Investigation of sustainable resource management of Jiaoxi hot spring by using numerical simulation in a heterogeneous hydrogeological model

< Build Jiaoxi heterogeneous hydrogeological model>

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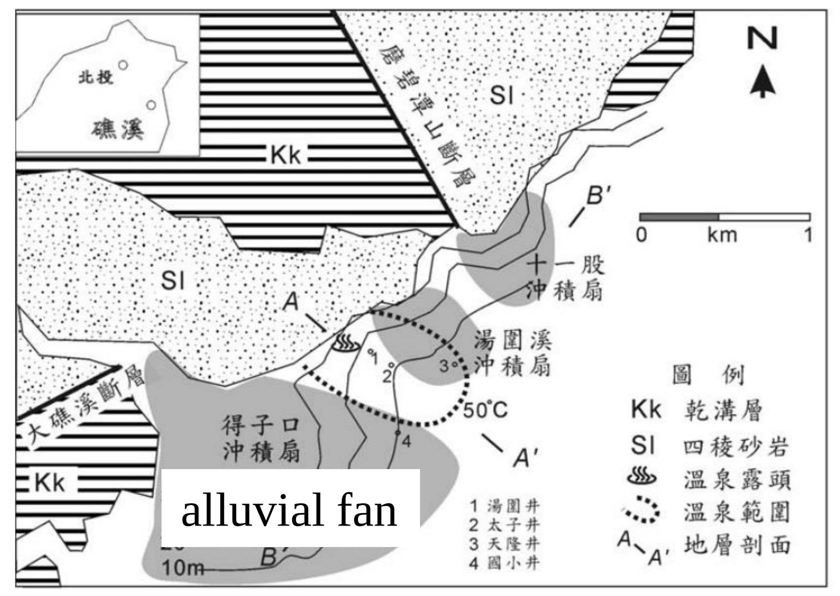
Outline

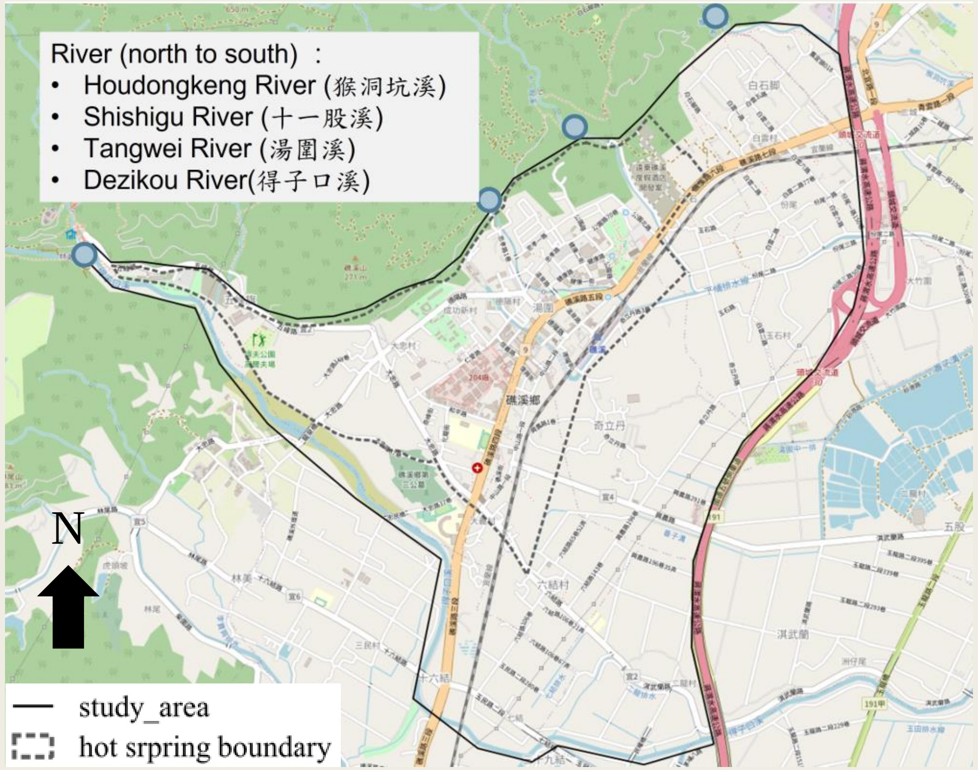
- Introduction
- Methodology
- Results and discussion
- Conclusions
- Future work

Introduction

- Jiaoxi has a unique flatland sodium bicarbonate hot spring in Taiwan, which always attracts tourists from all over the country during holidays.
- As the number of tourists increases, the usage of hot springs also increases accordingly.
- This study intends to combine geological models and hydrological data for establishing an appropriate pumping quantity on hot spring usage.



(陳文福、呂學諭，2010)



Introduction

Groundwater Modeling System

Drilling borehole data

- Yilan county government
- Engineering geological investigation databank
- Hydrogeological database

Hydrological observation data

- <River data>
  Yilan county government
- <Groundwater level>
  WRA website
  Jiaoxi monitoring well

Geological model

- Sediment (heterogeneity)
- Basement (homogeneity)

