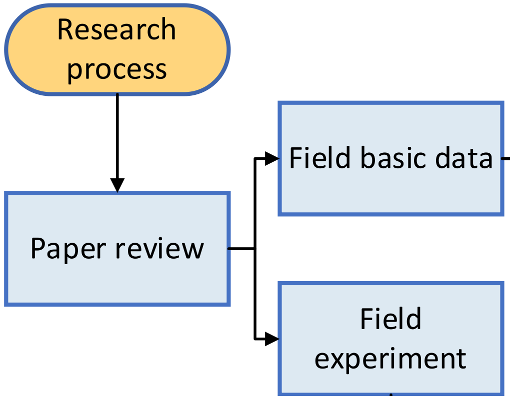


(Jamin et al., 2020)



(Bakker et al., 2014)

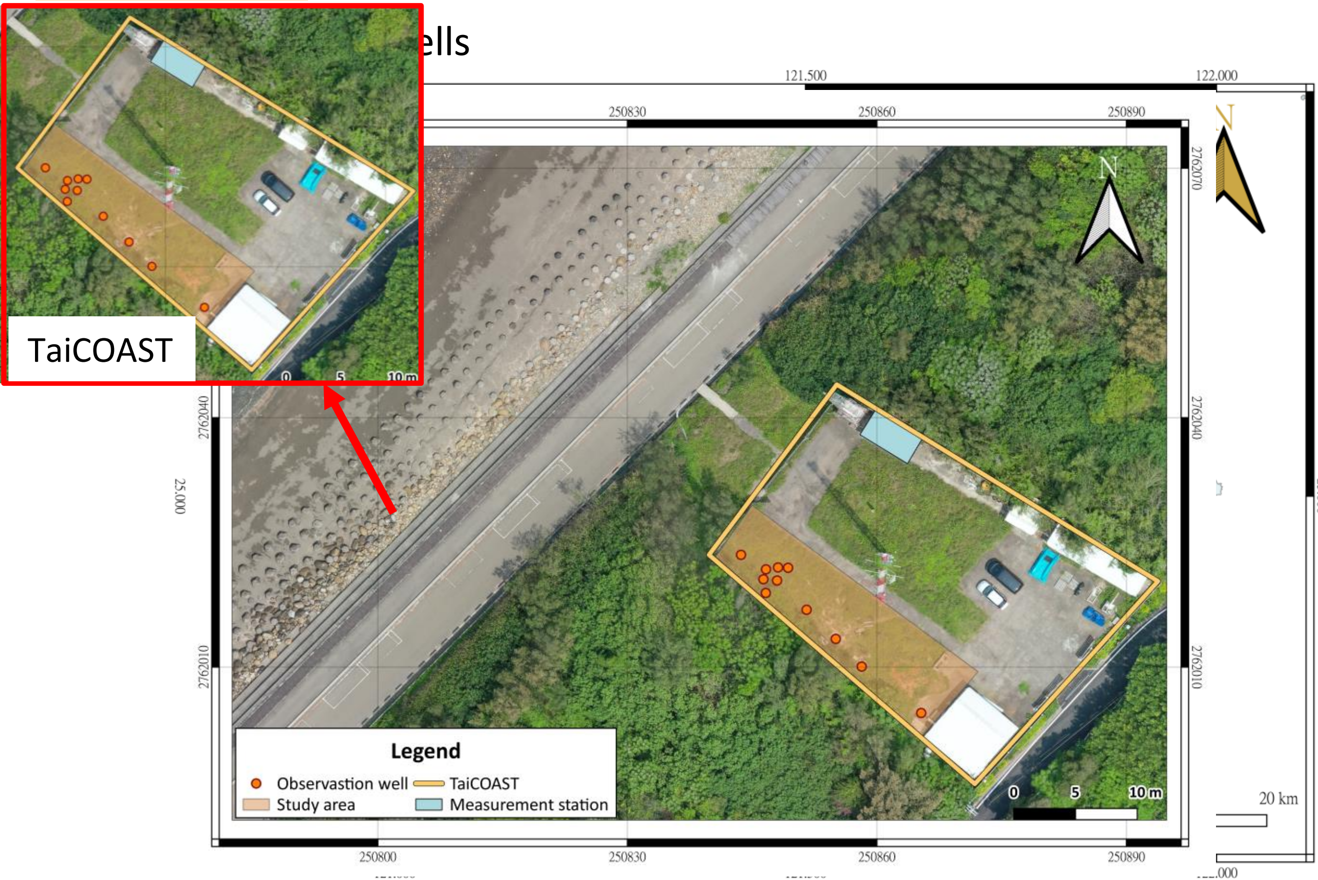
Work flow


Research process
Paper review
Field basic data
Field experiment

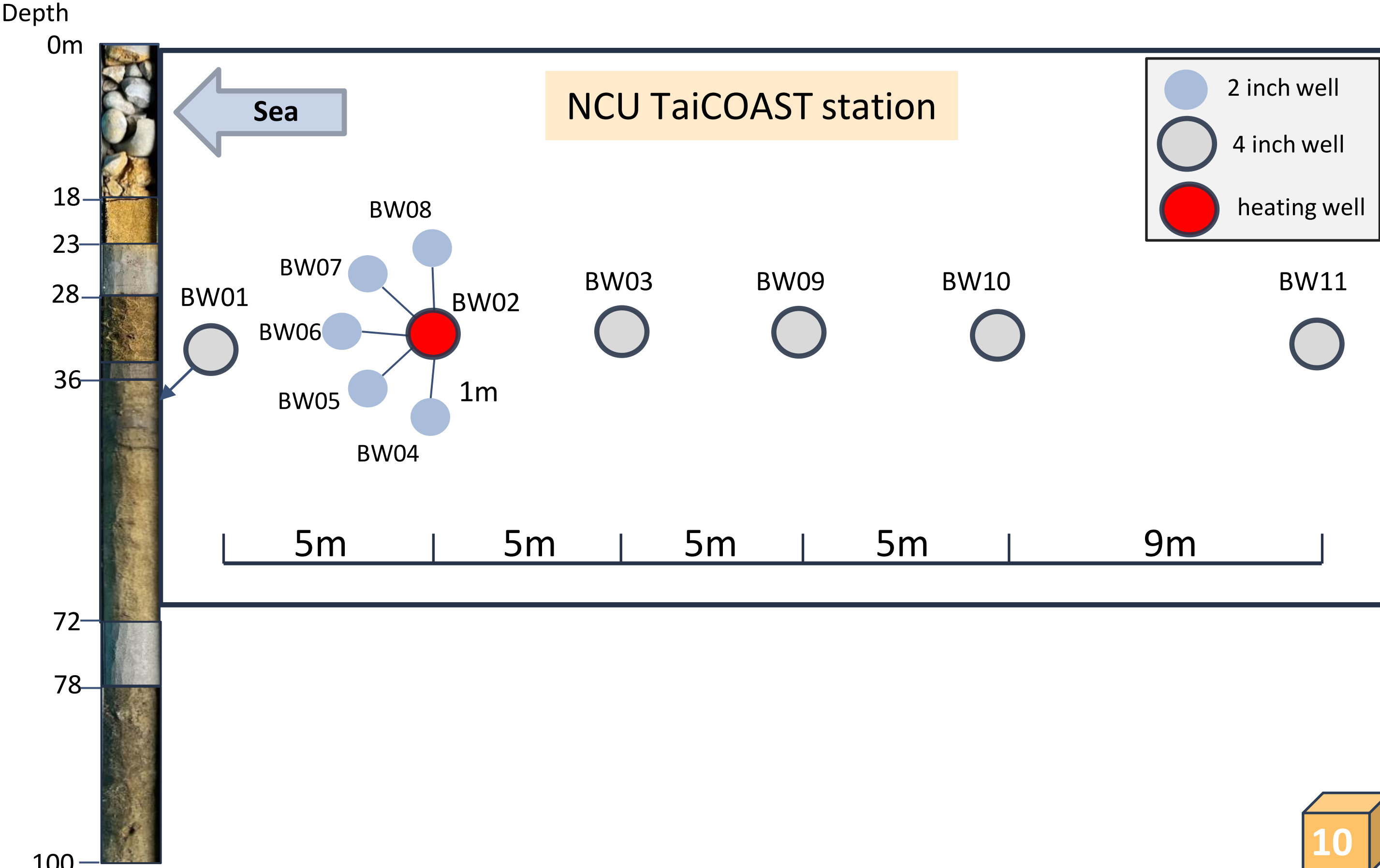
Methodology

Study area

ells

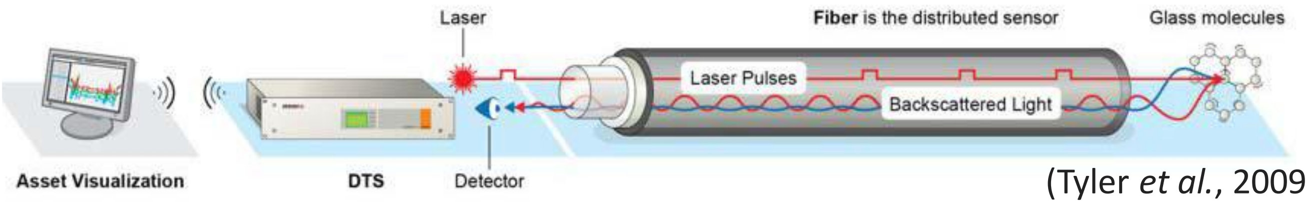


