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50 IWRA | DAEGU METROPOLITAN CITY | KOREA WATER RESOURCES ASSOCIATION | K water Korea Water Resources Corporation | Ministry of Environment

TECHNOLOGY DEVELOPMENT FOR OPTIMAL OPE RATION OF GROUNDWATER USING EXISTING WELLS TO COPE WITH DROUGHT

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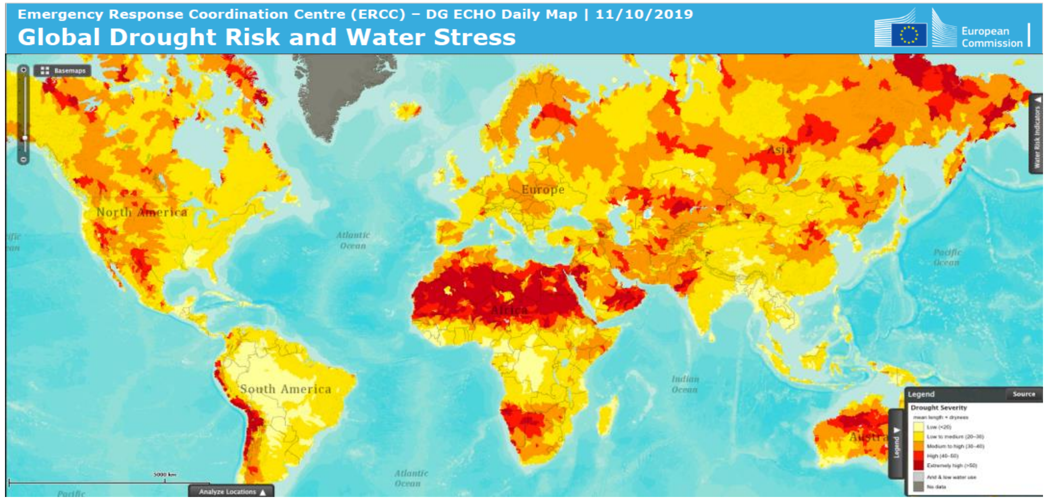
1. OVERVIEW

Natural disasters causing scarcity and pollution

- In the recent decades natural disasters keep increasing all over the world
- Drought is causing scarcity of the existent resources and flood is causing an important pollution of surface resources



- Groundwater became the best alternative for drinking water supply in emergencies (UNESCO, 2011), case of Japan after the Great East Japan Earthquake in 2011
- It is the most available source of drinking water in arid and semi-arid regions

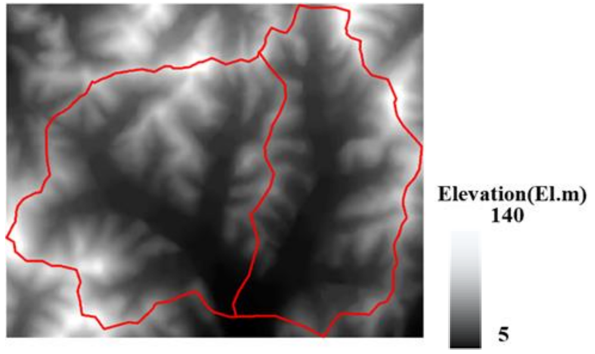
2. OBJECTIVES

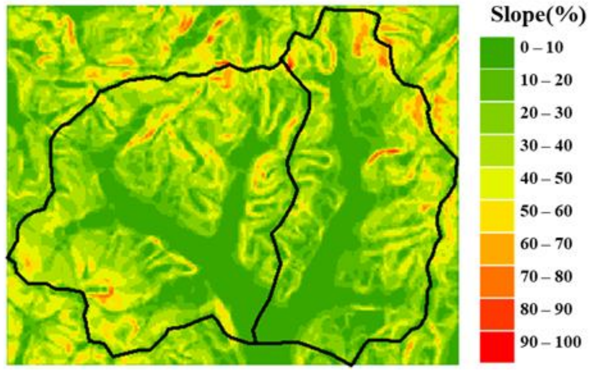
Research objectives

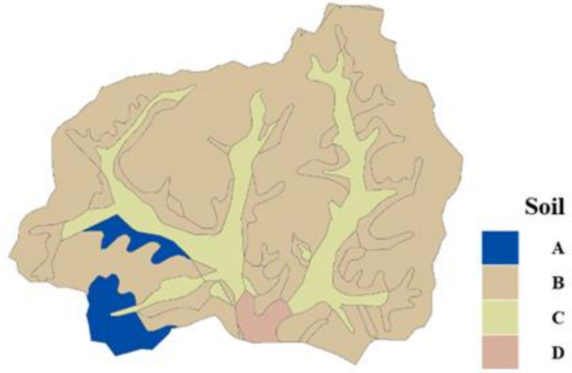
- Enhance the sustainable use and management of groundwater as a strategic resource for long term drought risk reduction as well as enhancing the resilience of farming system a groundwater dependent cities and natural ecosystems.
- Examine the relevance and options for developing and adopting such groundwater based natural infrastructure solution in disaster risk reduction.
- An integrated approach for groundwater use to reduce the risks from multi-hazards resulting from hydrological imbalance
- Controlled well network system to avoid wasting the existing resource by controlling water intake
- Minimize groundwater pumping in the highest usage period while still reaching the demand.
- Optimal groundwater use considering water level decrease
- Preserve the actual quantity of groundwater to use for emergency or drought period