Set boundary conditions

Use groundwater level to choose the suitable geological model

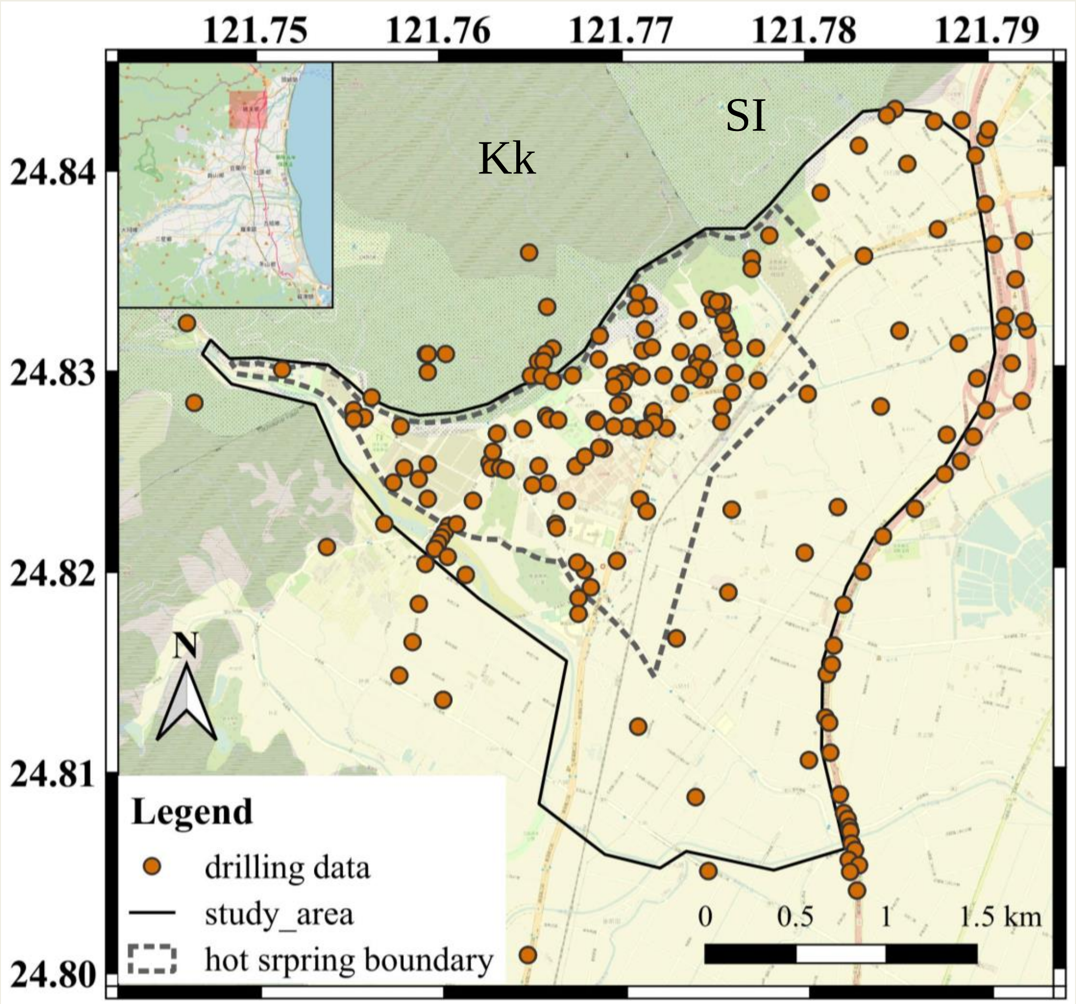
Input pumping data, recharge quantity

Groundwater model validation

Groundwater management

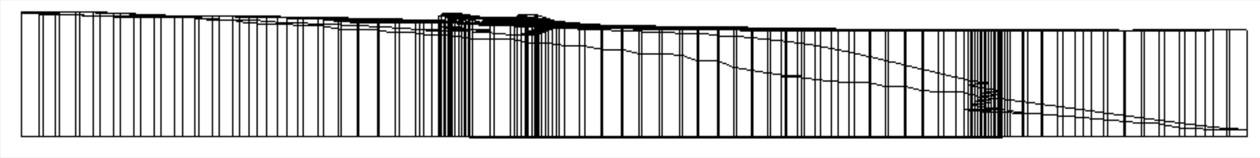
Introduction

- There are 196 boreholes.
- Among them, 19 boreholes have recorded basement material.
- Basement material ：
  - Kankou Formation(Kk)：Slate, Argillite.
  - Szuling Sandstone(SI)：Sandstone with thin layer argillite.

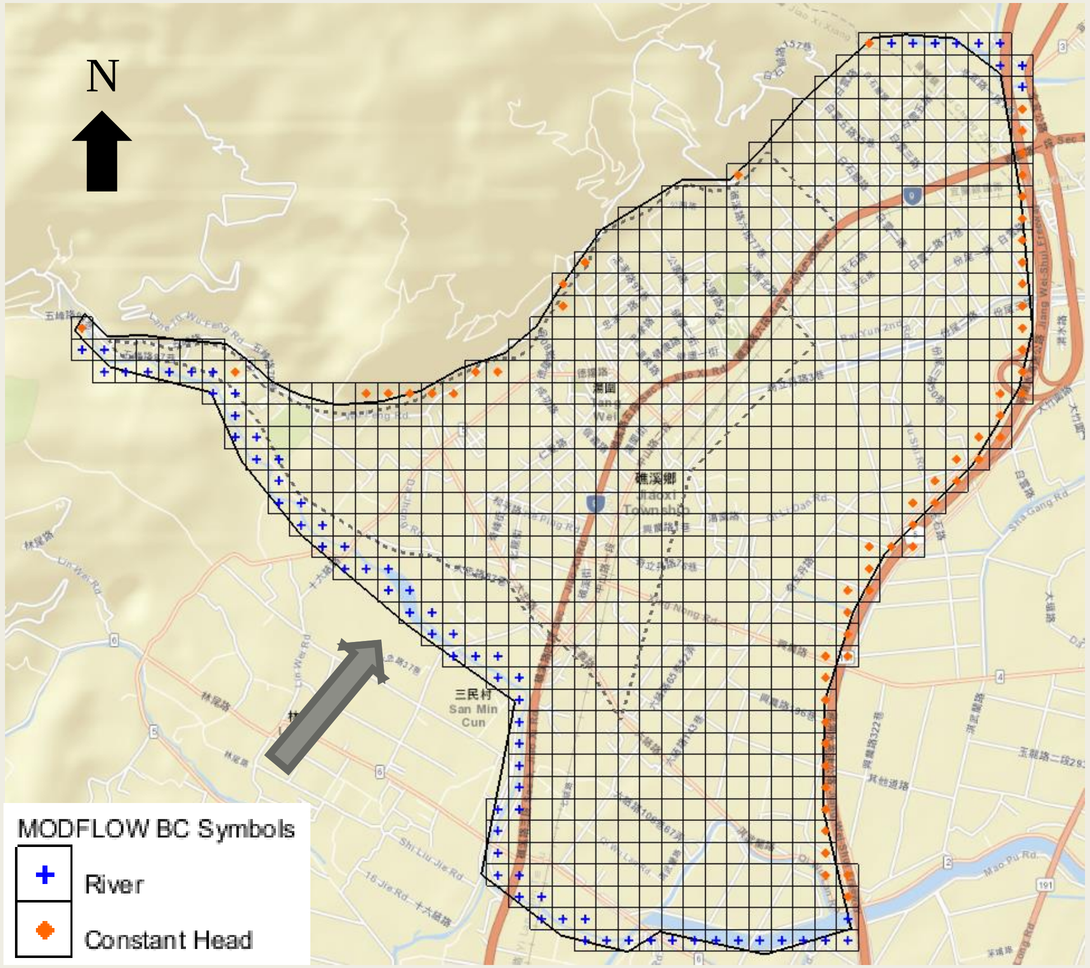


Introduction

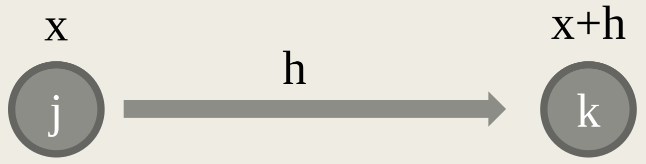
- Grid size : 100*100
- Two layers model (sedimentary layer and basement)



