The Impacts of Unsaturated Zone Geological Materials on the Relationship Between Rainfall and Groundwater Level

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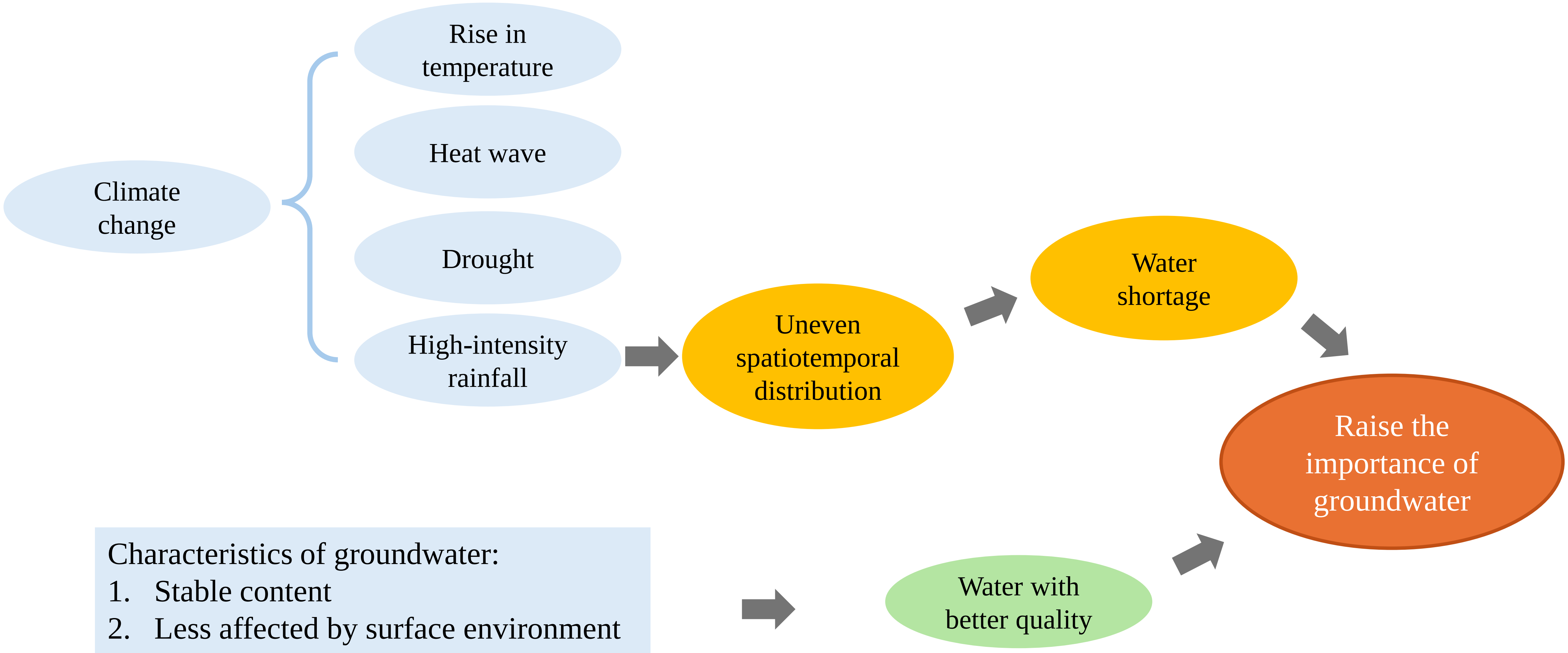
Outline