Study area


Depth
0m
18
23
28
36
72
78
100
Sea
NCU TaiCOAST station
2 inch well
4 inch well
heating well
BW08
BW07
BW01
BW02
BW06
BW05
BW04
1m
BW03
BW09
BW10
BW11
5m
5m
5m
5m
9m

Field test

Distributed Temperature Sensing (DTS) technology enables downhole temperature monitoring to study hydrogeological processes at high frequency and spatial resolution



(Tyler *et al.*, 2009)

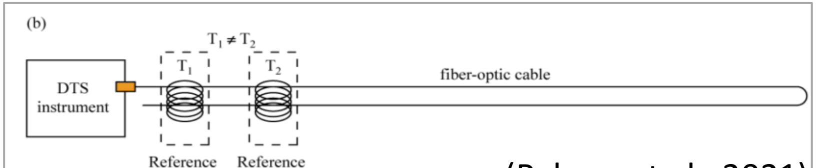
SILIXA(DTS)

Fiber optical

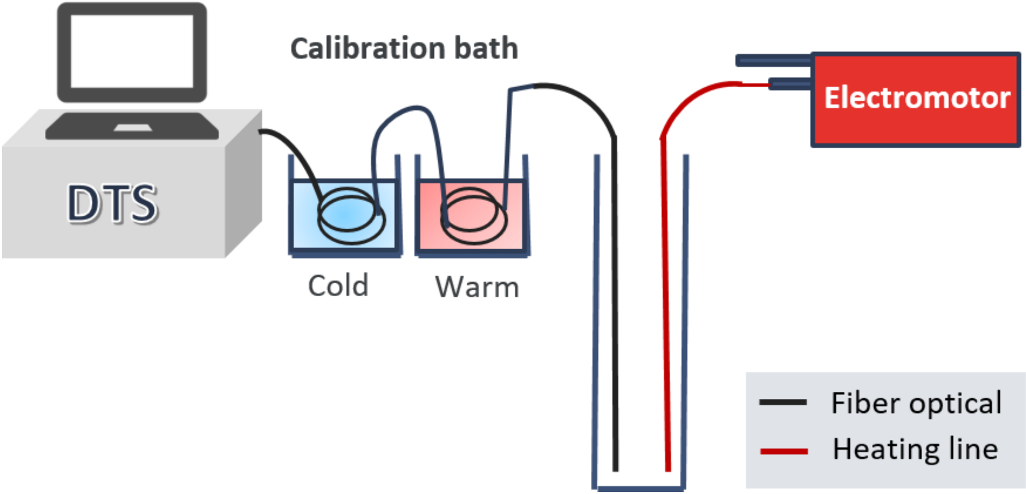
Field test

Configuration

- Sampling interval= 0.254m
- Measurement time ≧5 sec
- Duplexed single-ended configuration



(Pehme et al., 2021)