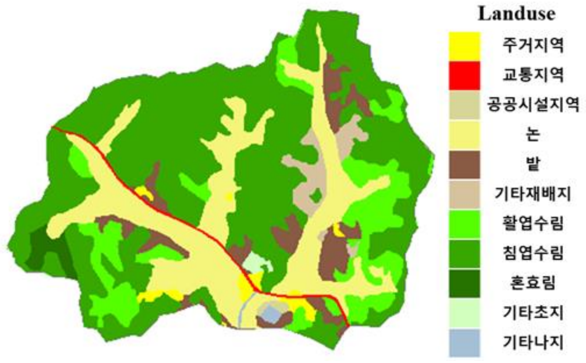
3. METHODS AND RESULTS

Study area









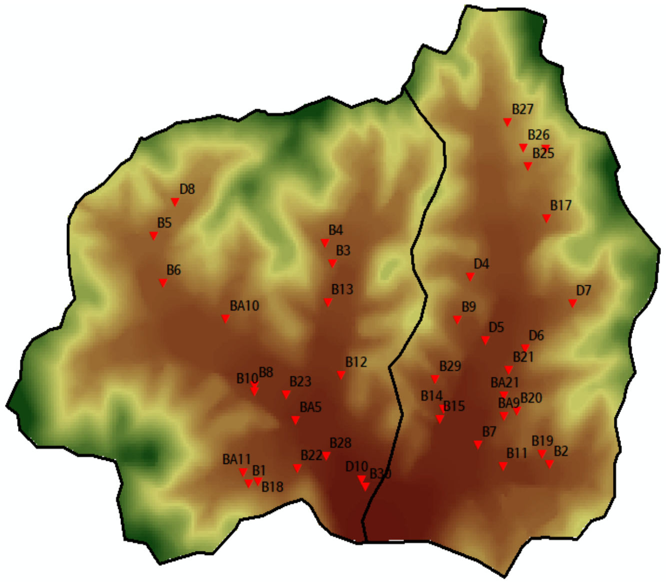
The research area is about 9.83 km2 and located in Hongseong-gu, about 120km southeast of Seoul. It is highly surrounded by mountains (60 to 140m above sea level)

72% of the of the overall area is mountainous and only 15.4% is agricultural area. The observed soil are classified into 4 hydrological soil groups (A,B,C and D) based on the infiltration rate.

The aquifer thickness in the mountainous area is relatively same as the as the one in the flat area due to high slope (steep area) which reduces the infiltration rate. In recent decades, groundwater level declined is observed because of the increasing agricultural area and rainfall decreasing. Therefore, groundwater management is essential for not only supplying water for agricultural use but also for domestic use by keeping the resource available for long term usage.

3. METHODS AND RESULTS

Study area : Well Network System facilities



Wells location map

The study region contains in total fifty wells; 41pumping wells and 9 for groundwater level observation.

The area is divided into 2 different regions based on the existing rivers and aquifer productivity. Region 1 in the west contains 20 pumping wells with a daily total pumping rate about 1072 m3/d and the region 2 in the east contains 21 pumping wells with a total pumping rate of 1284 m3/d.

The aquifer is found to be more productive in the region 1 (also highest hydraulic conductivity) than the region 2 and an integrated management system of all the existing wells is important for better management.

	Kx = Ky (m/d)	**Kz (m/d)**
Region 1	**0.50**	**0.05**
Region 2	**0.20**	**0.02**

Using monthly groundwater use the use percentage showed that more than 45% of the yearly groundwater use is from May. This high usage is related to the irrigation of paddy and farm .

month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
USE(%)	0.7	1.1	0.6	7.9	45.4	21	3.3	17.8	2	0	0.1	0

3. METHODS AND RESULTS

Groundwater use control

Based on the high groundwater use, it is important to organize an optimal operating scenario for existing wells, by establishing an analysis model for the groundwater level variation according to the operation of existing wells in the research area.

