Groundwater Simulation and Management in Taoyuan: Impact of Laterite Layers and Pond Recharge

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OUTLINE

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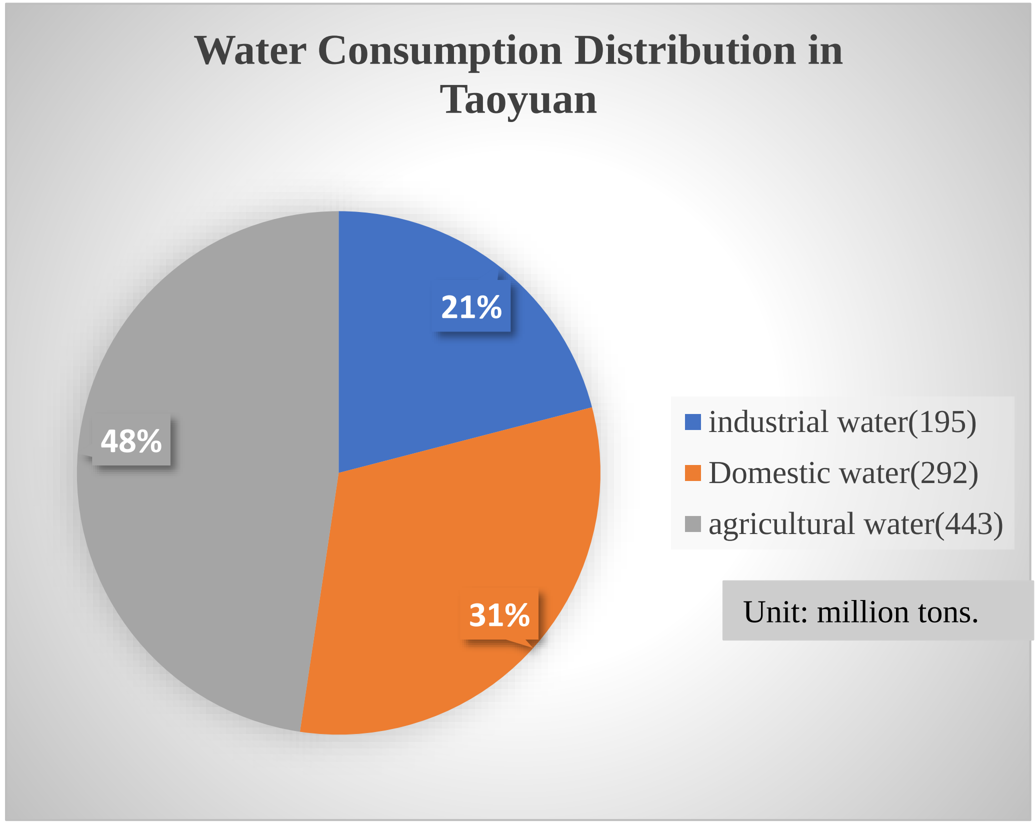
Water Resources in Taoyuan

- 1220 km^2
- High annual rainfall rate

  Average Annual Rainfall : 2,500 mm
- The annual water consumption in the Taoyuan area is approximately 931 million tons.
- Industrial water usage reaching 195 million tons, over 80% of which comes from groundwater.
- The laterite layer affects rainfall infiltration into groundwater recharge.

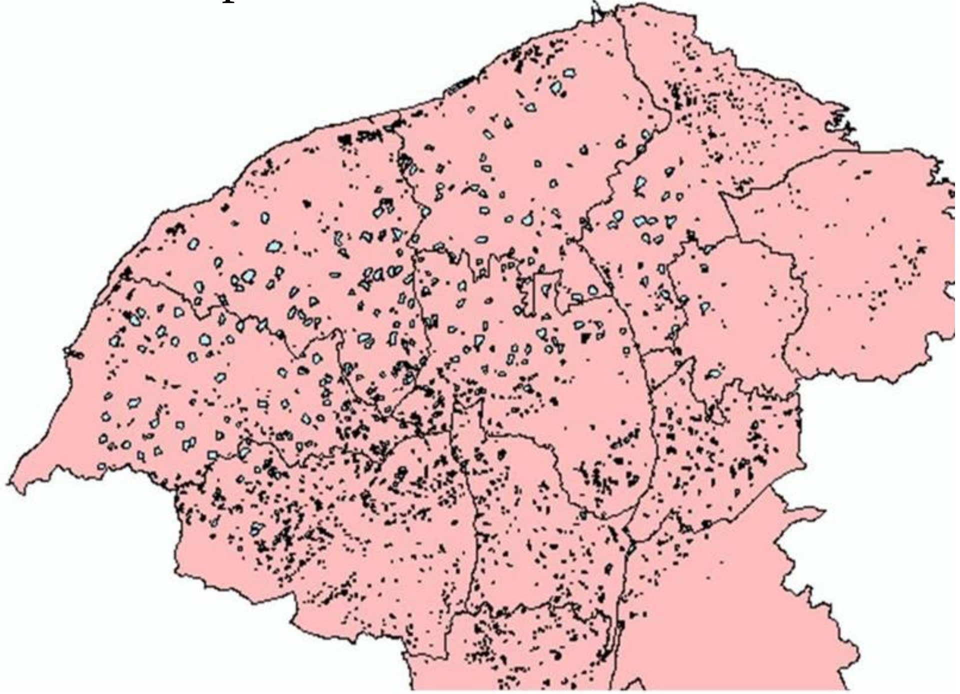


Laterite

- As extreme climate change intensifies, leading to uneven spatiotemporal distribution of precipitation, groundwater has become a crucial source for stable water supply.

- The Taoyuan region has a large presence of laterite and gravel layers, whose geological structure may affect groundwater recharge and flow.

Due to the low permeability of the laterite layer, which makes it suitable for water retention, a large number of ponds were constructed to store rainfall, creating the unique landscape known as the "Land of a Thousand Ponds



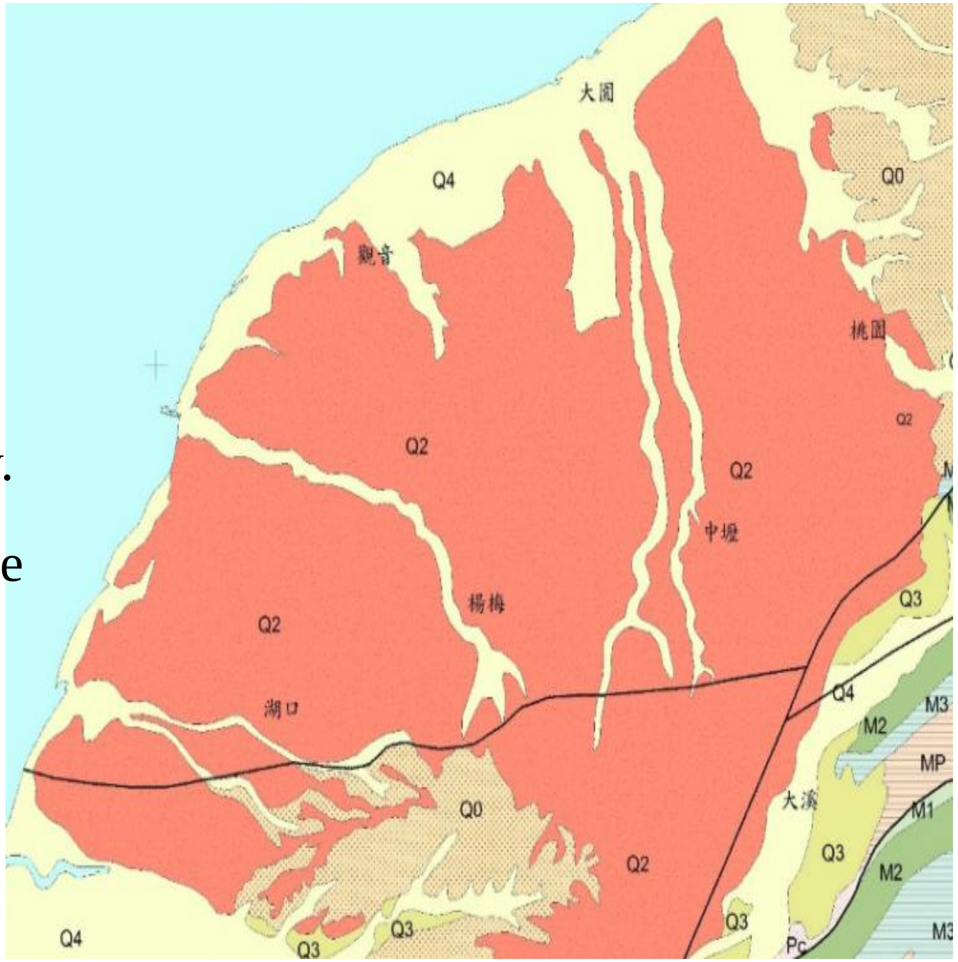


Fig from (CGS,2000)

- lateritic soil thickness ~3m-5m

Motivation

- Exploring the unique geological structure of the Taoyuan region—combining the low-permeability laterite layer with the high hydraulic conductivity gravel layer and the groundwater recharge process .

- Ponds are an important source of local water resources and serve as a potential source for groundwater recharge, introducing greater uncertainty into water resource management .

