2022 / 11 / 25

Applied Geology – Seminar

The impact of climate conditions and pumping strategies on the groundwater system in the Mekong Delta, Vietnam

Speaker: Kim-Hung Nguyen

Advisor: Prof. Chuen-Fa Ni

OVERVIEW

- 1. Introduction
- 2. Background
- 3. Methodology
- 4. Results & Discussion
- 5. Conclusions

1. INTRODUCTION

- Groundwater - valua

variety of purposes,

especially important

Delta. (Home of 18

produces half of Vie

contributes a signifi

country's GDP)

Fig 1. Groundwater extraction for agriculture

© Courtesy Laura Erban

❖ Motivation:

- Groundwater level is declining
- Total dissolved solids (TDS) is rising

→ Groundwater is becoming salty.

❖ Questions:

- Future evolution of groundwater system?
- Where and when will GW get salty?

❖ Objectives:

- Forecast groundwater level and salinity

→ Provide an efficient tool for managing groundwater resources.

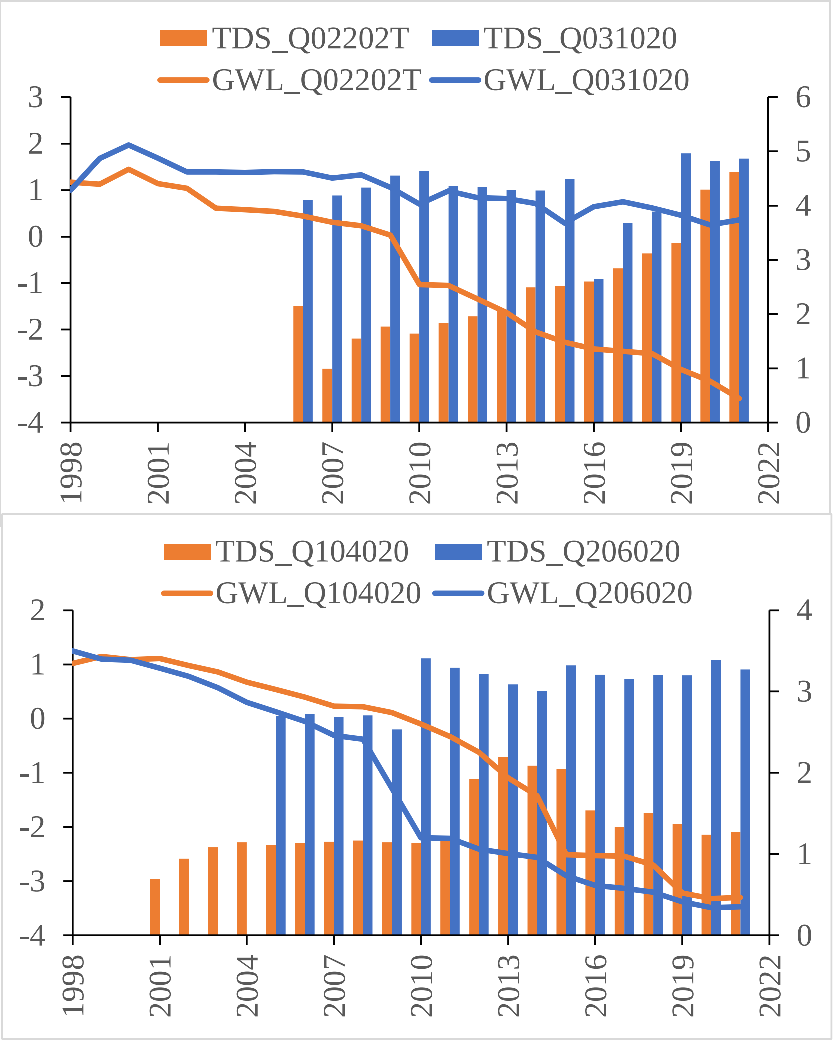


Fig 2. Observed groundwater levels and TDS

2. BACKGROUND

❖ Study area:

- Vietnamese Mekong Delta (VMD)
- Area: 40,000 km^2
- Elevation: 0.8m amsl.
- Complex groundwater and surface-water system

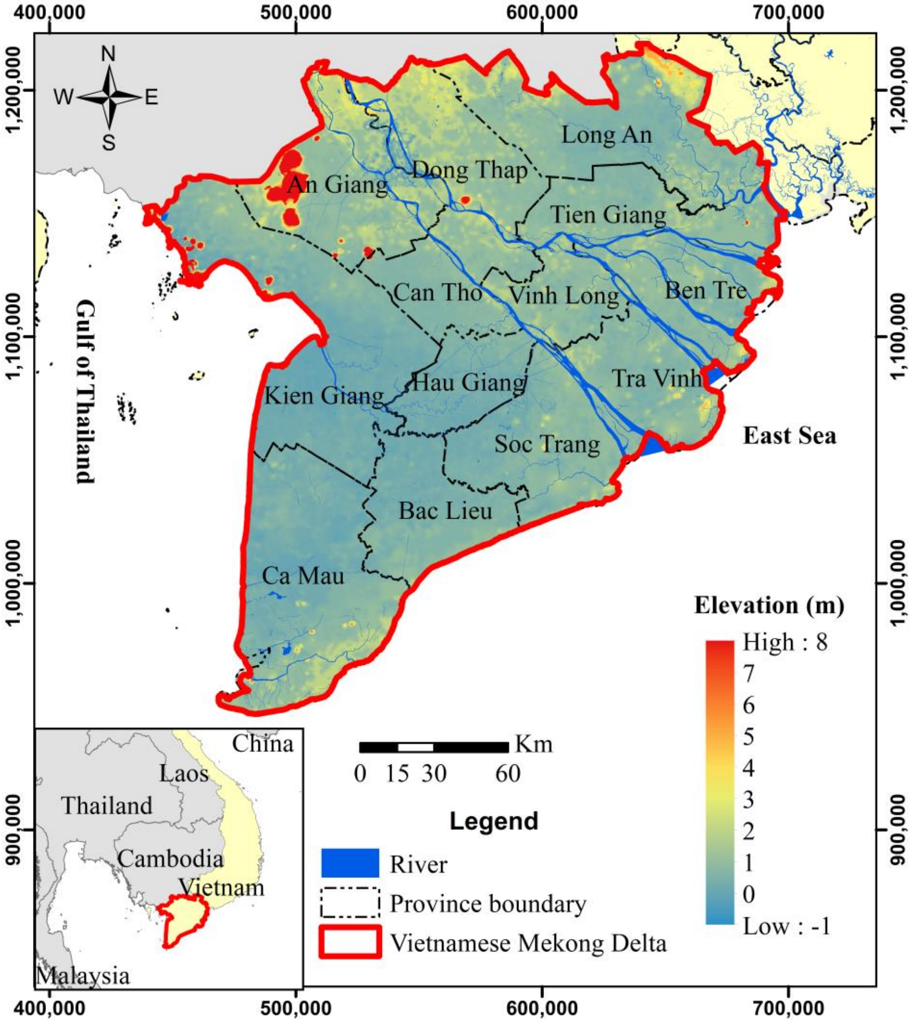


Fig 3. Study area

❖ Groundwater system: 7 aquitards and 7 aquifers

- Holocene (qh)
- Upper Pleistocene (qp_3)
- Upper-Middle Pleistocene (qp_{2-3})
- Lower Pleistocene (qp_1)
- Middle Pliocene (n_2^2)
- Lower Pliocene (n_2^1)
- Upper Miocene (n_1^3)