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

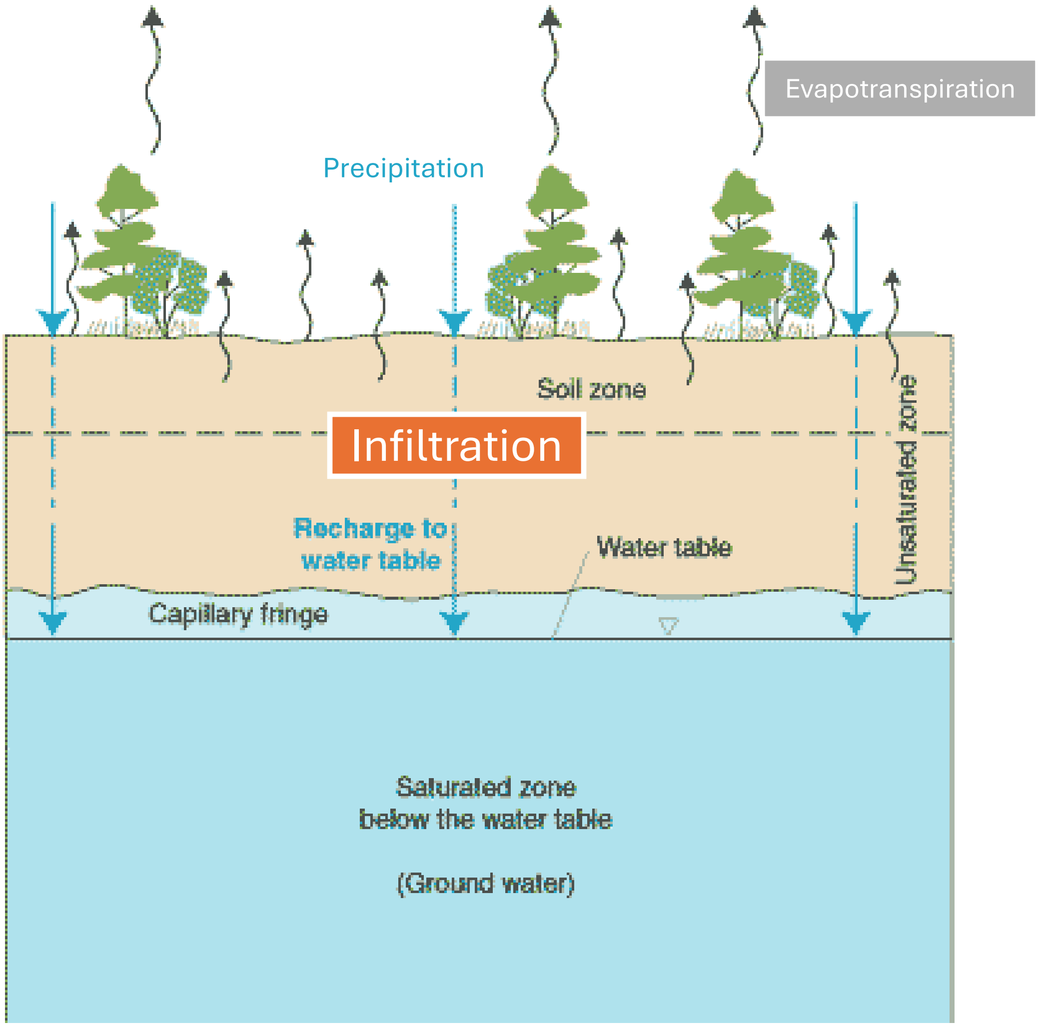
Why we concern about groundwater?



Characteristics of groundwater:

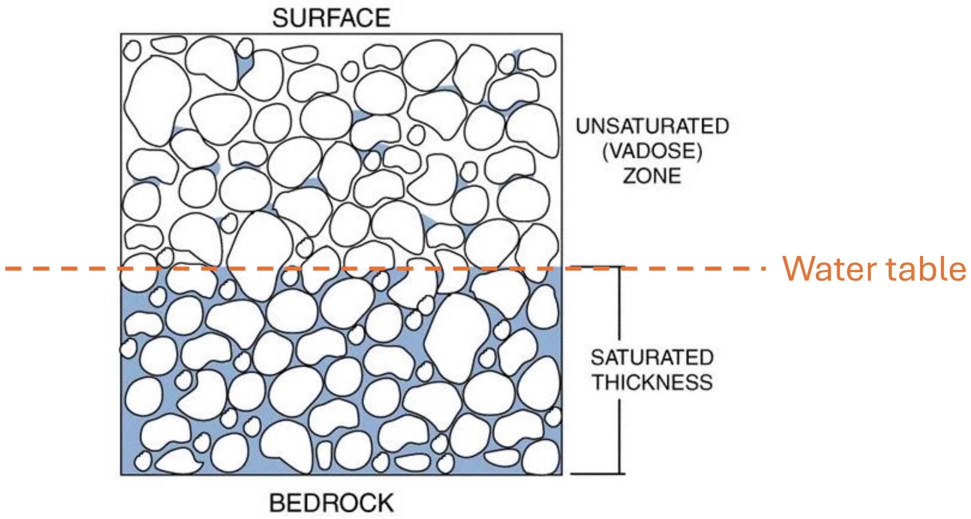
1. Stable content
2. Less affected by surface environment
3. Relatively clean

Pathways to recharge groundwater & explanation of saturated / unsaturated zone



Source: https://pubs.usgs.gov/circ/circ1186/html/gen_facts.html

FIGURE 1. SATURATED AND UNSATURATED ZONE IN AQUIFER



	Saturated zone	Unsaturated zone
Position	Below water table	Above water table
Pore space filling	Water	Air + water
Capillary pressure	Positive	Negative
Water movement	Hydraulic gradient	Capillary + gravity
Mass flow direction	Horizontal	Vertical

The difference between Longtan and other area in Taoyuan

- 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》)

- Taoyuan is commonly covered by lateritic gravel.

