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Simulation of Interaction Between Groundwater and Surface Water in Safwan-Zubair Area, South of Iraq

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Abstract

Groundwater in arid and semi-arid regions, such as the studied area (Safwan Al-Zubair area, south of Iraq), is of specific meaning as a major source for domestic use and irrigation demand. There is a need to better understand the interactions between groundwater and surface water (Shatt Al-Basrah Canal). These interactions can negatively affect the quality of groundwater in this area, especially that the water of Shatt Al-Basrah Canal contains highly concentrated pollutants. The aim of the study is to investigate the temporal disparity of river-aquifer interactions and count the amount of river interchange among canal and aquifer. In this research, a new concept of paradigm will be advanced utilizing RIVER package of Groundwater River Paradigm (MODFLOW) for the simulation of river-aquifer interaction operations. Six monitoring wells are chosen to evaluate the preliminary and historical groundwater hydraulic heads for six months and then use all collected data in Modflow to execute the simulation of numerical modeling to assessment the interaction between surface water and groundwater. The amount of seepage out from the canal towards the aquifer was (64.99 m^3/day) in wet season (winter season), as a result of the high levels of the surface water compared to the hydraulic heads of groundwater. The amount of seepage in dry season towards the aquifer is equal to (336.8 m^3/day).

Keywords: Groundwater, Shatt Al-Basrah, Interactions, Simulation, Safwan-Zubair area.

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1. Introduction

Water safety is an urgent problem in the world due to climate alteration and inconsistency, and increased demand for water due to population growing and economic improvement. Both surface water and groundwater are considered necessary and important resources to meet water requirements for various uses. The groundwater in many countries is widely used in national economy for various aims, such as drinkable, industrialized water supply, irrigation and mineral water.

Groundwater is an important source in the study area and is usually used for agriculture, while there is a problem in the same area related to the Shatt Al-Basrah canal because the water of this canal is polluted. Usually, the amounts of pollutants that flow into the canal from the factories, as well as the drainage of wastewater [1]. There is a need to better understand the interactions between groundwater and surface water (Shatt Al-Basrah Canal). These interactions can negatively affect the quality of groundwater in this area; especially that the water of Shatt Al-Basrah Canal contains highly concentrated pollutants.

There are many studies conducted in this field (the interactions between groundwater and surface water), Jolly et al. (2008) conducted evaluation of groundwater-surface water interactions in dry/semi-dry wetlands and the ramifications of salinity for wetland ecology [2]. Fleckenstein et al. (2010) presented a study on groundwater-surface water interaction [3], the studied area in European Geosciences Union (EGU) General assembly was held in Vienna, and the researchers adopted numerical models to discover hypotheses and to improve new concept of models of GW-SW interactions. Brunner et al. (2010) conducted a modeling for surface water-groundwater interaction using Modflow [4], this work was bankrolled by the National Water Commission in Australia and the Flinders Research Centre for Coastal and Catchment Environments. Ghosh et al. (2014) presented a study on interaction of aquifer and river-canal network near well field [5]. Haridwar and Madlala (2015), evaluated the surface water and groundwater interaction in higher part of Berg River catchment, South Africa [6], the researcher adopted in his study several methods oncoming to locate surface water and groundwater (GW-SW) interactions to count and describe the goodness of water sources in a cracked crag aquifer scheme in higher part of water area of the Berg River. Cai et al. (2020) presented a study on the interaction between surface Water and groundwater in Yinchuan Plain, china [7], three exemplary shapes are chosen to build two-dimensional hydrogeological structure models, utilizing an integrated tactic connecting field exploration, numerical emulation, hydro geochemistry and isotope analysis. From a review of previous research can be concluded, numerical groundwater flow modeling is a useful means for better understanding the process of surface water and groundwater interactions.

