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Groundwater modeling for sustainable groundwater utilization in Mekong delta

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18th December, 2019

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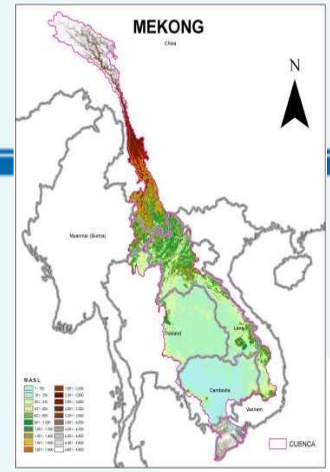
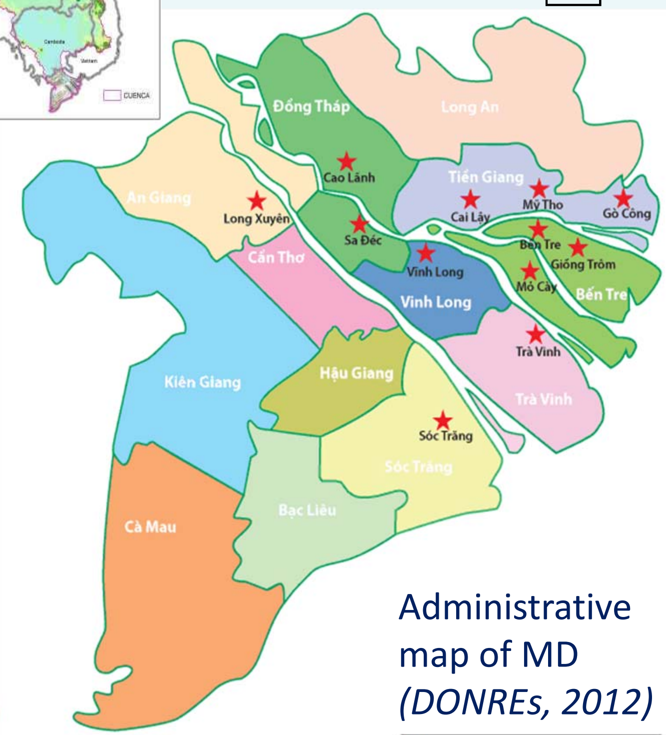
1. Introduction

- MD is one of the most vulnerable regions in the world under impacts of climate change and sea level rise.
- Stress on freshwater demand in MD:
  - Water shortage and drought in dry season
  - Population → high water demand

⇒ GW use has been increasing due to relative stabilization of quality and quantity.



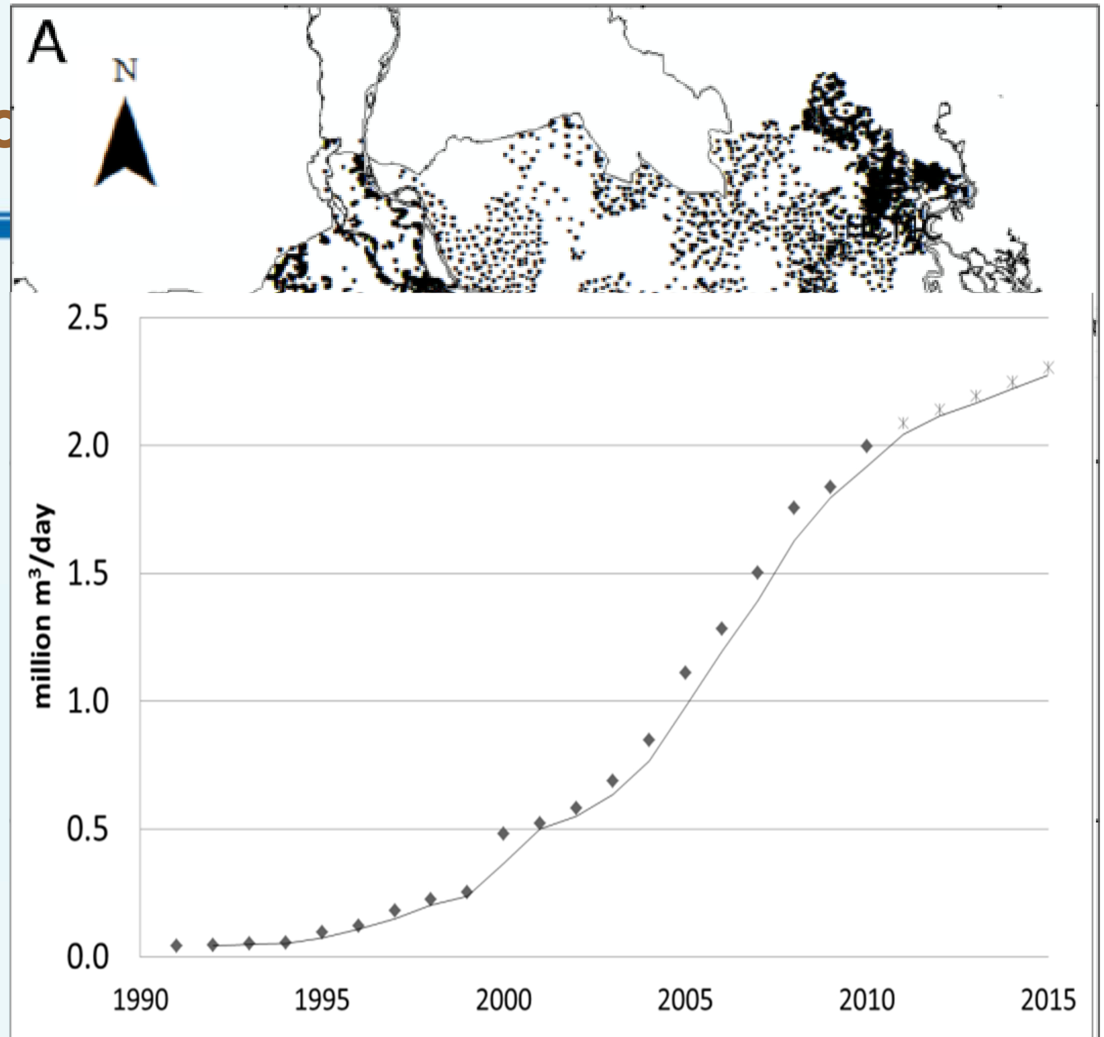


Administrative map of MD *(DONREs, 2012)*

1. Introduction (co

- GW use in MD:
  - A million extraction wells with depth 10 - 300 m *(MONRE, 2011)*
  - Strongly extracted in coastal areas of MD *(DWRPIS, 2013)*
  - More than 2 million m^3/day *(Minderhoud, 2016)* mainly used for aquaculture, agriculture, domestic water supply

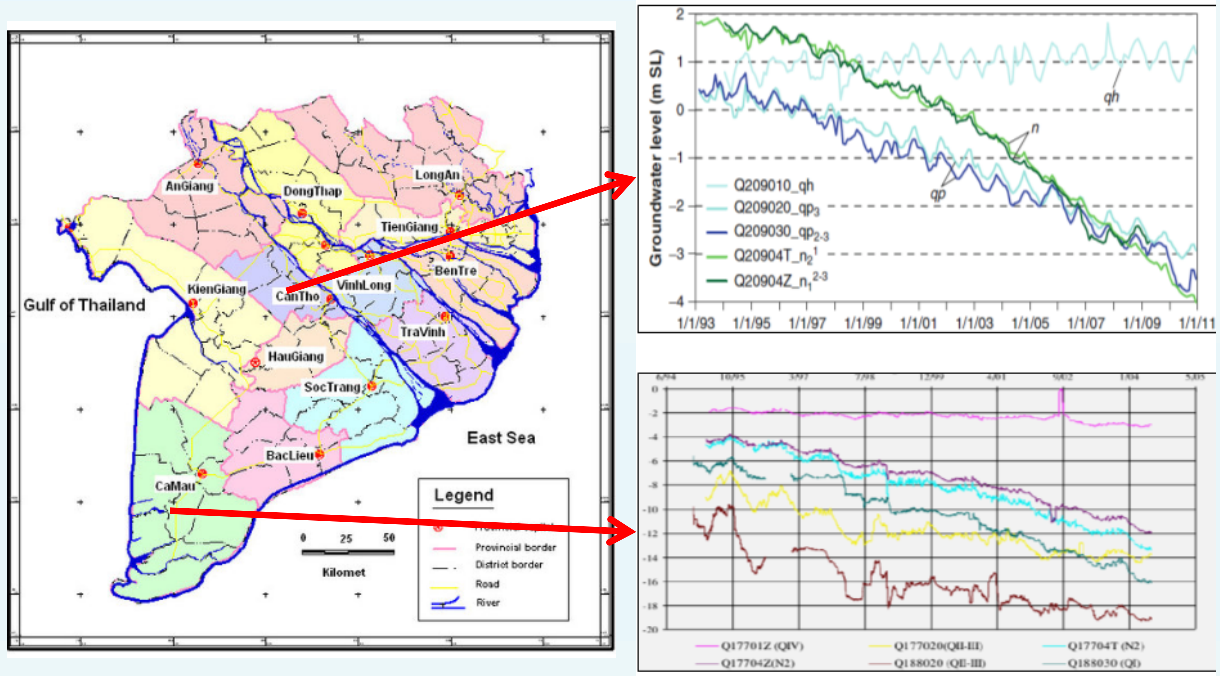
⇒ enhancing management on GW is needed



Estimated groundwater extraction in the Mekong delta

1. Introduction (cont.)

- Problems on GW use:
  - Decline in GW levels & degradation in GW quality in some urban and coastal areas of MD
  - Land subsidence caused by the decline of GW levels
  - The possible climate change will affect the GW system ultimately



Decline in GW level in urban and coastal area (DWRPIS, 2013)

⇒ need to develop an assessment tool for GW modelling to reach the sustainable GW utililization.

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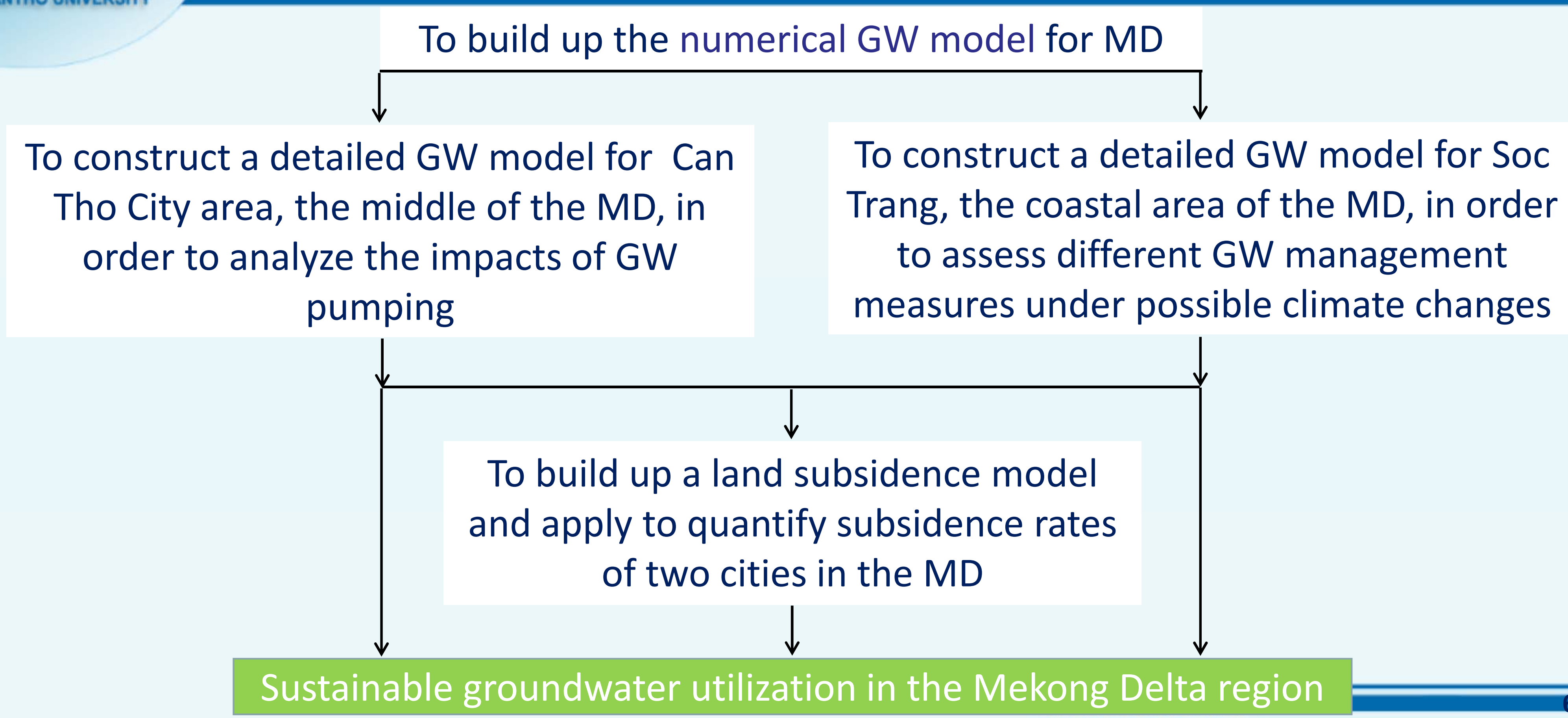
1. Introduction (cont.)



