111-2 Seminar

Evaluation of Groundwater Management level by Numerical Modeling in the Taipei Basin, Taiwan

Presenter: Yu An Chien

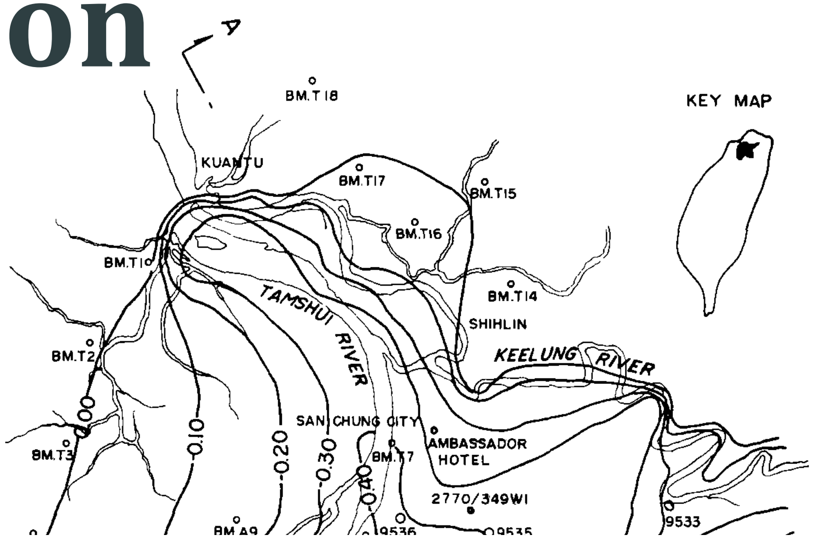
Advisor: Prof. Shih Jung Wang

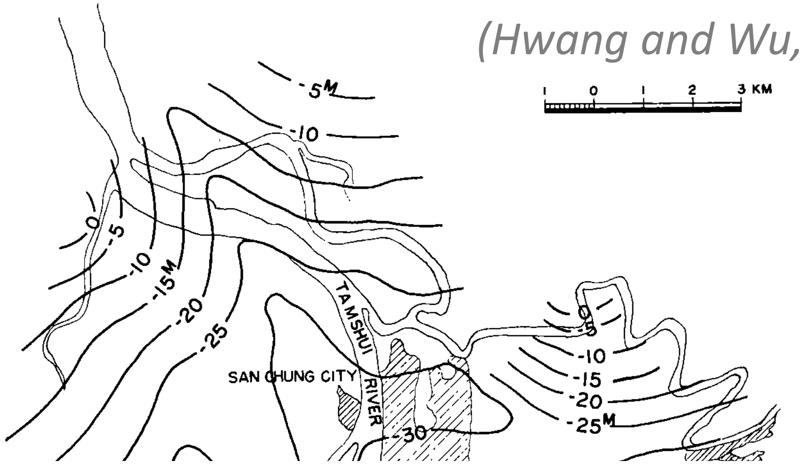
Date : 2023.03.31

– GeoHydraulics Research Group

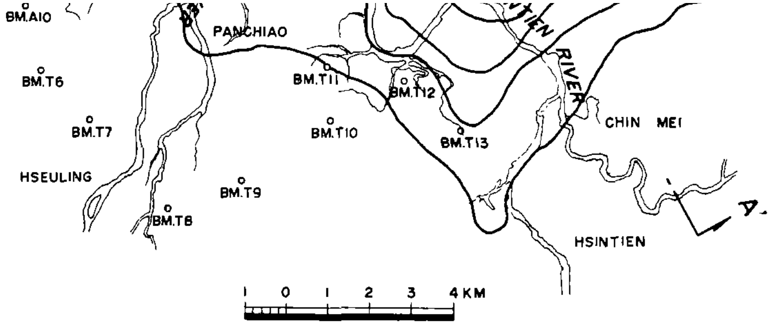
Motivation

(Hwang and Wu, 1969)





✓ Therefore, effective groundwater resource management is crucial.



→ **Land subsidence from 1963-1967**

→ **Hydraulic head in 1968**

- **Groundwater decline** has been a primary cause land subsidence
- **Groundwater level increased** caused engineering problems, such as soil liquefaction.

Objective

Groundwater management levels

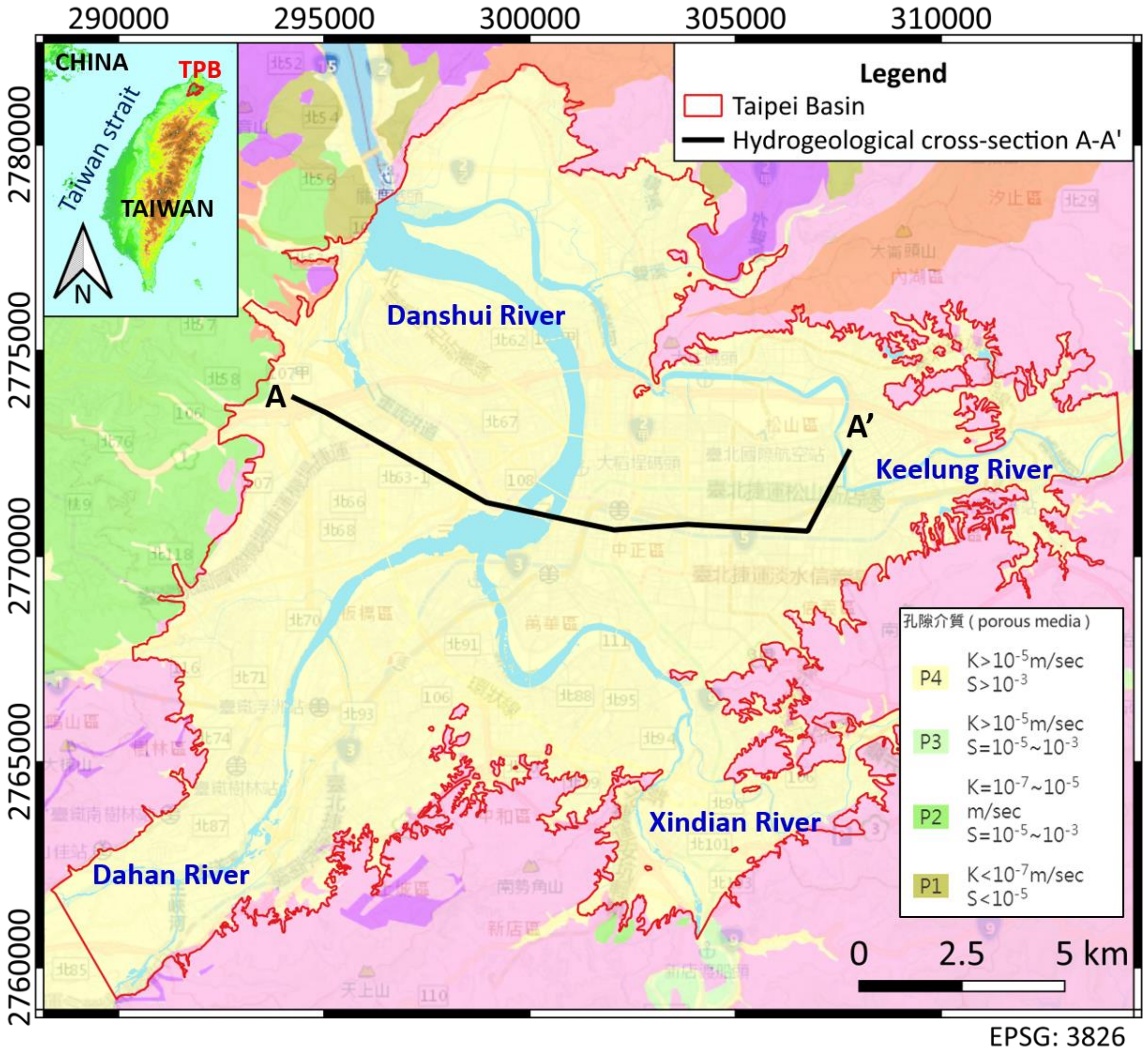
This study developed numerical models to quantify the groundwater level and land subsidence.