Technology Development Milestones

THMC

USA
FEMWATER

USA
HYDROGEOCHEM

IAEA

NCU, TAIWAN
THMC

1980 — 1990 — 2013 — 2025

1980
H (Flow and transport)

1990
T (Thermal transport)
H (Flow and transport)
C (Chemical reaction)

2013
T (Thermal transport)
H (Multiple phase flow)
M (Mechanical)
C (Chemical reaction)

Professor

Gour-Tsyh (George) Yeh

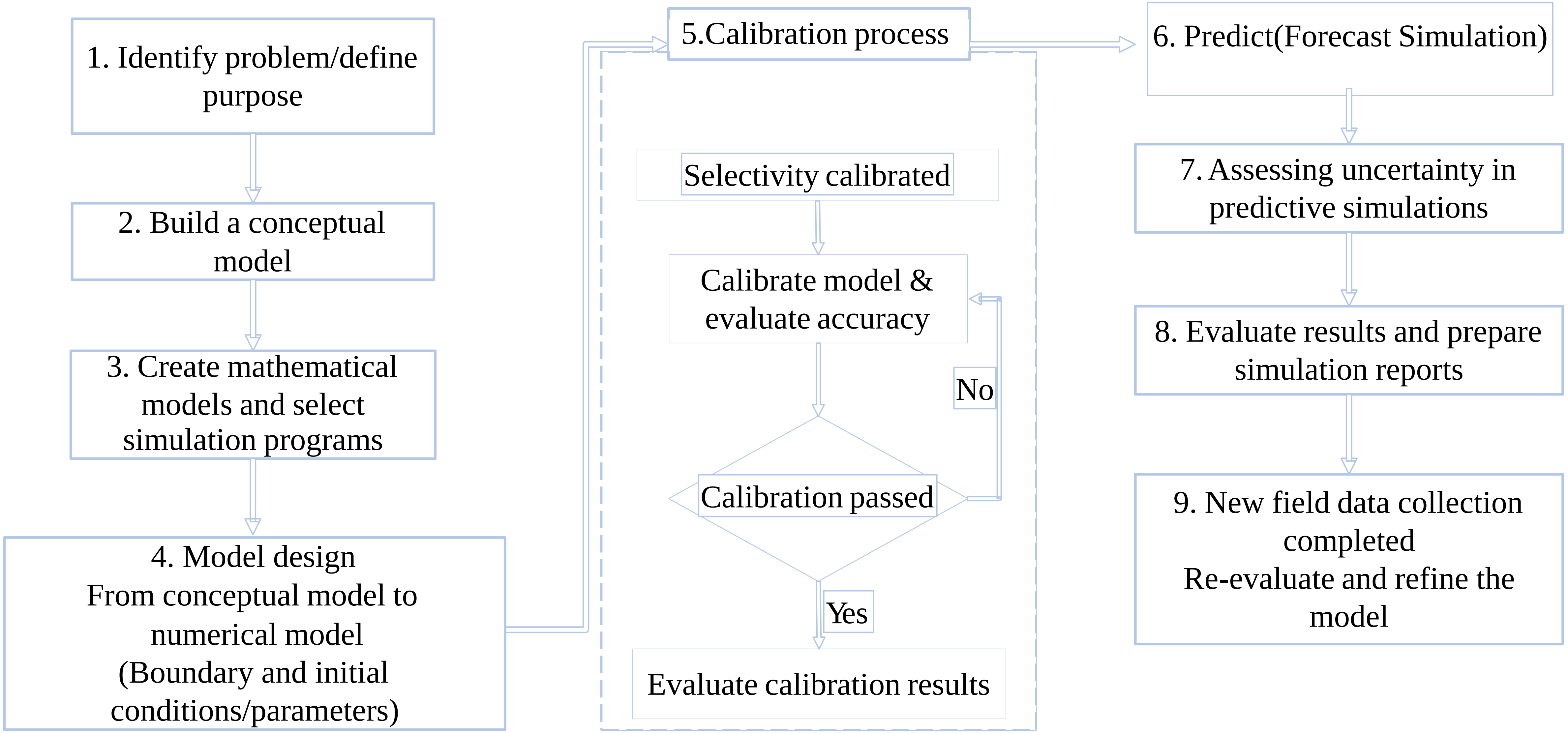
*Pioneer in the research of **Thermal** transport, **Hydraulic** flow, **Mechanical** and Reactive **Chemical** transport*

Objective

Using the THMC software, a groundwater flow model is established that simultaneously considers the spatial distribution characteristics of the laterite and gravel layers, in order to simulate groundwater flow dynamics under different geological conditions.

- Exploring the Flow Exchange Mechanism between Saturated and Unsaturated Zones
- Quantifying the Impact of Pond Recharge
- Providing an Explanation of Groundwater Flow Dynamics

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)
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:

$$\frac{\rho}{\rho_0} F \frac{\partial h}{\partial t} = \nabla \cdot \left[K \cdot \left(\nabla h + \frac{\rho}{\rho_0} \nabla Z_0 \right) \right] + \frac{\rho^*}{\rho_0} q$$

Storage term

Transport term

Source/Sink term

(Yeh et al., 1994a, 1994b)

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)
k: permeability tensor (L^2)
F: generalized storage coefficient (1/L)

Governing equation

F: generalized storage coefficient (1/L)

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

K : hydraulic conductivity tensor (L/T)

$$K = \frac{\rho g}{\mu} \mathrm{k}$$

Darcy's velocity (L/T)

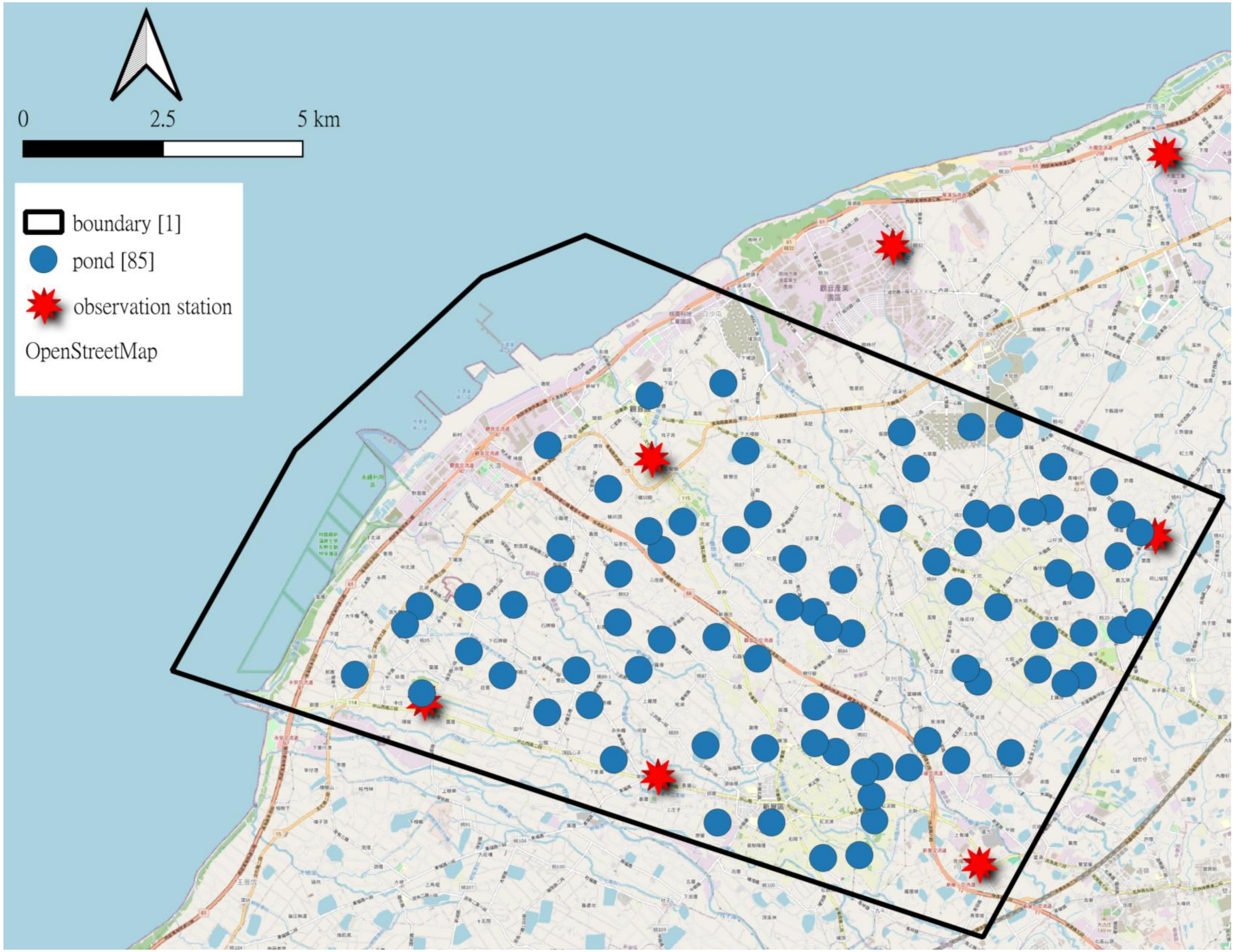
$$V = -K \cdot (\frac{\rho_0}{\rho} \nabla h + \nabla Z_0)$$

μ_0: fluid dynamic viscosity at zero chemical concentration($M/L\ /T$)
μ: fluid dynamic viscosity with dissolved chemical concentrations
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)

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)