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2. The numerical GW model for MD

- The groundwater modeling of entire MD was developed to advance the methods and approach used for:
  - Flexibility to generate high resolution model grids everywhere when needed
  - Flexibility to use /start with a coarser model grid
  - Reasonable runtimes / high performance computing
  - Provision of the boundary conditions for the successive detailed modeling

⇒ stands for **I**nteractive **MOD**eling and a developing software based upon the concept of MODFLOW (USGS), made by Deltares in 2009

  - User-friendly interface, GW flow models in many scales
  - High-resolution 3D MODFLOW groundwater computations

2. The numerical GW model for MD (cont.)

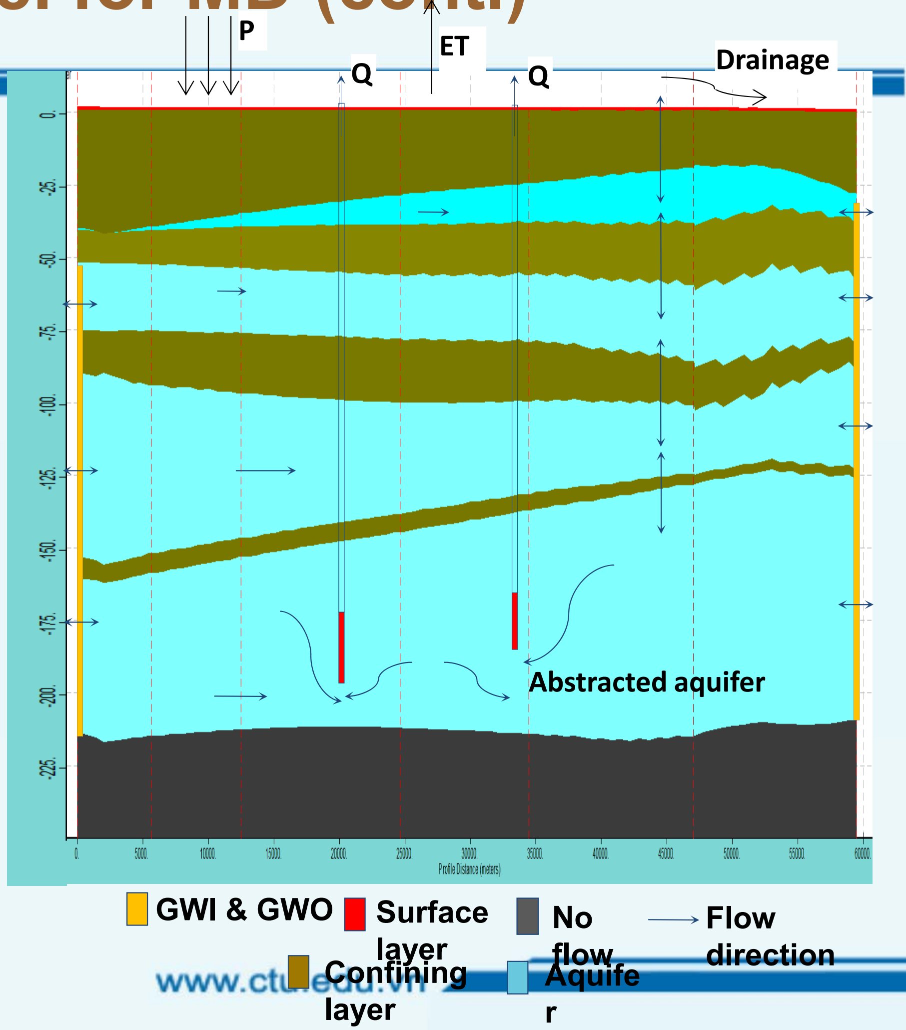
- The groundwater balance:

(GWI + P + RR + DP) – (GWO + Q + D + SPD + ET) = Δ GWS

Positive: GWI is the GW inflow; LR is the recharge from local rainfall; RR is the recharge from the Rivers; DP is the deep percolation from the upper system.

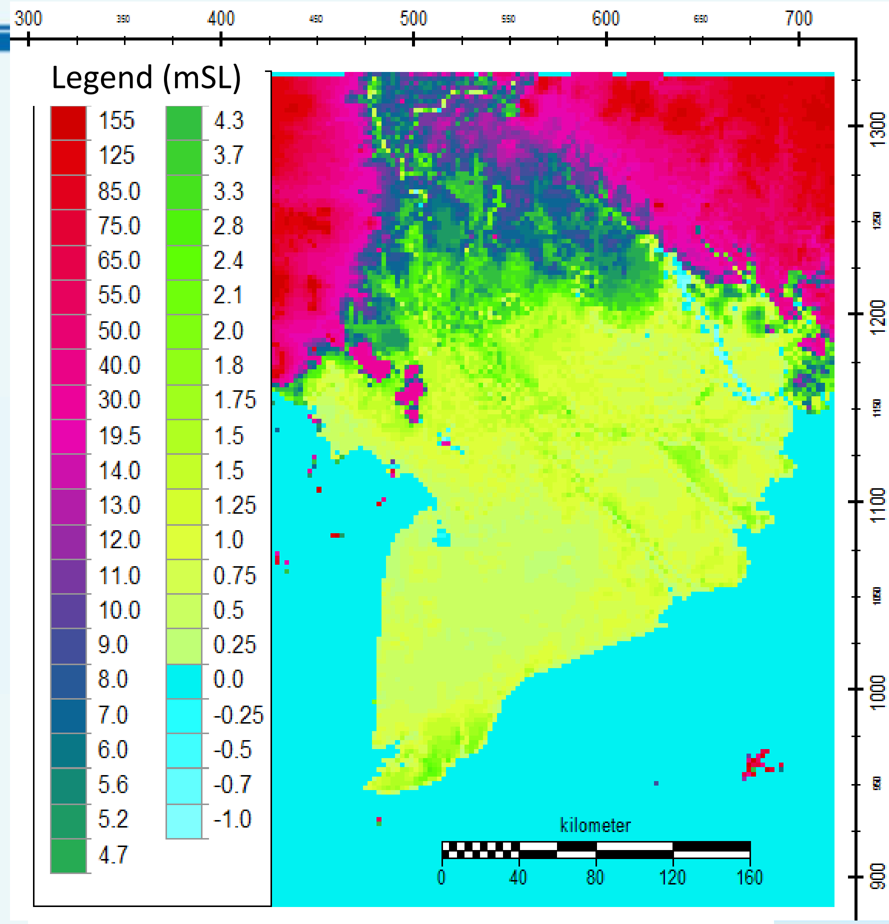
Negative: GWO is the GW outflow; Q is actual GW pumpage (exploitation); D is surface drainage; ET is the evapo-transpiration losses.

Δ GWS is the change in GW storage



2. The numerical GW model for MD (cont.)

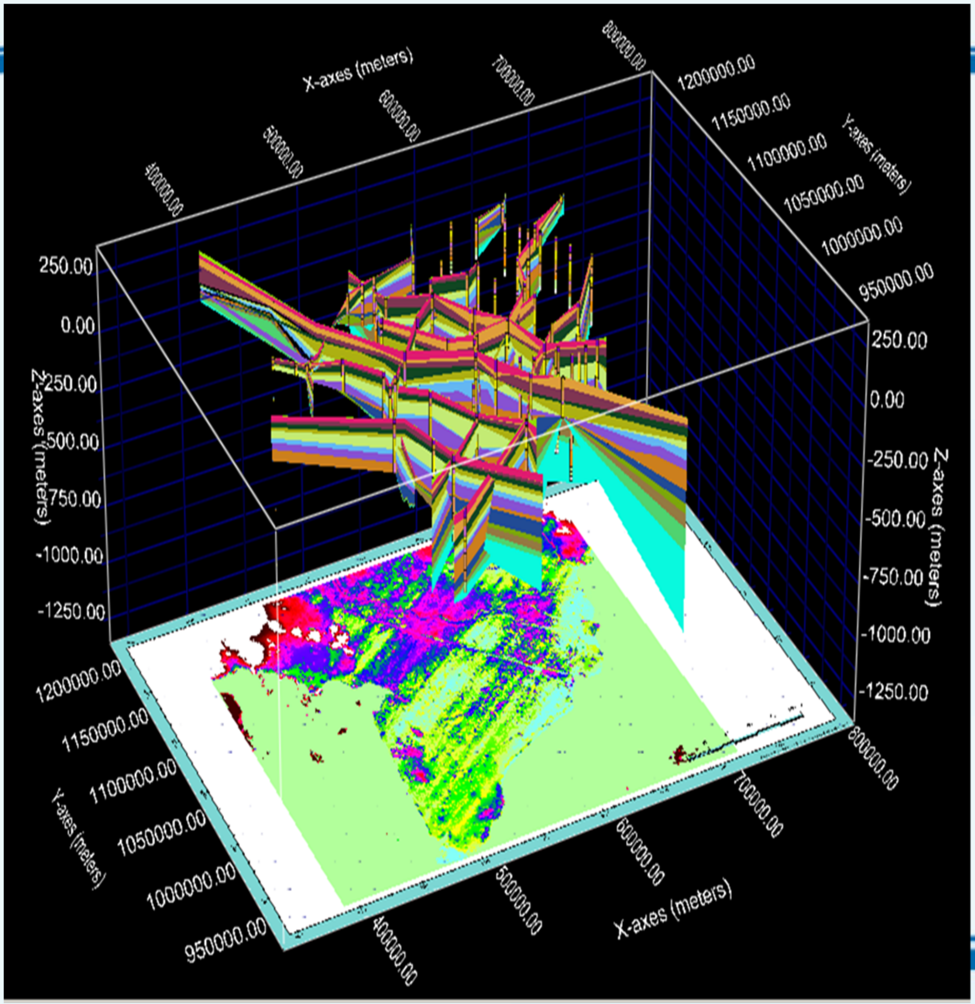
- Digital elevation map:
  - DEM on resolution of 90 m x 90 m was set up
  - Identifying the top of the hydrological system and the drainage levels



DEM of Mekong Delta (Sources from DWRPIS)

2. The numerical GW model for MD (cont.)

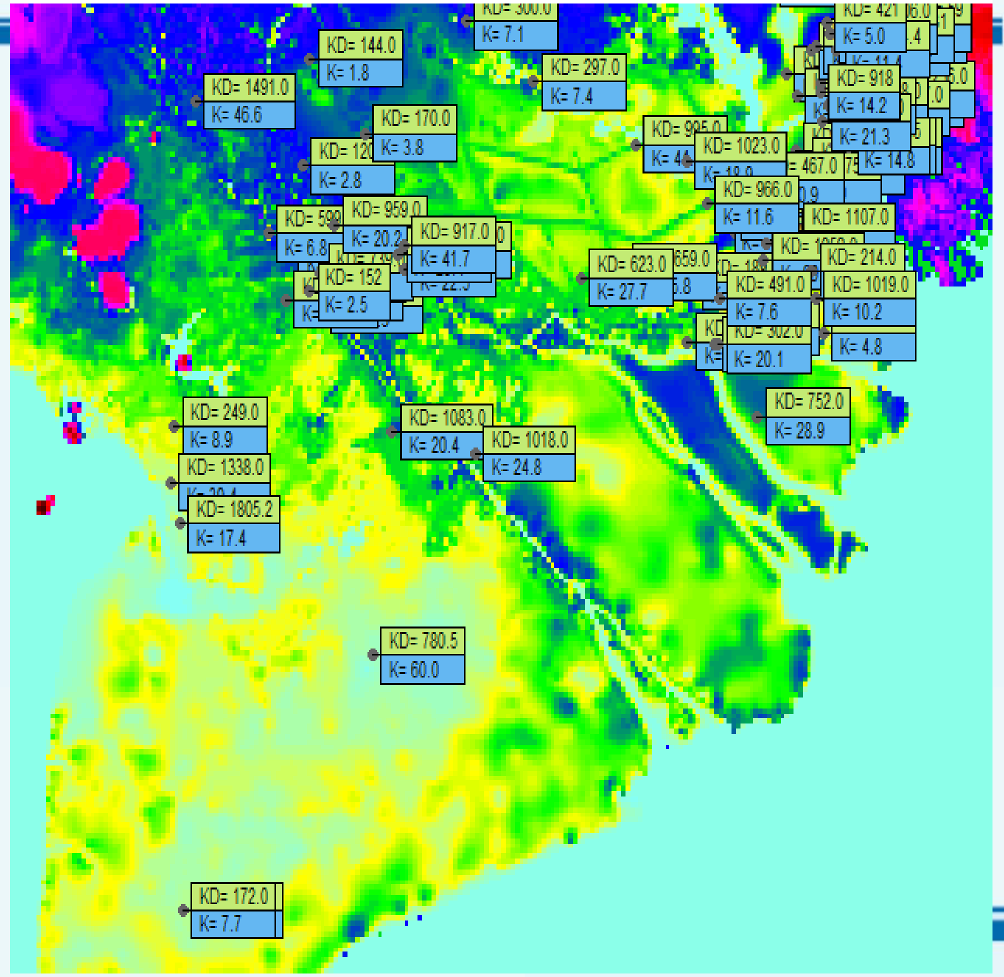
- Hydro-geological structure:
  - 9 cross-sections was built from a total of 95 boreholes
  - Hydro-geological profiles were set up by interpolation



Boreholes structure & Constructed Hydro-geological profiles

2. The numerical GW model for MD (cont.)

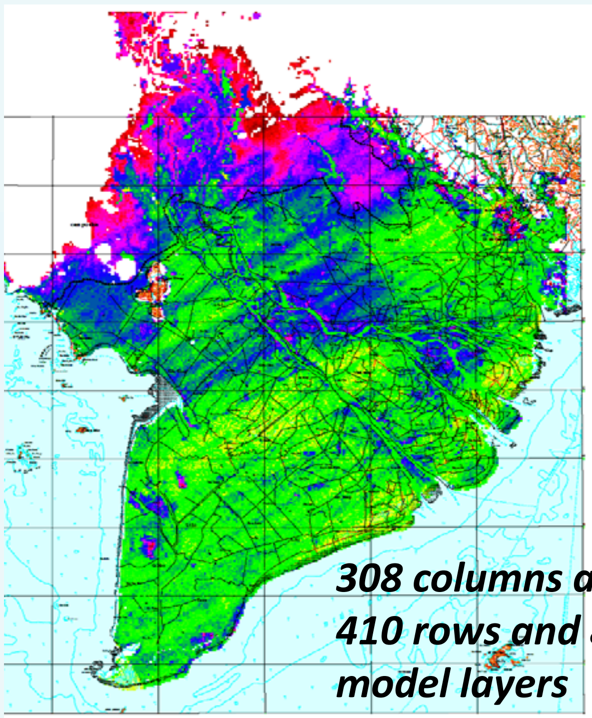
- Hydraulic conductivity:
  - Conductivities (Kh, Kv), storage coefficient (S) were determined by pumping tests method
  - Interpolated layer permeability from pumping test points were used to input the permeability field for aquifers



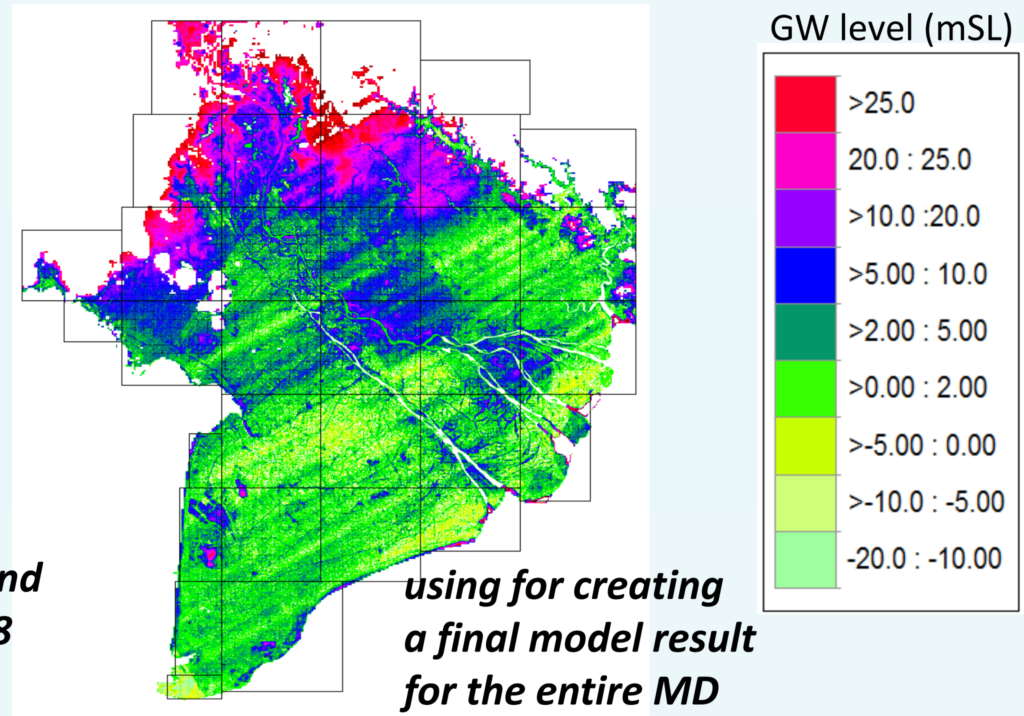
Kd =Kh (m/d),
K = Kv (m/d)

