Using the THMC model to simulate groundwater flow beneath the laterite layer in the Taoyuan area and the impact of ponds

Presenter: Li-Yuan Hsu
Advisor : Prof. Jui-Sheng Chen
Date : 2024/10/04

OUTLINE

01

Introduction

02

Methodology

03

Preliminary Results

04

Conclusions
Future work

- The increasing frequency of extreme hydrological events, coupled with the uneven distribution of rainfall in Taiwan and the pressure on water demand brought about by urban development, has made the search for and development of alternative water resources more urgent.

- The groundwater model allows for the exploration of groundwater usage, available water resources, and control measures, with the aim of achieving sustainable water resources through reasonable use and regulation

- Groundwater models play an important role in the development and management of groundwater resources, and in predicting effects of management measures.

  - as interpretative tools for investigating groundwater system dynamics and understanding the flow patterns.

Literature reviews

Zhou et al. (2011). Provide a comprehensive review of the methodologies and applications of regional groundwater flow models and They highlight the challenges in capturing the complexities of groundwater systems

Hill et al. (2006). Starting with a simple model and gradually increasing its complexity based on available data and model predictions helps to better understand the underlying hydrological processes

Objective

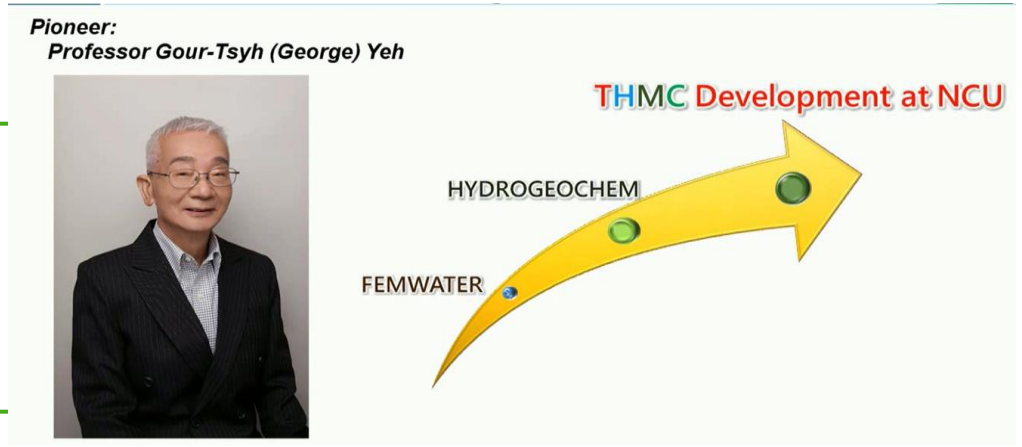
Using the THMC numerical model to simulate groundwater flow in the Taoyuan area and

investigate the region unique hydrological characteristics.

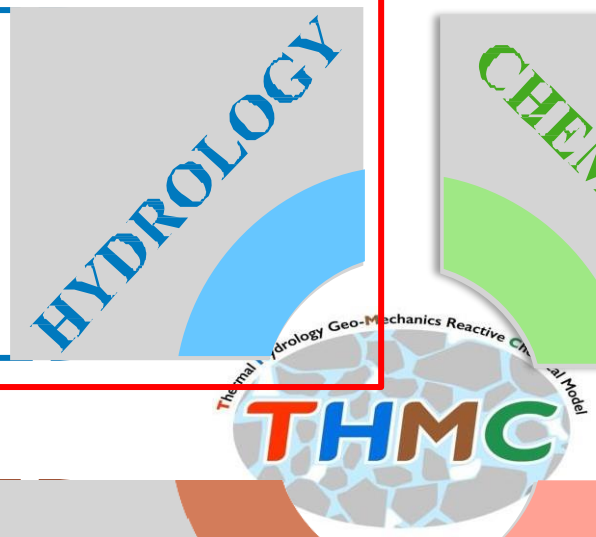
To provide a clear explanation of groundwater flow movements, focusing on the processes of infiltration after rainfall, evapotranspiration, and the assessment of available water quantity, while examining the role of ponds in influencing these dynamics.

THMC software application

- ✓ Wide application
- ✓ Graphical Users Interface (GUI) display
- ✓ Accurately predict subsurface process



- Groundwater management
- Groundwater recharger



- Water quality assessment
- Seawater intrusion
- Land utilization management

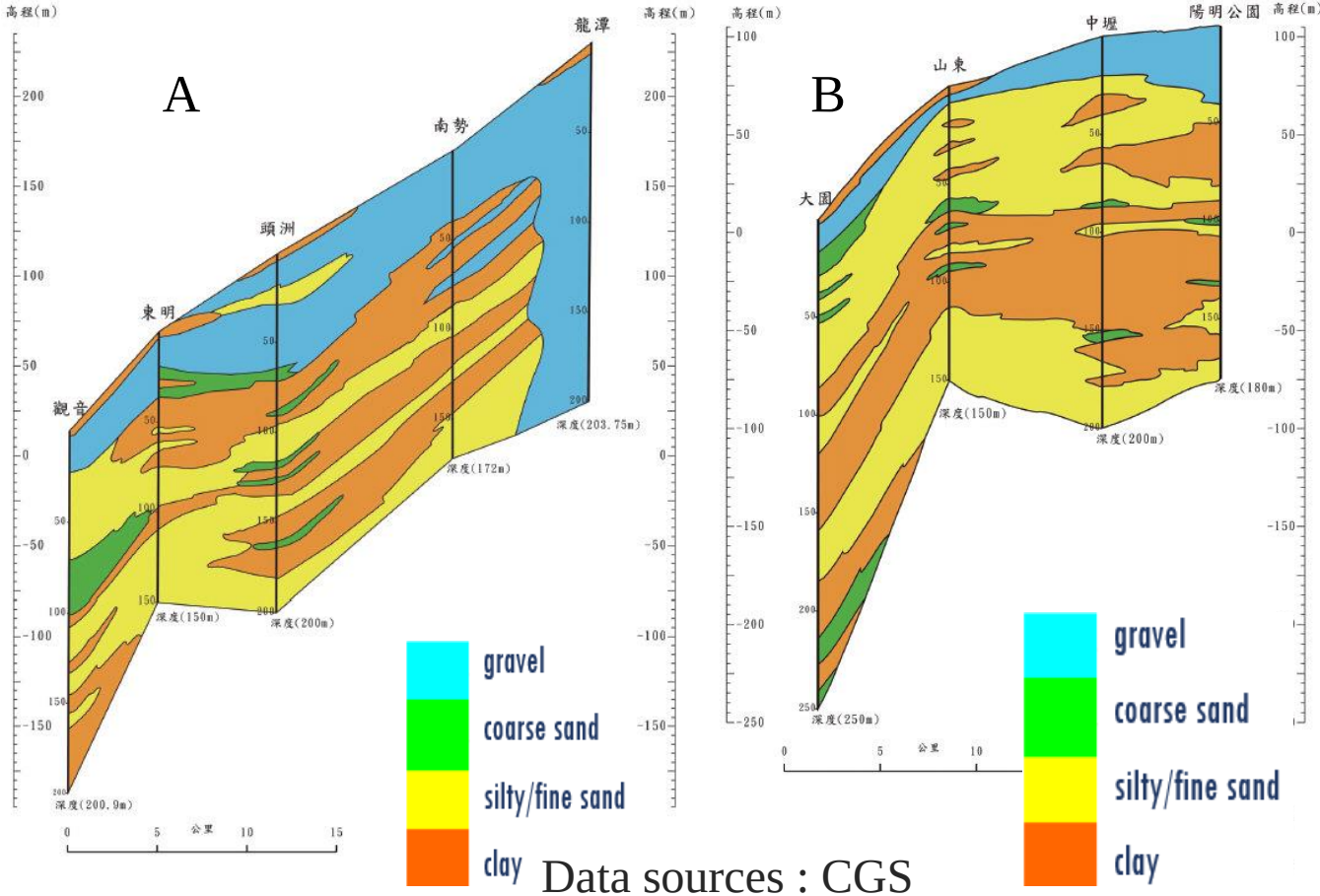
- Slope area management
- Subsidence assessment
- Conservation of soil and water assessment

- Hot spring groundwater
- Geothermal energy

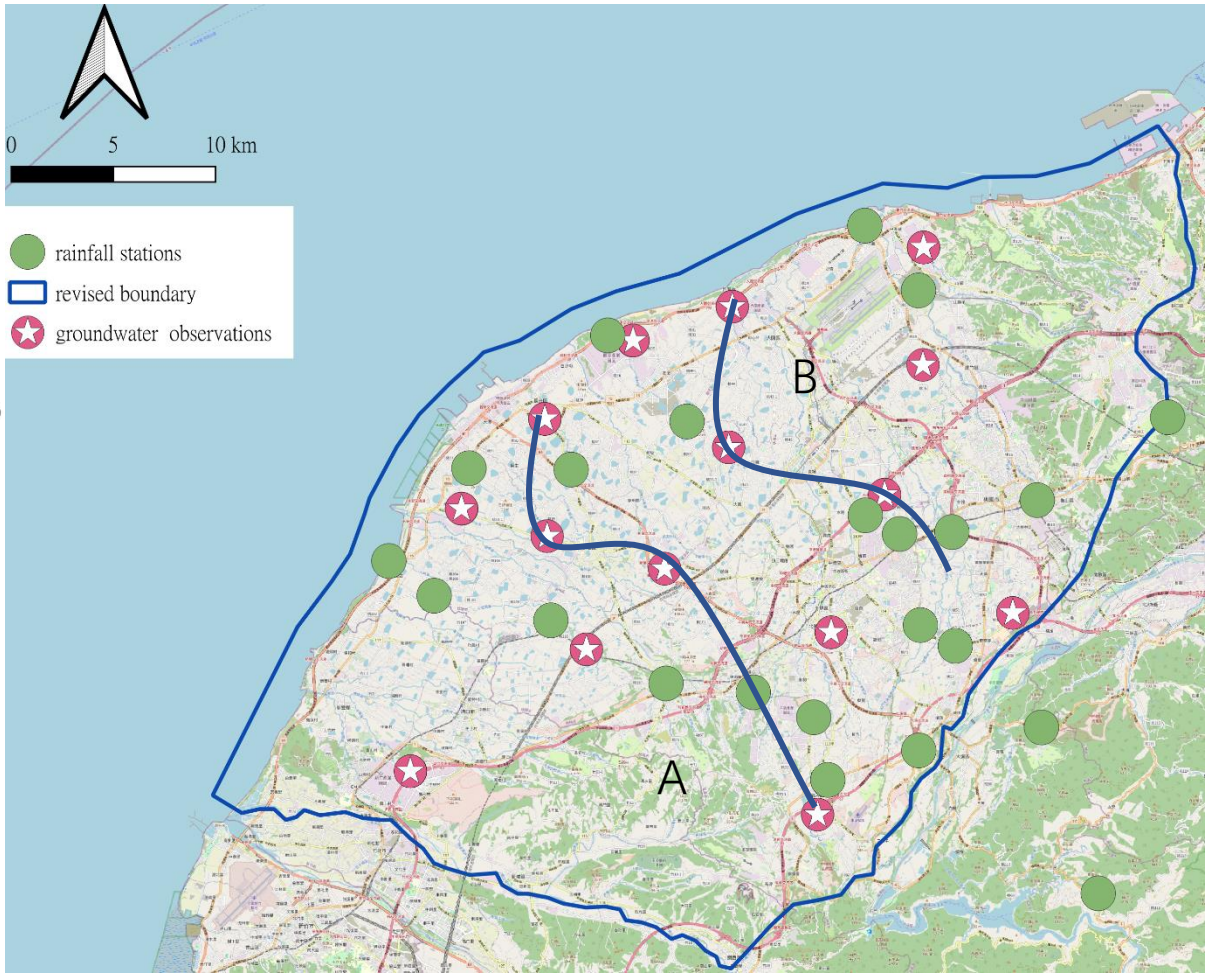
Study area – Taoyuan

- 1220 km^2
- High annual rainfall rate

  Average Annual Rainfall : 1,500 - 2,000 mm

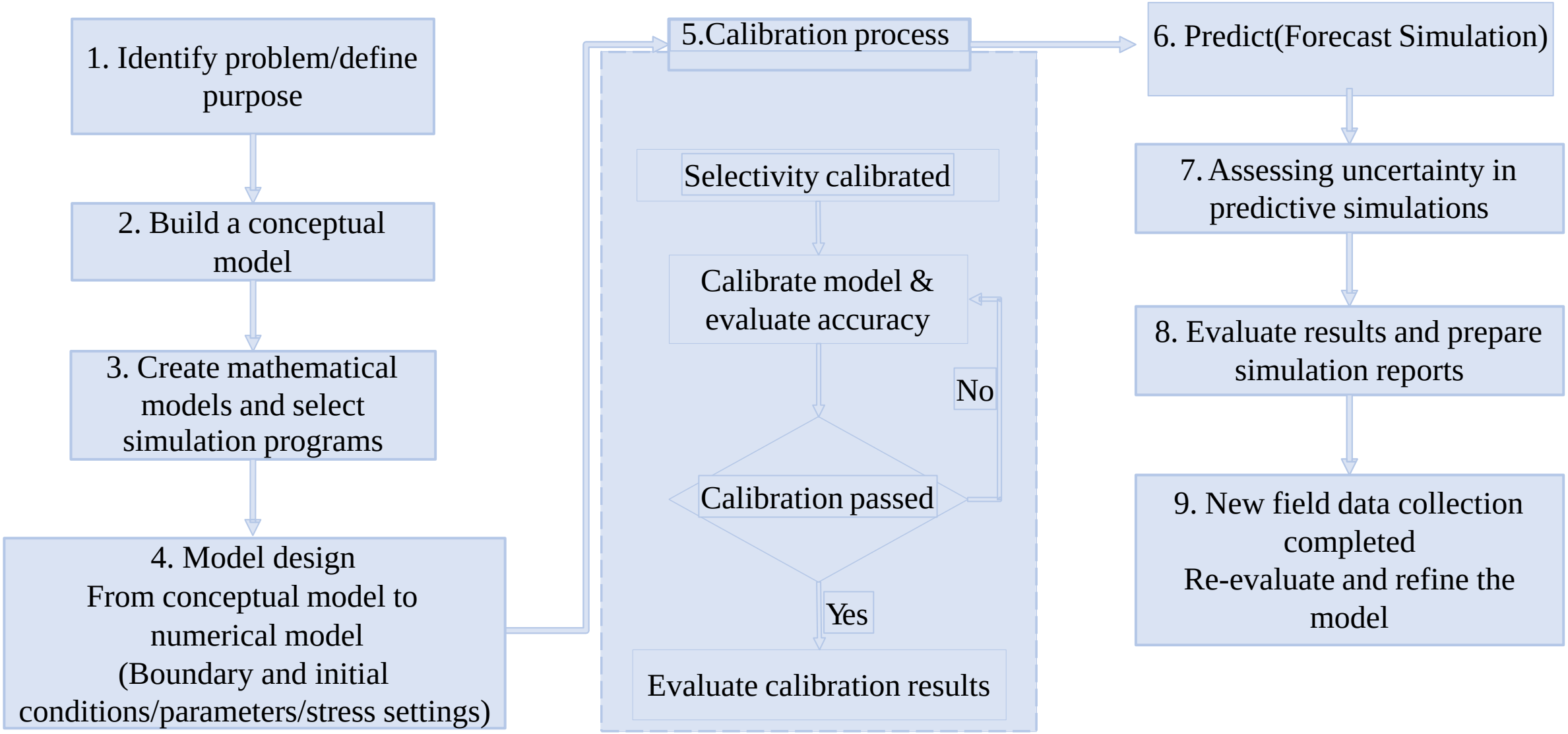


Data sources : CGS



- Aquifer: high permeable coarse sediment.
- Aquitard: low permeable fine sediments.
- Laterite Layer: Located on the surface about 3 - 5 meters.

Flow chart


1. Identify problem/define purpose
2. Build a conceptual model
3. Create mathematical models and select simulation programs
4. Model design
From conceptual model to numerical model
(Boundary and initial conditions/parameters/stress settings)
5.Calibration process
Selectivity calibrated
Calibrate model & evaluate accuracy
No
Calibration passed
Yes
Evaluate calibration results
6. Predict(Forecast Simulation)
7. Assessing uncertainty in predictive simulations
8. Evaluate results and prepare simulation reports
9. New field data collection completed
Re-evaluate and refine the model

Governing equation

Governing equation for flow through saturated-unsaturated media using in software follow below equation:

$$\frac{\rho}{\rho_0} F \frac{\partial h}{\partial t} = \nabla \cdot \left[K \cdot \left(\nabla h + \frac{\rho}{\rho_0} \nabla Z_0 \right) \right] + \frac{\rho^*}{\rho_0} \mathrm{q} \qquad \text{(Yeh et al., 1994a, 1994b)}$$

θ: effective moisture content (L^3/L^3) h: pressure head (L)
t: time (T)
z: potential head (L)
q: source/sink of fluid [$(L^3/L^3)/T$]
ρ : referenced fluid density at zero chemical concentration (M/L^3)
ρ: fluid density with dissolved chemical concentrations (M/L^3)
ρ^*: fluid density of either injection (ρ^*) or withdraw (= ρ)

μ_0: fluid dynamic viscosity at zero chemical concentration ($M/L\ /T$)
μ: fluid dynamic viscosity with dissolved chemical concentrations (($M/L\ )/T$)
α': modified compressibility of the soil matrix (1/L)
β': modified compressibility of the liquid (1/L)
n_e: effective porosity (L^3/L^3)
S: degree of effective saturation of water g: gravity (L/T^2)
k: permeability tensor (L^2)
$\boldsymbol{k_s}$: saturated permeability tensor (L^2)
$\boldsymbol{K_{so}}$: referenced saturated hydraulic conductivity tensor (L/T)
k_r: relative permeability or relative hydraulic conductivity (dimensionless)

F: generalized storage coefficient (1/L)

$$F = \alpha' \frac{\theta}{n_e} + \beta' \theta + n_e \frac{dS}{dh}$$

K : hydraulic conductivity tensor (L/T)

$$K = \frac{\rho g}{\mu} \mathrm{k} = \frac{\frac{\rho}{\rho_0} \rho 0 g}{\frac{\mu}{\mu_0} \mu 0} \mathrm{K}_s k_r = \frac{\frac{\rho}{\rho_0}}{\frac{\mu}{\mu_0}} \mathrm{K}_{so} k_r$$

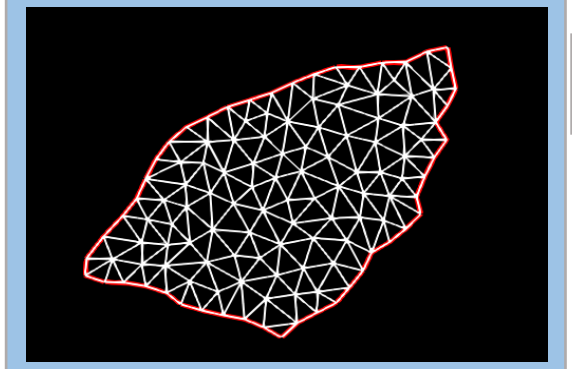
Darcy's velocity (L/T)

$$V = -K \cdot \left(\frac{\rho_0}{\rho} \nabla h + \nabla Z_0 \right)$$

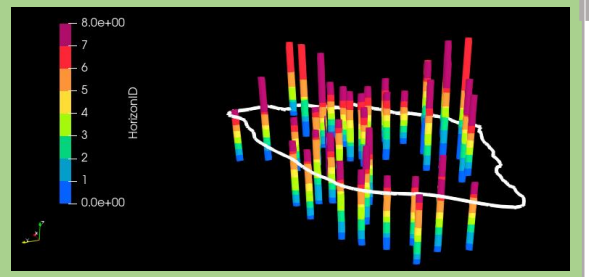
Mesh generation

- Algorithm in Alan M. Lemon(2003) to construct geological model

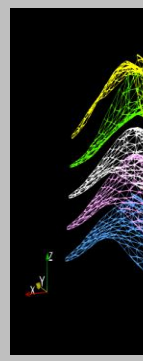
Simplified boundary (ESRI Shapefile)