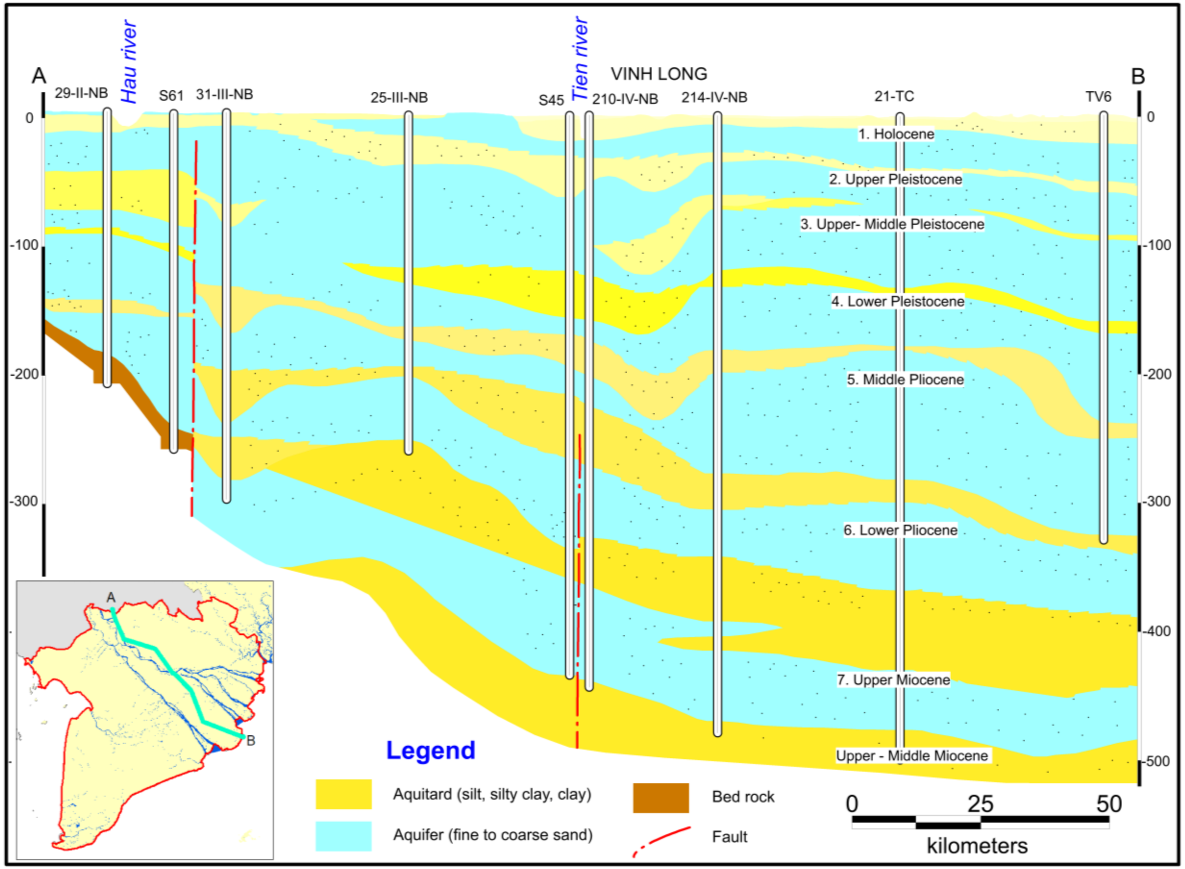


Fig 4. Cross-section of the VMD (modified after Nguyen et al. 2004)

3. METHODOLOGY

❖ **USGS - MODFLOW:**

- Groundwater Flow in 3-Dimensions

❖ **USGS - MT3D:**

- Groundwater Solute Transport in 3-Dimensions

❖ **USGS - SEAWAT:**

- Variable-Density Groundwater Flow and Transport

- Coupled version of MODFLOW and MT3D

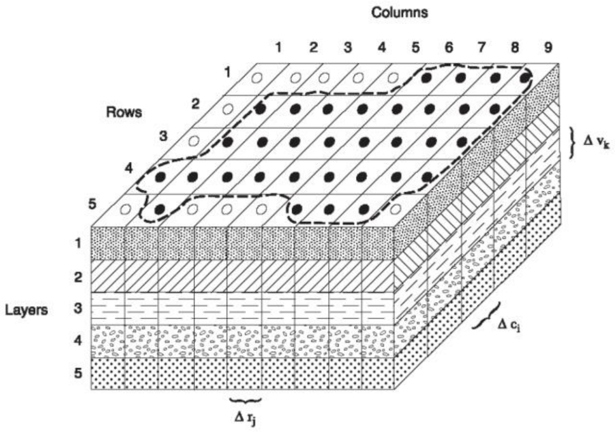
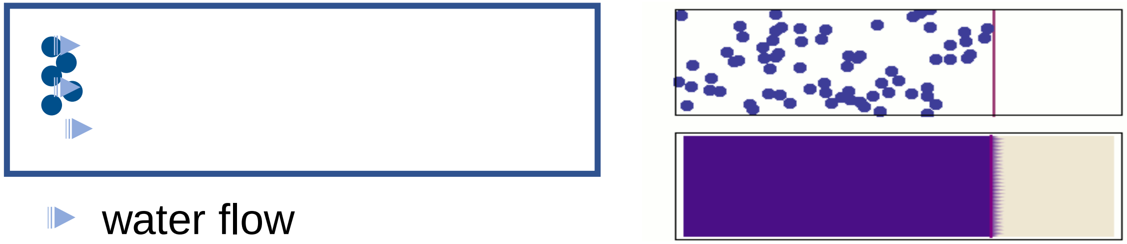


Fig 5. A discretized hypothetical aquifer system (Harbaugh, 2005)