- ✓ To obtain a better understanding of a system, from the geological and hydrological points of view.
- ✓ To offer information for the design of a monitoring network or field experiments by predicting the system's future behavior. *(Bear and Cheng, 2010)*

Introduction

Background

◆Elevations lower than 20 meters



地下水系統分層架構（地下水層 F，阻水層 T）		地層分層 (鄧屬予等,1999)
大漢溪與淡水河為界線		
西部	東部	
T1	T1	松山層
F1	F1	
T2	T2	
F2-1	F2	景美層
T2-1		五股層
F2-2		
T2-2		
F2-3		
T3	T3	板橋層
F3	F3	
BR		第三系沉積岩

資料來源: 江崇榮等(2012)

F1 & T1

- Sand and Clay
- Sand with Gravel layer
- Unconfined

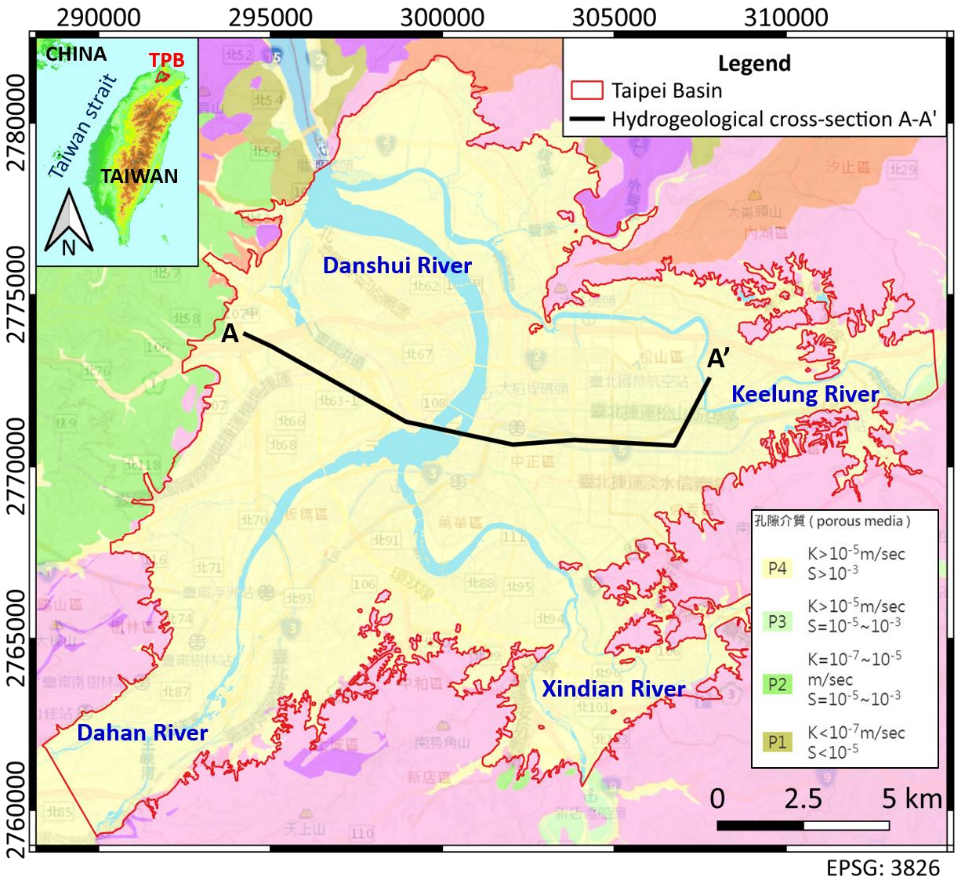
F2 & T2

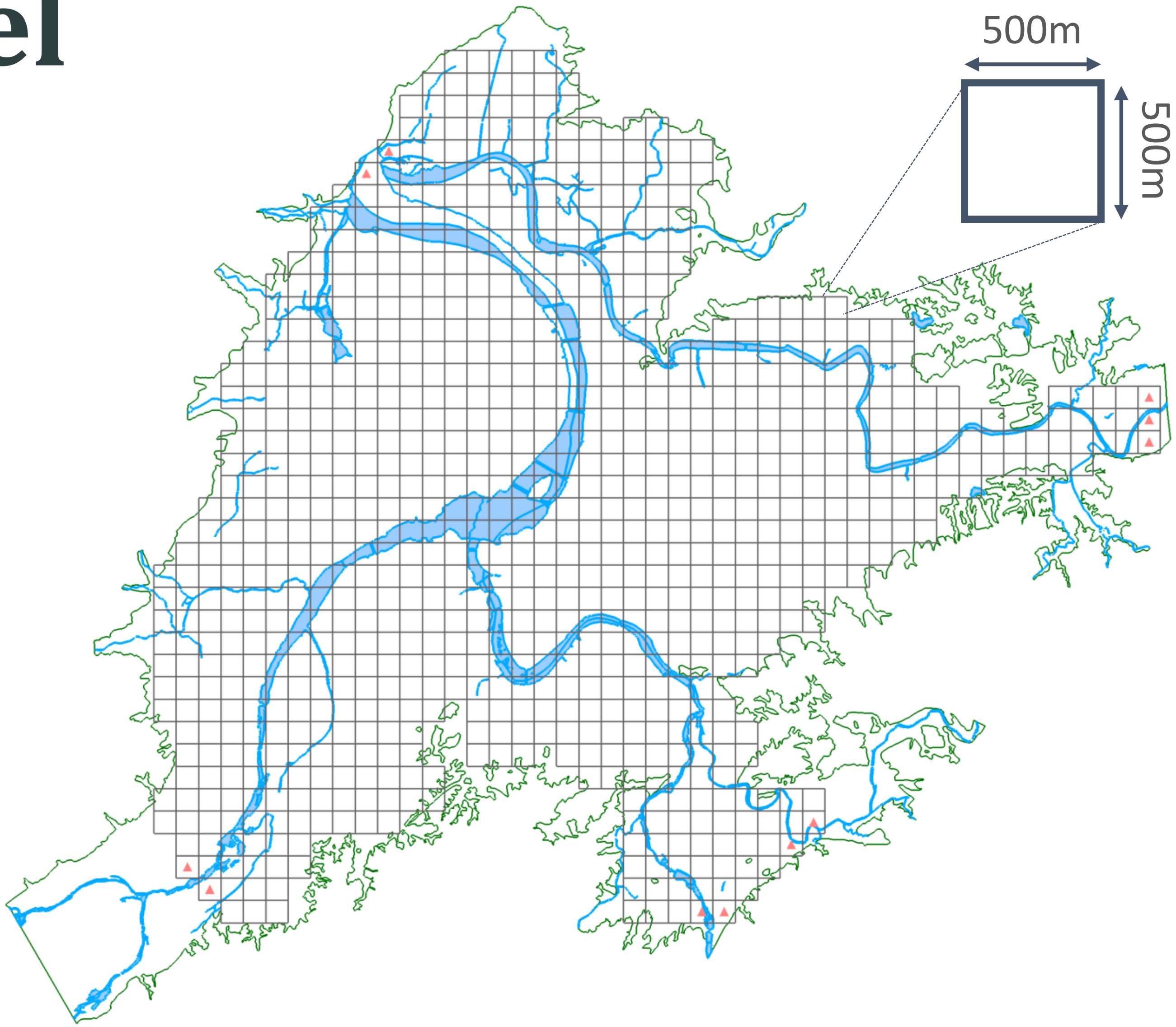
- Gravel layer
- Confined

F3 & T3

- Clay layer / Gravel layer

Conceptual model

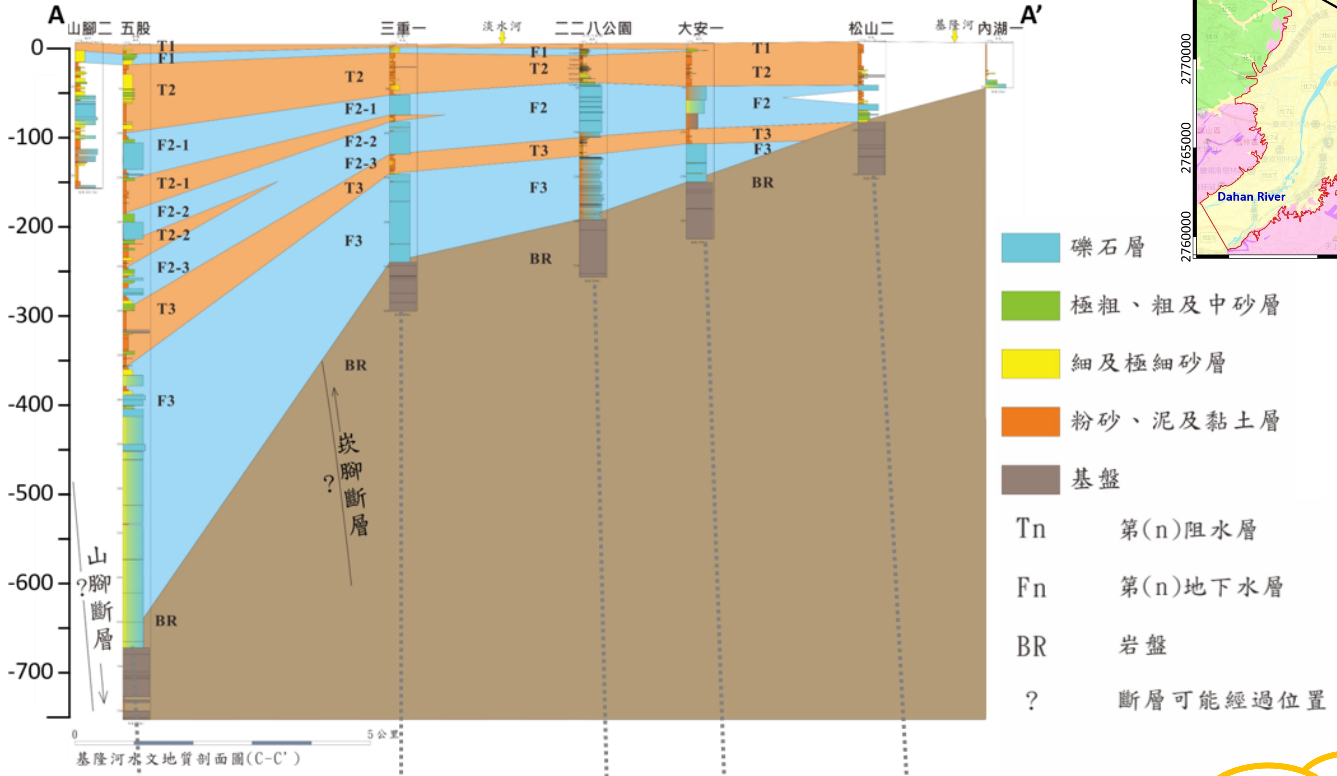


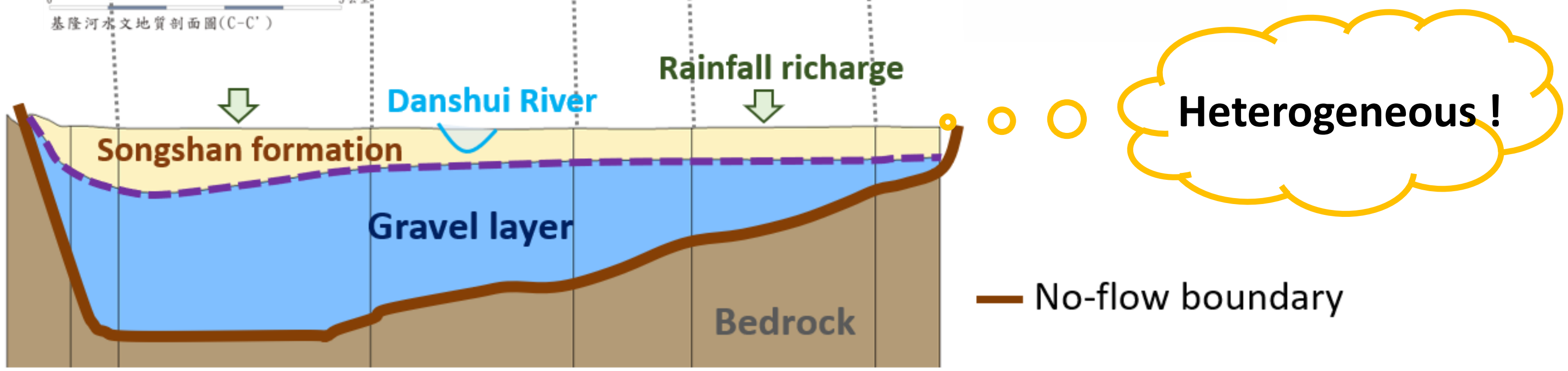


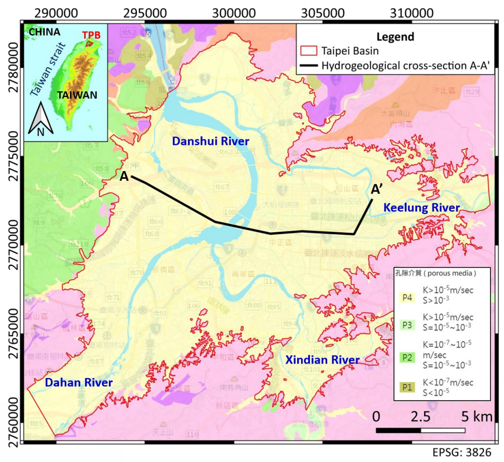
No-flow boundaries were assigned to the edge of the study area

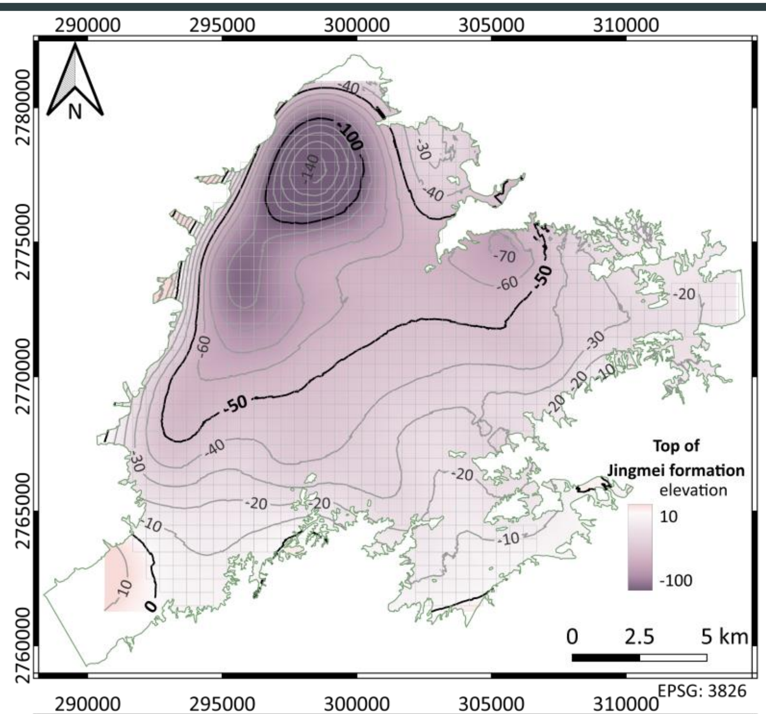
▲ **Constant head boundary** (Dirichlet boundary condition)