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

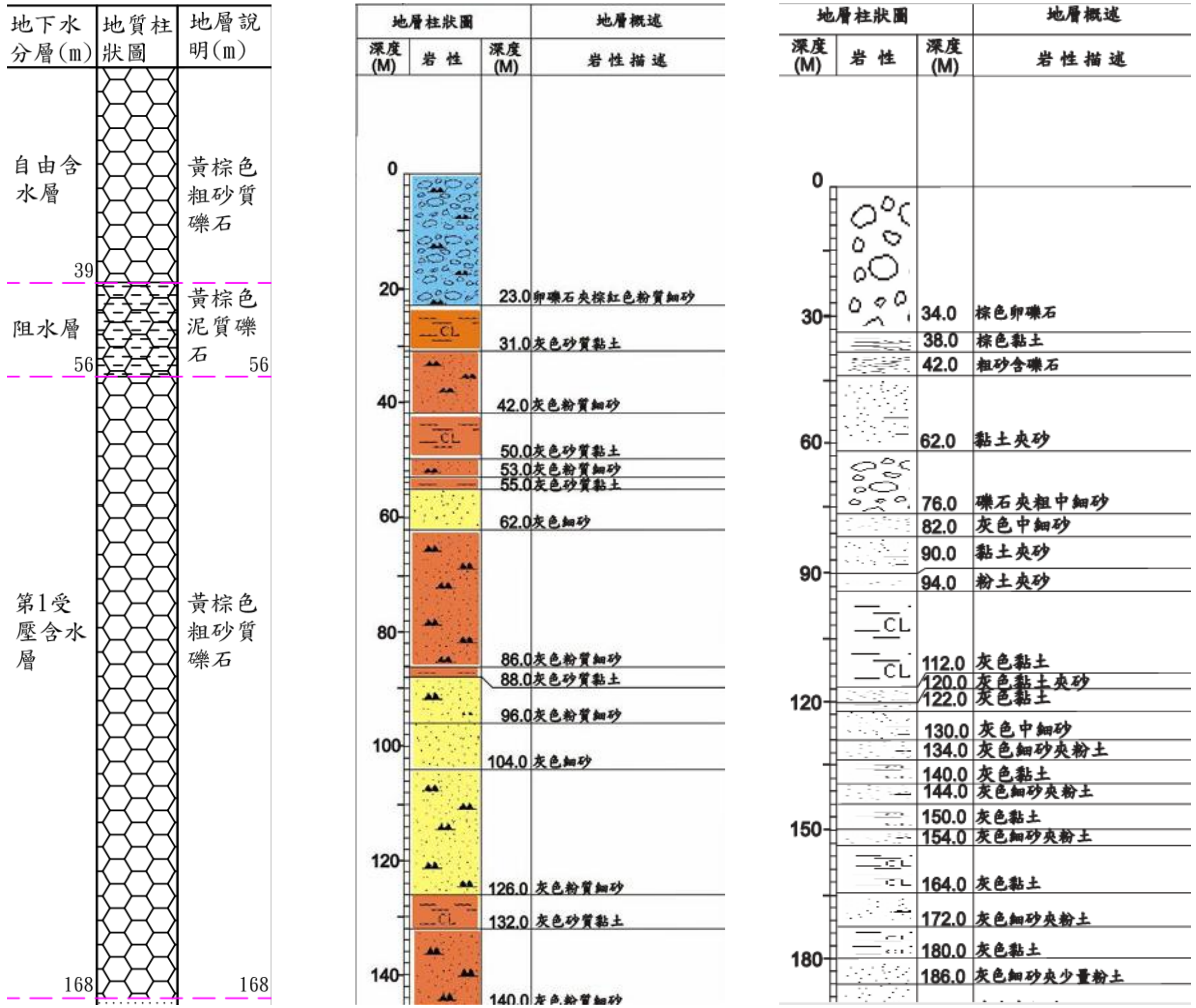
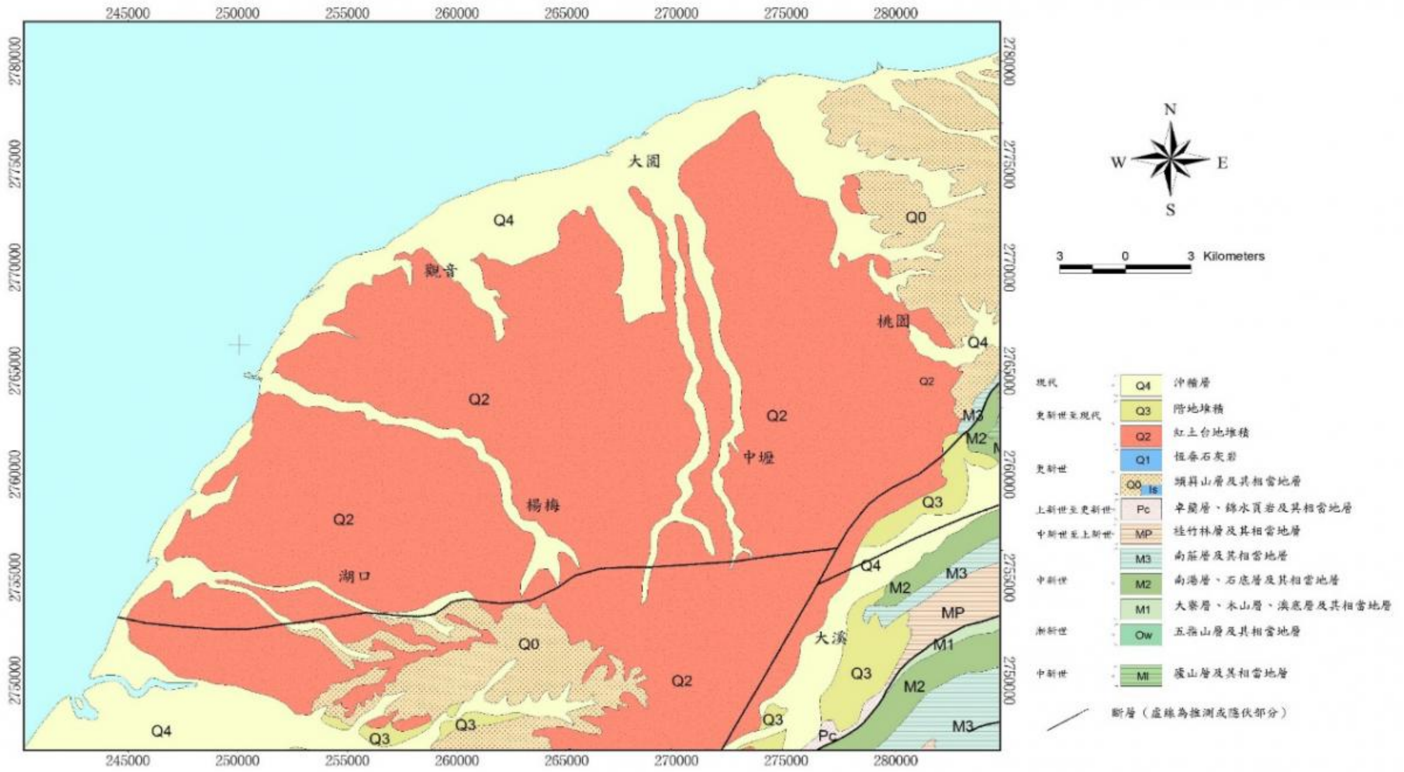


