Influences of Geological Materials on Rainfall and Groundwater Level

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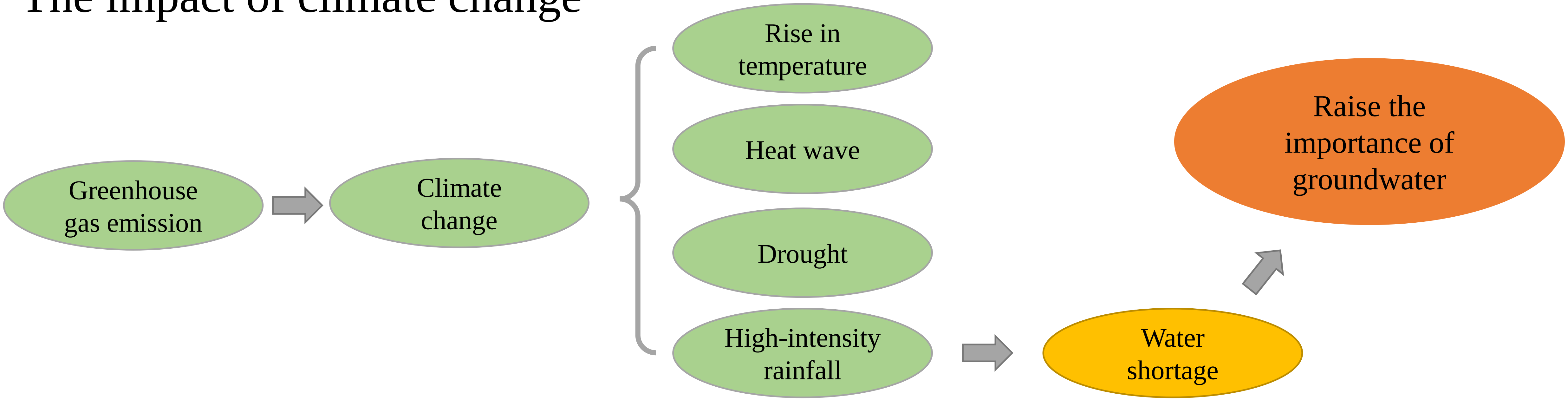
Outline

- Introduction
- Methodology
- Preliminary results
- Conclusions
- Future work

The impact of climate change



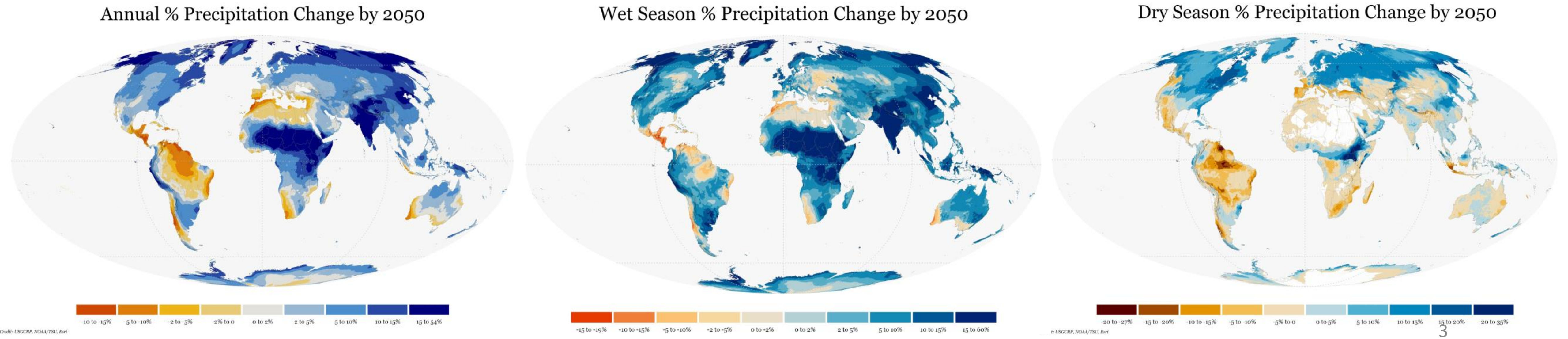
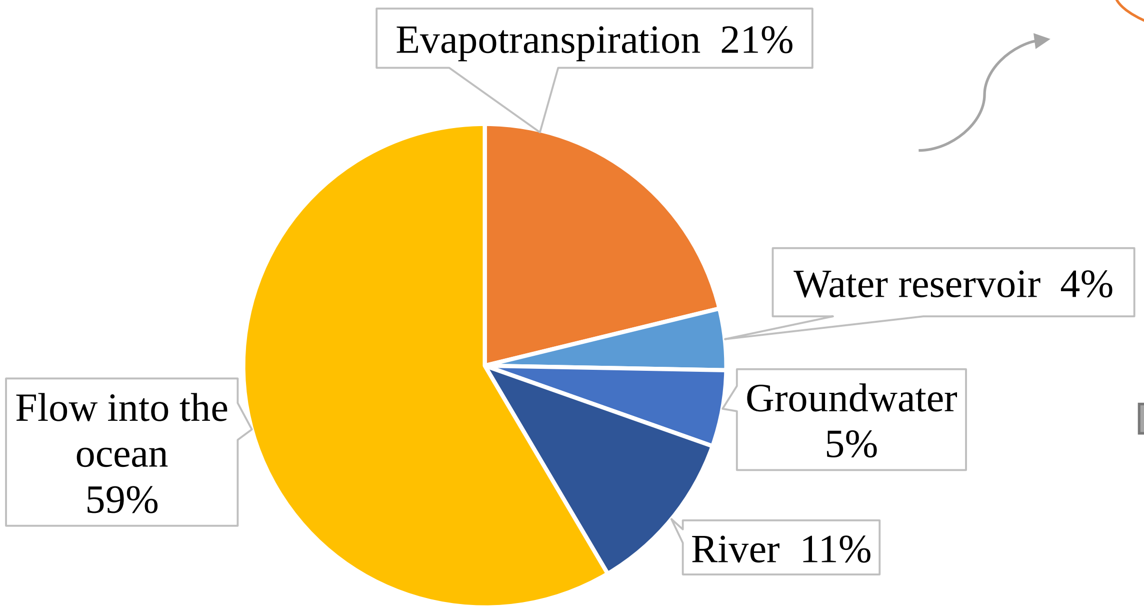


Fig. from https://www.esri.com/arcgis-blog/products/arcgis-living-atlas/mapping/climate-extremes-heavy-rains/

The importance of groundwater

Where does all the rain in Taiwan go?



Reference: https://www.taisounds.com/news/content/116/57825

Only 20% of water can be used!

Capability of groundwater:
- ✓ Drinking water source
- ✓ Agricultural irrigation
- ✓ Industrial usage
- ✓ Ecological balance
- ✓ Drought resistance
- ✓ Geological stability

- When suffering from water shortage, groundwater will be the suitable choice for emergency use.

