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

Presenter:許安誼 An-Yi Hsu
Advisor:倪春發 Prof. Chuen-Fa Ni

Table of contents

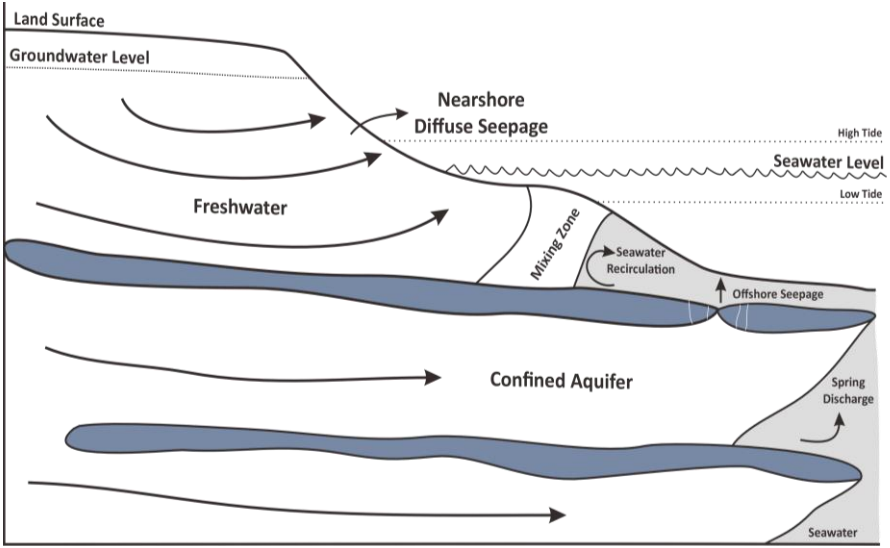
Introduction

Coastal aquifer

(Hailong Li et al., 2002)

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

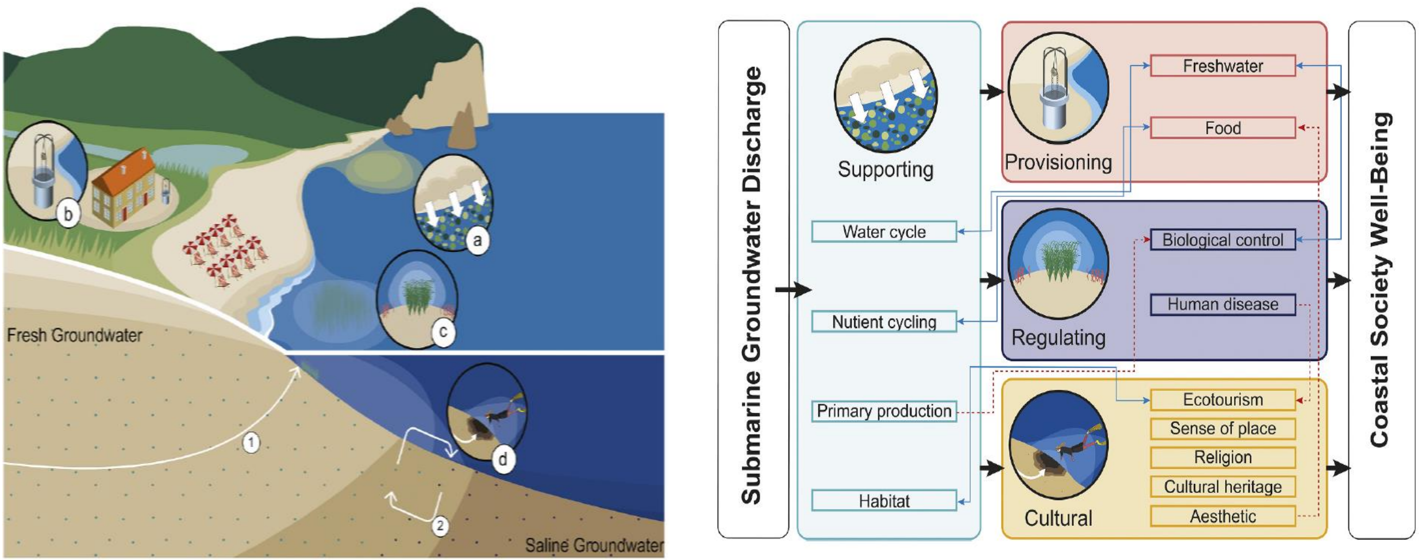
Seawater intrusion \ Stability of coastal structures \ Deterioration of marine environment



- To facilitate subsequent planning of water resources management, it is essential to determine the coastal aquifer's dynamic exchange with ocean.