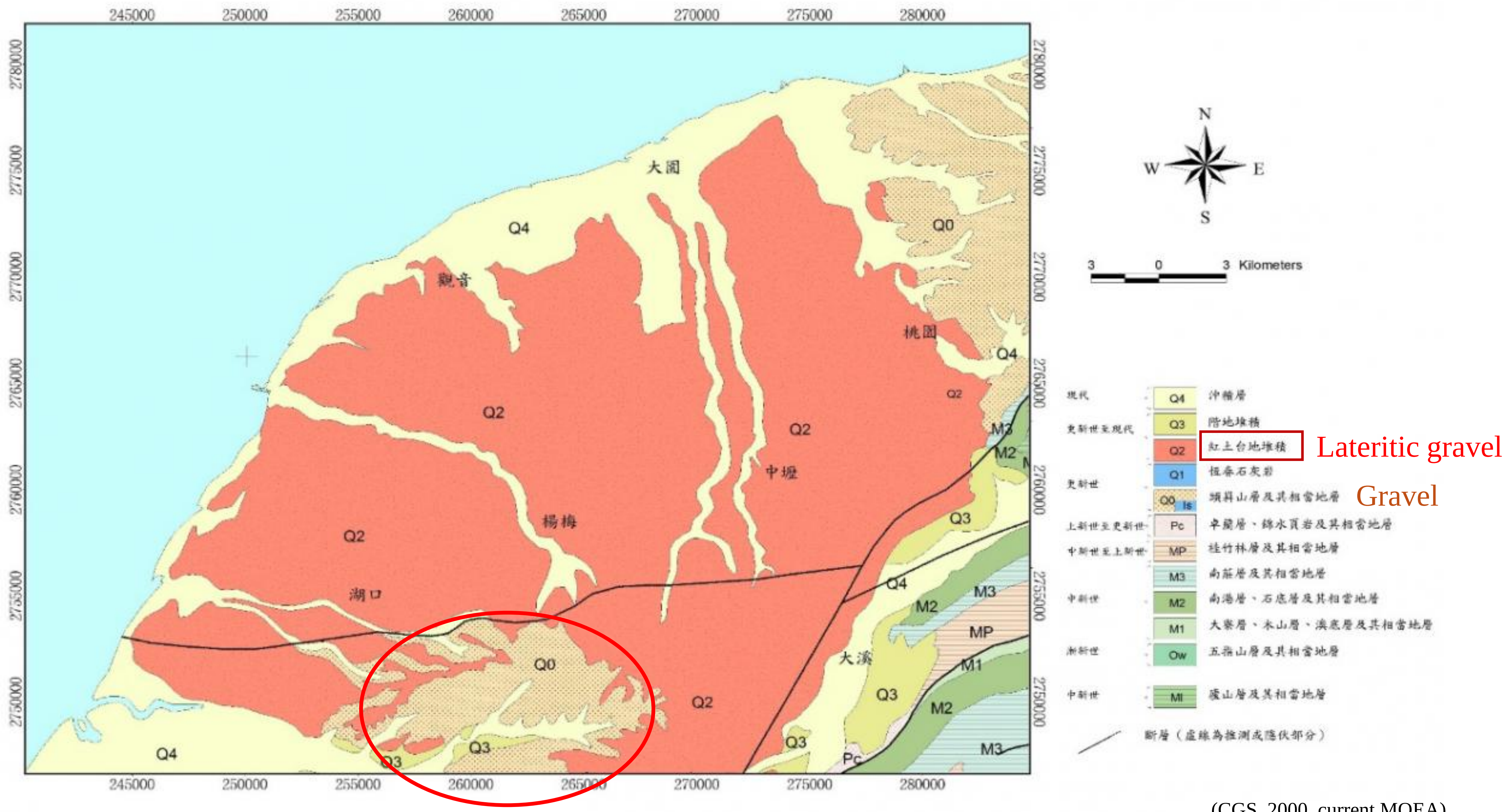
Fig. 龍潭, 八德(1) , 瑞原(1) Groundwater observation well lithology description

Lateritic gravel

- Main distribution: Hilly areas of the western foothills and several plateau areas.
- Thickness: 3m ~ 5m
- Composition: Unconsolidated gravel mixed with sand or silt-sized convex lenses.
- Characteristics: Dense texture, poor selectivity, poor permeability.