Relationship between precipitation and groundwater level

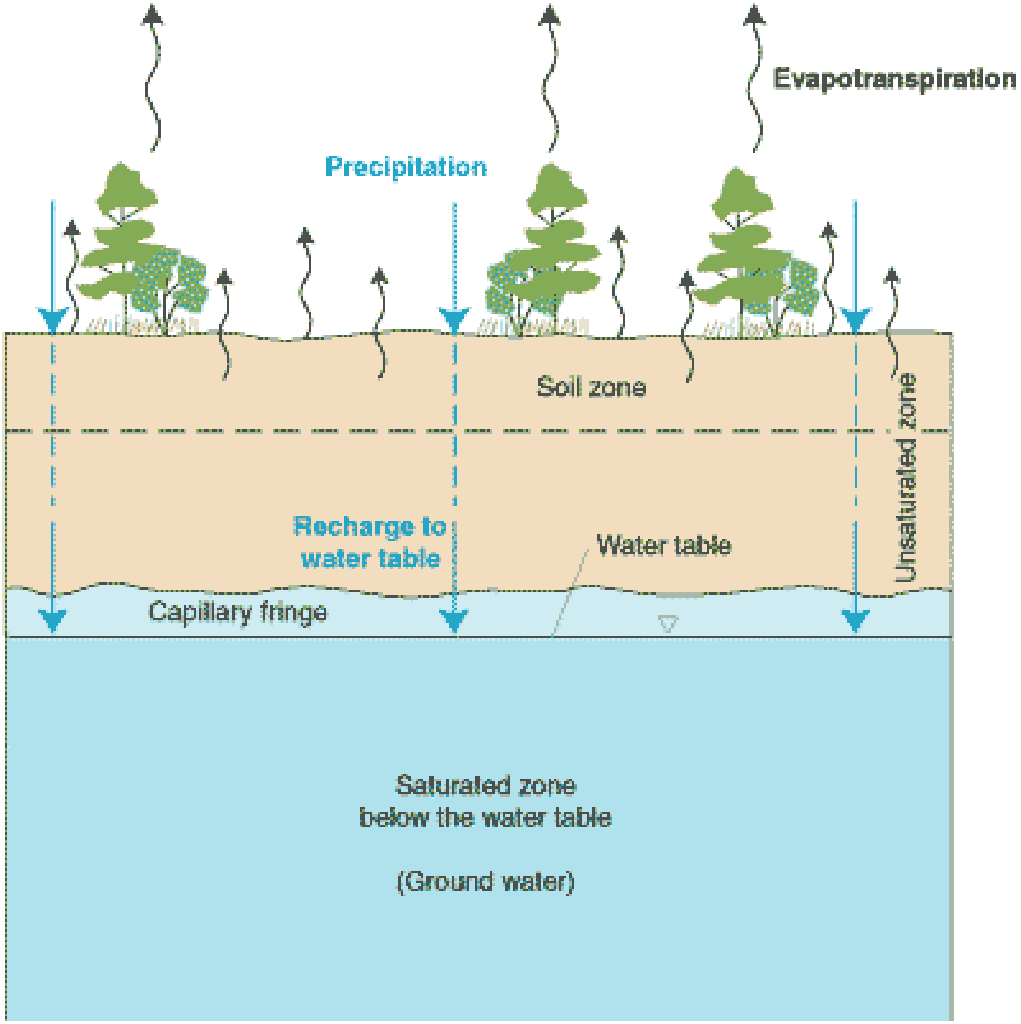
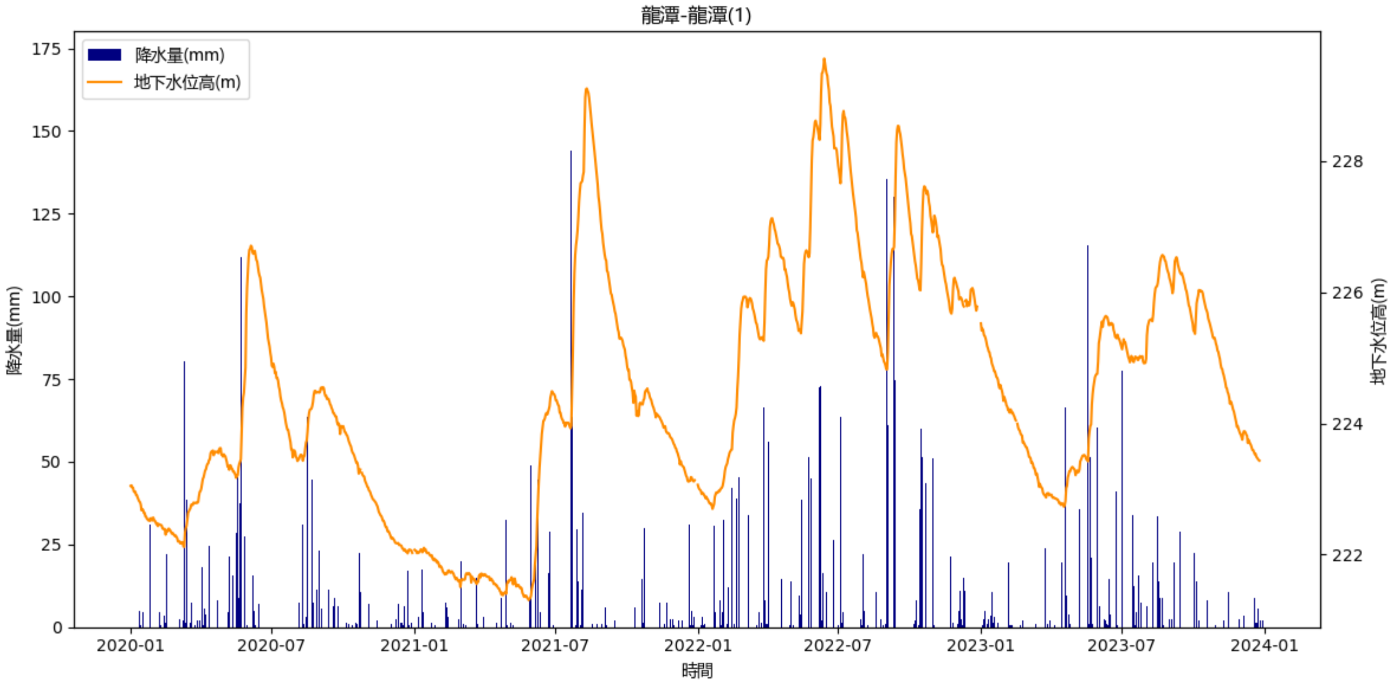


Fig. Relationship between precipitation and groundwater level
Source: https://pubs.usgs.gov/circ/circ1186/html/gen_facts.html



