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Groundwater Flow and Hydrologic Budget for Sawa Lake in Iraq

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Abstract__The amount of water entering the lake and the amount of water leaked from the Sawa Lake for the period (2014-2015) were calculated. The amount of water contained in the limits (225,602,326m^3) and quantity of water leaking from the lake reached the limits (173,925,261,67m^3) and net amount of water entering the lake (51,677,065.12m^3).The mathematical model of the GMSv10 software was designed to simulate the groundwater movement of the study area in a grid. Total number of cells (1079) the cell area is 0.25 km^2 and the total area is about 300km^2. Several factors have been taken into account in this design: the nature of the change in hydraulic properties, hydraulic gradient, and the distribution of wells in the area and the availability of information on groundwater levels at specific points. The thickness of the cell depends on the upper and lower elevation of the aquifer.The GMS software is implemented throughout the fallowing scenarios:

Scenarios I: It was considered that the water levels in Sawa Lake are not affected by the groundwater levels in the area around the lake by considering the water levels in the lake is fixed

Scenarios II: The water levels of Sawa Lake were considered to be affected by the groundwater levels surrounding the lake by considering the water level in the lake is variable.

The steady state flow is the first step in determining the behavior of the system under normal circumstances. This helps to understand this behavior first and then use the results of this condition as initial inputs for the unstable flow of state that are the basis of the long-term behavior of the aquifer by different pumping processes. The model was run with wells in the area for three years and took a reading of the output drawdown and every six months, where The highest drawdown in the level of groundwater up to 10 meters after the operation of the model for three years and in the vicinity of the wells in the region.

Index Terms— Sawa Lake, Hydrologic Budget, Groundwater, GMSv10,

1. INTRODUCTION

The groundwater is considered as the main source of water in areas southern desert of Iraq, for lack of sources of surface water, and with the request increase on the water during the last years for the paucity of rainfalls, and the random drill phenomenon which which form a large danger on the groundwater exploitation with correct method. Therefore, we need to increase the studies and researches about locations and thicknesses of the aquifers,

Sawa Lake is a strange lake in Iraq characterized by the highest salinity value among the Iraqi inland waters. It is a mixo-mesohaline water body of no inflow and flowflow. The lake is an elongated closed basin with no tributary of surface water available to it. This lake may be fed by groundwater of the Euphrates and Dammam aquifers through system of joints, cracks and fissures. Its water level fluctuates during dry and wet seasons. Its water does not dry up because of the equilibrium state between water feed up and evaporation [1].

The water chemistry, which is unique among Iraqi lakes, suggests that, it is probably of relatively recent karstic origin and not a relic of a mid- Holocene origin. It formed over limestone rock. The water in this lake is extremely salty due to heavy evaporation in the searing heat of Mesopotamia, even more than the water in the Arabian Gulf.

The net flow of water to Lake Sawa was calculated in the same manner as [2] by calculating the amount of water received and the amount of water leaking from the lake and determining the amount of net water entering the lake. A relationship was also drawn between the elevation and the area of the lake and the volume of water stored in the lake.

The flow of groundwater was simulated in the study area using GMS v10 and the adoption of a modflow application from the program. The model was prepared according to the following scenarios. The expected drawdown in groundwater was calculated due to the operation of wells in the study area for a period of three years results were read for every six months.

Scenarios I: Water levels at Lake Sawa were not affected by groundwater levels in the area around the lake, given that the lake's water levels were constant

Scenarios II: Lake Sawa water levels were considered to be affected by the groundwater levels surrounding the lake, given that the water level of the lake is variable

This study aims to:

1- Calculating the capacity of the lake reservoir and preparing the elevation-volume-area curve
2- Calculate the net amount of water flowing to Lake Sawa
3- Simulating the movement of groundwater in the study area and determining the amount of drawdown in groundwater levels due to the operation of existing wells in the area through the use of GMS v10.

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2. General Descriptions And Location

There is no surface water source feeding the Sawa Lake. The source may be groundwater. It is a land locked lake with maximum length of 4.74 km and maximum width of 1.77 km isolated by gypsum barrier with total path of 12.5 km surrounding the lake. Sawa Lake lies between longitudes (44° 59' 29.01" and 45° 01' 46.61") and Latitudes (31° 17' 43.10" and 31° 19' 49.79"). Sawa Lake locates about 23 km to the west of Al-Samawa city, in Al- Muthanna province. It is accessible by road that goes parallel to AL-Atshan River a branch of the Euphrates River.