(CGS, 2000, current MOEA)



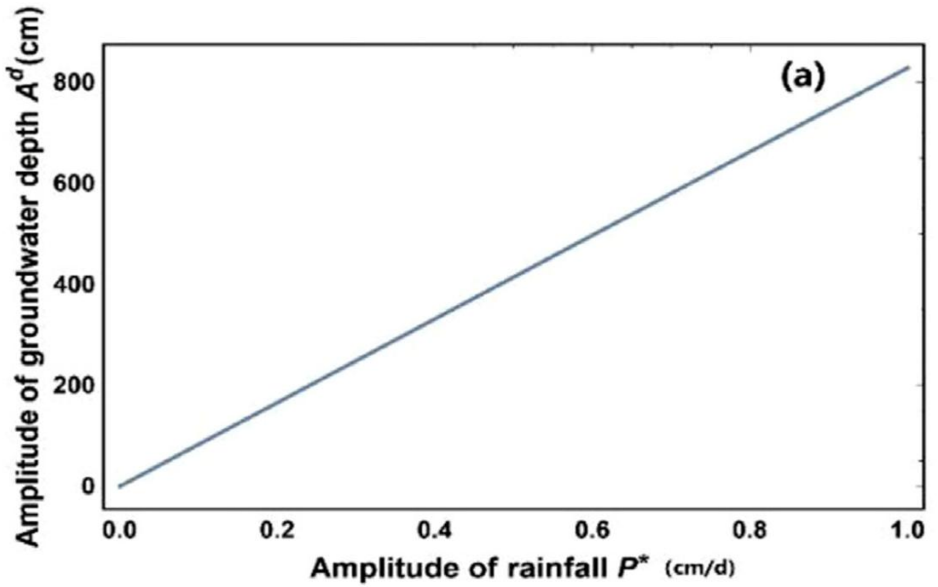
(CGS, 2000, current MOEA)

Literature review

- Guo et al. (2021) → The amplitude of precipitation has linear impacts on amplitude of depth to water table (DWT).

- Zhang et al. (2017) → Groundwater levels rise rapidly after rainfall, and the rate of recovery is related to rainfall intensity and duration, as well as soil permeability.

- Cai et al. (2016): The correlation analyses of rainfall and groundwater-level variations show the rapid groundwater-level response to rainfall (<2 h) at wells in subsoil and transition zone as well as at wells installed in the shallow and deep bedrock units at the base of the hillslope.



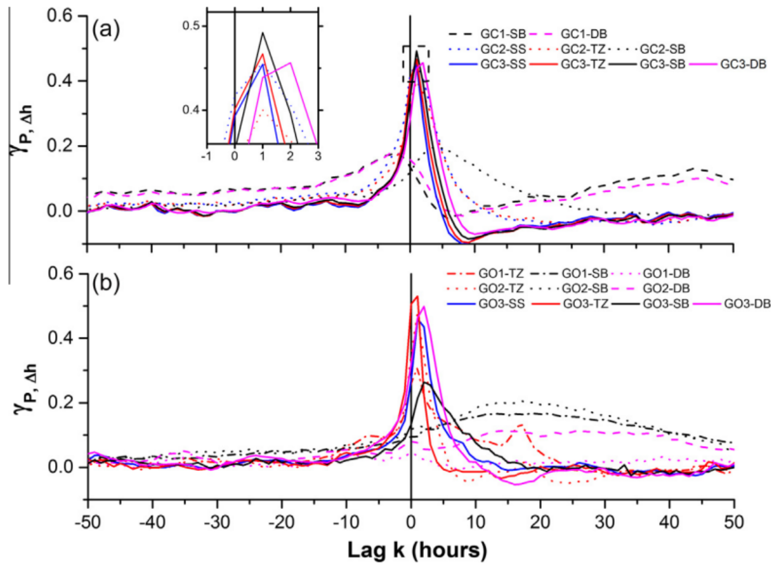
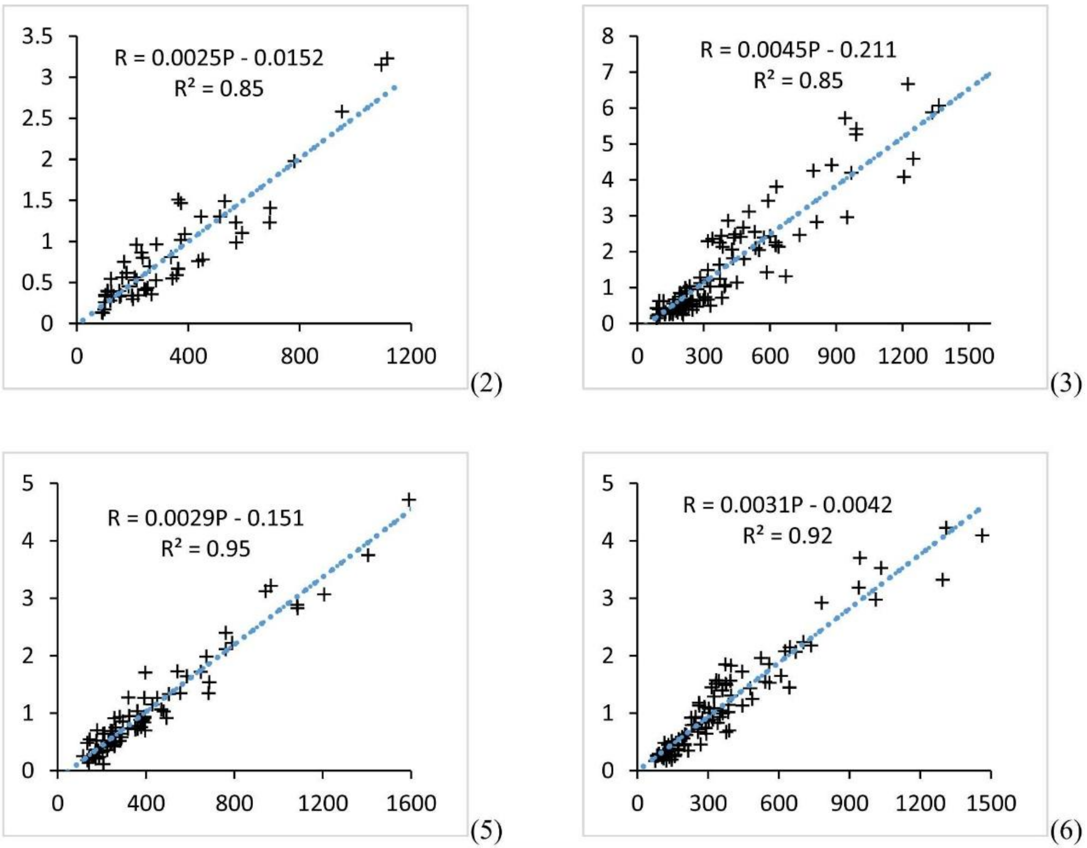