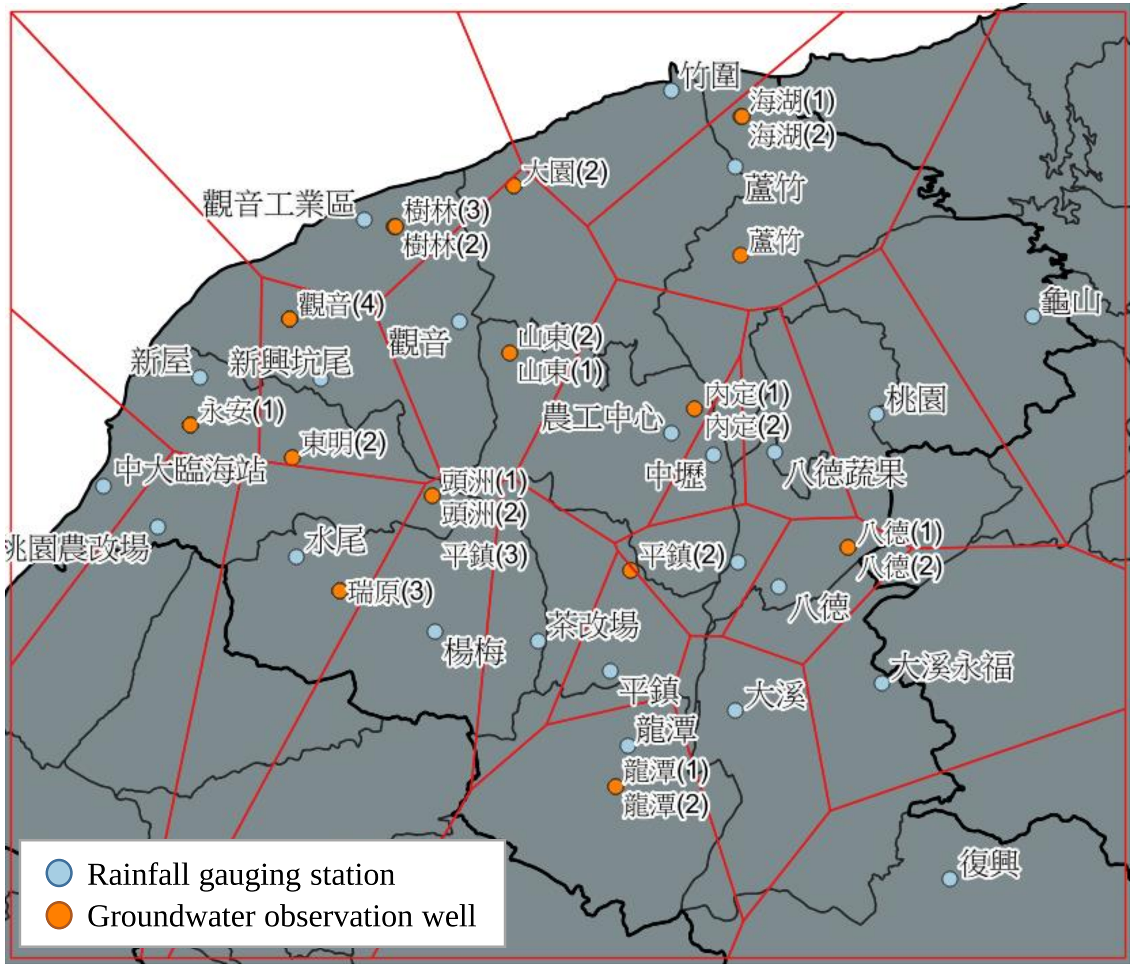
Under normal circumstances, the amount of rainfall will directly affect the groundwater level.

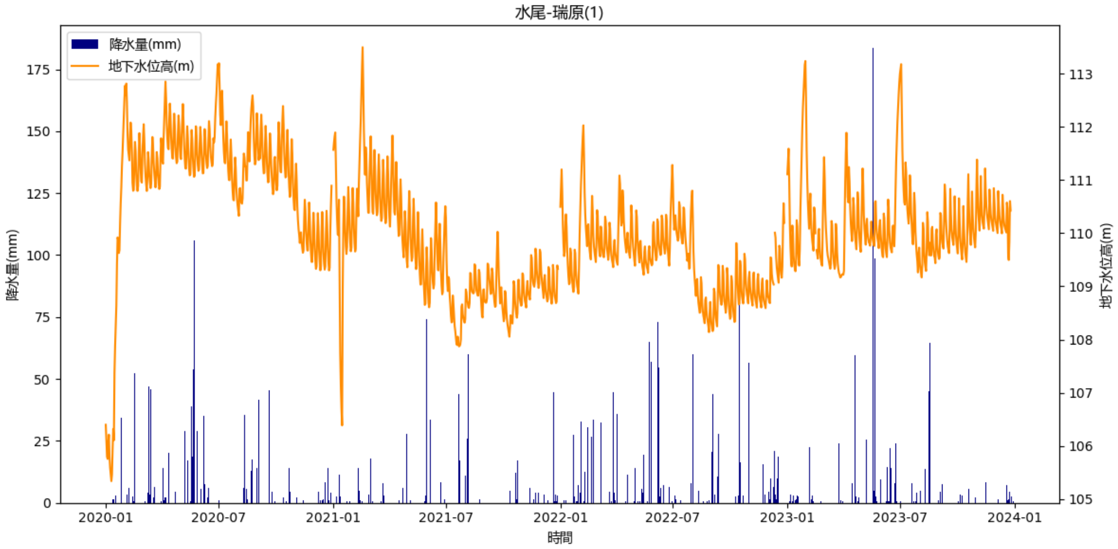
Literature review

- Guo, et al. (2021) built a conceptual model → The amplitude of precipitation has linear impacts on amplitude of depth to water table (DWT).
- Zhang, et al. (2017) used a hydrological model to analyze changes in groundwater levels with rainfall events in Florida → Groundwater levels rise rapidly after rainfall, and the rate of recovery is related to rainfall intensity and duration, as well as soil permeability.
- Hussain et al. (2022) used WASH123D to simulate and observed a good linear correlation relationship between groundwater level responses to associated rainfall in Kaohsiung city.

➢ The relationship between rainfall and groundwater level is obvious in most of the county in Taiwan and abroad.