The aim of the current research is to examine the time-based difference of river-aquifer interactions and count the quantity of river interchange among canal and aquifer. In this research, a new concept of paradigm will be advanced utilizing RIVER package of Groundwater River Paradigm (Modflow) for the emulation of river-aquifer interaction operations.

2. Location of the studied area

Shatt Al-Basrah canal is lying at Basrah region, south of Iraq. Shatt Al-Basrah Waterway is about (38 km) long. The coordinates of the Waterway are ranged 47º 00' E to 47º 60' E and 30º 20' N to 30º 60' N [8]. No any kind of works which can be anthropogenic have been stated along the Waterway banks. The water of Waterway exporter is Al-Hammar march in the north of the Waterway, crossing close to Zubair - Safwan area, and thereafter it emptying to Khor Al-Zubair Waterway. The Waterway of Shatt Al-Basrah is the second lengthiest, next the Shatt Al-Arab River, and the first water plushest Waterway in Basrah. Fig. 1 illustrate the plot of the area of study, Zubair-Safwan area, which is the southernmost part of Iraq, is one of the oldest areas that the groundwater has been exploited for nearly 50 years, agriculture in Zubair-Safwan area depends on irrigation utilizing groundwater. As an outcome of the growing needed for groundwater, particularly after the appearance of dryness in Iraq escorted by shortage of water, there is a great need for protecting the groundwater obtainability in the study zone [9].

Fig. 1 Illustrate the plot of the area of study.

3. Field works

Six monitoring wells are used for measuring the groundwater levels on daily basis (every ten days) throughout six months from December, 2021 till June, 2022. The locations of these wells are presented in Table 1.

The equipment utilized to execute the domain action contain, Differential Global Position System type (DGPS) TOPCON PN #: 51842, portable GPS for determining coordinates of wells, measurement tape type laser and Eco sounder for determining the deepness of water in each well. In the same period, three stations were chosen to measure the water surface elevations in the Shatt Al-Basrah channel. The collected data from the field works for measuring the groundwater hydraulic heads (six wells) and the water surface elevations of Shatt Al-Basrah canal are shown in Table 2 and Table 3, respectively. The locations of groundwater wells were gotten from the directorate of water resources / groundwater branch in Zubair city for the year 2021. All hand excavated wells and pipe wells in the research area pull groundwater for household plus agricultural uses. The pumping period in these wells during one day was obtained from the directorate of water resources / groundwater branch in Zubair city.

Table 1. local coordinates of monitoring wells.

Well Nos.	Easting	Northing
	UTM (Meter)	
W1	30.352993	47.748558
W2	30.346001	47.761002
W3	30.341999	47.771
W4	30.341999	47.737
W5	30.339399	47.745701
W6	30.33688	47.75783

Table 2. Observed hydraulic heads (m) for monitoring wells during the period (Dec. /2021 - June. /2022).

Date of measurement	Hydraulic heads (m)					
	W1	W2	W3	W4	W5	W6
10/12/2021	-0.83	-0.303	-0.726	0.545	-0.66	-0.446
20/12/2021	-0.84	-0.327	-0.726	0.555	-0.65	-0.446
30/12/2021	-0.83	-0.343	-0.726	0.545	-0.66	-0.438
10/1/2022	-0.78	-0.336	-0.67	0.545	-0.66	-0.439
20/1/2022	-0.79	-0.323	-0.696	0.545	-0.64	-0.437
30/1/2022	-0.83	-0.353	-0.726	0.565	-0.65	-0.438
10/2/2022	-0.81	-0.343	-0.706	0.545	-0.65	-0.447
20/2/2022	-0.8	-0.333	-0.726	0.545	-0.64	-0.446
30/2/2022	-0.82	-0.323	-0.736	0.535	-0.64	-0.446
10/4/2022	-0.8	-0.343	-0.716	0.515	-0.65	-0.46
20/4/2022	-0.85	-0.353	-0.756	0.505	-0.67	-0.459
30/4/2022	-0.83	-0.333	-0.716	0.485	-0.66	-0.46
10/5/2022	-0.84	-0.353	-0.731	0.485	-0.67	-0.456
20/5/2022	-0.84	-0.333	-0.746	0.505	-0.68	-0.456
30/5/2022	-0.86	-0.348	-0.746	0.495	-0.68	-0.496
10/6/2022	-0.85	-0.343	-0.736	0.475	-0.69	-0.476
20/6/2022	-0.84	-0.353	-0.726	0.475	-0.69	-0.476
30/6/2022	-0.86	-0.353	-0.746	0.475	-0.69	-0.476