- Boundary conditions:
  - North and south side : river
  - East side : constant head
  - West side : few points of constant head



Methodology – Markov chain



x : a spital location

h : separation vector

k, j : categories of material

t_{jk} : transition probability

- Use 1D continuous-lag Markov chain model

$$t_{jk}(h) = Pr\{k \ occurs \ at \ x + h | \ j \ occurs \ at \ x\}$$

We found material j at x, so what is the probability of finding material k at x+h?

- **Transition rate matrix** in z direction R_z

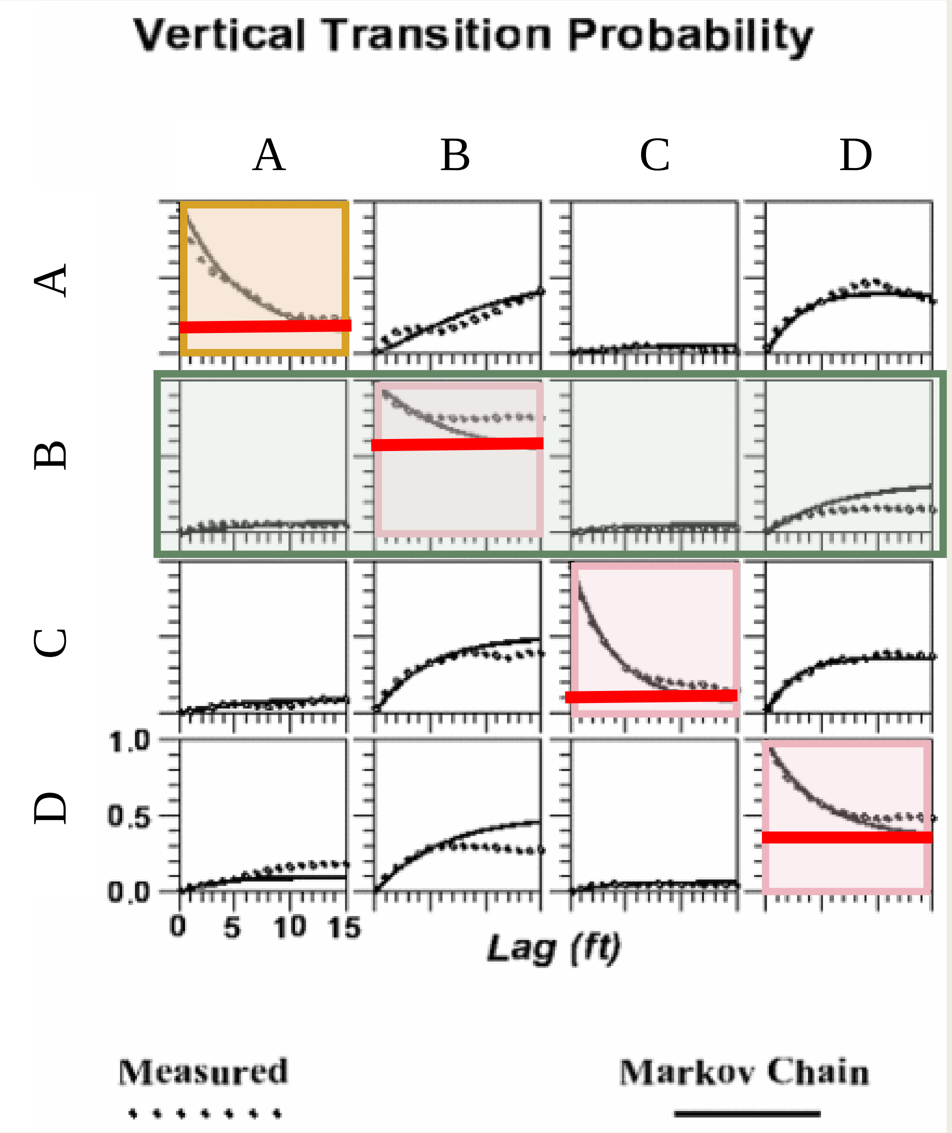
$$R_z = \begin{bmatrix} r_{jj,z} & \cdots & r_{jk,z} \\ \vdots & \ddots & \vdots \\ r_{kj,z} & \cdots & r_{kk,z} \end{bmatrix} \qquad r_{jk,z} = \frac{\partial t_{jk}(0)}{\partial h_z}$$

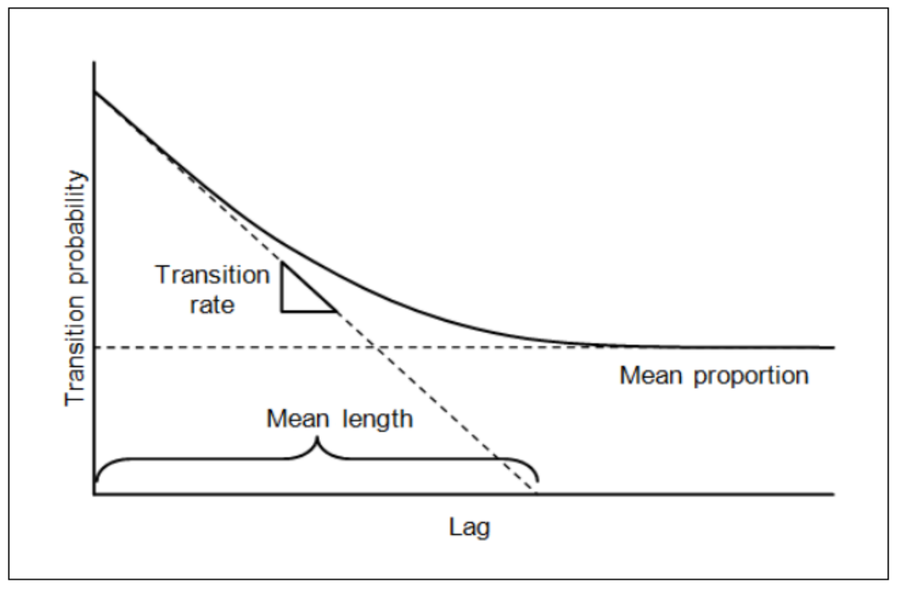
$r_{jk,z}$: the rate change from category j to category k per unit length in the direction z