2. The numerical GW model for MD (cont.)

- Results of steady state simulation



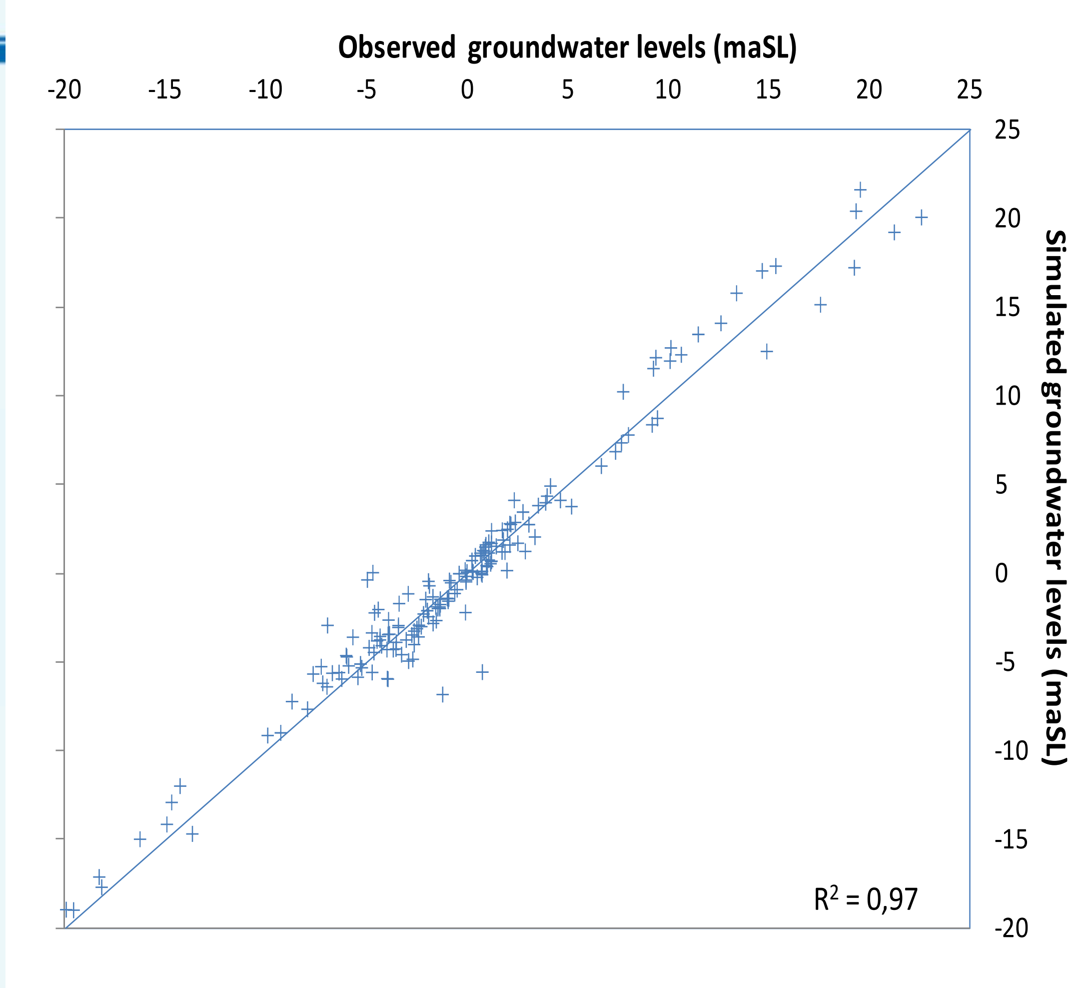
308 columns and 410 rows and 8 model layers (1,000 x 1,000 m)



using for creating a final model result for the entire MD at (100 x 100 m)

2. The numerical GW model for MD (cont.)

- Model evaluation:
  - Calibration target is the observed groundwater levels at 168 monitoring wells whole MD in December, 2011
  - Model showed fairly good agreement between simulated values and the observed values



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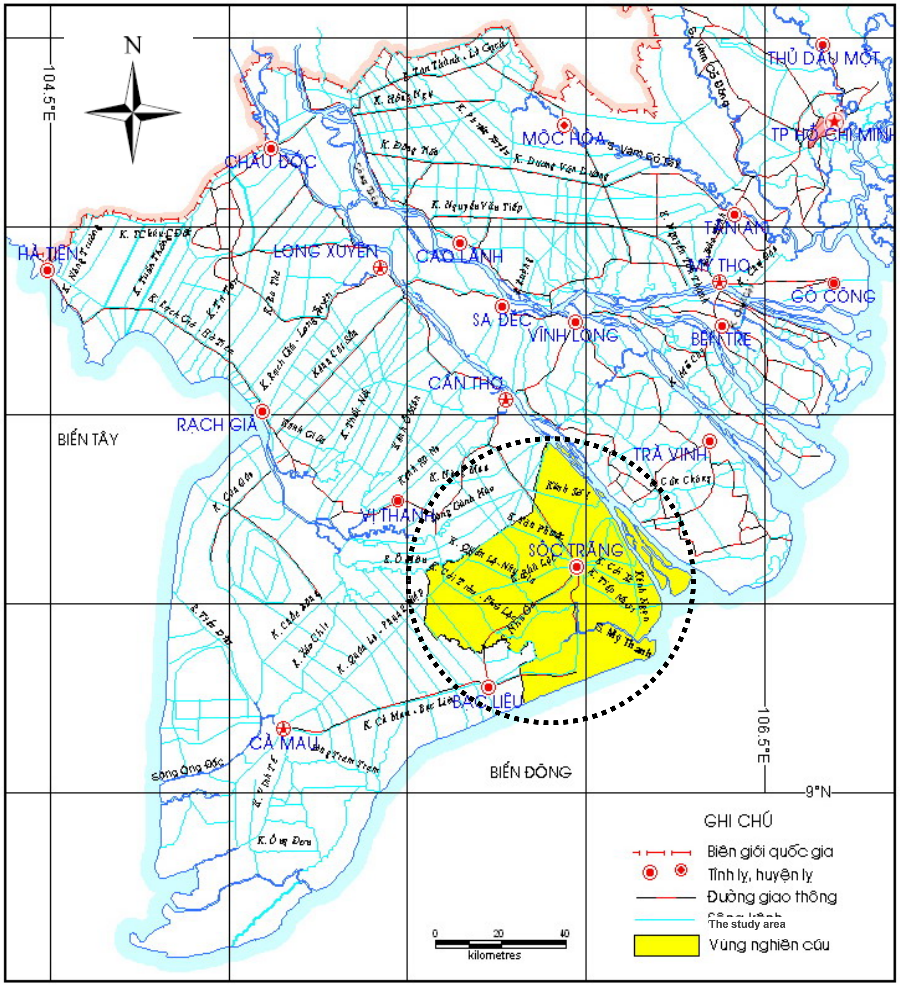
2. The numerical GW model for MD (cont.)

- Disscussion:
  - Flexible to use/ start with a coarser model grid for generating high resolution model grids in any small/interested region
  - Appropriate model which can provide initial & boundary condition in any interested case study within MD region
- Conclusion:
  - A GW model for MD region was calibrated which can be used for multi-grid scale
  - The detailed structure of MD model was built by updating the model inputs
- However, the additional information and new data are required for updating of the model on regular basis

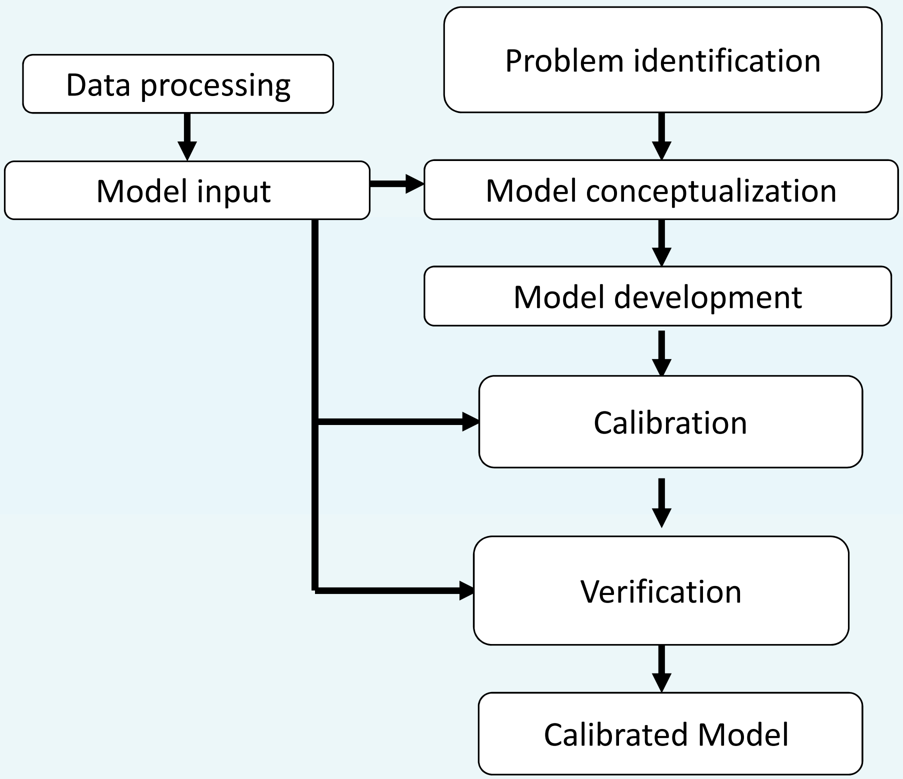
3. Assess different GW management measure

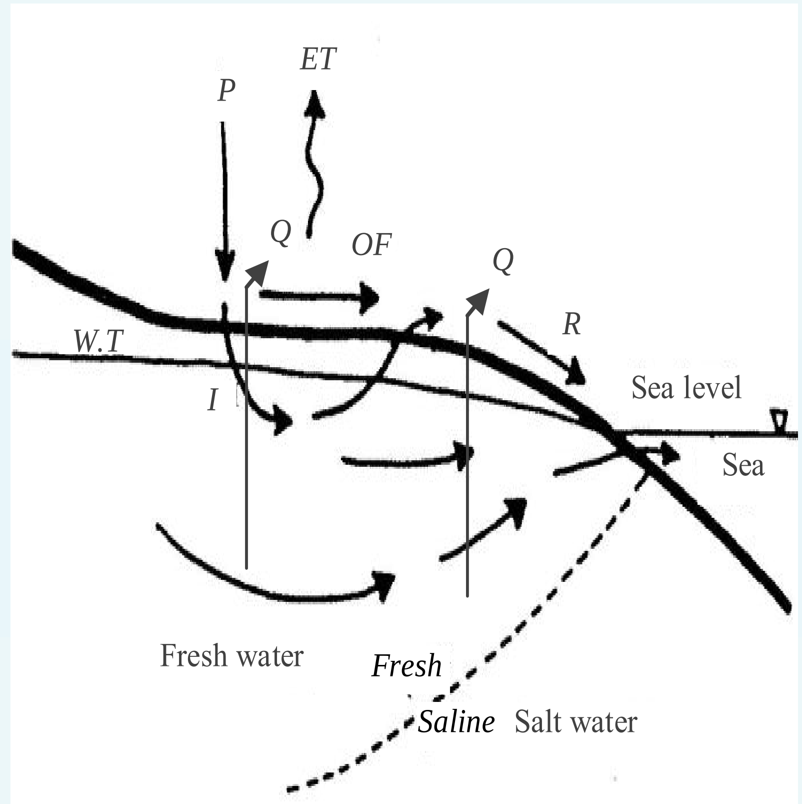
- Study area: Soc Trang province
  - GW is dominant source of freshwater
  - Rapid increase in GW use for the recent 10 years
- Objective:
  - To build up the GW model for long-term simulation
  - To simulate aquifer responses to different GW management measures and the future changes in climatic conditions for assessing appropriate GW management



