ASSESSMENT OF IMPACTS OF

GROUNDWATER ABSTRACTION AND CLIMATE CHANGE ON

GROUNDWATER RESOURCES IN MEKONG DELTA, VIET NAM

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1. AREA CHARACTERISTICS

Location:

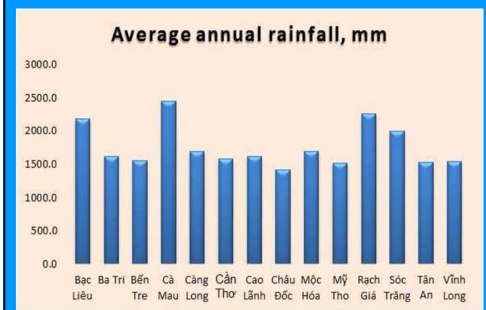
- Area = 3.96 M ha,
  Population = 16.7 M,
  Provinces = 13

Hydrology

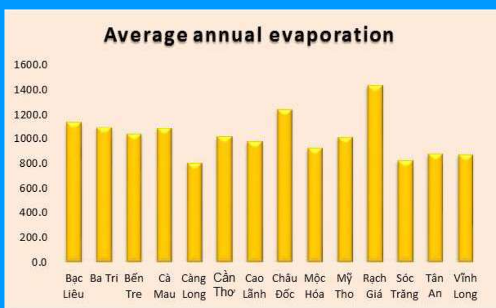
- Main natural river systems are the Tien river and Hau river system; the Vam Co river system; and Cai Lon and Cai Be river system
- A very dense manmade canal network with 3 levels of major, primary and secondary canals.
- The primary and secondary canals have a high density of some 80-100 m/ha,
- A total of 30,000-40,000 km of canals in all the Mekong Delta.

1. AREA CHARACTERISTICS

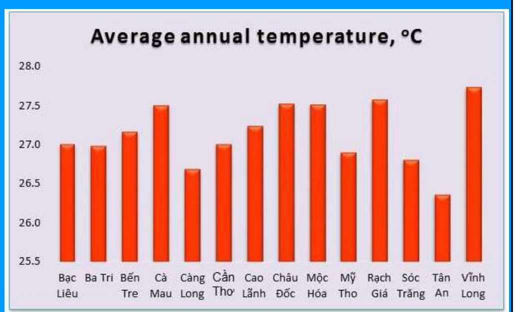
Climate



The average annual rainfall is from 1,400 -2,400 mm/year



The average annual temperature varies in range of 26.5-28^{o}C



The average annual temperature varies in range of 26.5-28^{o}C.

1. AREA CHARACTERISTICS

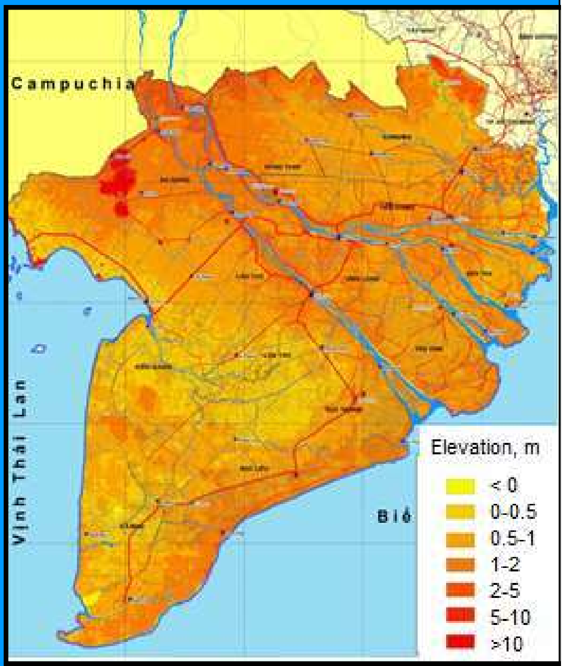
Topography

- Average elevation of 0.7 to 1.2 m, except for some high hills in the northern delta province of An Giang
- Along the Cambodian border, elevation is from the 2.0 to 4.0 m high, then lower to the central plains in the 1.0 to 1.5 m high, and only 0 0.3 to 0,7 m in the tidal, coastal area.

Geology

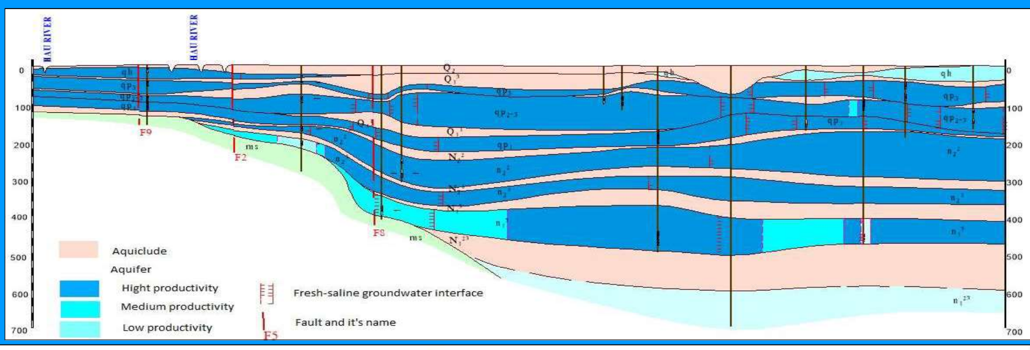
- Stratigraphy consists of intrusive, extrusive rocks and sedimentary formations of Devon to Quaternary age.
- The intrusive and extrusive rocks act as a basement, while the sedimentary formations are the cover layers
- The sedimentary formations consists of middle-upper Miocen (N_1^{2-3}), upper Miocene (N_1^3), lower Pliocene (N_2^1), middle Pliocene (N_2^2), lower Pleistocene (Q_1^1), middle- upper Pleistocene (Q_1^{2-3}), upper Pleistocene (Q_1^3), lower- middle Holocene (Q_2^{1-2}), middle-upper Holocene (Q_2^{2-3}), and upper Holocene (Q_2^3) formations.