Diagonal transition $(r_{11}, r_{22}, \dots, r_{NN}) = \dfrac{1}{\boldsymbol{mean\ length}(\bar{L}_k)}$

Material's continuity

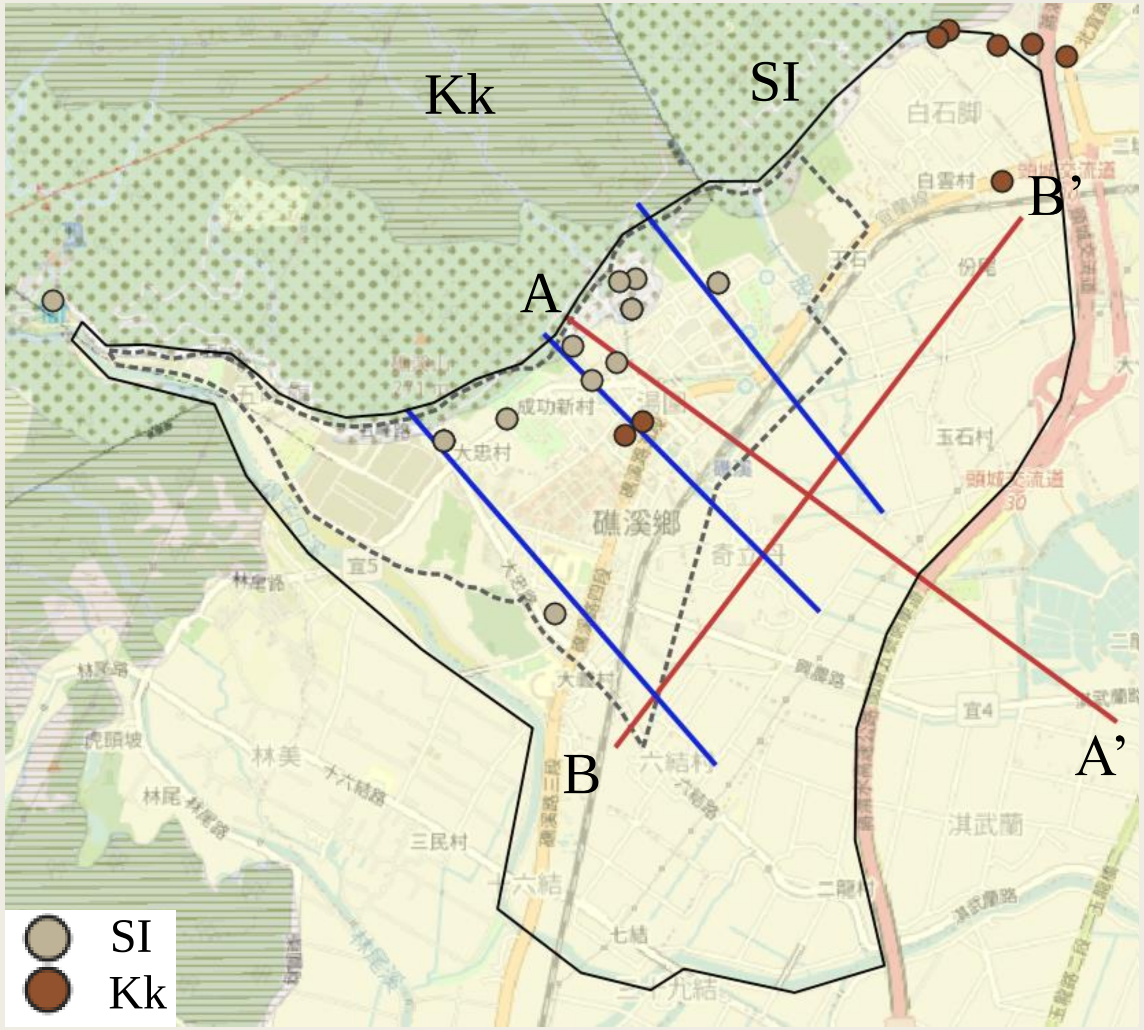
Methodology – Markov chain



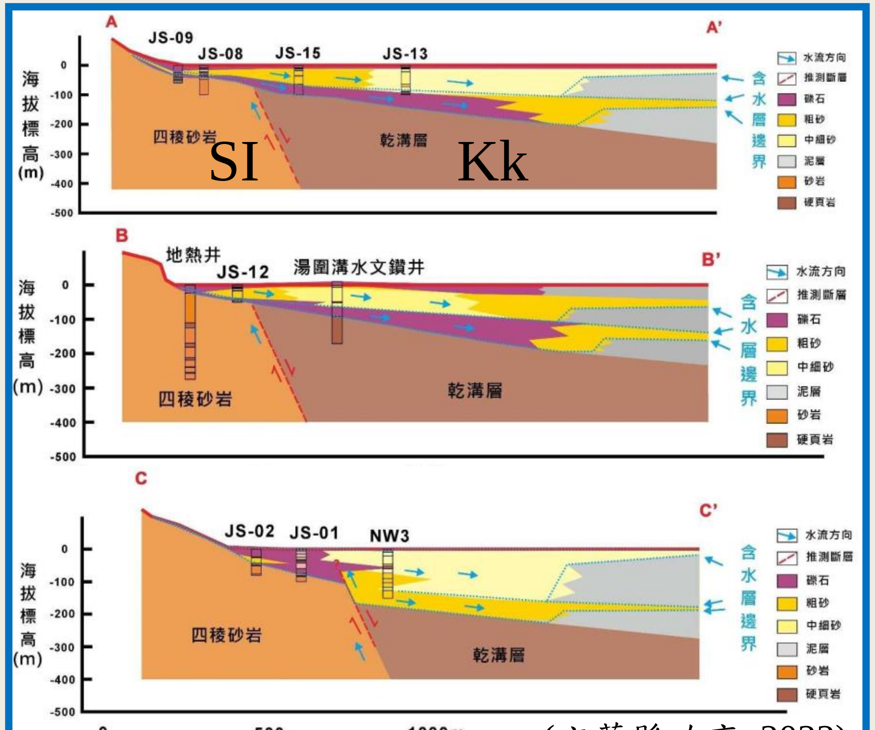


- Mean proportion, transition rates $(r_{jk,z})$, and mean lengths define the Markov Chains.
- Material B has the highest mean proportion. (= other material are easy to change to material B)
- From left to right, material B respectively change to material A,B,C,D’s probability.