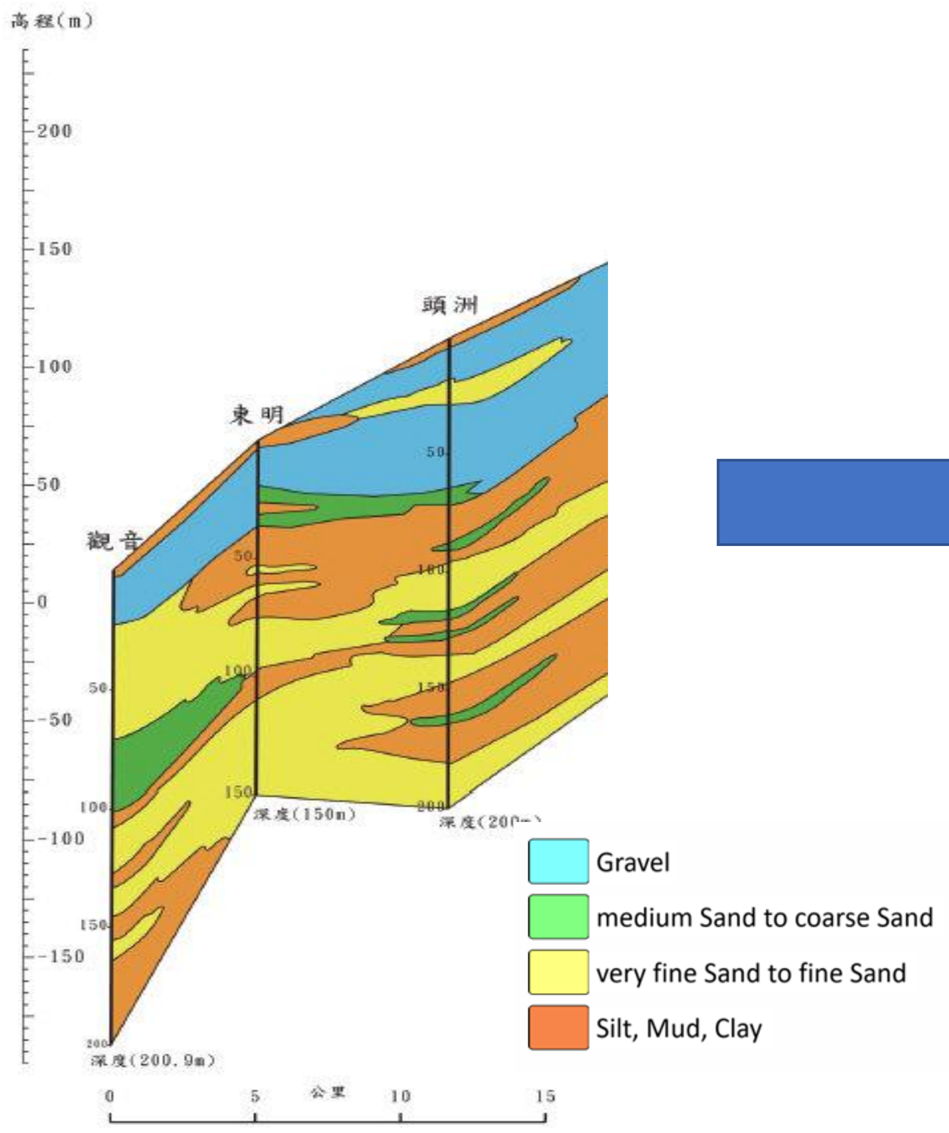
Study Area -Guanyin

- $135.6\ km^2$
- There are 85 ponds in the area
- High groundwater utilization demand
- The annual groundwater extraction in the area reaches 4 million tons

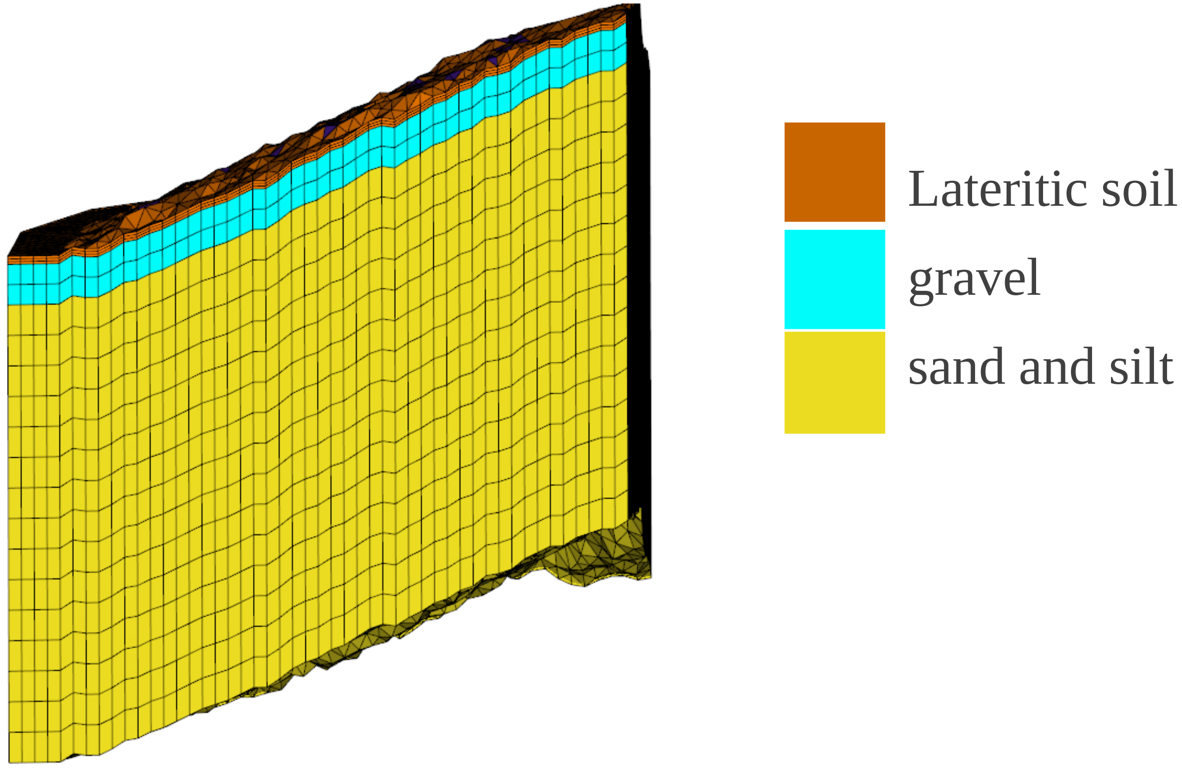


Parameter settings

Conceptual model



DATA SOURCE: CGS



- Using 5 hydrological borehole data, 3 rainfall stations and pumping data to establish the model

Mesh Info.

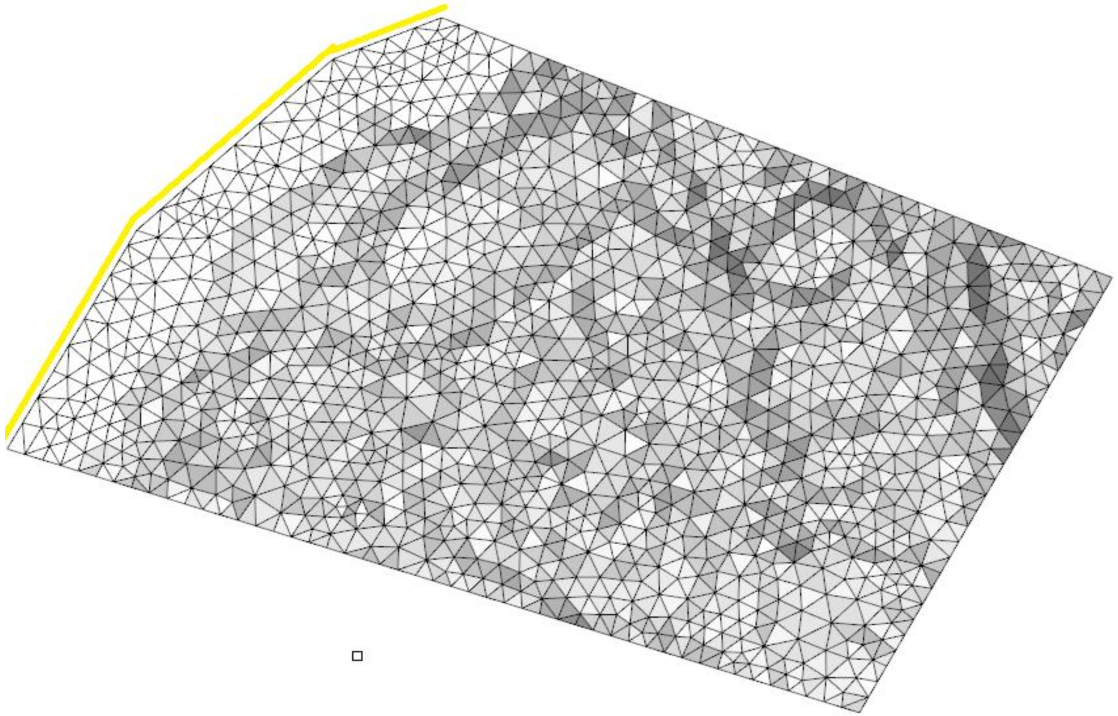
- system of triangular prism
- 25,452 nodes
- 45,700 elements (2285/layer*20 layers)

Parameter settings

Boundary Conditions

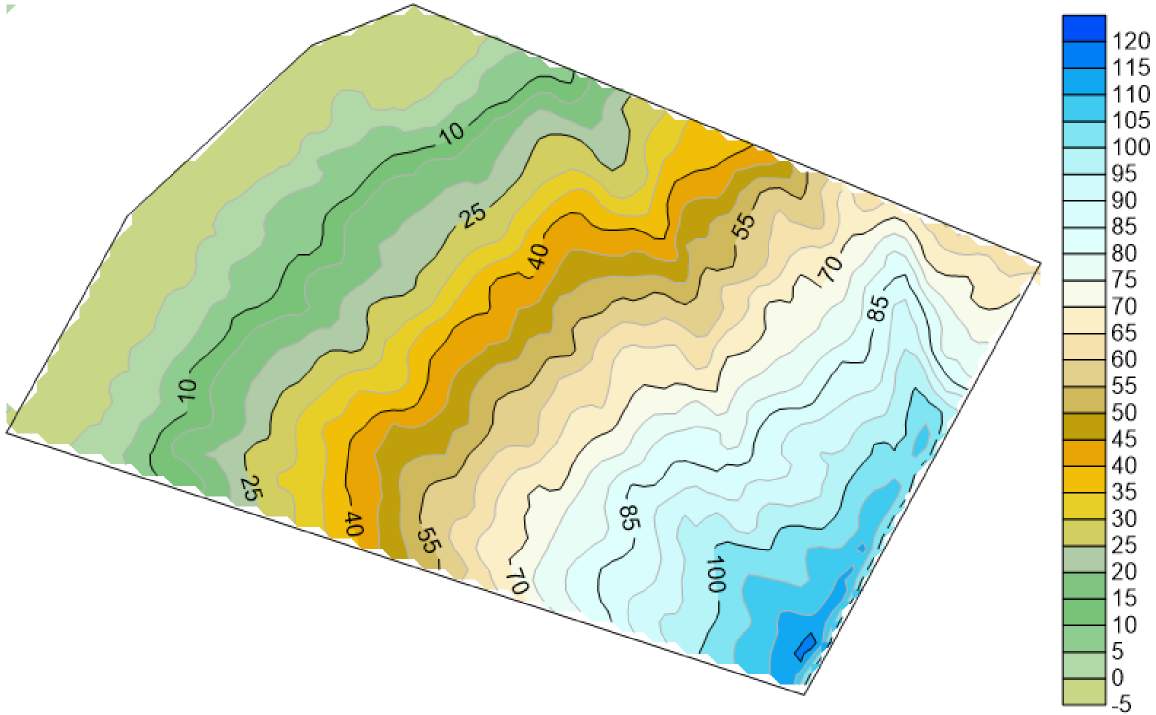
Steady-state simulation for Initial condition