The Lake is free of mechanical sediments. Generally, there is no mechanical deposition except that fine dust particles derived mainly from the atmosphere [3]

The lake has an elongated shape with NW-SE trend Fig. (1). The study area is part of a gypsiferous plain, and it is characterized by a flat land, as part of the southern part of the Western Desert. The topographic gradient of this area increases generally from the northeast to southwest with average elevation 2.7m per Kilometer [4] this area is also characterized by several important phenomena such a Sabkha and sand dune.

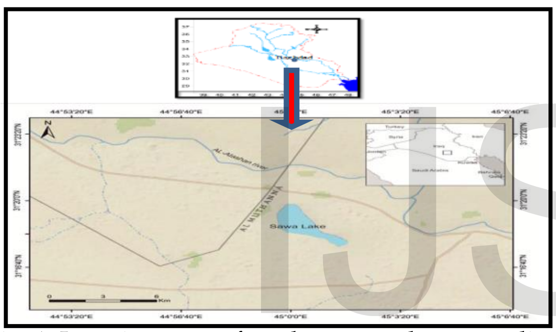

Fig. 1: Location map of study area and surrounding

3. Geology and hydrology of the study area

The Southern Desert represents the southern parts of Iraq Fig. (2) and Fig. (3). It lies to the west of Euphrates River and Shatt Al-Arab and extends to west and south into Saudi Arabia and Kuwait. It is divided from the Western Desert by Wadi Al-Khair. The eastern and, partly, the northern parts are located within the southern part of the Mesopotamian Zone. Whereas, the remaining parts belong to the Salman Zone of the Stable Shelf [5].From topographic point of view most of the Southern Desert, especially the external southern and southwestern parts represent rolling plain covered entirely with residual soil with angular fragments of limestone and chert and it is dissected by numerous shallow, basin like depressions and sharp escarpments, along it's southwestern boundary. The drainage pattern is interior, with most of the surface water percolating underground or forming rain pools (playas). The northern and northeastern parts of the Southern Desert are flat to slightly rolling areas, dissected by shallow wadis debouching into marshes and depressions bordering the Euphrates River. The eastern and southeastern parts are slightly rolling, sandy to gravelly, covered mostly by Dibdibba Formation, while considerably covered by Al-Batin Alluvial fan south of Basrah. In these parts, the wadis are very shallow and broad, draining into marshes and sabkha bordering the Euphrates River. Sand dunes exist in a belt of variable width from Samawa, along the northeastern side of the Southern Desert, to Iraqi – Kuwait borders. The Southern Desert is built up of very gently dipping sedimentary strata, composed mostly of carbonate sequences. Clay, sand and evaporite influences are common throughout them. The strata are inclined with very gentle slope towards the Mesopotamian Plain. The regional strike of these strata runs in a northwest – southeast direction being sub-parallel to the Euphrates River. In the south of the region it swings southwards to become in a north – south direction being sub parallel to the Shatt Al-Arab.

Al-Rawi and Al- Hadithi (1968) that the springs in Samawa salt deposits that are the main source of salt deposits. The source of Samawa springs are the water of the Euphrates aquifer, the marine water origin mixed and diluted with water of Dammam aquifer of meteoric water in percolation and rose through the joints, crakes and fissures., The relative high concentration of $CaSO_4$ in water is a result of the weathering of anhydrite rocks of the Rus Formation by the water of Dammam Formation. The source of the Sawa Lake water is the springs percolating from Euphrates and Dammam aquifers. The area is covered by recent alluvial and dune sediments that vary in thickness from1 to 10 m. It is underlain by recent salts deposit (Fig.4). Geology plays a role and is considered as an essential factor in determination of the quality of water according to the reports [6].