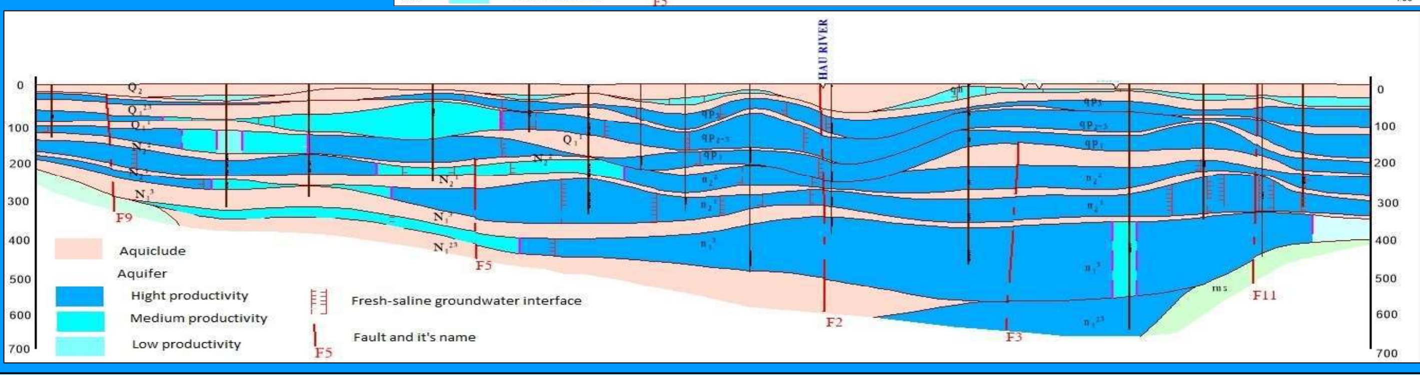
- Each sedimentary formation has two parts. The upper part is composed of a low permeable silt, clay or silty clay. A lower rather permeable part consists of fine to coarse sand, gravel, and pebble.



1. AREA CHARACTERISTICS

Hydrogeology: 7 aquifers (qh; qp_3; qp_{2-3}; qp_1; n_2^2; n_2^1; and n_1^3)

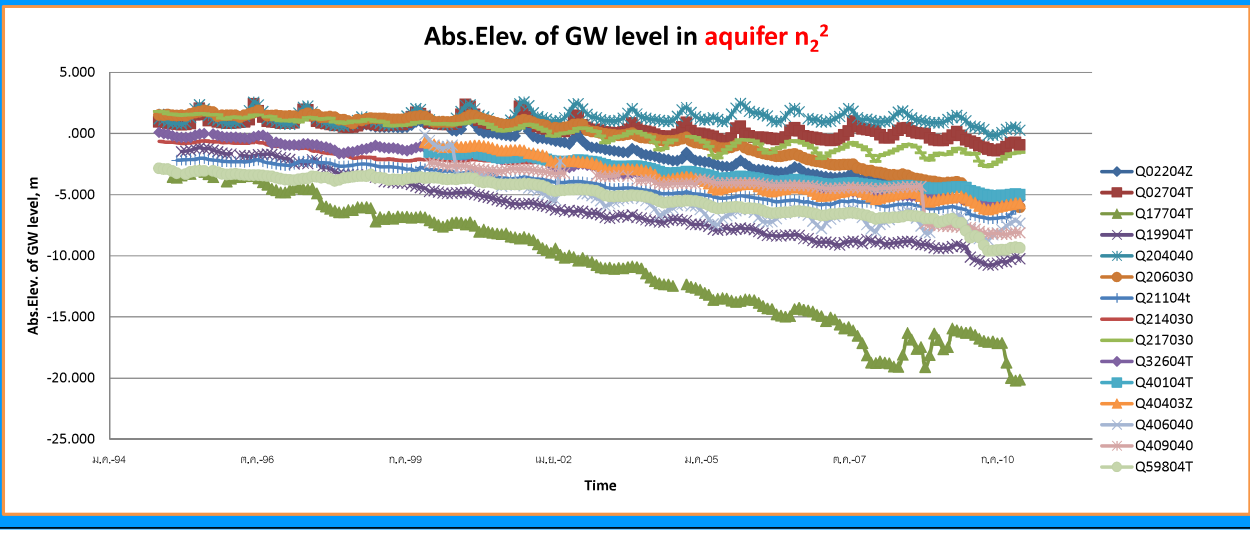




2. PROBLEM DESCRIPTIONS

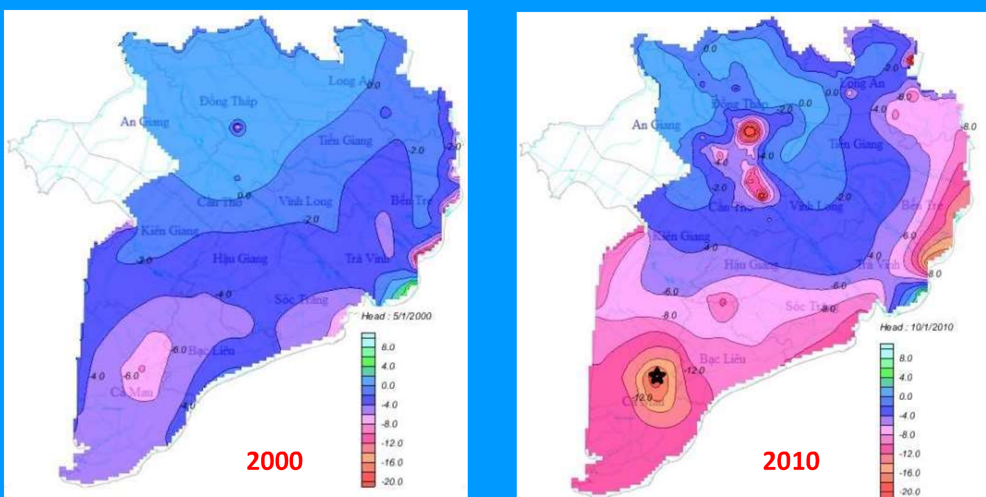
- **GW level reduction**

During a period of 1995-2010 the rates of GW reduction are 0,266; 0,365, 0,434; 0,285; 0,30; 0,15 và 0,064 m/year for aquifers n_1^3, n_2^1, n_2^2, qp_1, qp_{2-3}, qp_3 and qh, respectively