Coastal line total head = 0



- ✓ Dirichlet boundary condition
- ✓ Rainfall : variable BC

Initial head distribution results



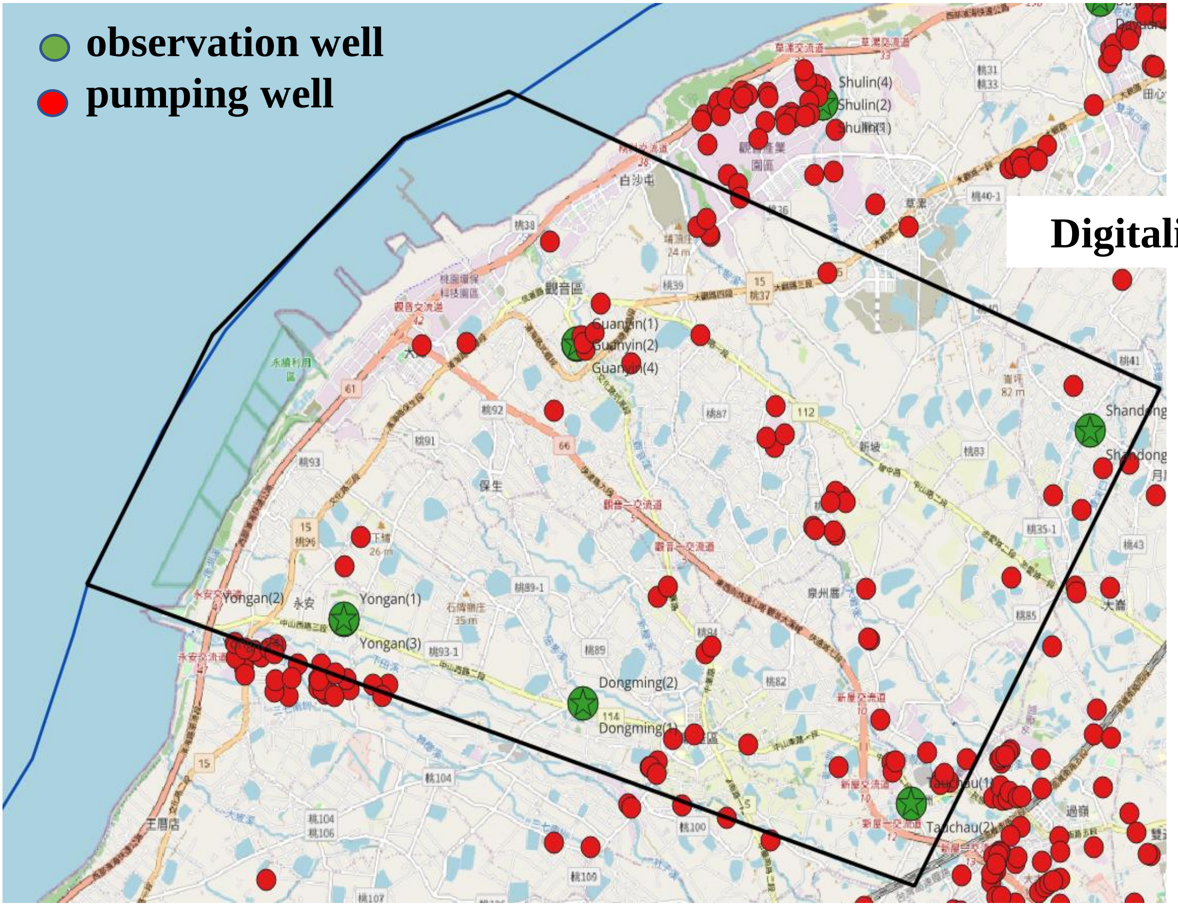
Unit: m

- ➢ This distribution serves as the initial condition for the subsequent transient simulation

Parameter settings

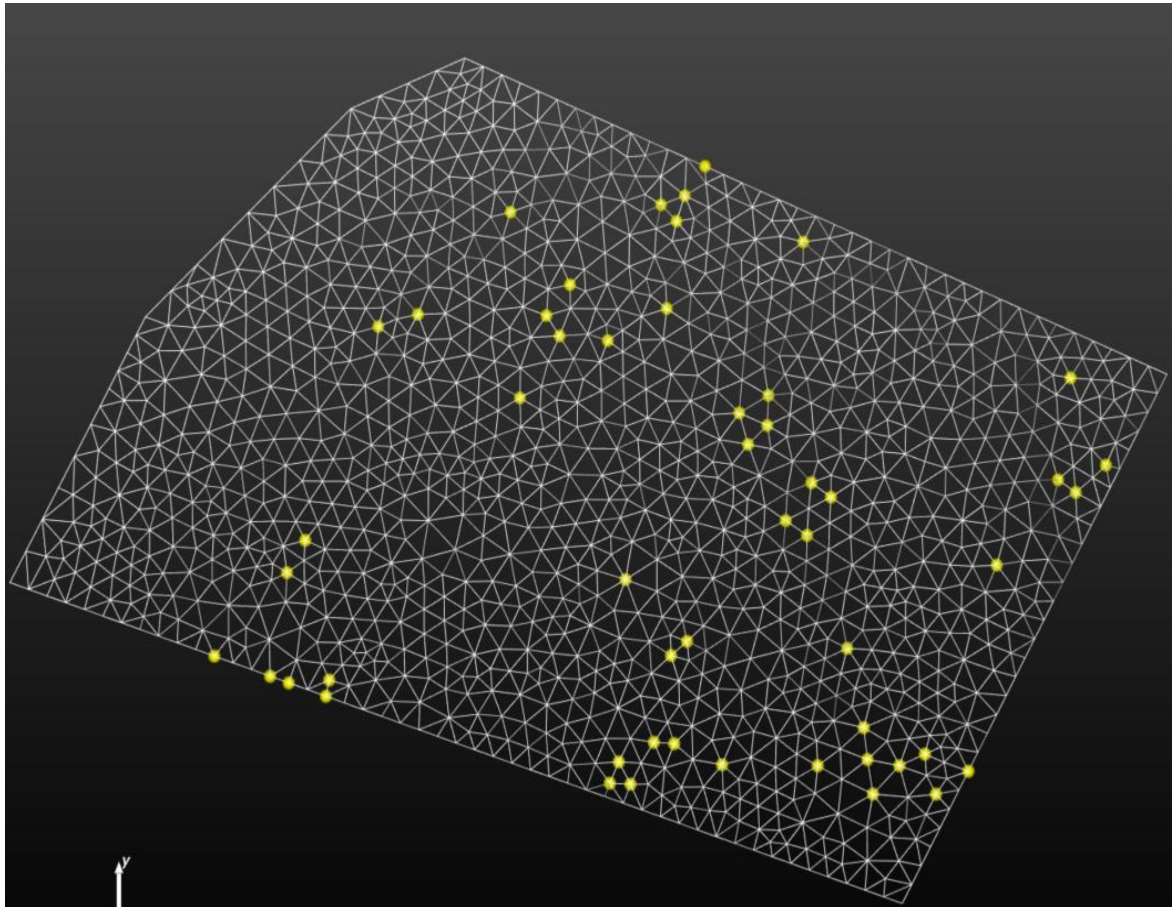
Data input (Transient simulation)

pumping data



- **Taoyuan Pumping Data Distribution Map**

Digitalized results



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

Parameter settings

Data input (Transient simulation)