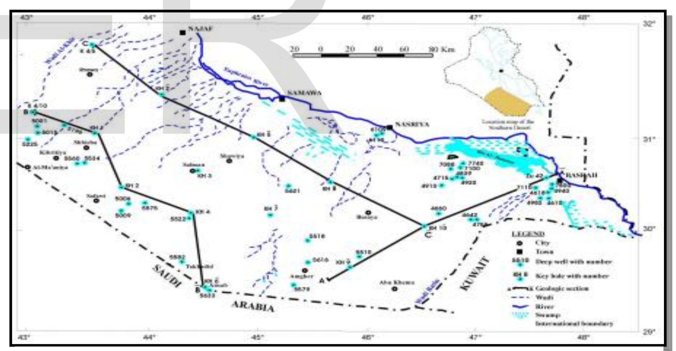

Fig. 2: Location map of the Iraqi Southern Desert, shows location of selected wells (modified after [7])

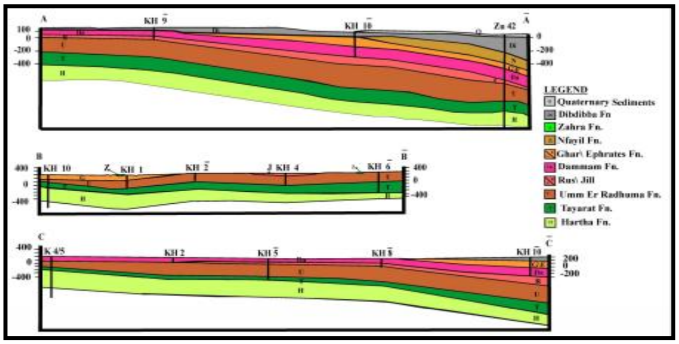

Fig. 3: Geological cross section in the Iraqi Southern Desert (after [7])

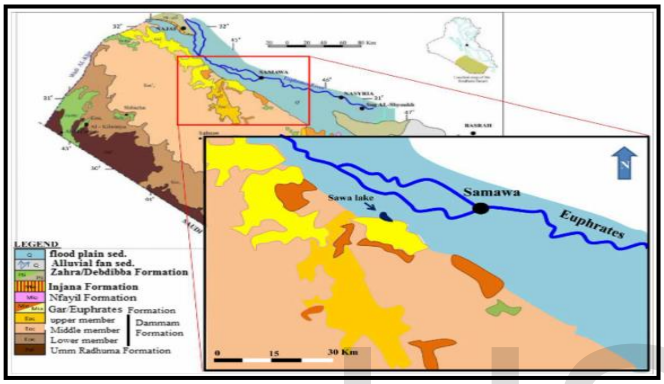

Fig. 4: Geological map of the study area and the surrounding areas (After [8])

4. Reservoir Characteristics

For the water management calculations are needed the reservoir characteristics in form of volume curves, elevation and area curves. These curves are based of the reservoir topographic description are explained the relation between volume and area curves form the elevation. For the needs of the simulation water balance analysis, the curves are described mathematically with few multi graded polynomials.

The characteristic curves indicating the Elevation – Volume – Area curve is shown in fig. (5), also the elevation – area – volume relation is given in table (1).

Table (1): Represents the elevation – area – volume relation

Elevation	*Area (m^2)*	*Δ Volume (m^3)*	*Volume (m^3)*
15	14000	0	0
15.5	735000	1700879	1700879
16	2520000	9231911	10932790
16.5	3430000	17780000	28712790
17	4480000	23660000	52372790

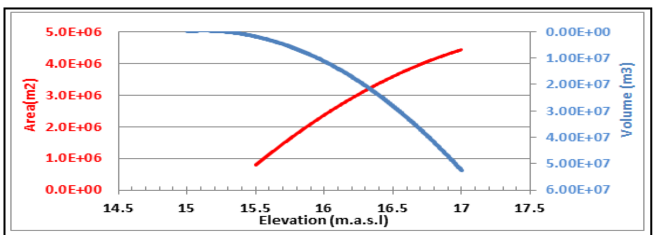

Fig. 5: Elevation– Volume– Area curve

5. Compute Groundwater Flow

The method used to calculate the net groundwater flow was the same as that used by Pollman and others (1991) and can be described as: The hydrologic budget for Lake. The hydrological budget formula assumes that the runoff to the lake is negligible. Analysis of changes in the size of the lake that occurred immediately after the rainstorms confirmed this assumption. The following equations were used to calculate the net flow of groundwater entering the lake [9].

$$Q_{net,i} = Q_{I_i} - Q_{O,i} = (\hat{Q}_{I,i} - \varepsilon_{\hat{Q}_{I,i}}) - (\hat{Q}_{O,i} - \varepsilon_{\hat{Q}_{o,i}}) \quad (1)$$

$$Q_{net,i} = (\Delta\hat{V}_i - \varepsilon_{\Delta\hat{V}_i}) - (\hat{p}_i - \varepsilon_{\hat{p}_i}) + (\hat{E}_i - \varepsilon_{\hat{E}_i}) \quad (2)$$

