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Hydraulic Parameters for the Euphrates Aquifer in the Southern Part of Haditha district, Al-Anbar Governorate

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Abstract

One of the primary goals of any study involving groundwater is to make an exact assessment of the physical properties of the layers containing the water. One of the most fruitful ways to approach this goal is to conduct a pumping test for the aquifer. To make the most use of groundwater in terms of sustainable water management, this study attempts to assess its hydraulic features relative to the most significant aquifer represented in the Euphrates formation. A pumping test was carried out on 6 wells where each well is accompanied by an observation well. Cooper-Jacob and Theis Recovery methods were used to determine the aquifer transmissivity and storage coefficient. The ranges for permeability, transmissivity, and specific yield are (0.42 - 3.05 m/day, 13.89 -76.47 m^2/ day, and 0.018 - 0.036) respectively, whereas, calculated transmissivities based on specific capacity showed a wide range from 30.85 m^2/day to 120.96 m^2/day. This wide range reflects the complex lithology of the aquifer, which was influenced by structural elements including stress and joint density.

Keywords: Hydraulic Parameters, Euphrates Aquifer, Haditha District, Anbar Governorate.

المعاملات الهيدروليكية لخزان الفرات في الجزء الجنوبي من قضاء حديثة، بمحافظة الأنبار

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الخلاصة

أحد الأهداف الأساسية لأي دراسة تشمل المياه الجوفية هو إجراء تقييم دقيق للخصائص الفيزيائية للطبقات التي تحتوي على المياه. من أكثر الطرق المثمرة لتحقيق هذا الهدف هو إجراء اختبار الضخ للخزان الجوفي. من أجل تحقيق أقصى استفادة من المياه الجوفية من حيث الإدارة المستدامة للمياه، تحاول هذه الدراسة تقييم الخصائص الهيدروليكية بالنسبة لأهم خزان للمياه الجوفية والمتمثل في تكوين الفرات. تم أجراء اختبار الضخ لستة ابار حيث يصاحب كل بئر من ابار الضخ بئر مراقبة، واستخدام طريقتي كوبر- جاكوب وثايس لأسترجاع المنسوب لتحديد معاملات الناقلية والخزن. أظهرت مديات معاملات النفاذية والناقلية والخزن الجوفي القيم التالية 0.42 – 3.05 م / اليوم، 13.89 – 76.47 م2 / اليوم، و0.018 –0.036) على التوالي، في حين أظهرت النفاذية المحسوبة على أساس السعة النوعية تباينًا كبيرًا، من 30.85 م ^{2} / يوم إلى 120.96 م ^{2} / يوم. يعزى هذا التباين لليثولوجية المعقدة للخزان والمتأثرة بالعناصر التركيبية التي تشمل الأجهاد وكثافة الفواصل.

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1. Introduction

When surface water is scarce or nonexistent, groundwater becomes increasingly important for agriculture, municipal, rural supplies, environmental protection, the growth of social and economic activity. Relentless pumping of water from aquifers for various uses is the leading cause of groundwater depletion in many parts of the world [1]. As a result, we are facing a crisis as groundwater levels continue to drop. As a sub-discipline of hydrology, groundwater hydrology looks at the presence, quality and movement of water found below the Earth's surface. One of the most crucial aspects of groundwater research is attempting to estimate the physical parameters of water-bearing strata. Aquifer water levels (or total heads) can be monitored over time as a result of well withdrawals, making this a useful method for determining these features over time [2]. An aquifer test is a sort of study in which researchers pump a well for a constant pace at an extended time (often several hours into some days), and then monitor the rise and fall of water levels in observation wells located at different distances of the well being pumped [3,4]. Theoretical models are used in the evaluation and analysis of aquifer test results, making it a scientific activity that requires the geologist to be well-versed in such models before undertaking any test studies on geological formations. The geologist conducting test investigations of the geological formations in the research region needs a firm grasp of these models before proceeding [5]. Geology and groundwater studies were carried out in the western desert of Al-Anbar governorate, in the westernmost part of the governorate [6,7,8,9] and the easternmost part of it [10,11,12], where the present study is located in south Haditha district between (42º 16' - 42º 25' E) and (34º 1' - 34º 6' N) (Figure 1) covering an area of 120 km^2. The area is flat and rises gradually to the west, except for the northwest part, whereas slopes have a gentle gradient toward the north. Elevation in the area extends from a high of 168 m in the Alkhasfa region to less than 111 m in Alus town.