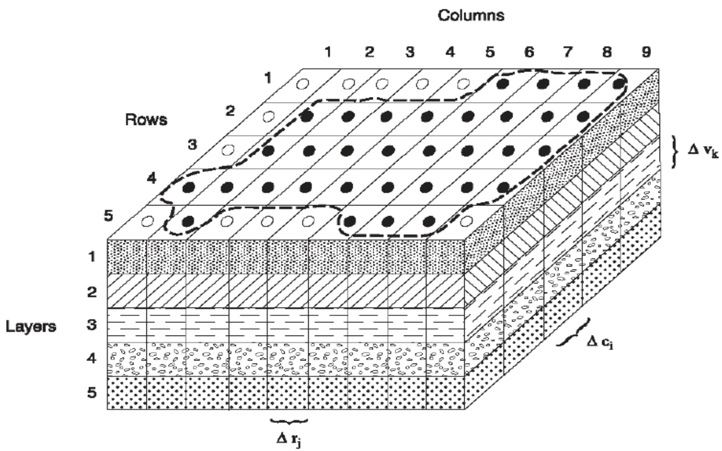
Heating line

MODFLOW-2005

- 3D finite-difference ground-water model (USGS)
- Including many packages to handle different conditions

Governing equation:

$$\frac{\partial}{\partial x}\left[K_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y \frac{\partial h}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_z \frac{\partial h}{\partial z}\right] + W = S_s \frac{\partial h}{\partial t}$$



(McDonald et al., 1988)

K_x K_y K_z	(L/T)	Hydraulic conductivity
h	(L)	Potentiometric head
S_s	(L^{-1})	Specific storage
W	(T^{-1})	Source or sink of water
t	(T)	Time

MT3DMS

- 3D groundwater solute transport model (USGS)
- Simulate the solute transport in soil pore media during groundwater flow.
- Heat transport is analogous to solute transport in groundwater modeling, adapted equation to assign suitable thermal parameters for temperature species

Dispersion and diffusion Advection Source and sink

$$\frac{\partial(\theta C^k)}{\partial t} = \boxed{\frac{\partial}{\partial x_i}\left(\theta Dij \frac{\partial C^k}{\partial x_j}\right)} - \boxed{\frac{\partial}{\partial x_i}(\theta V_i C^k)} + \boxed{q_s C_s^k} + \Sigma R_n$$

Solute transport equation

$$\left(1 + \frac{\rho_b K_d^t}{\theta}\right)\frac{\partial(\theta T)}{\partial t} = \boxed{\nabla\left[\theta\left(D_m^t + \alpha\frac{q}{\theta}\right)\nabla T\right]} - \boxed{\nabla(qT)} - \boxed{q_s' T_s}$$

Heat transport equation

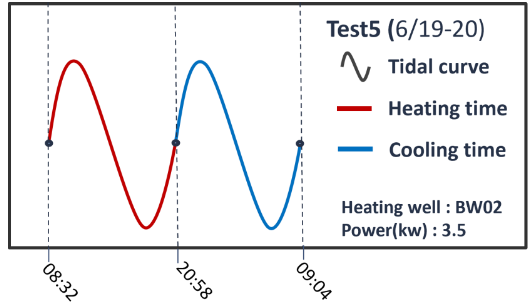
θ: porosity of soil
ρ_b : bulk density of solid
α : heat dispersion tensor
q : velocity of groundwater
q_s' : fluid source or sink
t: time

Dij : hydrodynamic dispersion coefficient
C^k : concentration of species k
V_i : velocity of groundwater in pore media
C_s^k : source or sink concentration of species k
R_n: chemical reaction

K_d^t: distribution coefficient of thermal
T: temperature
D_m^T : thermal conduction
T_s: source temperature