Observation of other places in Taoyuan





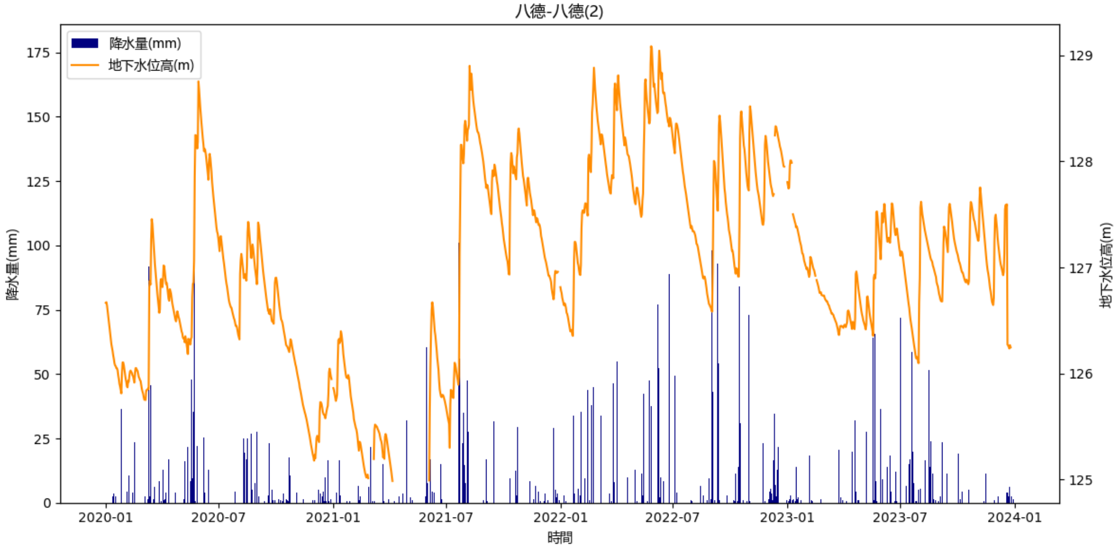


Fig. Distribution map of rainfall gauging stations and groundwater observation wells in Taoyuan City

The difference between Longtan and other area in Taoyuan

- Taoyuan is commonly covered by lateritic soil → low permeability

  (lateritic soil thickness ~3m-5m)

- Longtan has the thickest gravel layer among all the other sites.

(reference:李錫堤教授《桃園台地的地形與地質》)

Material and thickness may be key to differences in how groundwater flows.

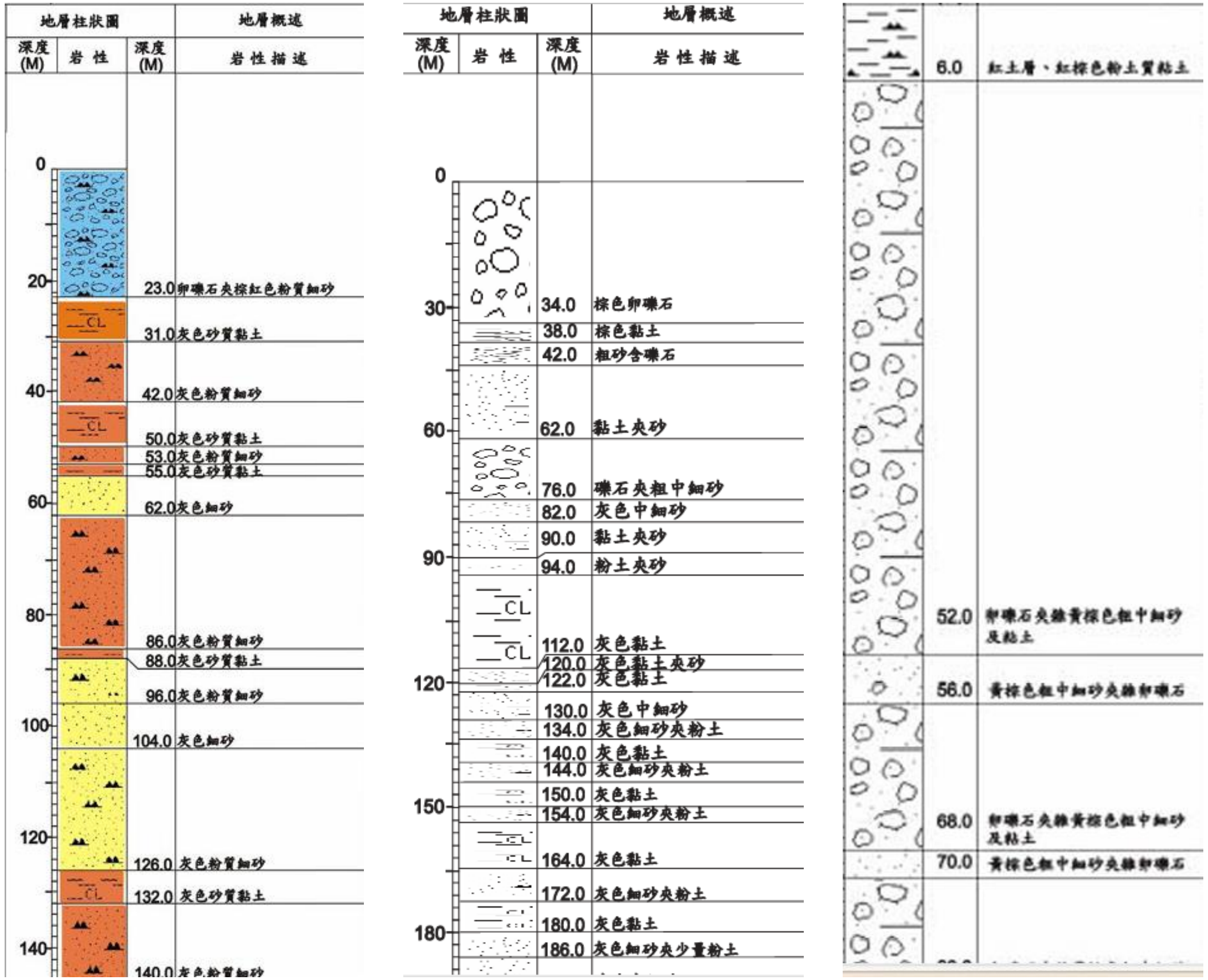


Fig. 八德(1) , 瑞原(1) and 龍潭(1) Groundwater observation well lithology description

About THMC

- A model developed by hydroscience chair professor Gour-Tsyh Yeh.
- Physical based comprehensive computational model for simulating coupling thermal, hydraulic, geo-mechanical, and chemical processes in subsurface media.
- Considered unsaturated and saturated zones in simulation.

1981

FEMWATER

1. Flow
2. Solute transport

1991

HYDROGEOCHEM

1. Flow
2. Solute transport and chemical reaction
3. Heat transfer

2021

THMC

1. Flow
2. Solute transport and chemical reaction
3. Heat transfer
4. Geomechanics

Fig. Chair professor Gour-Tsyh Yeh

	THMC	MODFLOW
Saturated zone	V	V
Unsaturated zone	V	X

- THMC is the most efficient and with the most complete features.
- MODFLOW cannot simulate flow in unsaturated zone.
- Infiltration in MODFLOW is assumed time-invariant $\rightarrow$ not accurate!

Objective

- Use THMC to establish hypothetical two-dimensional models to simulate different materials and stratigraphic arrangements to see the impact on the relationship between rainfall and groundwater level changes.