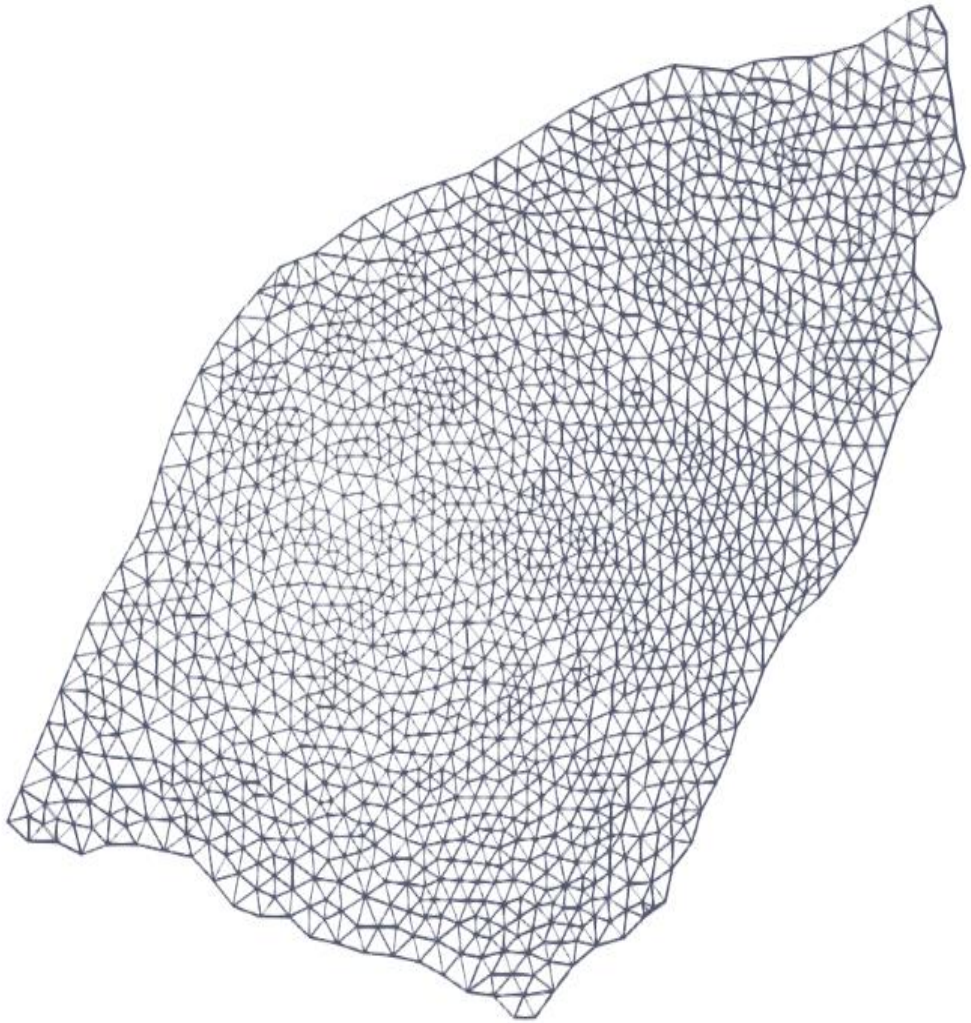
well logging (Borehole Data)



2D r



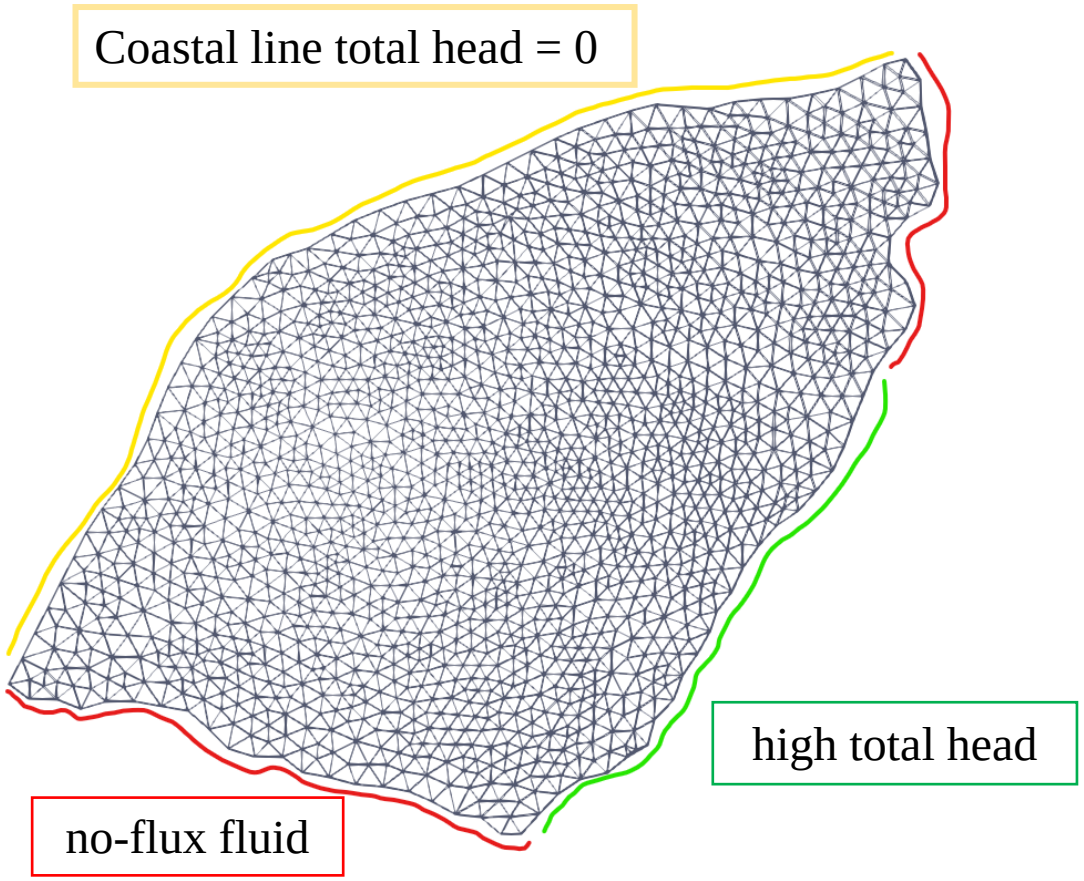
Import shapefile → Import borehole data → Cons



Mesh Info.	
	❖ system of triangular prism
	❖ 37,506 nodes
	❖ 69,360 elements (3468/layer*20 layers)

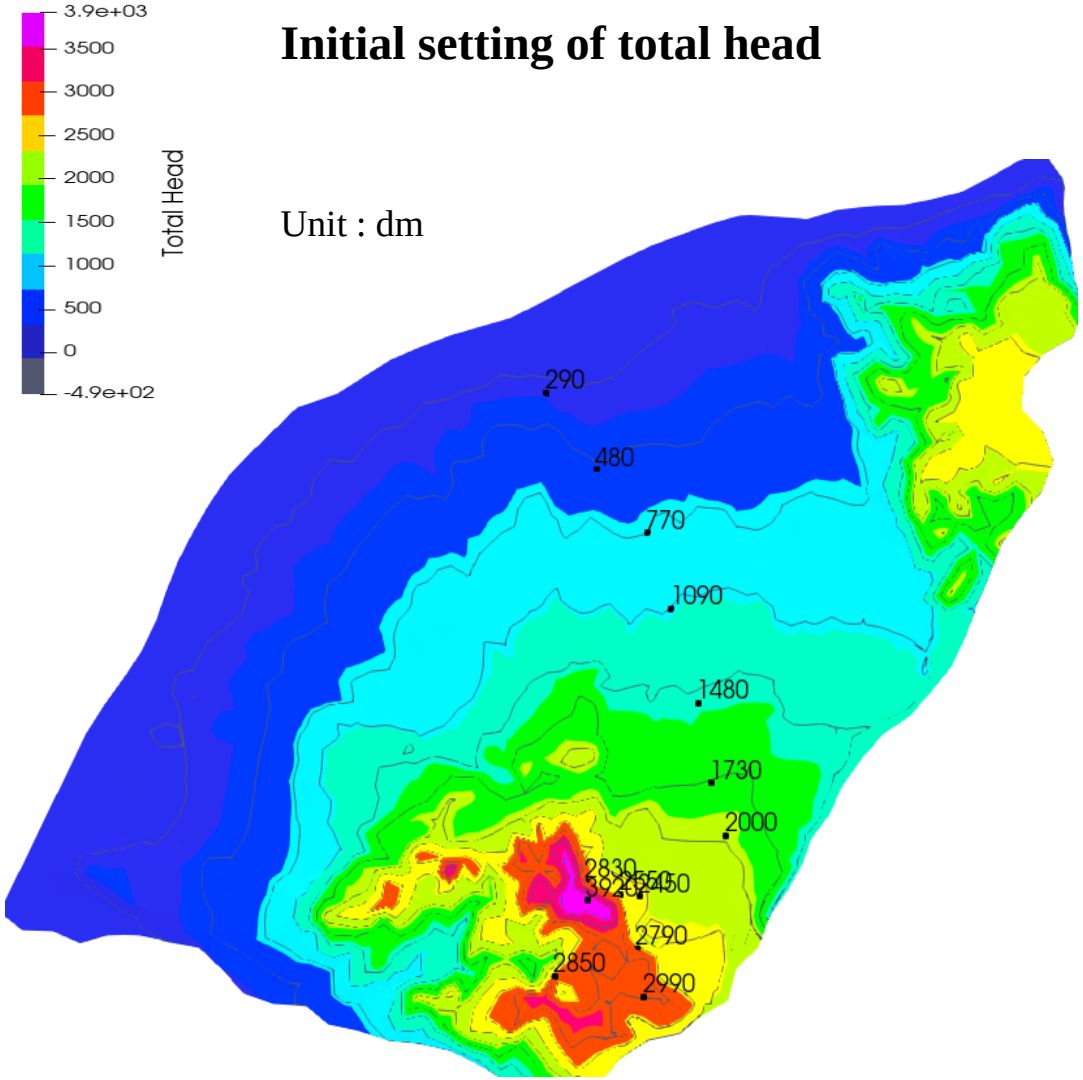
Boundary Conditions

Steady-state simulation for Initial condition

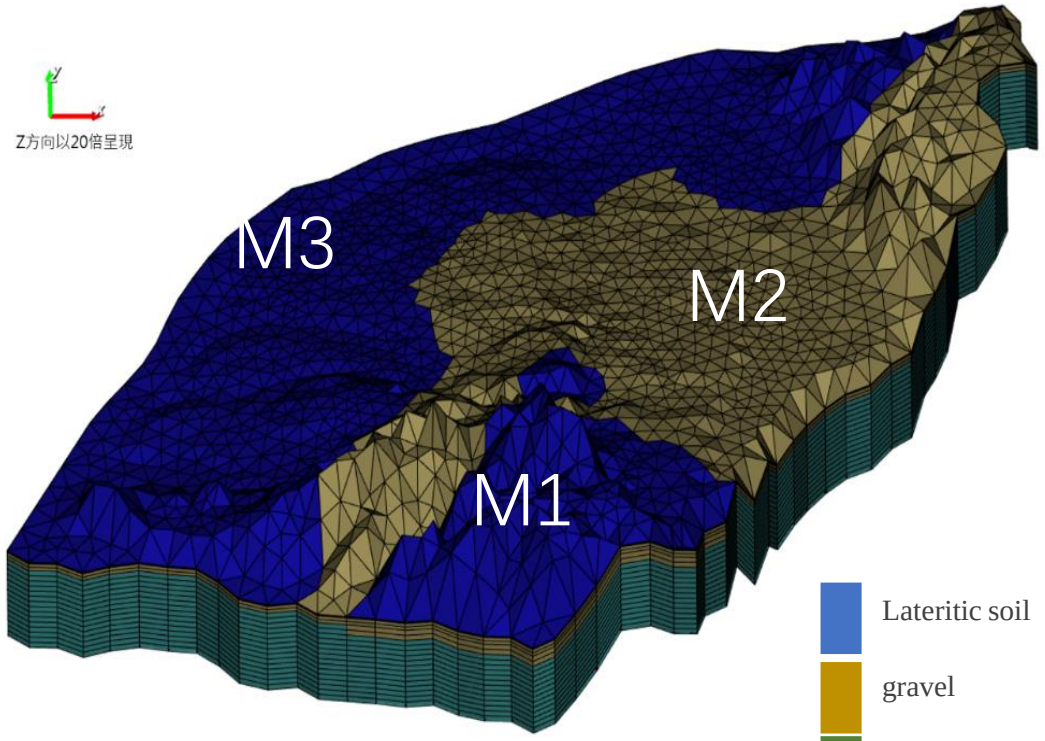


- ✓ Dirichlet boundary condition
- ✓ Rainfall : variable BC

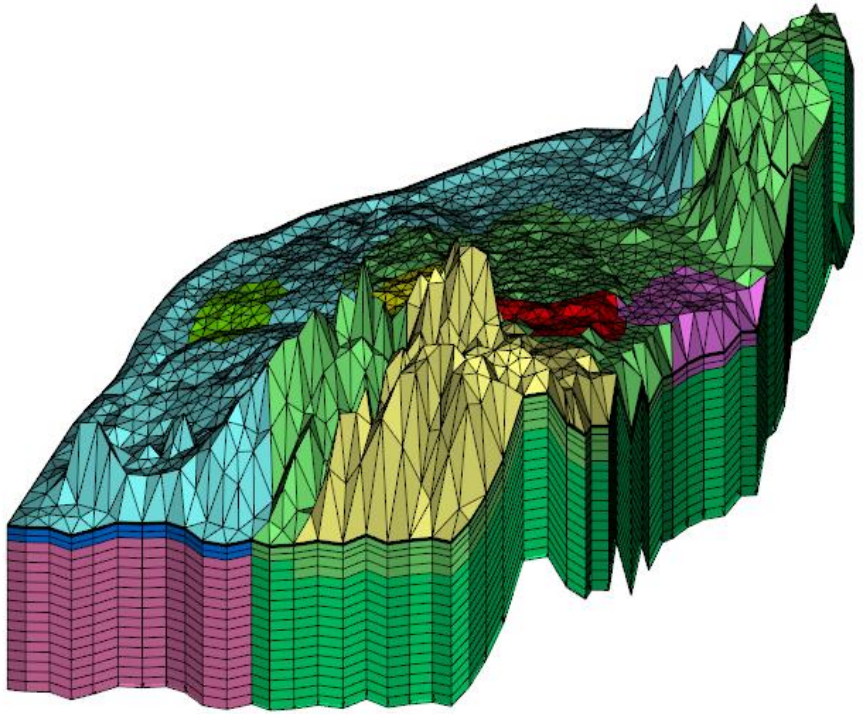
Initial setting of total head



Hydraulic conductivity (K)



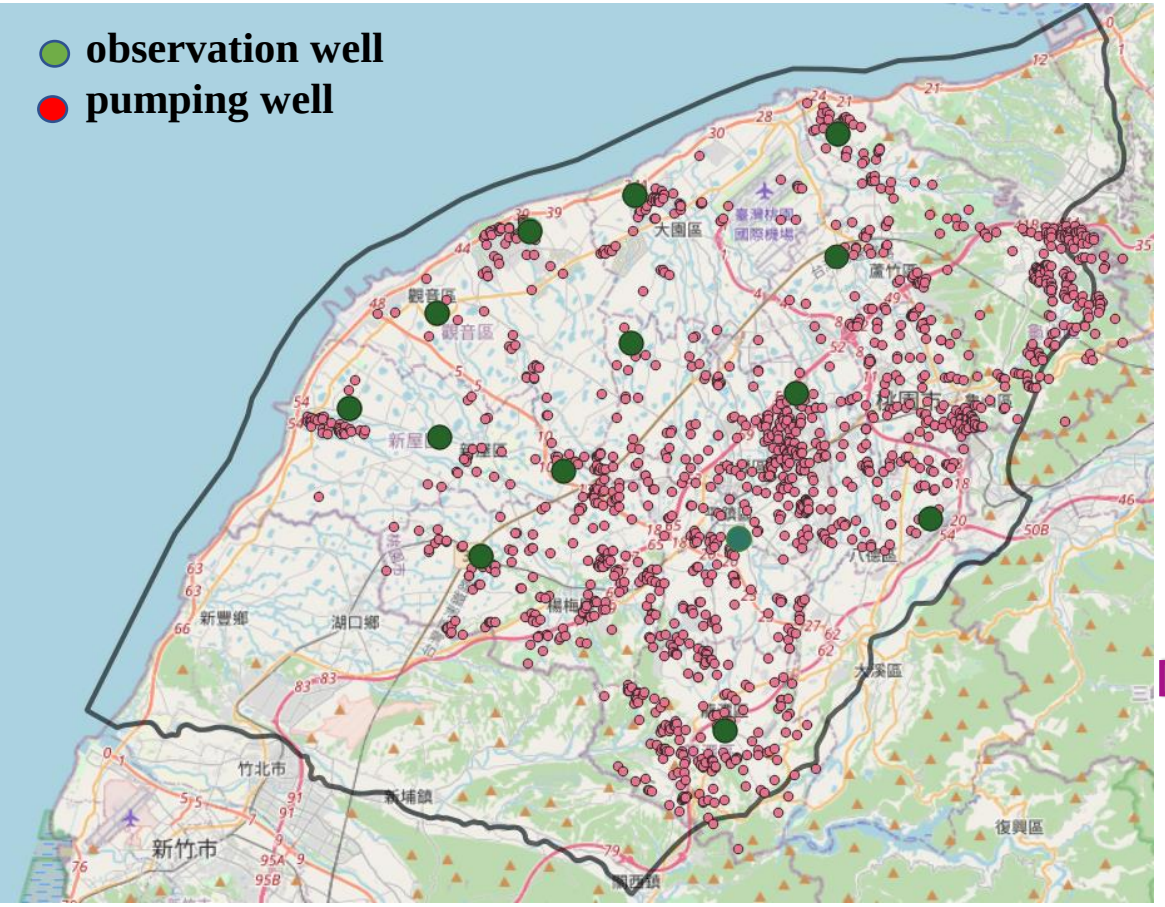
Subdivision with surface material



Soil material	classify	Kxx (m/sec)	Kyy (m/sec)	Kzz (m/sec)
M1	gravel	0.0085	0.0085	0.00015
M2	gravel	0.01	0.01	0.00005
M3	silt	0.00001	0.00001	0.0000003
M4	silt	0.001	0.001	0.00001
M5	silt	0.0005	0.0005	0.00001
M6	silt	0.0008	0.0008	0.0000005
M7	gravel	0.009	0.09	0.00003
M8	gravel	0.011	0.011	0.00005
M9	gravel	0.012	0.012	0.00004
M10	silt	0.001	0.001	0.00003

Data input (Transient simulation)

pumping data

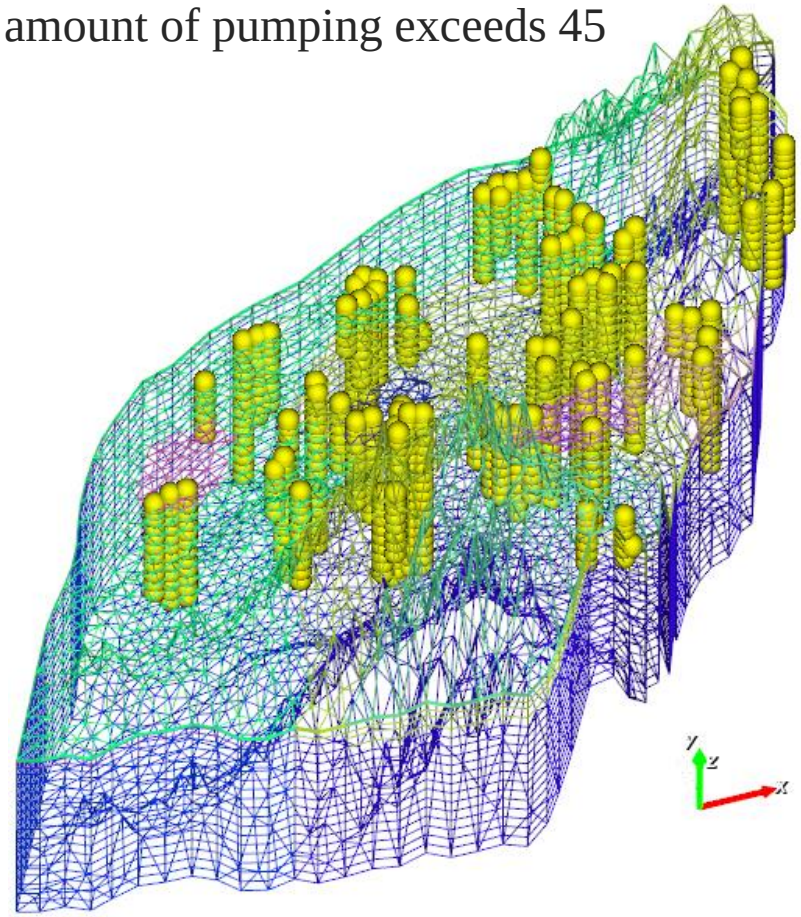


- **Taoyuan Pumping Data Distribution Map**

❖ Taoyuan: industrial and commercial city in Taiwan

❖ The average annual amount of pumping exceeds 45 million tons.