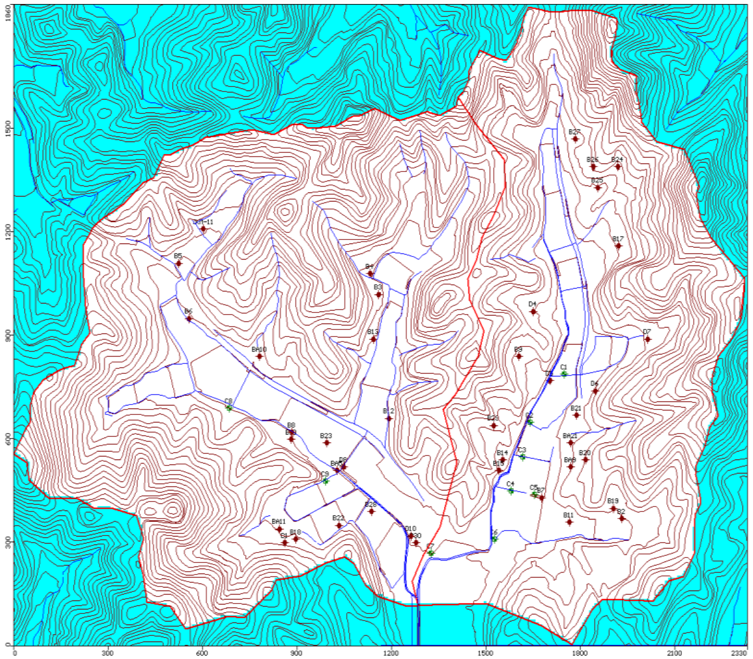
Depth to water table average within the area is about 21.63 m.

Previously we have found that the critical depth to water table is reached when groundwater level decreased for 7.13m. Therefore depth to water table should not fall more than 28.76m. The Well Network System (WNS) will be set to stop when that level is reached and supply water would apply additional supply system.

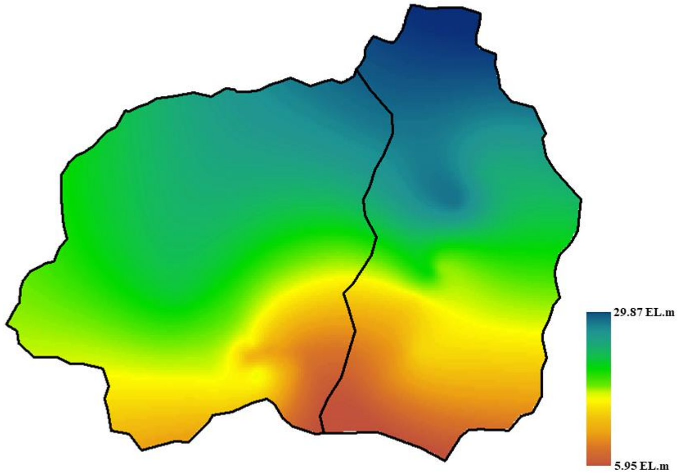
Considering the previous conditions, existing report data were used, and a groundwater flow analysis model was built using Visual MODFLOW

3. METHODS AND RESULTS

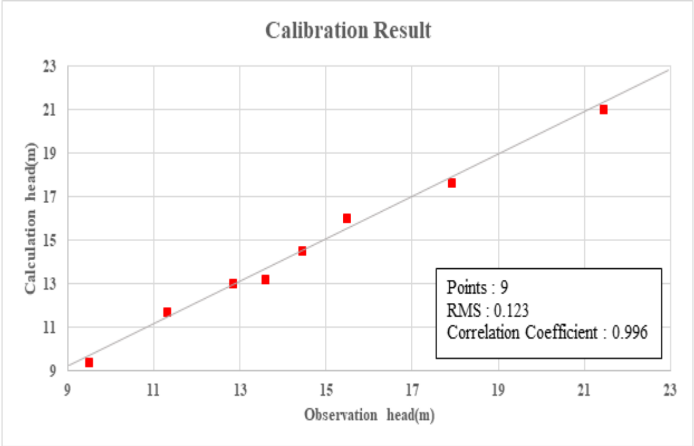
Model calibration for groundwater flow simulation