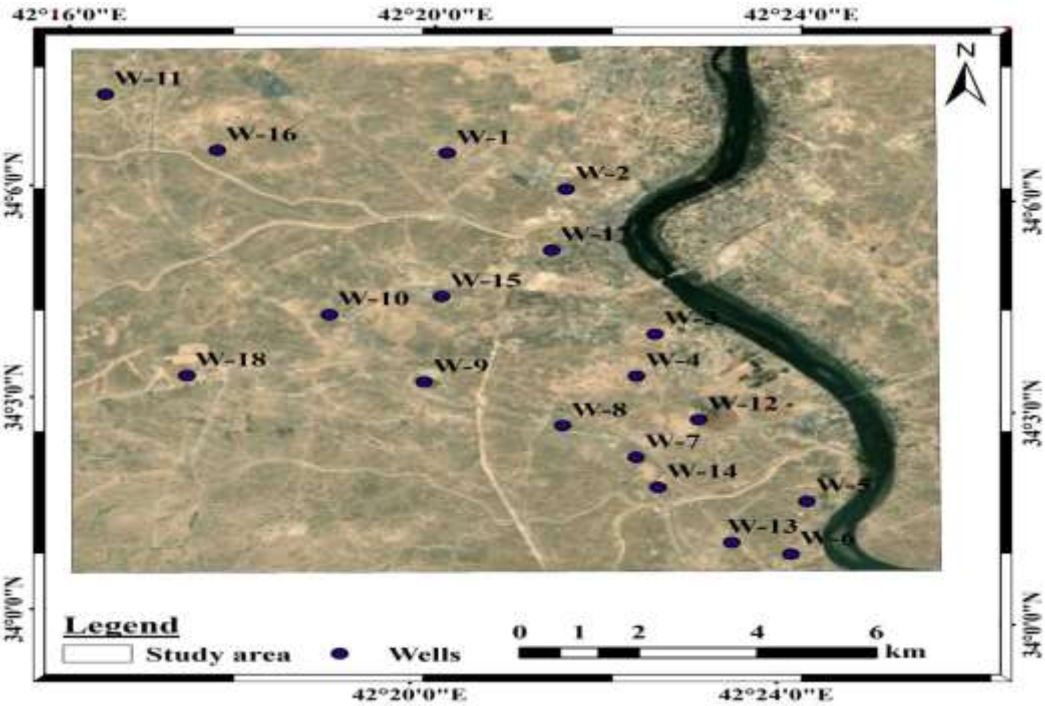


Figure 1: Location of the study area

2. Geological Setting

The exposed rock units in the study area range in age from lower Oligocene to Quaternary sediments (Figures 2 and 3).

The upper Oligocene Anah Formation is characterized by the presence of cavities of varying widths throughout the coralline, massive, dolomitic limestone and very hard limestone that make up the Formation [10].

Euphrates formation of Lower Miocene is composed of recrystallized cherty; silicified; ferruginous, and marly limestone with greenish marl and thin basal conglomerate or basal clastic. The widest exposure of this formation in the western desert is found in WadiFuhaimi, which is located in Anah Trough within the stable shelf [10].

The Middle Miocene Fatha formation is only exposed in two small places in the Western Desert's center and east. Typical cyclic lithological components that distinguish this formation in the study area are composed of limestone, gypsum, marl and claystone [10]. Quaternary sediments covering parts of the study area consist mostly of sand, silt, and clay that were deposited in the recent and Pleistocene epochs. When compared to the underlying Euphrates and Fatha Formations, the Quaternary sediments are unconsolidated and typically finer-grained. The deposits that formed during the Quaternary period are residual soil of the Pleistocene and Holocene ages that consist of sandy; silty clayey; brown soil, with fragments of limestone [10].