SGD

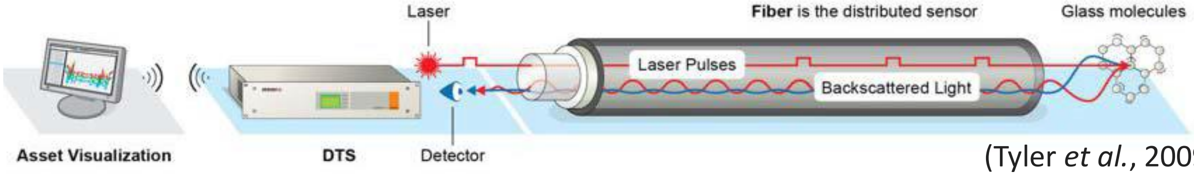
- **S**ubmarine **G**roundwater **D**ischarge (SGD) is recognized as a fundamental hydrological process that supports many coastal biogeochemical cycles and social-ecological systems
- Important land-to-sea material transport pipeline, such as nutrient salts



(Aaron et al., 2021)

Observed temperature data

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



(Tyler *et al.*, 2009)

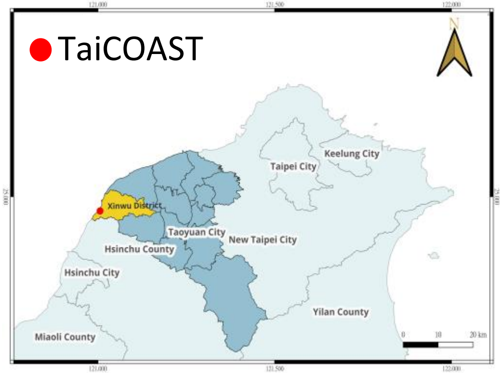
Range	Channels	Resolution		Measurement Time	Fibre Type	Referencing
		Sampling	Temperature			
0 - 5km*	4	25cm	0.01°C	≥5 sec	50/125μm multimode	x2 PT-100 probes

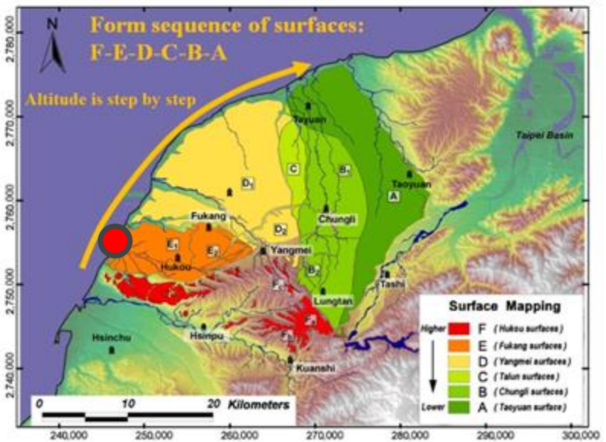
Fiber optical

Silixa Ltd

Study area

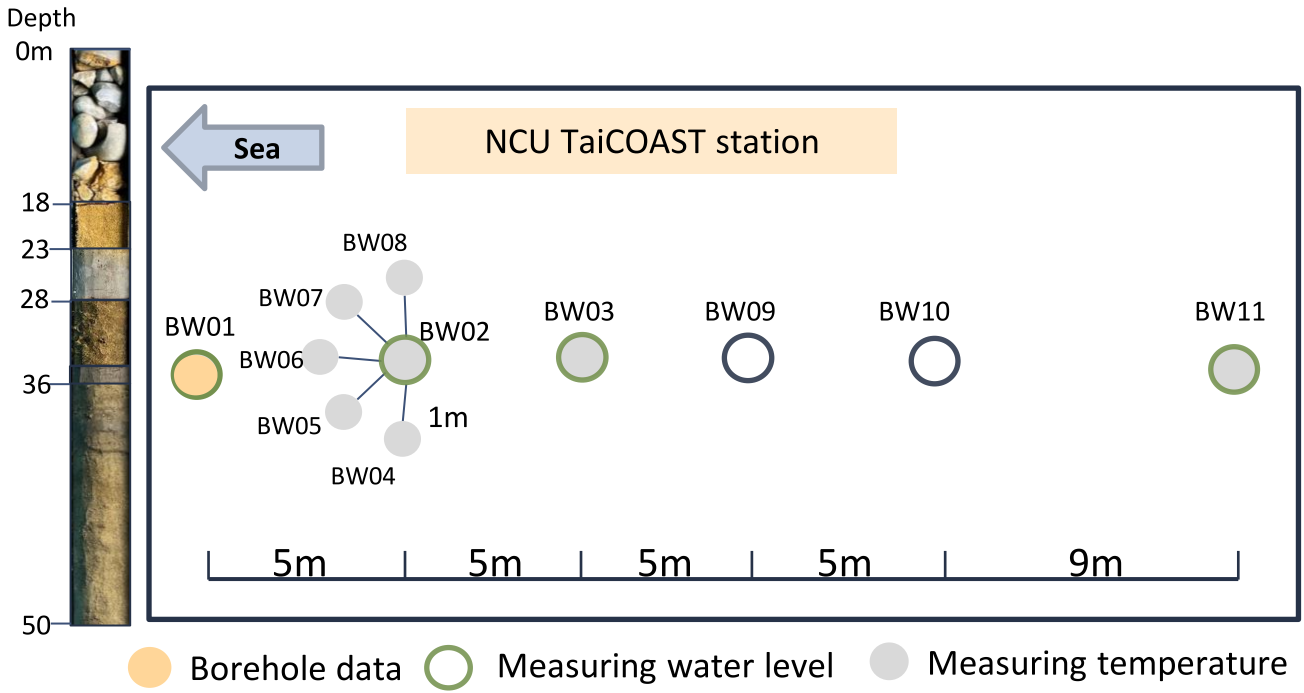
- Located at Taoyuan Tableland in northwestern Taiwan
- Due to the considerable distance from the nearby major river, the Dahan River, there is a scarcity of groundwater resources.
- The groundwater level in this area is influenced by the semi-diurnal tide.



