MATHEMATICAL MODEL FOR GROUNDWATER FLOW WEST AL-RAZZAZAH LAKE, IRAQI WESTERN DESERT

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ABSTRACT

The groundwater in the studied area is found in two main aquifers, within Umm Er Radhuma – Dammam and Tayarat formations, which consist of intensively faulted, fractured and karstified limestone and dolomite. The source of aquifers recharge is subsurface flow from the regional aquifer that extends in the Saudi Arabian territory, in addition to small amount of precipitation that percolates and affects the upper aquifer precisely. Thus, groundwater flows from southwest towards northeast direction that coincides with the topographic slope. The aquifers are non homogeneous, where the hydraulic conductivity varies both vertically and laterally due to the effect of karst features and directions of fracturing. The whole aquifer system can be considered very interesting for its high discharge and recharge rates with negligible drawdown.

Mathematical model was designed to show the behavior of flow in the upper aquifer (Umm Er Radhuma – Dammam) and to study the possibility of increasing the discharge rate to 3750 l/ sec from the basin to utilize it in agricultural projects. Accordingly, the mean yearly drawdown through the period 2003 – 2018 is expected to be ranging from 4 m in the west to 50 m in the east, which in turn will effect the springs outflow that contribute in recharging of Al-Razzazah Lake.

نموذج رياضي لحركة المياه الجوفية
غرب بحيرة الرزازة، الصحراء الغربية العراقية

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المستخلص

تتواجد المياه الجوفية لمنطقة الدراسة في خزانين رئيسيين ضمن الصخور الجيرية والدولومايتية لتكوينات الدمام – أم الرضومة والطيارات والتي تتصف بكثافة الصدوع والشقوق وبانتشار ظاهرة الكارست فيها. يعد الجريان تحت السطحي المصدر الرئيسي لتغذية هذين الخزانين، إضافة إلى الترشيح الحاصل من مياه الأمطار على مساحة تكشف التكوينات الحاملة للمياه الجوفية عبر الصدوع، الشقوق والفواصل، حيث تجري هذه المياه من جنوب غرب المنطقة باتجاه الشمال الشرقي نحو بحيرة الرزازة متبعة الانحدار الطوبوغرافي. يتصف هذين الخزانين بطبيعة ناضحة غير متجانسة مع تباين في قيم معاملات الناقلية والنفاذية من موقع لآخر، كما يتصل الخزانين هيدروليكيا فيما بينها كلما اتجهنا شرقا من خلال كثرة الشقوق والفواصل، وتمتاز بقابلية عالية على استعادة منسوبها بسبب سرعة التغذية العالية فيها.

تم تطبيق نموذج رياضي لحركة المياه الجوفية لخزان ام الرضومة – الدمام، وتم اعتماد هذا النموذج لأجل دراسة وضع المنسوب الجوفي عند زيادة التصريف الحالي للمنطقة إلى 3750 لتر/ ثانية للفترة مابين الأعوام 2003 - 2018، وتبين أن مستويات المياه الجوفية ستكون في هبوط مستمر يتراوح مابين 4 متر غربا إلى 50 متر شرقا وهذا بدوره سيؤثر على استمرارية تدفق العيون التي تميز المنطقة.

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INTRODUCTION

The studied area is located in the Western Desert of Iraq. It extends from Wadi Al-Sluge in the west, Wadi Al-Ghadaf in the north, Wadi Al-Ubaiyidh in the south and the Euphrates Fault Zone in the east, between longitude 42º 00' - 43º 45' East and latitude 32º 00' - 33º 15' North (Fig.1).

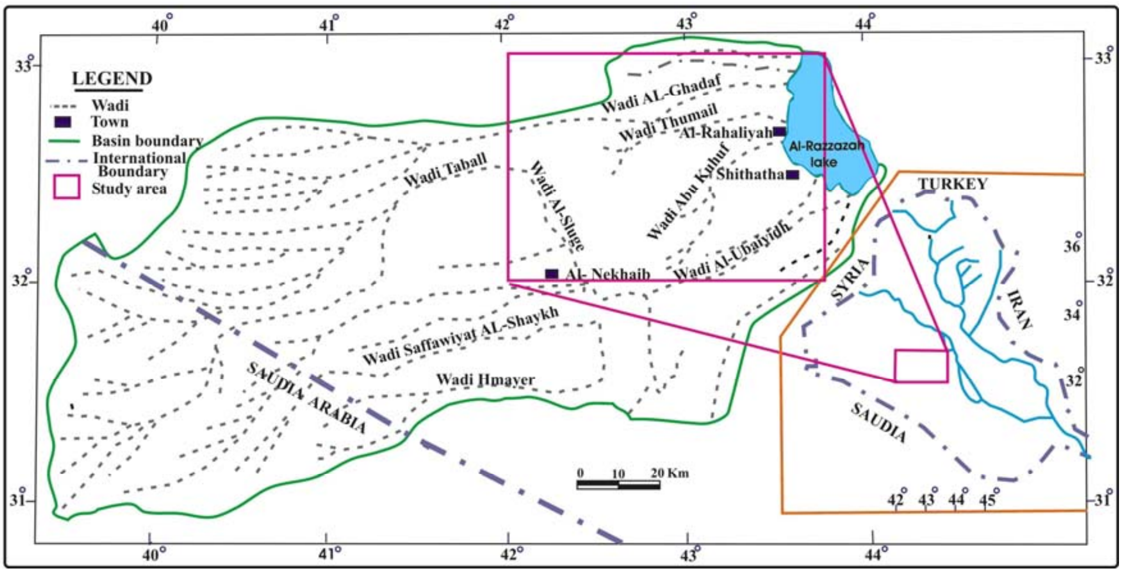

Fig.1: Location map of Al-Razzazah Basin

According to the data recorded by the Iraqi Meteorological Organization (2002), the area is of desert arid climate with high annual evaporation rate, which is about 1079 mm and low annual precipitation, which is about 69 mm, in the recharge area. The potential rate of evaporation in the Western Desert is several times more than the average rainfall; rainfall is rather sporadic, but it occurs very rapidly during a short time. Some of the rain water infiltrate into the ground surface and percolate to the aquifer as a recharge, or lost by evaporation. The study also concerns with the role of deep faults, which act as passages for water to move through different aquifers in its way to springs.

GEOLOGICAL SETTING

The basin is mostly covered by the Nfayil Formation of Middle Miocene age, which forms scattered outcrops in the eastern part of the basin (Fig.2), while the Zahra Formation, of Pliocene – Pleistocene age covers the middle part of the basin, except along the southern borders, where Umm Er Radhuma Formation of Paleocene age is exposed, followed by Dammam Formation of Eocene age. Patches of Euphrates Formation of Early Miocene are scattered in the middle part of the basin, and small area of Tayarat Formation of Late Cretaceous age crops out in the northwest (Sissakian, 2000).