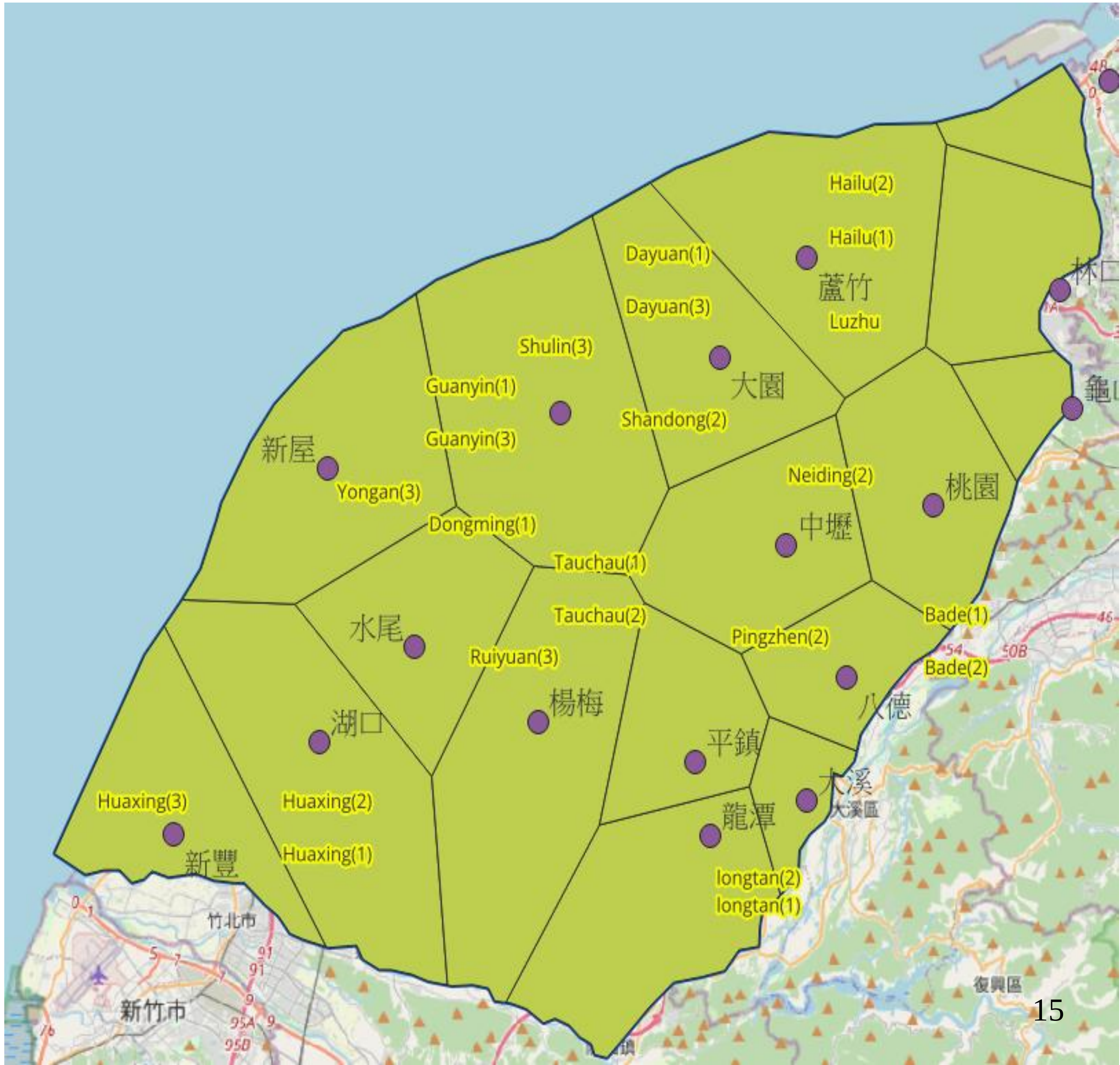
Rainfall setting

- Data from rainfall stations in Taoyuan

站號	站名	年降雨量(mm)				
		108 年	109 年	110 年	111 年	112 年
467050	新屋	2,141	2,140	1,205	1,875	1,178
C0C480	桃園	2,348	2,332	1,677	2,602	1,088
C0C490	八德	2,501	2,486	2,082	2,808	1,636
C0C540	大園	2,154	2,135	1,389	2,320	-
C0C590	觀音	2,199	2,176	1,327	2,317	1,095
C0C620	蘆竹	2,022	2,010	1,357	2,304	1,027
C0C630	大溪	2,164	2,152	1,899	2,714	1,584
C0C650	平鎮	2,008	1,999	1,492	2,888	1,238
C0C660	楊梅	2,404	2,387	1,565	2,639	1,397
C0C670	龍潭	2,576	2,559	1,922	3,104	1,771
C0C680	龜山	2,457	2,451	1,641	2,771	1,464
C0C700	中壢	2,266	2,248	1,519	2,459	1,203
C1C510	水尾	2,156	2,139	1,176	2,173	1,273
C0AD10	八里	2,167	2,156	1,545	2,430	1,062
C0AH50	林口	2,187	2,169	1,531	2,657	1,259
C0D590	新豐	2,169	2,153	1,100	2,013	1,321
C0D650	湖口	1,972	1,958	1,031	1,770	1,222

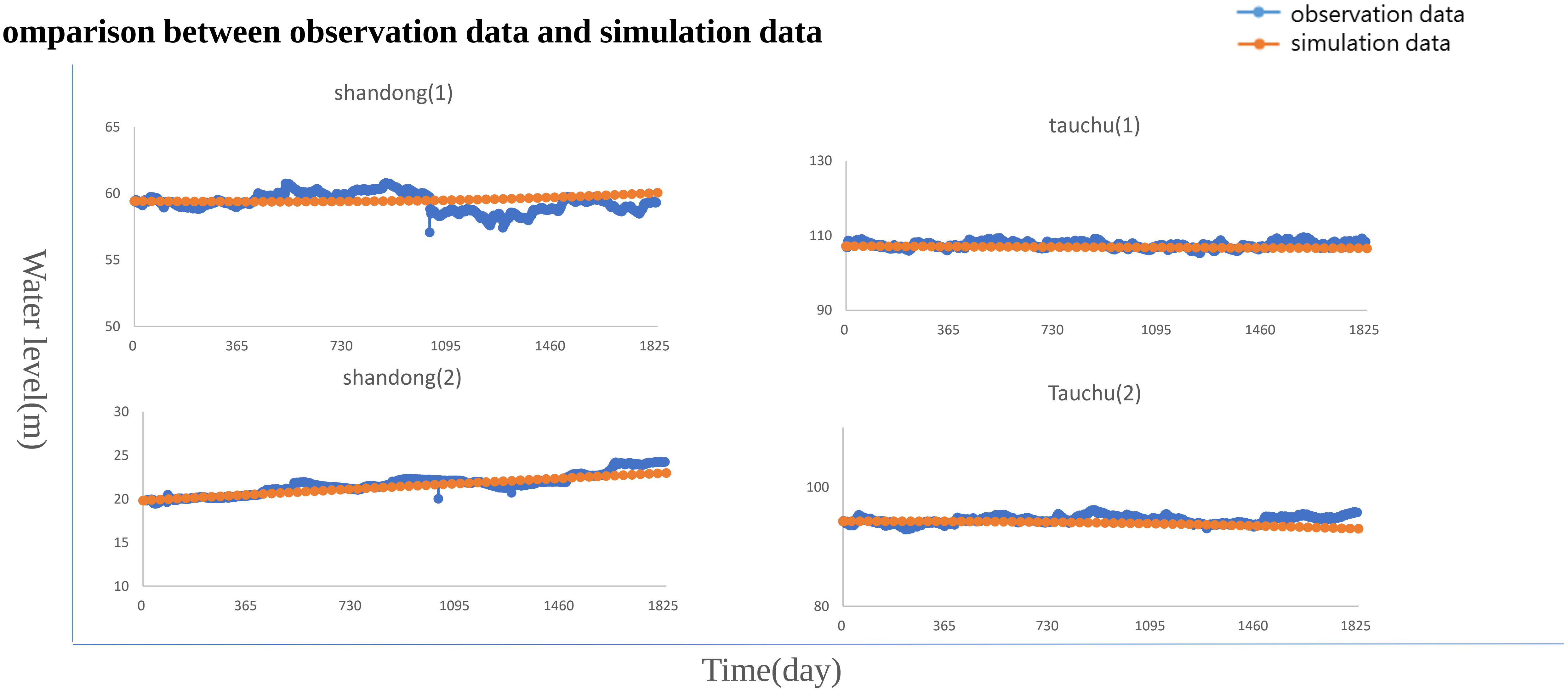
- Thiessen's Polygon Method : 17 regions