Thus an estimate $Q_{net,i}$ of can be computed as:

$$\hat{Q}_{net,i} = \Delta\hat{V}_i + \hat{p}_i + \hat{E}_i \quad (3)$$

Where:

$\Delta\hat{V}_i$: is the lake volume change during time interval i ,

$\hat{P}_i$: is precipitation,

$\hat{E}_i$: is lake evaporation

$\hat{Q}_{I,i}$: is ground-water inflow to Lake,

$\hat{Q}_{o,i}$: is leakage from Lake to the contiguous ground-water system,

$\varepsilon_{\hat{\theta}_i} = \hat{\theta}_i - \theta_i$ is the error associated with the estimate, $\hat{\theta}_i$, of the hydrologic variable (for example, is the estimate of the actual amount of precipitation that occurred during time interval i, and $\varepsilon_{p,i} = P_i - P$ is the error associated with the precipitation estimate)

The available data on the volume of the reservoirs in Sawa Lake for the period (2014-2015) were adopted and by the equation (3) the amounts of groundwater flow to the Sawa Lake were shown in Table (2) Based on the results of the calculations above, the volume of water coming to the lake during the period (2014-2015) was about 225,602,326 m^3. The volume of water leaking from the lake was 173,925,261,67m^3 and the volume of water reaching the lake was 51,677,065.12m^3.

Table (2): Monthly net groundwater flow to Sawa Lake

years	Month	Average lake volume (m3)	Change In Lake Volume (m3)	Precipitation (m3)	Evaporation (m3)	Net Groundwater Flow (m3)
2014	Jan	29,070,983.58	18,420,773.51	108,762.27	223,192.92	18,535,204.16
	Feb	28,975,333.08	-18,381,635.64	12,378.09	366,744.99	-18,027,268.73
	Mar	28,833,770.34	-18,323,476.53	52,912.17	597,554.75	-17,778,833.95
	Apr	28,718,989.74	-18,276,114.53	37,664.74	796,943.69	-17,516,835.59
	May	28,540,558.08	-18,202,121.93	2,105.11	772,927.94	-17,431,299.10
	Jun	28,435,168.62	18,158,209.31	0.00	781,226.95	18,939,436.26
	Jul	28,354,126.56	-18,124,335.76	0.00	856,274.62	-17,268,061.14
	Aug	28,437,255.54	18,159,080.37	0.00	874,405.71	19,033,486.09
	Sep	28,595,513.64	18,224,958.57	0.00	685,558.76	18,910,517.33
	Oct	28,736,380.74	18,283,302.45	87,325.58	492,614.86	18,688,591.73
	Nov	28,928,029.56	18,362,232.85	90,105.56	308,125.68	18,580,252.97
	Dec	29,026,462.62	18,402,572.54	0.00	264,075.34	18,666,647.88
2015	Jan	28,780,273.74	-18,301,425.14	2,114.42	347,821.43	-17,955,718.13
	Feb	28,685,579.75	-18,262,293.89	24,625.37	423,908.18	-17,863,011.08
	Mar	28,545,432.64	-18,204,149.24	22,456.58	662,469.05	-17,564,136.77
	Apr	28,431,799.84	-18,156,803.08	12,255.15	895,326.11	-17,273,732.11
	May	28,255,152.50	-18,082,842.36	4,187.98	1,189,736.60	-16,897,293.74
	Jun	28,150,816.93	-18,038,952.75	0.00	1,357,398.49	-16,681,554.26
	Jul	28,070,585.29	-18,005,099.00	0.00	1,632,550.72	-16,372,548.28
	Aug	28,152,882.98	18,039,823.33	0.00	1,258,524.62	19,298,347.96
	Sep	28,309,558.50	18,105,668.24	0.00	939,758.93	19,045,427.18
	Oct	28,449,016.93	18,163,988.36	5,604.14	742,899.00	18,901,283.21
	Nov	28,638,749.26	18,242,895.31	94,901.81	352,894.13	18,500,887.63
	Dec	28,736,197.99	18,283,226.94	72,536.33	291,553.78	18,502,244.39

6. Application of Numerical Model

The mathematical model of the study area was designed in the form of a grid consisting of 30 rows and 40 columns. The total numbers of cells are (1079). The cell area is (0.25) km2 and the total area is approximately equal (300km2) as shown in Fig. (5). several factors were considered in this design: the nature of the change in hydraulic properties, the hydraulic gradient, and the distribution of wells in the area and the availability of information on groundwater levels at specific points. The thickness of the cell depends on the upper and lower elevation of the aquifer.