Governing equations for flow through saturated-unsaturated media

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

ρ: fluid density with dissolved chemical concentrations (M/L^3)
ρ_0: referenced fluid density at reference pressure p_0= 1atm, reference temperatureT_0=298 °K and zero chemical concentration (M/L^3)
ρ^{ss}: fluid density of either injection or withdraw (M/L^3)
h: pressure head (L)
t: time (T)
F: generalized storage coefficient (1/L)
K: hydraulic conductivity tensor (L/T)
z: potential head (L)
q: source / sink of fluid [(L^3 / L^3)/T]

Generalized storage coefficient F

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

α': modified compressibility of the soil matrix (1/L)
β': modified compressibility of the liquid (1/L)
θ_e: effective moisture content (L^3/L^3)
n_e: effective porosity (L^3/L^3)
S: degree of effective saturation of water
h: pressure head (L)

Hydraulic conductivity tensor **K**

$$K = \frac{\rho g}{\mu} k = \frac{\frac{\rho}{\rho_0}}{\frac{\mu}{\mu_0}} \frac{\rho_0 g}{\mu_0} k_s k_r = \frac{\frac{\rho}{\rho_0}}{\frac{\mu}{\mu_0}} K_{so} k_r$$

ρ: fluid density with dissolved chemical concentration
ρ_0: referenced fluid density at zero chemical concentration (M/L^3)
μ: fluid dynamic viscosity with dissolved chemical concentration [(M/L)/T]
μ_0: fluid dynamic viscosity at zero chemical concentration [(M/L)/T]
k: permeability tensor (L^2)
$\mathbf{k_s}$: saturated permeability tensor (L^2)
$\mathbf{K_{so}}$: referenced saturated hydraulic conductivity tensor (L/T)
$\mathbf{k_r}$: relative permeability or relative hydraulic conductivity (dimensionless)
g: gravity (L/T^2)

Darcy velocity V (L/T)

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

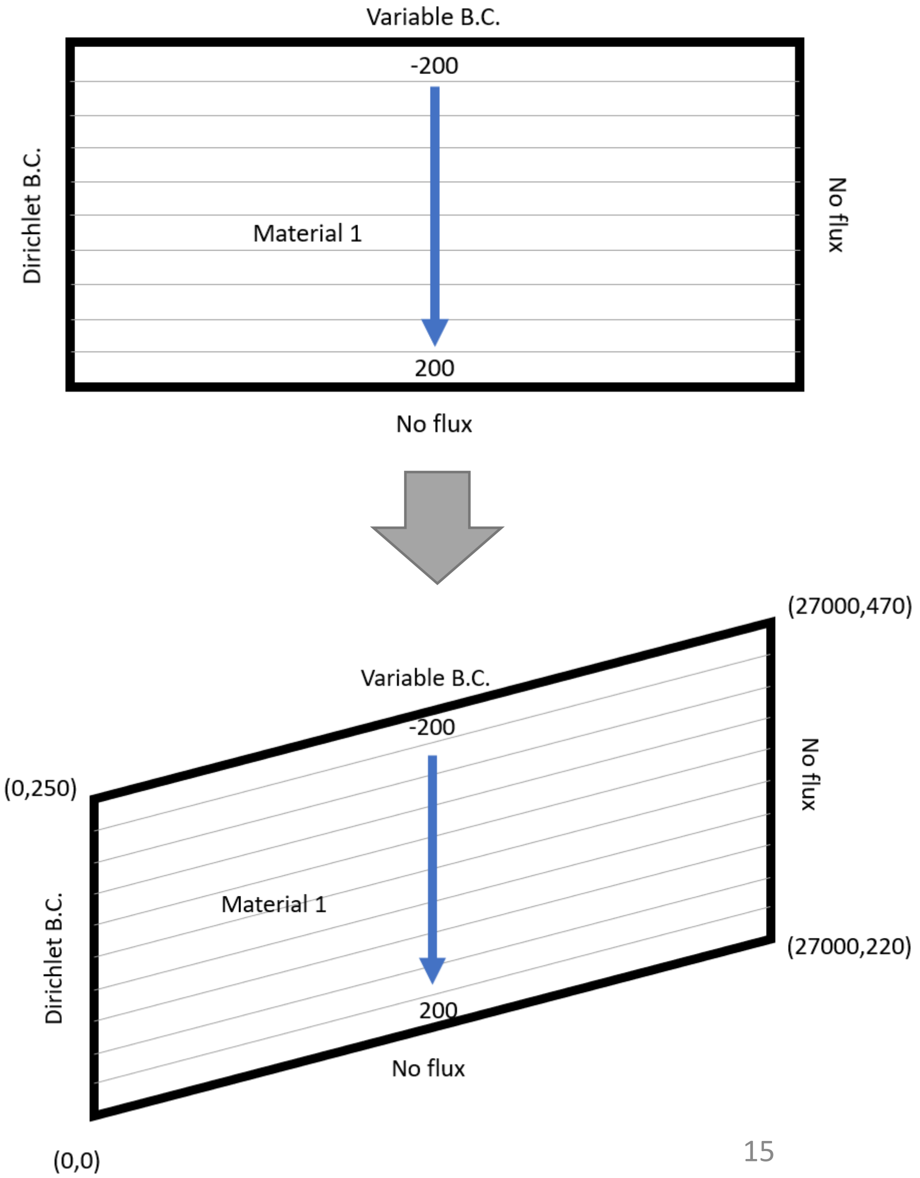
ρ: fluid density with dissolved chemical concentration
ρ_0: referenced fluid density at zero chemical concentration (M/L^3)
h: pressure head (L)
t: time (T)
K: hydraulic conductivity tensor (L/T)
z: potential head (L)

Different stage of conceptual model

- Single homogeneous material
- Two-layered lateral material
- Multiple material with different strata arrangement