Result screen of model calibration



Groundwater level spatial distribution in steady state

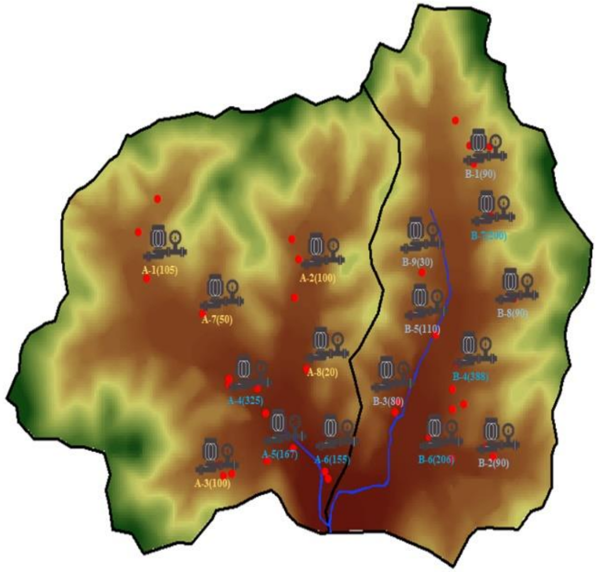


Model calibration scatter diagram result

The calibrated model was evaluated using Root Mean Square Error (RMSE) and Correlation coefficient (r^2). The calibration scatter diagram showed a good match between the observed values and the calculated value from the model, with RMSE of 0.123 m and correlation coefficient of 0.99 which are acceptable values.

3. METHODS AND RESULTS

Scenarios application and results



Wells with high pumping rate

After calibration we have run our model using 5 different scenarios:

Considering all the existing wells we first have 130 000 scenarios then we have selected all the wells with pumping rate higher than $150m^3/d$.

- Therefore, except A-4 ($375m^3/d$), A-5 ($167m^3/d$), and A-6 ($155m^3/d$) wells in the region 1; B-4 ($388m^3/d$), B-6 ($206m^3/d$), and B-7 ($200m^3/d$) in the region 2, all the other wells are 100% operating.

56 existing management scenarios were constructed

- Scenario 1 (SC1) uses 100% of all groups, Scenario 2 (SC2) 4 groups are not operating; In the case of Scenario 3 (SC3) three selected groups are not operating, while in Scenario 4 (SC4) two groups will not operate and in Scenario 5 (SC5) only 1 group will not operate

The average monthly depth to water table and the amount of water use for each scenario was evaluated using Visual MODFLOW.

3. METHODS AND RESULTS

Scenarios configurations

The scenarios are configured using field pipeline connection between the pumping wells, the proximity of the wells to the farms and the distance between the wells

Scenario 1

	Region 1								Region 2								
Group	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
ON/OFF	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Scenario 2

	Region 1								Region 2								
Group	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
Sc2-1	O	O	O	O	O		O	O	O	O	O		O			O	O
Sc2-2	O	O	O	O		O	O	O	O	O	O		O			O	O
Sc2-3	O	O	O	O			O	O	O	O	O	O	O			O	O
Sc2-4	O	O	O	O			O	O	O	O	O		O	O		O	O
Sc2-5	O	O	O	O			O	O	O	O	O		O		O	O	O
Sc2-6	O	O	O		O	O	O	O	O	O	O		O			O	O
Sc2-7	O	O	O		O		O	O	O	O	O	O	O			O	O
Sc2-8	O	O	O		O		O	O	O	O	O		O	O		O	O
Sc2-9	O	O	O		O		O	O	O	O	O		O		O	O	O
Sc2-10	O	O	O			O	O	O	O	O	O	O	O			O	O
Sc2-11	O	O	O			O	O	O	O	O	O		O	O		O	O
Sc2-12	O	O	O			O	O	O	O	O	O		O		O	O	O
Sc2-13	O	O	O				O	O	O	O	O	O	O	O		O	O
Sc2-14	O	O	O				O	O	O	O	O	O	O		O	O	O
Sc2-15	O	O	O				O	O	O	O	O		O	O	O	O	O

Scenario 3

	Region 1								Region 2								
Group	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
Sc3-1	O	O	O	O	O	O	O	O	O	O	O		O			O	O
Sc3-2	O	O	O	O	O		O	O	O	O	O	O	O			O	O
Sc3-3	O	O	O	O	O		O	O	O	O	O		O	O		O	O
Sc3-4	O	O	O	O	O		O	O	O	O	O		O		O	O	O
Sc3-5	O	O	O	O		O	O	O	O	O	O	O	O			O	O
Sc3-6	O	O	O	O		O	O	O	O	O	O		O	O		O	O
Sc3-7	O	O	O	O		O	O	O	O	O	O		O		O	O	O
Sc3-8	O	O	O	O			O	O	O	O	O	O	O	O		O	O
Sc3-9	O	O	O	O			O	O	O	O	O	O	O		O	O	O
Sc3-10	O	O	O	O			O	O	O	O	O		O	O	O	O	O
Sc3-11	O	O	O		O	O	O	O	O	O	O	O	O			O	O
Sc3-12	O	O	O		O	O	O	O	O	O	O		O	O		O	O
Sc3-13	O	O	O		O	O	O	O	O	O	O		O		O	O	O
Sc3-14	O	O	O		O		O	O	O	O	O	O	O	O		O	O
Sc3-15	O	O	O		O		O	O	O	O	O	O	O		O	O	O
Sc3-16	O	O	O		O		O	O	O	O	O		O	O	O	O	O
Sc3-17	O	O	O			O	O	O	O	O	O	O	O	O		O	O
Sc3-18	O	O	O			O	O	O	O	O	O	O	O		O	O	O
Sc3-19	O	O	O			O	O	O	O	O	O		O	O	O	O	O
Sc3-20	O	O	O				O	O	O	O	O	O	O	O	O	O	O