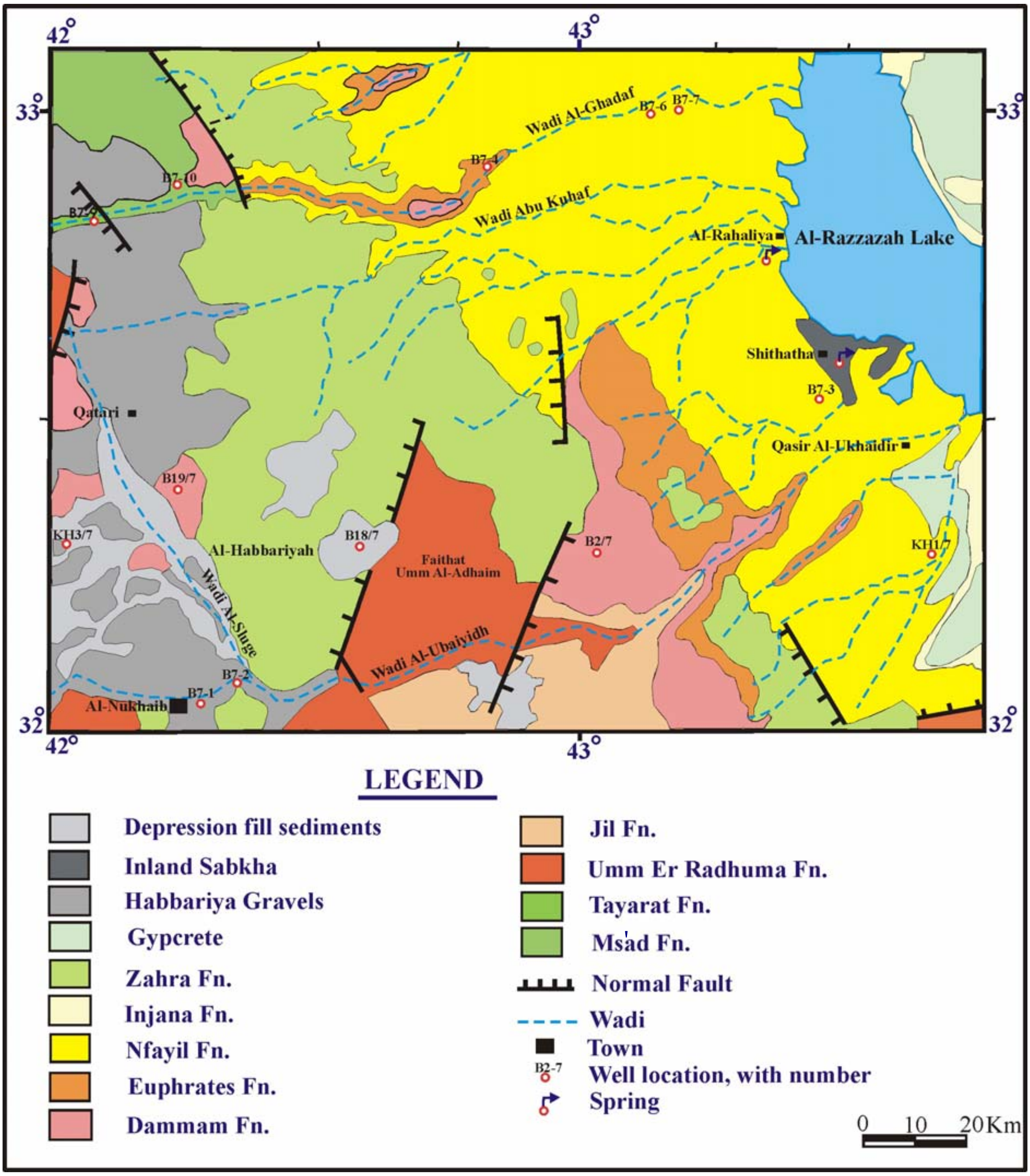

Fig.2: Geologic Map of Al-Razzazah Basin
(modified from Sissakian, 2000)

The stratigraphic sequence deduced from the concerned key wells shows that the deepest reached formation is the Tayarat Formation (Fig.3) (Consortium, 1977). Structurally, the area is located within the Stable Shelf; it extends within the Salman – Hadhar and Ma'aniya – Rutbah Zones (Fig.4) (Al-Kadhimi *et al.*, 1996). The Euphrates Fault, which belongs to Abu Jir Fault Zone extends along the eastern boundary, that is a deep northwest – southeast trending fault zone. Four main sets of faults are recognized in the area (Fig.5); the east – west trending faults are the oldest deep basement faults (A-Kadhimi *et al*., 1996); the north – south trending faults, which belong to the Early Cambrian; the northeast – southwest trending deep faults, which is believed to be related to the early basement formation and the northwest – southeast trending faults, which are generally long faults. Al-Mubarak and Amin (1983), assumed the faults to be inherited from the Najd Orogeny and pass through periods of reactivation, especially during the Mesozoic – Tertiary that represents period of successive phases of Alpine Orogeny.

The folds are mostly wide and subsurface folds, with prevailing axes direction toward north, south and northwest – southeast; these forms reflect the morphology of the basement, which has the horst and graben forms structure. Subsurface folds are important in the hydrogeological studies because they could behave as water divides and/ or as separators between adjacent basins (Al-Shamma'a, 1993).