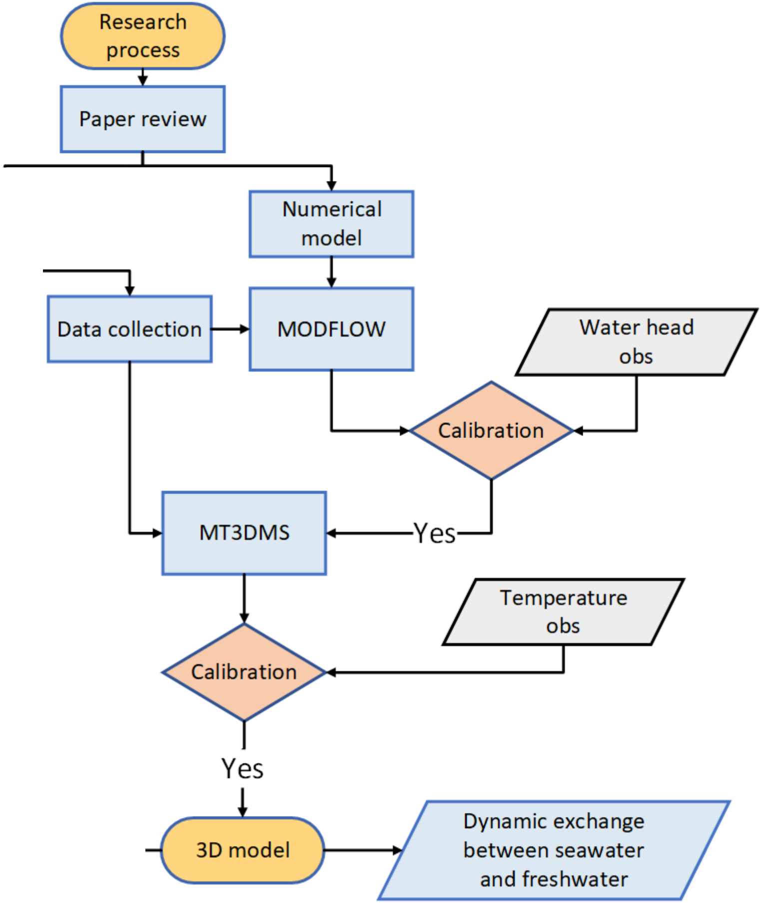


(王昱, 2003)

Study area


Depth
0m
18
23
28
36
50
Sea
NCU TaiCOAST station
BW08
BW07
BW06
BW05
BW04
BW01
BW02
1m
BW03
BW09
BW10
BW11
5m
5m
5m
5m
9m
Borehole data
Measuring water level
Measuring temperature

Work flow


Research process
Paper review
Numerical model
Data collection
MODFLOW
Water head obs
Calibration
MT3DMS
Yes
Temperature obs
Calibration
Yes
3D model
Dynamic exchange between seawater and freshwater

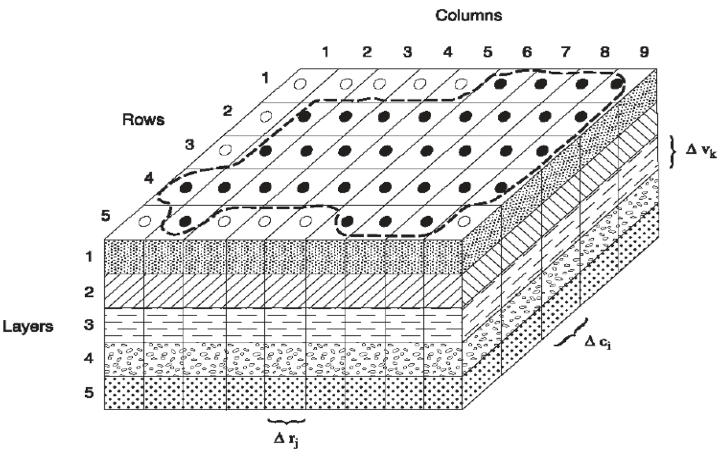
Methodology

MODFLOW

- 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 Advection Source and sink

$$\left(1+\frac{\rho_b K_d^k}{\theta}\right)\frac{\partial(\theta C^k)}{\partial t}=\boxed{\nabla\cdot\left[\theta\left(D_m^k+\alpha\frac{q}{\theta}\right)\nabla C^k\right]}-\boxed{\nabla\cdot(qC^k)}-\boxed{q_s' C_s^k}$$