Scenario 4

	Region 1								Region 2								
Group	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
Sc4-1	O	O	O	O	O	O	O	O	O	O	O	O	O			O	O
Sc4-2	O	O	O	O	O	O	O	O	O	O	O		O	O		O	O
Sc4-3	O	O	O	O	O	O	O	O	O	O	O		O		O	O	O
Sc4-4	O	O	O	O	O		O	O	O	O	O	O	O	O		O	O
Sc4-5	O	O	O	O	O		O	O	O	O	O	O	O		O	O	O
Sc4-6	O	O	O	O	O		O	O	O	O	O		O	O	O	O	O
Sc4-7	O	O	O	O		O	O	O	O	O	O	O	O	O		O	O
Sc4-8	O	O	O	O		O	O	O	O	O	O	O	O		O	O	O
Sc4-9	O	O	O	O		O	O	O	O	O	O		O	O	O	O	O
Sc4-10	O	O	O	O			O	O	O	O	O	O	O	O	O	O	O
Sc4-11	O	O	O		O	O	O	O	O	O	O	O	O	O		O	O
Sc4-12	O	O	O		O	O	O	O	O	O	O	O	O		O	O	O
Sc4-13	O	O	O		O	O	O	O	O	O	O		O	O	O	O	O
Sc4-14	O	O	O		O		O	O	O	O	O	O	O	O	O	O	O
Sc4-15	O	O	O			O	O	O	O	O	O	O	O	O	O	O	O

Scenario 5

구분	Region 1								Region 2								
Group	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
Sc5-1	O	O	O	O	O	O	O	O	O	O	O	O	O	O		O	O
Sc5-2	O	O	O	O	O	O	O	O	O	O	O	O	O		O	O	O
Sc5-3	O	O	O	O		O	O	O	O	O	O	O	O	O	O	O	O
Sc5-4	O	O	O	O	O		O	O	O	O	O	O	O	O	O	O	O
Sc5-5	O	O	O	O	O	O	O	O	O	O	O		O	O	O	O	O

3. METHODS AND RESULTS

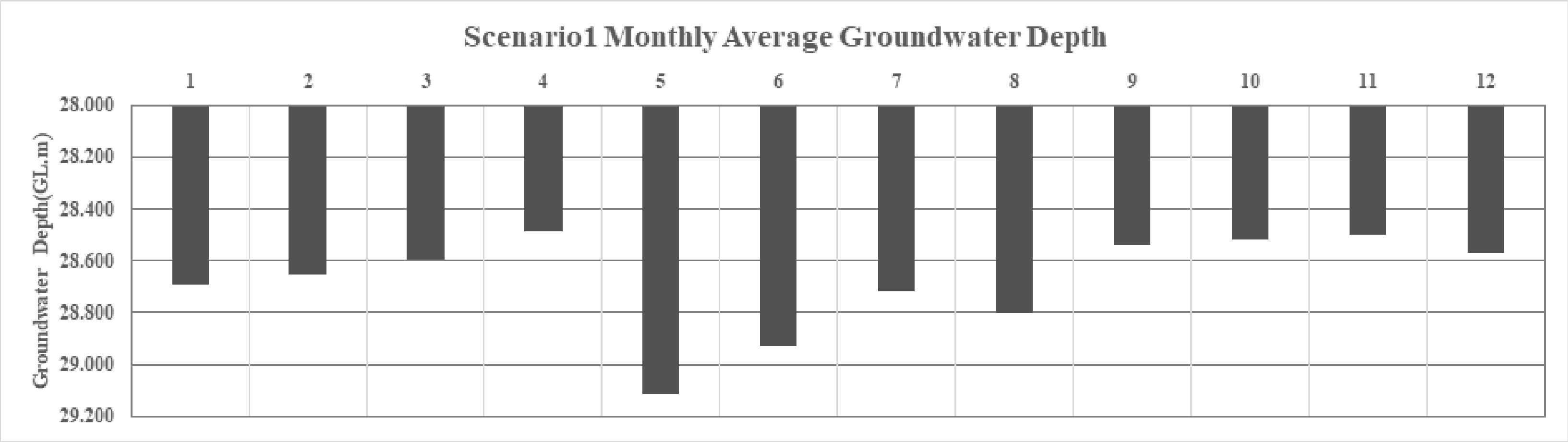
Scenario 1 results

The results of the monthly depth to water table variation using the different groups of scenarios

- Scenario 1 (SC1) consists of 100% use of existing wells in all groups.