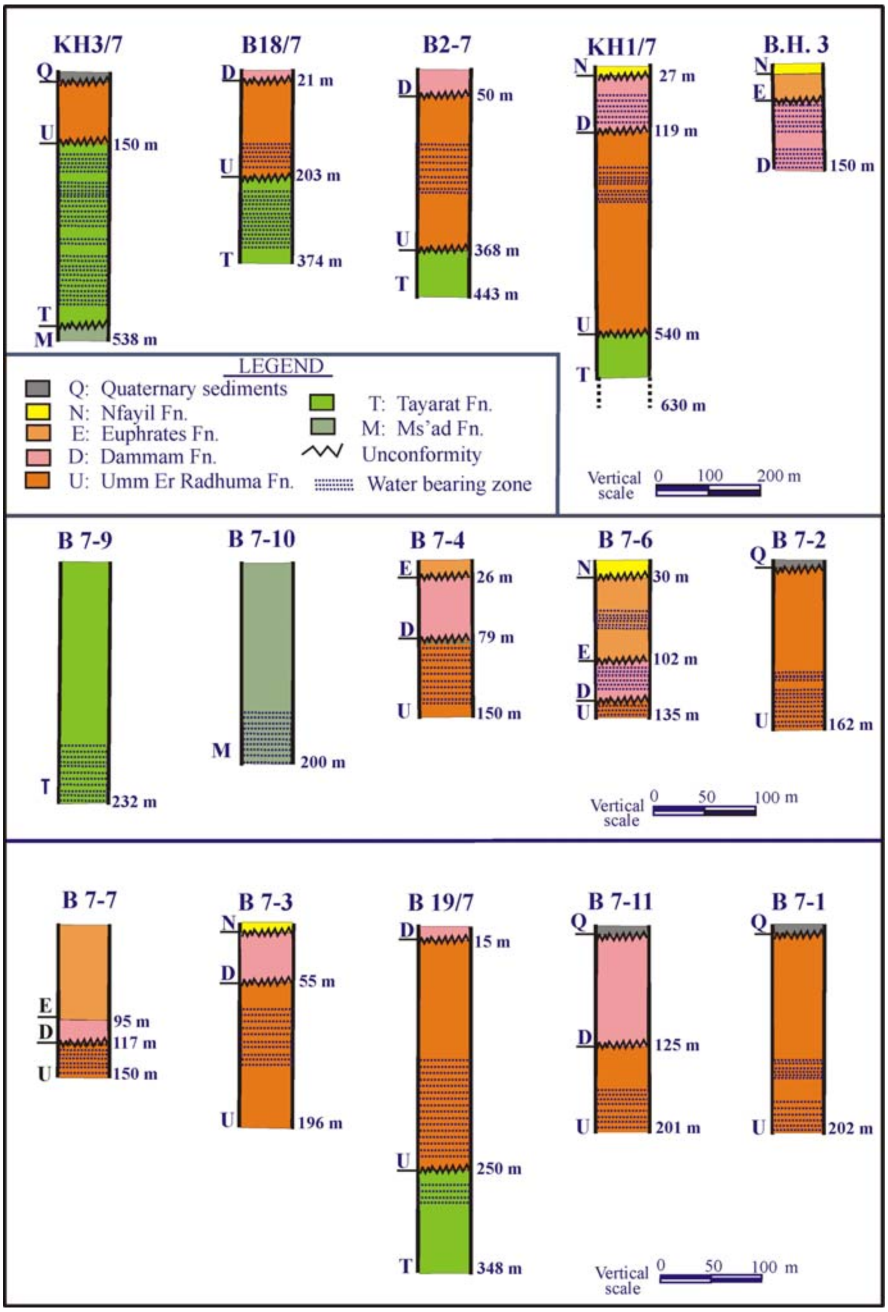

Fig.3: Stratigraphic columns of the drilled wells in the studied area (modified from Consortium, 1977)

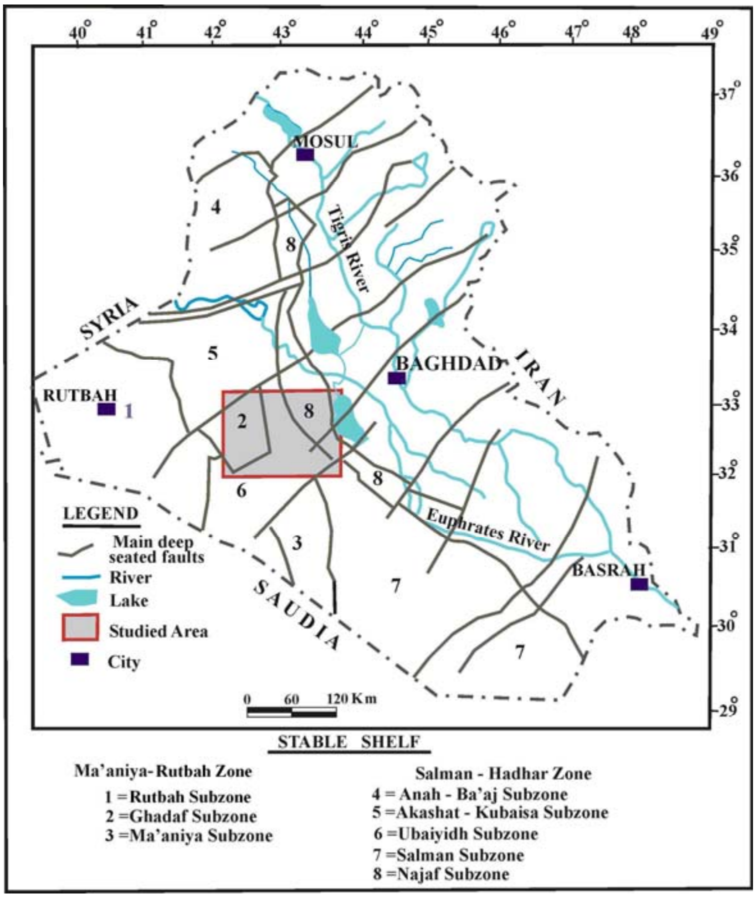

Fig.4: Tectonic position of the studied area
(modified from Al-Kadhimi *et al.*,1996)

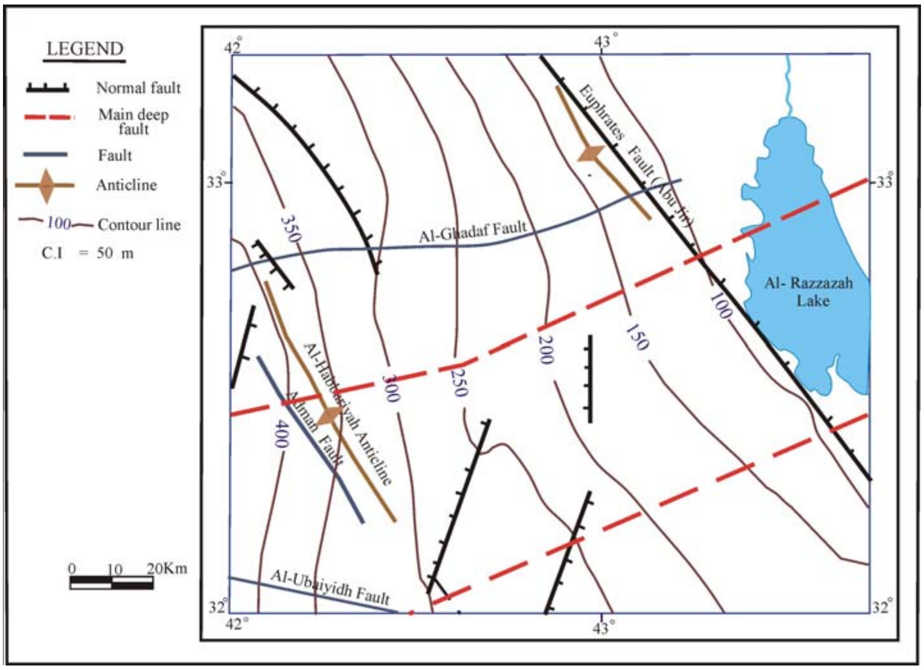

Fig.5: Structural map of the studied area
(after Al-Azzawi, 1988; Al-Kadhimi *et al.*, 1996 and Sissakian, 2000)