Digitalized results



❖ Search the nearest node for each pumping well, sum up the monthly amounts of pumping.

❖ 996 nodes for pumping wells.

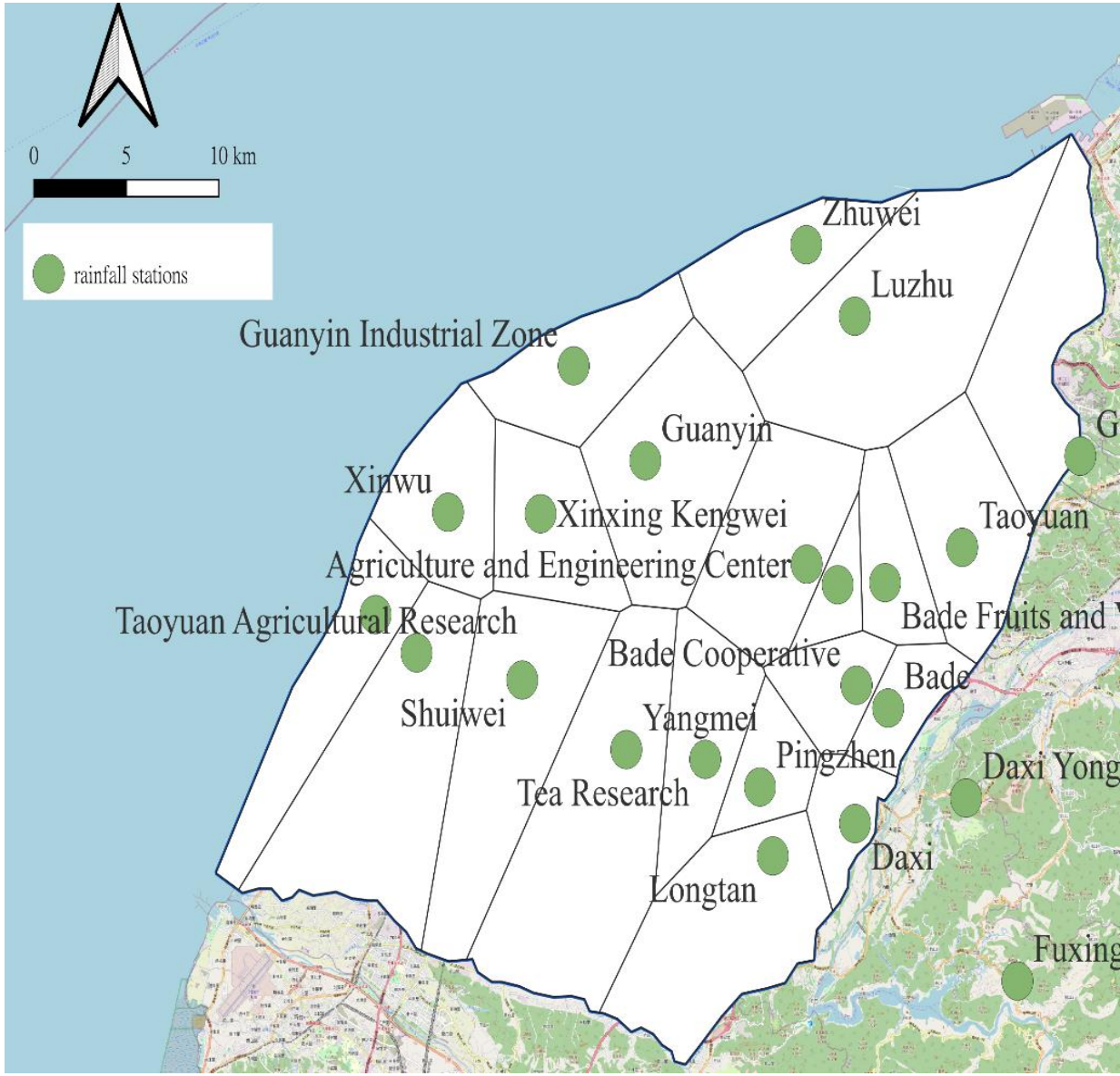
Data input (Transient simulation)

Rainfall setting

- Data from rainfall stations in Taoyuan

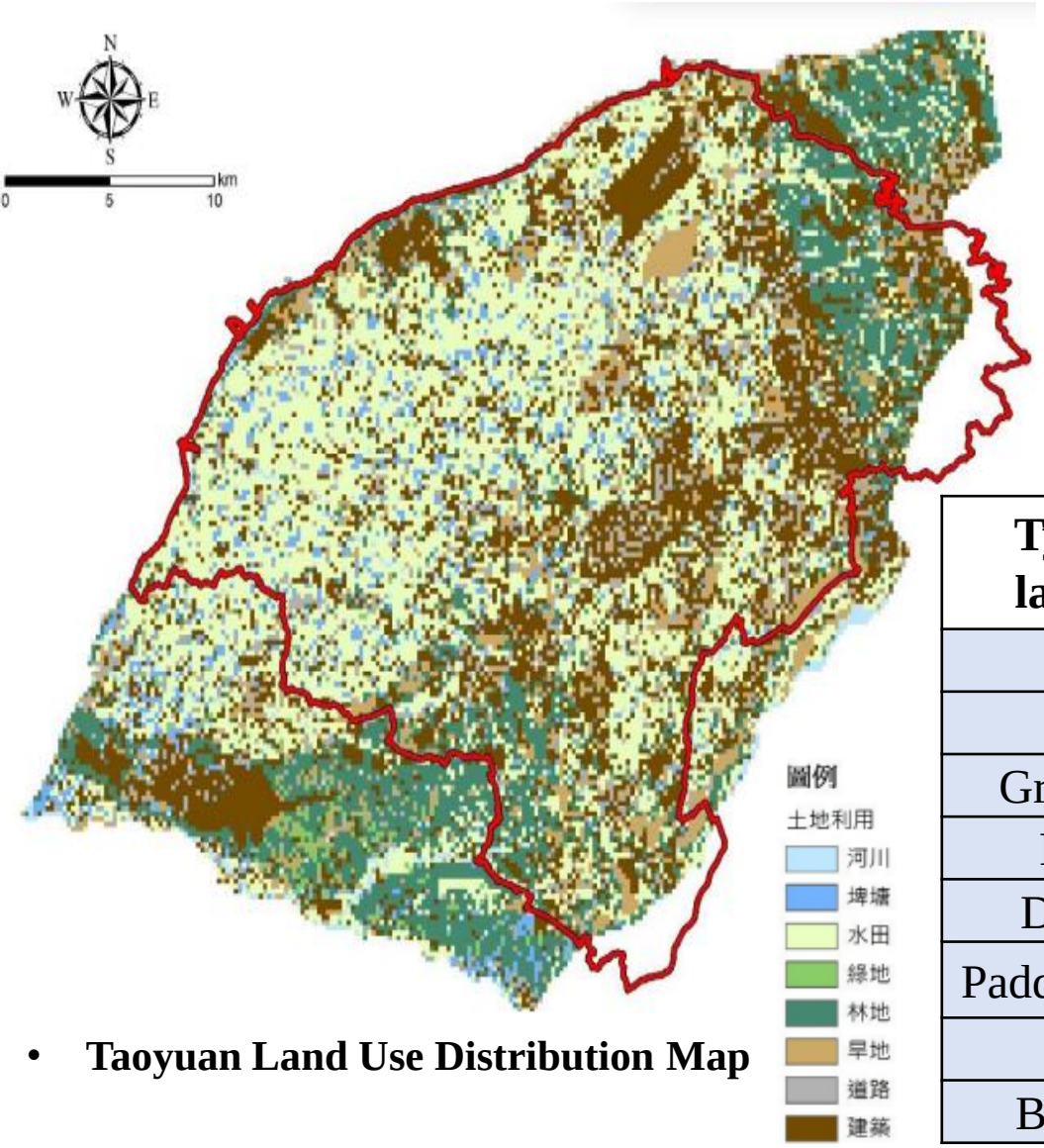
Name	Rainfall (mm)				
	2019	2020	2021	2022	2023
Agricultural research	2037.5	1078	1093	1784.5	1121
Tea Research	2560.5	1452.5	1551.0	2949.0	1351.5
Agriculture Center	1000.7	1001.5	1000.7	1000.6	1000.9
Bade	2497.5	1637.5	2082.	2780	1636
Bade Fruits Vegetables	--	1052.9	1148.5	2085.5	1308.5
Fuxing	2850.5	1936.0	2560.5	3112.5	2190.5
Taoyuan	2199.5	1560	1676	2602.0	1088
Bade	2497.5	1637.5	2082	2780	1636
Guanyin	2412	1497	1244	2313	1177
Luzhu	2054.5	1399.5	1356.5	2226	1030
Daxi	2161.5	1523	1841	2693	1562
Pingzhen	2005.5	1059	1428	2888	1238
Yangmei	2396.5	1315	1564	2648	1396.5
Longtan	2566	1707	1922	3087	1771
Guishan	2357	1687	1572	2770	1464
Zhongli	2214	1478	1518	2459	1202
Daxi Yongfu	2535	1696	2409	3072	2102
Zhuwei	-	-	-	1389	886
NCU Coastal Station	-	-	-	1610	1245
Guanyin Industrial Zone	-	-	-	1856	1174

- Thiessen's Polygon Method : 21 regions



Data input (Transient simulation)

Impermeable elements

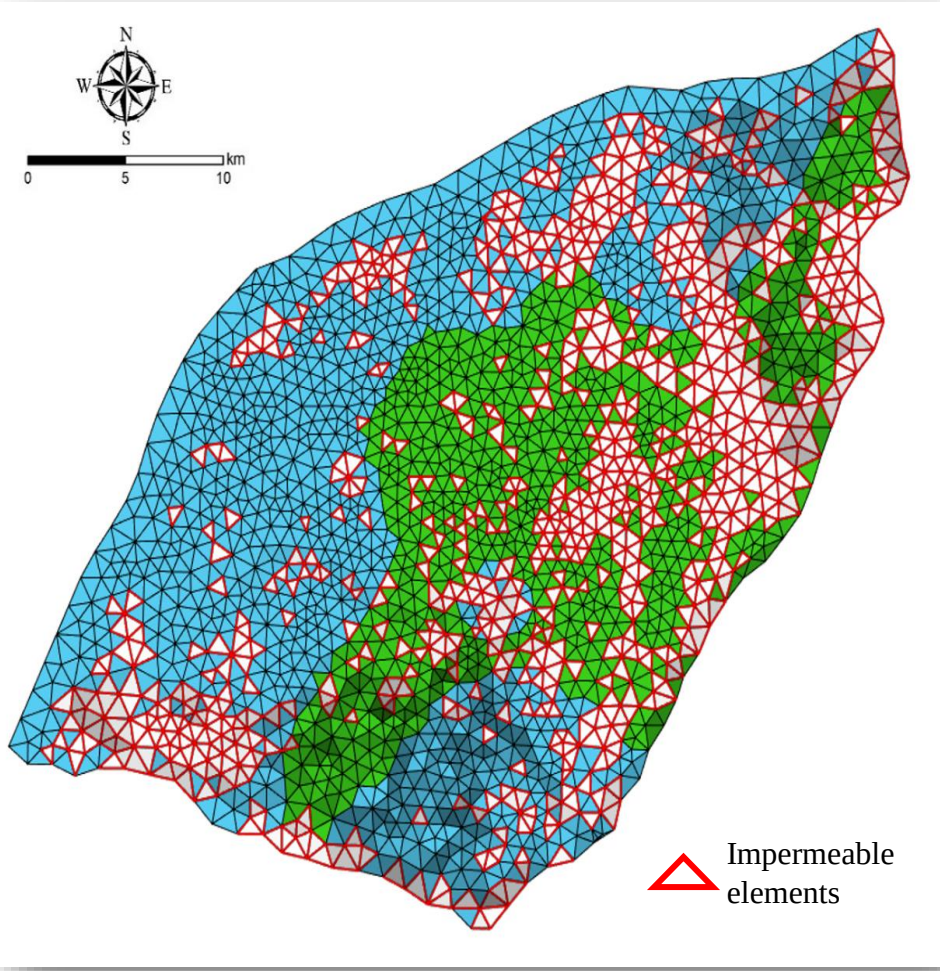


- **Taoyuan Land Use Distribution Map**

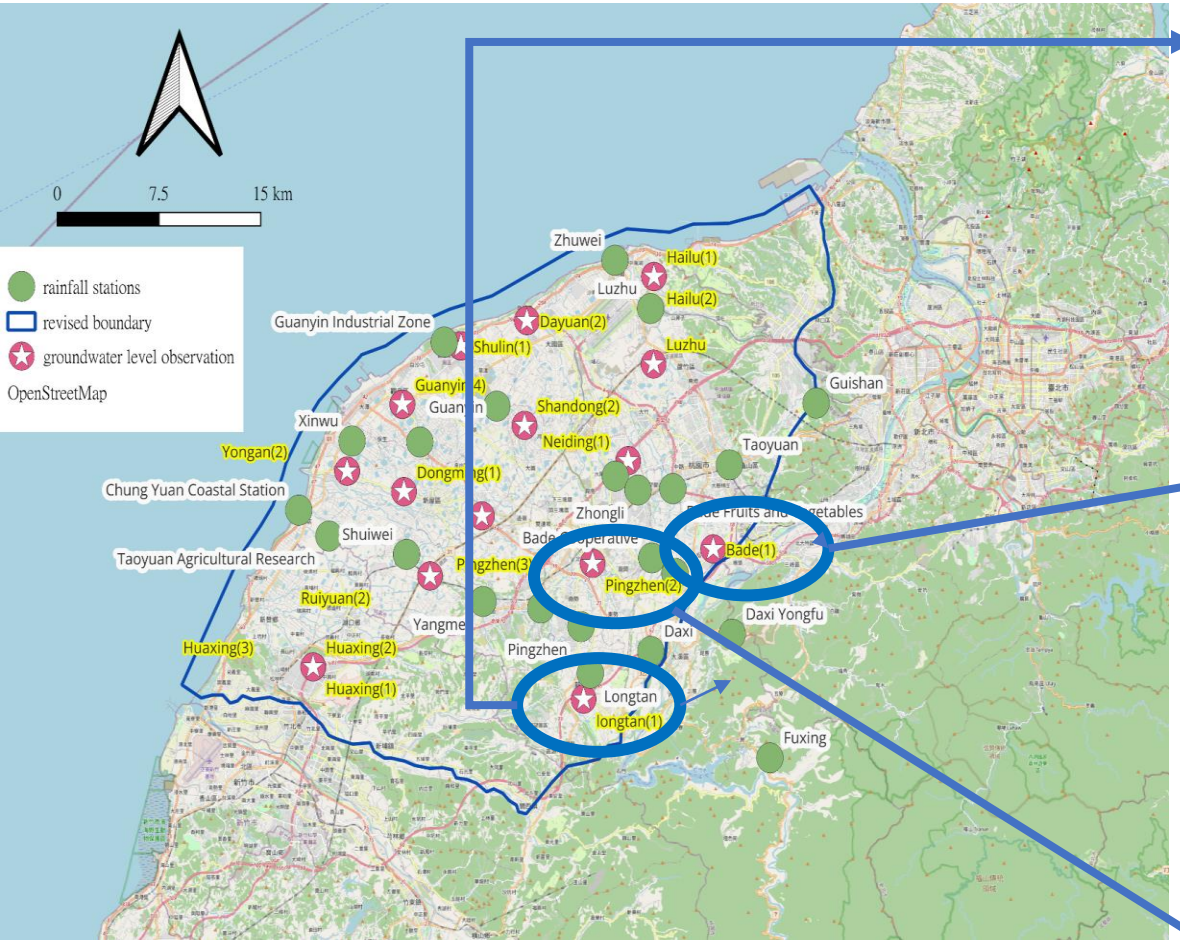
❖ Analysis of land use:

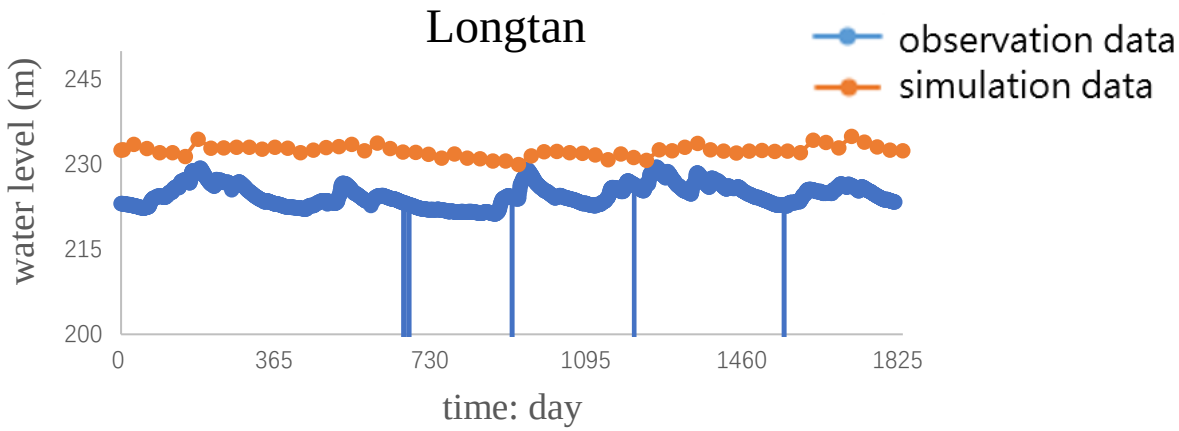
For surface elements covered by road and building, water from precipitation does not become recharge.