Solute transport equation

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

Heat transport equation

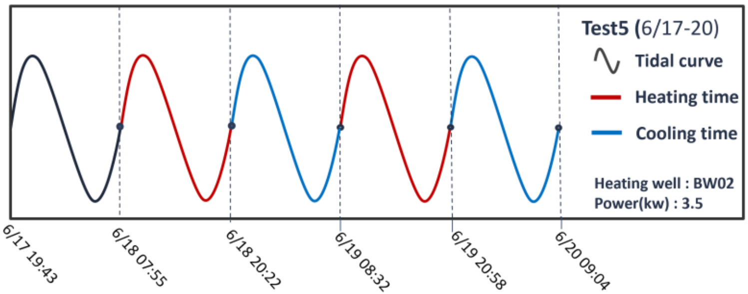
θ: porosity of soil
ρ_b : bulk density of solid
α : heat dispersion tensor
q : velocity of groundwater
q_s' : fluid source or sink
t: time

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

Model setup

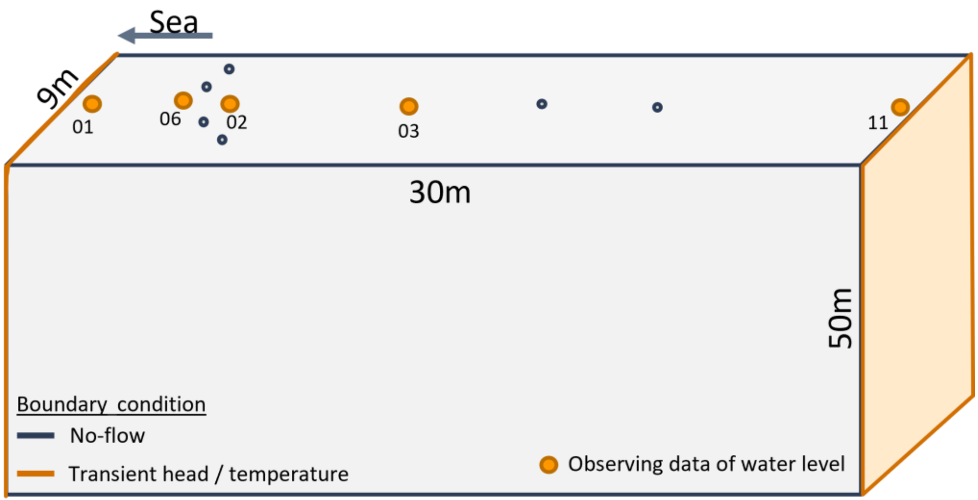
- Size : 9*30*50 (m)
- Grid size: $\Delta x, \Delta y, \Delta z = 1\text{m}$
- Time series: 3729 (min)
- Boundary : Transient/No-flow
- K-value : Falling head test (王新博, 2023)



Units:(m/d)

K1(z=1-18m)	0.17
K2(z=19-23m)	0.0216
K3(z=24-28m)	0.124
K4(z=29-35m)	0.298
K5(z=36-50m)	0.0021

(王新博, 2023)



Result

Flow field

- The results indicate that groundwater levels in this area are influenced by tides
- Have difference of approximately 0.4 meters between low and high tide levels .
- The overall groundwater flow direction in this area is from BW11 to BW01.