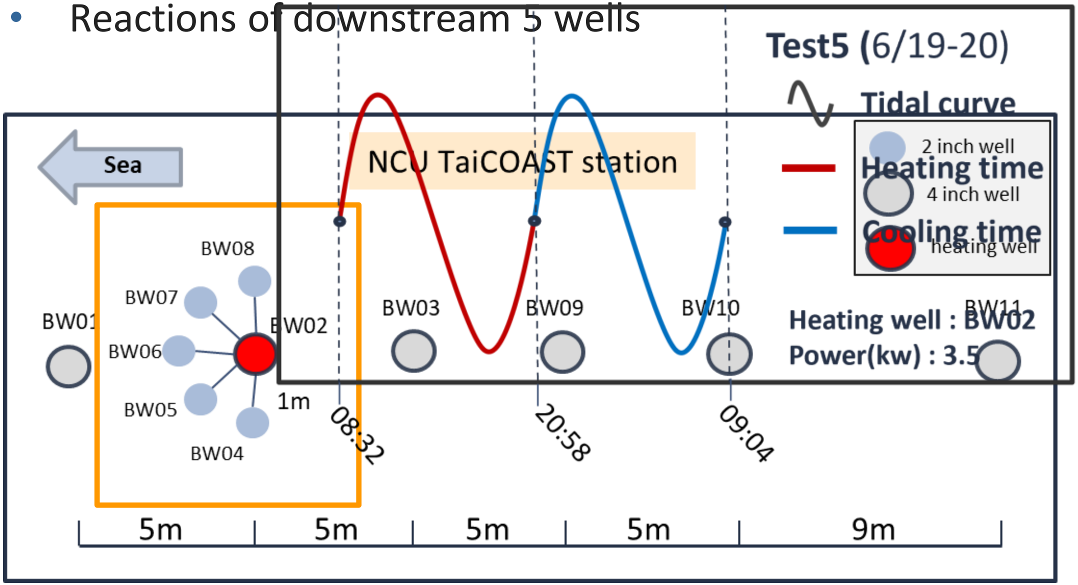
Result

Field test



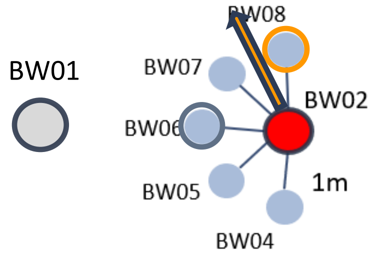
A-DTS heating test

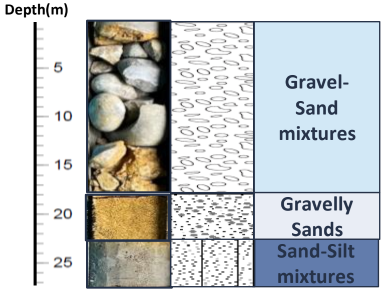
- Heat/Cool complete tidal cycle
- Monitor 11 wells simultaneously
- Reactions of downstream 5 wells