Table 3. water surface elevations (m) of Shatt Al-Basrah Canal during the period (Dec./2021 - June. /2022).

Shatt Al-Basrah Canal			
Selected Sections 1, 2, and 3			
Date of Measurement	Hydraulic Heads		
	Up Stream / (0 km) From Zubair Bridge	(4.5 km) From Zubair Bridge	Down Stream / (9 km) From Zubair Bridge
10/12/2021	2.187	2.13	2.062
20/12/2021	2.1824	2.1244	2.0584
30/12/2021	2.1783	2.1223	2.0573
10/1/2022	2.1738	2.1198	2.0558
20/1/2022	2.1694	2.1124	2.0514
30/1/2022	2.1654	2.1104	2.0494
10/2/2022	2.1607	2.1097	2.0477
20/2/2022	2.0947	2.0467	1.9817
30/2/2022	2.0257	1.9687	1.9027
10/4/2022	1.9527	1.8937	1.8267
20/4/2022	1.8767	1.8167	1.7527
30/4/2022	1.7977	1.7337	1.6707
10/5/2022	1.7137	1.6487	1.5827
20/5/2022	1.6257	1.5577	1.4927
30/5/2022	1.5358	1.4668	1.3988
10/6/2022	1.4408	1.3748	1.3088
20/6/2022	1.3808	1.3143	1.2423
30/6/2022	1.3128	1.2443	1.1713

4. MODFLOW structure

The mathematical model is founded on the following two equations, Darcy's law and conservation of mass equation. The grouping of these two equations outcomes in a partial differential equation leading the flow of groundwater.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)-W=S_S\frac{\partial h}{\partial t} \tag{1}$$

Where,
K_{xx} and K_{yy} : are parameters of hydraulic conductivity over the x and y as well as the coordinates axes, which are presumed to be equivalent to the main axes of hydraulic conductivity (LT^{-1}).
h : is potentiometric head (L).
W : is a volumetric flow per unit magnitude and denotes resources and/or discharges of water (T^{-1}).
t : is time (T).
Ss : is the particular storing known as the percentage of the size of water which can be inserted per unit size of aquifer material per unit variation in head (L^{-1}).
MODFLOW solves Eq. (1) using finite-difference method in which the groundwater flow system is divided into a grid of cells. For each cell, there is a single point called a node, at which the head is simulated. The amount of all fluxes into and out of the cell should be equivalent to proportion of variation in storing in the cell (continuity equation). The studied area is discretized into (3690 Cells) which are equally cell size (100 × 100) m. The number of rows is equal to (41), while the number of columns is equal to (90) and number of layers equal to (1), the total area selected for groundwater modeling is equal to 269,7 km².

5. Concept of model

The conceptualization's method is one particular but extremely significant motif of the forming. The appropriate meaning of the ease of a known hydrologic scheme is the cornerstone in the choice of the appropriate mathematical paradigm. Fig. 2 displays the proposed concept of model of the superficial aquifer of the Quaternary sediments in the area of study. A two dimensions' mathematical paradigm is offered to simulate the river system in the superficial aquifer, in other words this emulation is constant for upper layer only. It is presumed that the basis of the higher part of aquifer is an impervious border, and heads do not vary in the vertical direction ($\partial h/\partial z = 0$), i.e. the activity of the deeper aquifer is negligible.