HYDROGEOLOGY AND HYDRAULICS OF THE AQUIFERS

The basin consists of two aquifers, the Dammam – Umm Er Radhuma and Tayarat carbonate aquifers. The regional groundwater flow pattern is from southwest to northeast. The piezometric surface is relatively high, and the water moves from the main recharge area that extends along the southwest toward the Euphrates Fault Zone and discharges there (Fig.6). The Umm Er Radhuma – Dammam carbonate aquifer is one of the most important underground reservoirs in the studied area, which has been subjected to intensive recent investigations. The thickness of the aquifer increases toward the northeast, and the aquifer is gently dipping in the same direction. The aquifer is almost confined, where the transmissivity values ranges from (120 – 6000) m^2/ day, indicating that the aquifer is non homogeneous, while the specific yield is in the range of (0.1 – 37) l/ sec/ m (Al-Ghazi, 2004).

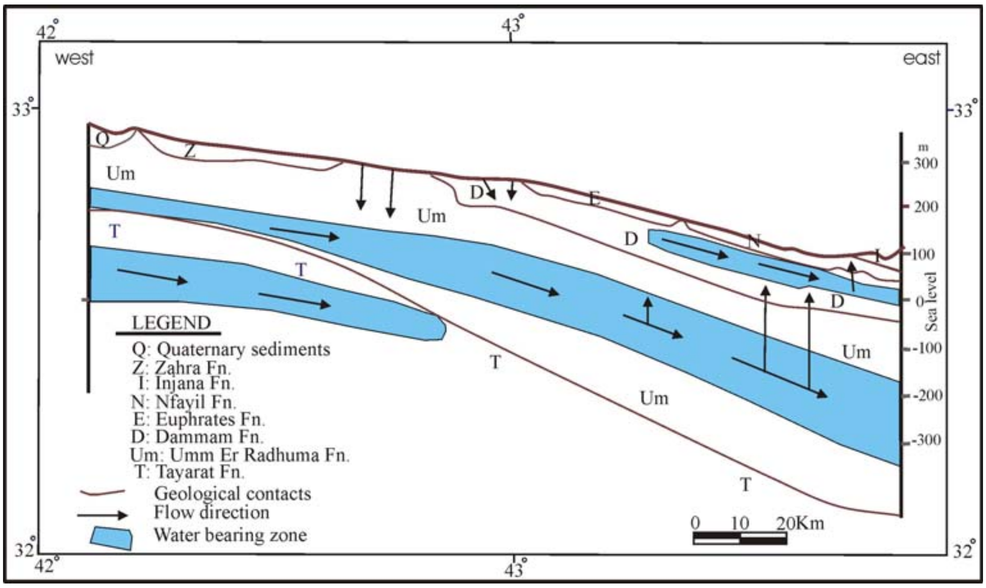

Fig.6: Hydrogeological model of the studied area

The Dammam Formation is separated from the Umm Er Radhuma Formation by a sequence of marl and marly limestone that belong to the Jil Formation of Early Eocene, which forms an aquiclude of (20 – 50) m, in thickness. Therefore, hydraulic connection appears between the ground water of Dammam and Umm Er Radhuma formations, east of longitude 43°. Consequently, the ground water in Dammam Formation is recharged from Umm Er Radhuma Formation. The aquifer is gently dipping from west to east, and higher karstification occurs along the wadis accompanied by shallow sinkholes. Moreover, there are number of depressions on the surface, which facilitate the surface recharge to reach the aquifer eastern of the area. The aquifer recharges from surface water also in areas where Umm Er Radhuma Formation is exposed, in addition to the main recharge source from the regional aquifer in Iraq and Saudi Arabia, as a subsurface flow.

The lower zone of Umm Er Radhuma Formation, which consists of alternations of impermeable marly limestone and marly dolomite beds, range in thickness from (200 – 300) m forms the impervious beds that confined the deeper Tayarat aquifer. The Tayarat carbonate aquifer is less fissured and hence is totally recharged from the subsurface flow. The transmissivity of the deep aquifer ranges between (0.5 – 128) m^2/ day, while the specific yield is (0.01 – 2.15) l/ sec/ m. These variations indicate that the Tayarat aquifer is also of inhomogeneous nature (Al-Ghazi, 2004).

APPLICATION OF THE MODEL ON THE STUDIED AREA

Conceptual model is created through the evaluation of the hydrogeologic data to provide a picture of the hydrogeologic setting over some regions of interest (Chiang and Kinzelbach, 2002 – 2003). The continuity of the model is replaced by a set of discrete nodes in a grid pattern covering the modeled area. A block centered grid technique was used, where the nodal points fall in the center of the grid. The grid consists of 9 columns and 7 rows, giving a total number of 63 nodes, with a cell width of 15 Km along both the columns and rows (Fig.7).