The first step in designing the model is a definition of the conceptual model of the studied system which explains the behavior of that system. The main source of recharge in the open aquifer in the region is represented by rainwater which is a major input of the hydrological system while the pumping from wells is a main output of the system.

Groundwater modeling system (GMS,V10) was used in the representation of the model of the study area.

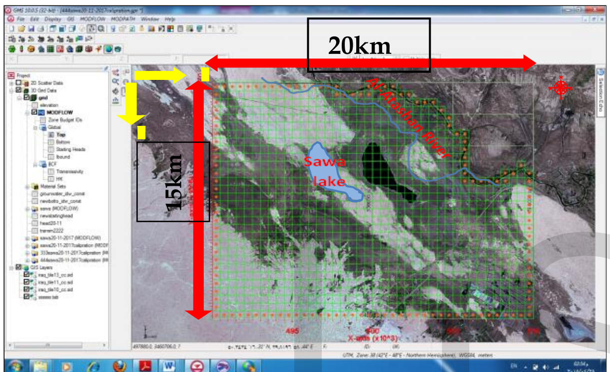

Fig.6: Grid design of study area

6.1. Initial and Boundary Conditions

Initial conditions represent the initial measurements of the groundwater level in each cell of the grid. This level can be considered as a reference whereas the calculated changes with time will be proportion for this level. The initial conditions can be obtained from the map of groundwater level Fig. (6) [10]. These initial conditions determine the hydraulic head as a function of space for a time equal to zero that means h = f (x, y, z; t = 0). The head distribution within the area at the initial time represent the initial condition in the steady state (t = 0). In this study, the boundary condition represents all nodes around the area of study which assigned as a specified head while all nodes outside the boundary of the modeled region are assigned as a fixed head (inactive cells) while the internal cells were considered as a variable head cells (active cells).

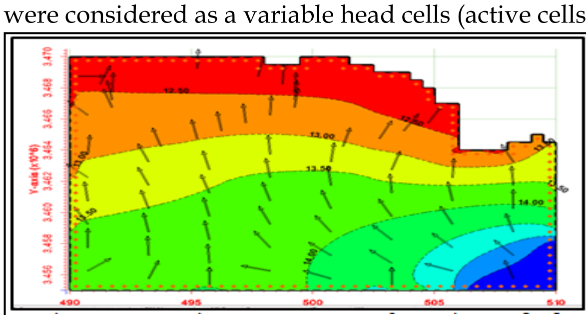

Fig. 7: Groundwater contour map for study area [10]

6.2. Numerical model Inputs

The accuracy of the model and confidence of the results depend on the availability and accuracy of information and how they describe the system which will be modeled in detail. The construction of any model requires the provision of information and data concerning the characteristics of the studied system in addition to determining the initial conditions and boundary conditions of the aquifer. The type of aquifer which will be modeled and the flow state determine the nature of the data needed for each cell of the numerical model network.

7. Steady State Flow Simulation:

A steady state flow is the first step in identifying the behavior of the system under normal conditions. This helps to understand this behavior first and then use the results of this condition as preliminary inputs to the unsteady state flow which is the basis for the long-term aquifer behavior with various pumping operations.

After the installation of all data and inputs of the numerical model, the model was run under stable flow conditions up to the field levels registered in the study area and the levels derived from the model to the highest level of conformance. This process often requires modifications in the values of the hydraulic conductivity or connectivity, The amount of water entering the model boundary is the ideal feeding of the layers of the aquifer and up to the levels to the match Fig.(7) and (8) shows a map of the similarity of the field aquifers with the derived numerical model for Scenarios one and Scenarios two respectively. It is noted that there is a good general consensus for these levels reflecting the general trend of flow. It is important to note that it is difficult to obtain a perfect match between the field and calculated values because the model is based on many theoretical assumptions. It is also difficult to have a porous media with the same characteristics on which the model is based and the same assumptions apply. Table (3) show the comparison between the field and derived levels of selected cells of the grid for Scenarios one.