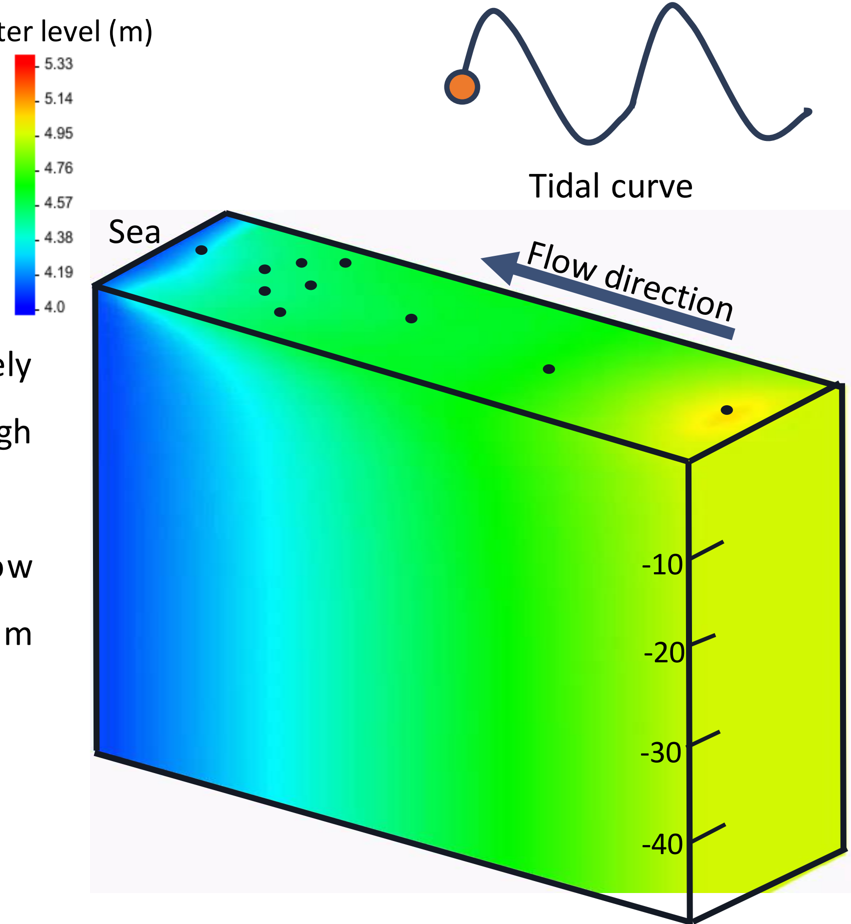
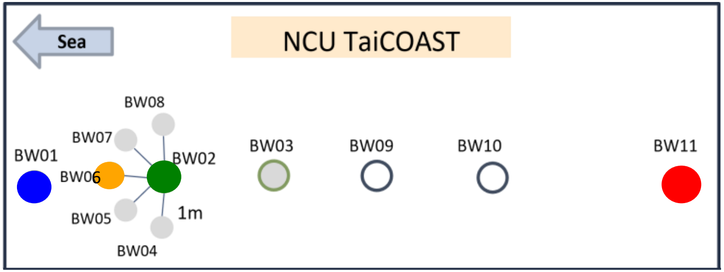
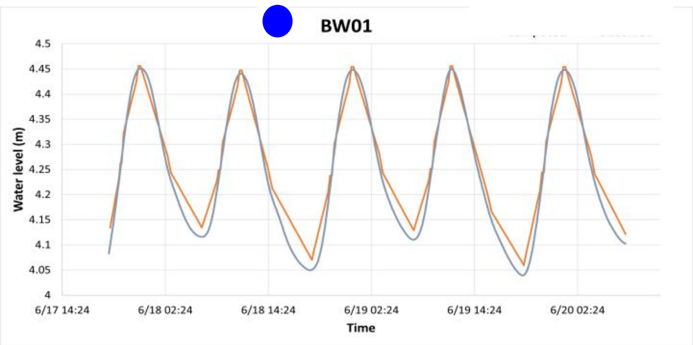