Fig. 5. Cross-correlation between rainfall and groundwater-level hydrographs at Glencastle (a) and Gortinlieve (b) sites.

Literature review

- Hussain et al. (2022) → 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.

Weaknesses

- Few articles focusing on the impact of lateritic gravel covering above.
- Current groundwater simulation software is based on the premise of discussing saturated zone.
- Most of the tools discussing unsaturated zones are add-on packages.

→ Few software could discuss both saturated and unsaturated layers independently.

THMC technology development milestones

USA — 1980 — **FEMWATER**

H (Flow and transport)

USA — 1990 — **HYDROGEOCHEM**

T (Thermal transport)

H (Flow and transport)

C (Chemical reaction)

NCU, TAIWAN — 2013 — **THMC**

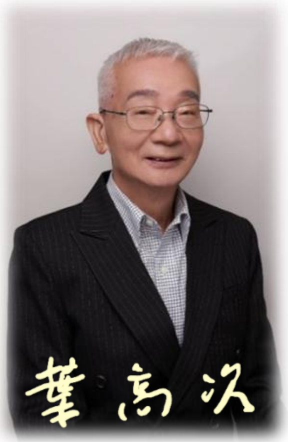
T (Thermal transport)

H (Multiple phase flow)

M (Mechanical)

C (Chemical reaction)