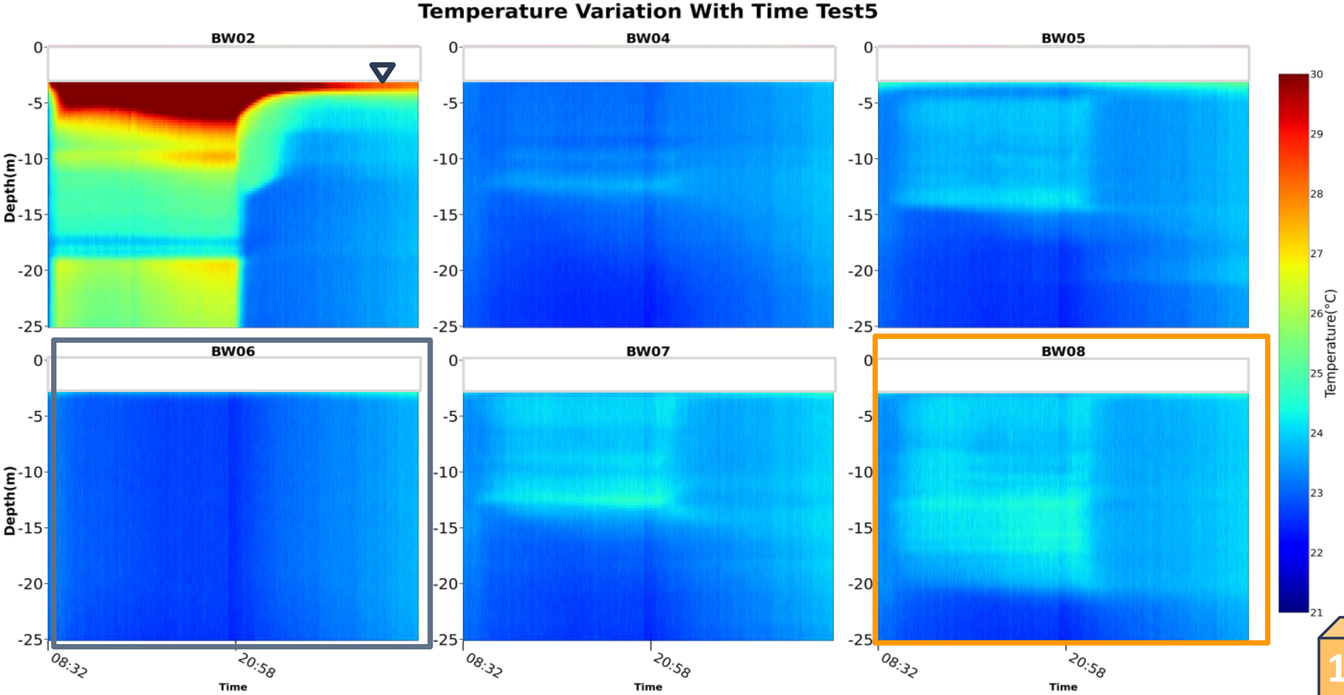


Field test

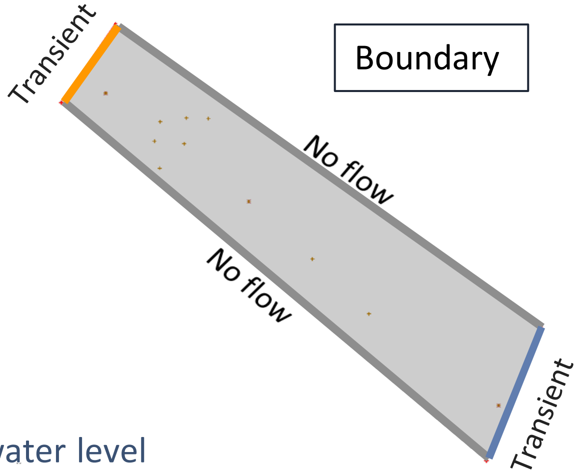
Assuming that the roughly direction of groundwater flow is between 7 and 8