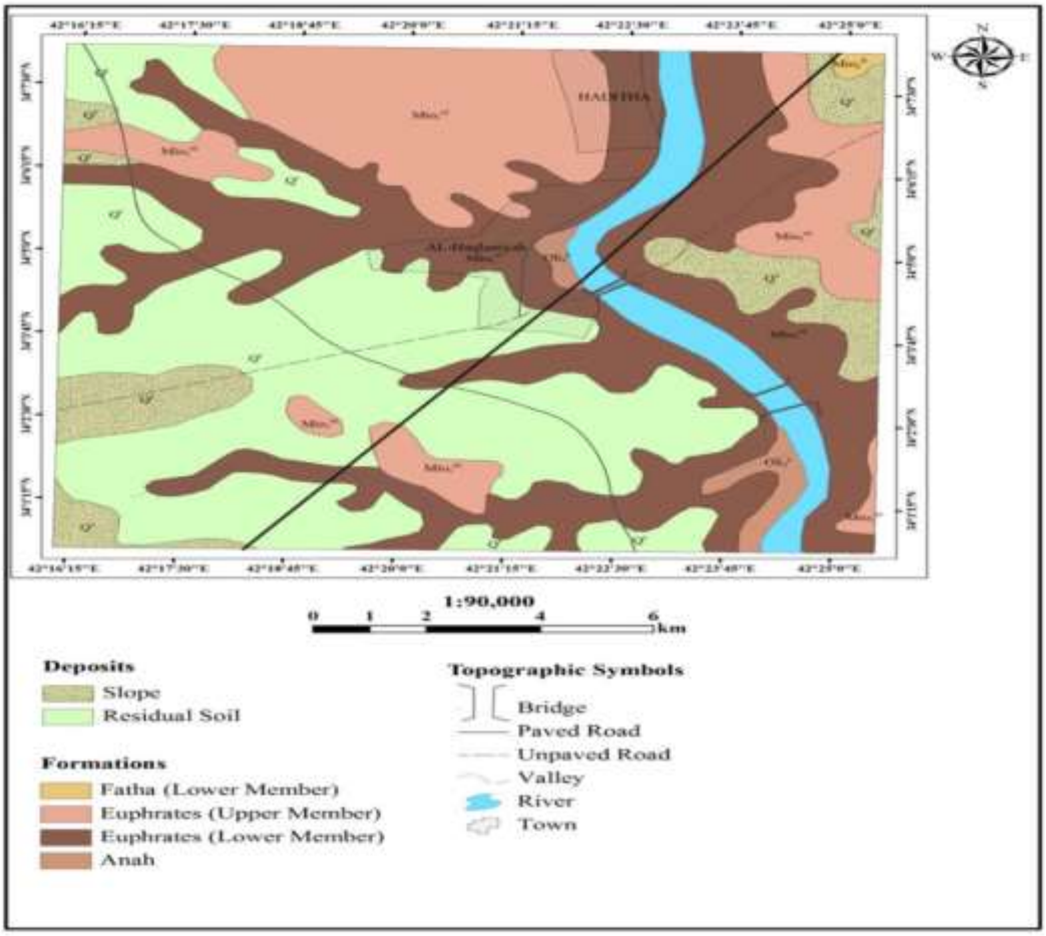


Figure 2: Geological map of the study area [11].