2. PROBLEM DESCRIPTIONS

- **Areas of cone depression**

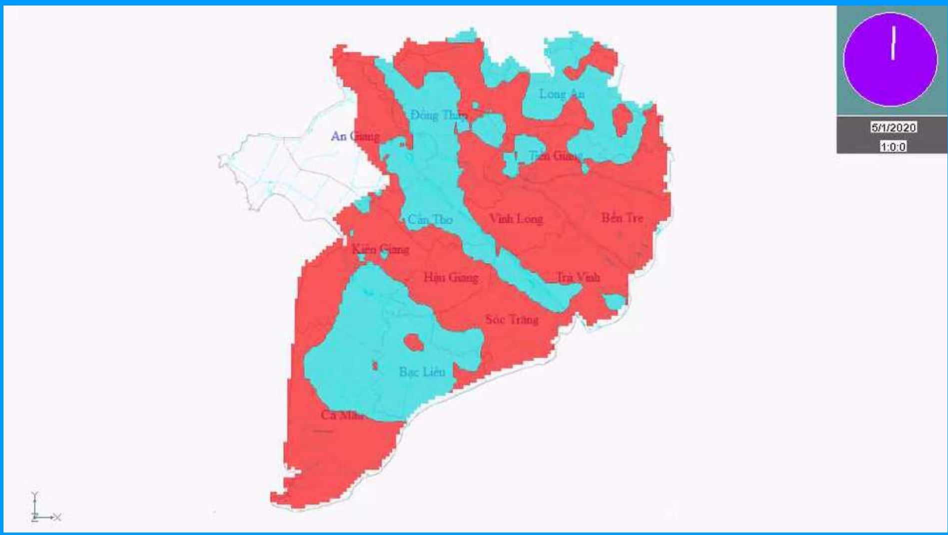


Aquifers n_2^2

2. PROBLEM DESCRIPTIONS

c. Saline water intrusion

Aquifers n_2^2



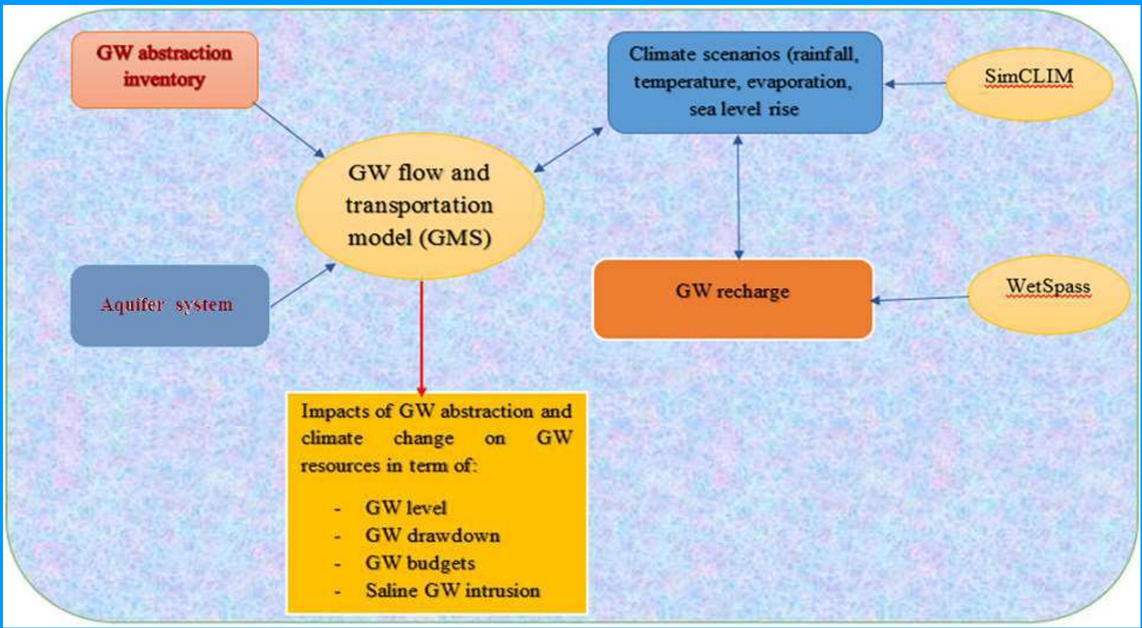
3. RESEARCH OBJECTIVES

- **General objectives**

  Assessment of impacts of GW abstraction activities and climate changes on groundwater resources

- **Specific objectives**
  - **Groundwater level changes due to GW abstraction in period of 2000 to 2010.**
  - **Impacts of climate change (rainfall, temperature, evaporation and sea level rise on:**
    - **GW level, GW drawdown and GW budget**
    - **Saline water intrusion**

4. RESEARCH METHOD



- Simulation time: 11 years (2000-2010)
- Stress period: 6 months (22 period)

- Simulation time: 90 years (2020-2100)
- Stress period: 10 year; and 6 months (18 period)