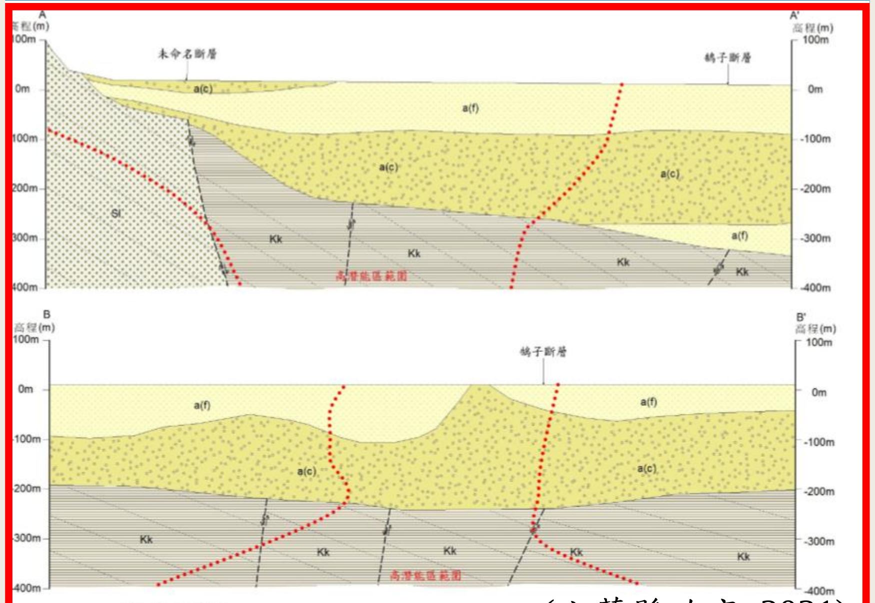
Results and discussion - basement



cross sections + geological map + drilling borehole data
→ basement model

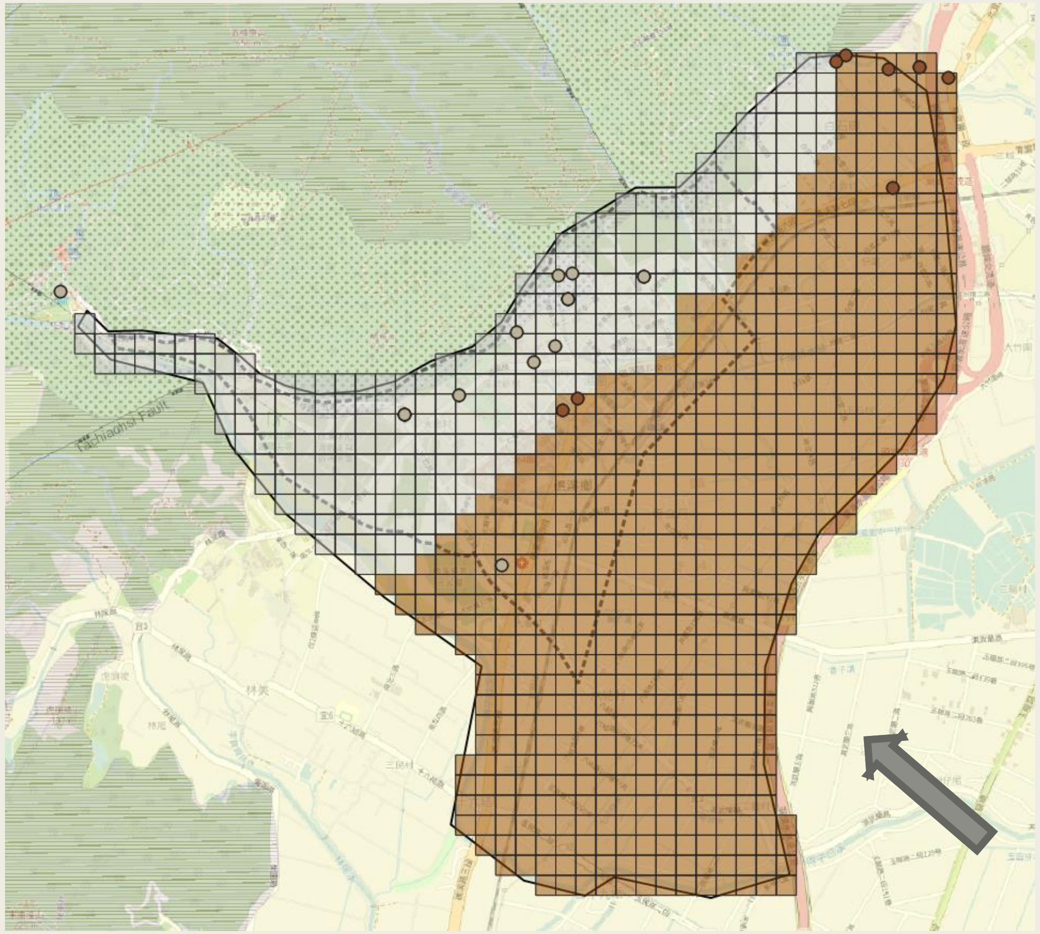


(宜蘭縣政府, 2022)