Single homogeneous material

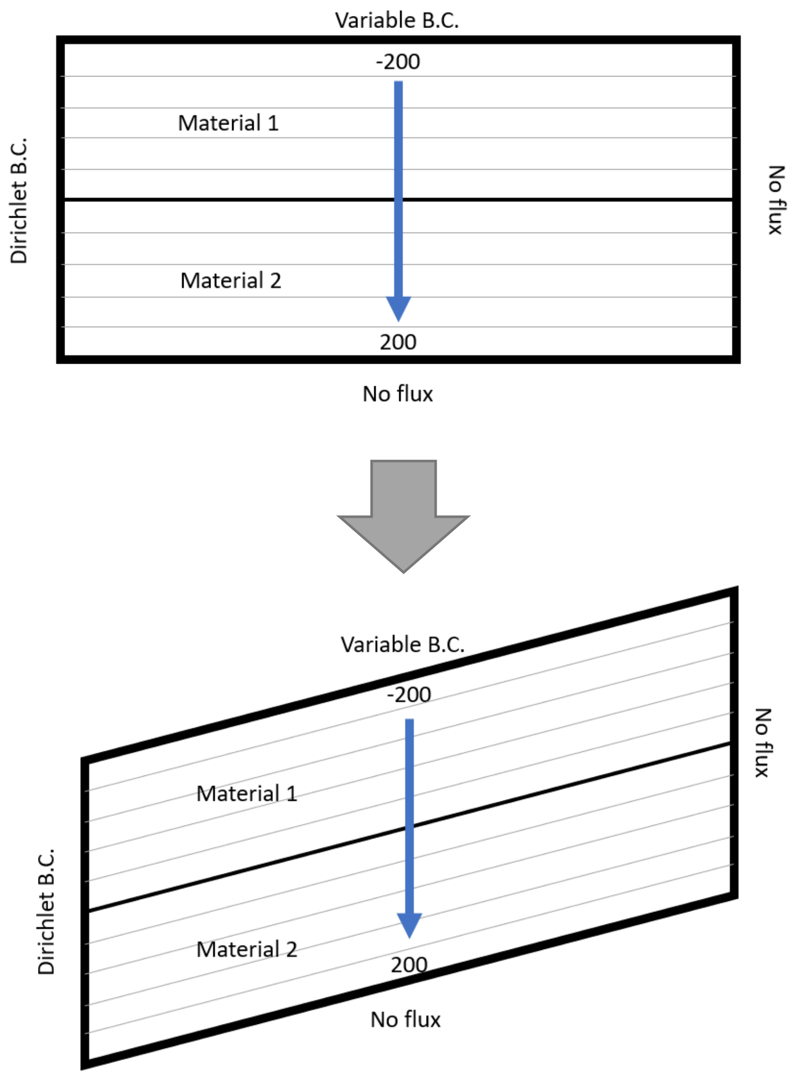
- Model size: 27000m*250m (quadrilateral)
- Elements: 10800 (1080*10)
- Total nodes: 11891 (1081*11)
- Material 1: gravel, clay, fine sand



Two-layered lateral material

- Size:
  - Layer 1: 27000m*125m
  - Layer 2: 27000m*125m
- Elements: 10800 (1080*10)
- Total nodes: 11891 (1081*11)
- Material: gravel, clay, fine sand

	1	2	3	4	5	6
Material 1	Gravel	Clay	Gravel	Fine sand	Fine sand	Clay
Material 2	Clay	Gravel	Fine sand	Gravel	Clay	Fine sand



Multi-material with different strata arrangement

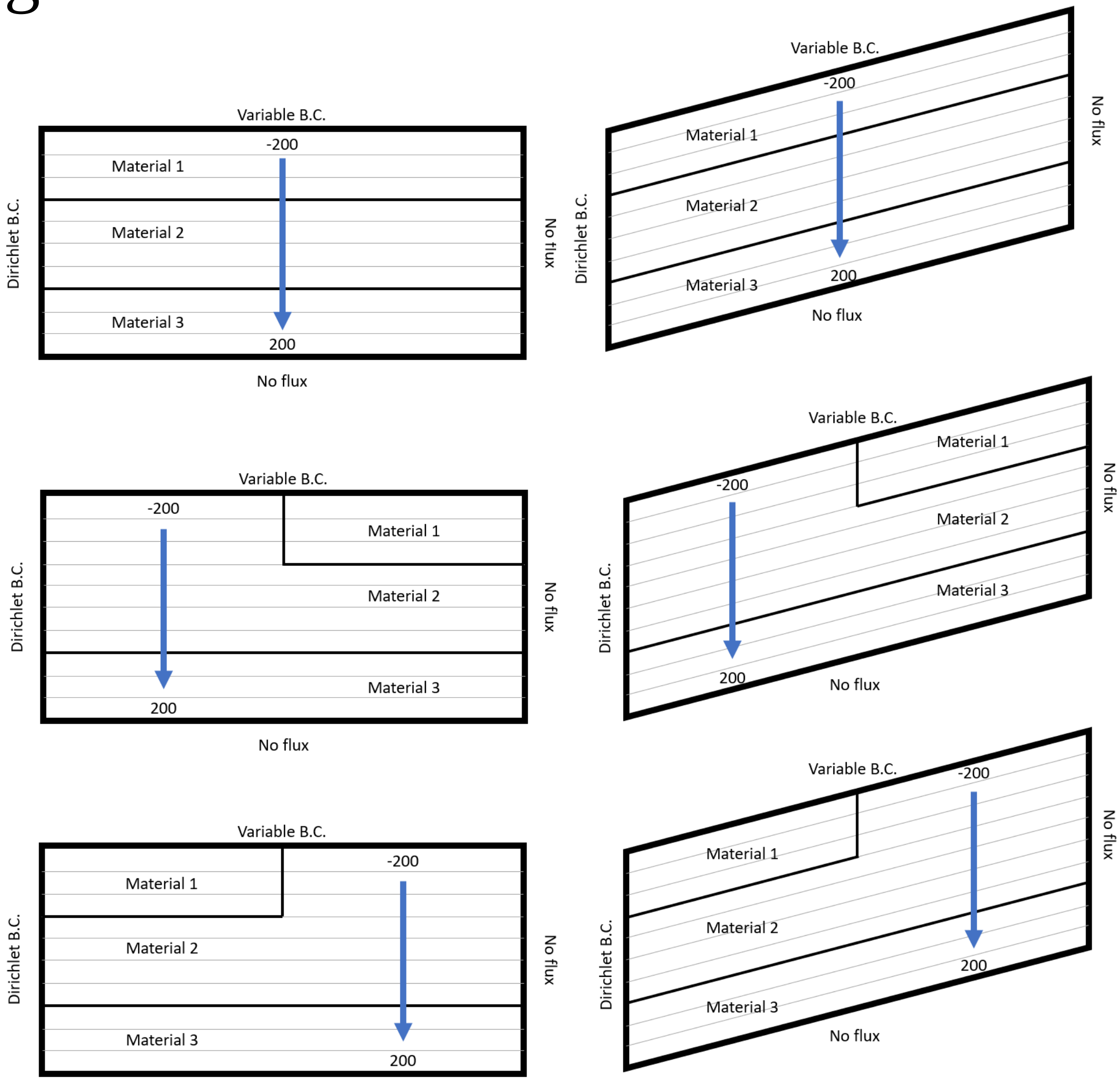
- Elements: 10800 (1080*10)
- Total nodes: 11891 (1081*11)

- Two material combination

	1	2	3	4	5	6
Material 1	gravel	clay	gravel	fine sand	fine sand	clay
Material 2	clay	gravel	fine sand	gravel	clay	fine sand
Material 3	gravel	clay	gravel	fine sand	fine sand	clay