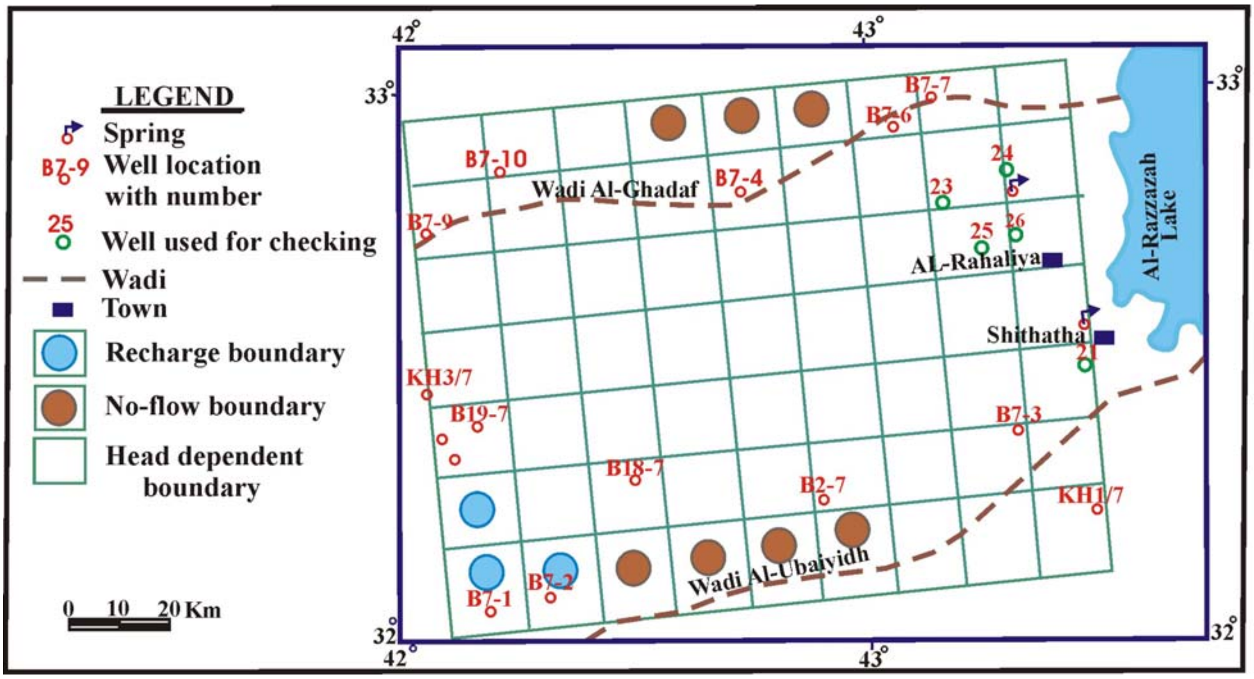

Fig.7: The model network of the studied area, showing the location of active grid cells and boundary conditions

A unique solution for the groundwater flow differential equations requires accurate definition of the boundary conditions, which describes the physical boundaries of the hydrogeological system (Reilly, 2001). The specific representation of the hydrogeological boundaries as model boundary conditions is as follows:

- **Boundary conditions associated with physical features at the lateral extent of the model:** The water divide of Kasra – Habariyah, which is located in the southwestern corner of the studied area, was treated in the model as a specified flow boundary due to its representation as a major source of subsurface inflow to the groundwater system. The northern and southern margins of the area were treated in the model as no-flow boundary that runs parallel to wadi Al-Ghadaf and wadi Al-Ubaiyidh Faults. Eastern margin was treated as a head-dependent flow boundary, since it represents the major discharge boundary for the system along a strip of springs that are aligned along the Euphrates Fault Zone.
- **Boundary conditions associated with physical features at the bottom of the model:** The boundary of the model is represented as a no-flow boundary condition due to the presence of a thick layer of marl and marly limestone corresponding to the underlying Tayarat Formation.

- **Boundary conditions associated with physical features at the top of the model:** The top of the model is represented by the water table elevation changes in the unconfined parts of the aquifer in areas where Umm Er Radhuma Formation is exposed, and by the elevation of the upper boundary of Dammam Formation, in areas where the aquifer is confined.

For steady state condition, there is no change for the head with time; hence a constant-head boundary was assigned to give the amount of the subsurface flow needed to maintain the water table in the observed position. The generated subsurface flow (inflow), which was quantified for the external cells, is then used for the constant flux boundaries during the no-steady state case. Therefore, all the constant head boundaries are changed in the non-steady state case to boundaries of constant flux of non-zero.

The input data for each cell, in the layer required by the computer code are dependent on the definition of the layer types. The aquifer is classified as confined/ unconfined aquifer within the studied area. Therefore, elevations of the bottom and top of the aquifer in addition to the hydraulic conductivity of the aquifer for each node are required, in order to account the anisotropy of the aquifer. The storage coefficients of the confined and unconfined sections are required only for transient simulation. The finite-difference flow equations in three dimensional terms require the definition of the conductance between the two vertically adjacent nodes (Anderson and Woessner, 1992). The conductance is defined as the hydraulic conductivity of the aquifer divided by its thickness. Some cells are classified as confined aquifer within the area; therefore, the transmissivities of this aquifer are needed in addition to the storage coefficients, if the simulation is transient.

The calibration of the model is the only way to verify the mathematical model with the measured data (Domenico and Schwartz, 1999). The model is calibrated for steady and non-steady states, where the steady state calibration process is restricted to few points, due to the lack of the hydraulic data. Therefore, the most important objective is to give a regional picture of the potentiometric surfaces as well as the ground water flow direction. Manual trial and error calibration is adopted in this study to adjust the input data of hydraulic conductivity (or transmissivity), storage, leakage across a confining layer used as a boundary flux to and from a surface water body and designation of the boundary conditions.

■ Application of the model in pre-development condition

The model was designed using a discharge rate of 247 l/ sec acquired from eleven wells distributed within the basin with an average discharge rate of 22.4 l/ sec for each well (Table 1). The steady-state calibration shows that the system is highly sensitive to the hydraulic conductance. Calibration involved making minor adjustments to this parameter until the steady-state model was successfully calibrated. The calibration criteria involved a good visual comparison between the measured and simulated potentiometric surfaces (Fig.8).

■ Application of the model in prediction and agricultural investments

Due to the results of the promising zones obtained from the hydrogeological evaluation (Fig.9) and to satisfy the needs of the groundwater for agricultural development, a project of increasing the discharge rates and utilizes them for long period (Leijnse and Hassan Zadah, 1994) was carried out.

Table 1: Drilled wells information (after Consortium, 1977)

Water point	Latitude / longitude	Elevation m (a.s.l.)	Drilling depth (m)	Water level: from surface (m) / above sea level (m)	Discharge: l/ sec / m^3/ day	Pumping time (minute) / Recovery time (minute)	ΔS Maximum drawdown (m)	Transmissivity m^2/ day	Hydraulic conductivity m/ day	Storage coefficient
KH1/ 7	32° 16' 07"	90.22	629.7	20.55	25.5	860	0.39	15506	172.28	$6.37x10^{-4}$
	43° 37' 15"			69.67	2203.2	20				
B7 – 7	32° 59' 11"	101.4	150	15.50	3.46	1440	16.42	27	0.442	–
	43° 08' 10"			85.90	298.94	600				
B7 – 6	32° 59' 07"	12.3	150	22.09	14.07	2880	18.4	171	1.29	–
	43° 08' 00"			90.13	1215.04	900				
B7 – 4	32° 53' 03"	170.7	150	36.9	25.55	2880	1.45	2692	79	–
	42° 48' 30"			133.3	2207.52	9				
B7 – 9	32° 48' 14"	358.92	232	173.74	19.05	2880	0.23	15529	316.91	–
	42° 02' 26"			185.08	1645.9	0.5				
B7 – 1	32° 02' 51"	311.8	202	121.75	12.491	750	21.32	120	3.529	–
	42° 13' 48"			190.05	1079.22	510				
B19/ 7	32° 21' 02"	326.9	268	173.3	25.55	900	0.81	6953	71.97	0.011
	42° 08' 08"			189.69	2207.5	1020				
B18/ 7	32° 18' 33"	285.36	374	96.31	23.9	1320	1.36	3455	33.22	–
	42° 32' 58"			189.05	2064.96	1440				
B2/ 7	32° 16'	234.19	443.7	139.78	25.55	2880	2.44	3672	41.72	–
	43° 01' 04"			94.22	2207.5	25				
B7 – 3	32° 33' 26"	95.6	196	32.12	25.55	2880	1.31	1879	37.97	–
	43° 26' 38"			72.48	2207.5	1260				
B7 – 2	32° 04' 48"	287.86	162	97.95	–	–	–	–	–	–
	42° 21' 52"			130.91	–	–				