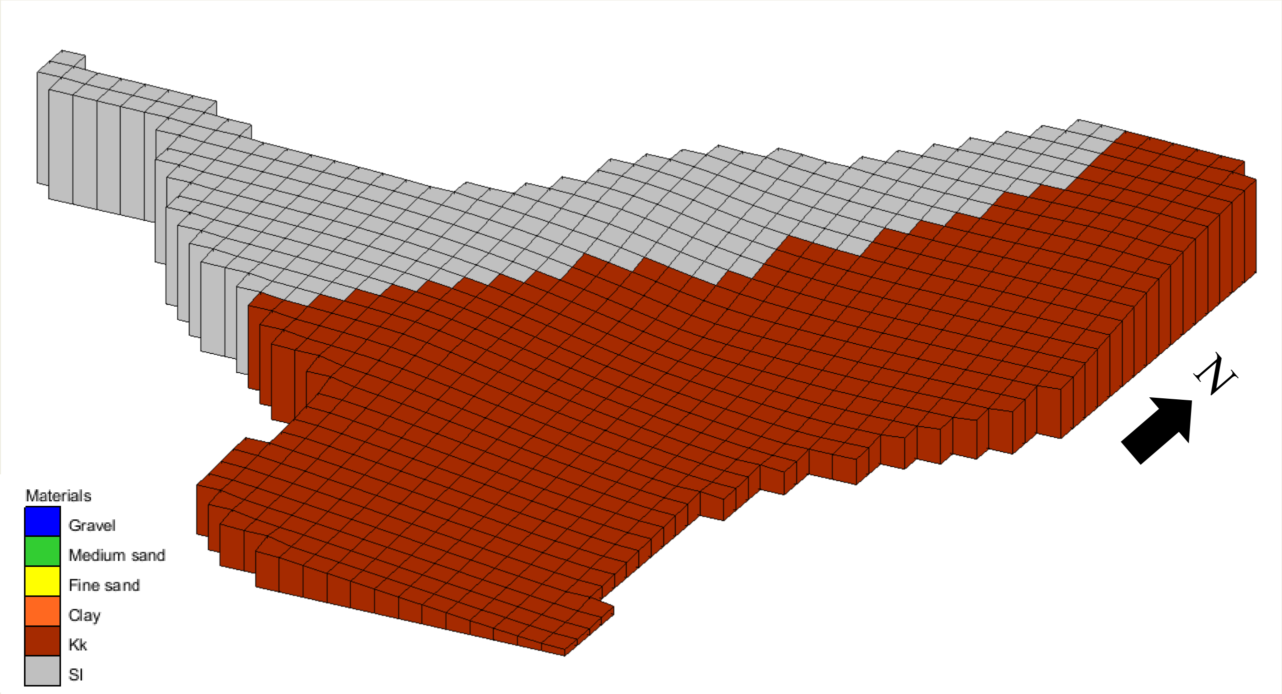


(宜蘭縣政府, 2021)