– Advection

– Dispersion



▶ water flow

● particle

Fig 6. Example of Advection, Dispersion motion

❖ GROUNDWATER FLOW MODEL

- 14 layers

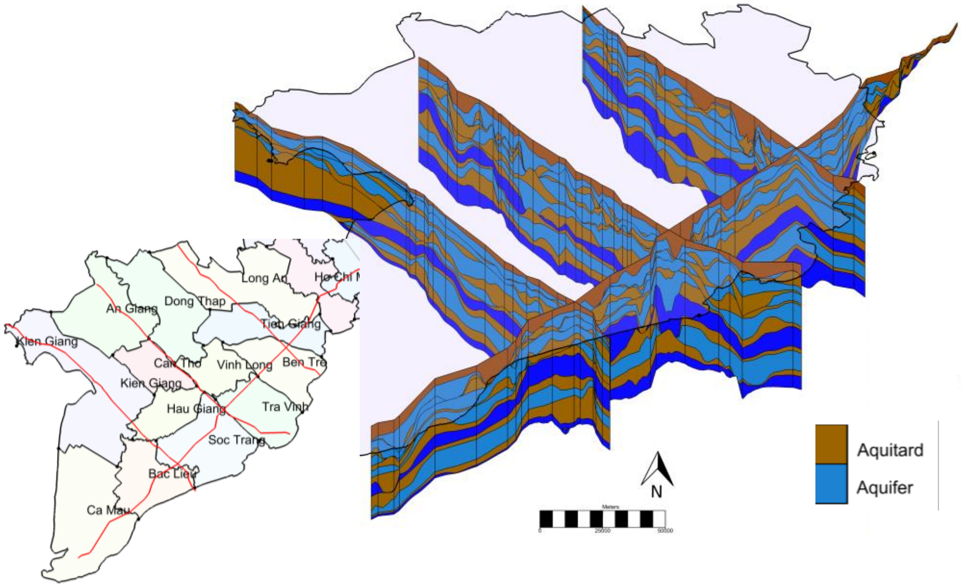


Fig 7. Hydrogeological fence diagram of the VMD

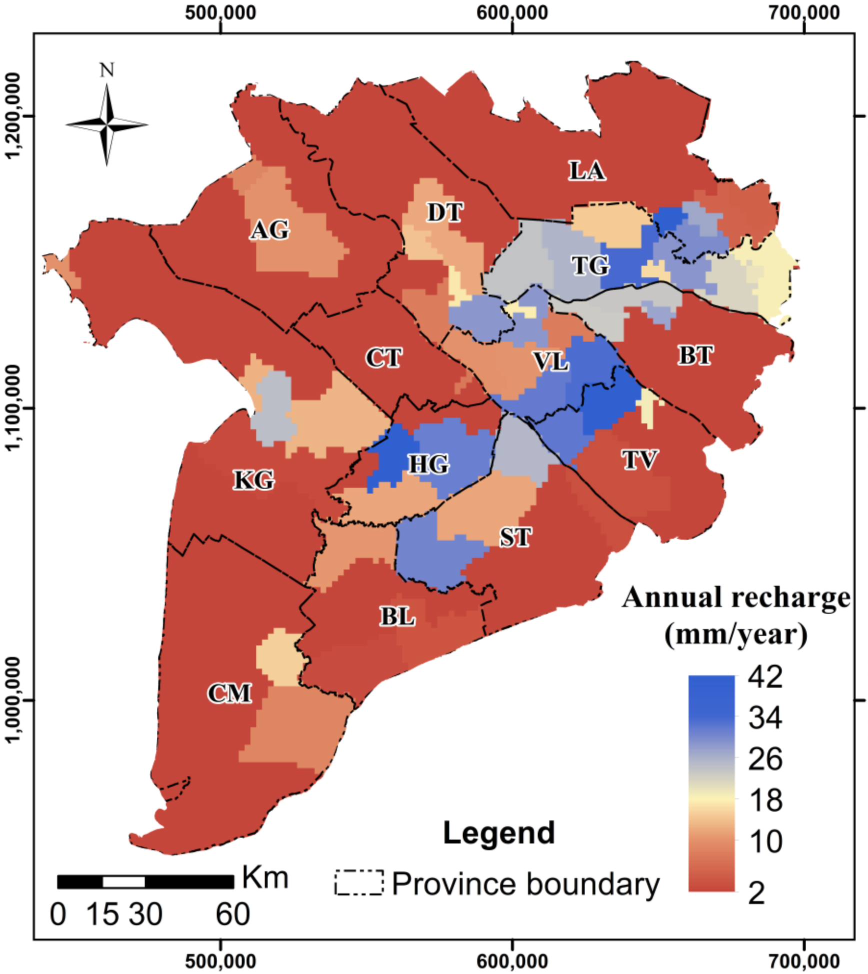


Fig 8. Spatial distribution of recharge

Boundary conditions

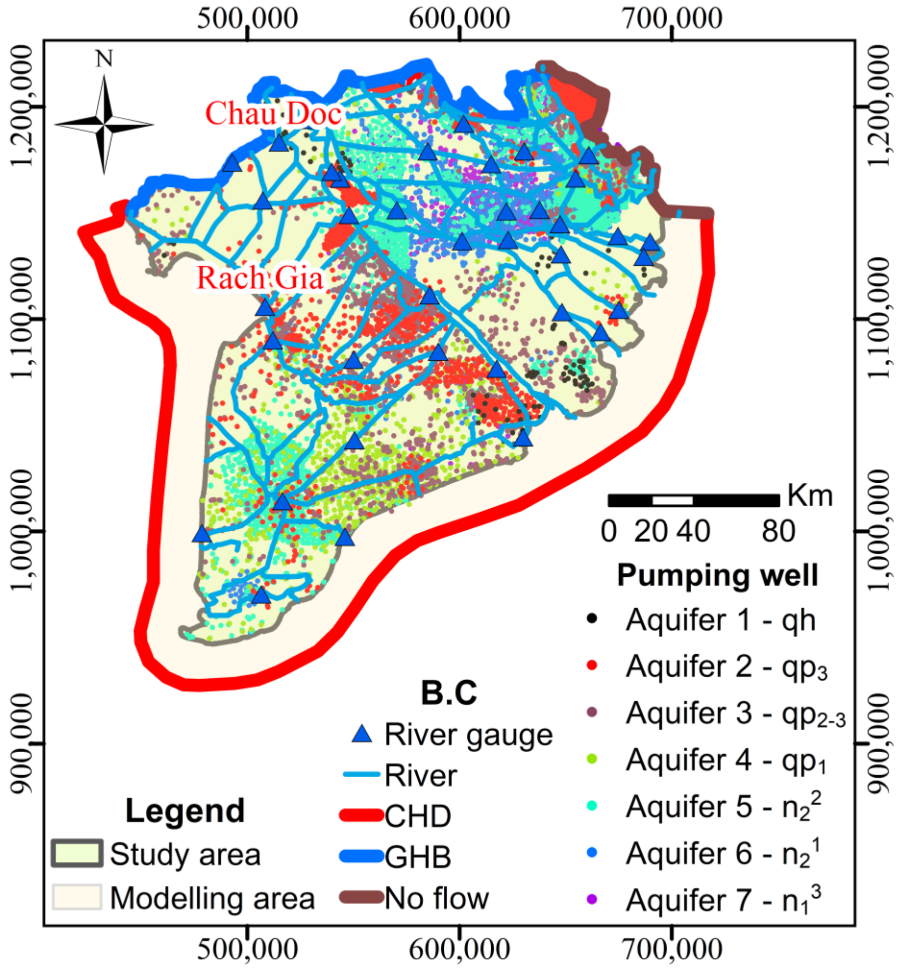


Fig 9. Boundary conditions for GW flow model

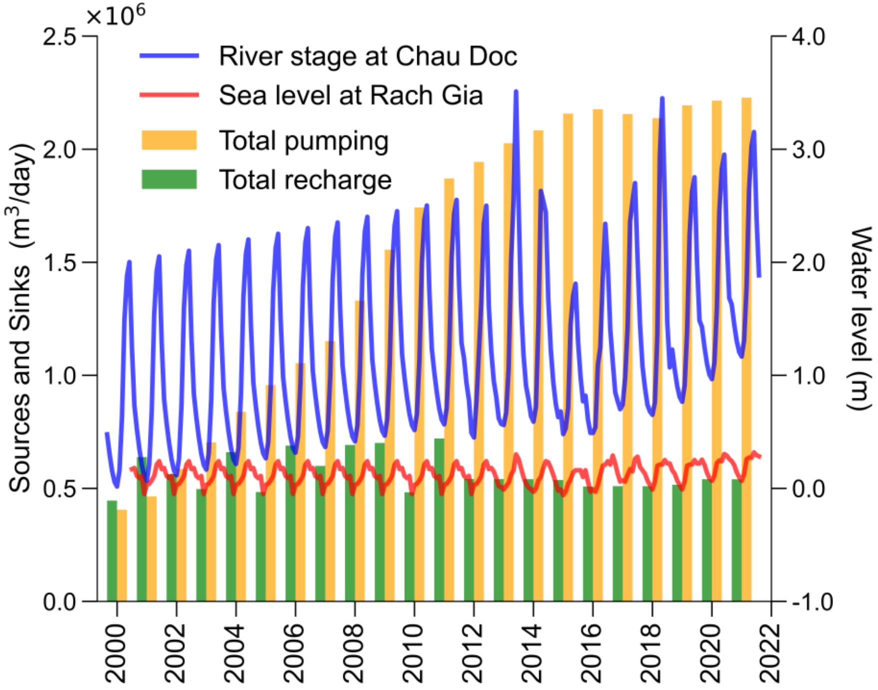


Fig 10. Boundary conditions value

❖ GROUNDWATER SALINITY MODEL

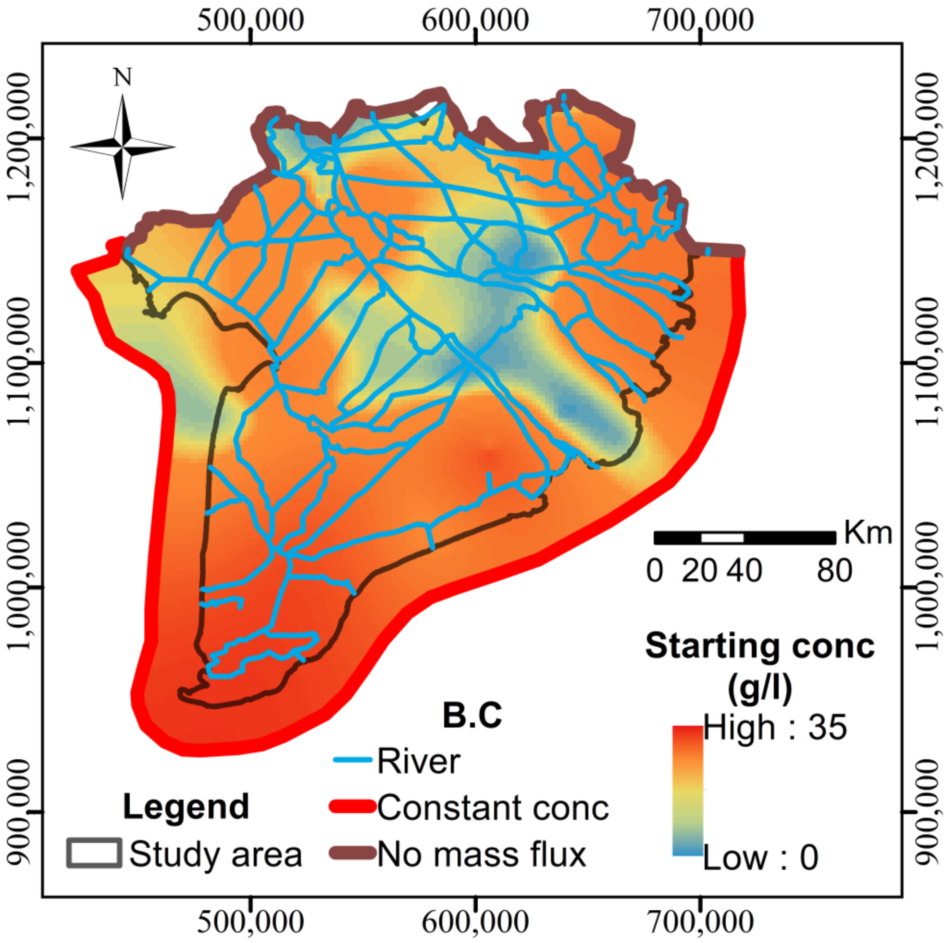
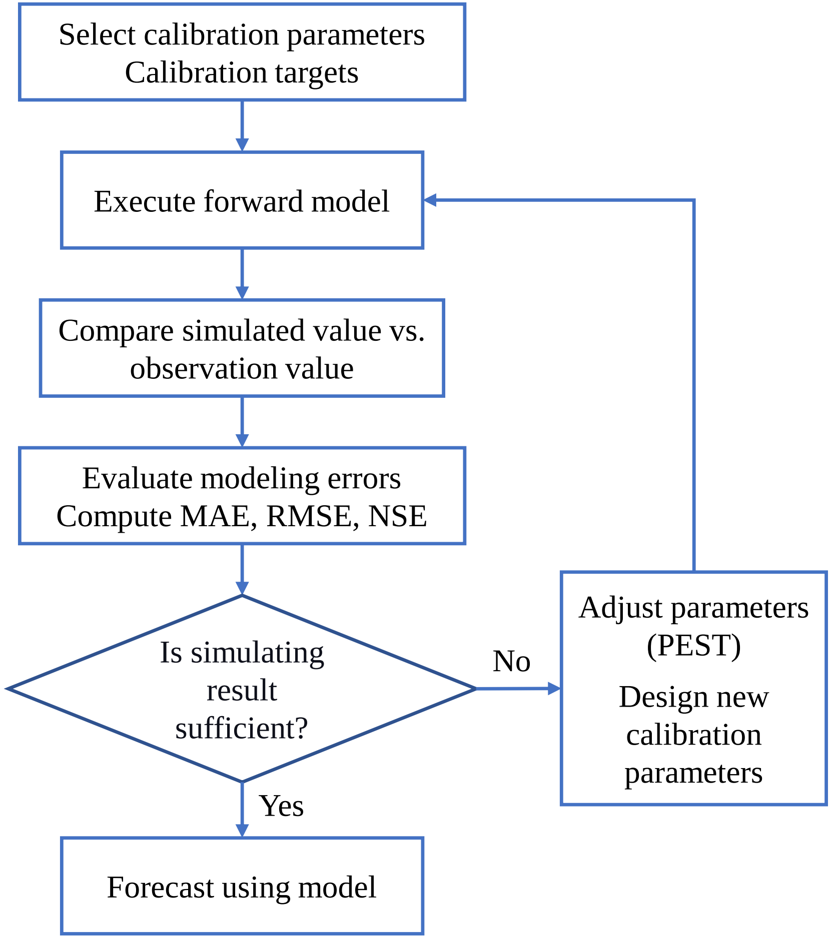


Fig 11. Boundary conditions for groundwater salinity model

❖ Calibration and evaluate model performance



Select calibration parameters
Calibration targets

Execute forward model

Compare simulated value vs. observation value

Evaluate modeling errors
Compute MAE, RMSE, NSE

Is simulating result sufficient?

No

Adjust parameters (PEST)
Design new calibration parameters

Yes

Forecast using model

Fig 13. General workflow for model calibration

- Evaluate model performance

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|h_{obs} - h_{sim}\right|_i$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_{obs} - h_{sim}\right)_i^2}$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left|h_{obs} - h_{sim}\right|_i^2}{\sum_{i=1}^{n}\left|h_{obs} - \overline{h_{obs}}\right|_i^2}$$

- Future scenario
  - Remain most boundary conditions, pumping rate.
  - Change the recharge (Shrestha et al., 2016) and sea level (Thuc et al., 2016)