MODFLOW



Conceptual model Setup

Grid size

Hydraulic conductivity (K) : Pumping test

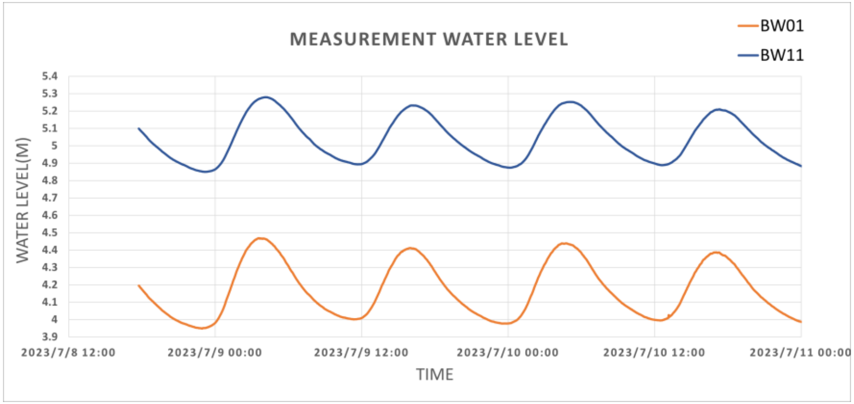
Top elevation : RTK

Boundary condition : Transient / no flow

Initial condition : BW01 & BW11 measurement water level

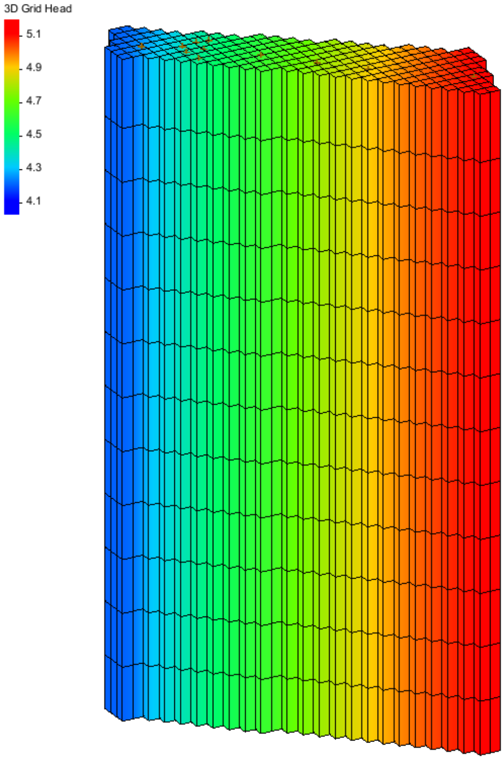
Grid size

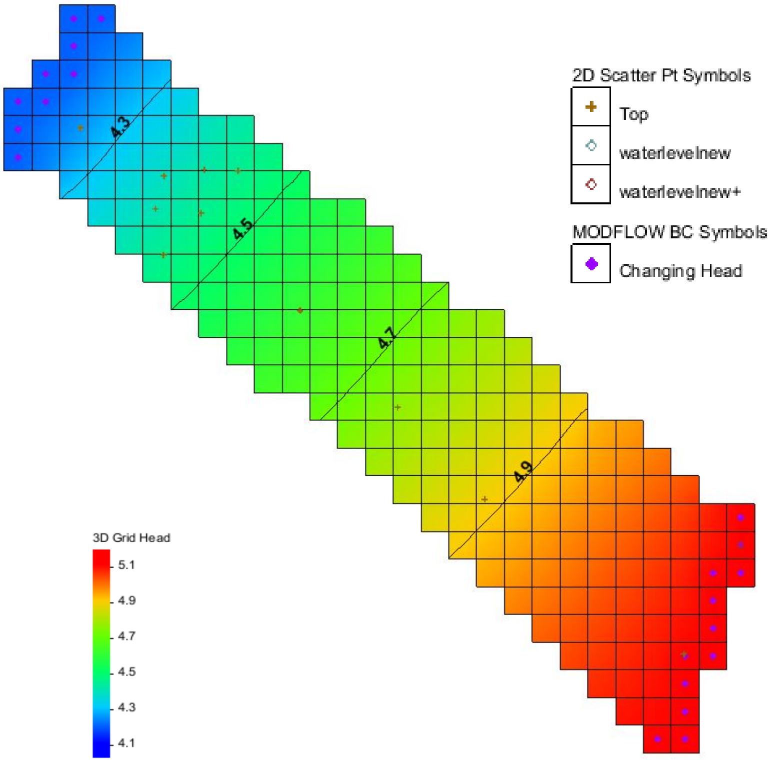
	X	Y	Z
Interval	1m/cell	1m/cell	5m/cell
Cells	27	27	12



MODFLOW

- The conceptual model has a generally groundwater flow direction is land to sea.

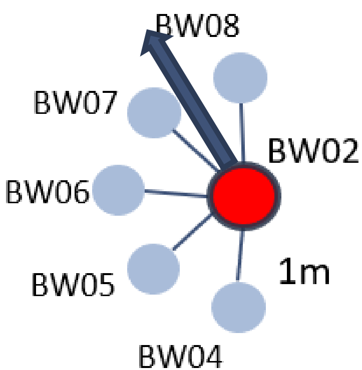




Conclusion

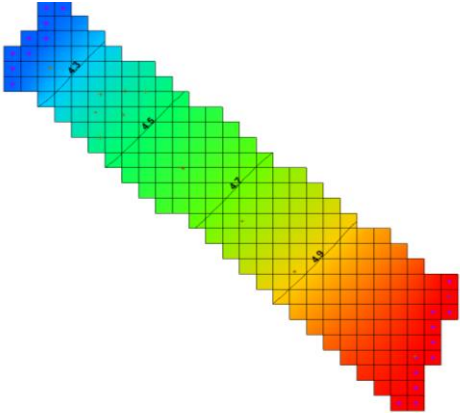
Field test

- Assuming that the roughly direction of groundwater flow is between BW07 and BW08



Simulation

- Now I use the experiment data and observation data to put into the model then established the basic conceptual flow field.
- The conceptual model has a generally groundwater flow direction is land to sea.



Future work

Future work

- Set smaller grid size in order to see the subtle changes.
- Set different K value in different layers.
- Combine MODFLOW with MT3DMS to create a temperature field.
- Calibrate and validate the model.
- Evaluate the layered flow characteristic in the coastal aquifer system.

Thank you for listening