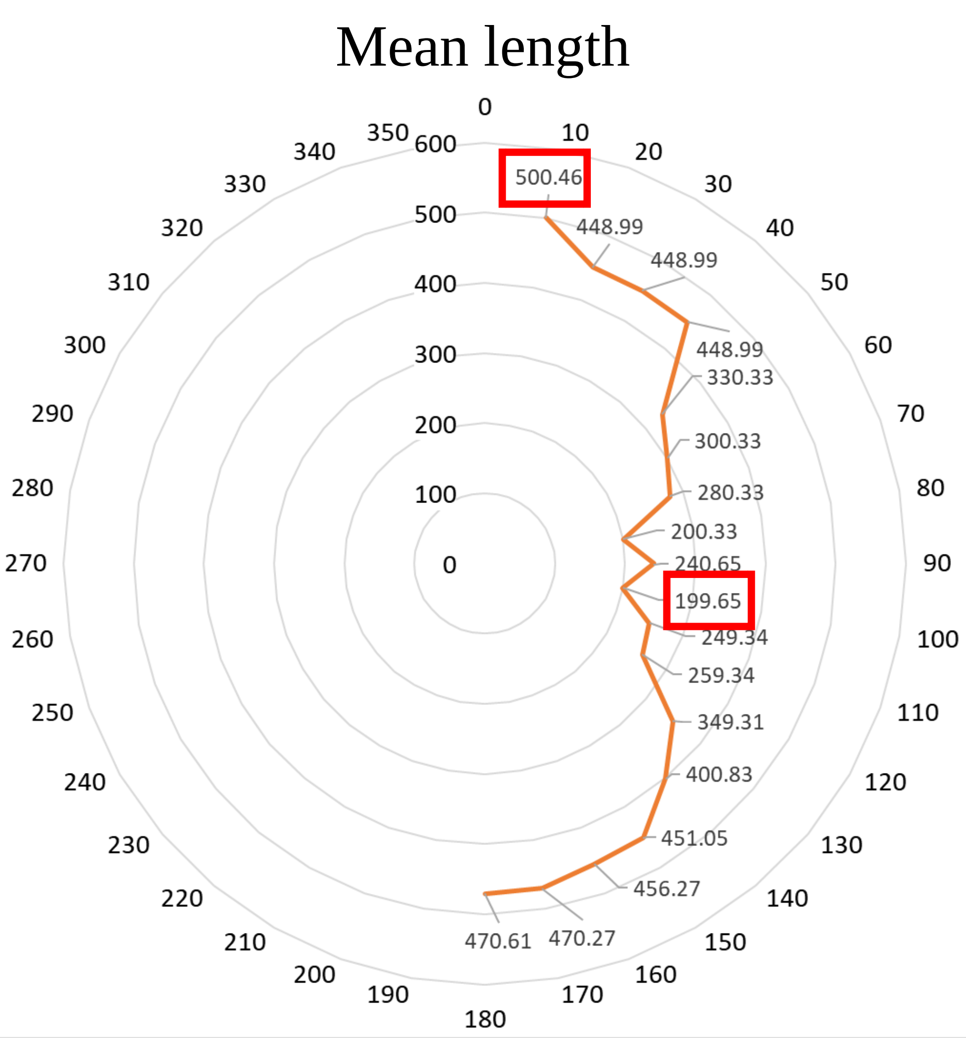
Results and discussion - basement



Homogeneous



Results and discussion - sedimentary layer

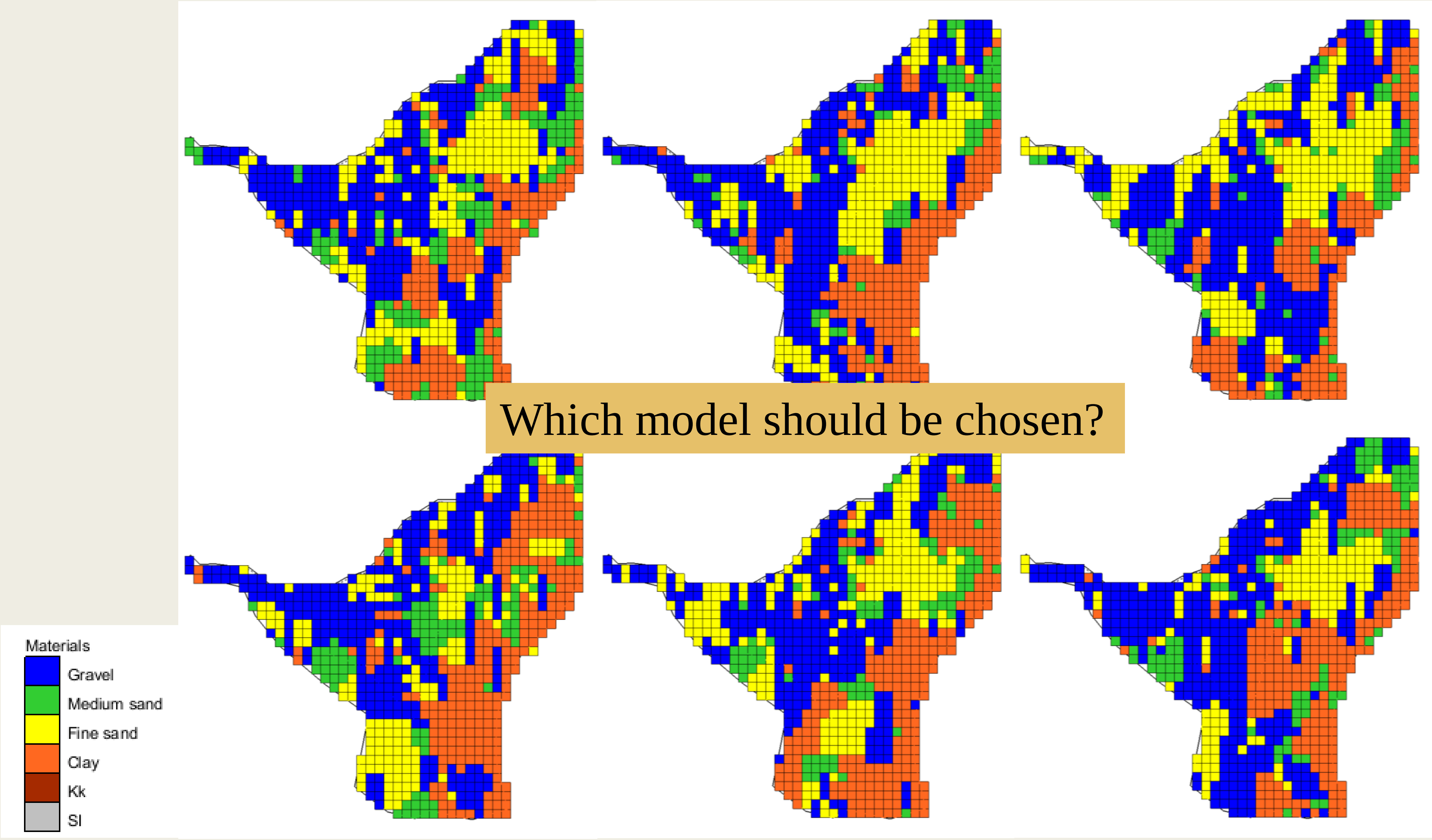


- Use rose diagram to find the principle continuity direction.
- In N10˚E, gravel has the maximum mean length.
- Find out other material's mean length in N10˚E.
- Set mean length to T-PROGS to create the sedimentary layer.

	N10˚E(10˚)	S80˚E (100˚)
Gravel	500	200
Coarse sand	250	250
*Fine sand	600	410
Clay and silt	320	250

* Background material

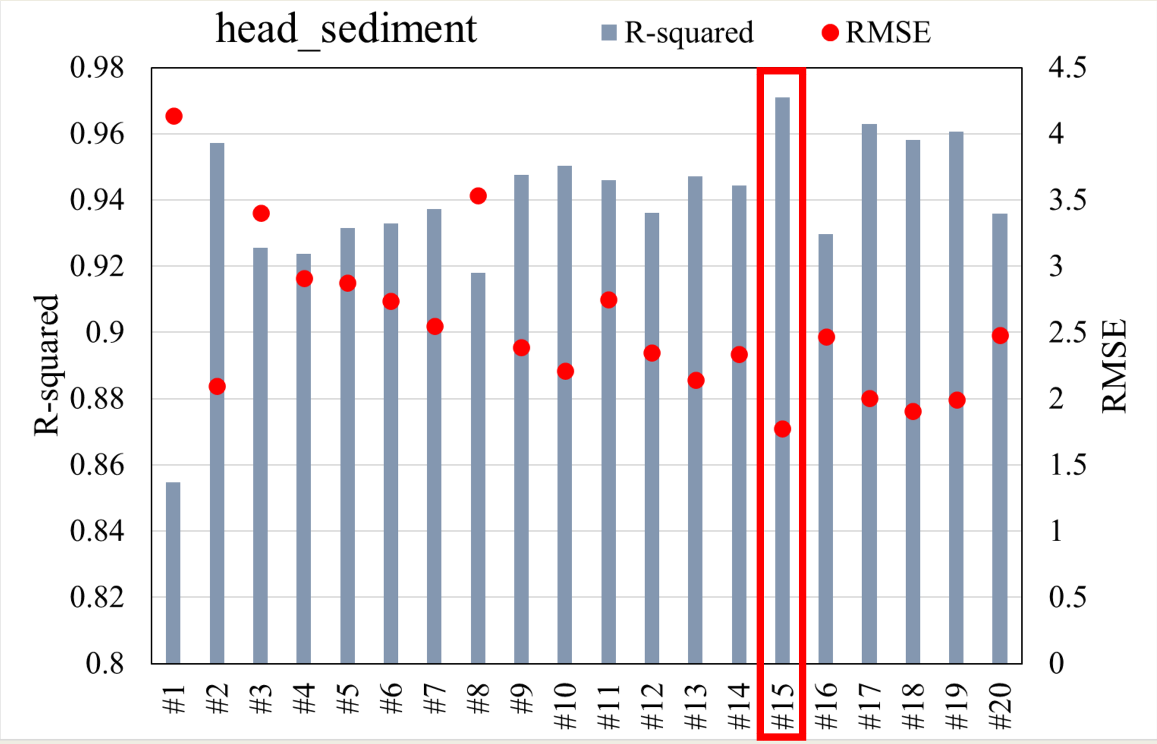
Results and discussion - sedimentary layer



Which model should be chosen?