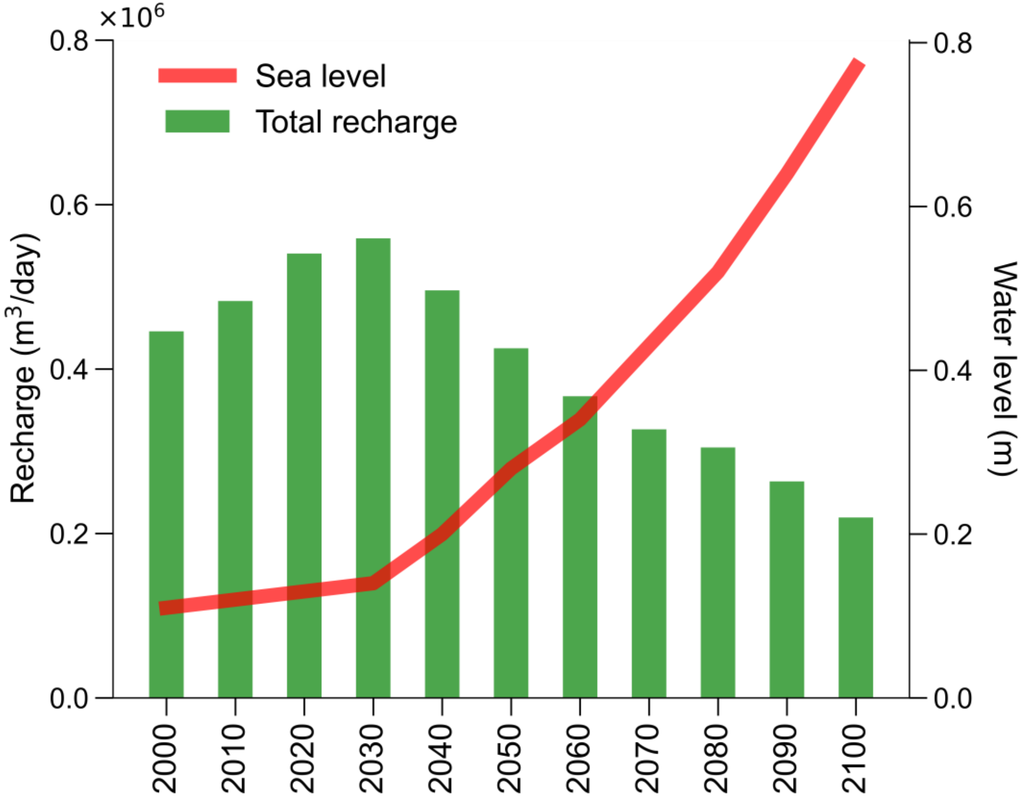


Fig 12. Predicted future boundary conditions value

4. RESULTS & DISCUSSION

❖ Groundwater flow model

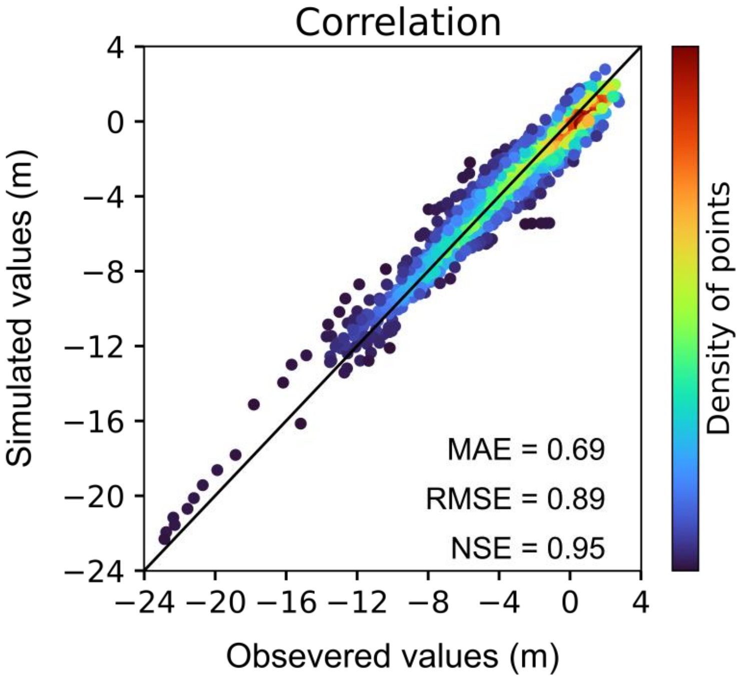


Fig 14. GW level Obs vs Sim

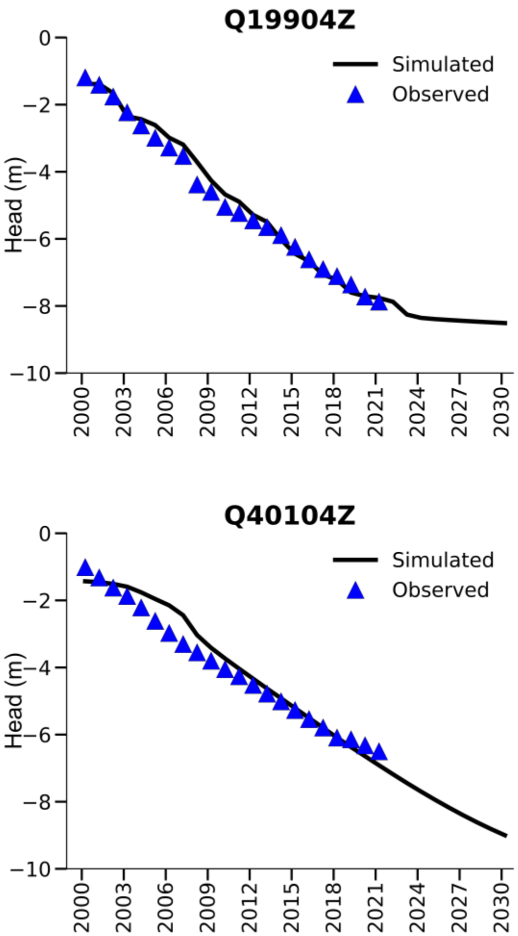