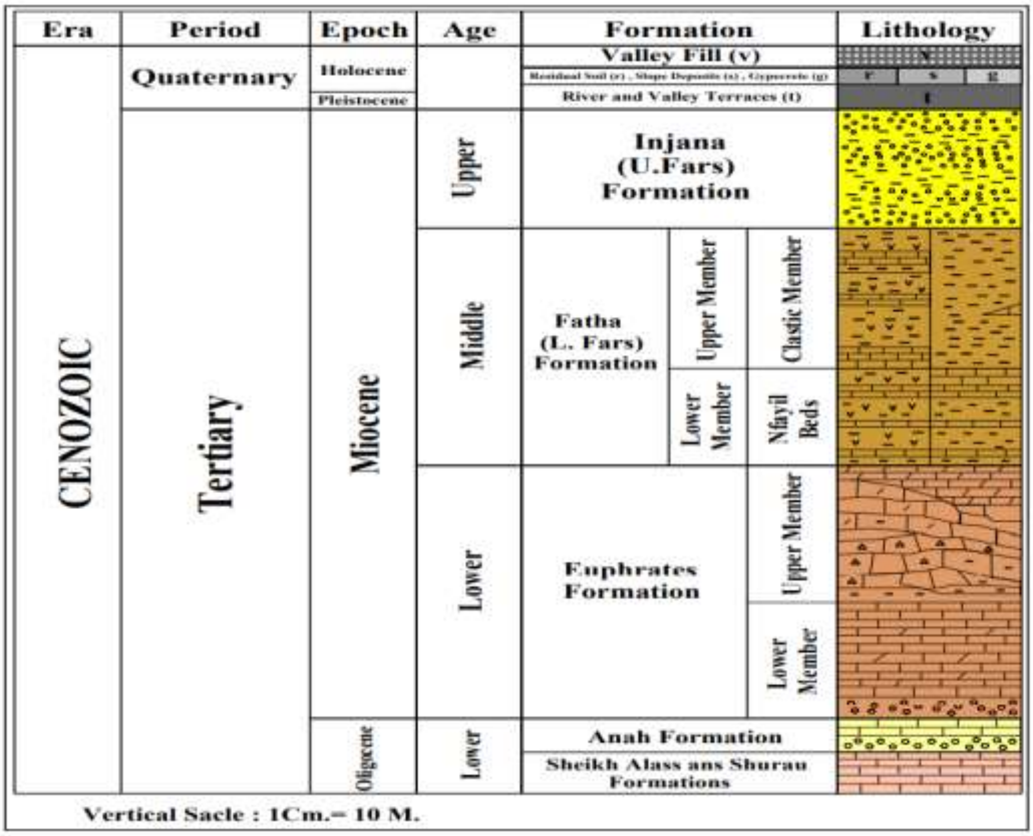
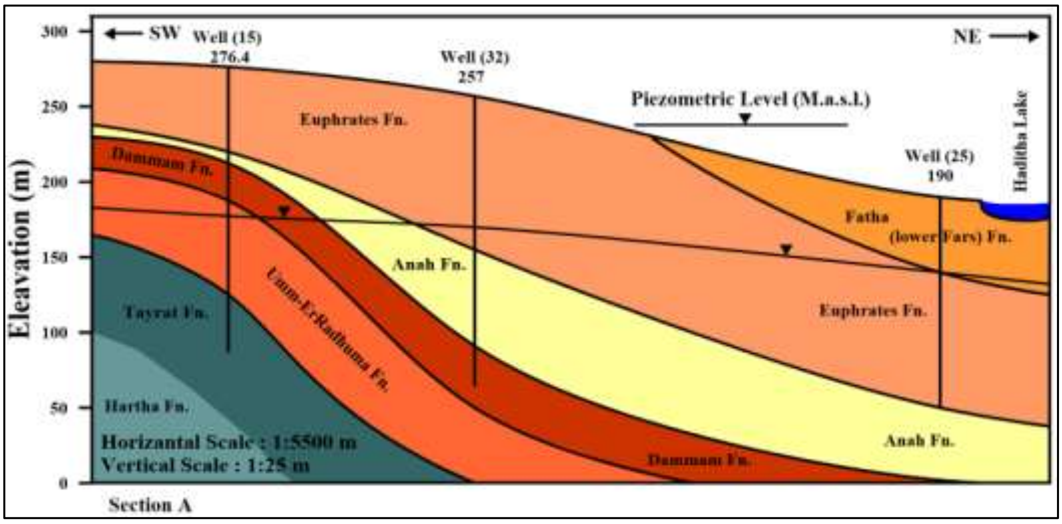


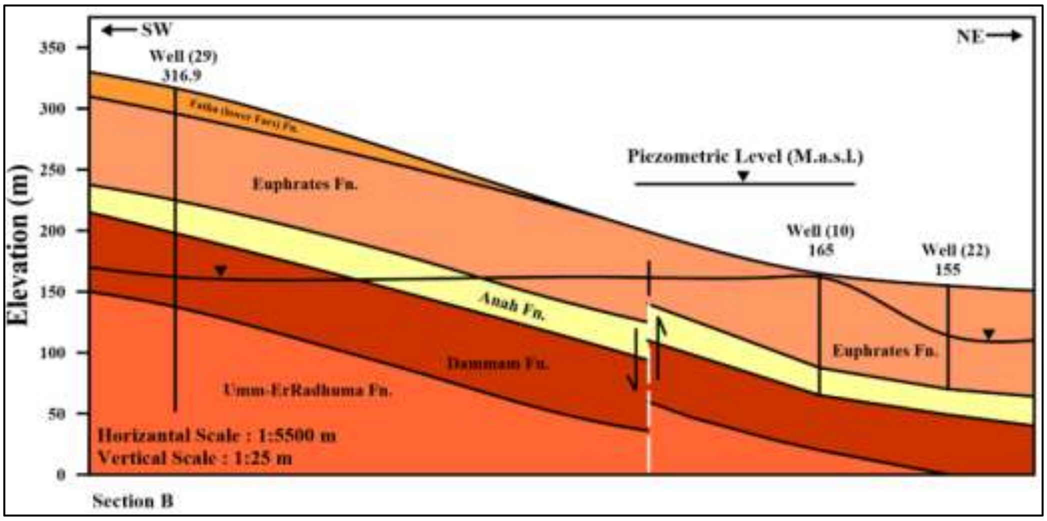
Figure 3: Stratified sequence of geological formations in the studied area [10]

The geological water-bearing formations in the western desert are gradually formed by Tayarat; Umm Er-Radhuma, and Dammam "subsurface" formations in the western part, Umm Er-Radhuma and Dammam formations in the central part; Euphrates as the essential formation and Anah with Fatha as an occasional formation at the east and northeast part of the area [10]

Euphrates Formation represents the upper groundwater aquifer in the study area, in the northern regions along the Euphrates River, which represents the discharge zones of groundwater [13].