Results and discussion - sedimentary layer + basement

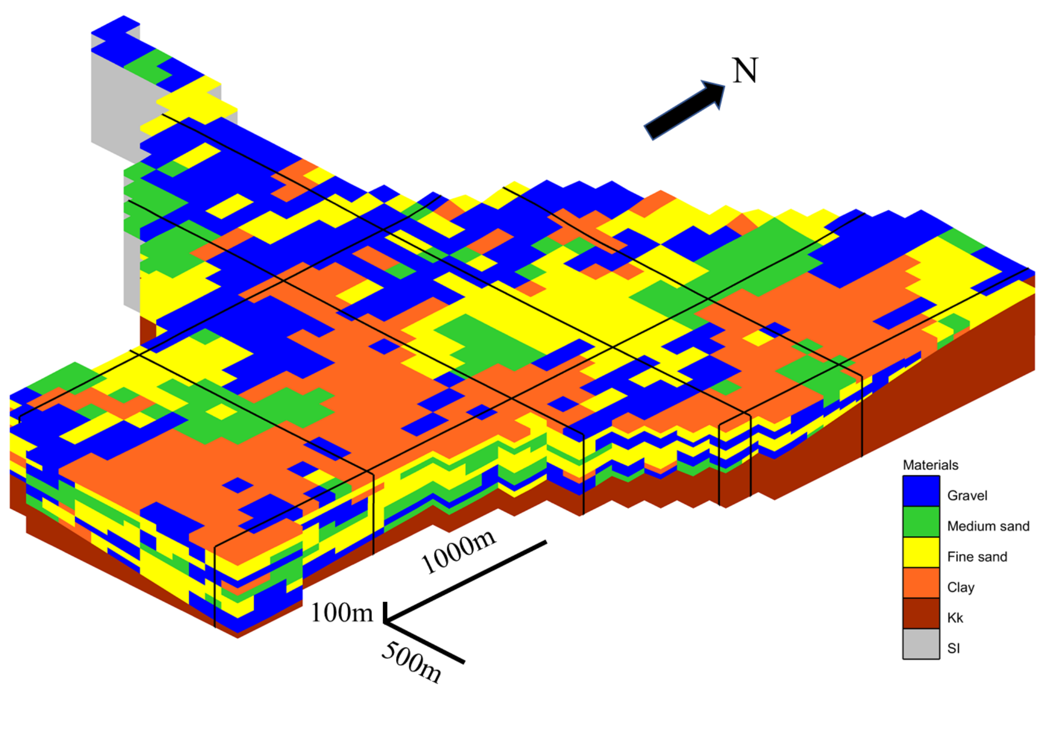
- Run MODFLOW with sediment and bedrock layers together to invert a representative model of heterogeneity in the sedimentary layer.
- Randomly choose 20 heterogeneous models to do the numerical simulation.
- Compare the average groundwater level value with each model's groundwater level.
- Use R^2 & RMSE to find the model with the lowest uncertainty.
- Model #15 will be the representative model.

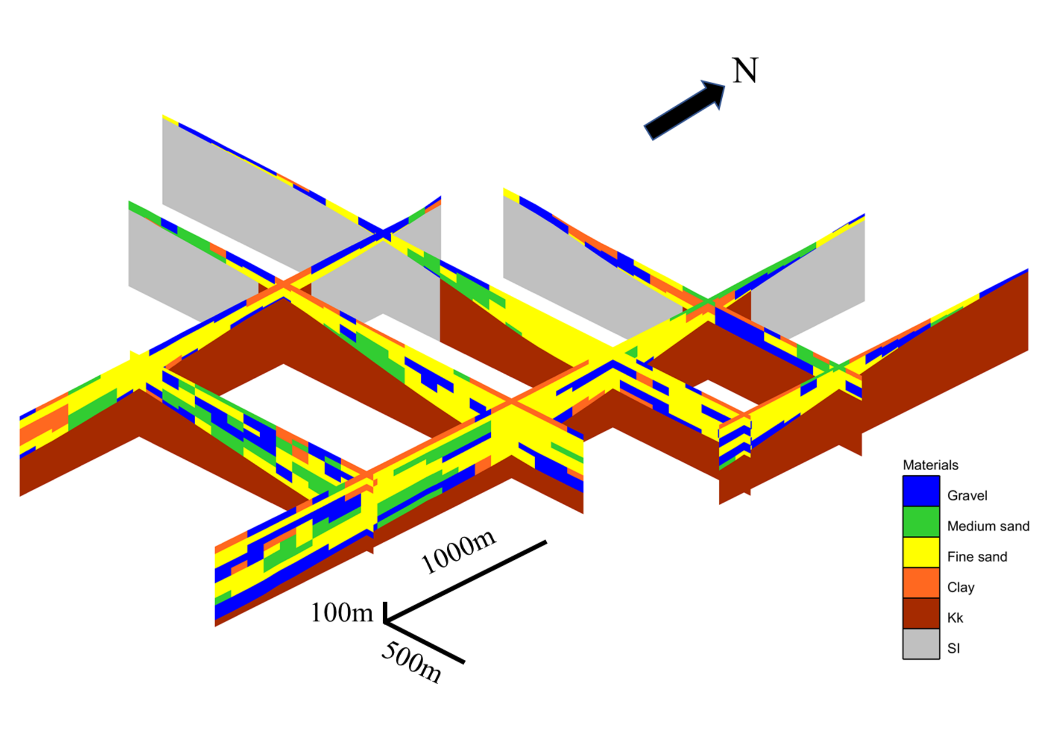


Conclusions

- Use rose-diagram shows that gravel material has the highest continuity in the N10°E direction.

- Choose the model with highest R^2 and lowest RMSE to be the representative model.





Future work

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Bedrock (homogeneity)

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Thanks for your listening