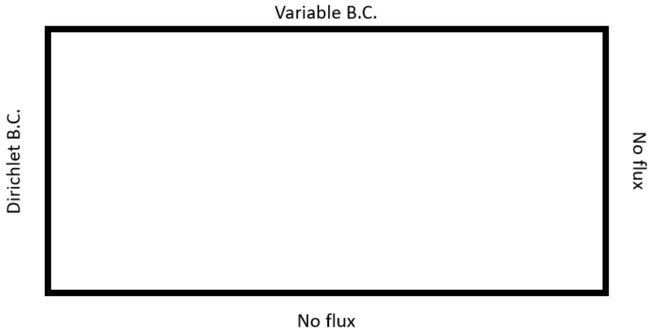
- Three material combination

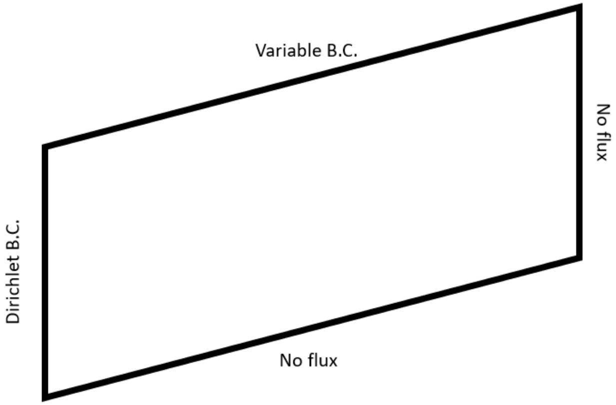
	1	2	3	4	5	6
Material 1	gravel	gravel	fine sand	fine sand	clay	clay
Material 2	fine sand	clay	gravel	clay	gravel	fine sand
Material 3	clay	fine sand	clay	gravel	fine sand	gravel



Initial condition and boundary conditions of numerical model

Type	Value	Location
Initial condition	-200 200 -80	Top boundary Bottom boundary Other nodes
Boundary condition (Dirichlet)	Total head = 0m	Left boundary
Boundary condition (Variable)	Rainfall: 2mm/day	Top boundary





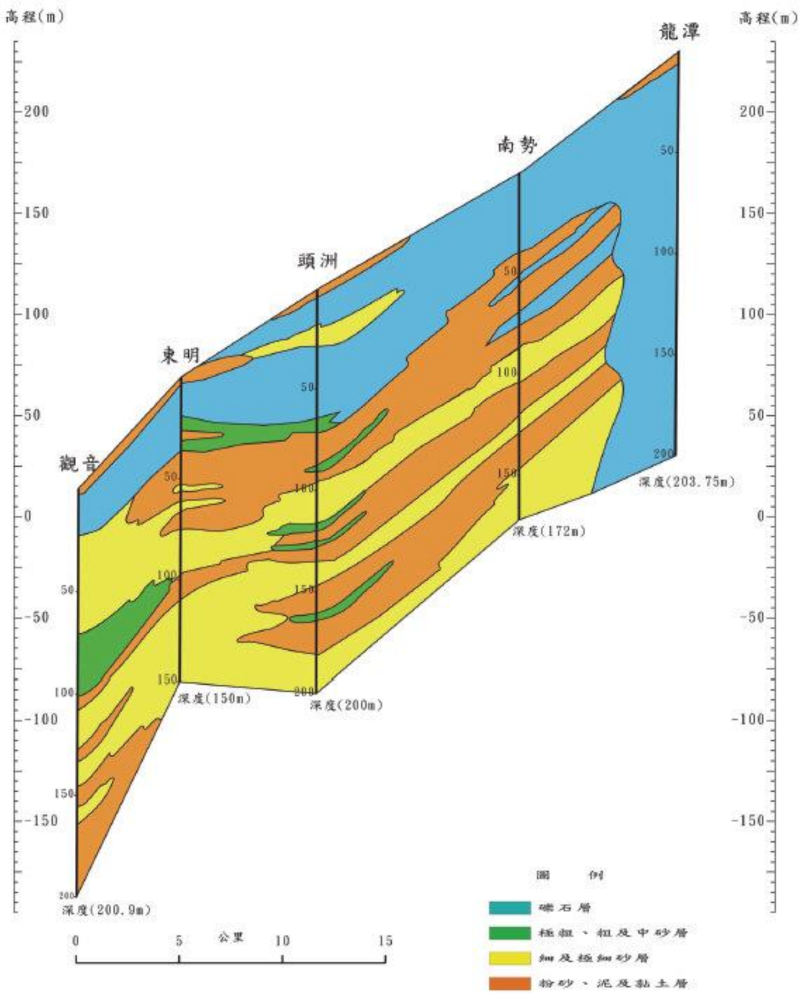


Fig. Guanyin-Longtan stratigraphic section
(from http://pc183.hy.ntu.edu.tw/gwater/d6.php)