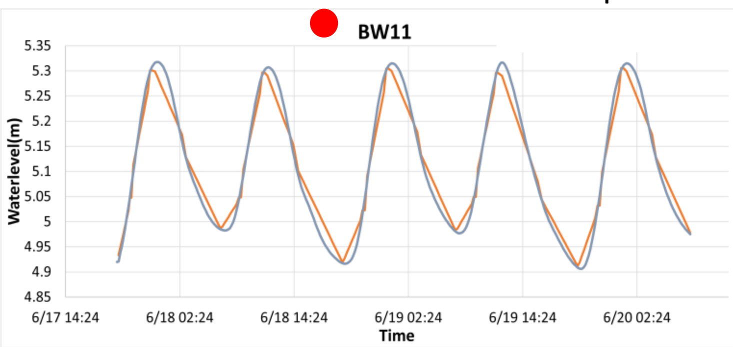
Fig. Simulation of in the flow field

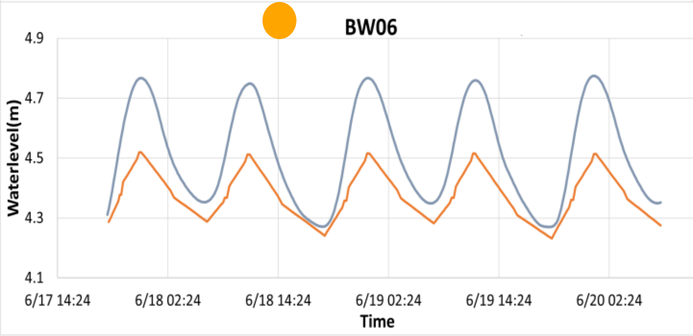
Flow field

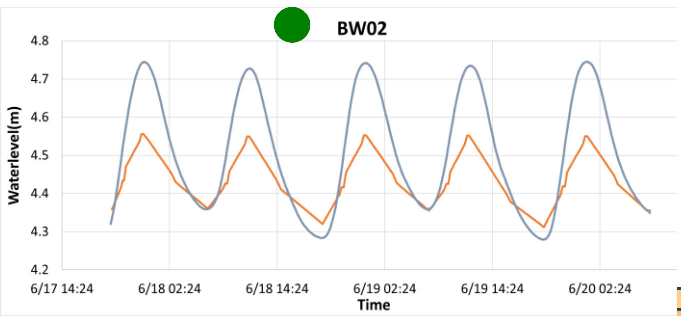


Observed
Computed

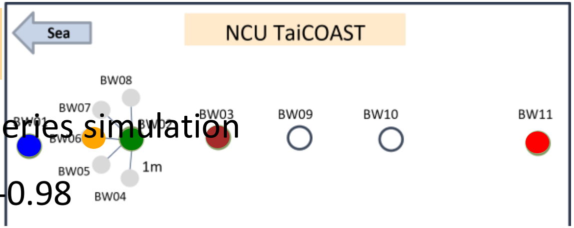


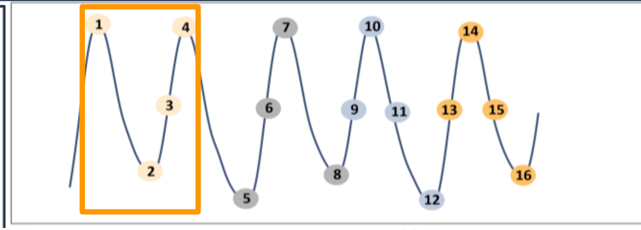






Flow field





Whole time series simulation

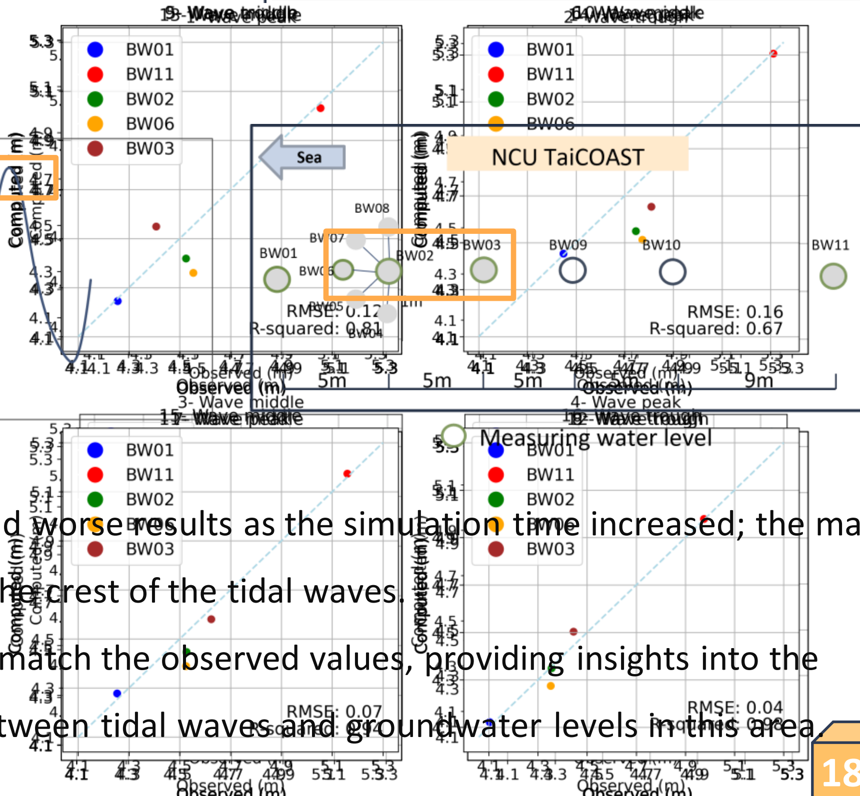
- R^2: 0.67-0.98
- RMSE : 0.04-0.16
- Most inaccurate : crest of tidal

Simulation of the 1st tidal wave

- R^2: 0.67-0.98
- RMSE : 0.04-0.16
- Most inaccurate : crest of tidal

shortage condition.

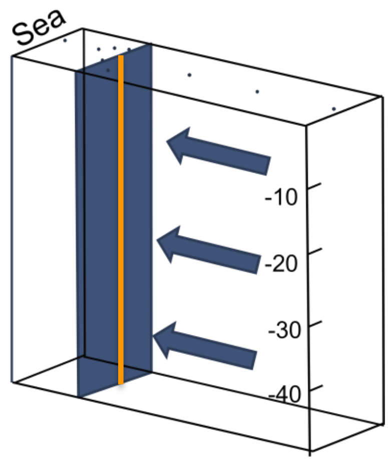
- Most inaccurate : crest of tidal

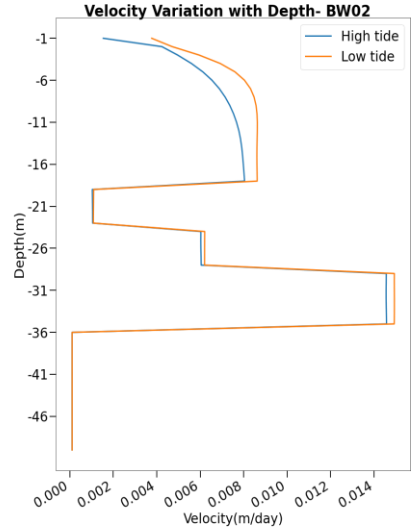


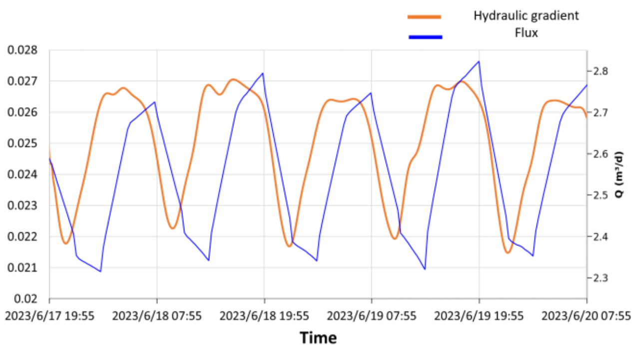
- Overall, the model did not yield worse results as the simulation time increased; the main discrepancy was observed in the crest of the tidal waves.
- The simulation results closely match the observed values, providing insights into the dynamic exchange process between tidal waves and groundwater levels in this area.