4. RESEARCH METHOD

Formulation of scenarios

Scenario	Low emission, B1	Medium emission, B2	High emission, A2
Average annual temperature	- The increase in average annual temperature is from 0.9 to 1.3⁰C (until 2050) and from 1.3 to 1.7⁰C (until 2100). - In dry season: the increase in average temperature is from 0.7 to 1.2⁰C (until 2050); and from 1.0 to 1.7⁰C (until 2100). - In rainy season: the increase in average temperature is from 1.1 to 1.5⁰ until 2050; and from 1.5 to 2.0⁰C until 2100.	- The increase in average annual temperature is from 1.0 to 1.4⁰C (until 2050) and from 2.0 to 2.6⁰C (until 2100). - In dry season: the increase in average temperature is from 0.8 to 1.3⁰C (until 2050); and from 1.5 to 2.0⁰C (until 2100). - In rainy season: the increase in average temperature is from 1.2 to 1.6⁰ until 2050; and from 2.3 to 2.9⁰C until 2100.	- The increase in average annual temperature is from 1.1 to 1.4⁰C (until 2050) and from 2.5 to 3.3⁰C (until 2100). - In dry season: the increase in average temperature is from 0.9 to 1.4⁰C (until 2050); and from 1.9 to 3.3⁰C (until 2100). - In rainy season: the increase in average temperature is from 1.2 to 1.6⁰ until 2050; and from 2.5 to 3.8⁰C until 2100.
Annual rainfall and seasonal rainfall	- Annual rainfall increases from 2.0 to 3.9% (until 2050) and from 2.7 to 5.3% (until 2100). - Dry seasonal rainfall decreases from 2.1 to 7.1% (until 2050) and from 2.8 to 9.9% (until 2100); - Rainy seasional rainfall increases from 1.4 to 7.7% (until 2050) and from 1.9 to 10.5% (until 2100);	- Annual rainfall increases from 2.1 to 4.2% (until 2050) and from 4.1 to 8.0% (until 2100). - Dry seasonal rainfall decreases from 2.3 to 7.8% (until 2050) and from 4.3 to 15.1% (until 2100); - Rainy seasional rainfall increases from 1.5 to 8.3% (until 2050) and from 3.0 to 15.9% (until 2100);	- Annual rainfall increases from 2.3 to 4.4% (until 2050) and from 5.2 to 10.2% (until 2100). - Dry seasonal rainfall decreases from 2.4 to 8.3% (until 2050) and from 5.5 to 19.3% (until 2100); - Rainy seasional rainfall increases from 1.6 to 8.8% (until 2050) and from 3.7 to 20.2% (until 2100);
Sea level rise	. - Sea level rises from 18 to 25cm until 2050, and from 49 to 64cm until 2100 - Sea level at East Sea rises from 22 to 26cm until 2050, and from 51 to 66 cm until 2100 - Sea level at West Sea rises from 24 to 28cm until 2050, and from 52 to 72 cm until 2100.	- Sea level rises from 24 to 27 cm until 2050, and from 57 to 73cm until 2100. - Sea level at East Sea rises from 23 to 27cm until 2050, and from 59 to 75 cm until 2100 - Sea level at West Sea rises from 25 to 30cm until 2050, and from 62 to 82 cm until 2100.	- Sea level rises from 26 to 29cm until 2050, and from 78 to 95cm until 2100. - Sea level at East Sea rises from 26 to 30cm until 2050, and from 79 to 99 cm until 2100 - Sea level at West Sea rises from 28 to 32cm until 2050, and from 85 to 105 cm until 2100.
Flooded area	If sea level rises 60 cm, the flooded area is 9.8% of Mekong Delta area.	If sea level rises 80 cm, the flooded area is 17.2% of Mekong Delta area.	If sea level rises 100 cm, the flooded area is 39.0% of Mekong Delta area.

4. RESEARCH METHOD

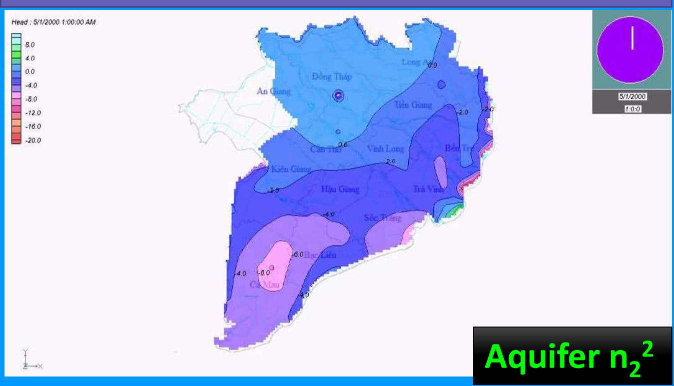
Simulation of scenarios

- 3 projected groundwater flow models for B1, B2 and A2 scenario, respectively. These model are based on the GW flow model for the period of 2000-2010 with additional and different inputs of general head, specified head, recharge amount for each scenario.
- 3 projected transportation models for B1, B2 and A2 scenario, respectively. These models are based on the 3 projected GW flow models with additional inputs for Initial TDS concentration, TDS recharge, TDS concentration at General Head, Long Dispersivity, Dispersion Package …
- Each model has:
  - Simulation time: 90 years (2020-2100)
  - Stress period: 10 year; and 6 months (18 period)