- In the case of Scenario 1 (SC1), it was found that groundwater levels were distributed at an average depth of 28.675GL.m from January to December except the month of May, where depth to water table has exceeded the critical value.

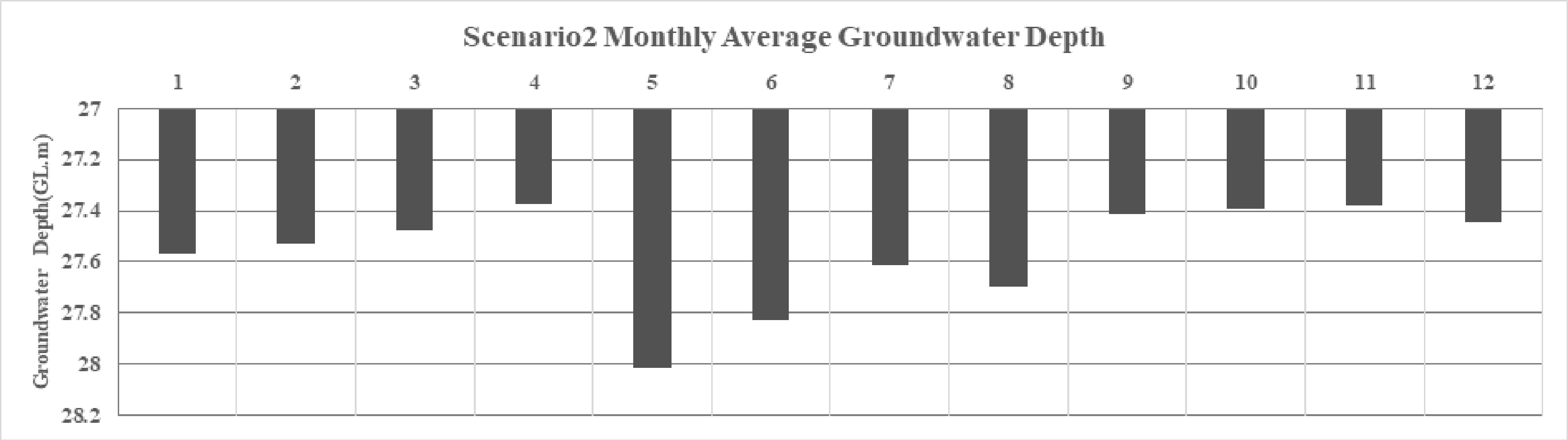
- The usage in May, June, and August is high and more efficient irrigation system is needed as the water intake is largely higher than the demand.



3. METHODS AND RESULTS

Scenario 2 results

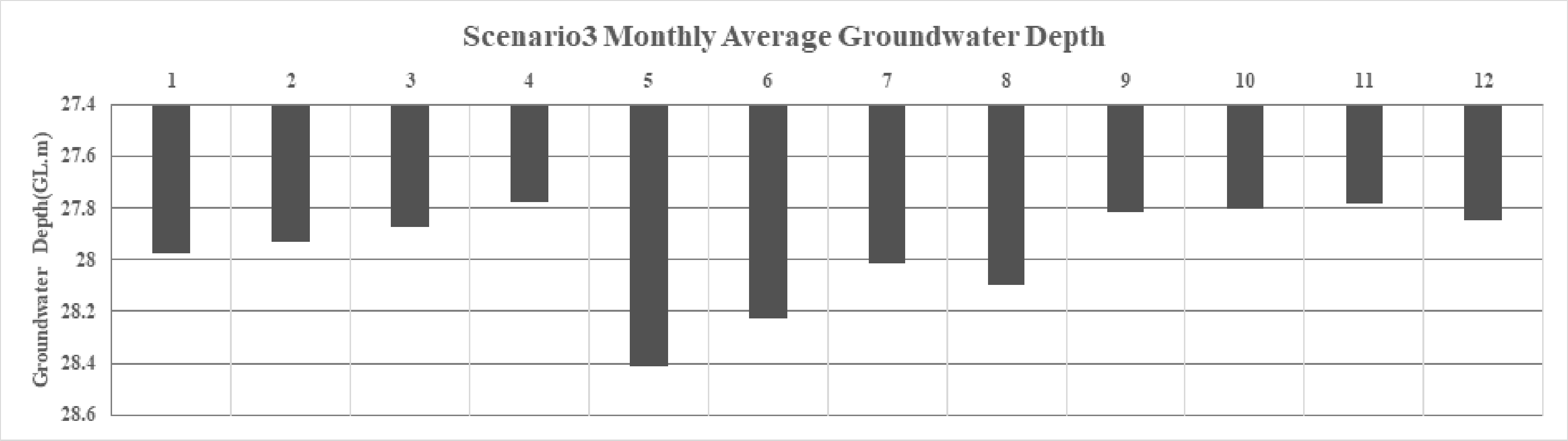
- In the case of Scenario 2 (SC2), it was found that groundwater levels were distributed at an average depth of 27.562 GL.m from January to December.
- In all cases of Scenario 2, the depth to water table critical value of 28.76GL.m was not reached, and it was analyzed that it could be operated according to all cases of the existing wells connection group.
- It was found that if 100% water intake is carried out according to the total pumping rate of Scenario 2, the average water intake of all cases is about 491,000 m^3/year, and the usual groundwater supply (266,000 m^3/year) in the study area can be satisfied.