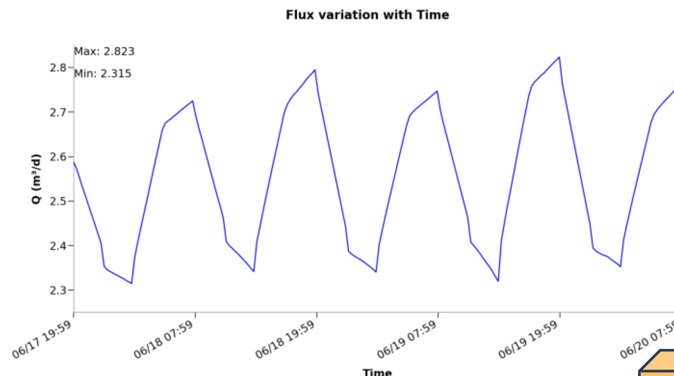
Flow field

- The velocity and flux in this area is also influenced by tides, it shows lower value during high tides.
- The flux of the profile section is correspond to the hydraulic gradient in this area.



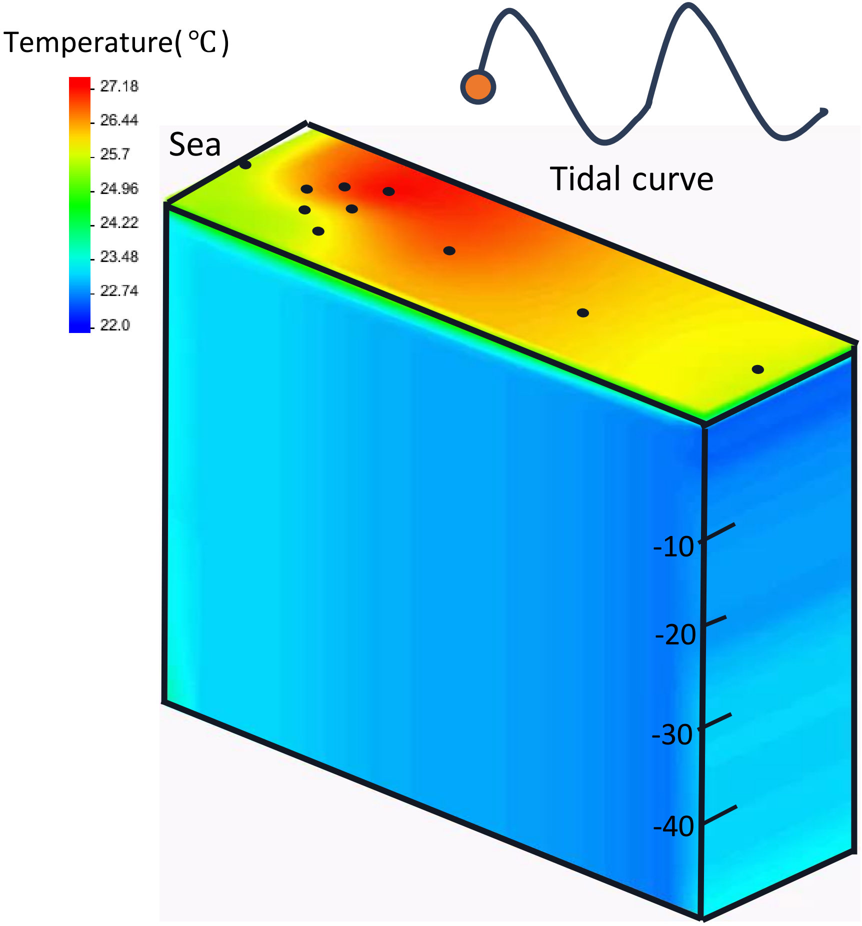




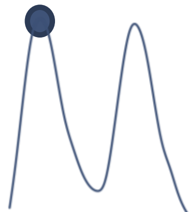


Temperature field

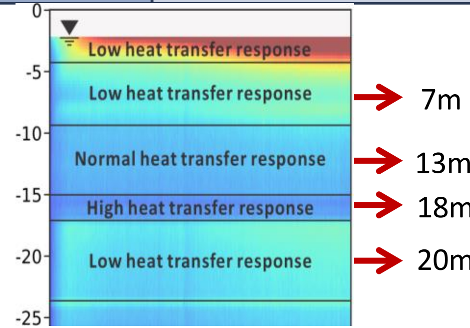
- The results indicate that temperatures in this area are not influenced by tides.
- However, the temperature field better illustrates the layered flow characteristics compared to the flow field.
- Excluding the upper heat storage layer, the groundwater temperature in this area is approximately between 22 ℃ and 23.5℃