3. Assess different GW management measure (cont.)

- Model building

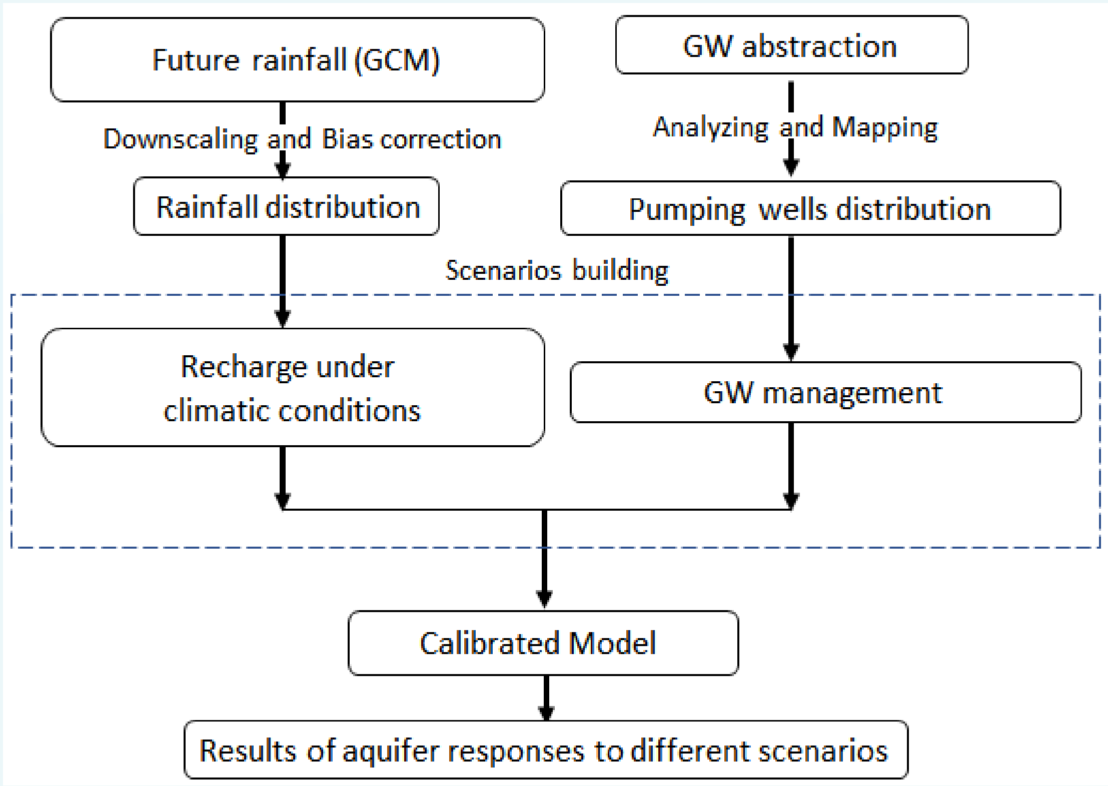




Simplified conceptual model of hydro-geologic system of the study area

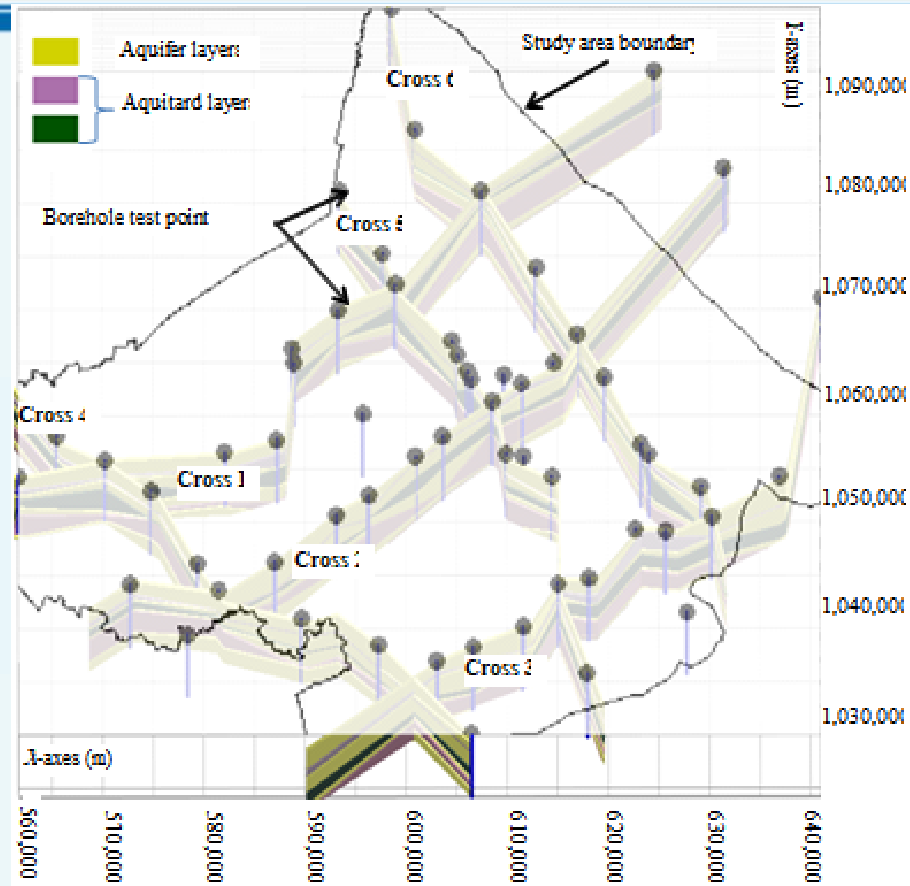
3. Assess different GW management measure (cont.)

- Model application for scenario simulation



3. Assess different GW management measure (cont.)

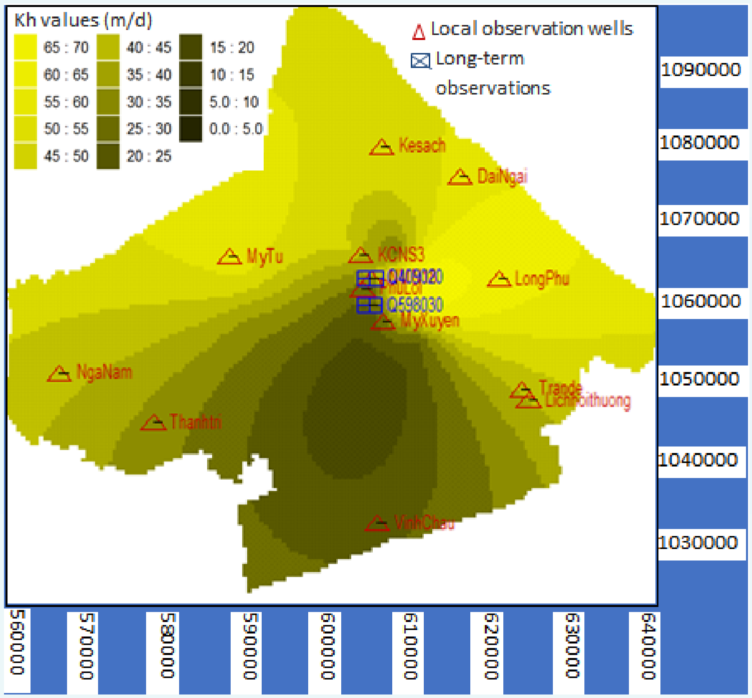
- Model input: hydro-geological profile
  - Most of the abstraction depths of the wells are from 80 m to 120 m → 100 m aquifer
  - The GW system from surface to 100-meter was divided into two main aquifers
  - 6 hydro-geological profiles were built by data of more than 60 boreholes test points



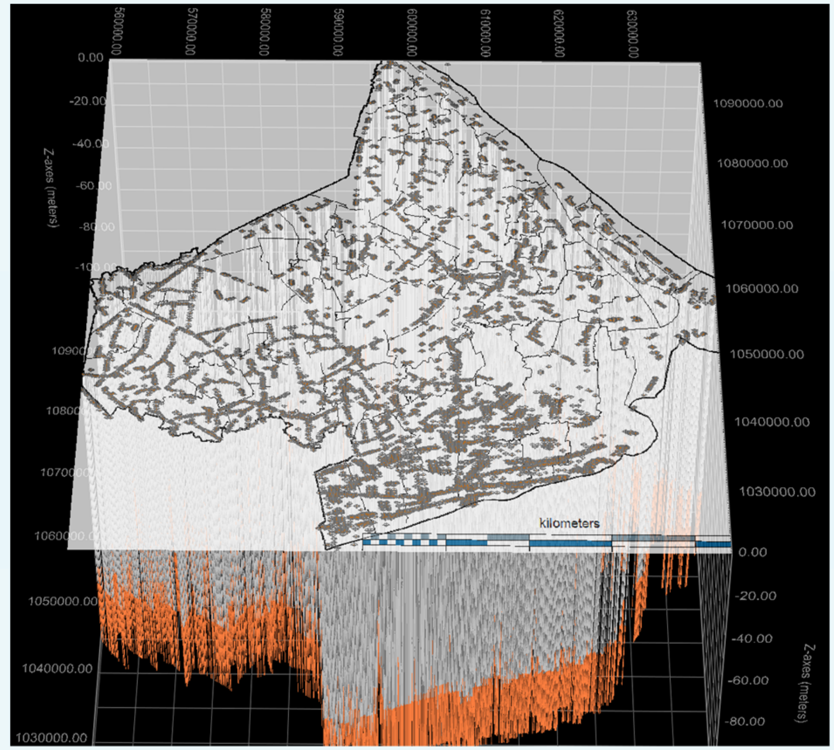
Constructed hydro-geological profiles for model input

3. Assess different GW management measure (cont.)

- Model input



The optimized hydraulic conductivity values (m/d) through the 9 monitored wells points



Complied extraction wells package for study area (> 8500 wells)

3. Assess different GW management measure (cont.)

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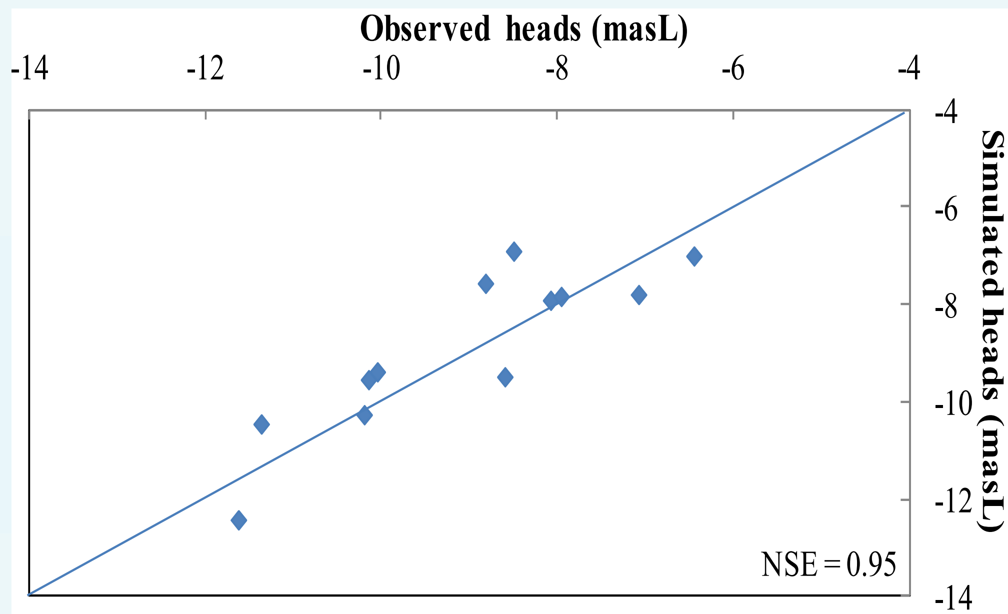
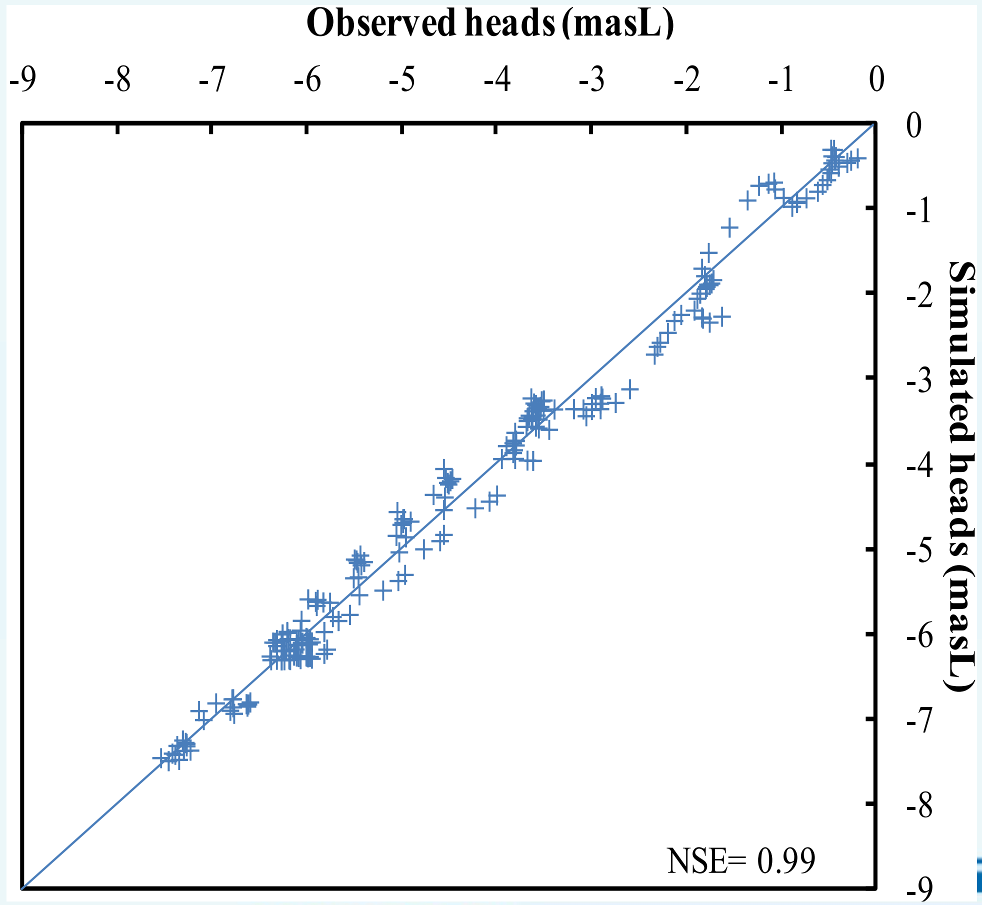
- Simulation results: 1st simulation with 12 observation wells on Dec 2013
  - GW level ranges from -4.0 to -12.0 (mSL)
  - Two areas of serious GW decline: Soc Trang city and Vinh Chau district
  - Good arrangement → initial condition for GW model management in future



3. Assess different GW management measure (cont.)

- Simulation results: 2nd simulation with 12 observation wells in long-term transition in 1994 - 2014 (monthly time series)
  - The trend of GW drawdown for the past decades
  - Fairly good matching & consistency with observations



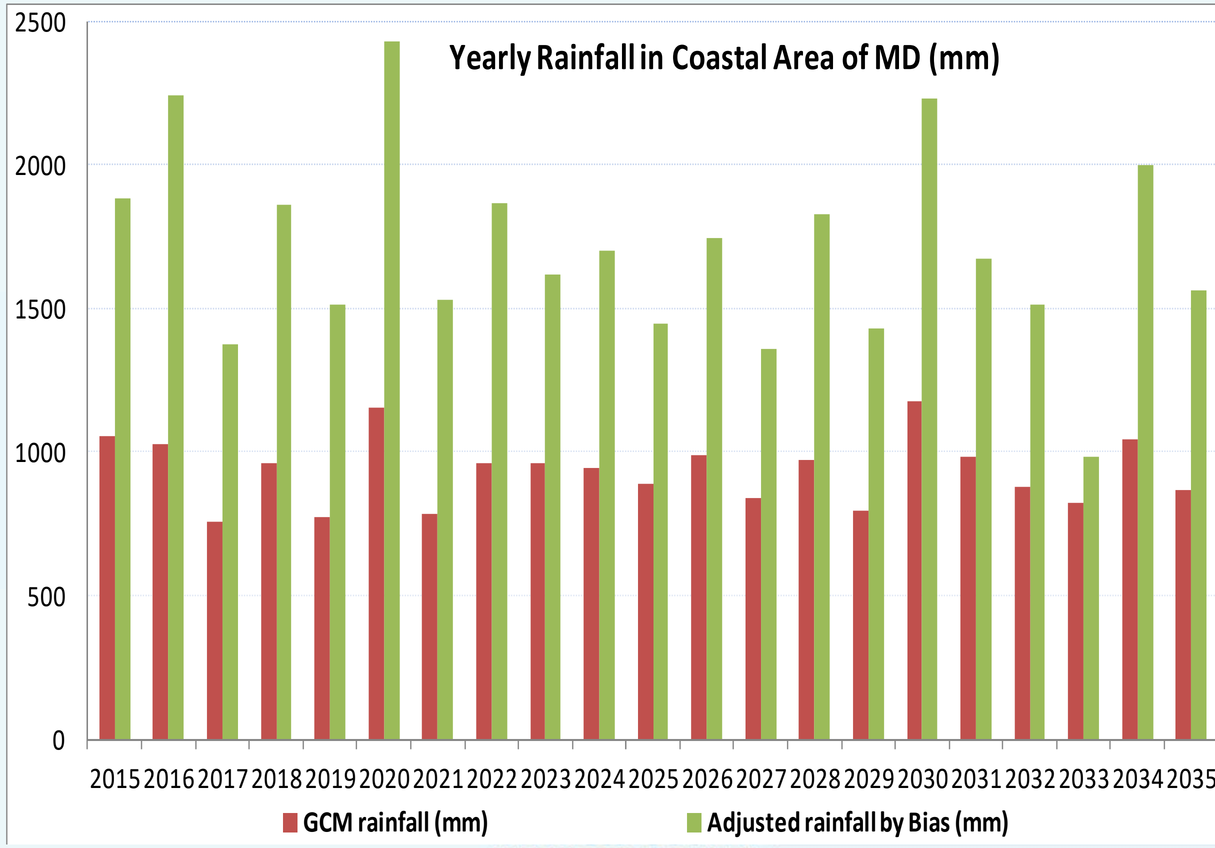
3. Assess different GW management measure (cont.)