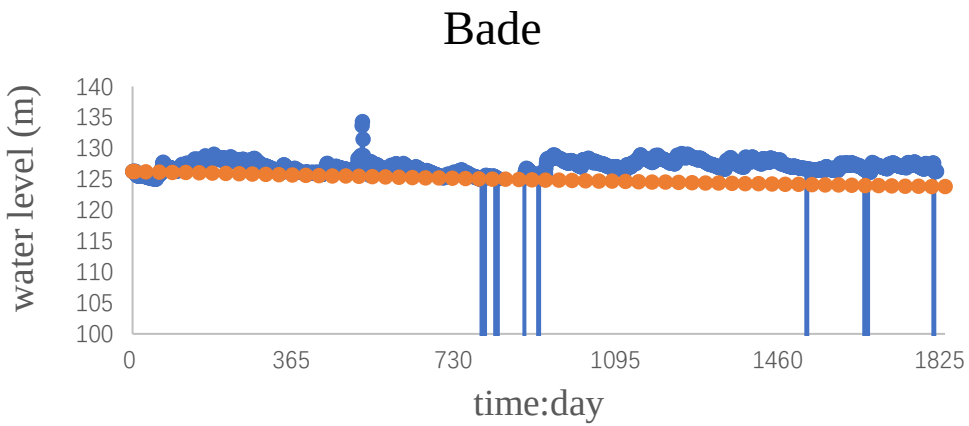
Types of land use	Types of permeability
River	River and pond
Pond	
Grass area	Permeable
Forest	
Dryland	
Paddy field	Paddy field
Road	Impermeable
Building	

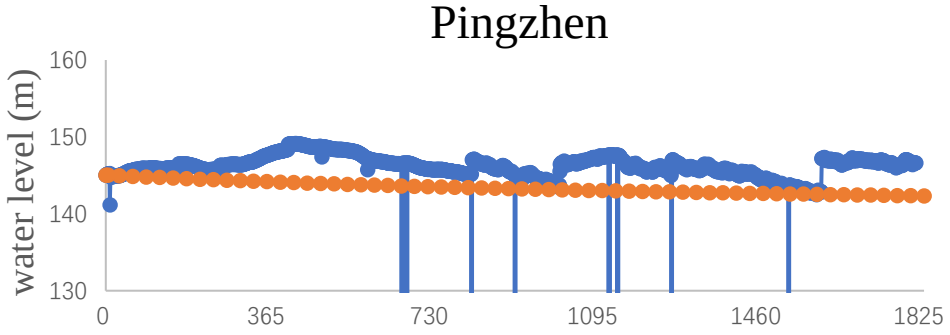


Comparison between observation data and simulation data from 2019 –2023 (TS)



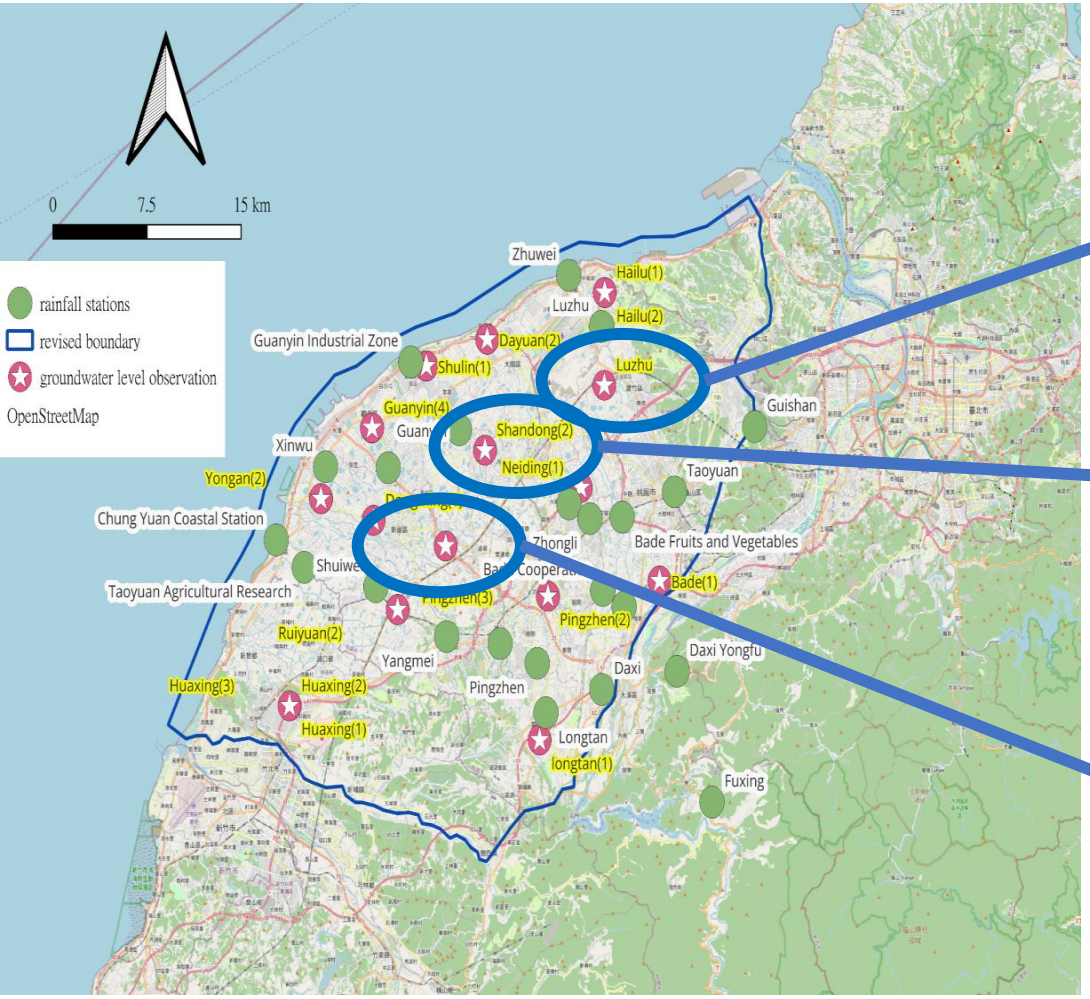


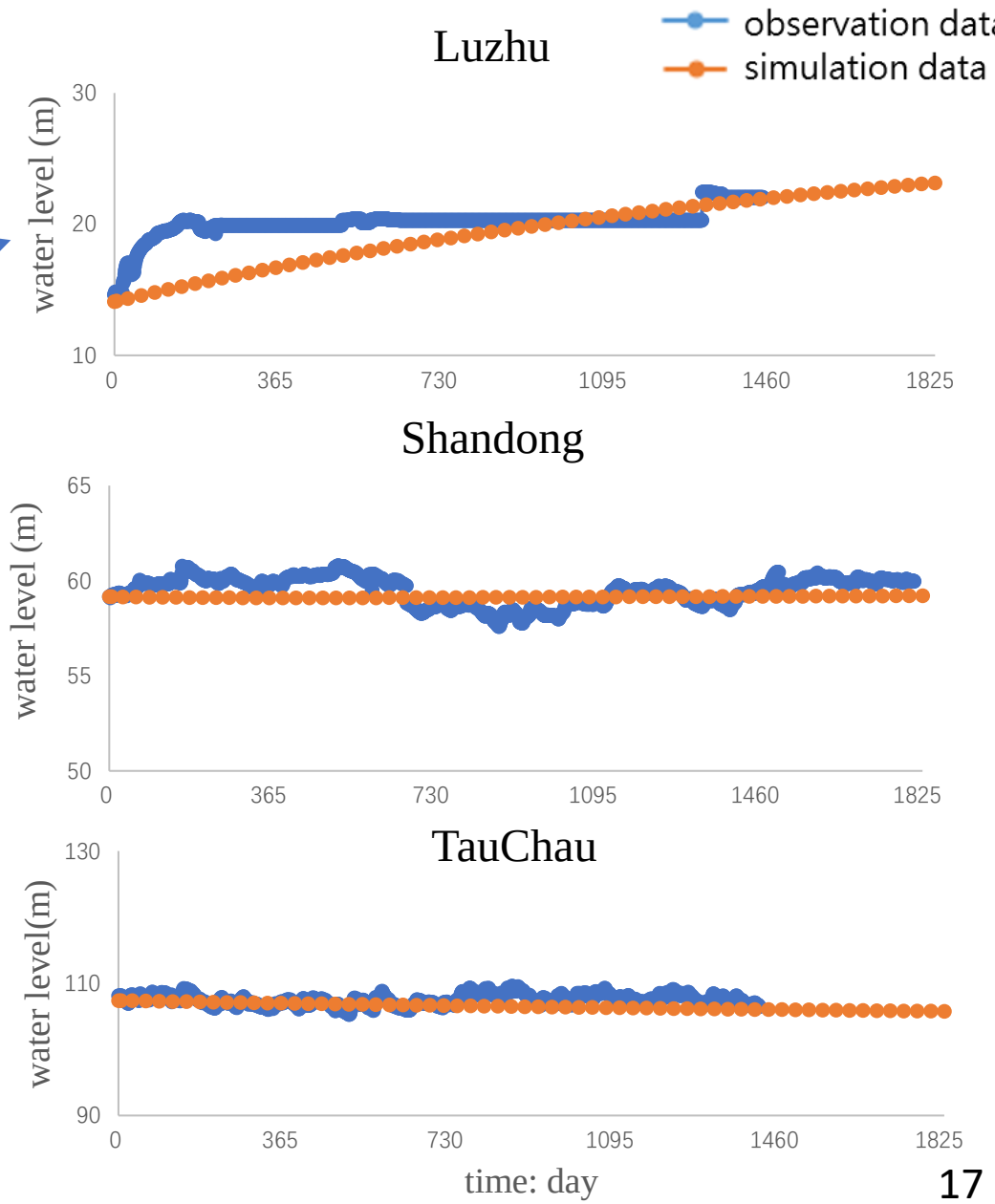




- Better simulation results are still needed for Pingzhen and Longtan.

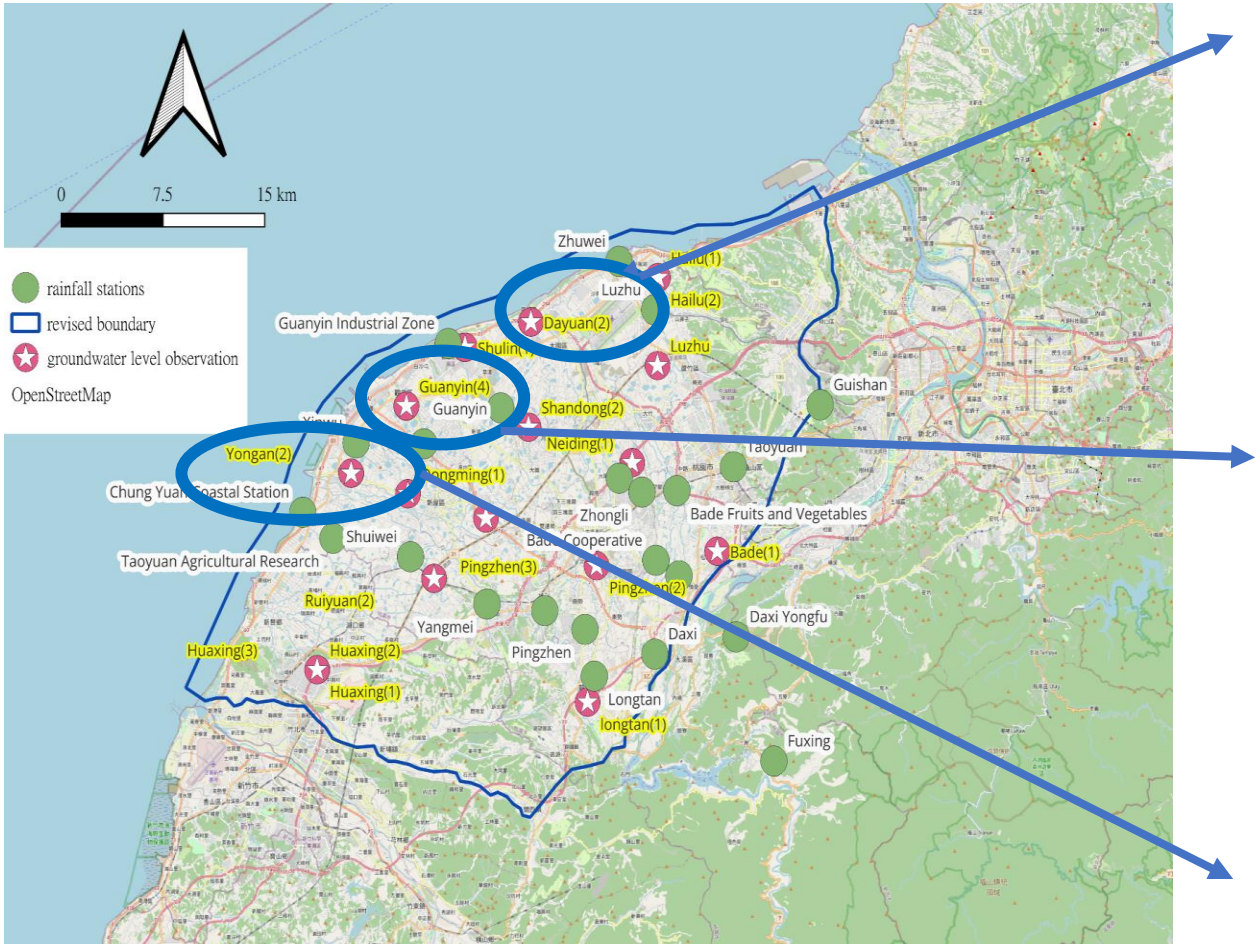
Comparison between observation data and simulation data from 2019 –2023 (TS)

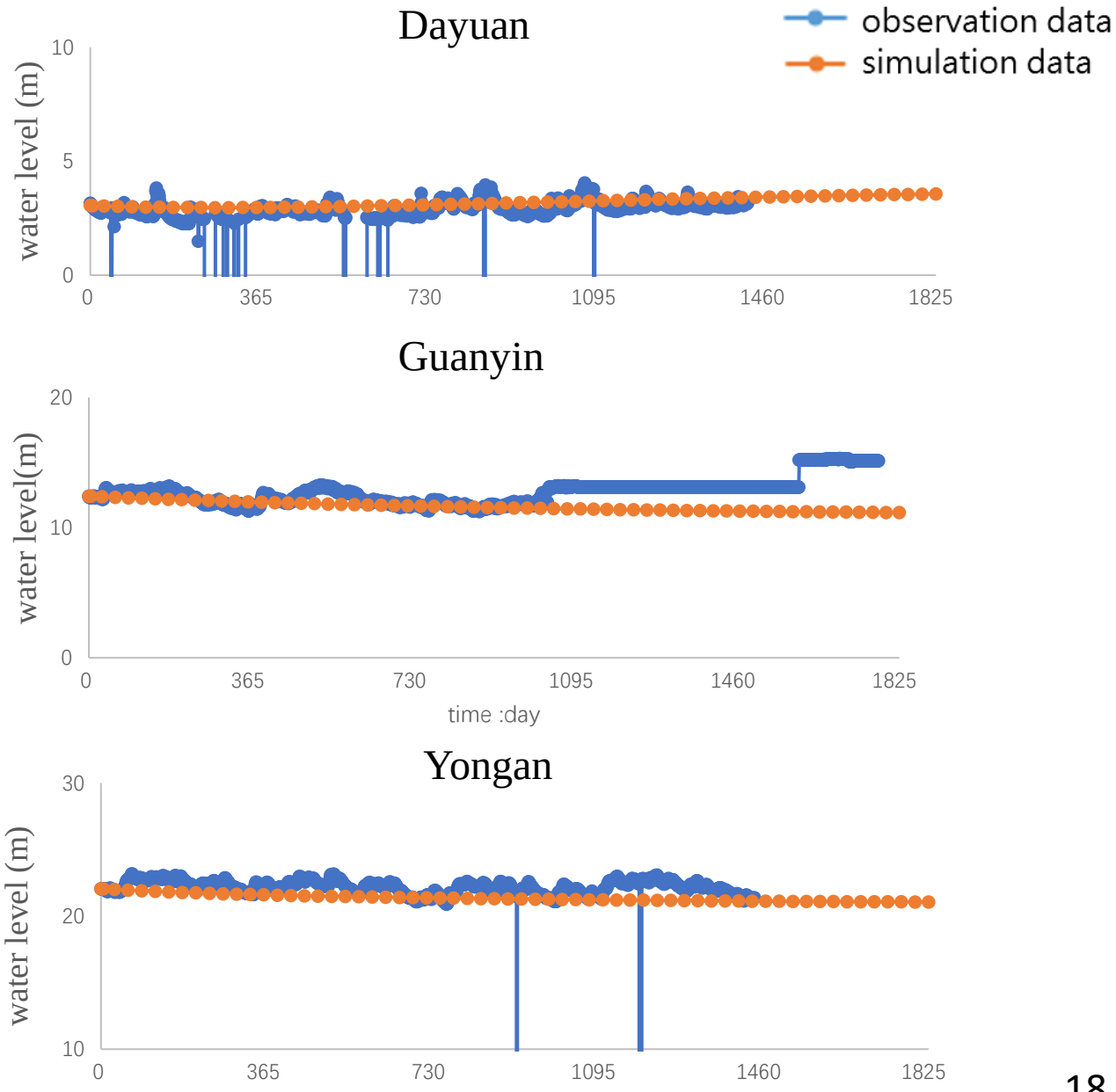




- The lack of data in Luzhu may lead to significant inaccuracies.

Comparison between observation data and simulation data from 2019 –2023 (TS)





- These simulation results may need further refinement.

Conclusions

- The preliminary establishment of the groundwater model for the Taoyuan area has been completed, but the initial results require further validation.

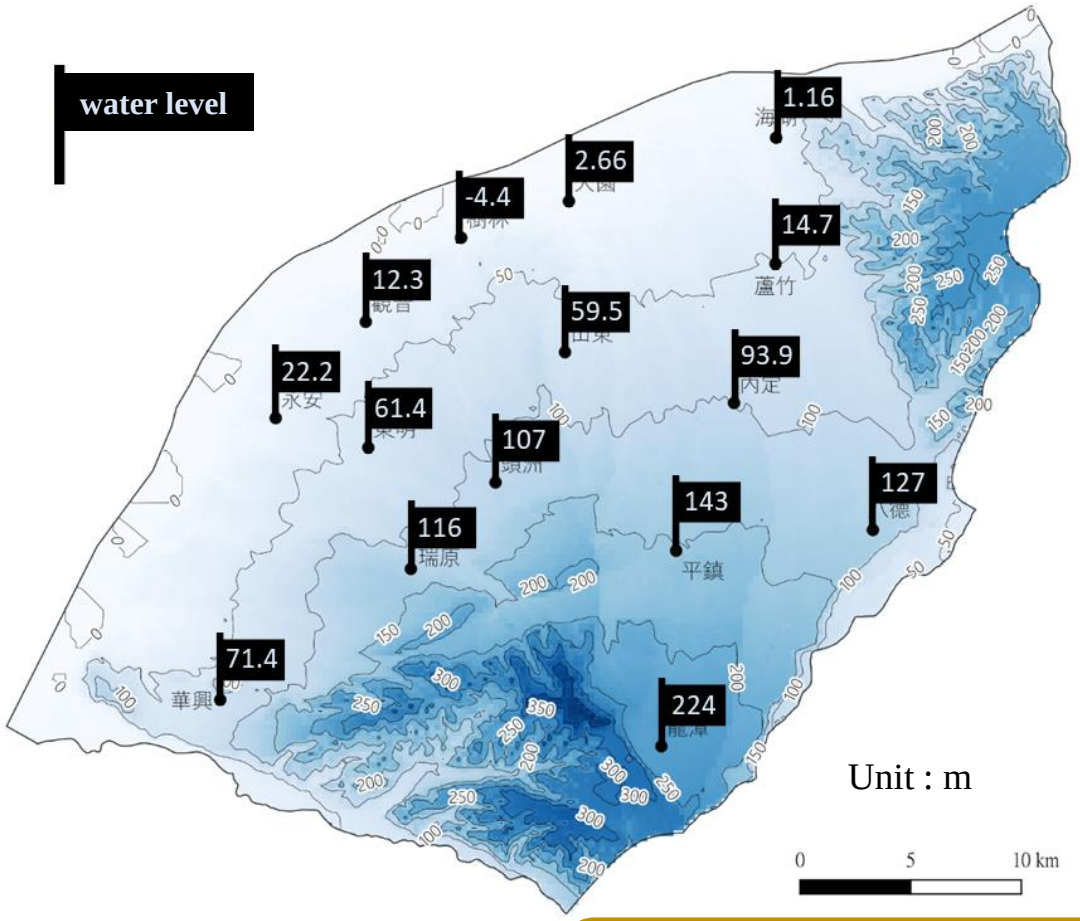
Future work

- Integrate irrigation ponds into the groundwater flow model.
- Continue calibration to improve the accuracy of the model.