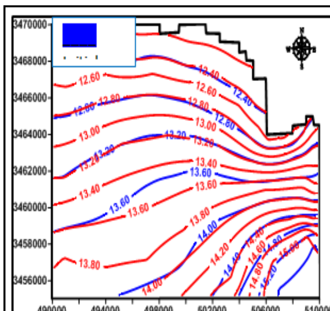

Fig.8: Initial and calculated head in the area of study for scenarios one

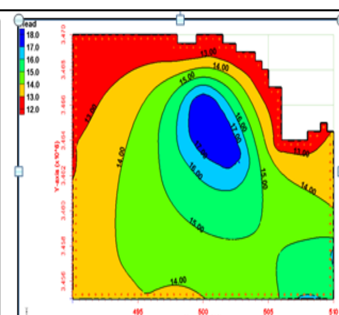

Fig.9: calculated head in the area of study for scenarios two

Table (3): Observed and calculated head values at selected nodal points for scenarios one

Cells I	Cells J	Observed Head (m)	Calculated Head (m)	Difference ΔH(m)
25	7	13.77	13.72	0.05
26	18	13.89	13.8	0.09
26	30	14.52	14.49	0.03
20	30	13.94	13.90	0.04
22	19	13.48	13.72	-0.24
22	10	13.66	13.62	0.04
16	7	13.26	13.24	0.02
14	18	13.36	13.30	0.06
13	28	12.98	13.00	-0.02
9	18	12.86	12.88	-0.02
9	7	12.77	12.78	-0.01
6	18	12.58	12.68	-0.10
4	26	12.13	12.15	-0.02
3	15	12.16	12.21	-0.05
3	4	12.4	12.4	0.00

Table (4):- hydrogeological properties for wells

Well No	Cells I	Cells J	Discharge (m^3/day)	Starting Head (m.a.s.l)	Bottom Elevation (m.a.s.l)	Transmissivity (m^2/day)
W1	6	8	500	12.96	-87.54	20.14
W2	10	29	398	12.58	-87.84	20.01
W3	17	18	164	13.5	-87.00	30.6
W4	19	9	231	13.5	-86.9	26.3
W5	18	34	165	13.7	-86.6	28.6

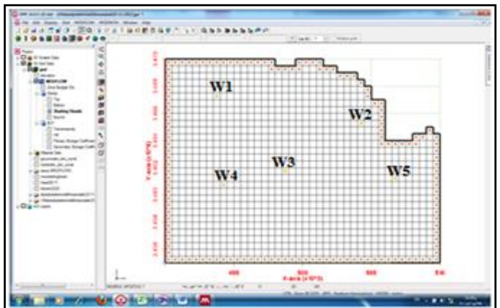

Fig.10: Wells location in study area

8. UNSTEADY STATE SIMULATION

This is the most important step in expressing the behavior of the aquifer as a result of its impact on pumping operations as it gives a long-term perception of this behavior.

The values of the resulting heads of the standard model for the steady flow state were used as primary inputs to represent the unsteady flow, and the wells in the modeled area Fig. (9) were operated and their characteristics are indicated in Table (4). As for the boundary conditions, the outer boundaries of the model were chosen as constant head. The use of these boundaries to represent the unsteady flow state is only if the studied system is part of a larger aquifer, provided that the boundaries are chosen away from the effect in the drainage areas, when the surface of the aquifer matches any water body, such as a sea or lake [11]. The rest of the cells were considered variable.

Due to no periodic readings data of the field aquifers during the operation of dug wells in the area and for long periods of time we were unable to calibrate the model under this case but the model was operated without running the wells. We did not notice any significant difference between the values of the heads of the model and the values of the resulting heads Run the model under Unsteady State for a period of two years with a six-month time increase taking into account only the wells already in the area for both scenarios.as shows in fig. (10) – (17).

When comparing the results of the drawdown of the scenario, it was noted that the drawdown in groundwater levels up to about 12 meters near the well (No1) and the rate of drawdown in the region up to 0.7 meters after two years operation of wells near the first scenario as for the second scenario, it was noted that the drawdown in groundwater levels up to about 10 meters near well (No1) and the rate of drawdown in groundwater levels is about 0.5 meters after two years of operation. This slight difference in the amount of drawdown indicates that the lake does not affect the groundwater levels in the area surrounding the lake.