- Model application: scenarios building

Scenario	Driver	Assumption
	Management options	**GW abstraction**
1	Baseline situation	Abstraction is maintained
2	Increased supply	Increasing of 1.8% per year (based on current trend)
3	Conservative policies	Reducing of 1% per year (recommended)
Scenario	**Driver**	**Assumption**
	Future climatic conditions	**Recharge by rainfall**
A	Current rainfall condition (mm)	Recharge by rainfall of 21 year period (1994 - 2014)
B	Future rainfall condition (mm)	Recharge by future rainfall (GCM) for period 2015 - 2035
C	Minor dry condition	Reduction in recharge by 5% loss of future rainfall
D	Major dry condition	Reduction in recharge by 15% loss of future rainfall

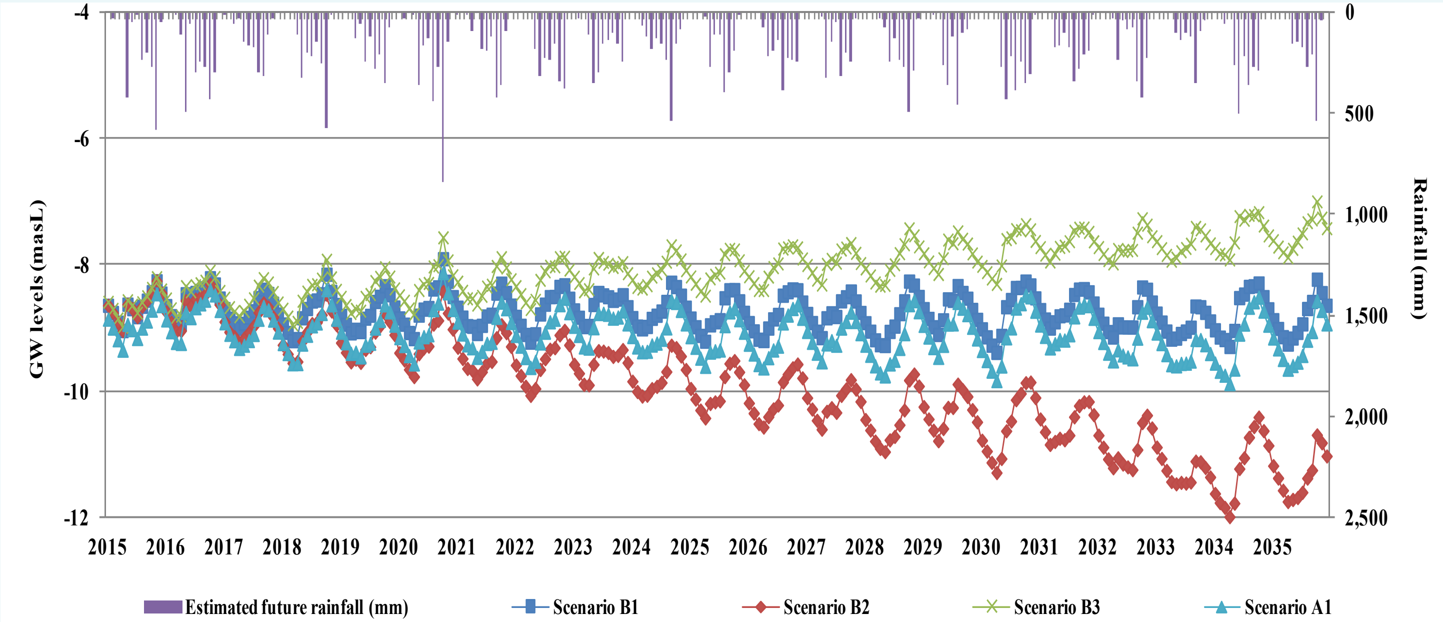
3. Assess different GW management measure (cont.)

- Future climate condition:
  - Rainfall:
    - 1706 mm/year in average
    - Increase in rainy season from June to November, vice versa
  - Recharge:
    - Ranges from 0.01 mm/d to 1 mm/d *(Boehmer, 2000)*
    - Not only influenced by rainfall loss (evaporation, overflow and runoff) but also long dry spell period
    - 0.62 mm/d in average (Korkmaz method)



3. Assess different GW management measure (cont.)

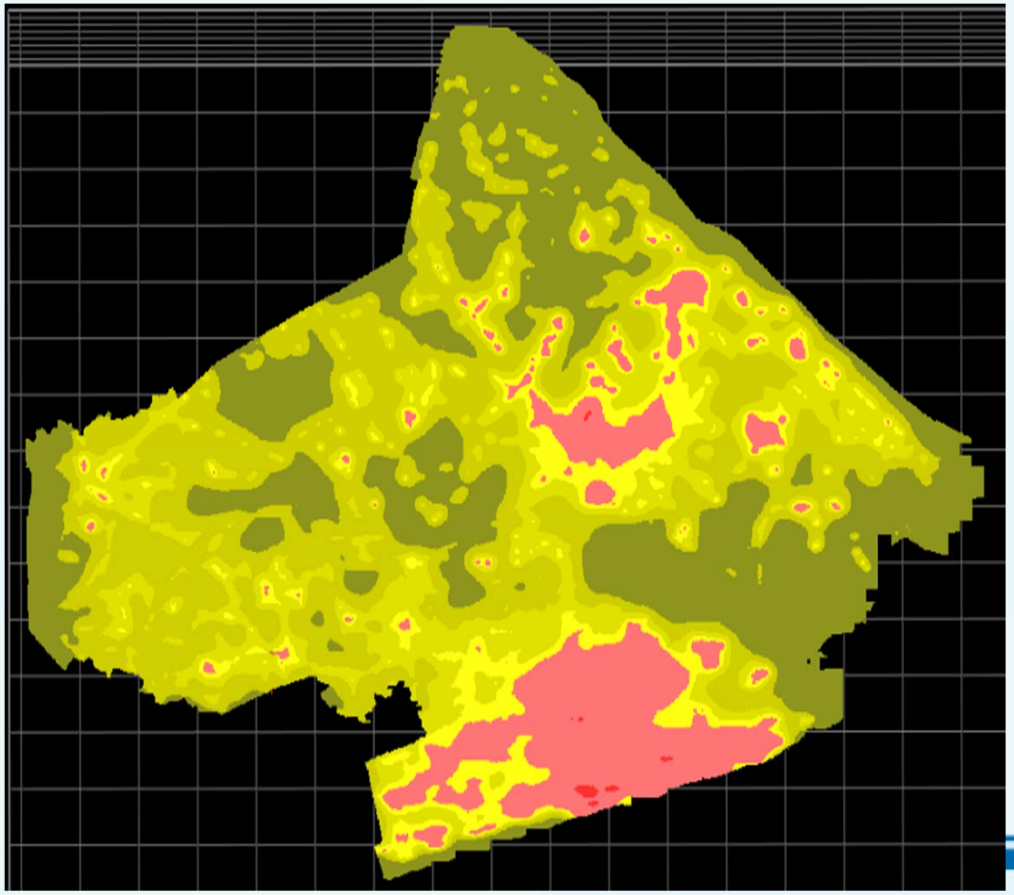
- Simulation of aquifer response to scenarios



A1: light decline of GW heads was recognized, GW level decline by ~ 0.05 m/yr
B1 (current pumping): GW levels mostly stabilized for the whole period
B2 (1.8% increase pumping): significant decline in GW levels in simulation period
B3 (1% decrease in pumping): GW could recover up 1.0 - 1.5 m

3. Assess different GW management measure (cont.)

- Simulation results
  - Risk scenarios
    - C2 (increased GW abstraction under minor reduction in recharge): an intense and continuing decline of the GW heads to -14 m
    - D2 (increased GW abstraction under major reduction in recharge): significant depletion of the GW aquifer appear in most of the area by 2035
  - Conservative scenarios
    - D3 (reduced pumping in major reduction in recharge): GW levels could recover to higher levels than the current aquifer

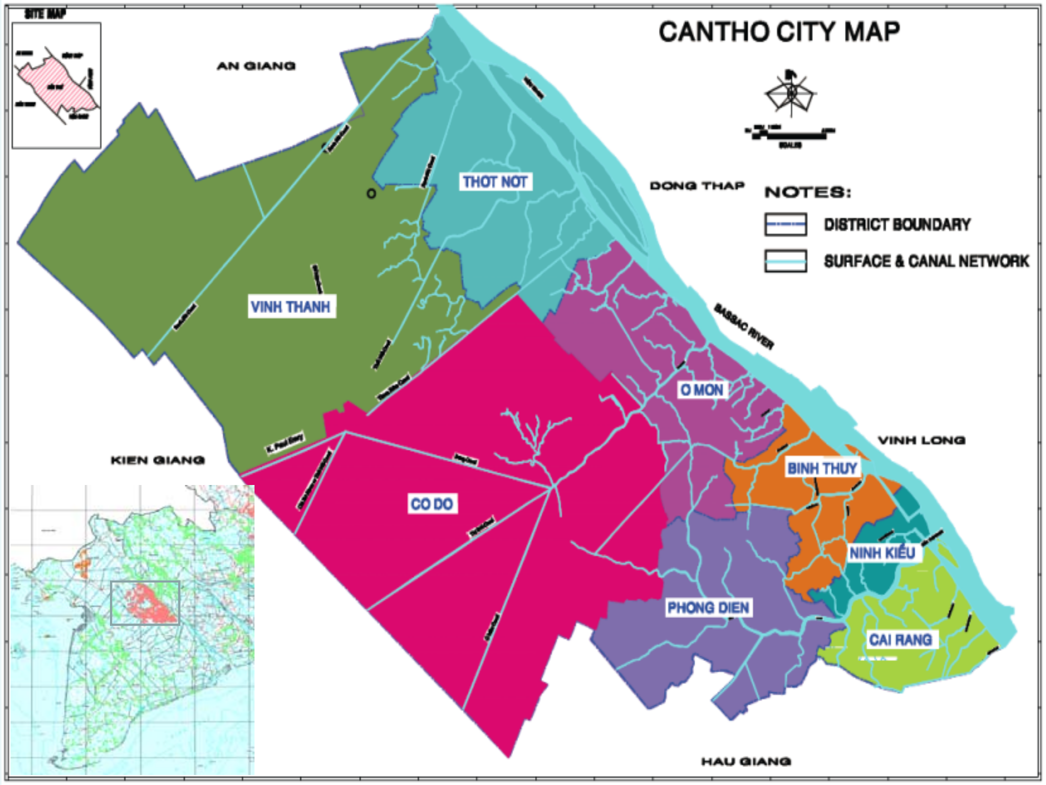


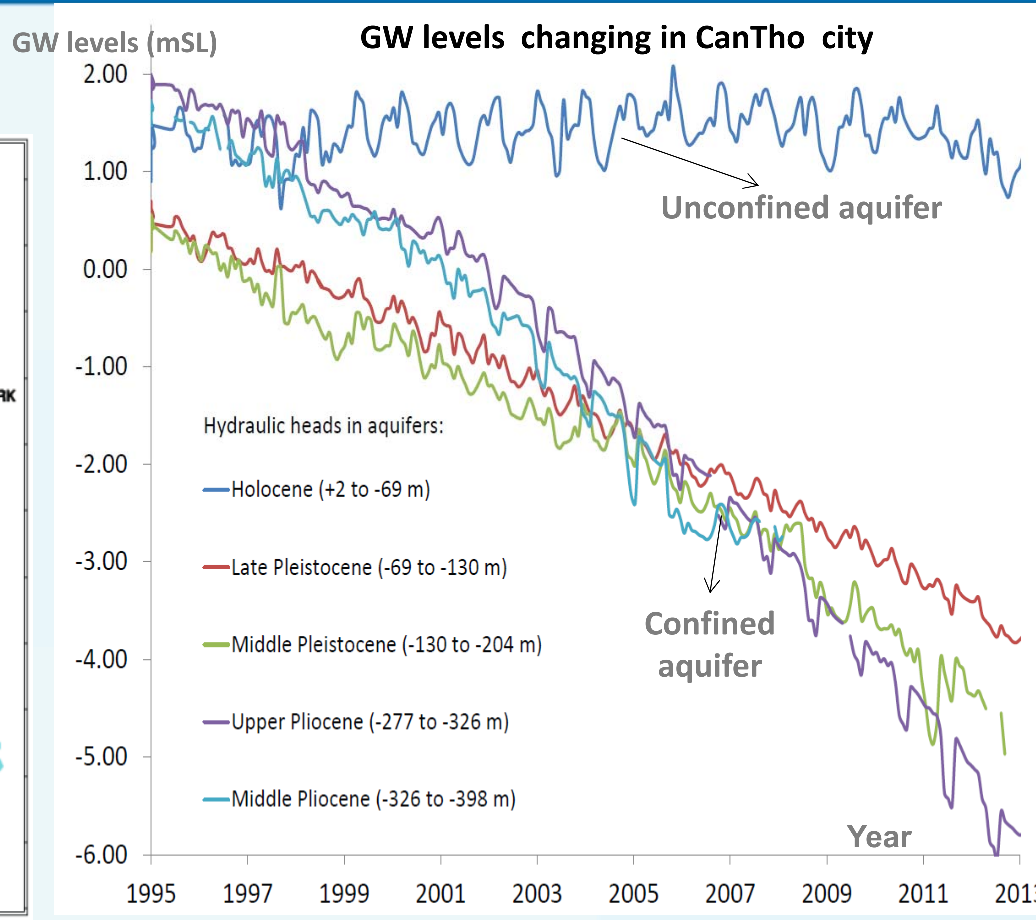
3. Assess different GW management measure (cont.)