Thanks for your attention

Initial condition

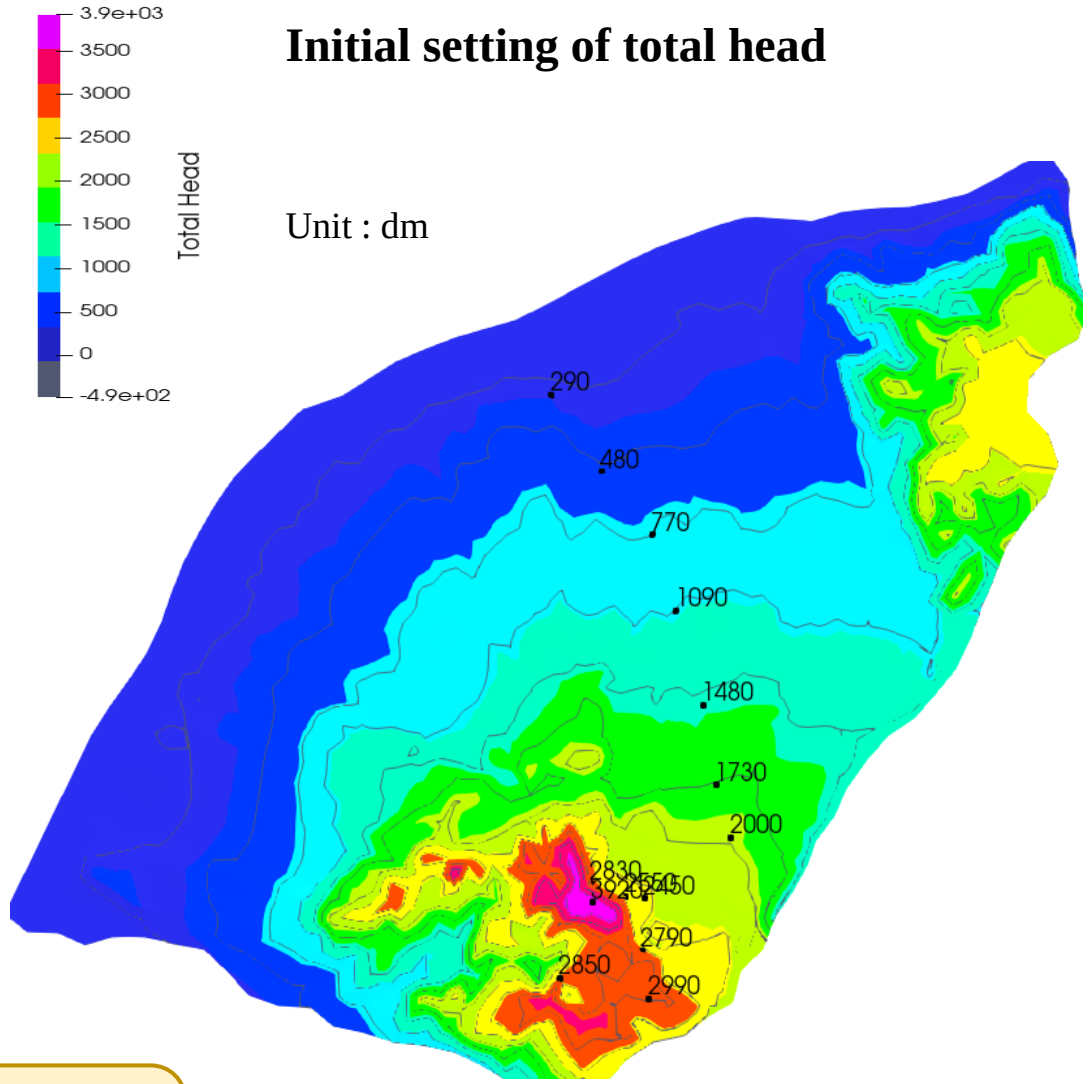
Steady-state simulation for Initial condition



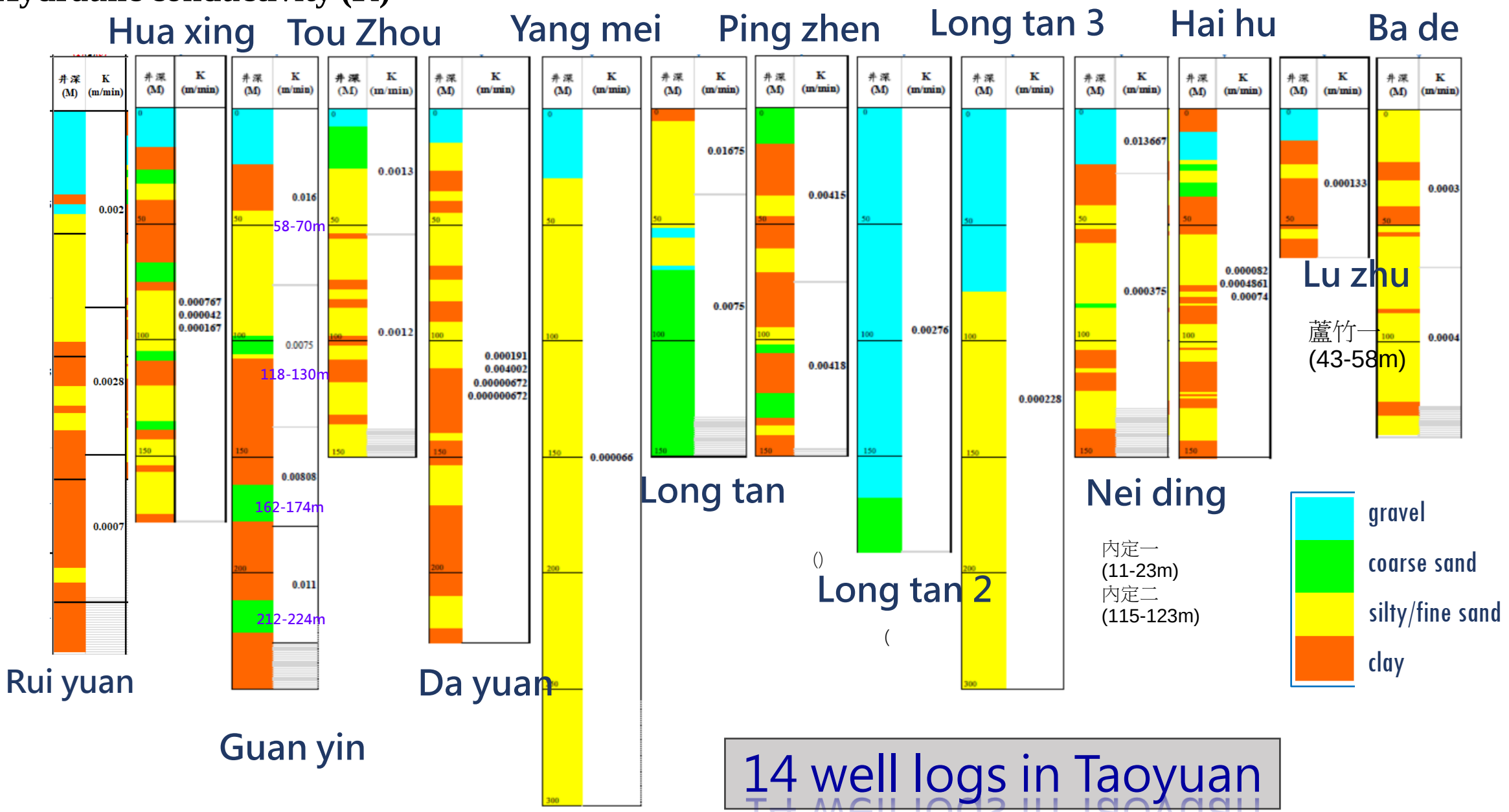
Data sources : WRA

- Dirichlet BC settings
  coastal boundary: constant head=0
  observation wells: constant head =observed data
- Average rainfall settings

Initial setting of total head



Hydraulic conductivity (K)



14 well logs in Taoyuan

Motivation

Industrial

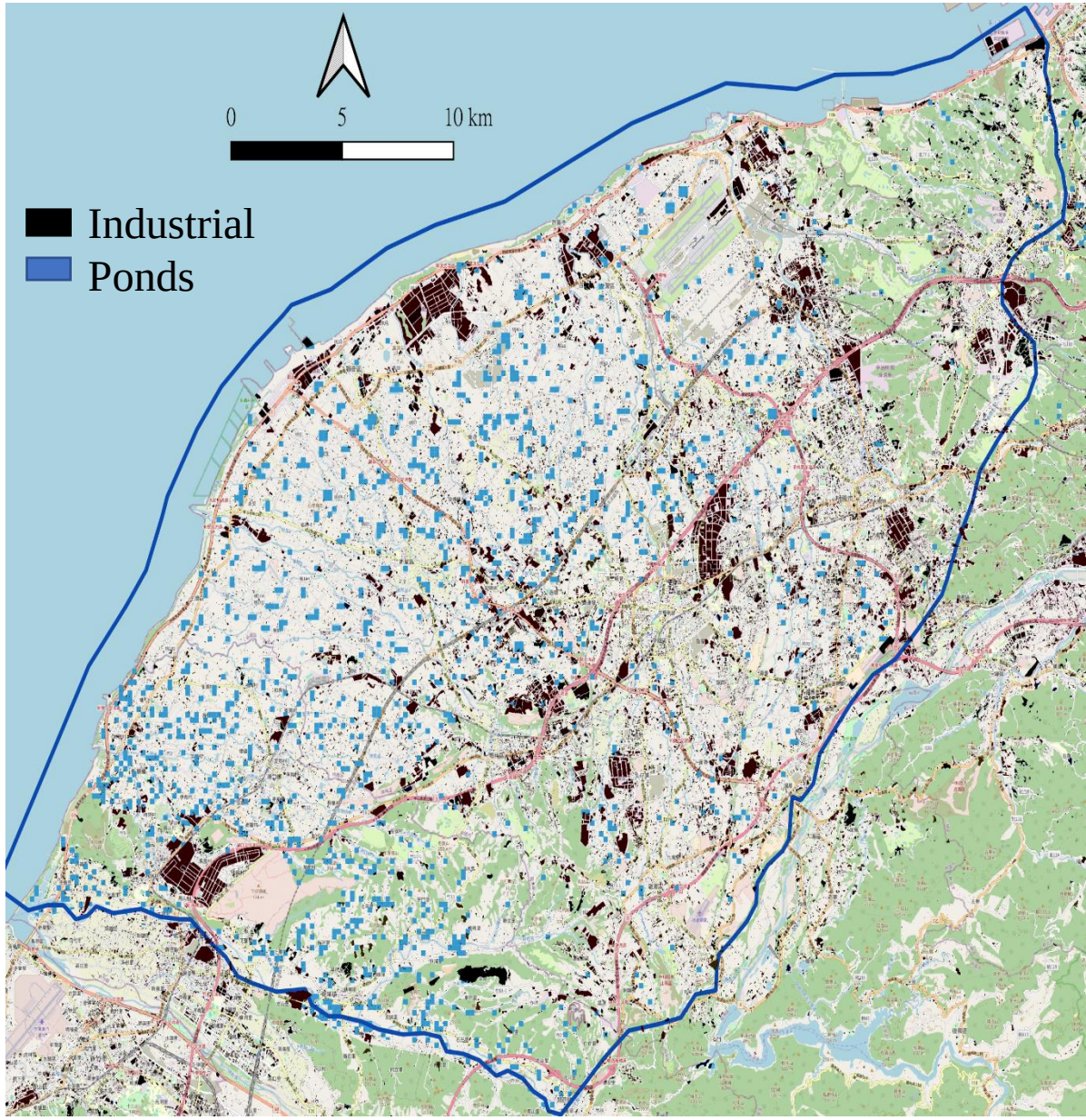
- Water Resource Demand
- Increase impermeability change runoff .

Laterite

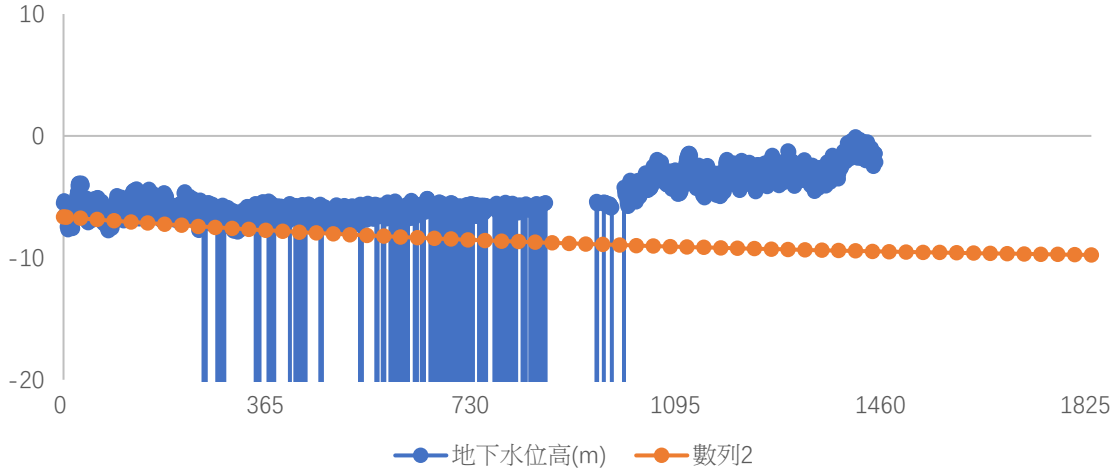
- Impact of Groundwater Recharge
- Constraining groundwater infiltration and recharge

Ponds

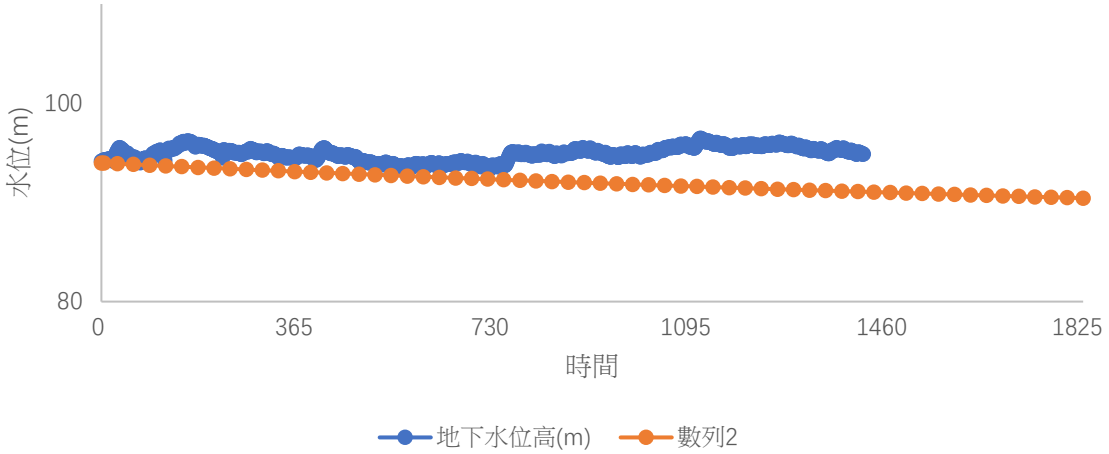
- Regulate water balance



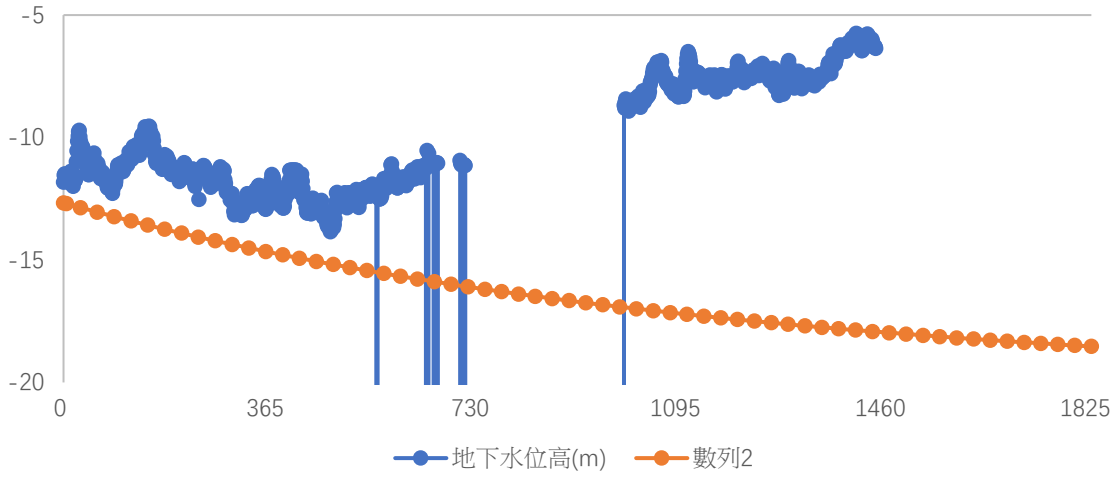
樹林(2)



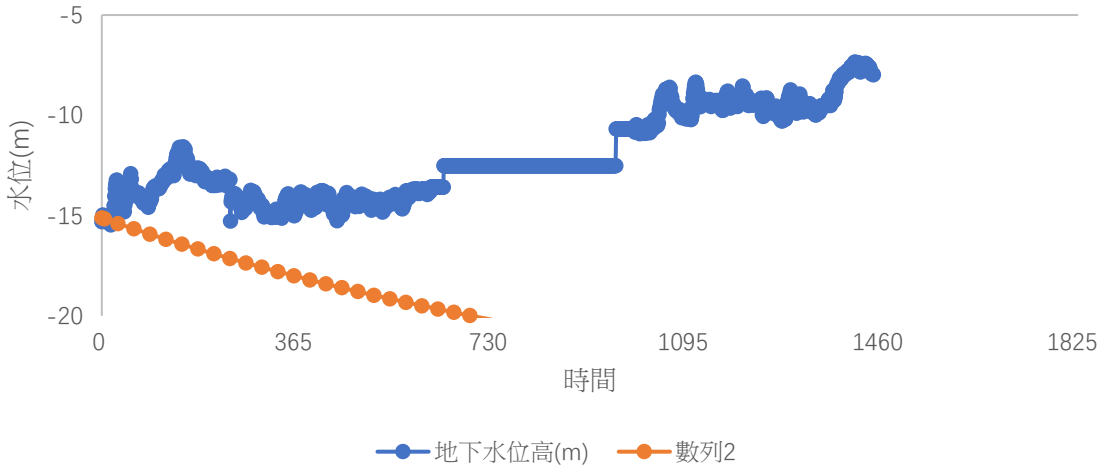
頭洲(2)