- Evaporation rate -3.0 mm/day



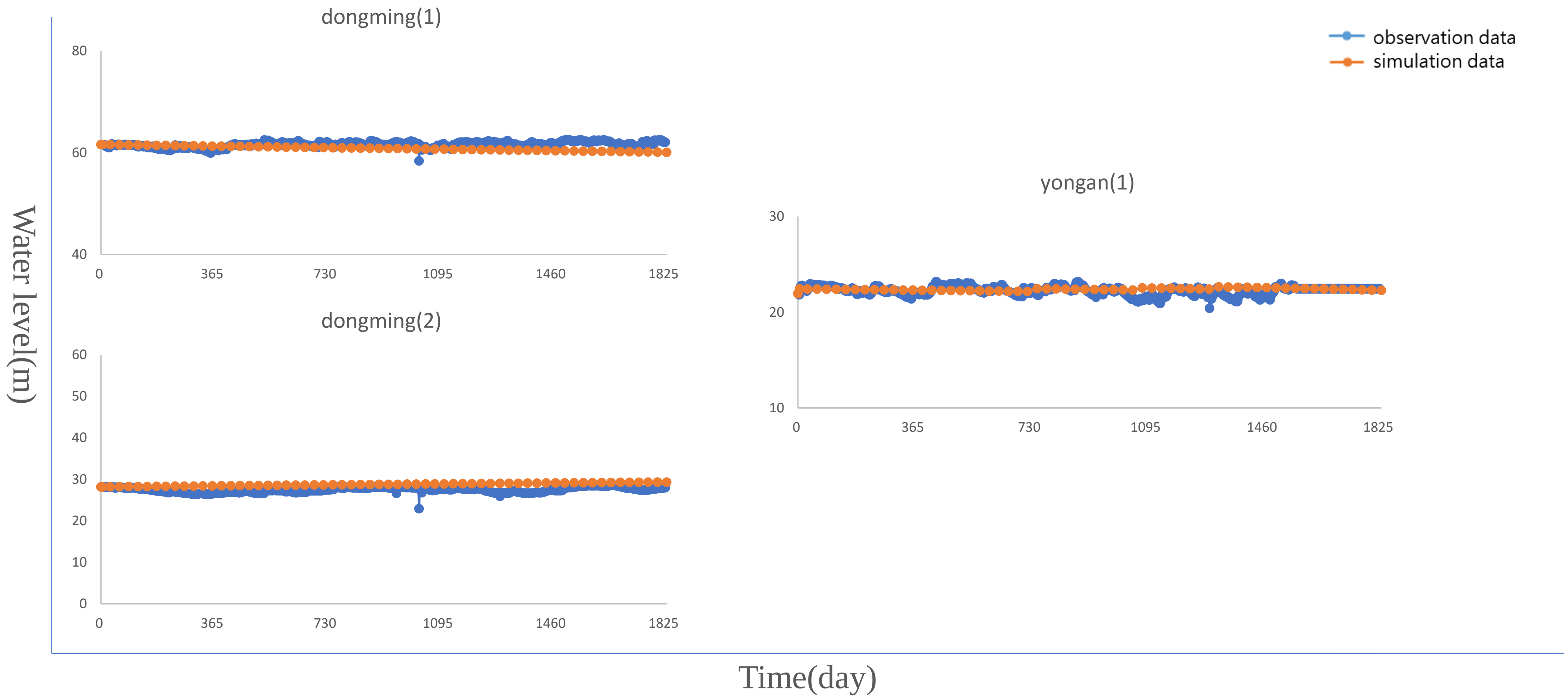
Preliminary Results

Comparison between observation data and simulation data



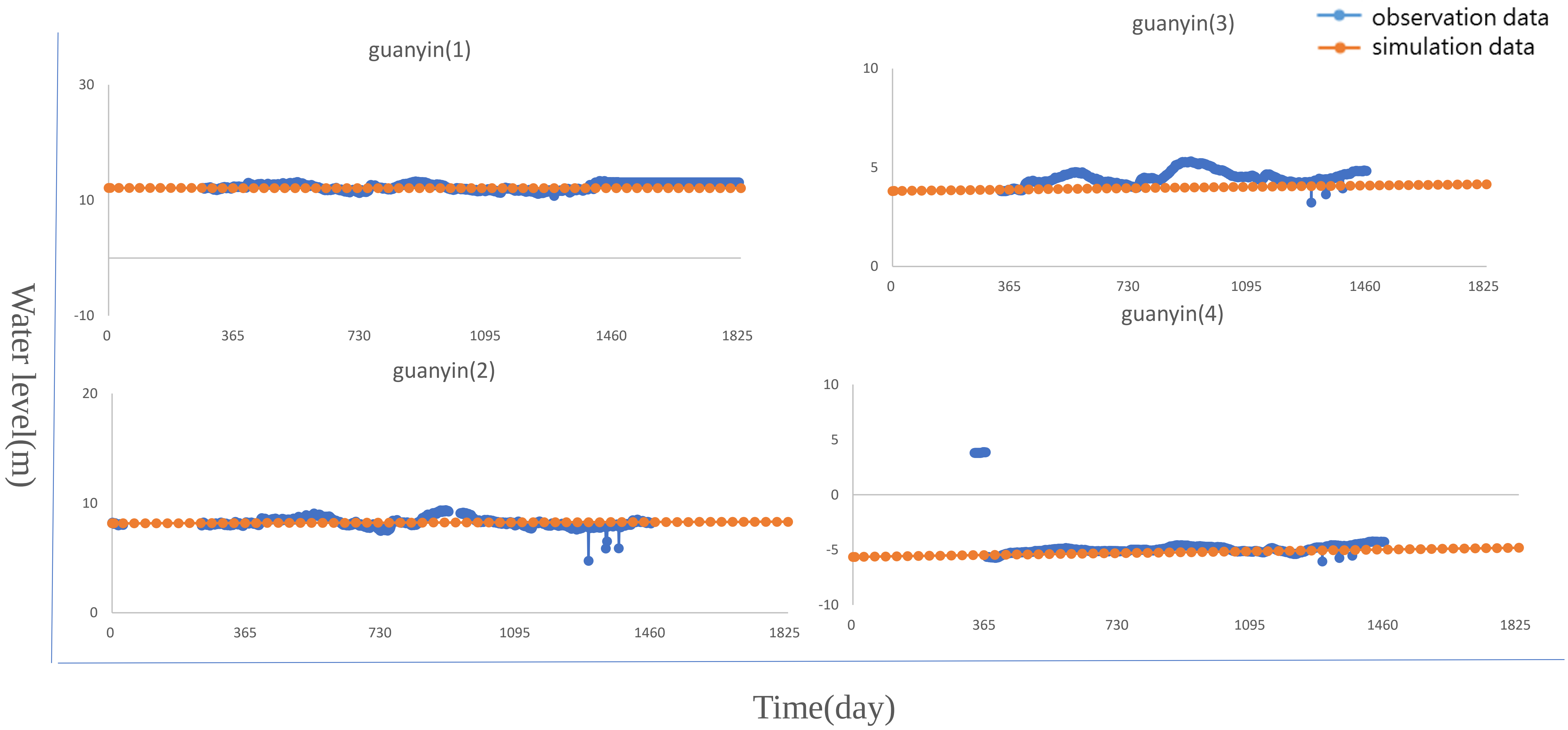
- The observation data in the Shandong region shows high variability, indicating that the model may require further parameter adjustments

Comparison between observation data and simulation data



➢ The model for this area may require further calibration to more accurately reflect the actual hydrological conditions.

Comparison between observation data and simulation data



➢ The simulation results are relatively close to the observed data but may underestimate water level fluctuations

Conclusions

- The pond model needs to consider more parameters that influence groundwater recharge. This not only improves accuracy but also provides more comprehensive water resource information for the region.

- The preliminary model has been completed, but additional parameters are needed for calibration and validation.

Future work

- Continue do calibration to improve the accuracy of model and do the calibration for the remain wells.

- The model will incorporate ponds ,and the results will be used for comparison.

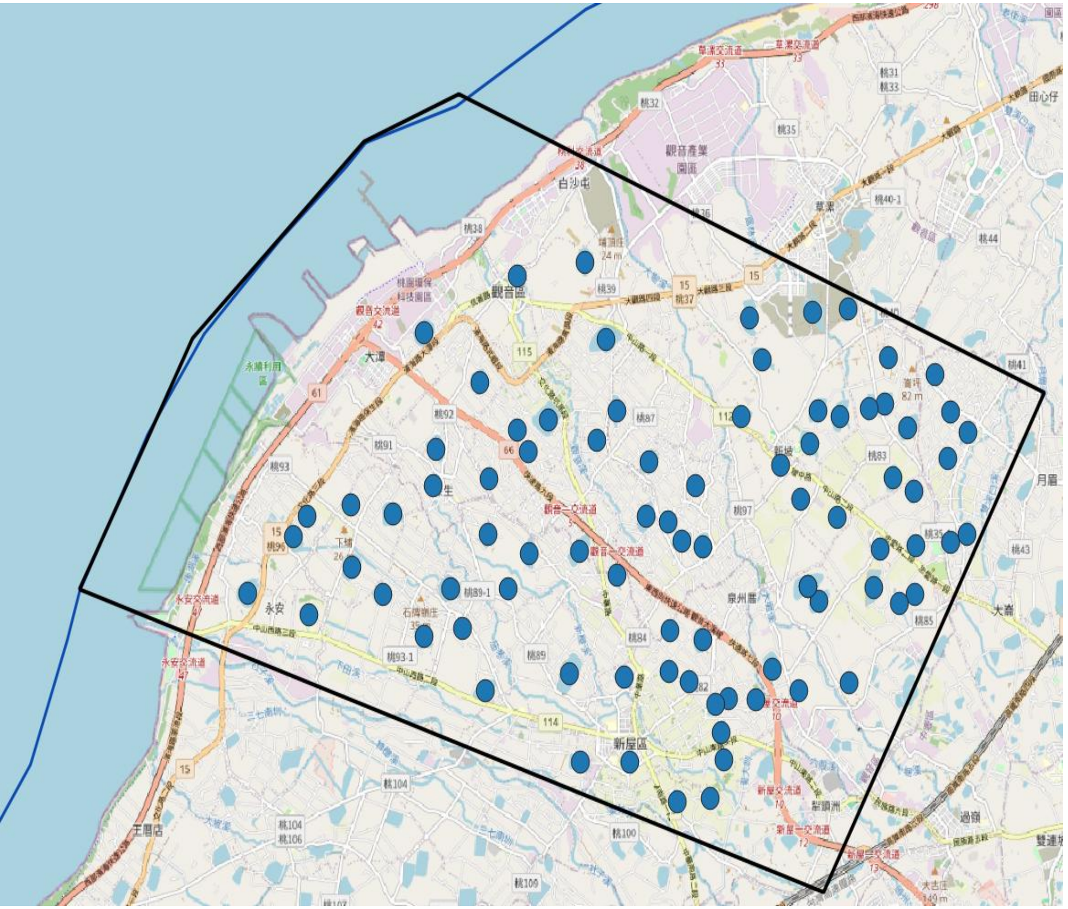
Thank you for your attention.