2025



Professor

Gour-Tsyh (George) Yeh

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

Advantages of THMC

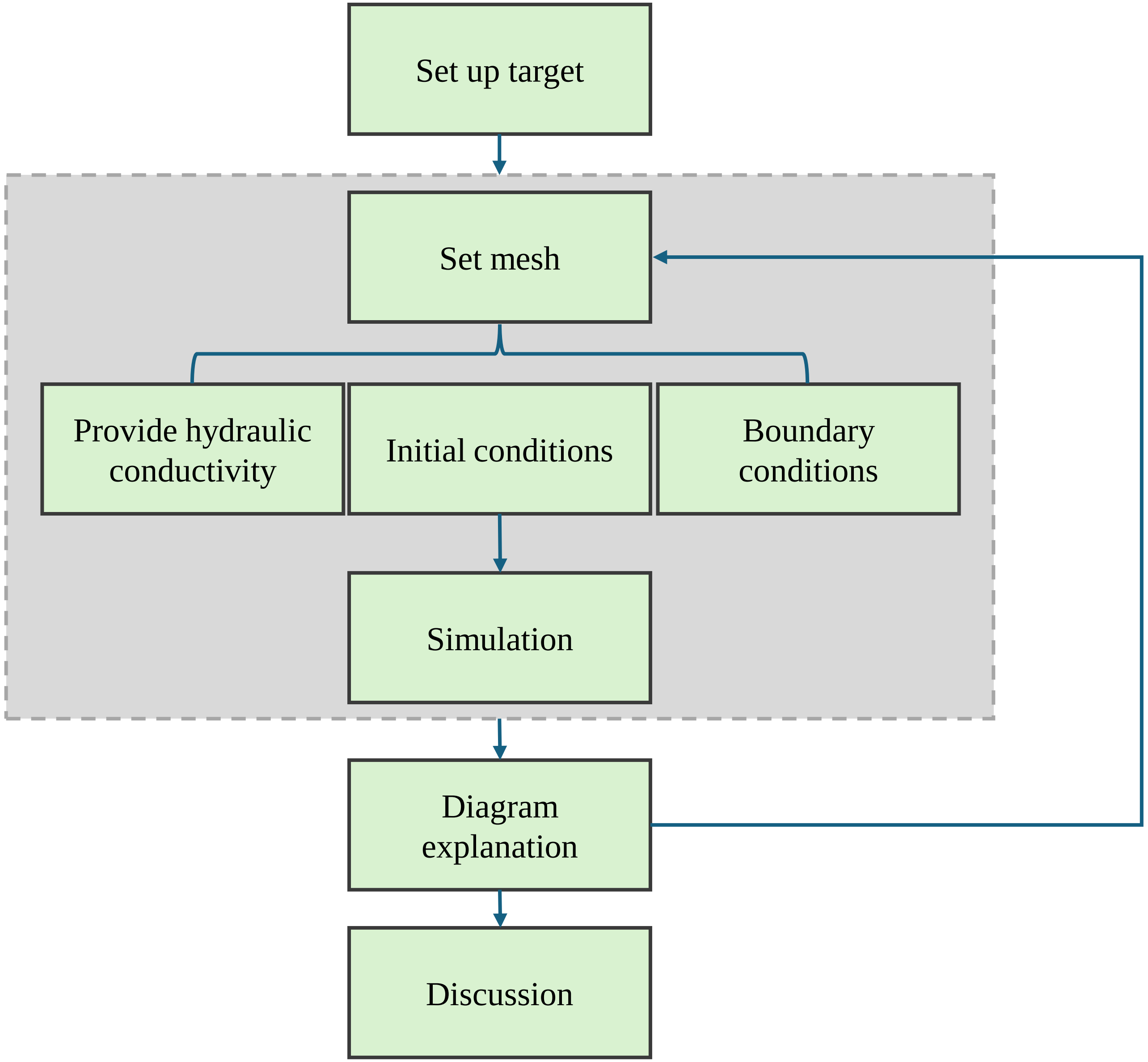
	THMC	MODFLOW	SEAWAT
Computation Method	Finite Element Method (FEM)	Finite Difference Method (FDM)	Finite Difference Method (FDM)
Saturated zone	V	V	V
Unsaturated zone	V	*X	X
User interface	V	X	X

*MODFLOW 6 (2017) Can also simulate unsaturated zone, but it has to attach additional modules.
ex. GWF, GWF-UZF（Unsaturated-Zone Flow）, GWF-SFR（Streamflow Routing）

Objective

Using THMC software to analyze the differences in rainfall recharge and groundwater level changes under the presence or absence of lateritic gravel.

Methodology - Flow chart



Governing equations for flow through saturated-unsaturated media

change in mass through time

net accumulation

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

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

density

head change

source/sink

Darcy velocity V (L/T)

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

Hydraulic conductivity tensor **K**

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

k → permeability tensor

Generalized storage coefficient F

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

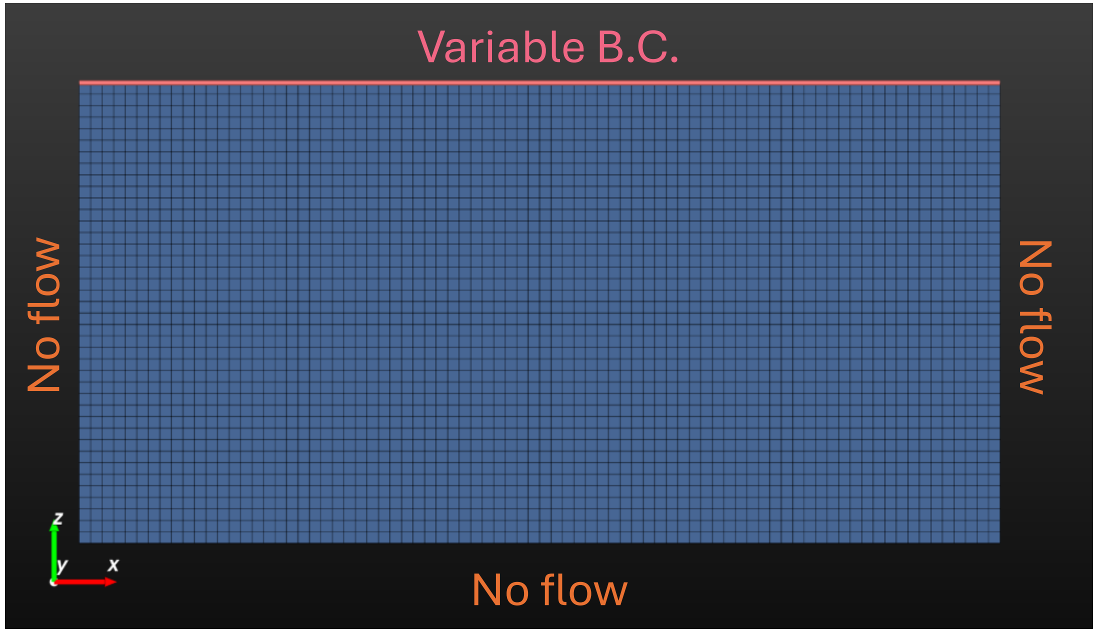
S → saturation

n_e → porosity

θ_e → effective water content

Conceptual model - homogeneous

- Frame size: 40m*20m
- Nodes: 81*41 = 3321
- Elements: 80*40 = 3200 (0.5m*0.5m each mesh)
- Porosity: 0.35
- Time: 14 days