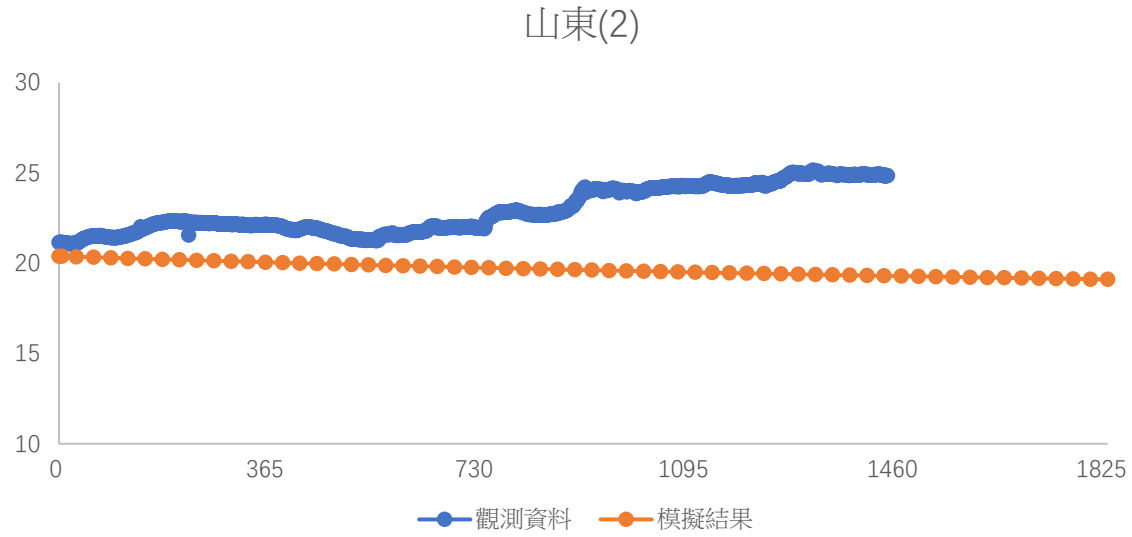


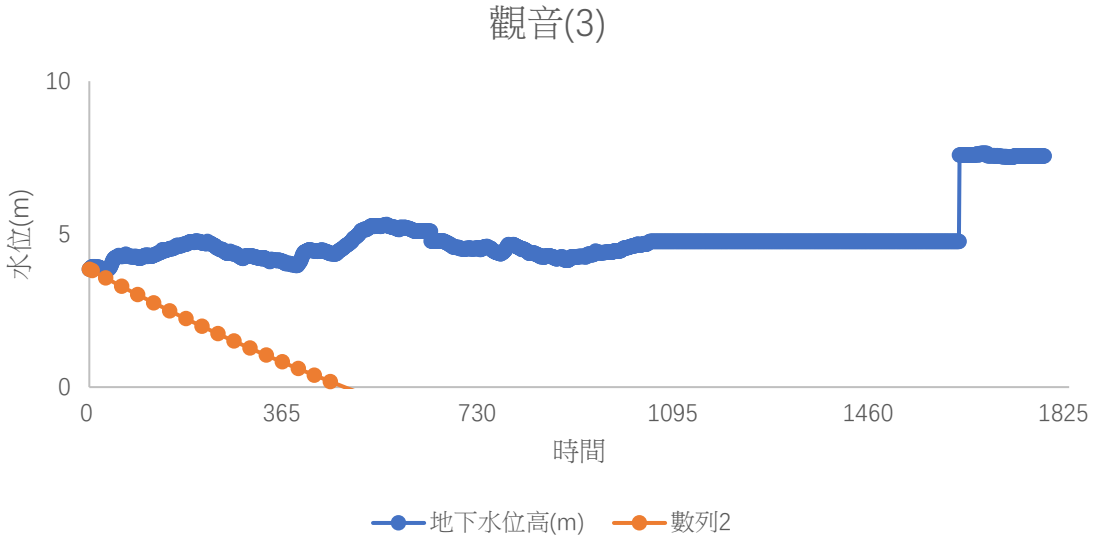
樹林(3)

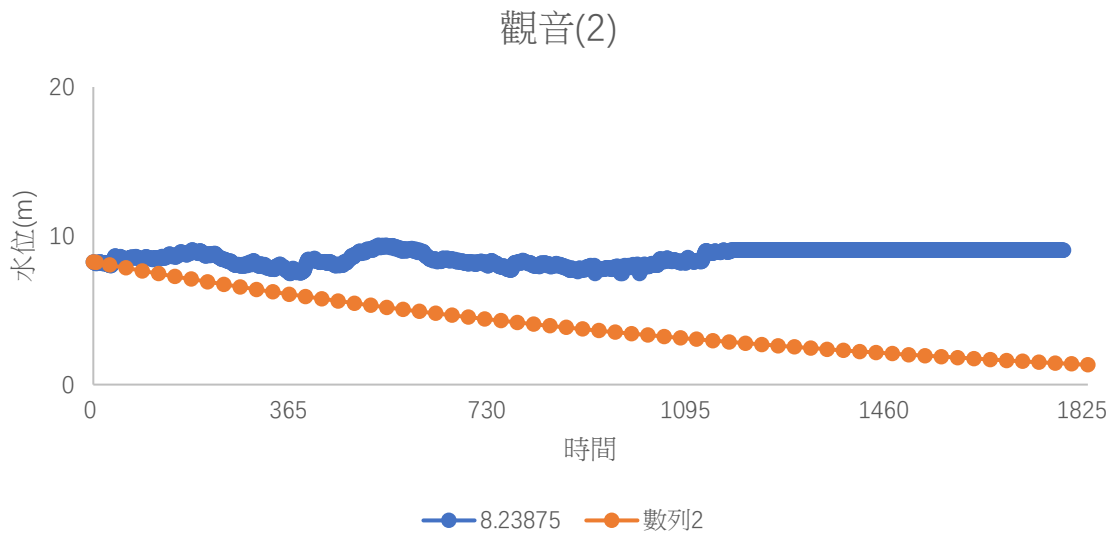


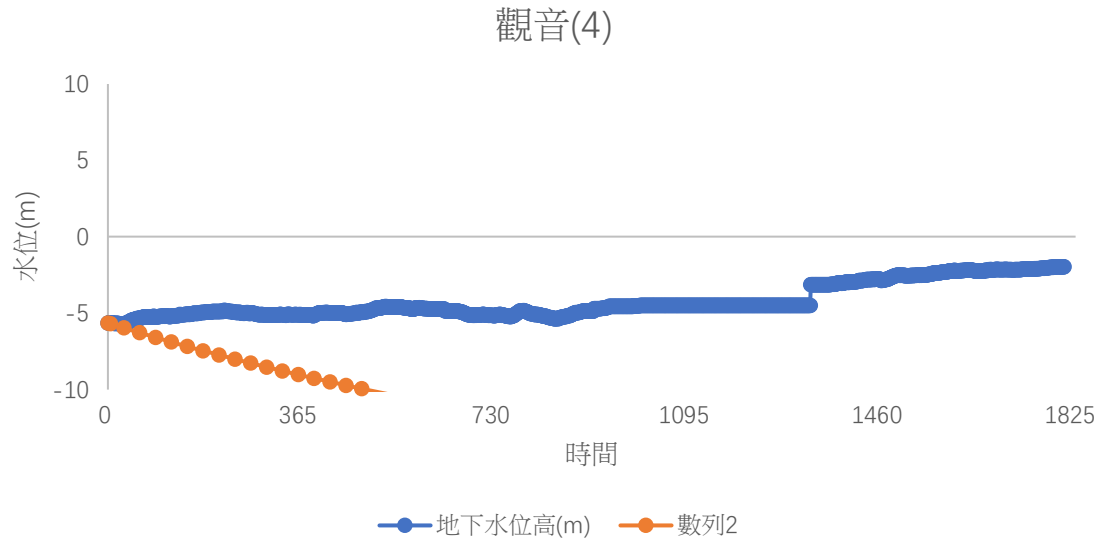
樹林(4)