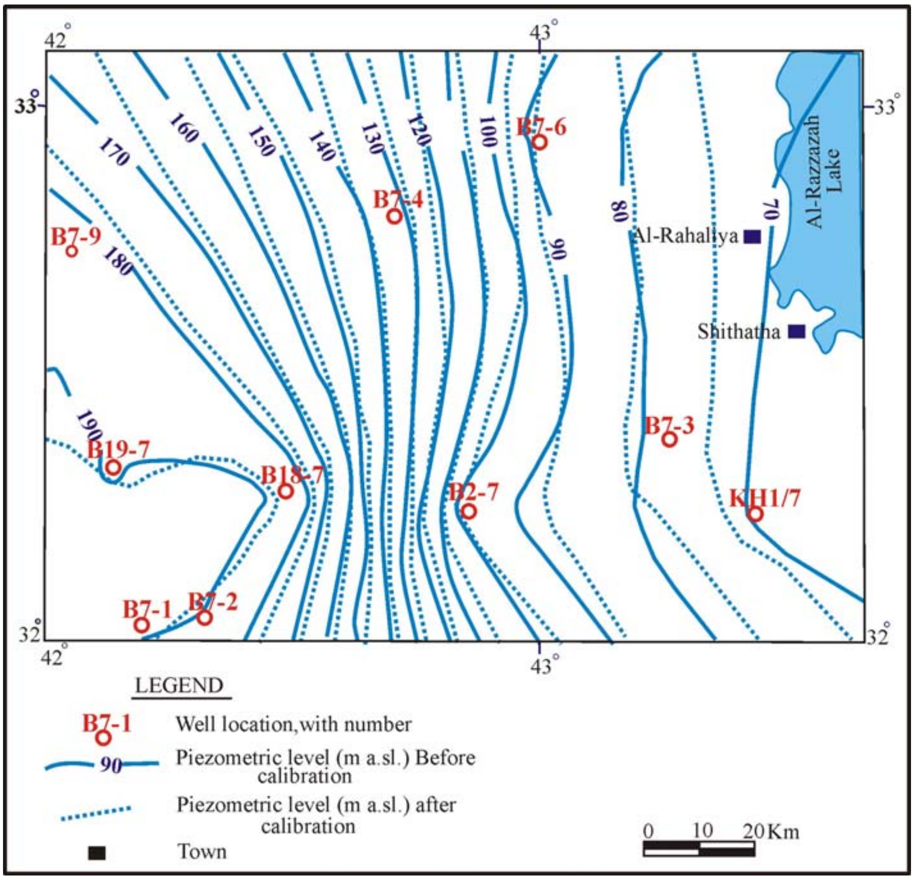

Fig.8: Steady-state calibration for pre-development condition

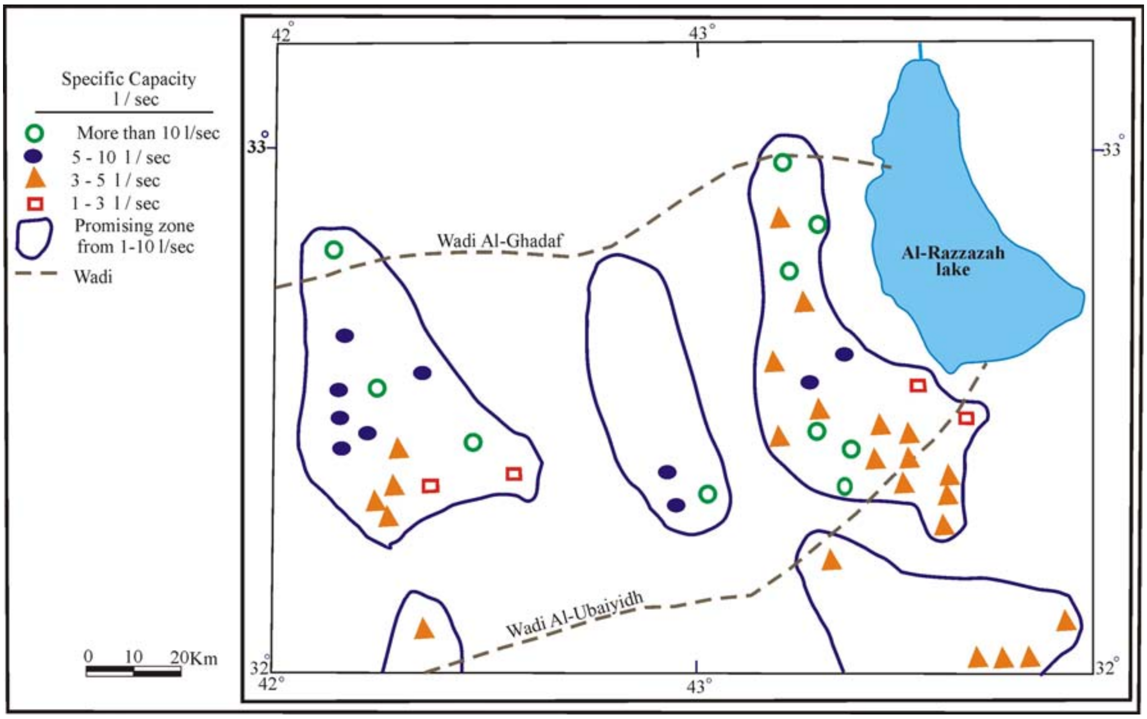

Fig.9: Promising zones for groundwater utilization in the studied area
(Al-Furat State Company, 2000)

A program for drilling of 150 production wells with an average discharge rate of 25 l/ sec for each well is suggested to improve the agricultural conditions in the basin. These wells are distributed within the promising cells, those which posses high specific yield. According to this fact, the wells are chosen to be drilled within a strip that runs to the west and along Al-Razzazah Lake (within the cells 2.8, 3.8, 4.8, 5.8 and 6.8). Each cell contains 30 wells with a separation distance of 500 m, to avoid drawdown interference due to pumping. The basin model is used to predict the probable changes in water levels for the period 2003 – 2018 due to continuous dewatering of 3996.7 l/ sec, which includes the existing discharge from the basin (247 l/ sec), in addition to the suggested increase in discharge from the new wells (3750 l/ sec). The model is run in three production periods, each period represents a five year time starting from 2003 to 2018 (Figs.10, 11, 12 and 13). The predicted drawdown ranges from 4 m, in the western parts of the basin to 50 m near Al-Razzazah Lake. This result is documented in the field by recognizing that some springs start to deplete due to the increase in abstraction against a decrease in the amount of recharge, as a result of retardation in the amount of precipitation and subsurface flow.