Fig 15. GWL Obs vs. Sim time series

❖ Groundwater salinity model

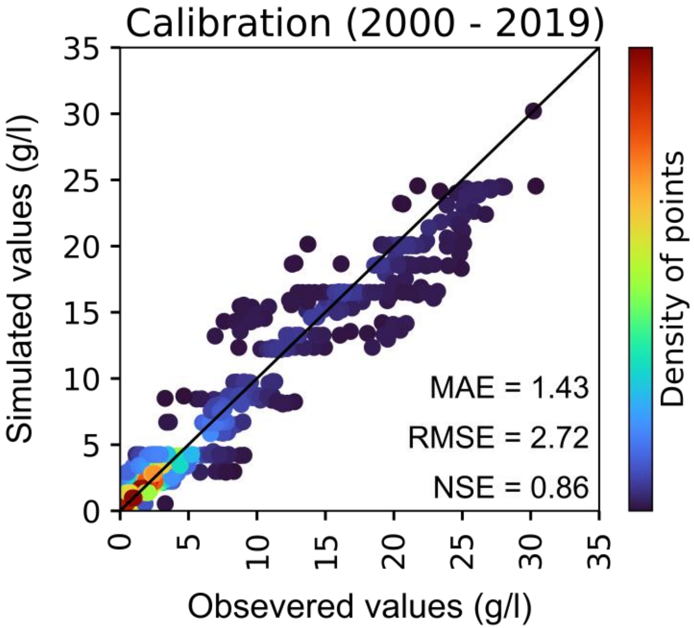


Fig 16. GW salinity Obs vs Sim

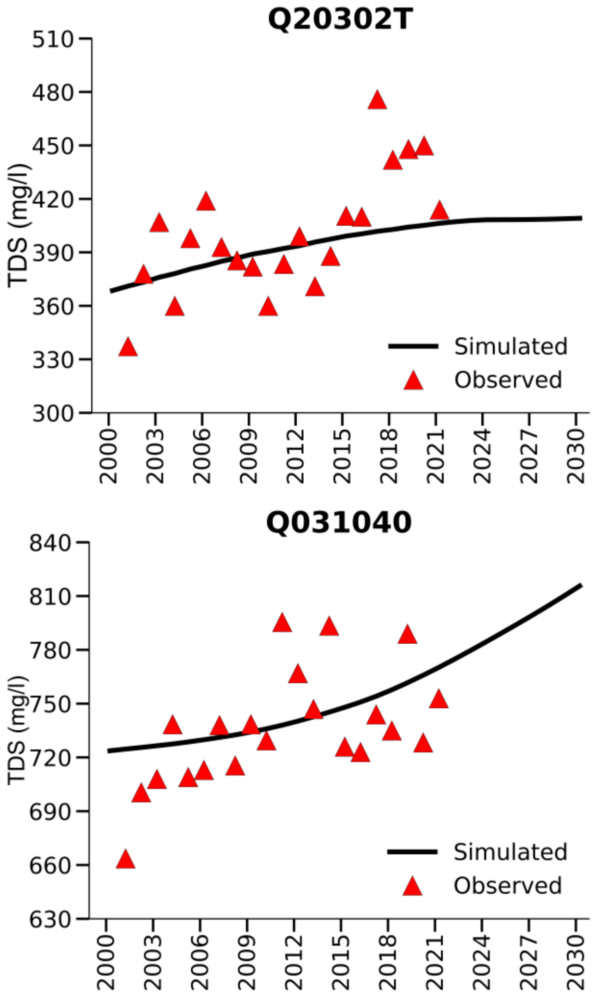
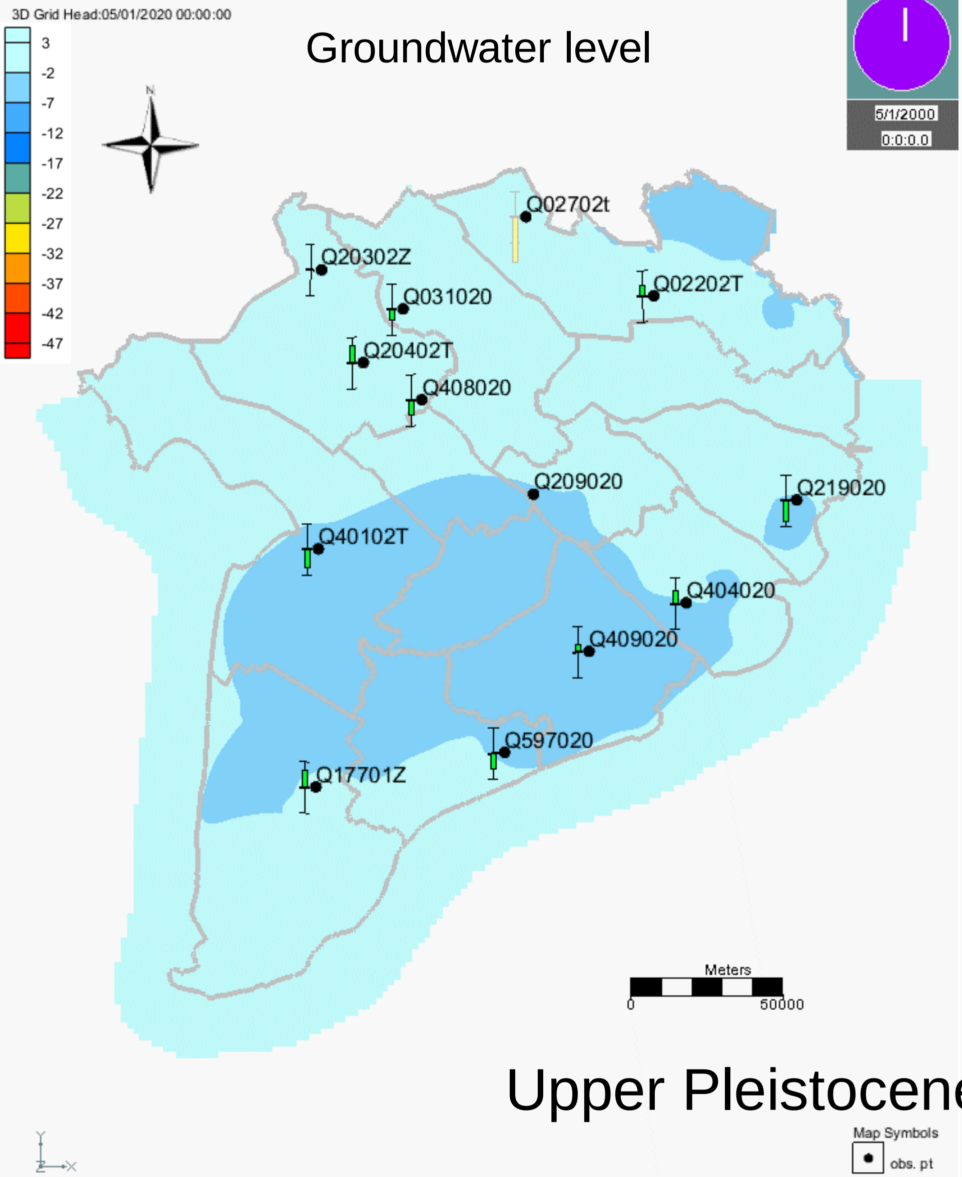
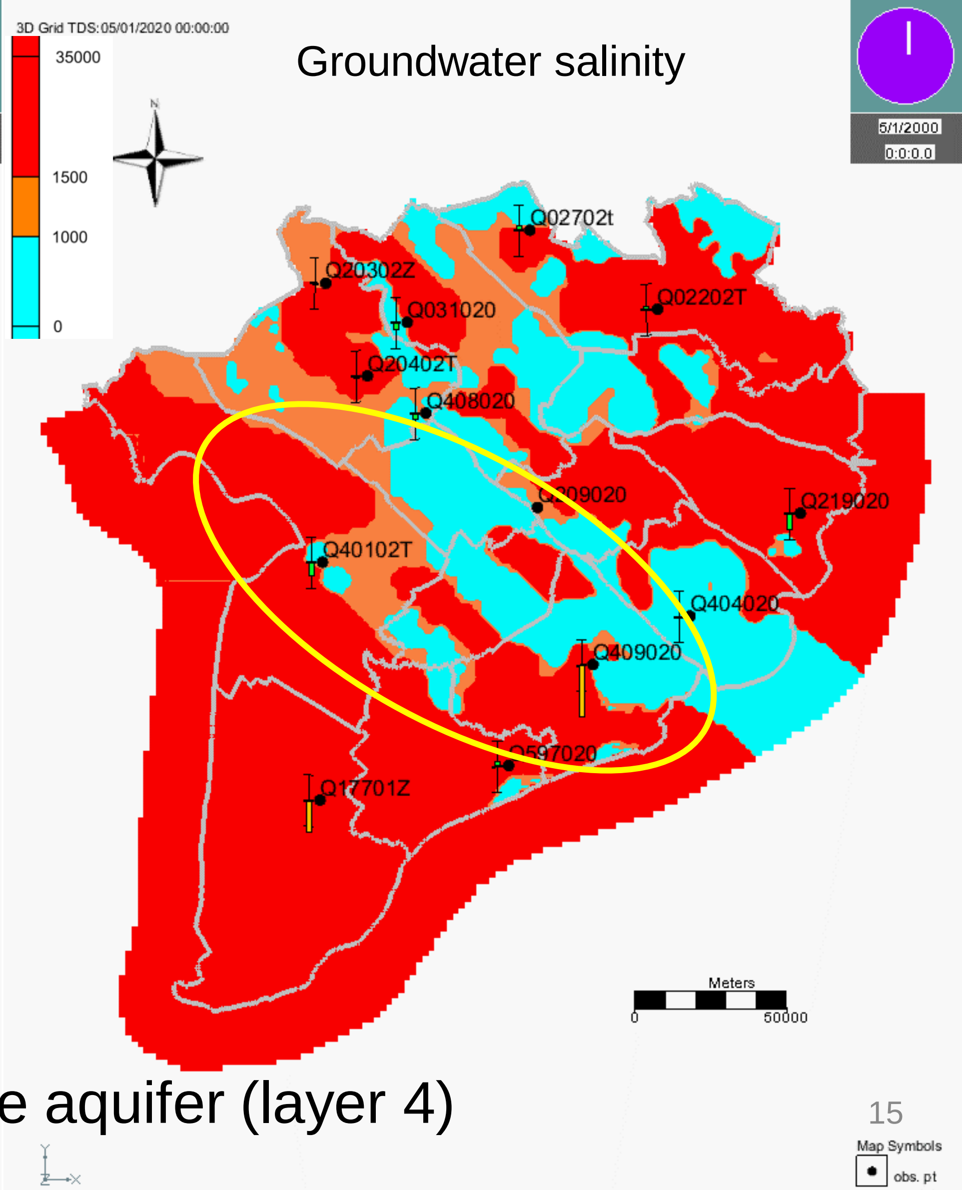