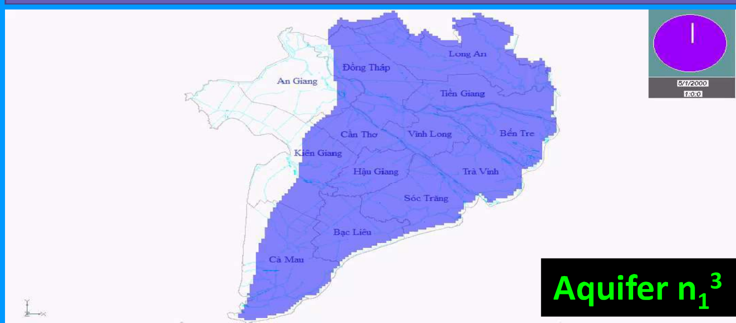
5. RESULTS OF MODELLING

2000-2010 GROUNDWATER FLOW MODEL

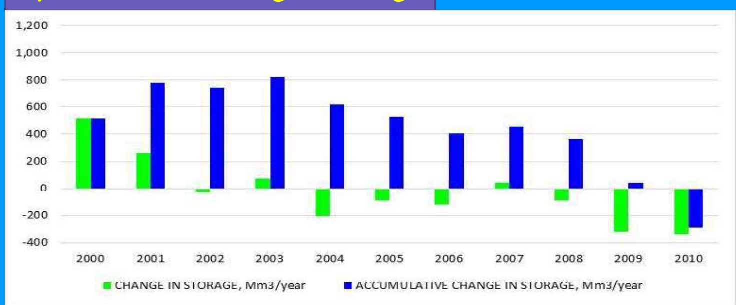
i) Contour map of groundwater levels



ii) Changes of area having drawdown greater than 3m



iii) Accumulative change in storage

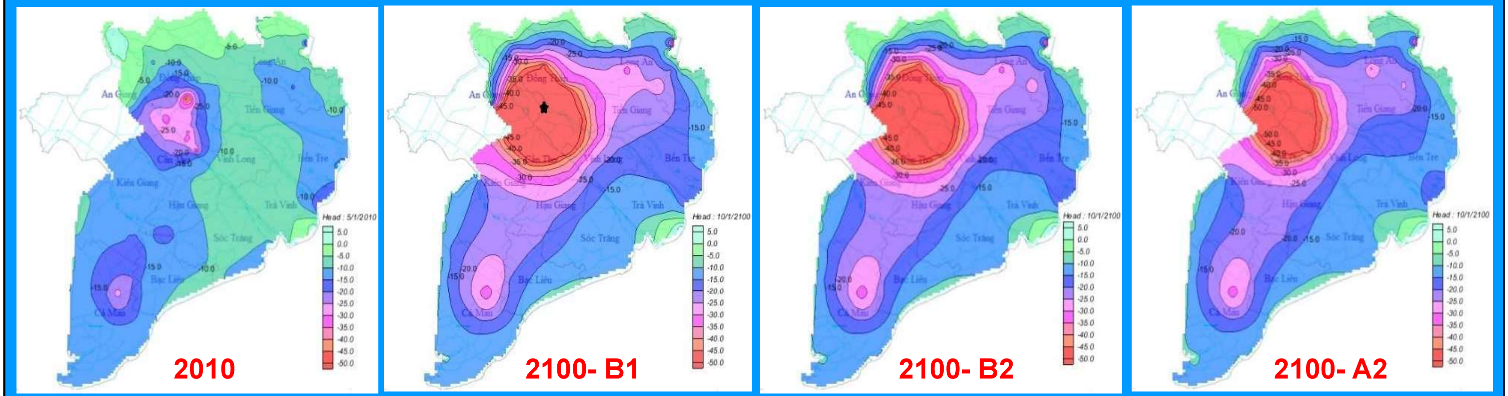


5. RESULTS OF MODELLING

Comparison of scenarios

Abs. GW levels

Aquifer n_2^2

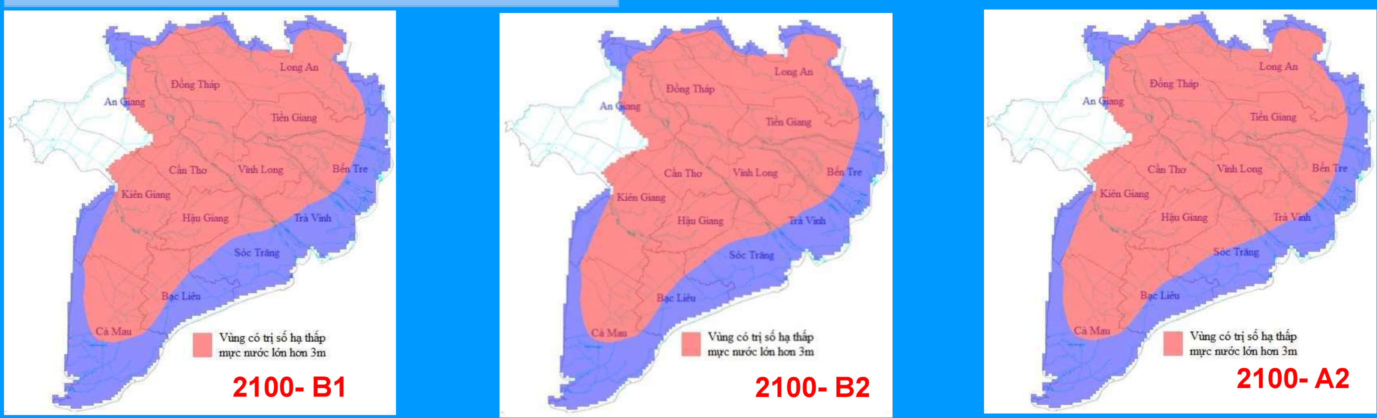


Scenario	Decrease in abs.GW level in comparison with that of 2010	Rate of Abs. GW level reduction, m/year
B1	37.274	0.414
B2	39.081	0.434
A2	44.509	0.495

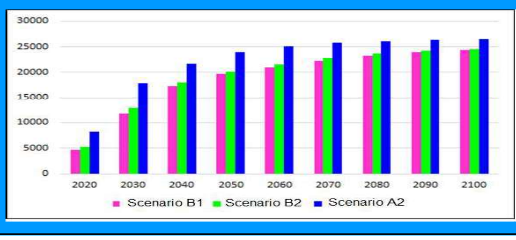
5. RESULTS OF MODELLING

Comparison of scenarios

Area having drawdown greater than 3m



Aquifer n_2^2



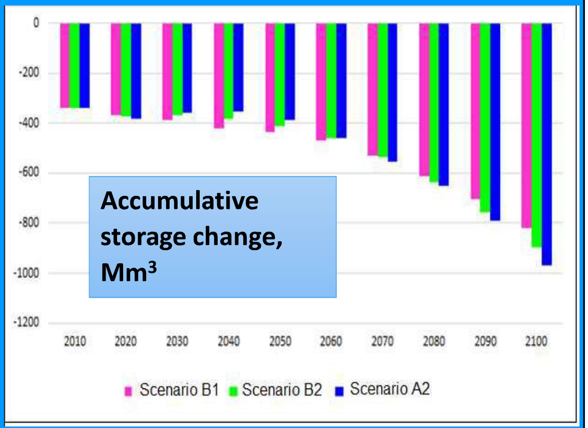
Scenario	2020	2030	2040	2050	2060	2070	2080	2090	2100
B1	4630	11781	17301	19620	21008	22181	23182	23917	24417
B2	5218	12823	17992	20136	21580	22779	23689	24248	24562
A2	8208	17863	21618	23887	25087	25719	26045	26378	26434