Type	Location	Value
Hydrological Variable	Top layer	0.5 mm/day 2 mm/day 5 mm/day 10 mm/day 30 mm/day 50 mm/day
Hydrological Initial	Each horizontal layer	-7m ~ 13m (top ~ bottom)

	K_{xx} (m/day)	K_{zz} (m/day)
Value	10 5	1 0.5

Parameter usage

- Range of hydraulic conductivity in different material

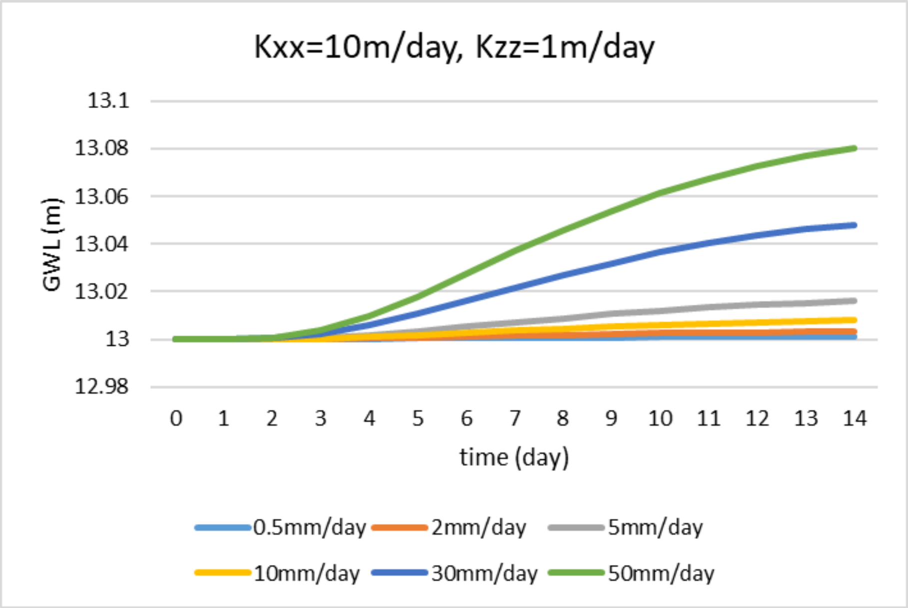
Material type	**K_{xx} (m/day)**	**K_{zz} (m/day)**
Gravel	$2.592 * 10^{1} \sim 2.592 * 10^{3}$	$2.592 \sim 2.592 * 10^{2}$
Sand	$1.728 * 10^{-2} \sim 1.728 * 10^{1}$	$1.728 * 10^{-3} \sim 1.728$
Clay	$8.64 * 10^{-7} \sim 4.32 * 10^{-4}$	$8.64 * 10^{-8} \sim 4.32 * 10^{-5}$

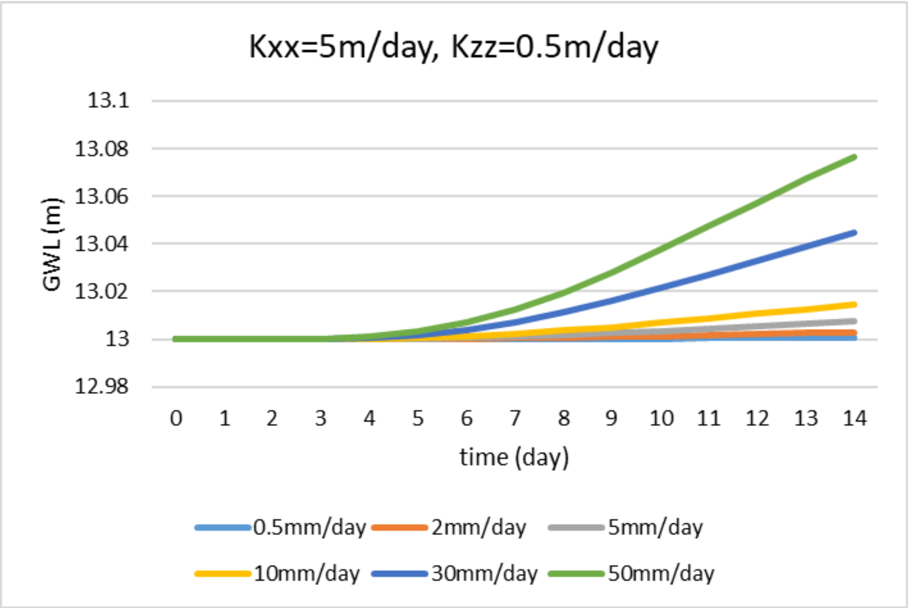
(Domenico and Schwartz (1990))

◆ Heterogeneous model will be built in the future.

Preliminary results

Groundwater level change in different K value and different rainfall rate





- There exists a positive correlation between rainfall rate and groundwater level.
- The larger the value of K, the more easily the fluid flows through the medium.

Conclusions

- When in homogeneous media, a larger hydraulic conductivity may lead to more rapid water level response.

Future work

- Set up more models to consider heterogeneous settings (frame size, materials, material arrangements)
- Provide more explanations of the simulation results

Thank you for your attention.