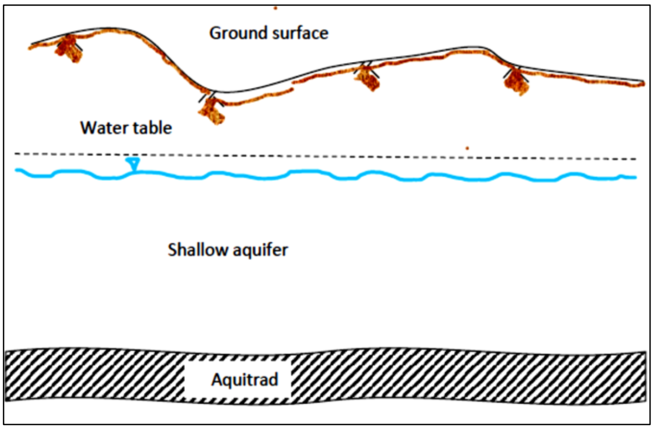


Fig. 2 displays the proposed concept of model of the superficial aquifer.

6. Initial assessment of hydraulic parameters

The hydraulic parameters of the aquifer system are provided to the model, and then the model resolves the groundwater flow and surface water equations. Two characteristics should be provided in the modeling of groundwater for unconfined aquifer, hydraulic conductivity and specific yield. The values of hydraulic conductivity (K) and specific yield (Sy) are used from previous research [10].

The river package is utilized to simulate the influx among an aquifer and a surface-water merit, like as rivers, lagoons or tanks. Rivers are well-identified by utilizing the River package dialog box of the Information Editor to allocate the next amounts to the paradigm cells in MODFLOW:

- (CRIV) [L^2T^{-1}] hydraulic conductance of the river bottom.
- (HRIV) [L] head in the river.
- (RBOT) [L] elevation of the bottom of the river bottom.
- [-] parameter number.

The worth CRIV of a river-cell is frequently specified as:

$$C_{RIV}=\frac{K.L.W}{M} \tag{2}$$

Where,
K : is the hydraulic conductivity of the river bottom substance.
L : is the length of the river in a cell.
W : is the width of the river.
M : is the thickness of the river bottom.
If CRIV is unidentified, it should be modified throughout a paradigm calibration.

7. Results and discussion

Model calibration involves adjusting values of model input limits in an effort to meet field requirements within some satisfactory standards. Modification to model parameters, stresses, and limitations will be limited to sensible limits that are founded on obtainable data. Model calibration needs that field circumstances at a site be correctly considered. Absence of good site representation may outcome in a model calibrated to a set of situations that are not descriptive of actual field circumstances. Calibration considered as a method for selecting paradigm constraints in order to achieve a pretty corresponding among observed and simulated hydraulic heads for the three months from December, 2021 to Febrauary, 2022. Whet, Calibration of paradigm has been accomplished out of methodical reallocation of hydraulic characteristics.

The calibration method is carried out based on the following statistical criteria. The statistical criteria between measured and calculated groundwater hydraulic heads for calibration and verification period are presented in Table 4 and 5, respectively. Fig. 3 illustrated the comparison between observed and calculated hydraulic heads.

$$Mean\ absolute\ error=\frac{1}{n}\sum_{i=1}^{n}\left|(h_m - h_s)_i\right| \tag{3}$$

$$Root\ mean\ squared\ error=\left[\frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i^2\right]^{0.5} \tag{4}$$