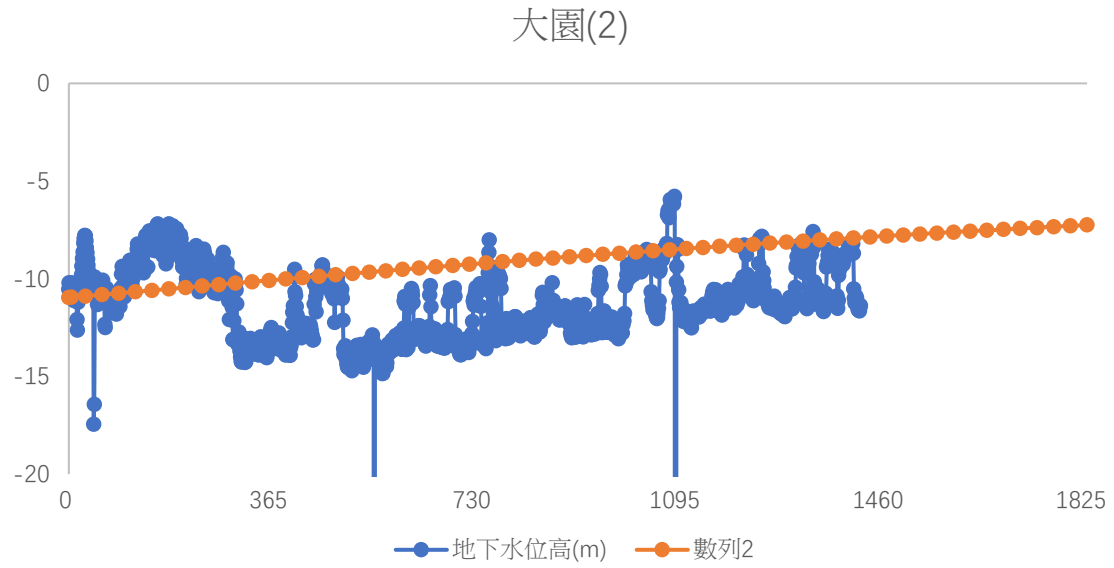


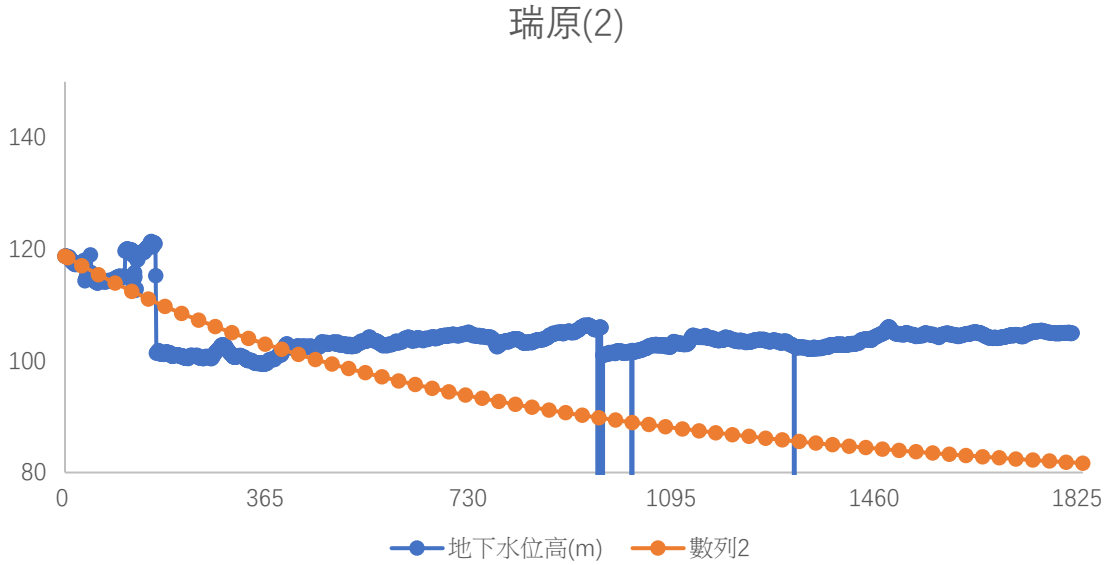

山東(2)
30
25
20
15
10
0
365
730
1095
1460
1825
觀測資料
模擬結果

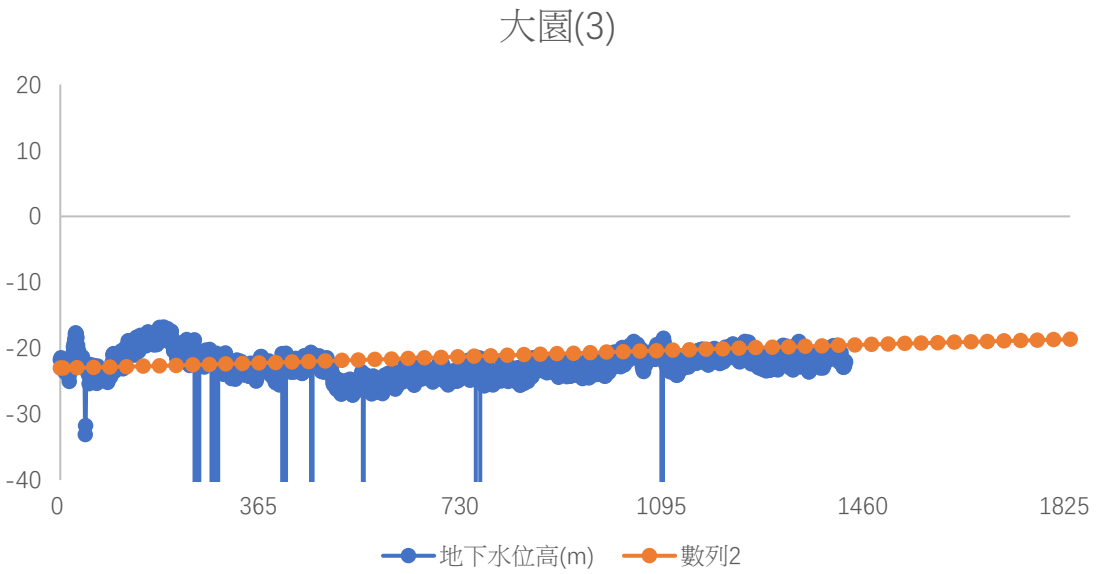

觀音(3)
10
5
0
水位(m)
0
365
730
1095
1460
1825
時間
地下水位高(m)
數列2

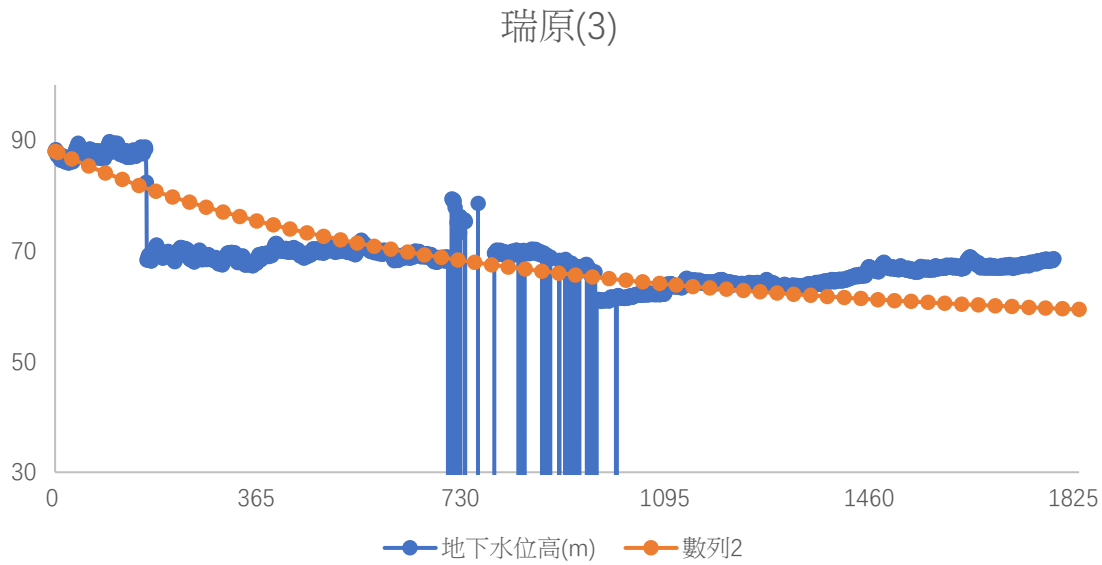

觀音(2)
20
10
0
水位(m)
0
365
730
1095
1460
1825
時間
8.23875
數列2


觀音(4)
10
5
0
-5
-10
水位(m)
0
365
730
1095
1460
1825
時間
地下水位高(m)
數列2

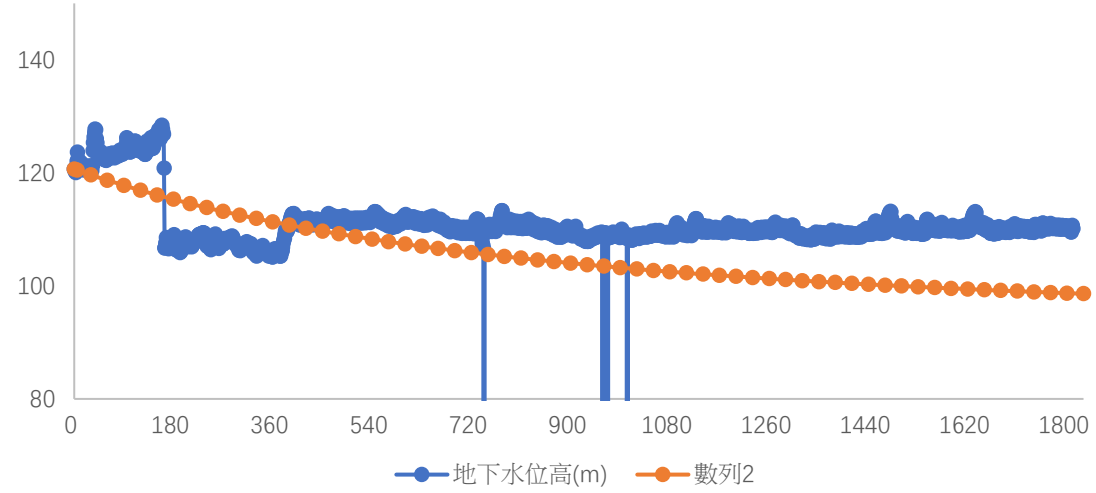

大園(2)
0
-5
-10
-15
-20
0
365
730
1095
1460
1825
地下水位高(m)
數列2


瑞原(2)
140
120
100
80
0
365
730
1095
1460
1825
地下水位高(m)
數列2

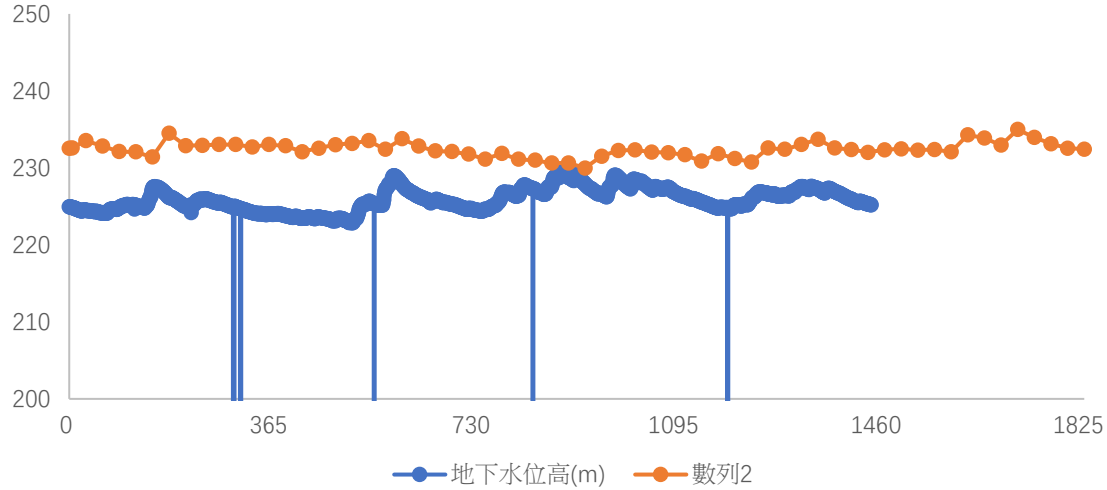

大園(3)
20
10
0
-10
-20
-30
-40
0
365
730
1095
1460
1825
地下水位高(m)
數列2


瑞原(3)
90
70
50
30
0
365
730
1095
1460
1825
地下水位高(m)
數列2

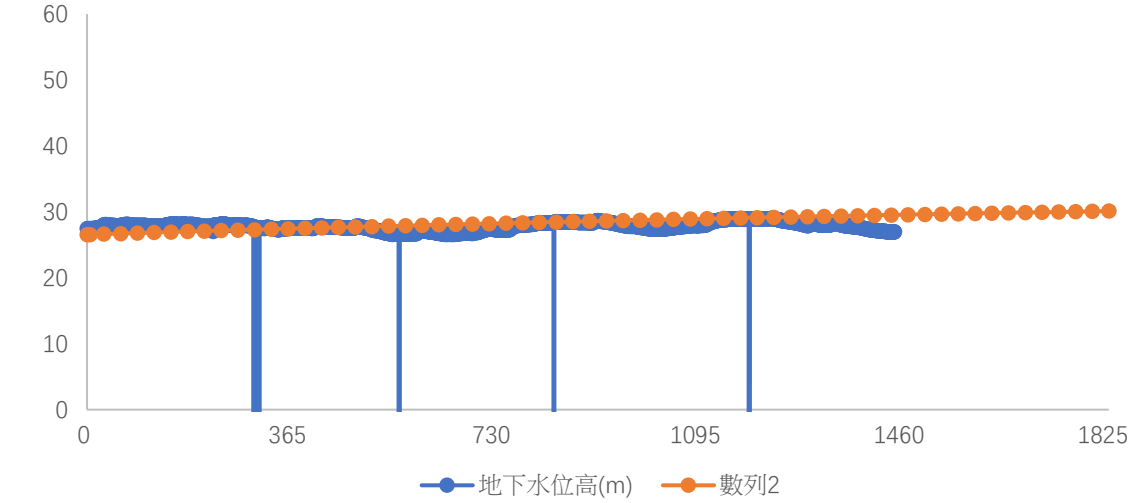
瑞原(1)



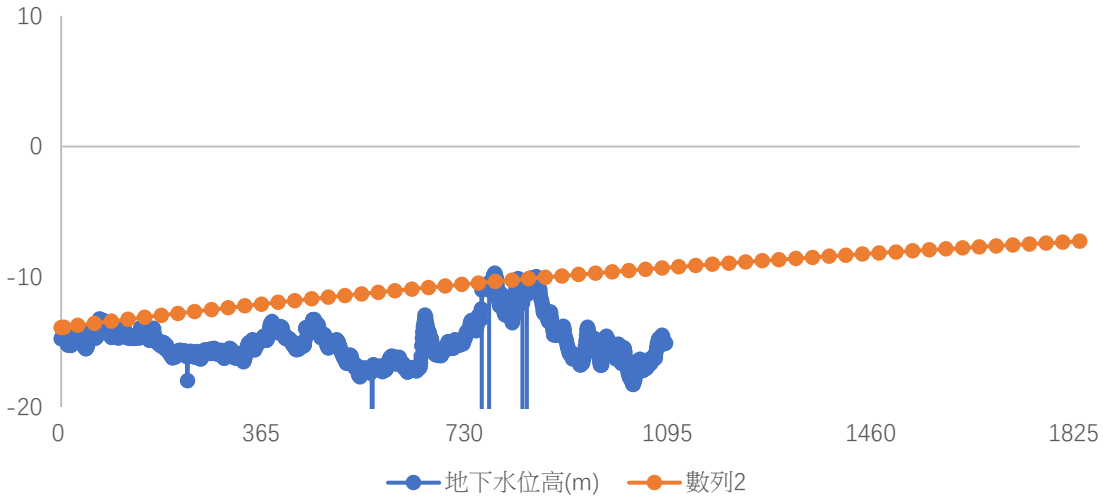
龍潭(2)

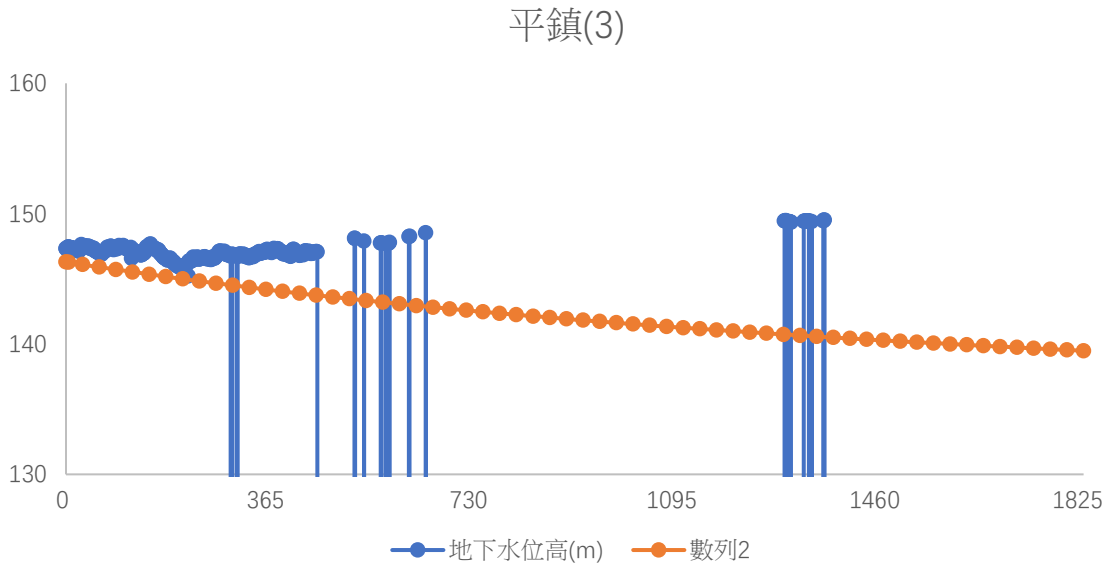


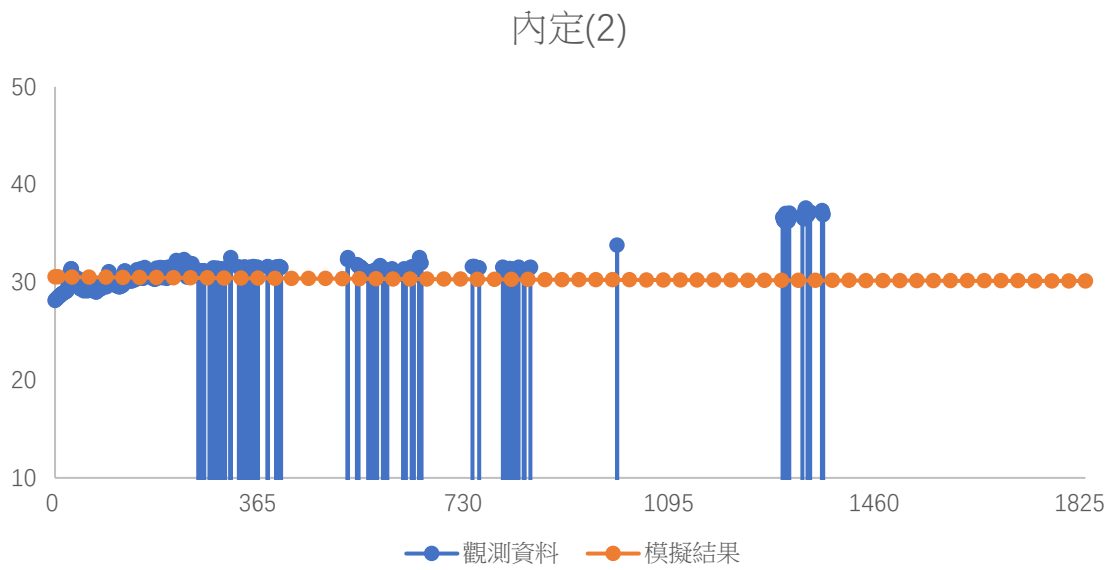
東明(2)

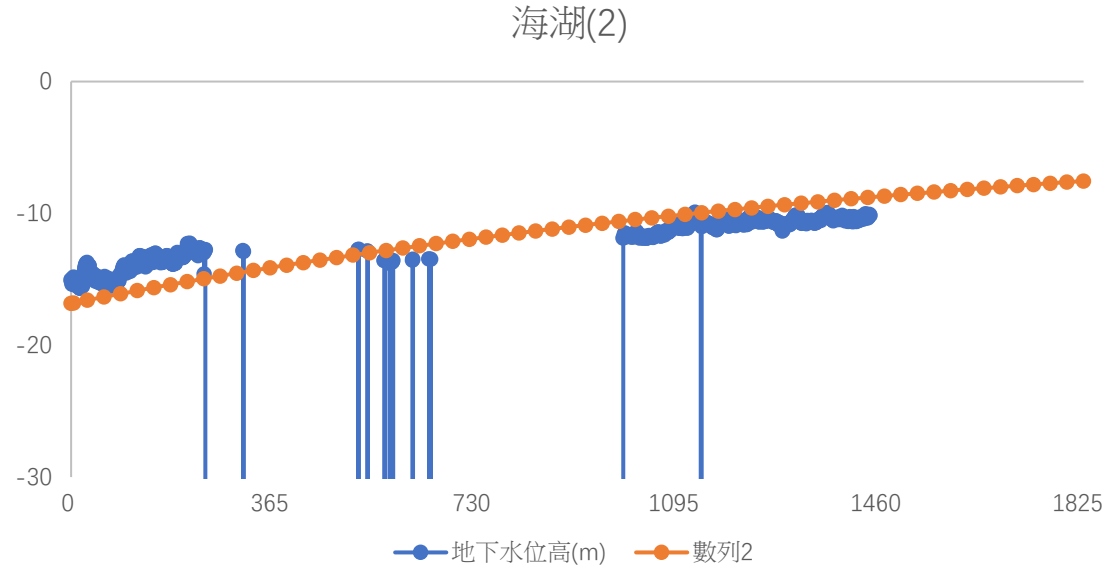


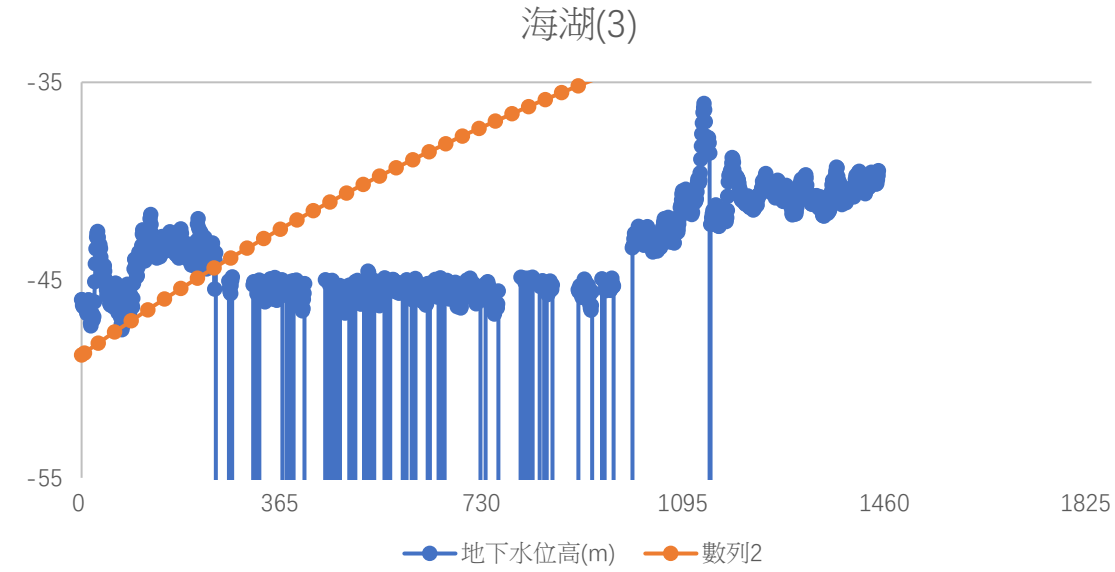
永安(2)




平鎮(3)
160
150
140
130
0
365
730
1095
1460
1825
地下水位高(m)
數列2

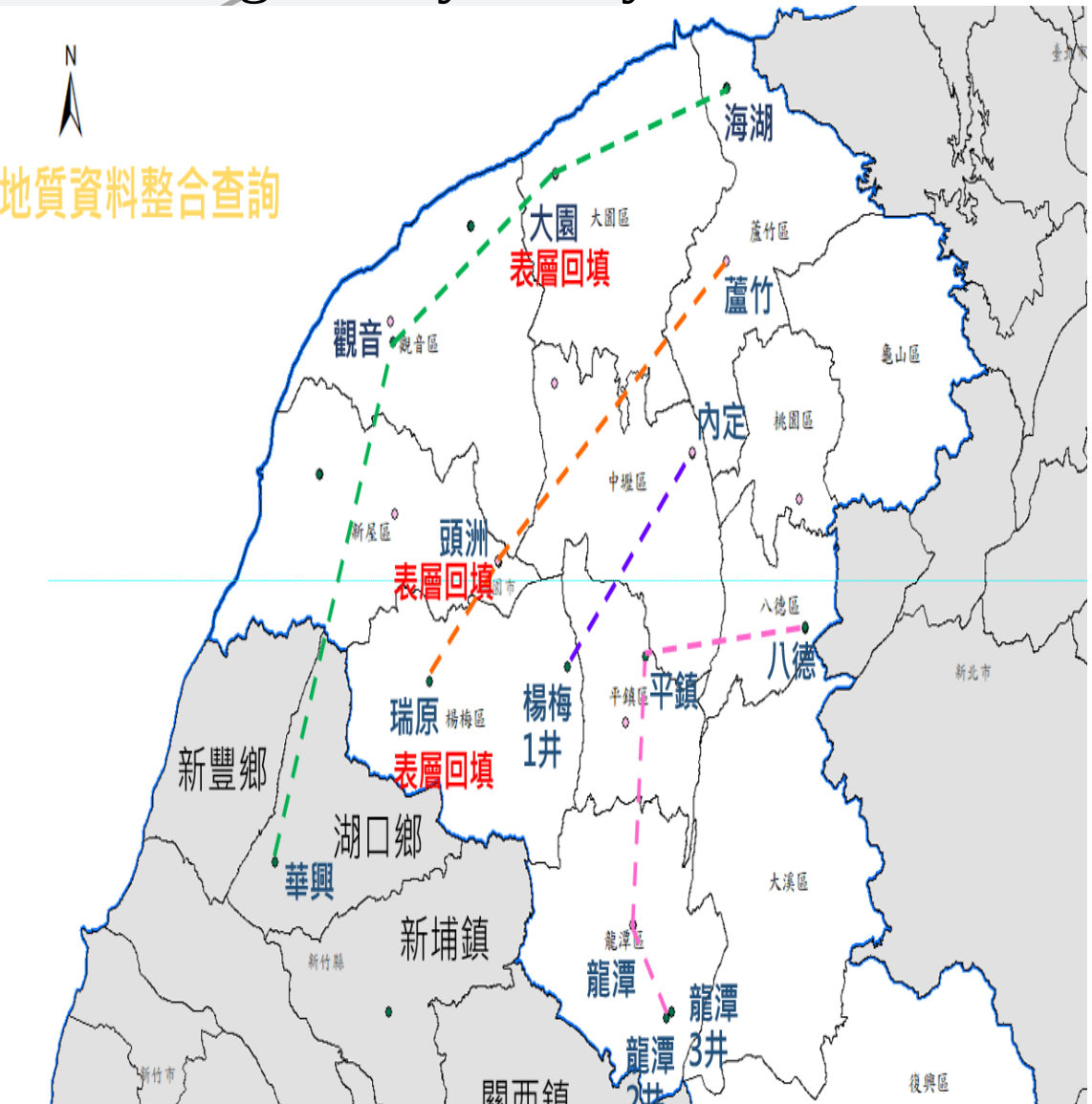

內定(2)
50
40
30
20
10
0
365
730
1095
1460
1825
觀測資料
模擬結果

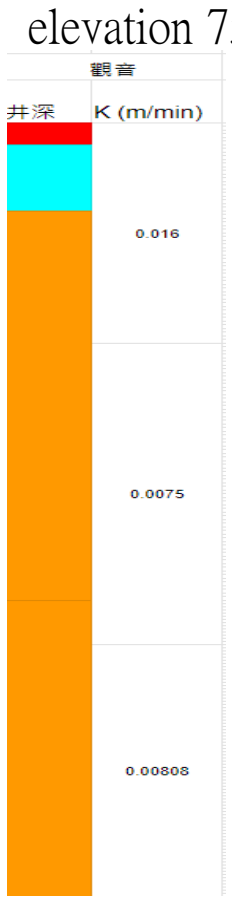

海湖(2)
0
-10
-20
-30
0
365
730
1095
1460
1825
地下水位高(m)
數列2

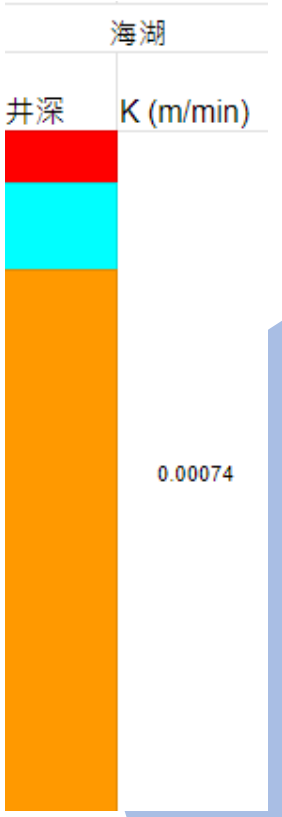

海湖(3)
-35
-45
-55
0
365
730
1095
1460
1825
地下水位高(m)
數列2

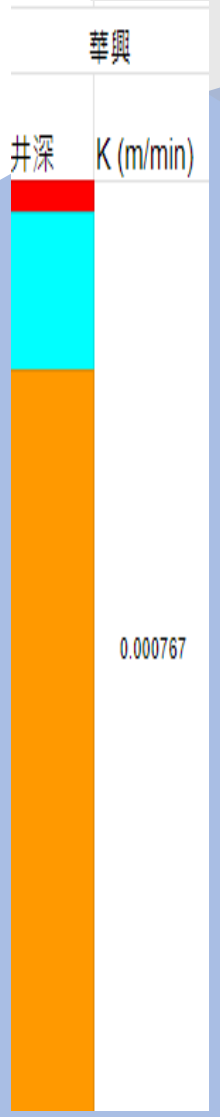
Other Collect data (K value))