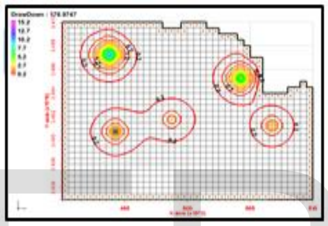
Fig. 11: Contour map for drawdown in the groundwater level when the model is run for 178days (scenario one)

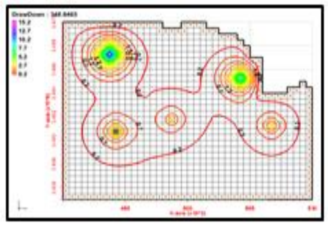
Fig. 12: Contour map for drawdown in the groundwater level when the model is run for 346days (scenario one)

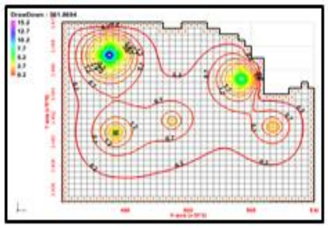
Fig. 13: Contour map for drawdown in the groundwater level when the model is run for 747days (scenario one)

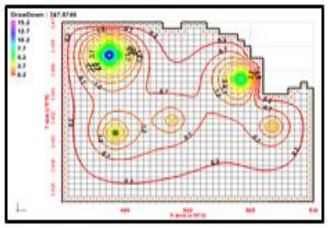
Fig.14:Contour map for drawdown in the groundwater level when the model is run for 561days (scenario one)

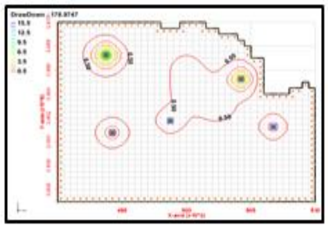
Fig.15: Contour map for drawdown in the groundwater level when the model is run for 178days (scenario two)

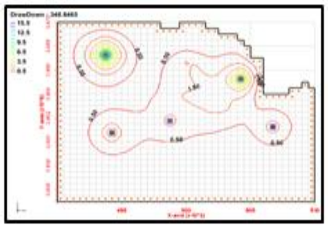
Fig 16: Contour map for drawdown in the groundwater level when the model is run for 346days (scenario two)

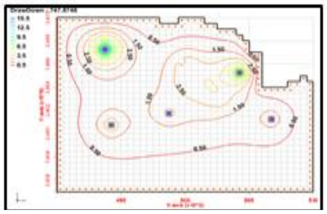

Fig.17: Contour map for drawdown in the groundwater level when the model is run for 747days (scenario two)

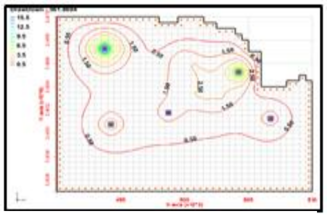

Fig 18: Contour map for drawdown in the groundwater level when the model is run for 561days (scenario two)

9. Conclusions

1. The groundwater movement from the south and south-east towards to the north in the study area
2. The reservoir capacity of Lake Sawa reaches 52372790 million cubic meters at level 17m.a.s.l
3. The amount of water entering the lake and the amount of water leaked from the Sawa Lake for the period (2014-2015) were calculated. The amount of water contained in the limits (225,602,326m^3) and quantity of water leaking from the lake reached the limits (173,925,261,67m^3) and net amount of water entering the lake (51,677,065.12m^3).
4. The highest drawdown in the level of groundwater up to 10 meters after the operation of the model for three years and in the vicinity of the wells in the region
5. The results of the operation of the mathematical model simulation showed that the water levels in Sawa Lake are not influenced by the change in the groundwater levels of the area surrounding the lake

10. Recommendations

According to the results of this study and for the purpose of updating and developing studies on the region independently we recommend the following:

1. Continuous monitoring of the flow of groundwater in the region through the drilling of control wells and different depths distributed in the region, in addition to the possibility of benefiting from them in the future in the development of the mathematical model, which simulates the movement and change of groundwater levels in the region.
2. Chemical examination of groundwater samples taken from observation wells that will be periodically drilled in the area for the purpose of determining the changes that will occur in groundwater quality.
3. Conducting observation pumping tests in specific areas of the region for the purpose of determining the geological properties of the aquifers in the area.
4. Install devices to measure the change of water depths in the lake with the chemical examination of water samples taken from the lake and periodically to determine the relationship between the change in the quality and levels of water in the lake with neighboring areas
5. Install stations to measure surface water discharges in the main valleys of the region and periodically
6. Install air monitoring equipment to record climate data (temperature, rainfall, evaporation, wind) for use in water resources assessment and future studies.

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