Fig 17. Obs vs. Sim time series



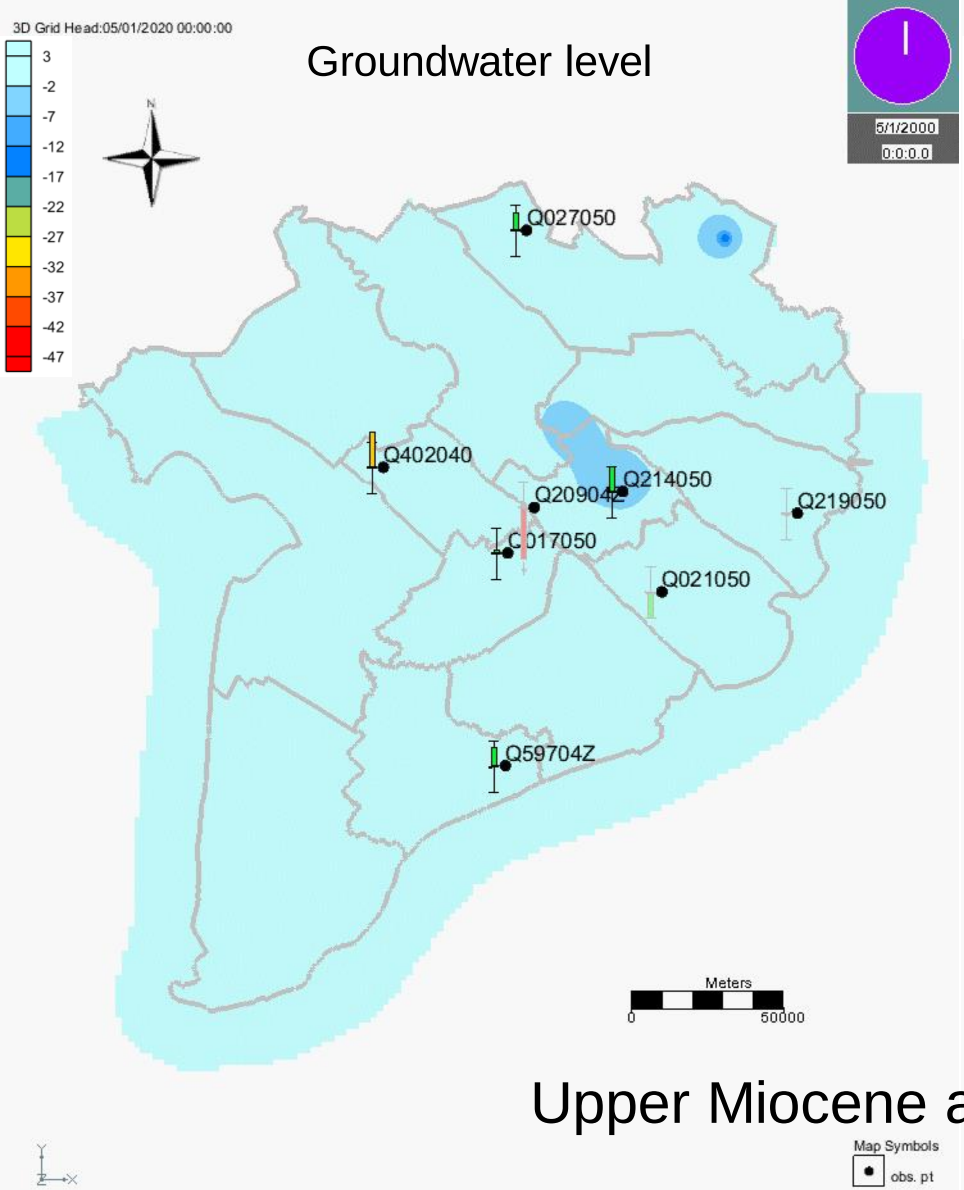
Groundwater level



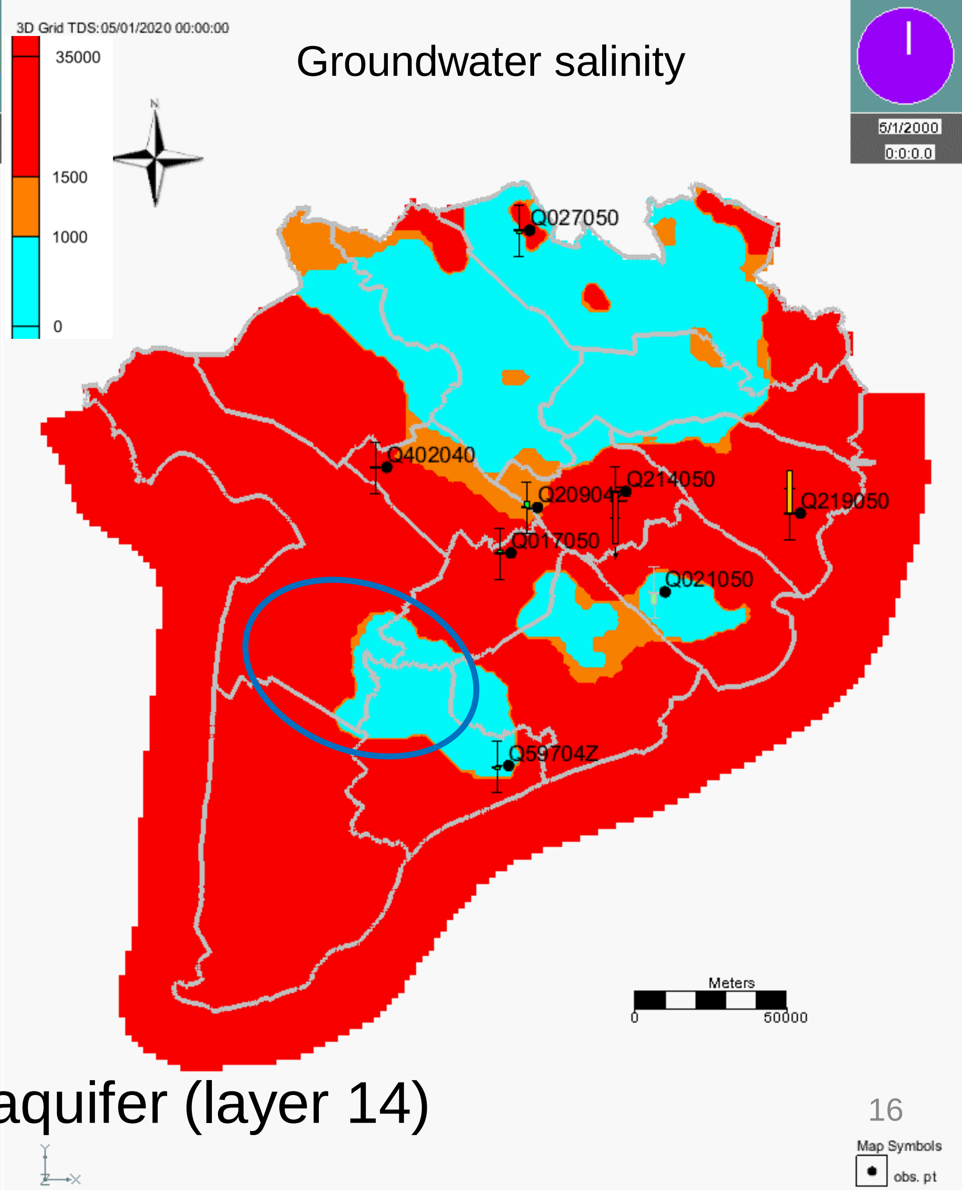
Groundwater salinity

Upper Pleistocene aquifer (layer 4)

Groundwater level



Groundwater salinity



Upper Miocene aquifer (layer 14)

Table 1. Predicted Groundwater level and Saltwater area

Aquifer	**2020**		**2050**		**2100**		**Salinized area (km^2)**
	Average GWL	Lowest GWL	Average GWL	Lowest GWL	Average GWL	Lowest GWL	
Holocene	0.57	-5.8	-0.03	-12.44	-1	-17.03	939
Upper Pleistocene	-3.29	-13.6	-5.34	-19	-6.79	-23.31	7,107
Upper- Middle Pleistocene	-4.86	-20.6	-7.92	-26.68	-9.62	-29.7	5,849
Lower Pleistocene	-4.64	-19.86	-5.68	-22.29	-5.96	-23.31	3,942
Middle Pliocene	-6.29	-24.18	-12.88	-26.77	-18.37	-37.96	954
Lower Pliocene	-7.21	-22.46	-12.42	-32.88	-13.33	-34.43	1,030
Upper Miocene	-8.44	-35.55	-13.77	-42.68	-14.79	-46.92	-43

5. CONCLUSIONS

❖ Groundwater model was developed and calibrated

Flow model (NSE > 0.95; RMSE < 1m)
Salinity model (NSE > 0.85; RMSE < 3 g/l)

+ reasonable scenario → Forecast groundwater level and salinity

❖ **Forecast**

- **Groundwater level**: continue to drop; deeper aquifers - greater decline.