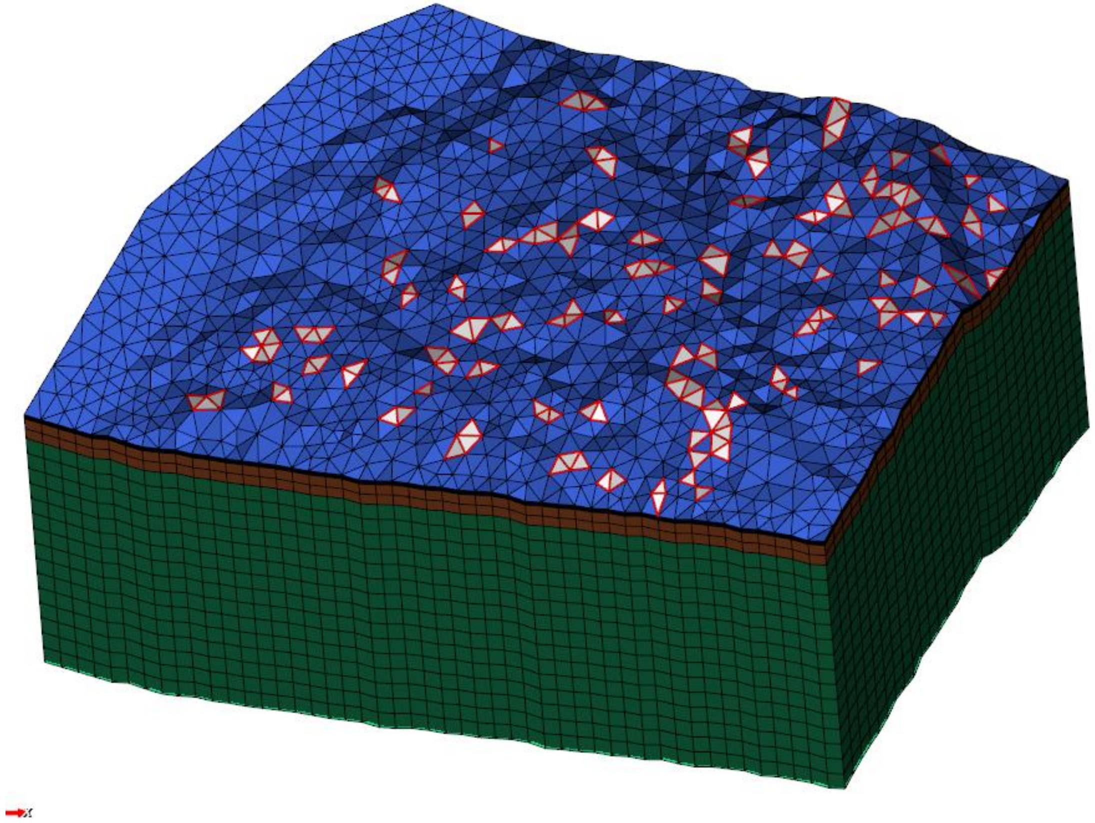
Methodology

Parameter settings

Data input (Transient simulation)

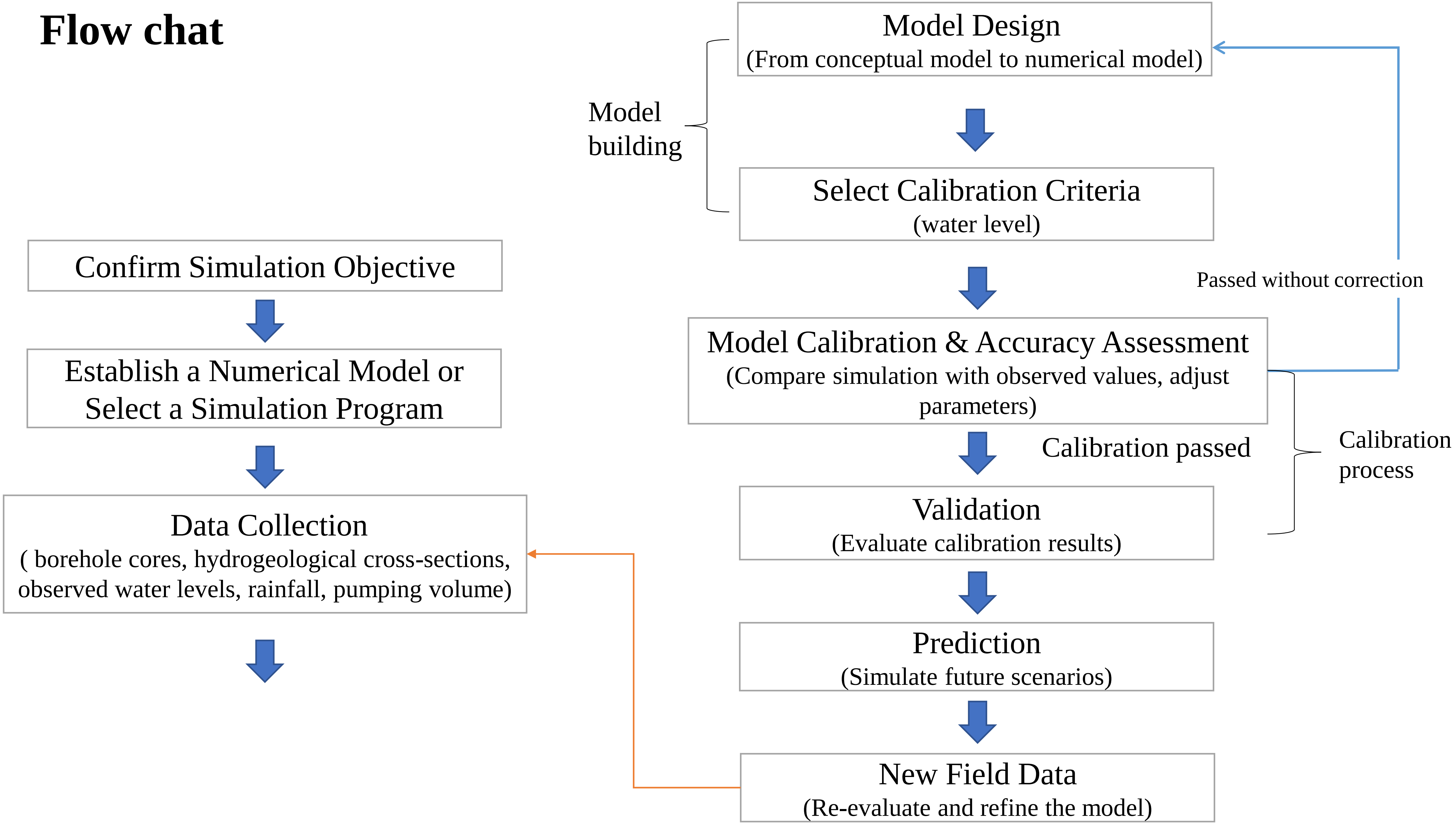
Pond setting





- The area has **85 ponds**, which are categorized into **three levels** and incorporated into the model for simulation.

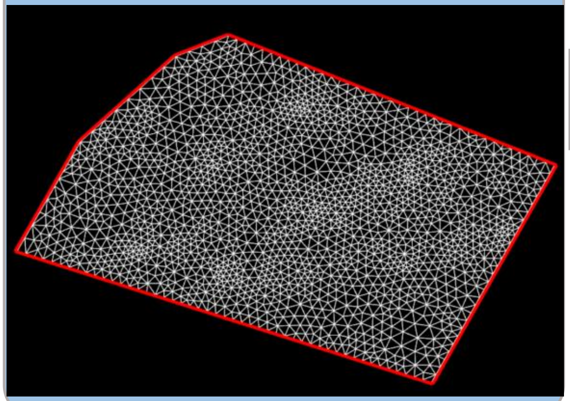
Flow chat


Confirm Simulation Objective
Establish a Numerical Model or Select a Simulation Program
Data Collection
(borehole cores, hydrogeological cross-sections, observed water levels, rainfall, pumping volume)
Model building
Model Design
(From conceptual model to numerical model)
Select Calibration Criteria
(water level)
Passed without correction
Model Calibration & Accuracy Assessment
(Compare simulation with observed values, adjust parameters)
Calibration passed
Calibration process
Validation
(Evaluate calibration results)
Prediction
(Simulate future scenarios)
New Field Data
(Re-evaluate and refine the model)

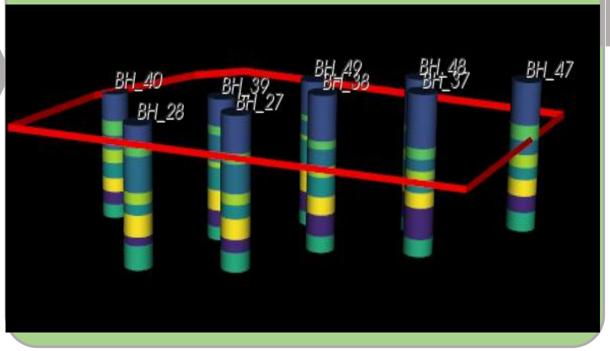
Methodology

Mesh generation

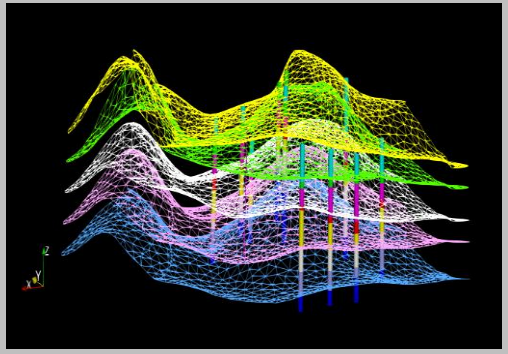
Simplified boundary (ESRI Shapefile)



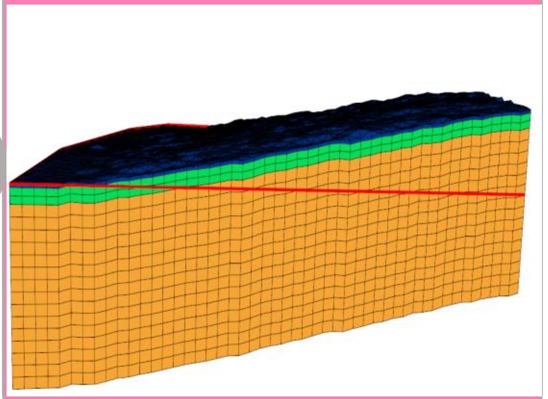
well logging (Borehole Data)



2D mesh in layers (TINs)



3D mesh in layers (Solids)



Import shapefile → Import borehole data → Construct 2D mesh → 3D geological model