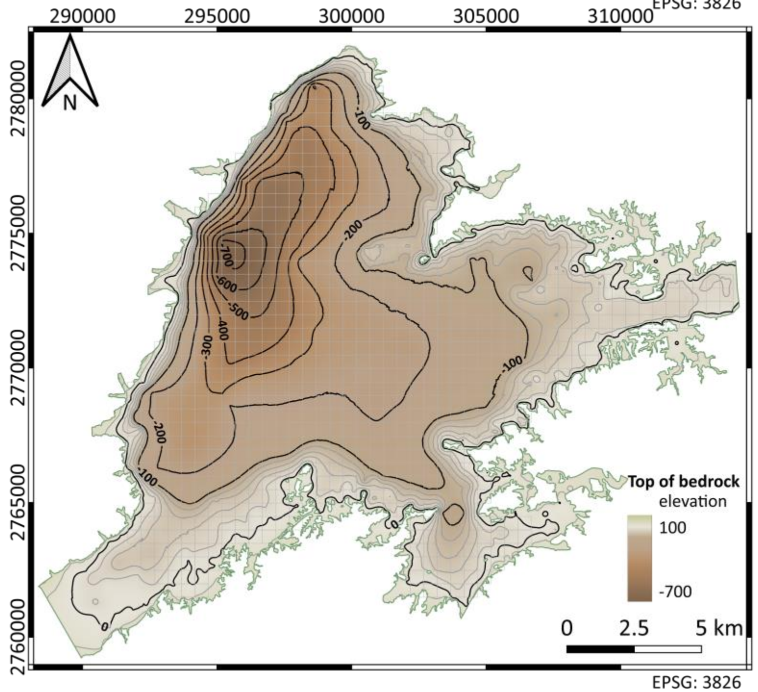
Conceptual model





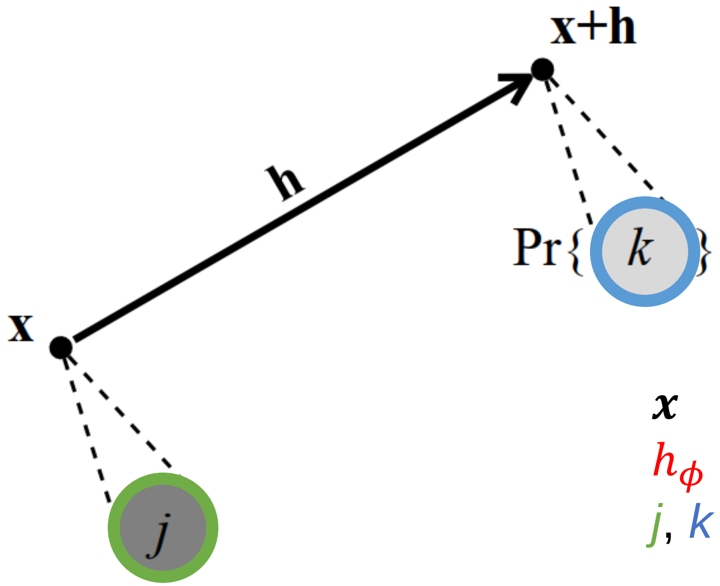






1D continuous-lag Markov chain model

- **Markov chain models** applied to time series assume, in theory, that future occurrences depend on the present and not on the past.
- This simple stochastic model can address spatial applications by replacing the time lag with a **spatial lag $\mathbf{h}_\phi$** in a direction ϕ. *(Krumbein, 1968; Agterberg, 1974, p. 457; Ross, 1993, p.290)*



$\boldsymbol{x}$ spatial location
h_ϕ lag along ϕ direction
j, k material

- R_ϕ is a transition rate matrix
  - $r_{jk,\phi}$ describing a **conditional rate** of change from **material j** to **material k** per lag in the **direction ϕ**.
- $$R_\phi = \begin{bmatrix} r_{11,\phi} & \cdots & r_{1k,\phi} \\ \vdots & \ddots & \vdots \\ r_{k1,\phi} & \cdots & r_{kk,\phi} \end{bmatrix}$$

Off-diagonal → transition rate

Diagonal → self-transitional

1D continuous-lag Markov chain model

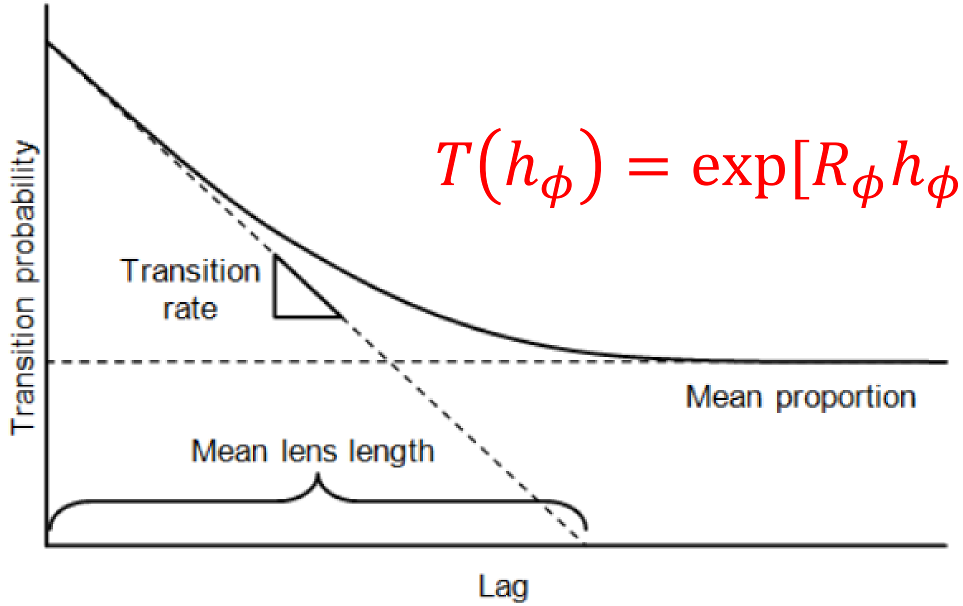
(Krumbein, 1968)

- $R_{\boldsymbol{\phi}}$ is a <u>transition rate matrix</u>
  - $R_\phi = \begin{bmatrix} r_{11,\phi} & \cdots & r_{1k,\phi} \\ \vdots & \ddots & \vdots \\ r_{k1,\phi} & \cdots & r_{kk,\phi} \end{bmatrix}$

$$r_{kk} = \text{self–transitional} = \frac{1}{Mean\ length\ (\bar{L}_k)}$$

$$r_{jk} = \frac{transition\ probability\ (t_{jk})}{Mean\ length\ (\bar{L}_j)}$$

- Transition probabilities $T(h_\phi)$



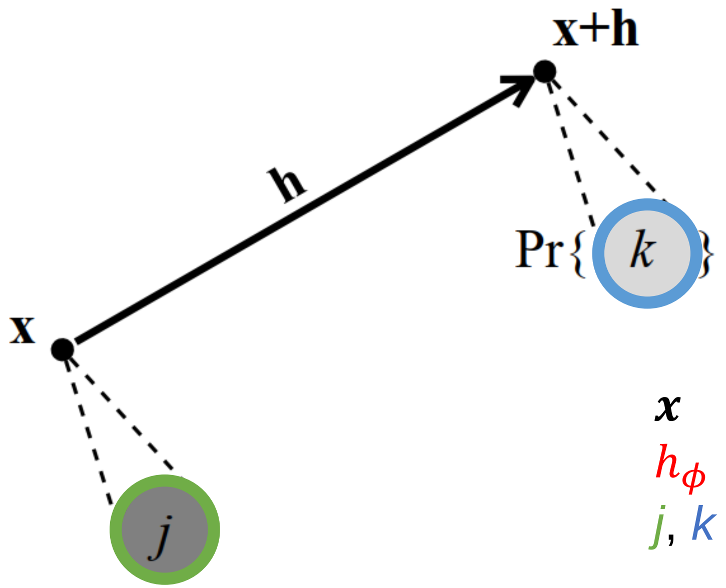
- By differentiation of Eq. above with respect to $\boldsymbol{h}$ at $\boldsymbol{h}$ = 0, the transition rates are related to Transition Probabilities by $\dfrac{\partial t_{jk}(0)}{\partial h_\phi} = r_{jk,z}$

1D continuous-lag Markov chain model

- Transition probabilities $T(h_\phi)$

$$\mathbf{T}(h_\phi) = \begin{bmatrix} t_{11}(h_\phi) & \cdots & t_{1K}(h_\phi) \\ \vdots & \ddots & \vdots \\ t_{K1}(h_\phi) & \cdots & t_{KK}(h_\phi) \end{bmatrix}$$

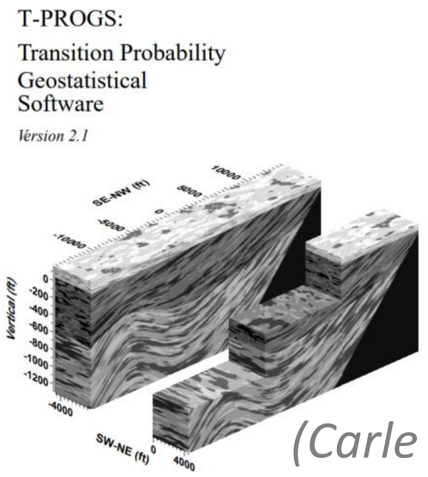
$$t_{jk}(h_\phi) = \Pr\{k \ occurs \ at \ \boldsymbol{x} + \boldsymbol{h}_\phi \mid j \ occurs \ at \ \boldsymbol{x}\}$$