5. RESULTS OF MODELLING

Comparison of scenarios

Change of storage and accumulative change of storage for the whole Mekong Delta

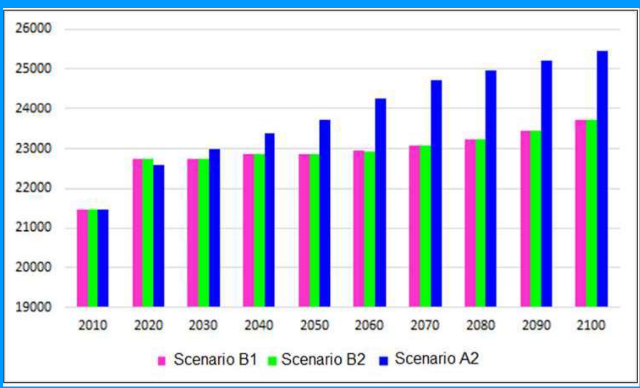
Year	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario B1										
Storage change, Mm^3/year	-336.7	-32.3	-15.9	-33.6	-14.6	-34.3	-61.3	-82.1	-95.0	-112.5
Accumulative storage change, Mm^3	-336.7	-369.0	-384.9	-418.6	-433.2	-467.5	-528.7	-610.8	-705.8	-818.3
Scenario B2										
Storage change, Mm^3/year	-336.7	-35.6	4.5	-15.8	-25.3	-50.0	-76.4	-100.5	-122.4	-137.7
Accumulative storage change, Mm^3	-336.7	-372.2	-367.7	-383.5	-408.9	-458.9	-535.3	-635.8	-758.2	-895.9
Scenario A2										
Storage change, Mm^3/year	-336.7	-45.6	22.3	5.5	-33.9	-69.1	-95.3	-98.7	-141.6	-175.9
Accumulative storage change, Mm^3	-336.7	-382.3	-359.9	-354.4	-388.3	-457.4	-552.7	-651.4	-793.0	-968.9



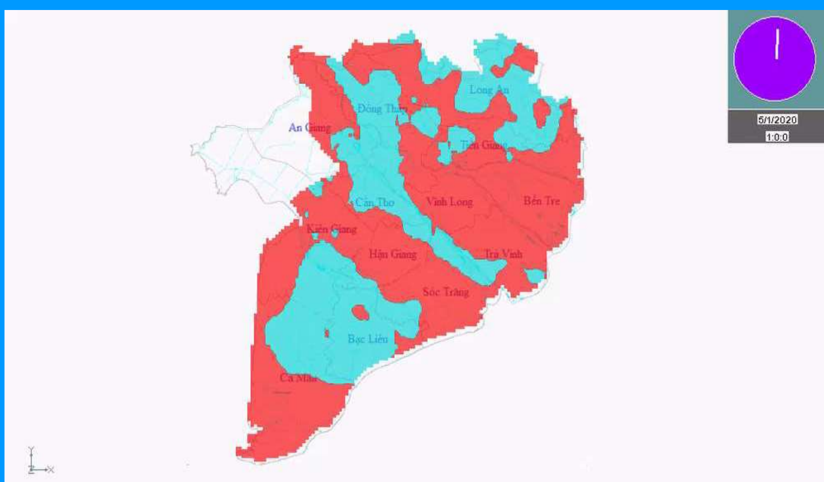
5. RESULTS OF MODELLING

Comparison of scenarios

Area with saline groundwater



Scenario A2 - Aquifer n_2^2



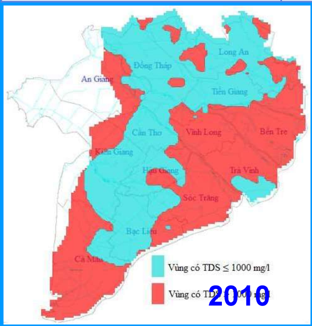
10. SIMULATION OF SCENARIOS

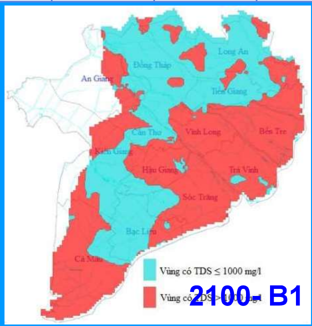
Comparison of scenarios

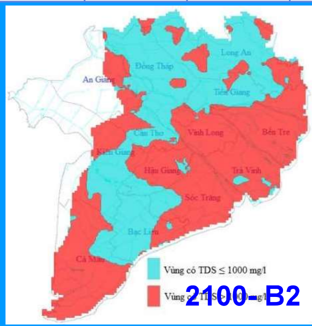
Area with saline groundwater

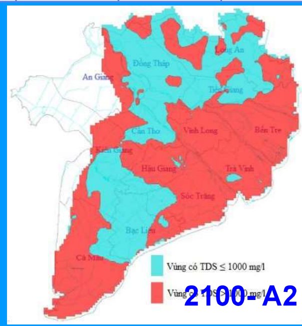
Aquifer n_2^1

	Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Area with saline groundwater, km²	B1	18122	18297	18512	18818	19137	19373	19543	19698	19831	19972
	B2	18122	18298	18510	18816	19133	19371	19542	19698	19818	19971
	A2	18122	18480	18950	19446	19835	20325	20637	20908	21166	21433
Change in area with saline GW in comparison with that of 2010, km²	B1		175	390	696	1015	1251	1421	1576	1709	1850
	B2		176	388	694	1011	1249	1420	1576	1696	1849
	A2		358	828	1324	1713	2203	2515	2786	3044	3311