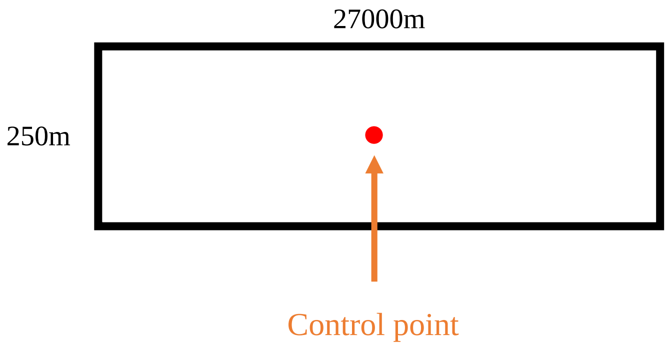
Parameters of numerical model

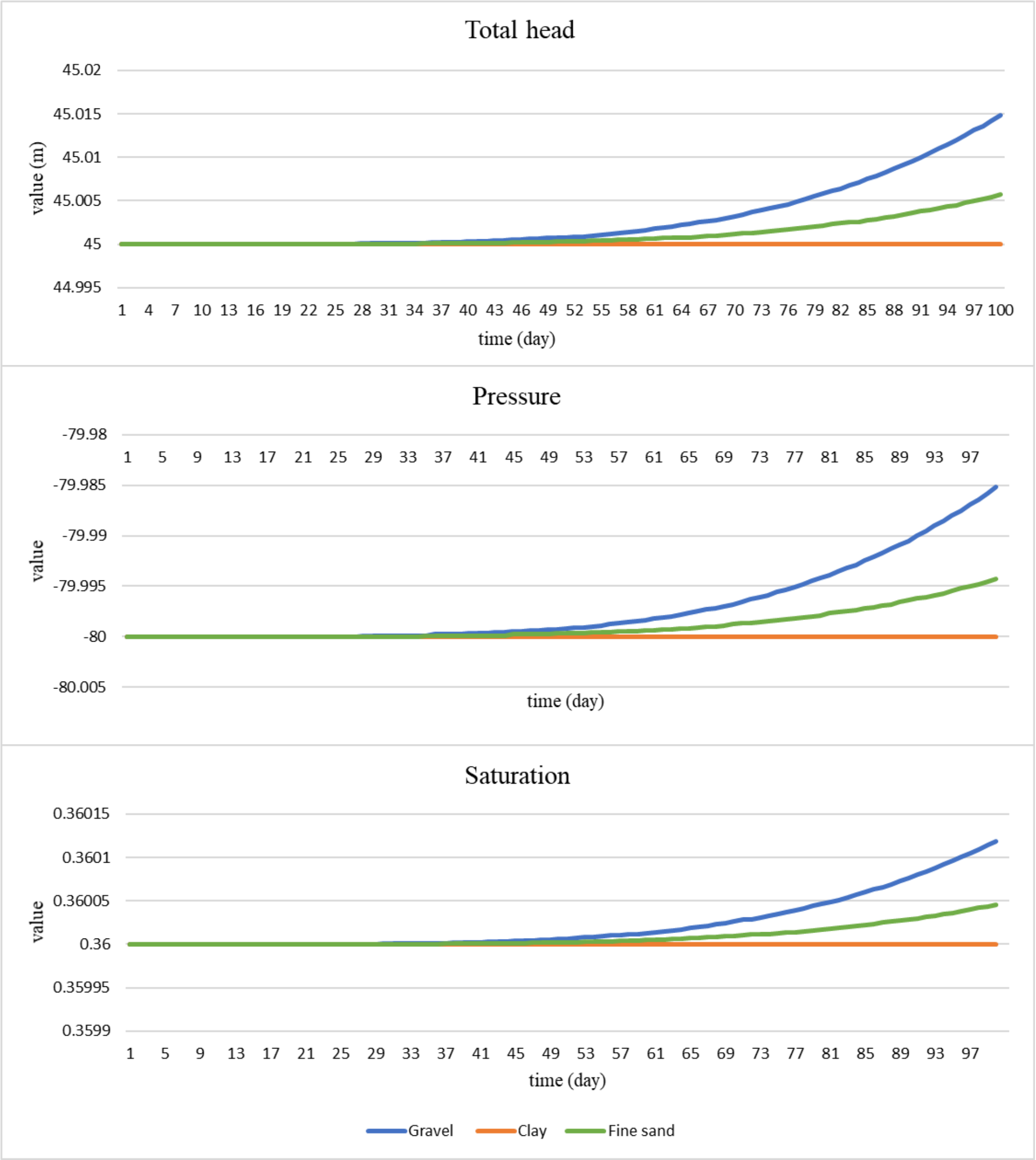
Material	Porosity	Kxx (m/day)	Kzz (m/day)
Gravel	0.35	$1.038*10^{3}$	$1.038*10^{2}$
Clay	0.55	$2.16432*10^{-6}$	$2.16432*10^{-7}$
Fine sand	0.4	8.64864	0.864864

Source: Domenico an Schwartz (1998)

- Time: 100 days

Results of single homogeneous material models

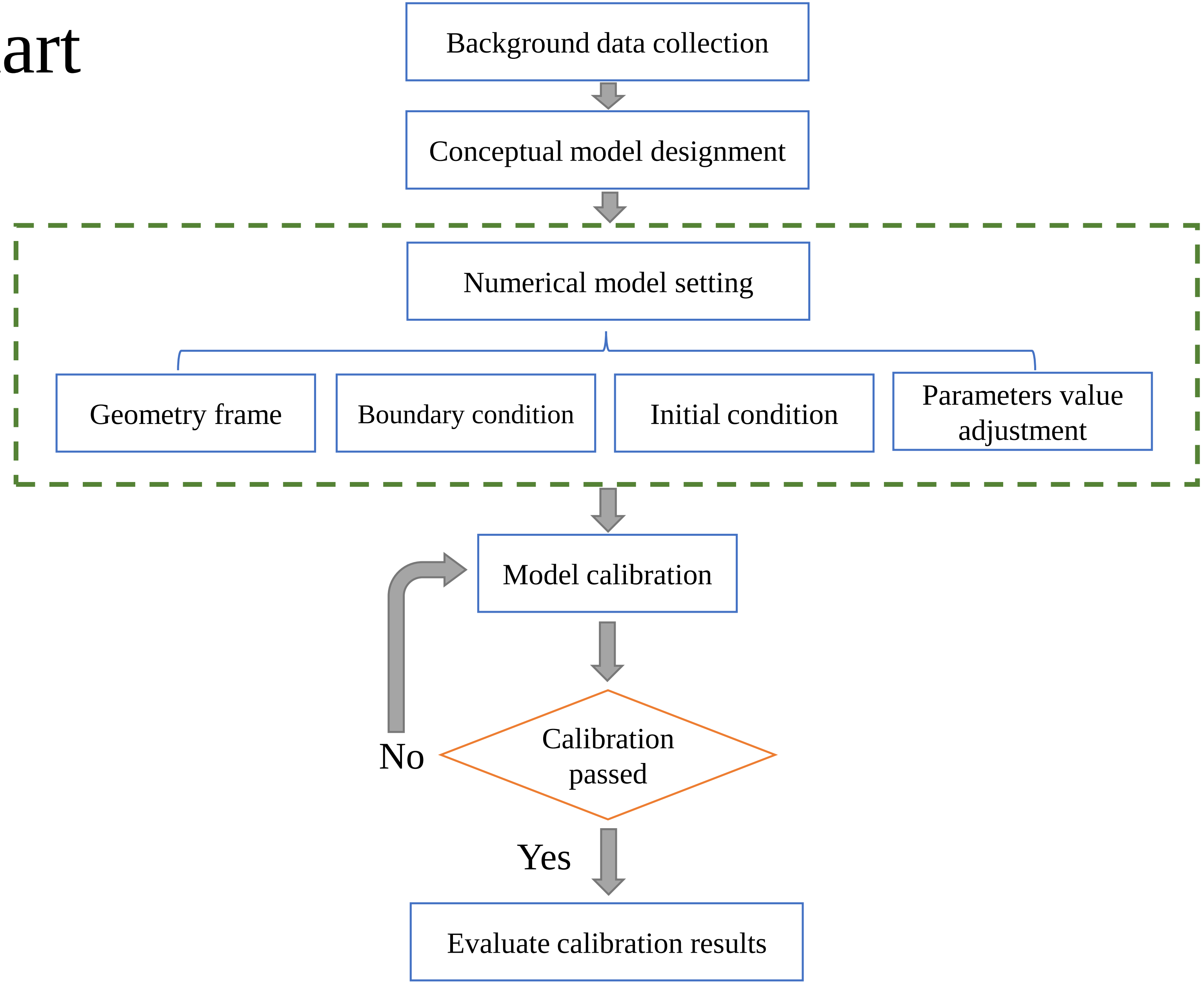




- Gravel (blue line) has the most significant change in total head, pressure, and saturation during simulation.

- It is hard for fluid to flow in clayey material.
- Clay makes it more difficult for groundwater to recharge.

Flow chart


Background data collection
Conceptual model designment
Numerical model setting
Geometry frame
Boundary condition
Initial condition
Parameters value adjustment
Model calibration
Calibration passed
No
Yes
Evaluate calibration results

Future work

- Set up more multi-material conceptual models
- Change the thickness of models
- Incorporate regional rainfall observation data into groundwater flow simulations

Thank you for your attention.