$\boldsymbol{x}$ spatial location

h_ϕ lag along ϕ direction

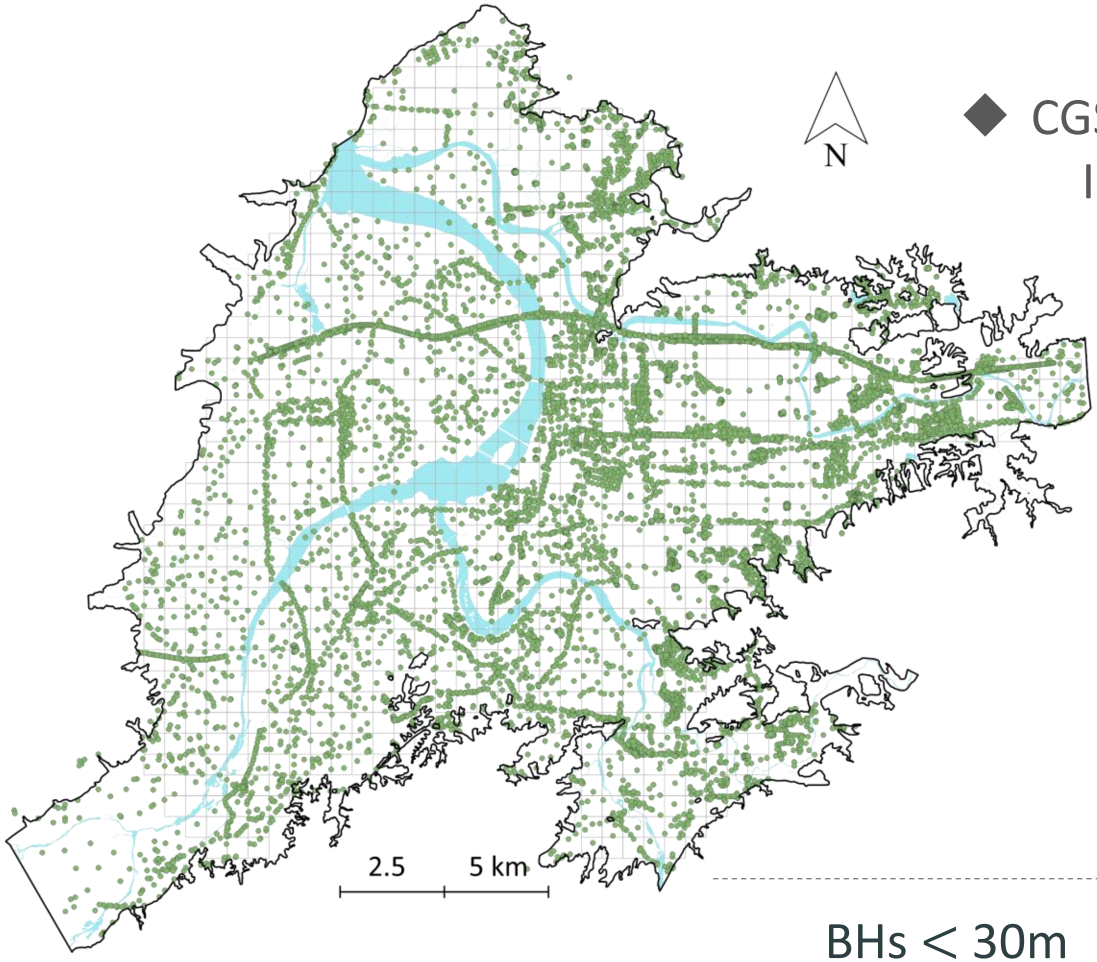
j, k material



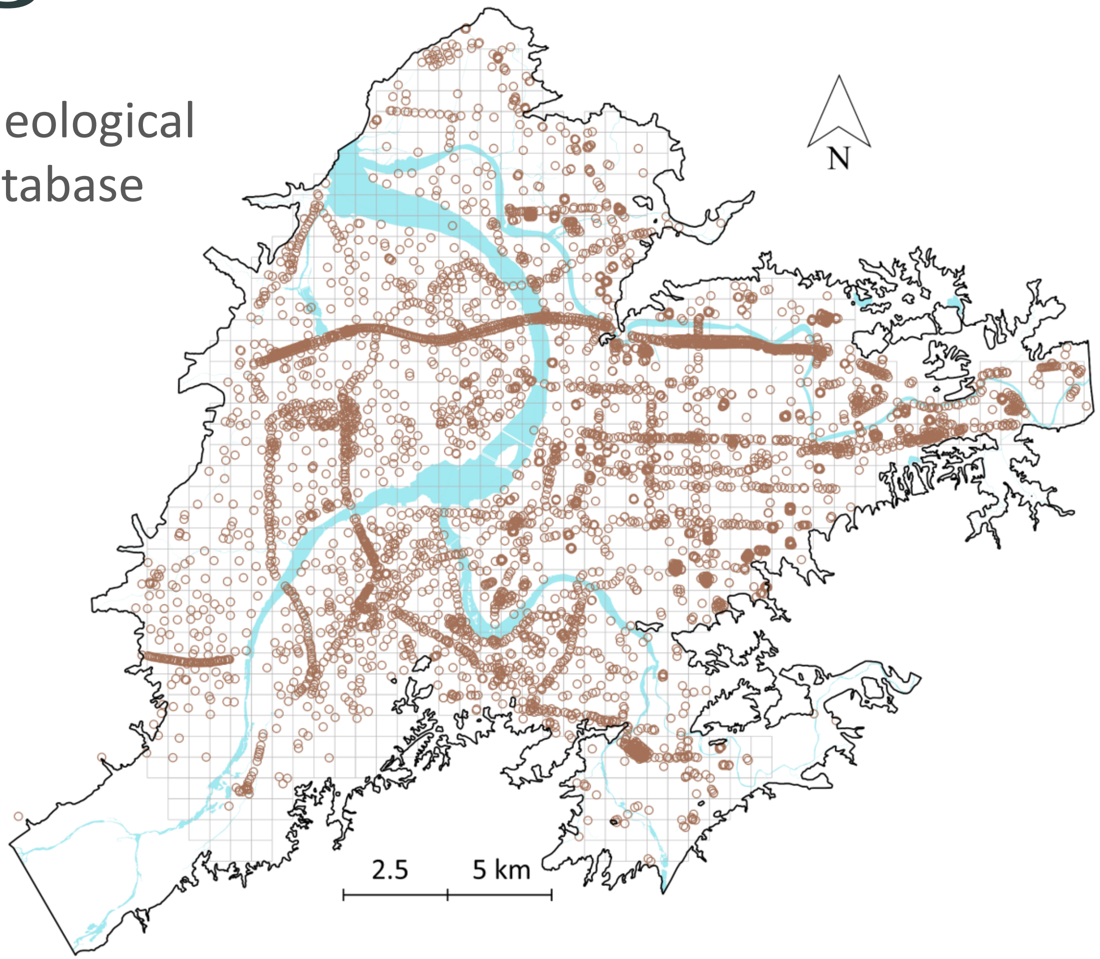
(Carle and Fogg, 1997)

- Gravel
- coarse Sand, medium Sand
- fine Sand, very fine Sand
- Silt, Mud, Clay