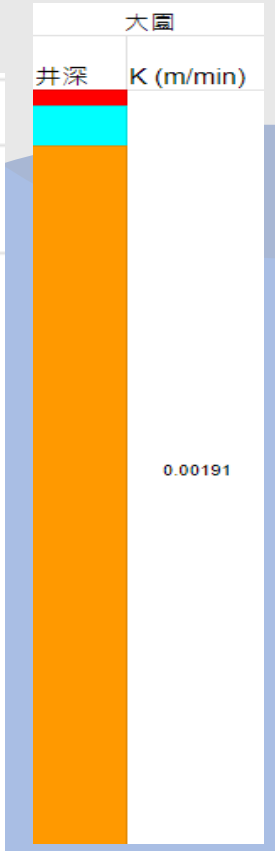
Huaxing-Guanyin-Dayuan-Hailu







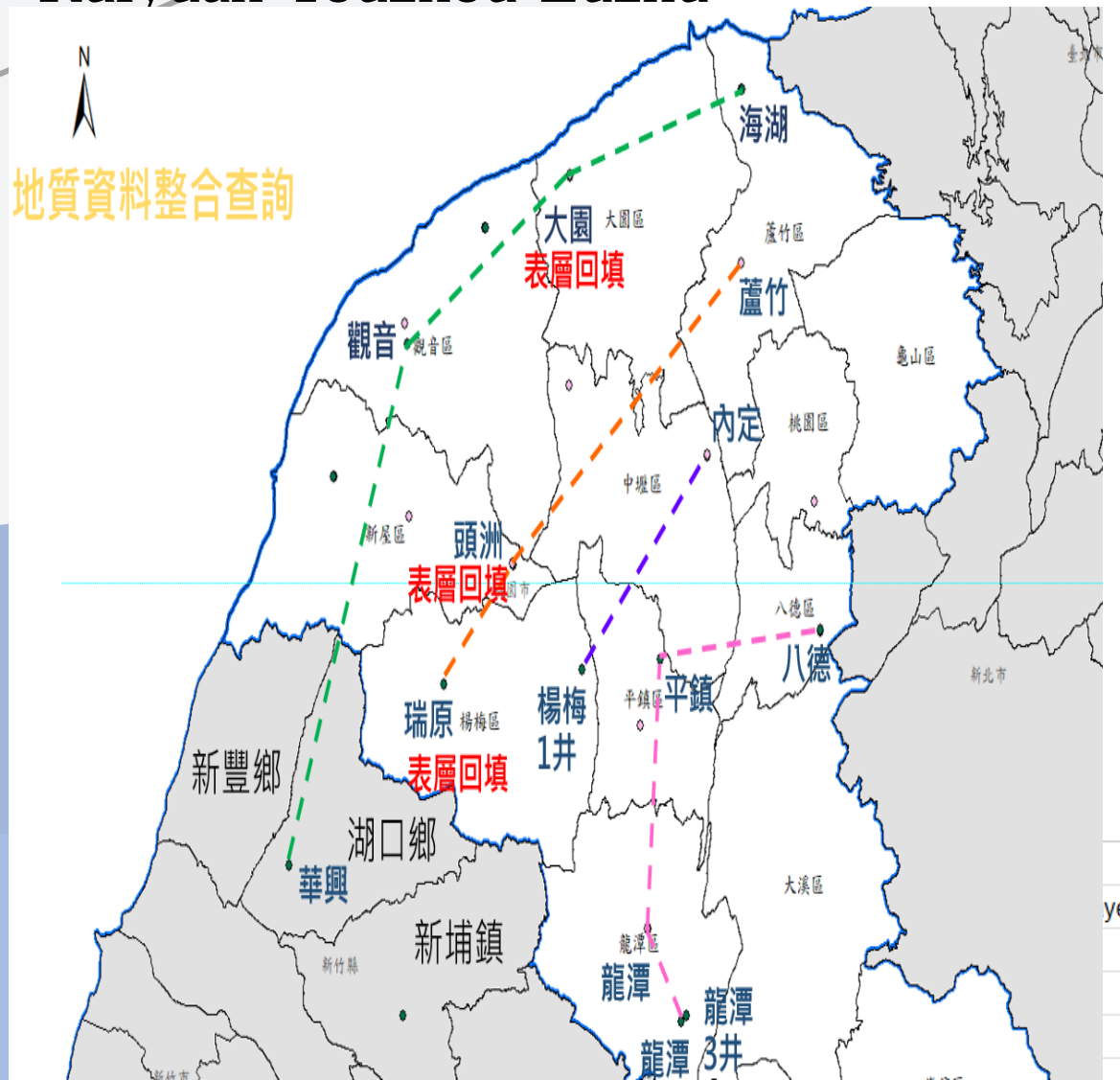


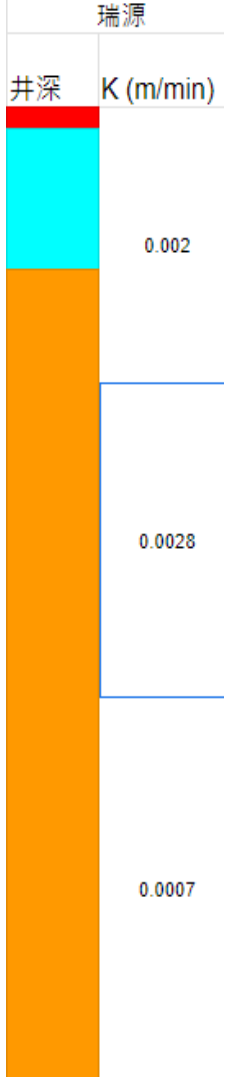


Guanyin 1(-32~-44m)
Guanyin 2(-92~-104m)
Guanyin 3(-136~-148m)
Guanyin 4(-186~-198m)

Other Collect data (K value))

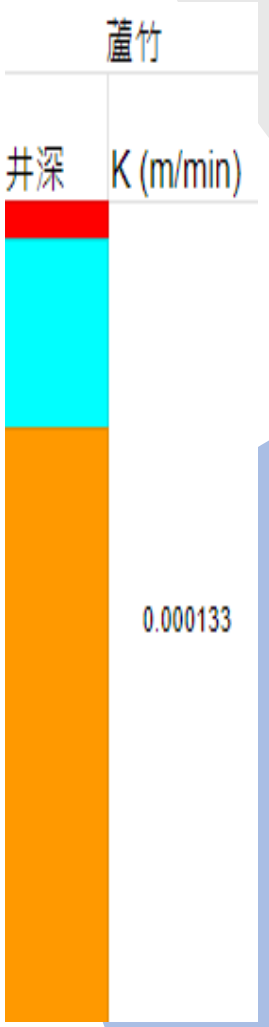
Ruiyuan-Touzhou-Luzhu





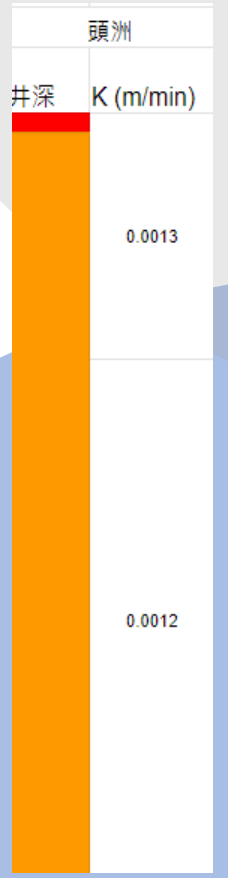
elevation147

Ruiyuan一(85~73m)
Ruiyuan二(25-13m)
Ruiyuan三(-33~-45m)



elevation113

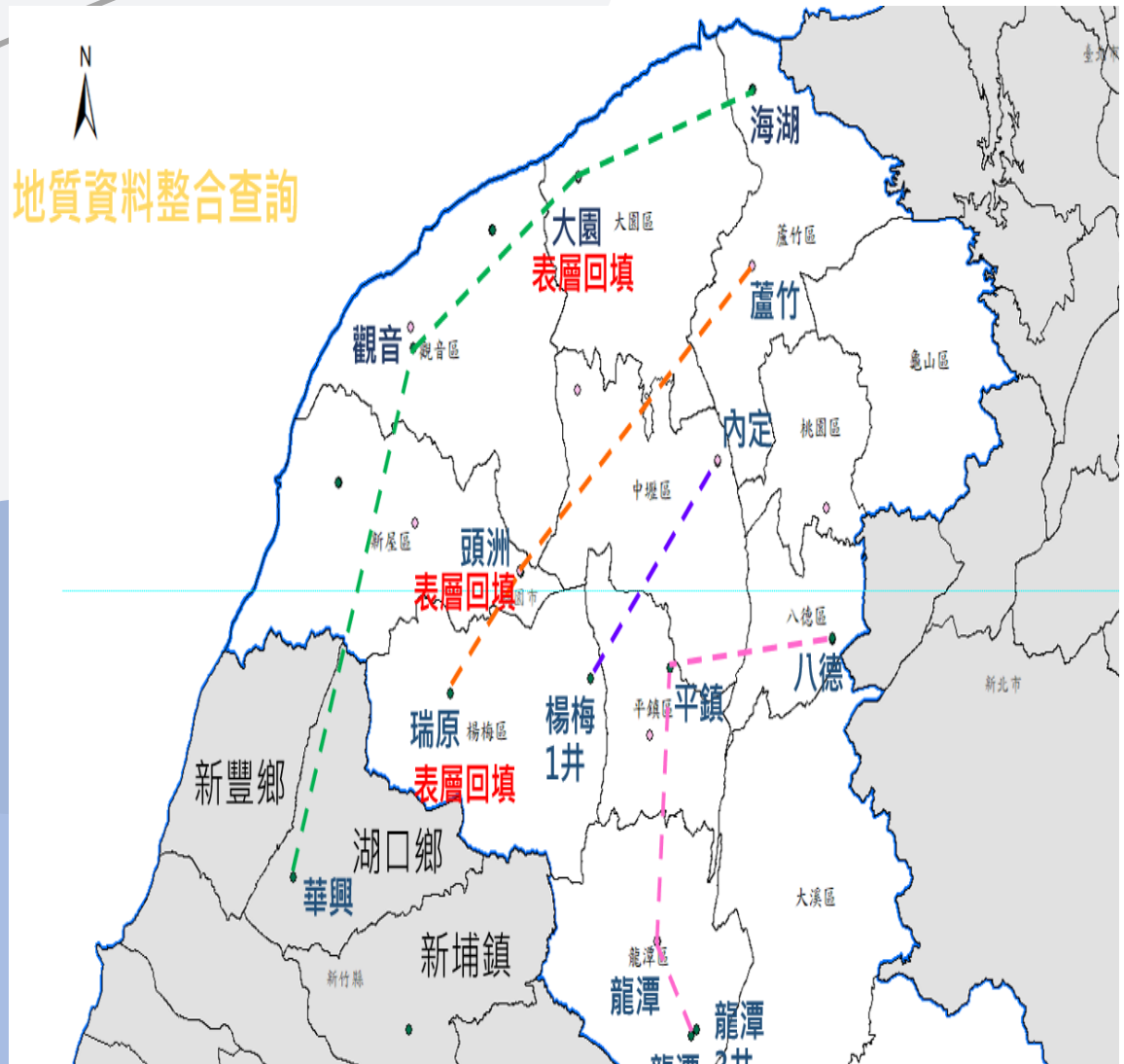
Touzhou一(83~65m)
Touzhou二(-7~-19m)

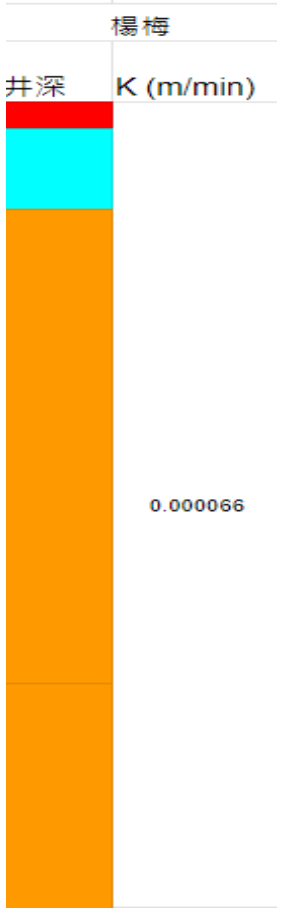


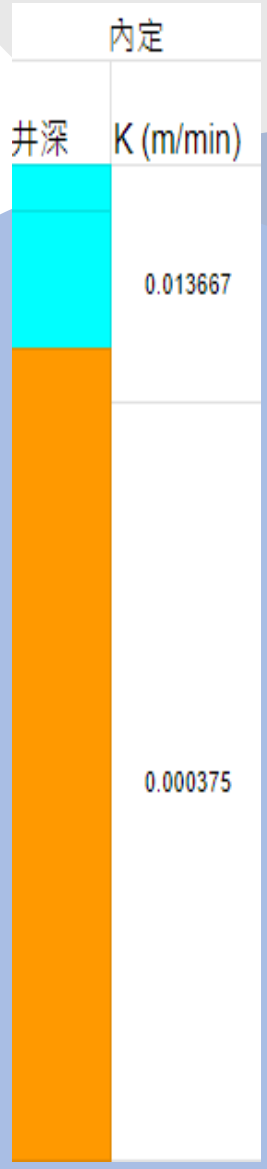
elevation51.3

Other Collect data (K value))

Yangmei-Neiding

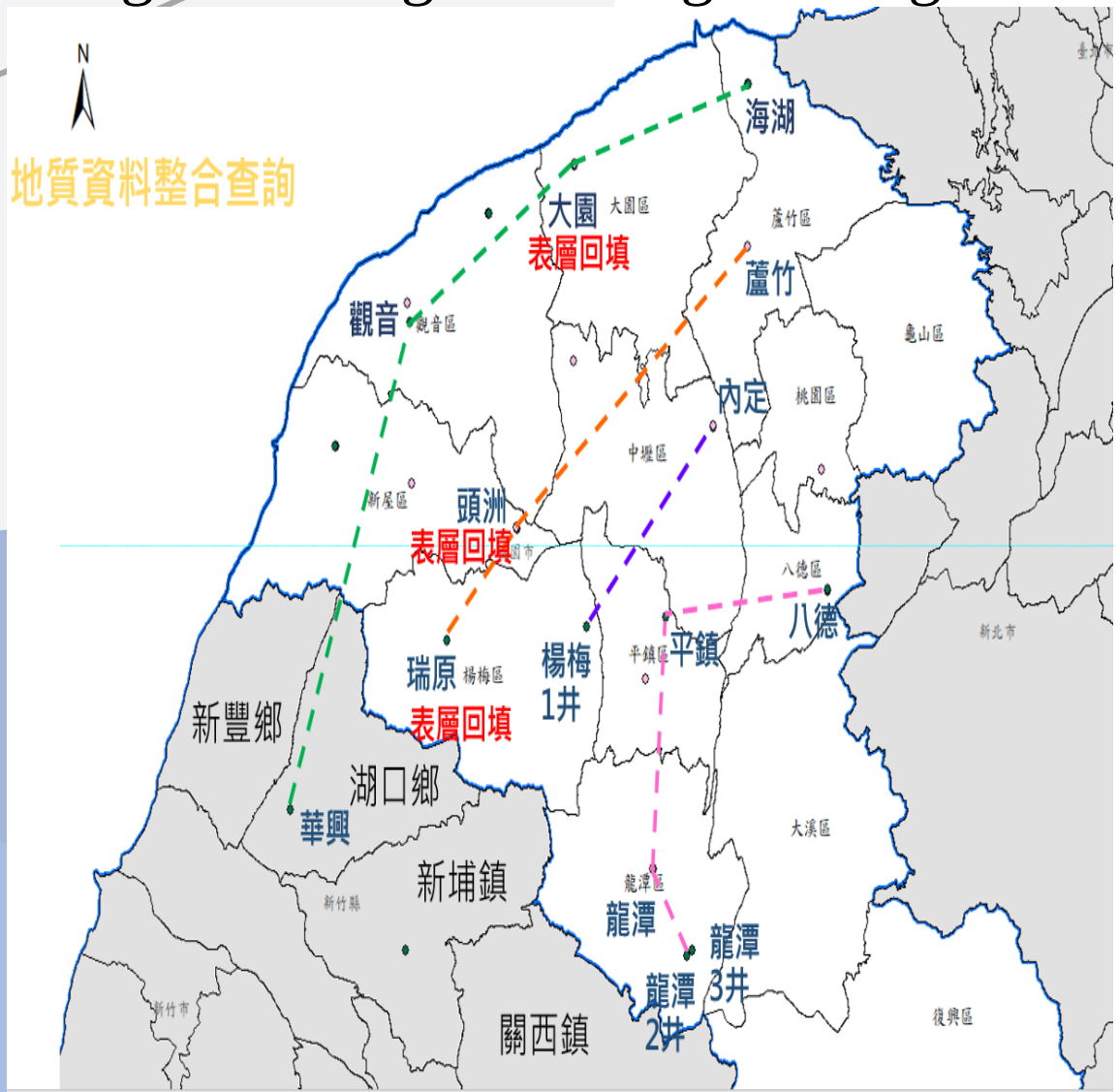


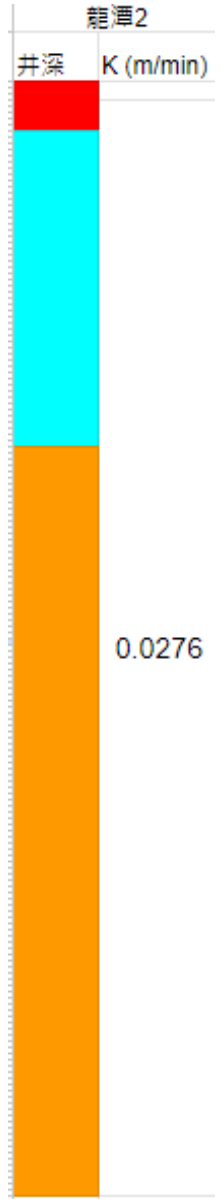




Other Collect data (K value))

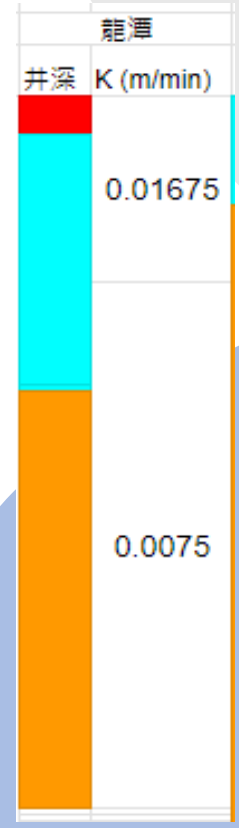
Longtan2-Longtan3-Longtan-Pingzhen-Bade





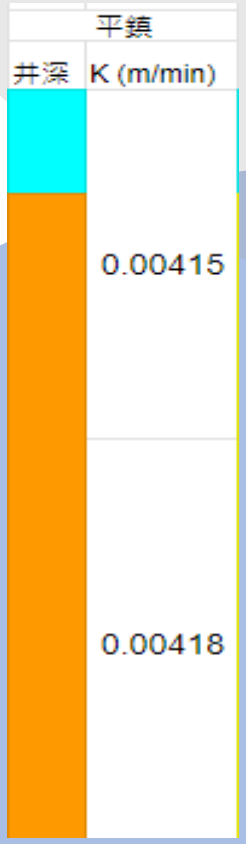
elevation210
.72

elevation203.5



elevation233

elevation156



elevation129