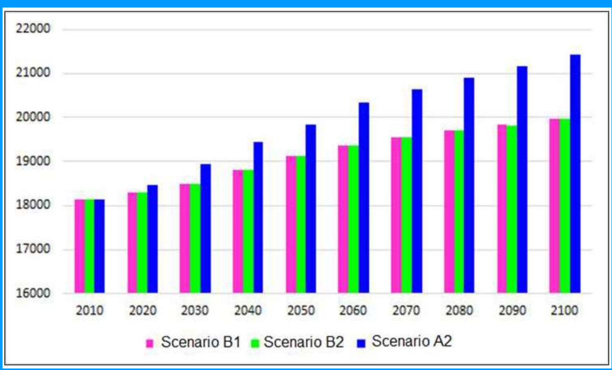


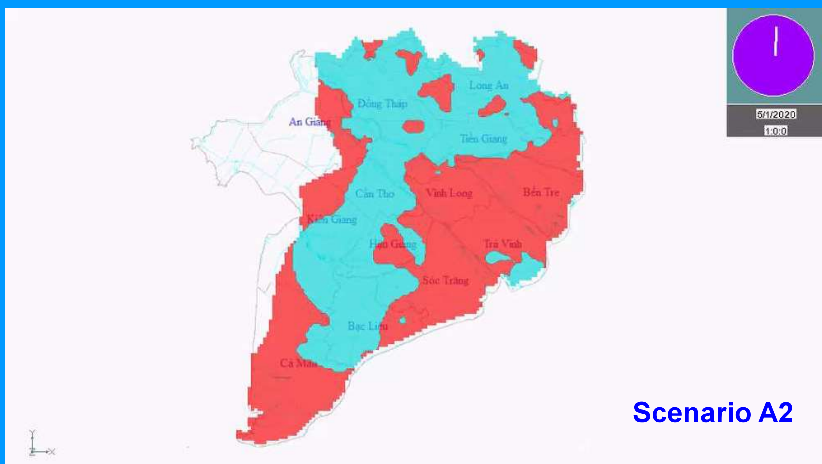
10. SIMULATION OF SCENARIOS

Comparison of scenarios

Aquifer n_2^1

Area with saline groundwater





6. CONCLUSIONS

Impacts of GW abstraction on GW resources

Change in absolute elevation of groundwater level (AE of GWL)

- The AE of GWL of 6 aquifers has been decreased clearly. The cone depression had occurred in all aquifers.
- The reduced rate of AE of GWL at the center of cone depression of each aquifer are 0.50; 1.76; 1.24; 1.98; 1.42 and 2.58m/year for aquifers qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 and n_1^3, respectively.

Change in areas having drawdown greater than 3m

- By the year 2010, the areas having drawdown greater than 3m are 18.9%, 36.6%, 42.5%, 51.5%, 81.1%, and 29.1% for aquifers qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 and n_1^3, respectively.
- The average rate of increase in the area are 678, 1308, 1519, 1699, 2548 and 835km^2/year for aquifers qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 va n_1^3, respectively.

Change of groundwater balance

- On the whole Mekong Delta, since 2004, yearly change of storage is negative and accumulative change of storage decreases from 515.4 Mm^3 by year of 2000 to -291.9 Mm3 by year of 2010, the rate of reduction of accumulative change of storage is 73.29 Mm^3/year. It is clear that GW is under depletion since 2004.

6. CONCLUSIONS CONCLUSIONS AND RECOMMENDATION

Impacts of climate change on GW resources

Change in absolute elevation of GW levels

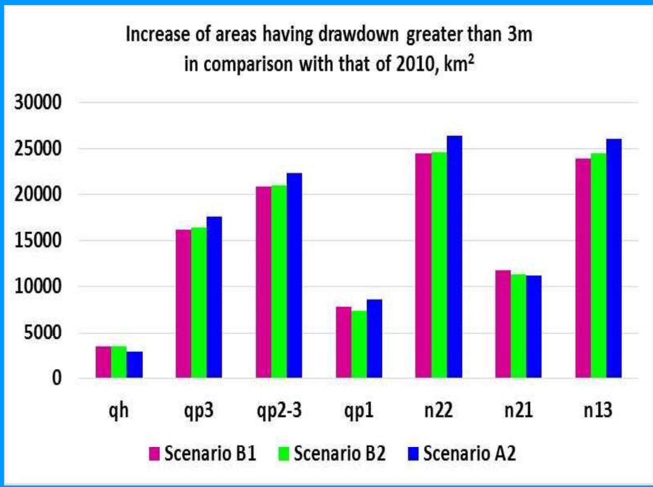
Aquifer	The AE of GW levels on 2100, m	The reduction of AE of GWL, in comparison with 2010, m	The average reduced rate of AE of GWL, m/year	The average reduced rate of AE of GWL of period 2000-2010.
qp3	-25 to -30	8.15 - 10.28	0.091 - 0.114	0.50 (5)
qp_{2-3}	-40 to -45	14.51 - 17.42	0.161 - 0.194	1.76 (9)
qp_1	-25 to -30	4.77 – 5.47	0.055 - 0.061	1.24 (20)
n_2^2	-70 to -75	37.27 – 44.51	0.414 - 0.495	1.98 (4)
n_2^1	-13 to -16	1.46 - 1.61	0.016 - 0.018	1.42 (89)
n_1^3	-42 to -55	20.53- 22.35	0.228 - 0.248	2.85 (10)

6. CONCLUSIONS CONCLUSIONS AND RECOMMENDATION

Impacts of climate change on GW resources

Change in areas having drawdown greater than 3m

Aquifer	qh	qp_3	qp_{2-3}	qp_1	n_2^2	n_2^1	n_1^3
Increase of areas having drawdown greater than 3m in comparison with that of 2010, km²							
Scenario B1	3468	16133	20885	7810	24417	11766	23910
Scenario B2	3480	16334	20963	7407	24562	11338	24484
Scenario A2	2855	17666	22382	8640	26434	11211	26058
Increase rate of area having drawdown greater than 3m, km²/year							
Scenario B1 [1]	38.5	179.3	232.1	86.8	271.3	130.7	265.7
Scenario B2 [2]	38.6	181.5	232.9	82.3	272.9	126.0	272.0
Scenario A2 [3]	31.7	186.9	248.7	91.6	293.7	124.6	289.5
Period of 2000-2010 [4]	-	677.8	1308.4	1519.4	1698.9	2548.3	834.9
Ratio of [4]/[1]	-	3.8	5.6	17.5	6.3	19.5	3.1
Ratio of [4]/[2]	-	3.7	5.6	18.5	6.2	20.2	3.1
Ratio of [4]/[3]	-	3.5	5.3	15.2	5.8	20.5	2.9