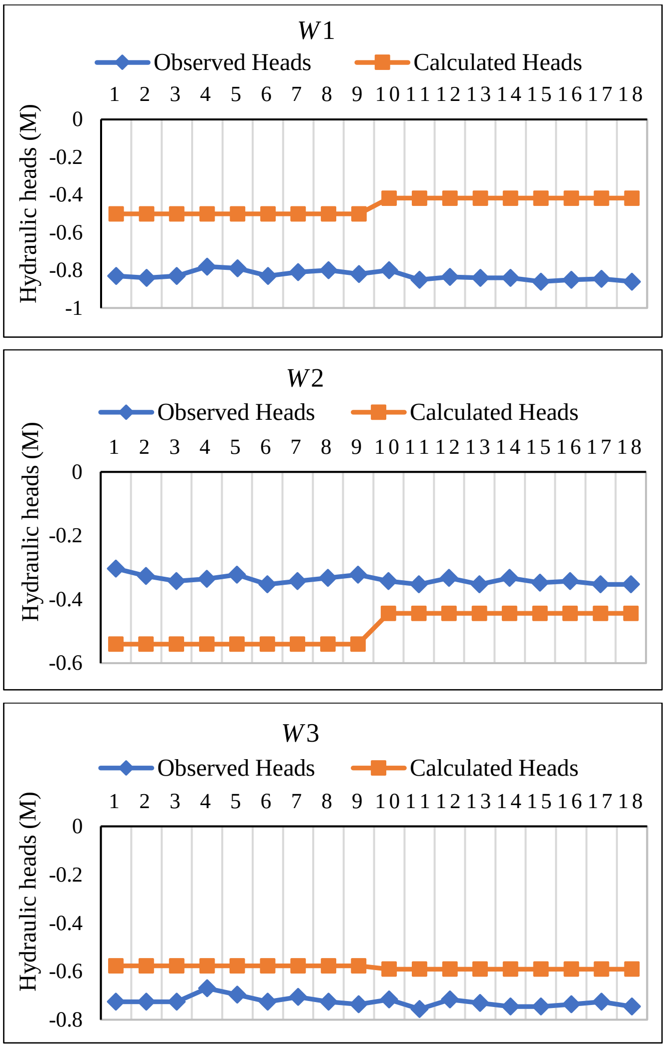
Where:
n : number of observation.
h_m : measured head.
h_s : simulated head.

Table 4. Statistics criteria for the unweighted groundwater levels for calibration period (Dec. /2021 - Feb. /2022).

Wells No.	Calibration statistics for period (Dec. /2021-Feb. /2022)	
	Mean absolute error	**Root mean squared error**
1	0.313	0.313
2	0.208	0.207
3	0.138	0.138
4	1.1	1.4
5	0.948	0.946
6	0.665	0.761

Table 5. Statistics criteria for the unweighted groundwater levels for verification period (Mar. /2022 - Jun. /2022).

Wells No.	Calibration statistics for period (Apr. /2022-Jun. /2022)	
	Mean absolute error	**Root mean squared error**
1	0.418	0.418
2	0.98	0.97
3	0.144	0.144
4	1.9	2.0
5	0.24	0.24
6	1.1	1.3