- Conclusion:
  - A calibrated groundwater model was established and applied for the simulations of the GW flow for the coastal area of MD
  - It was confirmed that the calibrated model could work properly to reproduce the distribution of the GW table and its response
  - Predicted groundwater situations and its responses relates to climatic conditions and the amount of pumpage were achieved by model application

4. Analyse the impact of GW pumping

- Study area



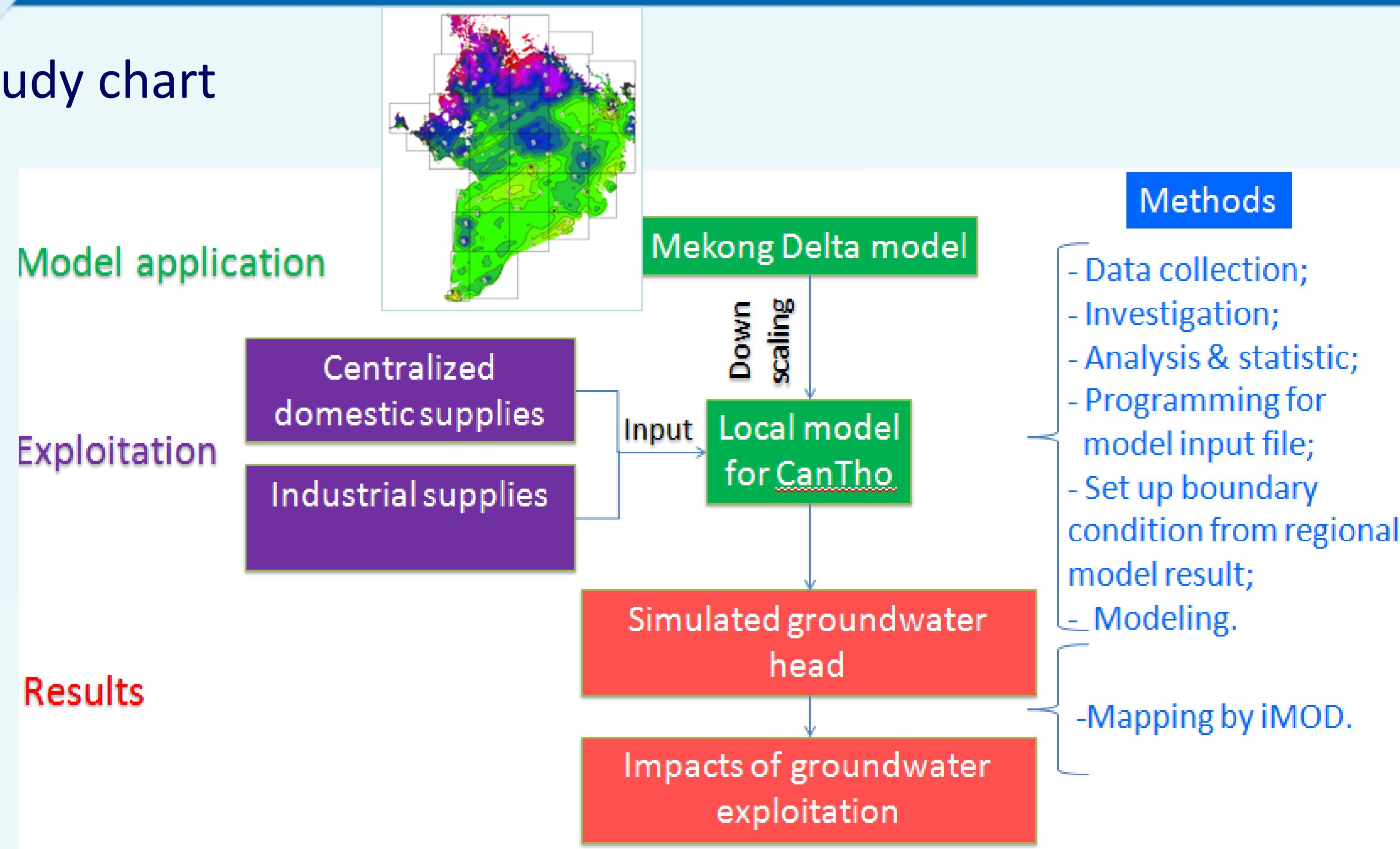


4. Analyse the impact of GW pumping (cont.)

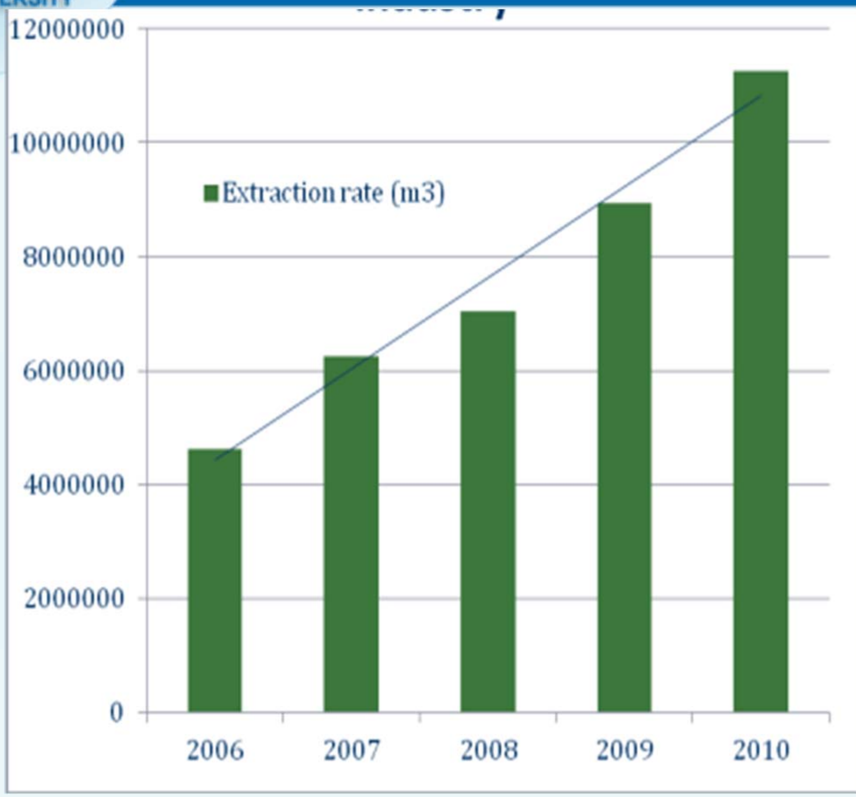
- Study objectives
  - To build up the groundwater model for CanTho city
  - To simulate the groundwater head distribution under current pumping
  - To predict the groundwater decline based on the trend of increased pumping until 2035
  - To evaluate the formation process of cones of depression under current and increased pumping operation on groundwater resources

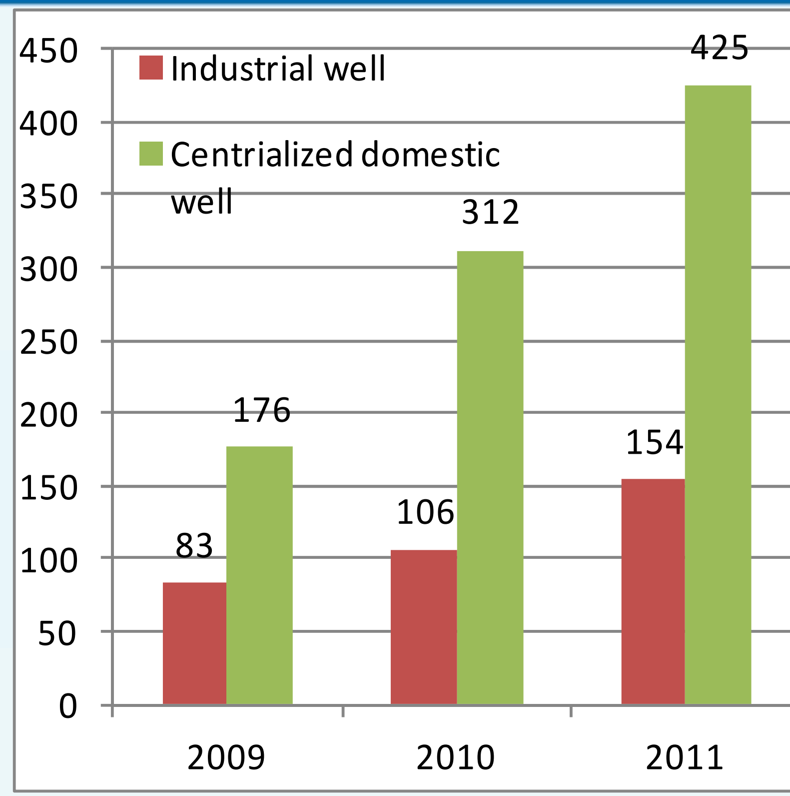
4. Analyse the impact of GW pumping (cont.)

- Study chart



4. Analyse the impact of GW pumping (cont.)

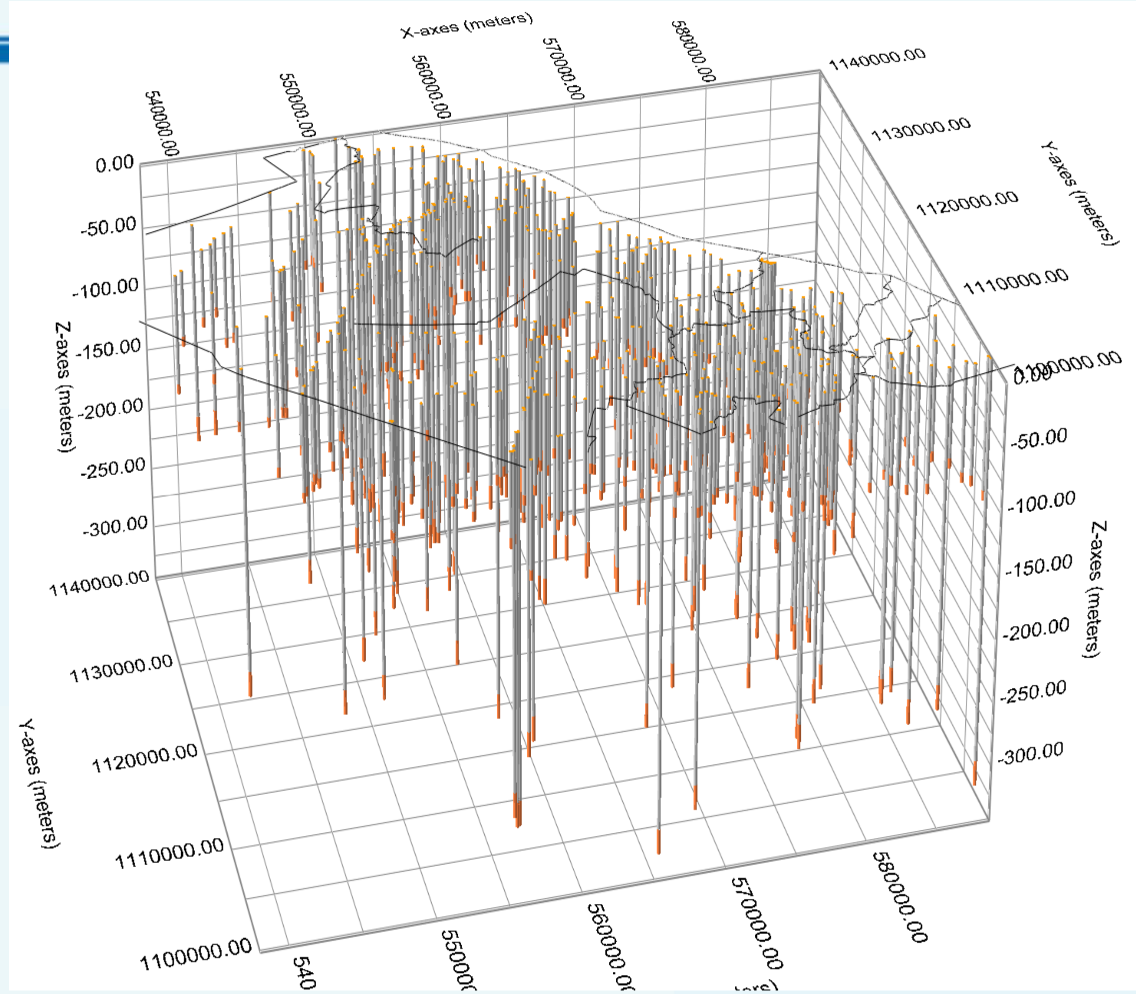




Trend of GW demand for industry and domestic use *(Can Tho city's CRWS, 2012)*

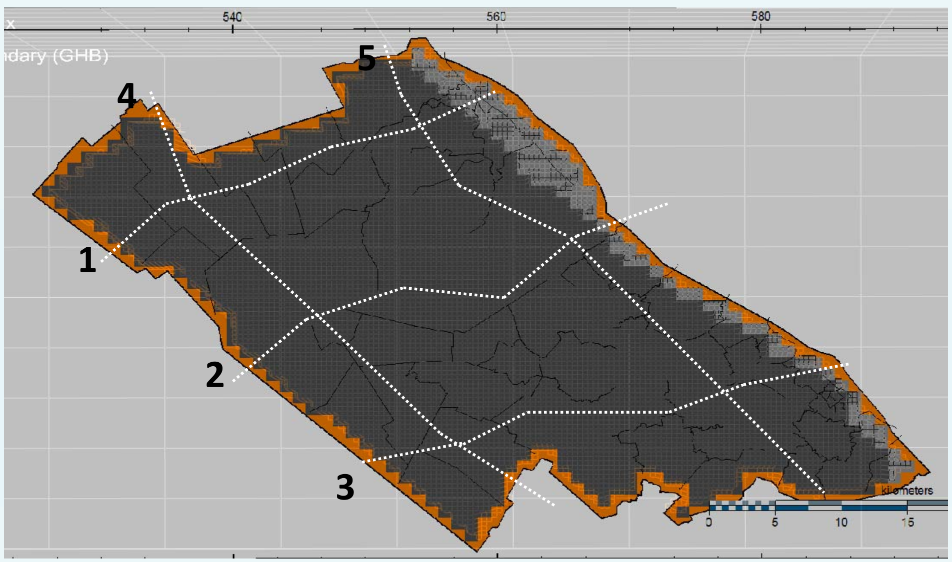
4. Analyse the impact of GW pumping (cont.)