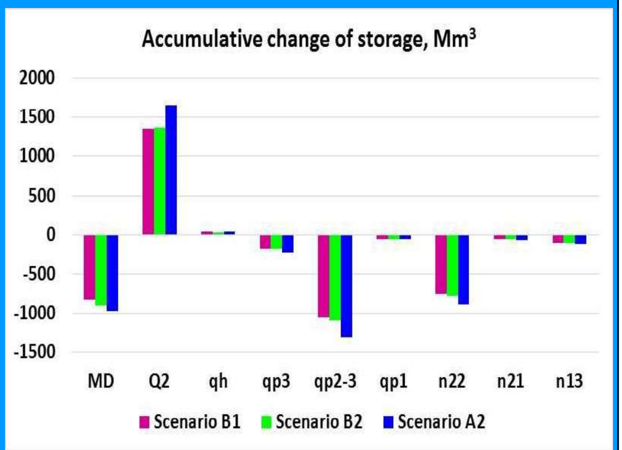


6. CONCLUSIONS CONCLUSIONS AND RECOMMENDATION

Impacts of climate change on GW resources

Accumulative change of storage

	MD	Q2	qh	qp_3	qp_{2-3}	qp_1	n_2^2	n_2^1	n_1^3
Accumulative change of storage, Mm³									
Scenario B1	-818.3	1356.0	36.7	-174.5	-1049.2	-53.7	-748.4	-62.5	-101.9
Scenario B2	-895.9	1358.7	34.0	-181.7	-1090.2	-53.1	-777.9	-62.9	-103.0
Scenario A2	-968.9	1653.6	37.7	-221.0	-1303.0	-54.7	-883.9	-63.3	-113.3
The rate of accumulative change of storage, Mm³/year									
Scenario B1	-5.35	10.64	0.22	-1.40	-7.86	-0.14	-5.79	-0.18	-0.66
Scenario B2	-6.21	10.67	0.19	-1.48	-8.32	-0.13	-6.12	-0.18	-0.67
Scenario A2	-7.02	13.95	0.23	-1.91	-10.68	-0.15	-7.29	-0.18	-0.79

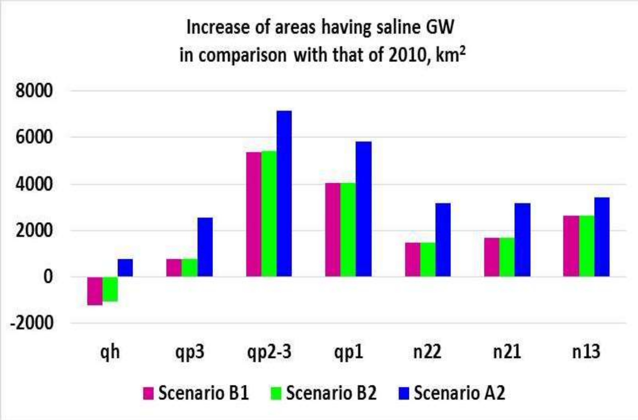


6. CONCLUSIONS CONCLUSIONS AND RECOMMENDATION

Impacts of climate change on GW resources

Change in areas having saline groundwater

Aquifer	qh	qp_3	qp_{2-3}	qp_1	n_2^2	n_2^1	n_1^3
Increase of areas having saline GW in comparison with that of 2010, km²							
Scenario B1	-1214	753	5389	4033	1471	1695	2637
Scenario B2	-1064	771	5407	4051	1472	1694	2638
Scenario A2	766	2538	7174	5818	3188	3156	3429
The rate of increase of areas having saline groundwater, km²/year							
Scenario B1	-13.49	8.37	59.88	44.82	16.35	18.83	29.31
Scenario B2	-11.82	8.57	60.08	45.02	16.36	18.83	29.31
Scenario A2	8.51	28.20	79.71	64.64	35.43	35.07	38.10



6. CONCLUSIONS AND RECOMMENDATION

Orientation of Planning of GW use and development

- Reduce the amount of groundwater abstraction
- Increase in recharge for groundwater to recover GW level and prevent GW depletions
- Use other sources of water for supply (rainfall, surface water…)

Measures should be done

- To build and implement National and Provincial Planning on Allocation and Protection of GW resources
- Identification of prohibited, restricted areas for groundwater extraction;
- Extraction of GW at deeper aquifers where they are not affected by recharge reduction
- Feasibility study and implementation of artificial groundwater recharge schemes
- To upgrade and complete the GW monitoring network

6. PROJECT PROPOSAL

1. **Upgrade and improvement the national monitoring network on water resources in term of:**
   - To increase the density
   - To collect the data automatically
   - To ensure the monitoring stations to operate in long-term
2. **Building, operation and maintaining a monitoring network on the land surface subsidence**
   - Assessment of existing land surface subsidence
   - Understanding the drivers of land surface subsidence
   - Monitoring land surface subsidence
   - Propose the measures to minimize land surface subsidence

6. PROJECT PROPOSAL

3. **Feasibility study and pilot implementation of artificial groundwater recharge schemes in coastal areas of Mekong Delta**
   - Test effectiveness of using artificial groundwater recharge in restoring depleted aquifer storage and sustaining urban water supply;
   - Select best site and suitable technology for artificial recharge a comprehensive feasibility study;
   - Pilot implementation of artificial recharge schemes where it is feasible;
   - Learn experiences from implementing artificial groundwater recharge schemes in different physical and social environments;
   - Develop knowledge bases for artificial groundwater recharge in Vietnam

6. PROJECT PROPOSAL

4. Designing, building, operation and maintaining a information system on water resources for Mekong Delta

- Assessment of existing data availability on water ressources for management in Mekong Delta (data catalogue)
- Propose structure and sharing the data in Mekong Delta
- Transfer WEB site and data catalogue for the serve in Vietnam
- Support preparation of suitable maps for management plan
- Recommendation for development of national information system on water resources

6. PROJECT PROPOSAL

5. Investigation on geological engineering conditions of costal line from Tien Giang to Ca Mau to serve for sea wall planning in the context of sea level rise

- **Investigation on** geological engineering conditions of costal line from Tien Giang to Ca Mau to serve for sea dyke planning
- Proposal of suitable type of sea walls for each area with difference in geological engineering conditions


Thank You For
Your Attention