3. METHODS AND RESULTS

Scenario 3 results

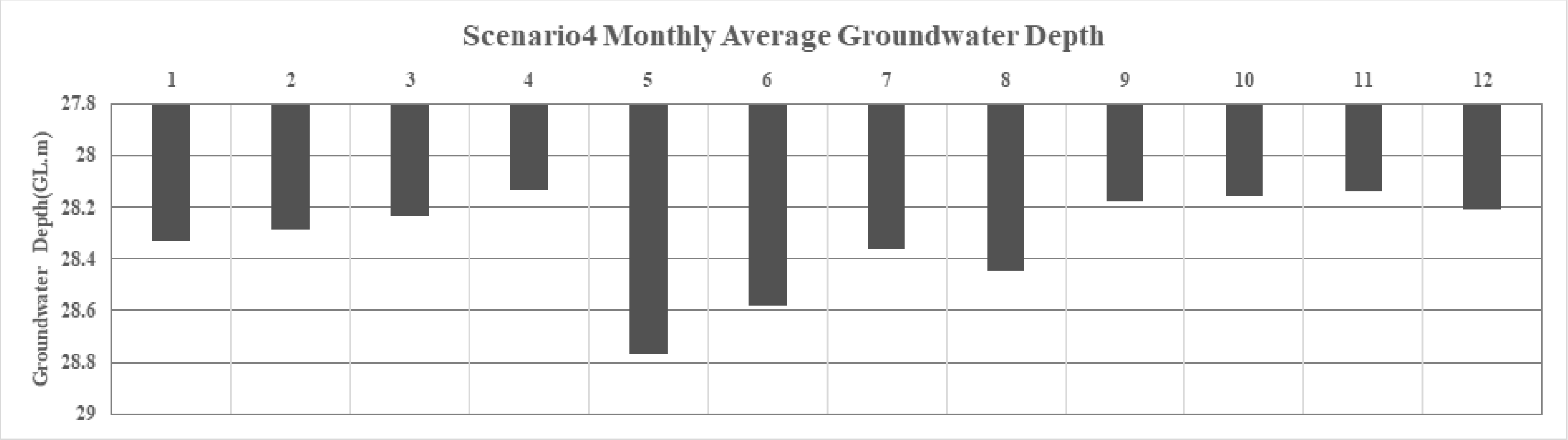
- In the case of Scenario 3 (SC3), it was found that groundwater levels were distributed at an average depth of 27.964GL.m from January to December.
- In all cases of Scenario 3, the depth to water table critical value of 28.76GL.m was not reached, and it was analyzed that it could be operated according to all cases of the existing connection group.
- According to the pumping rate of Scenario 3, the average intake of all cases is about 579,000 m^3/year , and it was found that the usual groundwater supply (266,000 m^3/year) in the study area can be satisfied.



3. METHODS AND RESULTS

Scenario 4 results

- In the case of Scenario 4 (SC4), it was found that groundwater levels were distributed at an average depth of 28.318 GL.m from January to December.
- In all cases of Scenario 4, the groundwater level depth reached 28.76GL.m, the critical depth to water, and alternatives such as securing additional water sources or reducing pumping volume were needed during that period; from the modeling results, it could be operated according to all cases except in May.
- According to the specific pump usage of Scenario 4, the average intake of all cases was found to be above 666,000 m^3/year, satisfying the usual groundwater supply (266,000//year) in the study area.