- GW pumping:
  - Almost of pumping wells are at -80 m to -200 m where called Pleistocene aquifer (-50 m to -300 m)
  - A total of 579 pumping wells at Pleistocene aquifer was complied as a well package inputs



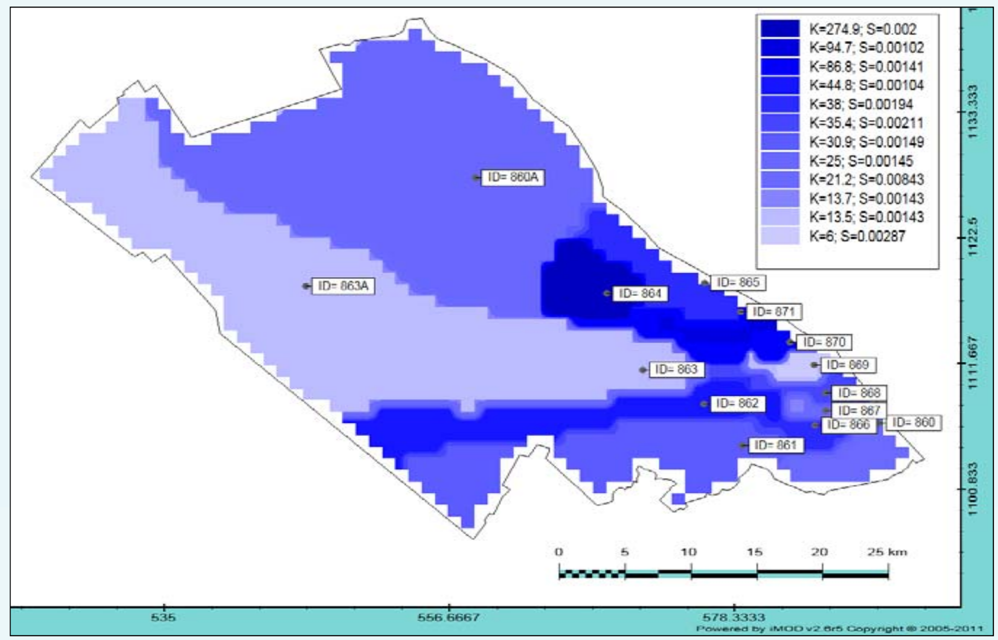
4. Analyse the impact of GW pumping (cont.)

- Model input



GW head boundary | **Head dependent flux** | **Specified head** | **Cross sections**

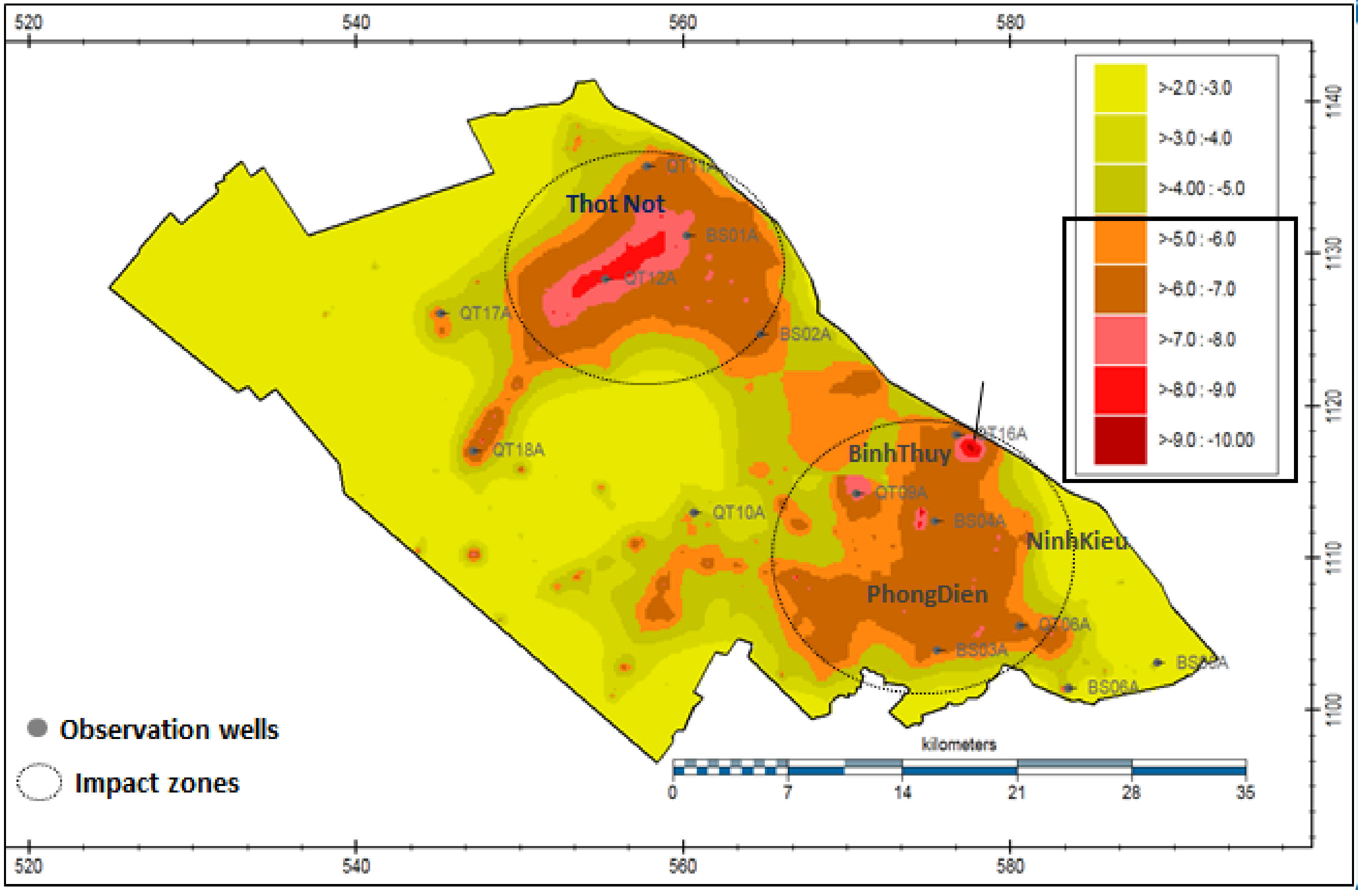
Model boundary



Hydraulic conductivity

4. Analyse the impact of GW pumping (cont.)

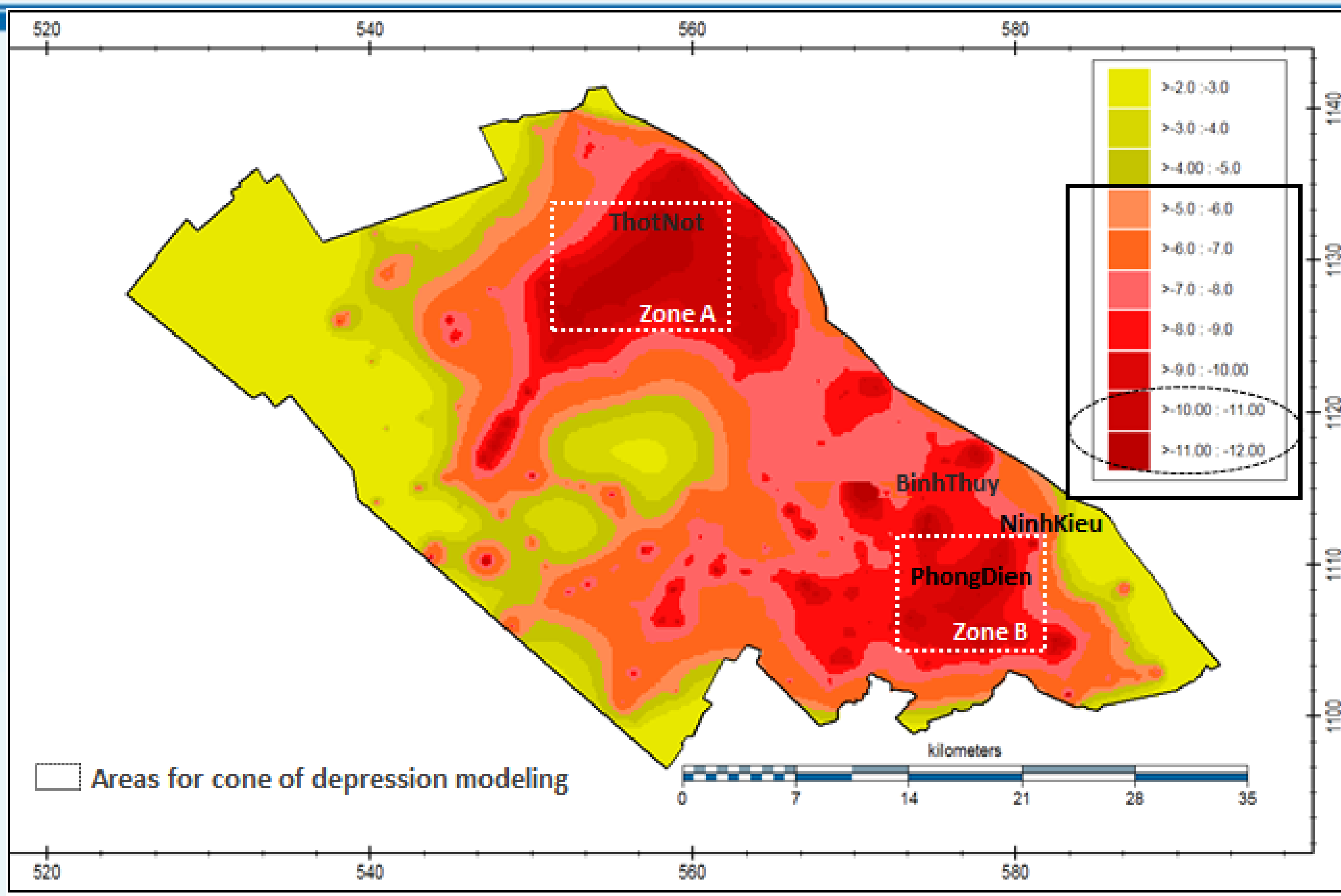
- Simulation results: impact by current pumping
  - GW level of 1/2 area of the city is lower 5 m depth due to pumping impact
  - Two areas are distinctive in GW drawdown



Spatial distribution of GW heads (maSL) under current pumping in the city

4. Analyse the impact of GW pumping (cont.)

- Increasing of GW pumping 2 times for domestic, 1.5 times for industry in 2035
  - GW decline 2 m more (average)
  - Resulting in > 2/3 area (lower 5 m depth of GW) of city aquifer



Spatial distribution of GW heads under increased pumping in the future

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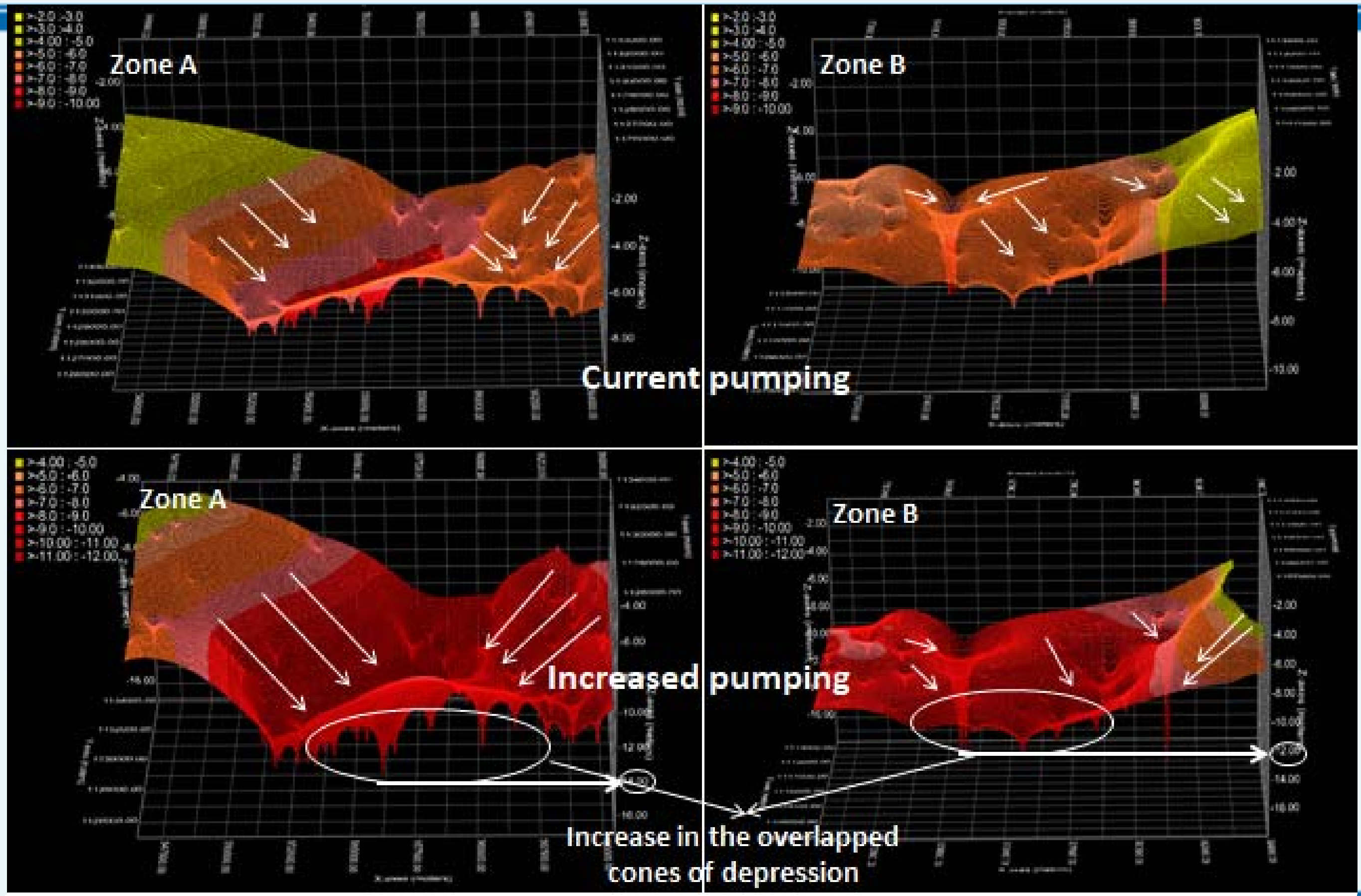
4. Analyse the impact of GW pumping (cont.)