Geological borehole data



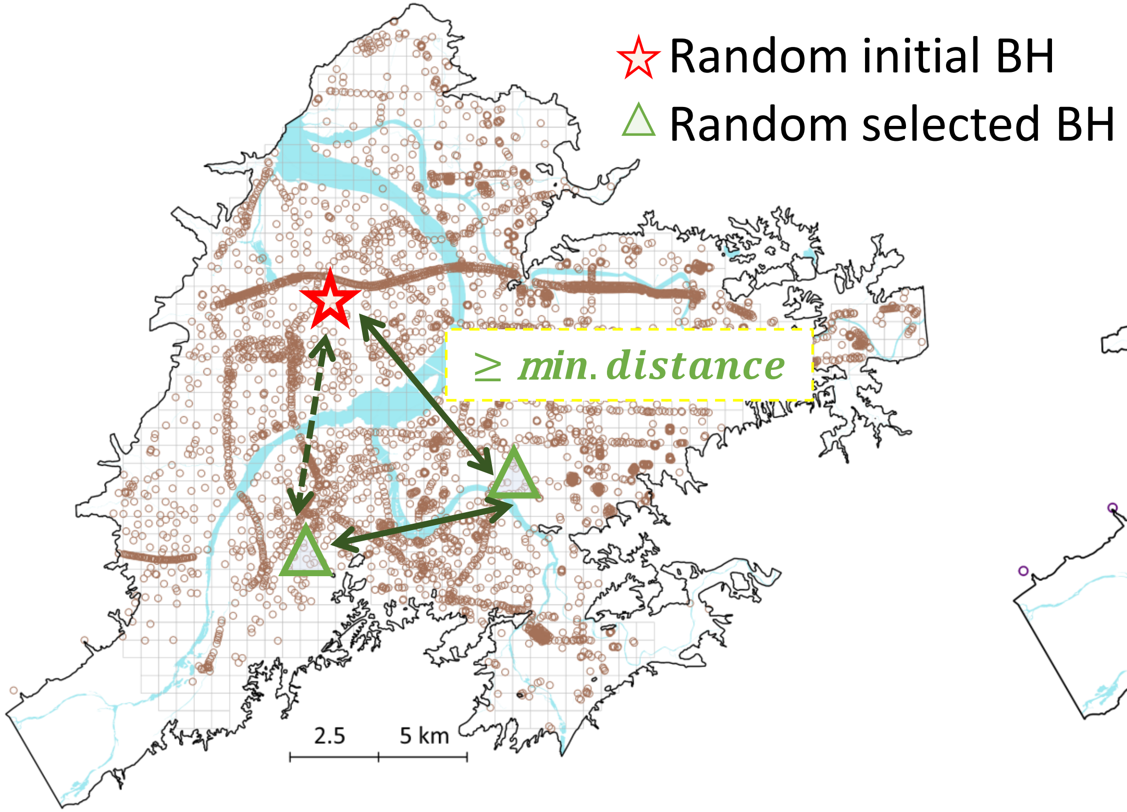
- CGS Engineering Geological Investigation Database

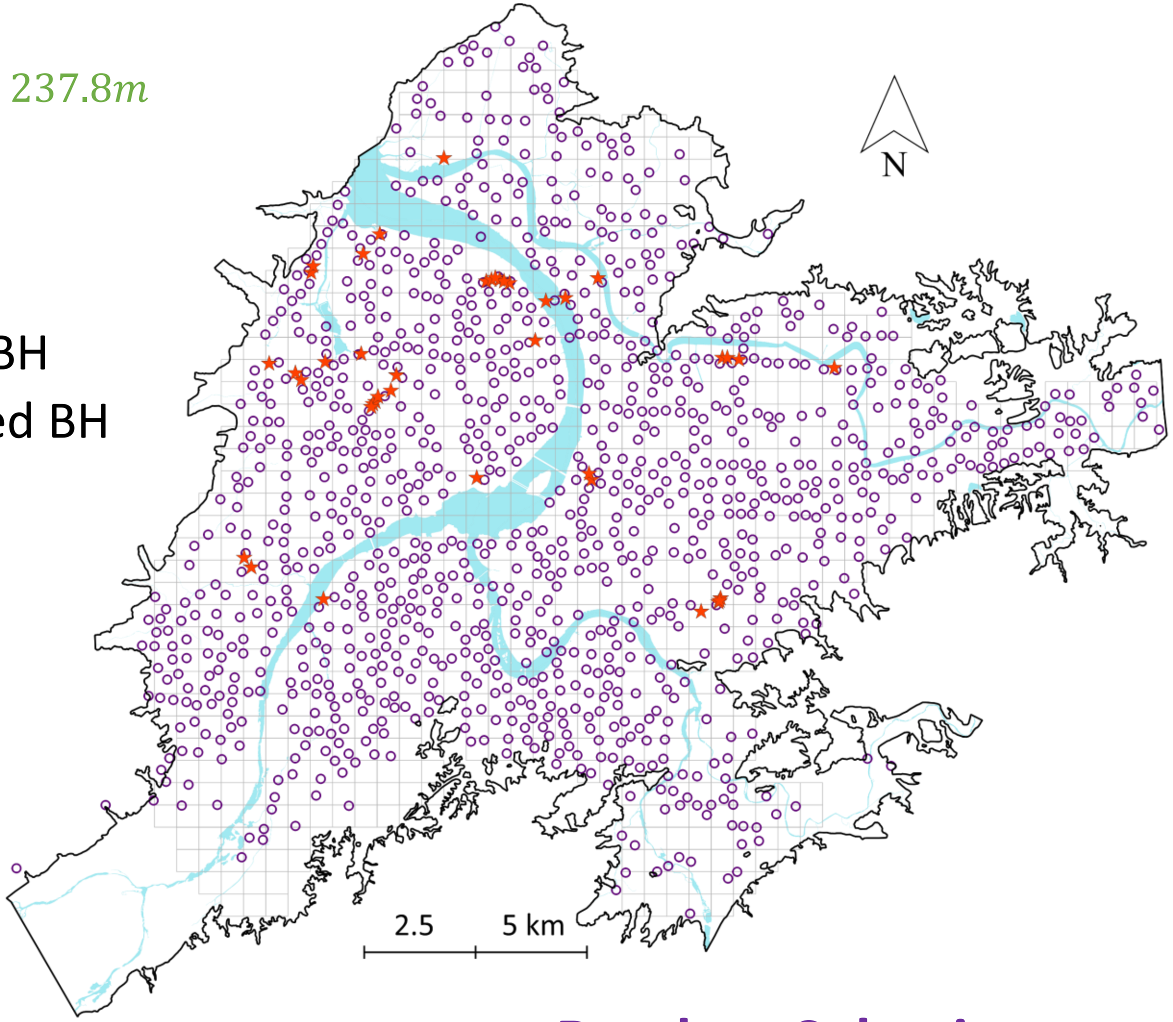


BHs < 30m	4783
30m ≤ BHs < 100m	4777
BHs ≥ 100m	40

Random selection

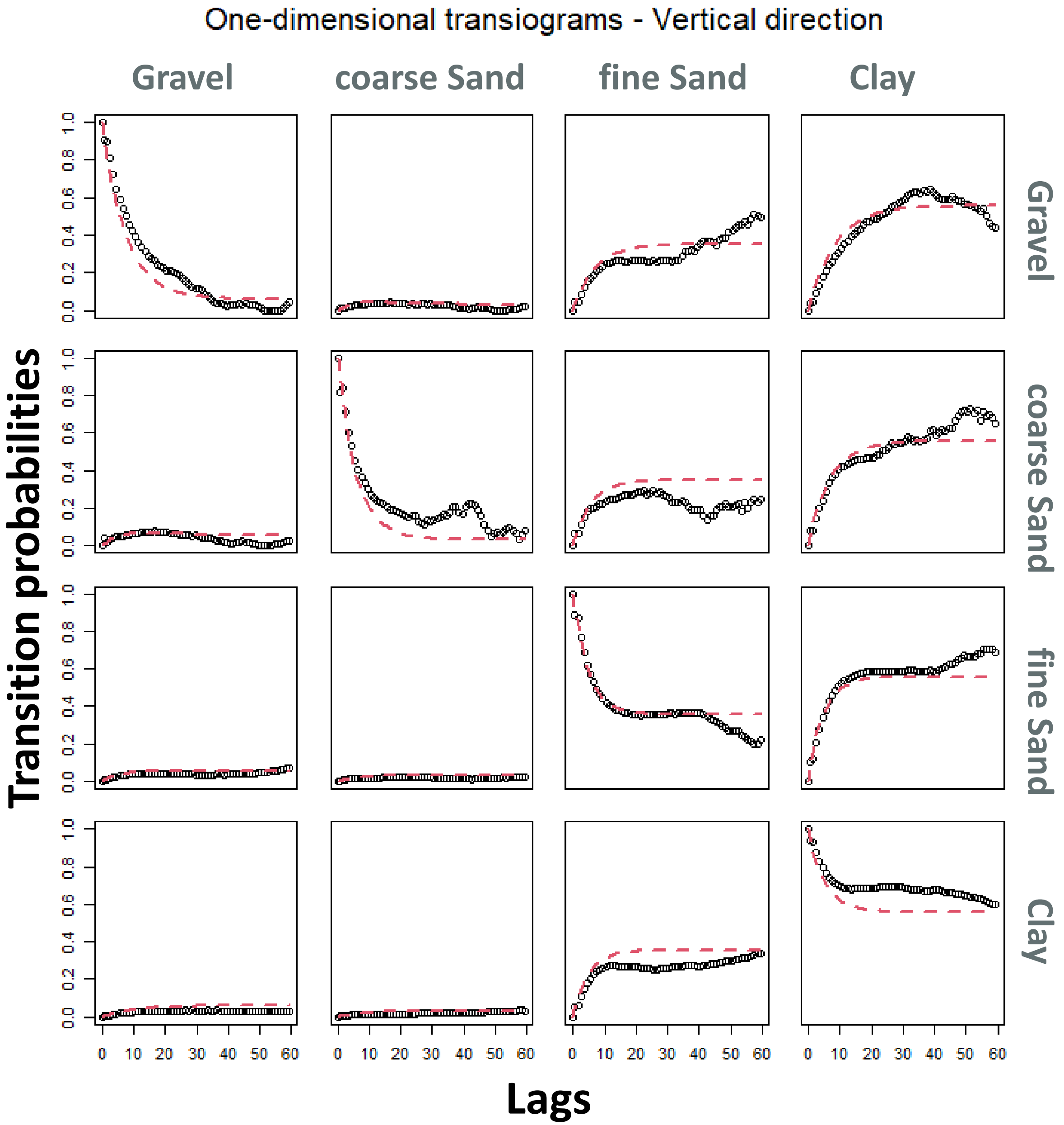
$$min.distance = \sqrt{\frac{Area}{No.BHs}} = \sqrt{\frac{270{,}200{,}372.06}{4777}} = 237.8m$$