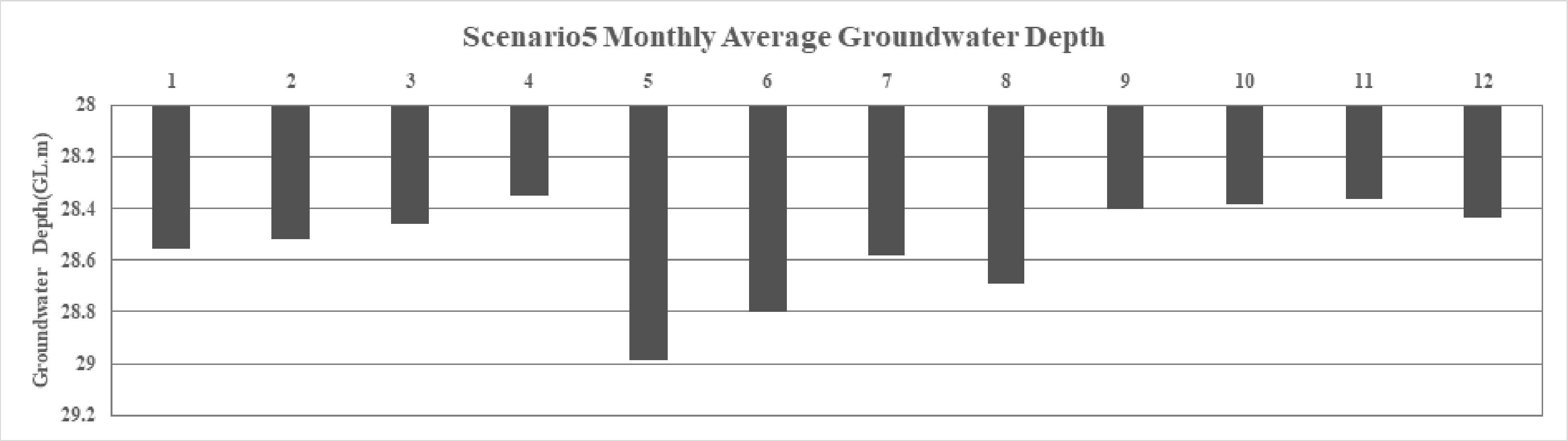
3. METHODS AND RESULTS

Scenario 5 results

- In the case of Scenario 5 (SC5), it was found that groundwater level were distributed at an average depth of 28.544 GL.m from January to December.

- In all cases of Scenario 5, the the depth to water table value reached 28.76GL.m, the highest annual groundwater decline limit is reached in May, June, and August, indicating that alternatives such as securing additional water sources or reducing water supply were needed.

- According to the total pumping rate of Scenario 5, the average intake of all cases was found to be about 760,000 m^3/year, satisfying the usual groundwater supply (266,000 m^3/year) in the study area.



SUMMARY

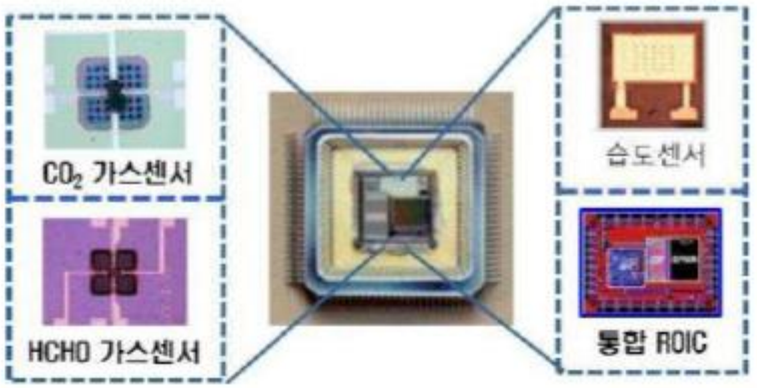
Scenario application for decision making

- 53 groups of 5 scenarios are evaluated in the present research
- The results of the depth to water table is obtained assuming that water demand is fully satisfied by the pumping rate from each group of pumping wells. It is expected that it will be possible to secure the necessary quantity and manage stable groundwater by applying the decisions from this research to determine whether the wells should operate or not.
- The results from this research is to support the decision-making in which group of pumping wells can be operated by considering both the monthly required water and depth to water table variation.
- If the average depth to water table reaches the critical value in the research area according to observation , it is difficult to secure the necessary quantity due to the existing irrigation, therefore, it is necessary to apply additional water sources
- If both the demand and the critical depth to water table limit are met, further research is needed for groundwater level depletion mitigation measure
- It is necessary to continuously observe whether or not the groundwater level decline limit is reached during the groundwater pumping scenarios application, and to stop the operation for stable groundwater management.

4. APPLICATION

- Monitoring system was installed where the pumping rate from each well and group of wells can be controlled and managed

- Necessity to construct conduct to easy the connection between the well in order to reach the water demand while avoiding groundwater level depletion



Monitoring site view

5. FUTURE RESEARCH

Future research

- How to keep groundwater level constant to preserve necessary water for emergency and drought
- Study a Managed Aquifer Recharge system as alternative for the study area
- Study the alternative of water pumping from different region for agricultural use in the study area