- Formation cones of depression:
  - Difficult to manage: reduces the water available to each well and can cause drying up wells
  - Forming vulnerable zones of land subsidence



Formed cones of depression 3D-simulation at current and increased pumping

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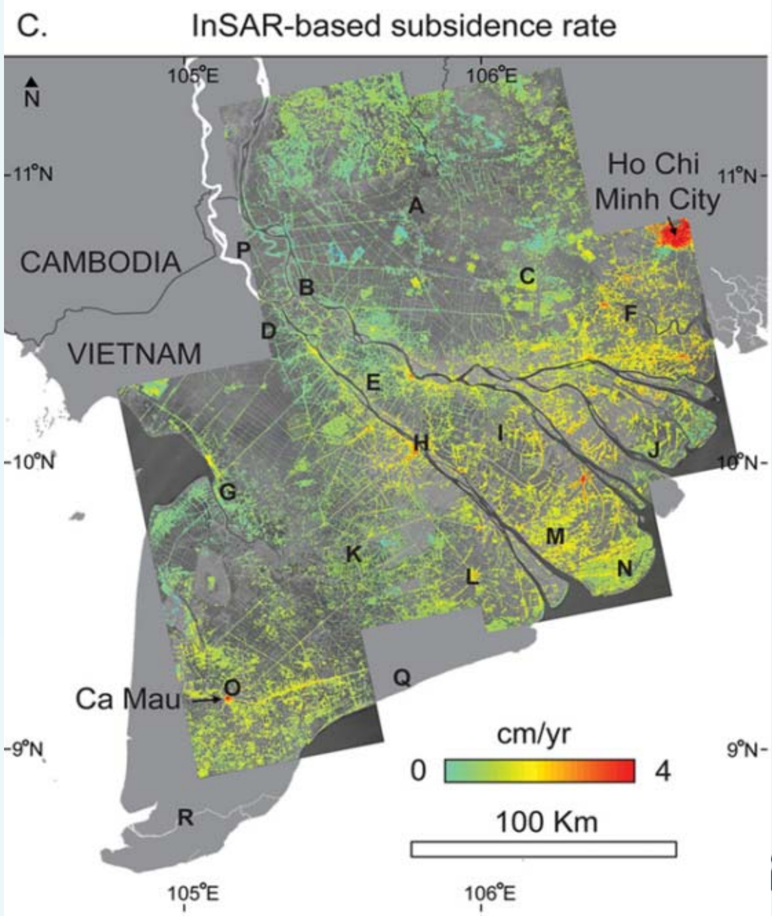
4. Analyse the impact of GW pumping (cont.)

- Conclusion:
  - The simulation indentified the vulnerable areas of GW decline due to current pumping rate
  - In the planning growing pumping, the simulation showed that the GW decline areas would be larger than current situation about 30%, and the maximum decline was predicted around 4 m to 5 m
  - Under current pumping, it was found that two cones of depression are forming. It reflects that the extraction wells locations have been developing inappropriately

5. Land subsidence model

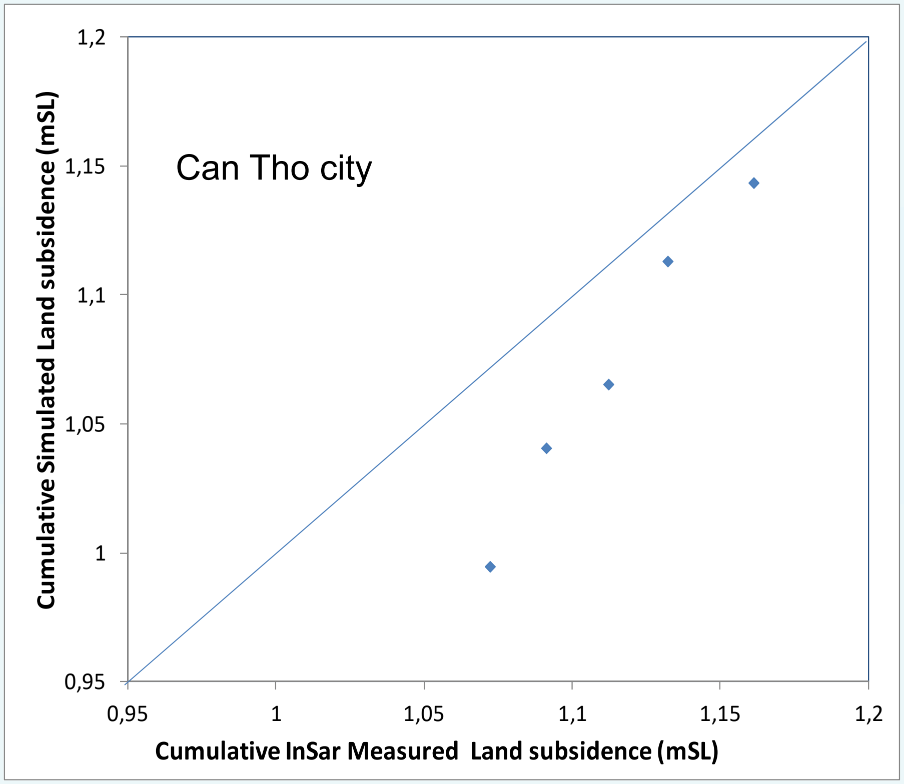
- InSAR-based subsidence rates from 2006 - 2010 in MD: 10 - 47 mm/yr
- Can Tho city land subsidence: 10 - 25 mm/yr
- Soc Trang province land subsidence: 10 - 27 mm/yr

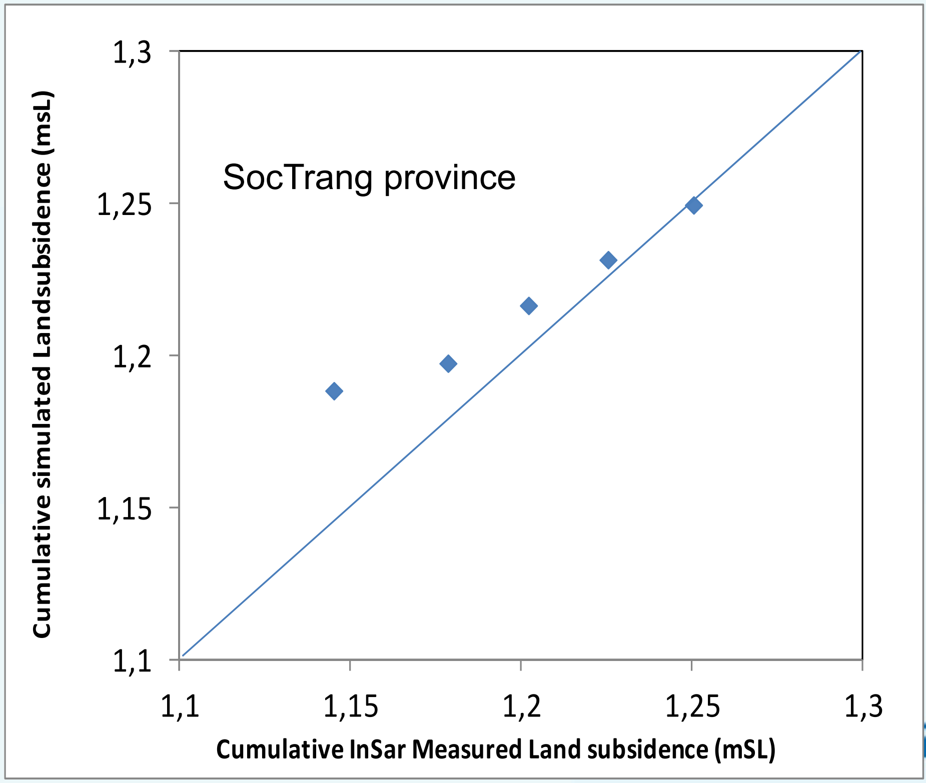


Source: Erban et al., 2014

5. Land subsidence model (cont.)

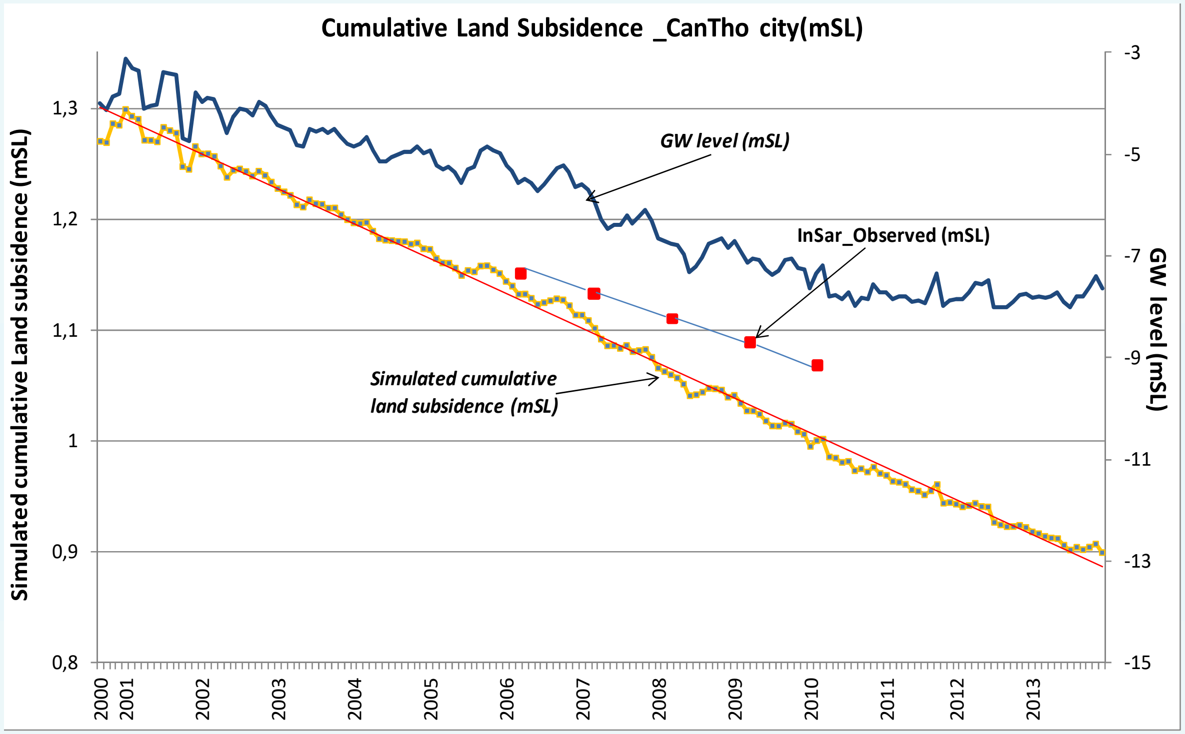
- Calibration using 2 observed inSar (5 years) land subsidence.





5. Land subsidence model (cont.)

- Simulation results at Can Tho city:
  - Long-term transient 2000 - 2013 monthly increments
  - Calibration target: a 5 years observation wells
  - The current rate of land subsidence is 2.3 cm/year



5. Land subsidence model (cont.)

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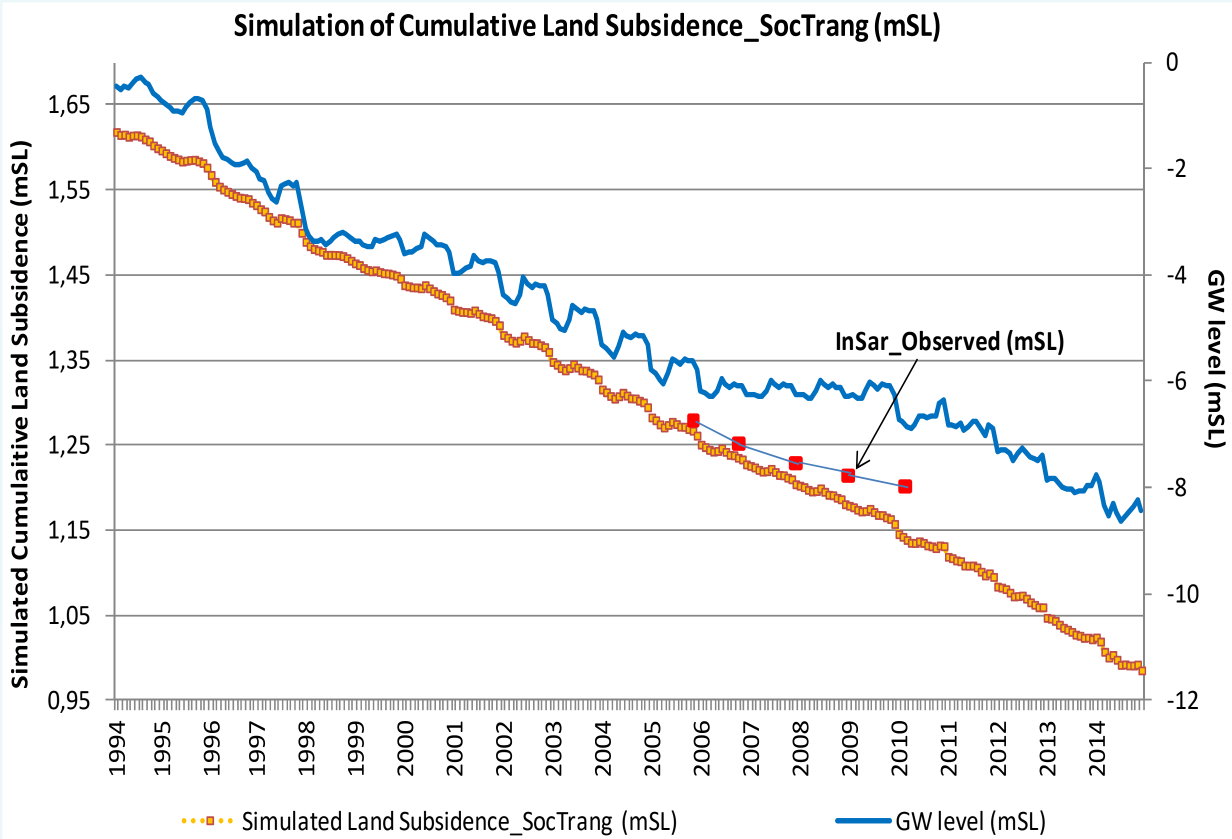
- Simulation results at Soc Trang province:
  - Long-term transient 1994 - 2014 monthly increments
  - Calibration target: a 5 years observation wells
  - The current rate of land subsidence is 3.0 cm/year



5. Land subsidence model (cont.)

- Conclusions:
  - The land subsidence in CanTho city was found in average range of 2.3 cm per year
  - In Soc Trang province, the cumulative subsidence was estimated of 65 cm (1994 - 2014), while the next 21 years showed 60 cm under the future rainfall condition (A1); significant cumulative land subsidence would be 71.4 cm (increase in pumping and major dry condition)
- The model is the first trying of land subsidence evaluation in MD under limited data $\Rightarrow$ should be continued to obtain more accuracy through detailed measurement and testing of soil properties

6. Overal conclusions

- Made clear that the GW use in MD is in over-exploitation and some regulation or conservation measures are required
- Need more cross-section studies from upstream to downstream of the MD that reaching the sustainable GW management/utilization in context of many impacts on the resources in the MD

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Thank you!