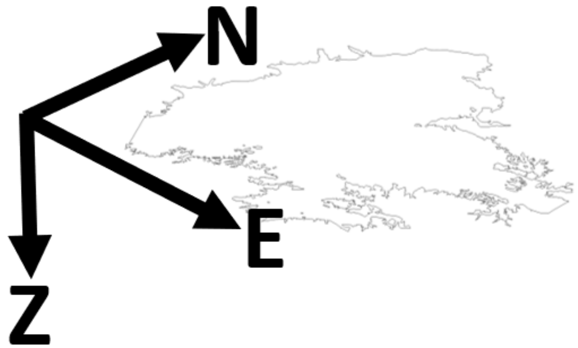




Random Selection	1089
Fixed boreholes	40

Geostatistical analysis

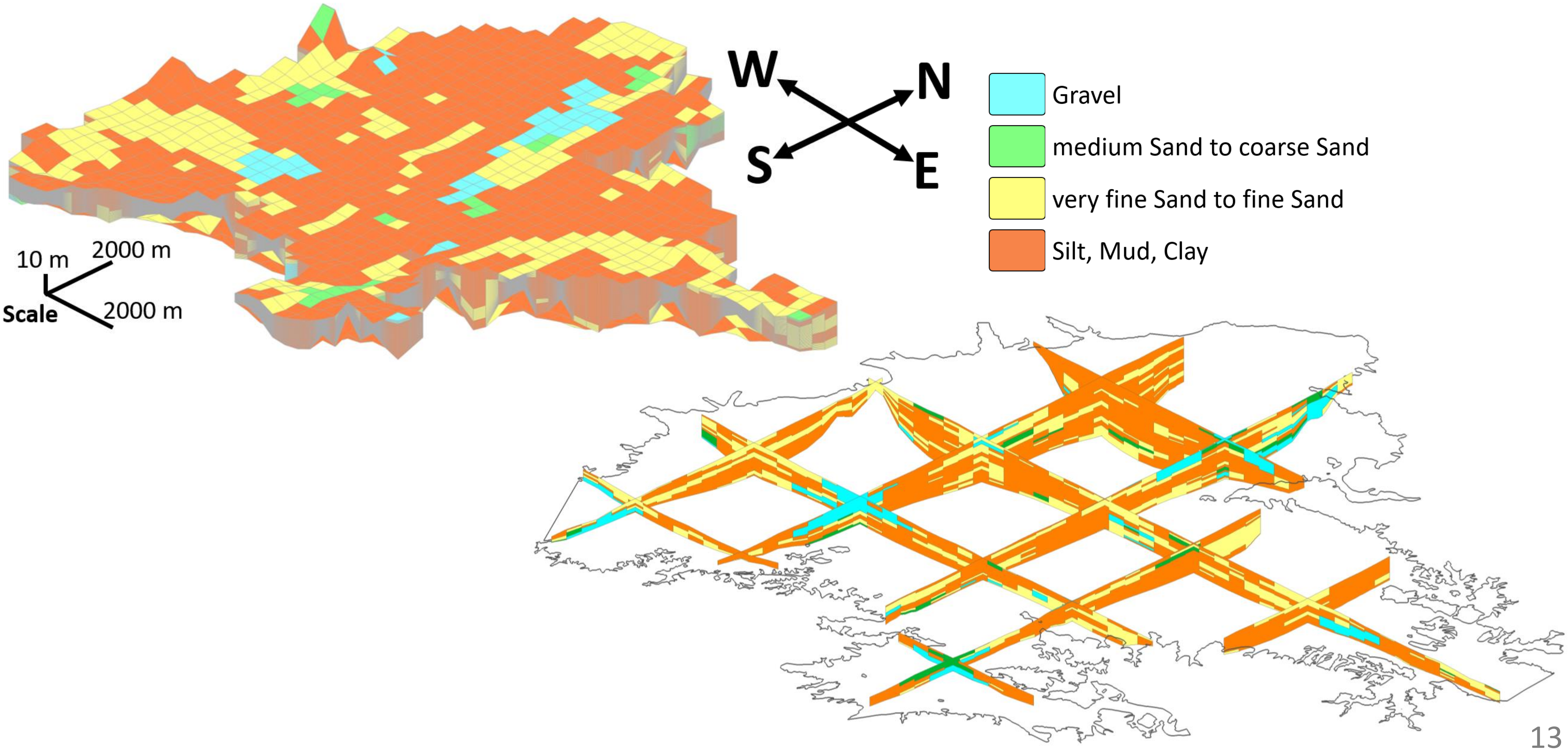




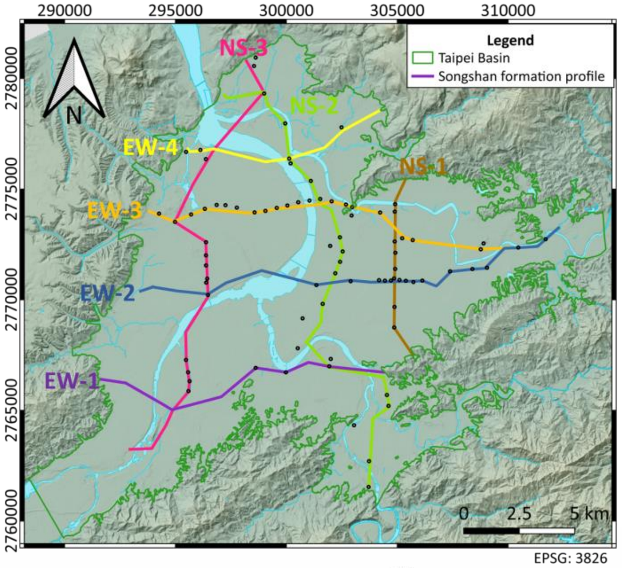
Materials	Volumetric Proportion	Mean length, $\bar{L}$ (m)		
		Vertical Lag = 1	E-W Lag = 500	N-S Lag = 500
Gravel	0.06	7.68	797.43	1176.87
coarse Sand	0.03	5.96	655.12	872.74
fine Sand	0.29	7.46	751.96	1173.79
Clay*	0.63	15.55	936.49	1339.30