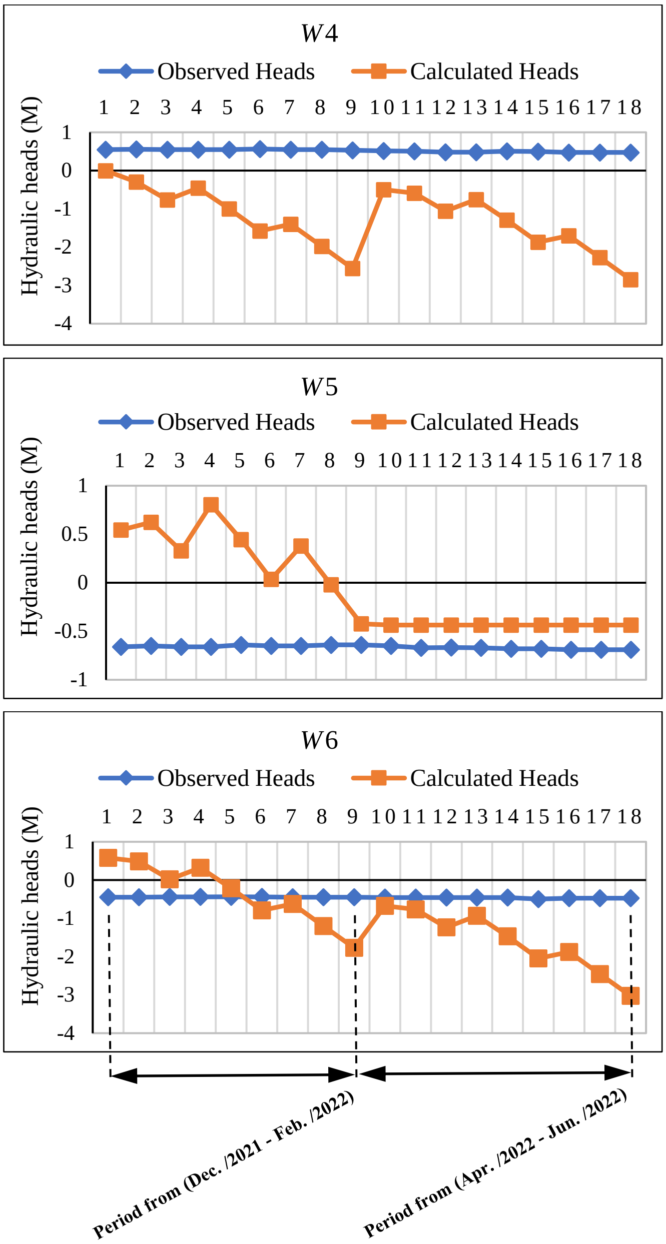


Fig. 3 Comparison between observed and calculated hydraulic heads.

Numerical resolution systems for concurrent neutralizations don't continuously outcome in a precise response, in specific, repeated solvers may stop repeating prior an adequately near estimate to the answer is achieved. A water budget delivers a sign of the whole suitability of the resolution. In the model package, the water budget is determined individually of the equation solution process, and in this logic may deliver separate indication of a lawful answer. The scheme of neutralizations resolved by the paradigm really contains of a river steadiness declaration for all paradigm cell. Continuousness must too be for the entire rivers into and out of the paradigm, the alteration among entire influx and entire discharge of water must equivalent the entire alteration in storing. This difference is then printed as a percent error. Inconsistency is calculated using the formula:

$$Discrepancy = \frac{100\,(INFL - OUT)}{\frac{(INFL + OUT)}{2}} \qquad (5)$$

Where:
INFL : is the entire influx to the scheme.
OUT : is the entire discharge.
Discrepancy : is the percentage inaccuracy expression. If the paradigm equations are properly resolved, the percentage error must be little. Tables 6 and 7 provide brief data on the flow system of the whole domain in winter and summer season respectively.

Table 6. Water budget of the entire paradigm area in winter season (the unit of flows is m^3/day).

```
File   Edit   Format   View   Help
PMWBLF (SUBREGIONAL WATER BUDGET) RUN RECORD
FLOWS ARE CONSIDERED "IN" IF THEY ARE ENTERING A SUBREGION
THE UNIT OF THE FLOWS IS [L^3/T]

TIME STEP    1 OF STRESS PERIOD    1

==============================================================
WATER BUDGET OF THE WHOLE MODEL DOMAIN:
==============================================================

       FLOW TERM            IN            OUT         IN-OUT
         STORAGE  7.9031763E+03  1.1068531E+04 -3.1653550E+03
   CONSTANT HEAD  0.0000000E+00  0.0000000E+00  0.0000000E+00
           WELLS  0.0000000E+00  2.0615759E+03 -2.0615759E+03
          DRAINS  0.0000000E+00  0.0000000E+00  0.0000000E+00
        RECHARGE  5.2918843E+03  0.0000000E+00  5.2918843E+03
              ET  0.0000000E+00  0.0000000E+00  0.0000000E+00
   RIVER LEAKAGE  5.8262646E+03  5.8912617E+03 -6.4997070E+01
 HEAD DEP BOUNDS  0.0000000E+00  0.0000000E+00  0.0000000E+00
  STREAM LEAKAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
INTERBED STORAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
MULTI-AQIFR WELL  0.0000000E+00  0.0000000E+00  0.0000000E+00
--------------------------------------------------------------
             SUM  1.9021324E+04  1.9021369E+04 -4.4921875E-02
 DISCREPANCY [%]  0.00
```