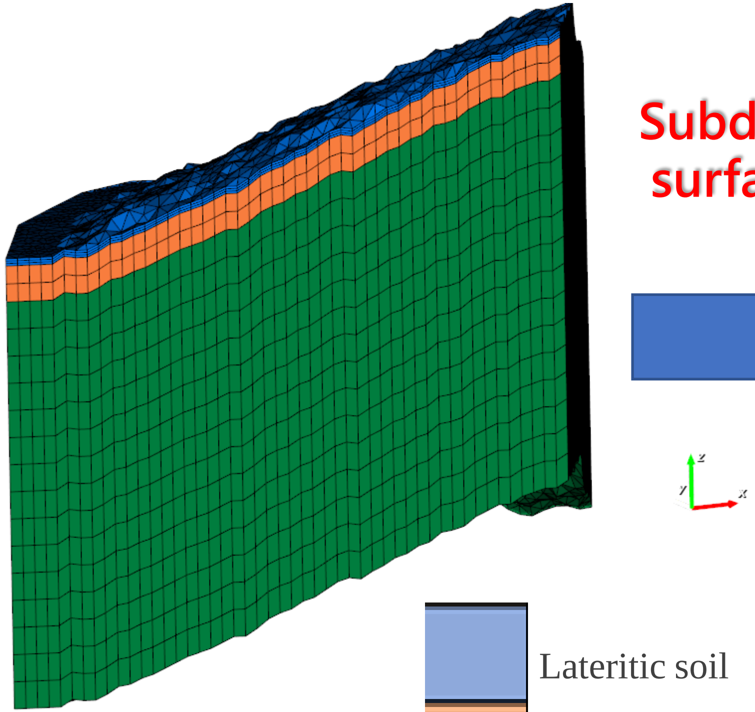
◆ Algorithm in Alan M. Lemon(2003) Building solid models from boreholes and user-defined cross-sections.

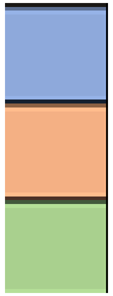
Mesh Info.	
	❖ system of triangular prism ❖ 25,452 nodes ❖ 45,700 elements (2285/layer*20 layers)

Methodology

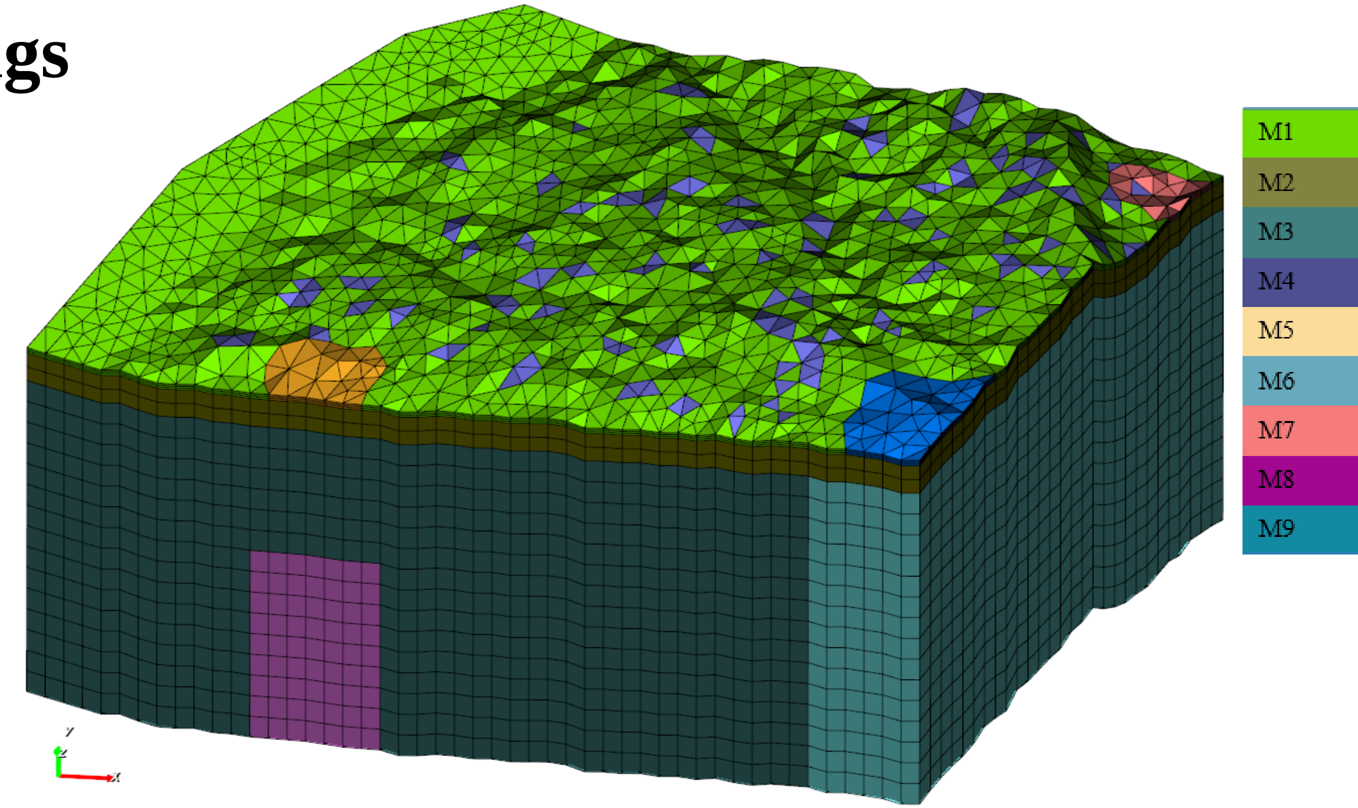
Parameter settings

Hydraulic conductivity (K)

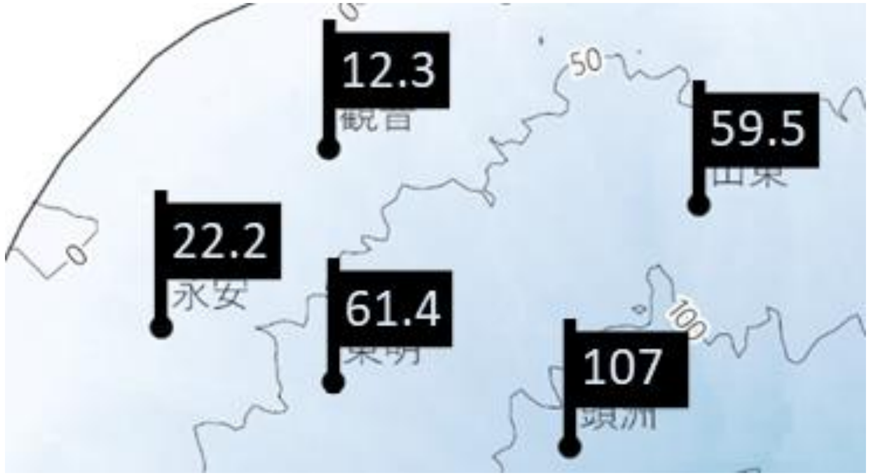


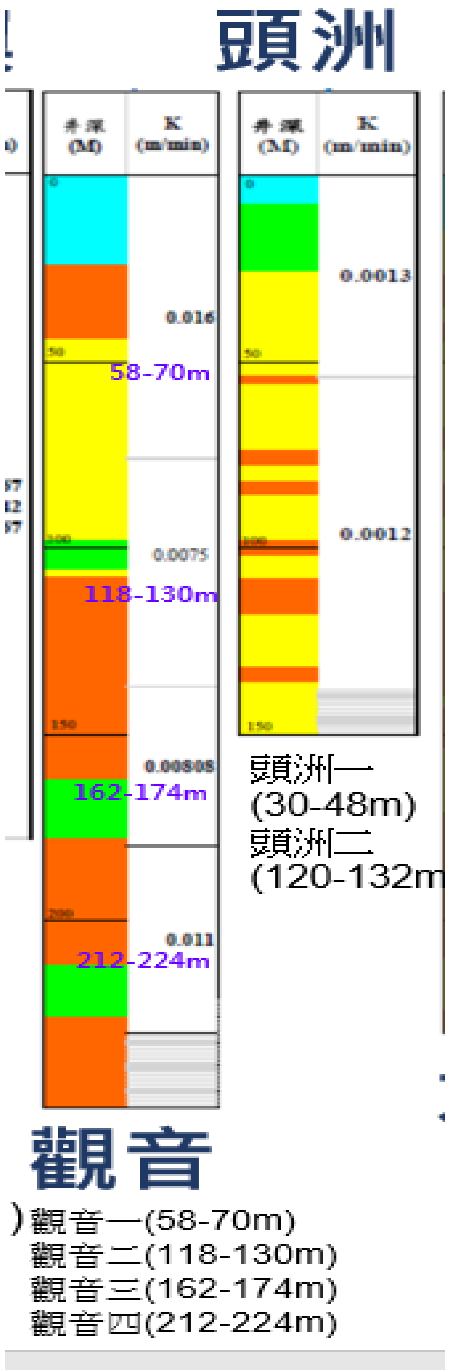


Subdivision with surface material



Soil material	Classify	Kx (m/sec)	Ky (m/sec)	Kz (m/sec)
M1	Silt	0.00075	0.00075	0.000012
M2	gravel	0.00125	0.00125	0.0000165
M3	silt	0.0008	0.0008	0.0000135
M4	silt	0.0005	0.0005	0.0012
M5	silt	0.0002	0.0002	0.00005
M6	gravel	0.0075	0.0075	0.000125
M7	silt	0.006	0.006	0.00025
M8	silt	0.001	0.001	0.00006
M9	silt	0.001	0.001	0.0000145


12.3
50
59.5
22.2
永安
61.4
100
107


頭洲
井深 (M)
K (m/min)
0.016
58-70m
0.0075
118-130m
0.00808
162-174m
0.011
212-224m
0.0013
0.0012
頭洲一 (30-48m)
頭洲二 (120-132m
觀音
觀音一(58-70m)
觀音二(118-130m)
觀音三(162-174m)
觀音四(212-224m)