*Background material

3D heterogeneously hydrogeological models



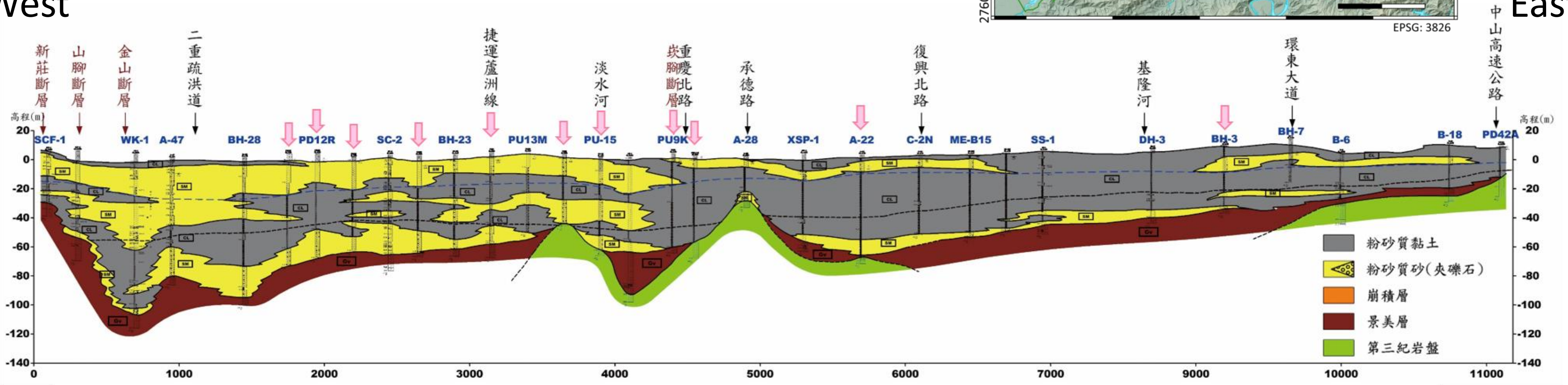
Results

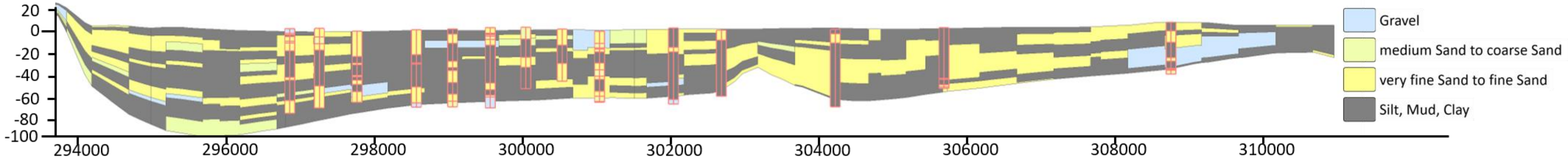


EW-3

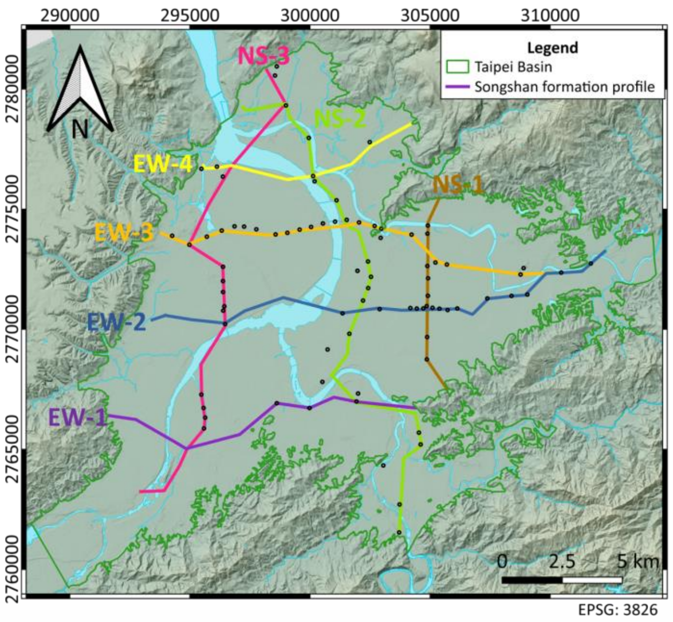
West

East





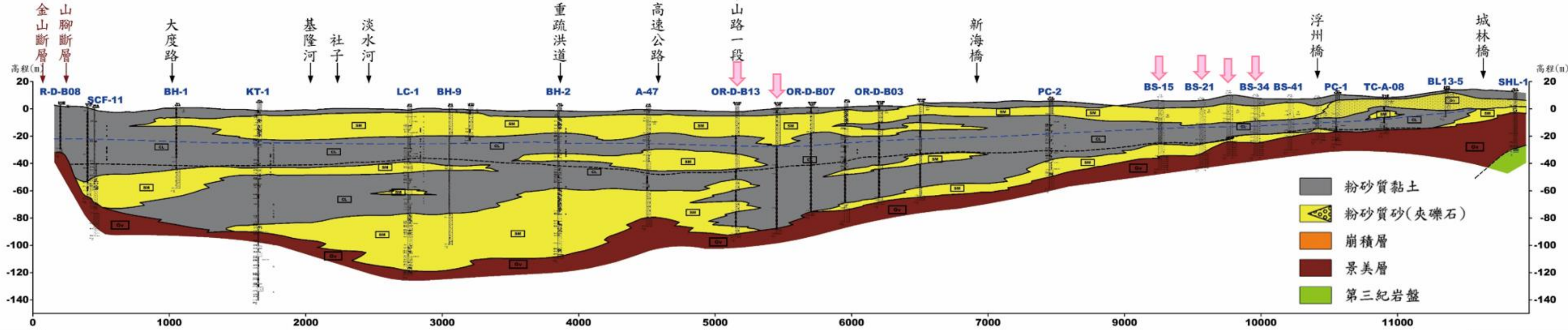
Results

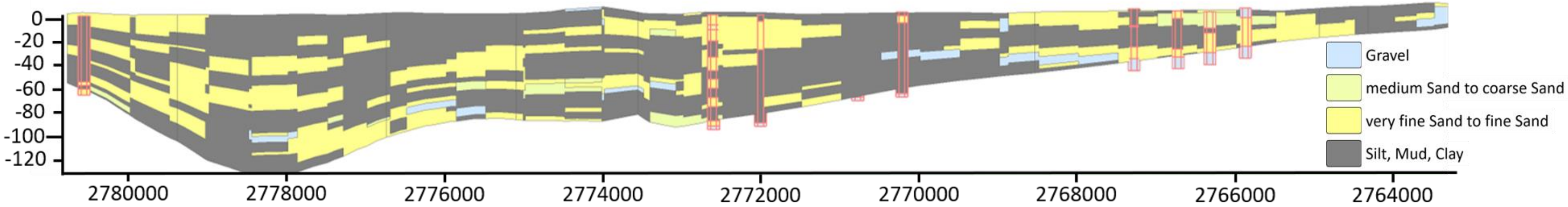


NS-3

North

South





Conclusions

◆ In this study, the transition probability in Markov chain approach was adopted to build the **heterogeneous hydrogeological model**.

Future Work

◆ Combining the steady-state hydrological observation data with the hydrogeological model through MODFLOW packages.

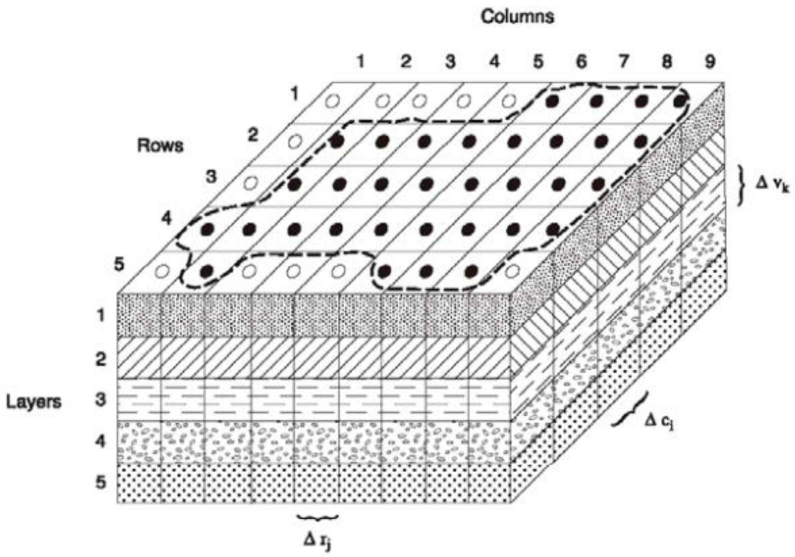
◆ Several pumping scenarios will be proposed to evaluate the land subsidence. → **SUB package**

MODFLOW

◆MODFLOW solves a distribution of hydraulic head in space and time

➢Three-dimensional transient groundwater flow equation *(McDonald and Harbaugh, 1988)*

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$



→Finite difference grid in Modflow

[L/T] hydraulic conductivity along the x, y, and z

[L] hydraulic head

[1/T] volumetric flux per unit volume (sources and/or sinks)

[1/L] specific storage

◆Numerical solution

➢Finite Difference (FD)

Groundwater Modeling System