Table 7. Water budget of the entire paradigm area in summer season (the unit of flows is m^3/day).

```
File   Edit   Format   View   Help
PMWBLF (SUBREGIONAL WATER BUDGET) RUN RECORD
FLOWS ARE CONSIDERED "IN" IF THEY ARE ENTERING A SUBREGION
THE UNIT OF THE FLOWS IS [L^3/T]

TIME STEP    1 OF STRESS PERIOD    9

==============================================================
WATER BUDGET OF THE WHOLE MODEL DOMAIN:
==============================================================

       FLOW TERM            IN            OUT         IN-OUT
         STORAGE  7.0707629E+02  3.7627953E+05 -3.7557247E+05
   CONSTANT HEAD  0.0000000E+00  0.0000000E+00  0.0000000E+00
           WELLS  0.0000000E+00  2.0615759E+03 -2.0615759E+03
          DRAINS  0.0000000E+00  0.0000000E+00  0.0000000E+00
        RECHARGE  3.8099941E+05  0.0000000E+00  3.8099941E+05
              ET  0.0000000E+00  0.0000000E+00  0.0000000E+00
   RIVER LEAKAGE  0.0000000E+00  3.3683262E+03 -3.3683262E+03
 HEAD DEP BOUNDS  0.0000000E+00  0.0000000E+00  0.0000000E+00
  STREAM LEAKAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
INTERBED STORAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
MULTI-AQIFR WELL  0.0000000E+00  0.0000000E+00  0.0000000E+00
--------------------------------------------------------------
             SUM  3.8170647E+05  3.8170944E+05 -2.9687500E+00
 DISCREPANCY [%]  0.00
```

The data mentioned in the above table gave us concluding about the program explained that the incoming amount of water to the canal was (5.8262646E+03) m^3/day and the out coming amount of water was (5.8912617E+03) m^3/day and the amount of seepage out from the canal towards the aquifer was (64.99) m^3/day in wet season (Winter season) as a result of the high levels of the surface water compared to the hydraulic heads of groundwater. The amount of seepage in dry season towards the aquifer is equal to (336.8) m^3/day, as a result of the high levels of the surface water compared to the hydraulic heads of groundwater. It can be seen that the quantities leaking from the canal towards the aquifer are large in the summer compared to the quantities in the winter. In other words, the amount of polluted water leaking into the groundwater is greater in the summer.

6. Conclusions

A finite difference two-dimensional model is utilized for modeling the groundwater flow for the interaction between Shatt Al-Basrah Canal and groundwater. Trial-and-error procedure was utilized to calibrate the model. Hydraulic conductivity and specific yield were suitable to adjust after each simulation run until a good match was obtained for the simulated and observed hydraulic heads. A verification test is ordinarily added to check the model accuracy to represent this hydrogeologic system.

The interactions can negatively affect the quality of groundwater in the studied area; especially that the water of Shatt Al-Basrah Canal contains highly concentrated pollutants. The amount of seepage out from the canal towards the aquifer was (64.99) m^3/day in wet season (winter season), as a result of the high levels of the surface water compared to the hydraulic heads of groundwater. The amount of water in dry season towards the aquifer is equal to (336.8) m^3/day, as a result of the high levels of the surface water compared to the hydraulic heads of groundwater. It can be noted that the quantities leaking from the canal towards the aquifer are large in the summer compared to the quantities in the winter. In other words, the amount of polluted water leaking into the groundwater is greater in the summer.

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