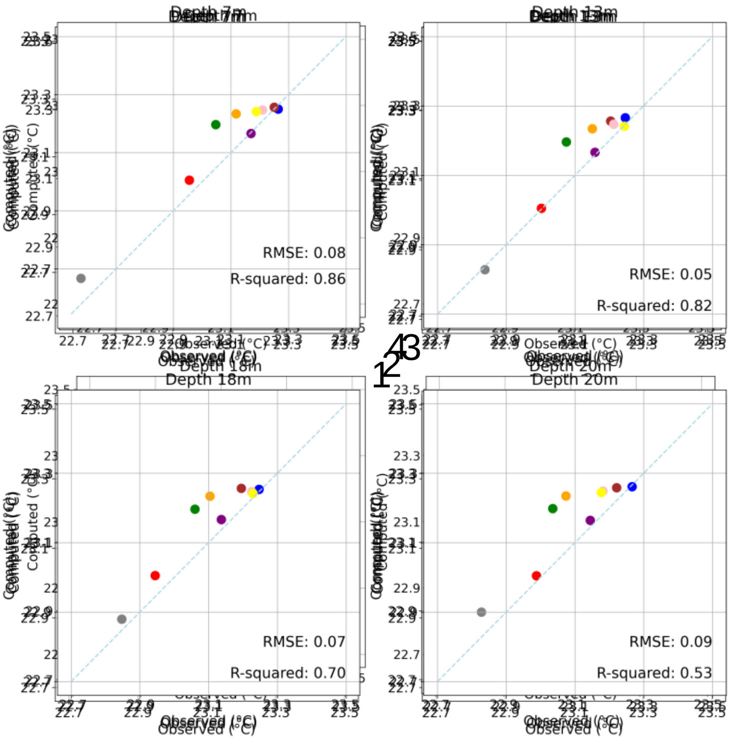
Temperature field



Tidal curve



(許家毓, 2023)



Simulation of Crest position of tidal curve

- R^2: 0.53-0.86
- RMSE : 0.05-0.09
- Most inaccurate : 20m

(Low heat transfer response)

Conclusion

- Overall, the **flow field** model did not yield worse results as the simulation time increased; the main discrepancy was observed in the crest of the tidal waves.
- The velocity and flux in this area is also influenced by tides, it shows lower value during high tides , revealing a difference of 0.5 (m^3/d) due to tidal effects..
- The result shows that **temperatures** in this area are not influenced by tides.
- The simulation results in the **temperature field** shows that the R^2 values range between 0.35 and 0.86. The RMSE values range between 0.13 and 0.08.
- However, the temperature field better illustrates the layered flow characteristics compared to the flow field.

Future work

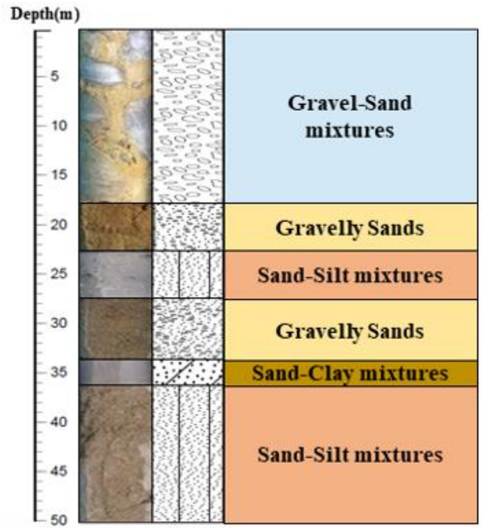
Future work

- Calibrate and validate the temperature simulation to make it more consistent with the observed data.
- Simulating the heating test and then use the temperature simulation to compute the layered groundwater outflow fluxes in this area.

Thank you for listening

Thermal Property Analyzer

- **Interpreting geological materials and measuring thermal parameters by core sample.**



Depth	0-18.0m	18.0-22.5m	22.5-26.7m	27.5-34.0m	34.0-36.0m	36.0-50.0m
Diffusivity(D)	0.35	0.435	0.335	0.494	0.494	0.609
Volume heat capacity(C)	2.645	1.282	2.2	2.907	1.909	2.913
Thermal conductivity(K)	1.976	0.655	0.8	0.55	0.943	1.773

Depth	0-18	18-22.5	22.5-26.7	27.5-34	34-36	36-50		
Thermal conductivity	1.976	0.655	0.8	0.55	0.943	1.733	porosity	0.3
DMCOEF	1.34826E-06	4E-07	5.45855E-07	3.75275E-07	6.43427E-07	1.18246E-06	density	99
							heat capacity	420

	K(m/d)
0~13m	1.885
14~17m	0.573
18~21m	0.678