  In 2100, the lowest GWL being -47 m in the Upper Miocene aquifer in Tien Giang.

- **Groundwater salinity**: significant in shallow aquifers.

  7100 km^2 freshwater will become saline water - upper Pleistocene aquifer.

→ An effective groundwater management strategy is necessary.

Thank You!
Q&A

Groundwater flow equation

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

Where:

x, y, z is Cartesian coordinate axis (L),

K_{xx}, K_{yy}, K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes (L/T) in anisotropic conditions,

h is the potentiometric head (L) at location x, y, z and time t,

t is time (T),

Q_s is a volumetric flux per unit volume representing sources and sinks of water, negative for flow out of the groundwater system, and positive for flow into the system (T^{-1}),

S_S is the specific storage of the porous material (L^{-1}).

Solute transport equation

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial \mathrm{C}}{\partial x_j}\right)-\frac{\partial}{\partial x_i}v_i\mathrm{C}+\frac{q_s}{n}\mathrm{C}_s=\frac{\partial \mathrm{C}}{\partial t}$$

Where:

x_i and x_j is the distance along the respective Cartesian coordinate axis (L),

n is effective porosity or volume of water content (-),

D_{ij} is the dispersion coefficient tensor (L^2/T),

C is the dissolved concentration (M/L^3)

v_i is the linear pore water velocity (L/T),

q_s is the volumetric flow rate per unit volume representing sources or sinks (1/T),

C_s is the source or sink concentration (M/L^3),

t is time (T).

Variable-density groundwater flow

$$
\begin{aligned}
&\frac{\partial}{\partial x}\left[\rho K_{fx}\left(\frac{\partial h_f}{\partial x}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\rho K_{fy}\left(\frac{\partial h_f}{\partial y}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial y}\right)\right]\\
&\frac{\partial}{\partial z}\left[\rho K_{fz}\left(\frac{\partial h_f}{\partial z}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial z}\right)\right]=\rho S_s\frac{\partial h_f}{\partial t}+\theta\frac{\partial \rho}{\partial C}\frac{\partial C}{\partial t}-\rho_s q_s
\end{aligned}
$$

Where:

x, y, z is coordinate direction,

K_{fx}, K_{fy}, K_{fz} are the hydraulic conductivities along the x, y, z direction, respectively (LT^{-1}),

h_f is is equivalent freshwater head (L),

ρ is the density of saline groundwater at a point in an aquifer (ML^{-3}),

ρ_f is the density of freshwater (ML^{-3}),

Z is elevation (L),

S_s is specific storage in terms of the freshwater head (L^{-1}),

t is time (T),

θ is effective porosity of material (-),

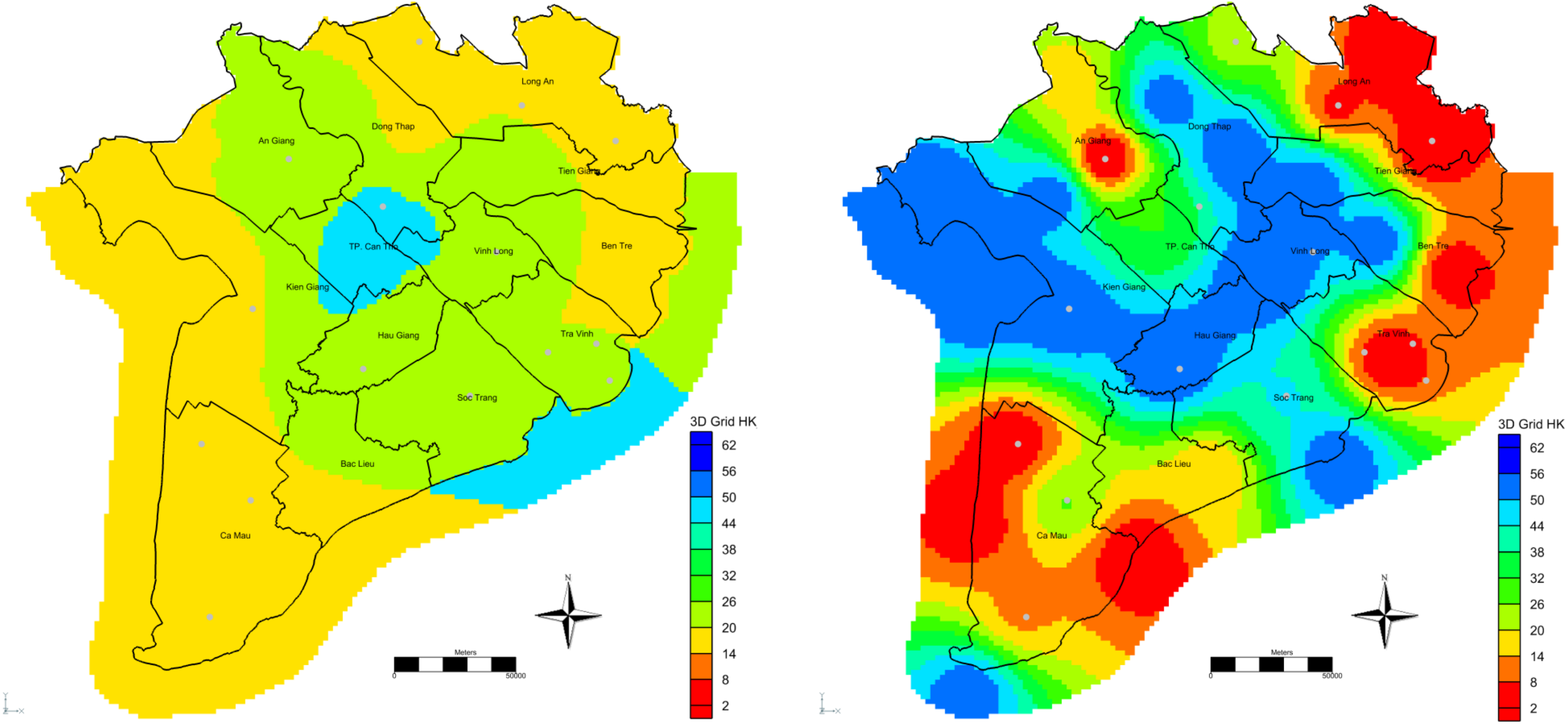
C is solute concentration (ML^{-3}),

ρ_s is density of entering or leaving water from source and sink (ML^{-3}),

q_s is volumetric flow rate per unit volume of aquifer representing sources and sinks (T^{-1}).

Table 1. groundwater level and Saltwater area statistics

Aquifer	2020		2050		2100		Salinized area (km^2)
	Average GWL	Lowest GWL	Average GWL	Lowest GWL	Average GWL	Lowest GWL	
Holocene	0.57	-5.8	-0.03	-12.44	-1	-17.03	939
Upper Pleistocene	-3.29	-13.6	-5.34	-19	-6.79	-23.31	7,107
Upper- Middle Pleistocene	-4.86	-20.6	-7.92	-26.68	-9.62	-29.7	5,849
Lower Pleistocene	-4.64	-19.86	-5.68	-22.29	-5.96	-23.31	3,942
Middle Pliocene	-6.29	-24.18	-12.88	-26.77	-18.37	-37.96	954
Lower Pliocene	-7.21	-22.46	-12.42	-32.88	-13.33	-34.43	1,030
Upper Miocene	-8.44	-35.55	-13.77	-42.68	-14.79	-46.92	-43



(a). Before calibration

(b). After calibration

Fig. Hydraulic conductivity before and after calibration