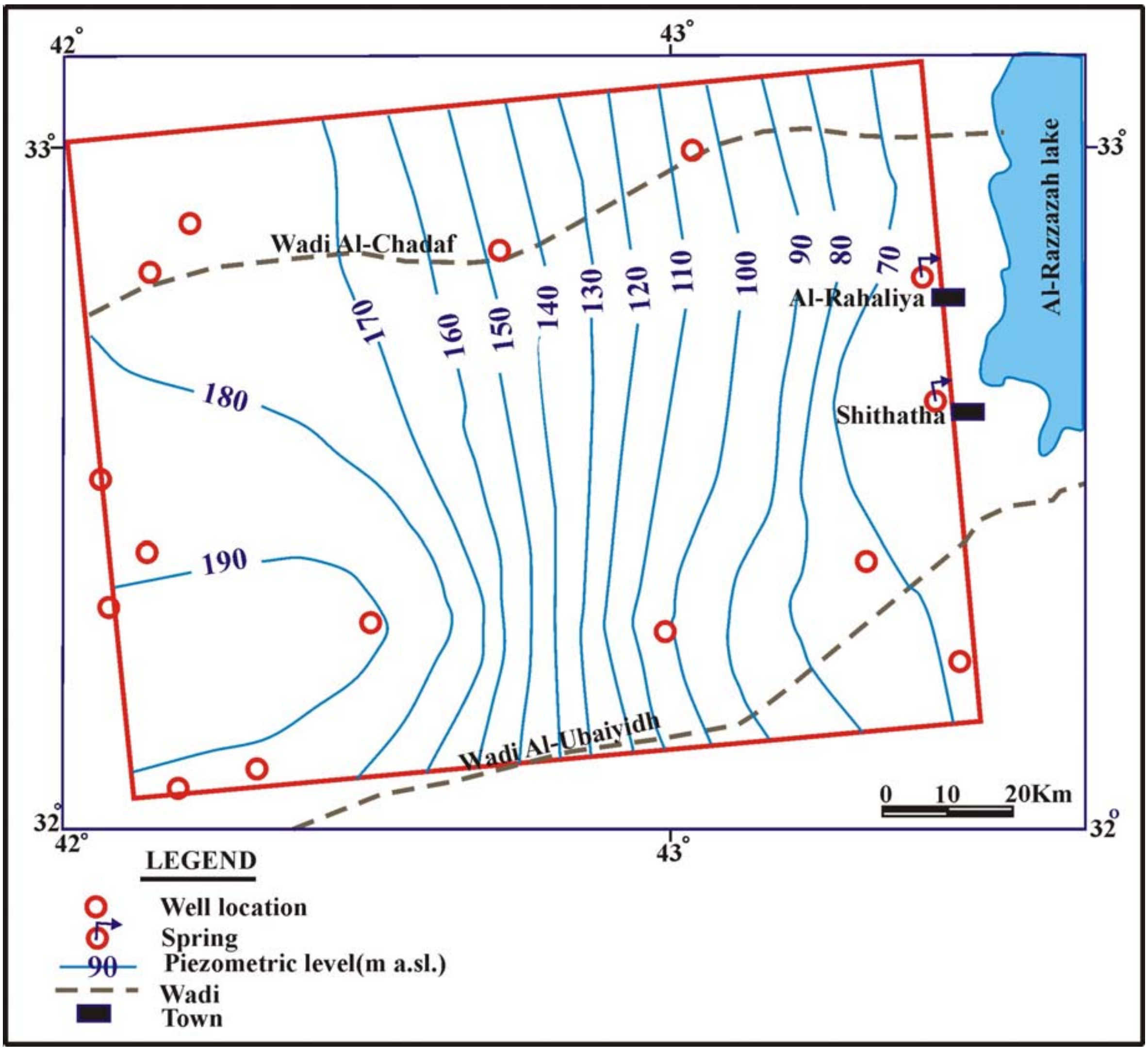

Fig.10: Predicted post development hydraulic head in the year 2003

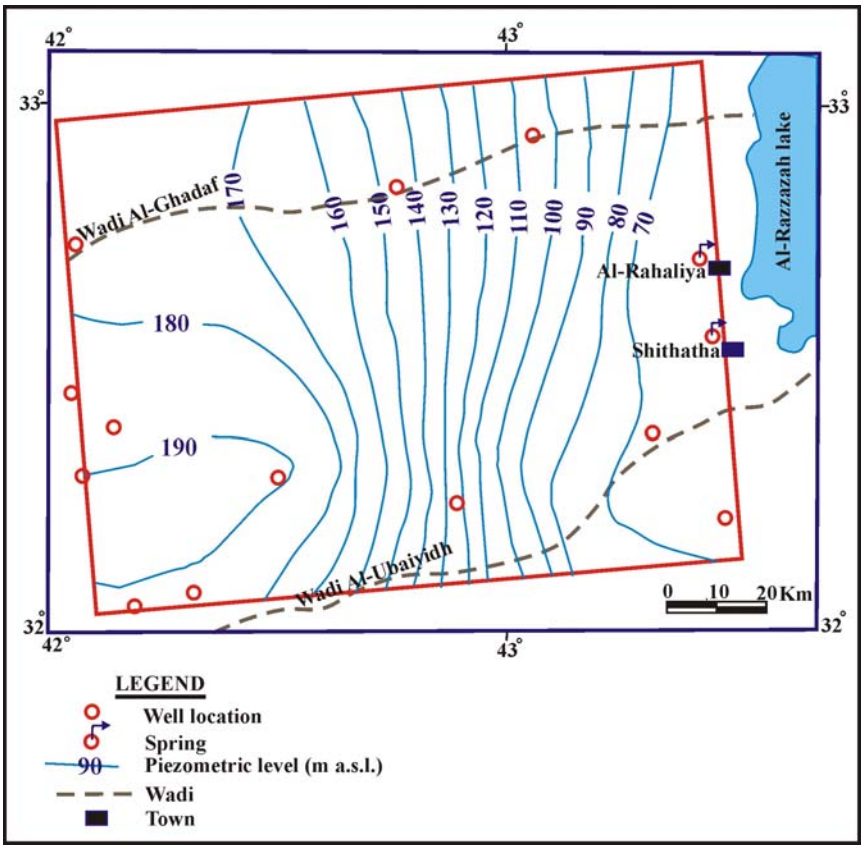

Fig.11: Predicted post development hydraulic head in the period of 2003 – 2008

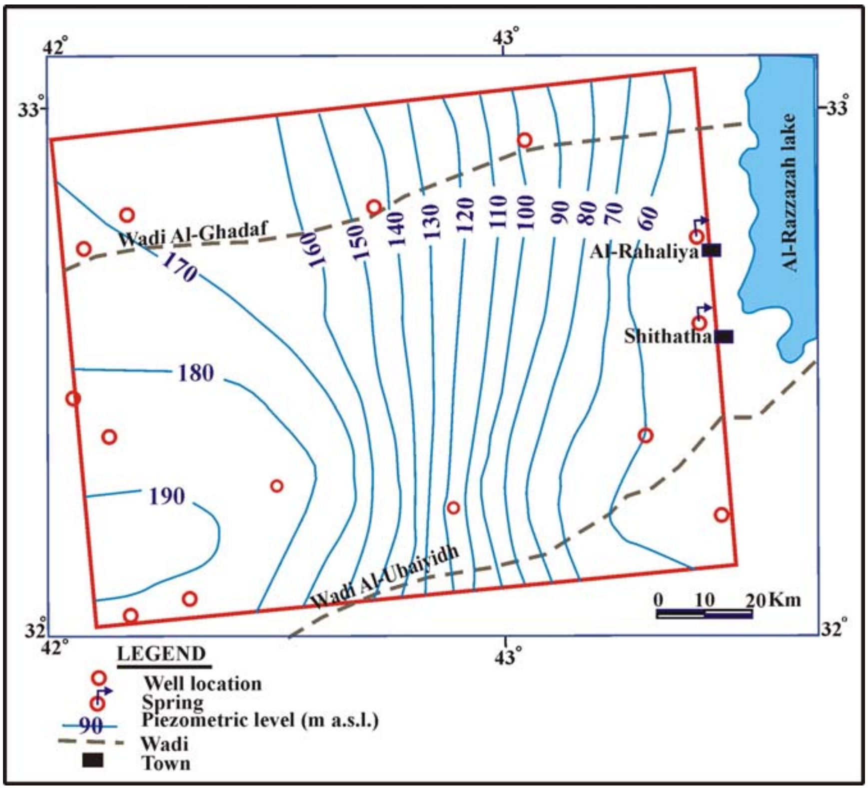

Fig. 12: Predicted post development hydraulic head in the period of 2008 – 2013

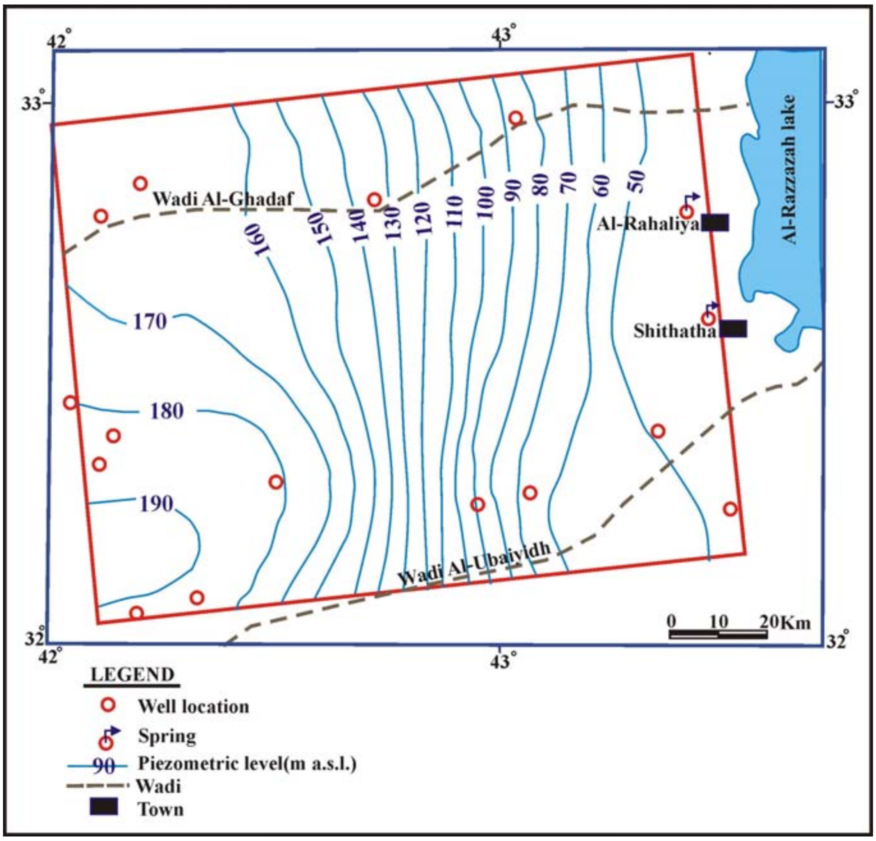

Fig. 13: Predicted post development hydraulic head in the period of 2013 – 2018

CONCLUSIONS

- The regional aquifer that lies within the Dammam – Umm Er Radhuma formations, west of Al-Razzazah Lake is considered to be the most important aquifer in the studied area. The transmissivity, hydraulic conductivity and isopach maps show that the aquifer is non homogeneous, both vertically and laterally. Generally, the aquifer is confined, except in some western parts of the area, whereas the aquifer becomes unconfined when Umm Er Radhuma formation is exposed.
- A groundwater flow model is designed to show the probable changes in the drawdown, as a result of applying a utilization scheme to develop the basin agriculturally. The model is built and calibrated using the results of the analytical analysis of pumping test data, which are executed in January 2000, with a total discharge rate of about 247 l/ sec.
- To use the model in prediction, the abstraction rates were increased to about 3997 l/ sec to cover the water demand in agricultural projects. The new abstraction sites are delineated from the specific yield zonation map. Running the model through the period 2003 – 2018 is to predict the water level changes and to put an optimal scheme to the effects of the new abstraction rates of the aquifer and the flowing continuity of the springs. The predicted drawdown ranges from about 4 m, in the western parts of the basin to reach 50 m, in the eastern parts, near Al-Razzazah Lake and the accompanied springs.
- The result shows that the spring's water may deplete, if the exploitation proceed in this rate with no increase in the recharge rates. The amount of precipitation is predicted to be decreased due to the climatic changes and this will also affect the amount of subsurface flow. Unless, this will change, the regional groundwater level will decrease with time and this will influence the existence of Al-Razzazah Lake.

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