(a)



(b)

Figure 4: Lateral, cross_sections in the studied area [10]

3. Materials and Methods

The materials used in this study including instruments, data information and software were:
1. Two-dimensional global positioning system (GPS) gadget for locating wells, and estimating their heights.
2. Echo sounder type YTP 010, France, for measuring the static water level in the wells and then for drawdown measurements during pumping and recovery tests.
3. Database of hydrogeological information and stratigraphic records [14].
4. Graphing pumping and recovery test results in Excel.

In unconfined aquifers, the head decreases over time. Water is released from storage here primarily to dewatering of the zone through which is travelling and only secondarily due to the compressibility of the water and aquifer material. After a few days without pumping, the drawdown is minimal beyond a radius of around 100 m from the well. An aquiclude, as depicted in Figure (5), can be used to extract groundwater from an unconfined aquifer. Key characteristics, like permeability, extension, and thickness, distinguish aquifers and determine their relative significance.

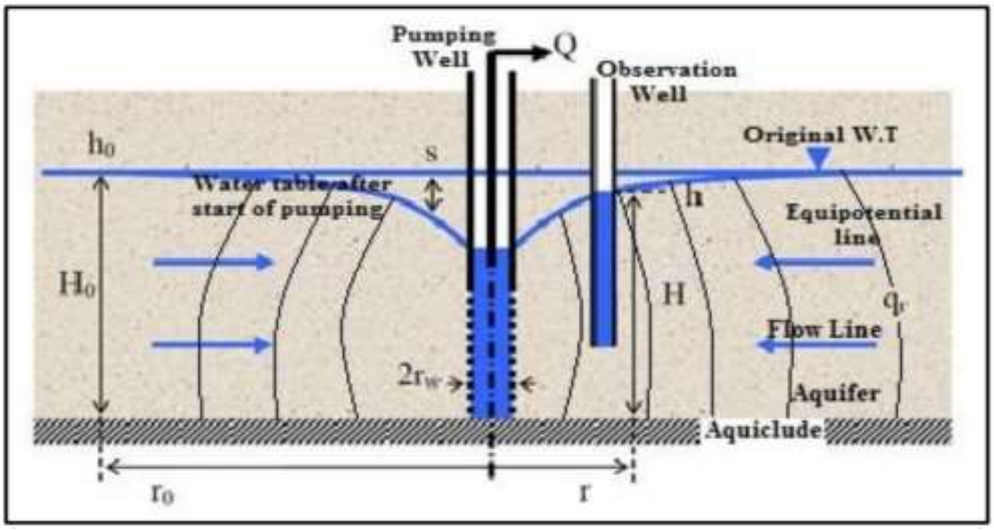


Figure 5: Sketch cross-section of a pumped unconfined aquifer [19]

By pumping water from a well deep into the aquifer, we can potentially see changes in water levels and in piezometers that are continuously discharging water from the well at known distances of the pumping well, according to the simple idea behind testing an aquifer. In the process of pumping, the water level drops, and a cone of depression forms rapidly as water is pumped out of the aquifer [17]. Since the aquifer's capacity to store water declines as time passes because of the resistance of porous media for water movement towards the well; the cone of depression broadens and deepens.

The hydrogeological features of the Euphrates aquifer were assessed by comparing the stratigraphic sequence of 18 wells drilled in the study area with Figure (4). The well-measured groundwater levels and the various water-bearing strata were also taken into account. An in-depth examination of the aquifer was performed during the fieldwork. At that time, its precise location, topography, depths, static water levels, thicknesses; and potential yields were all mapped out. Sounding boards and related equipment to ascertain the groundwater flow direction, groundwater flux, and groundwater flow velocity, the depth to groundwater at each of the 18 selected wells was measured using pressure transducers (Typ 010, France). A number from mathematical equations and models are used to derive the values of the hydraulic conductivity, transmissivity, and storage coefficient, such as the (Cooper-Jacob), [15], and Theis Recovery Test methods [16] in case of unsteady flow, by adopting the following equations [20]:

$T=\frac{2.3Q}{4\,\pi\,\Delta s}$ (1)

Where:
T: transmissivity in m^2 /day,
Q: discharge in m^3 /day, and
Δs: drawdown per log cycle (m).
Theis Recovery method uses the following equation:

$T=\frac{2.3Q}{4\,\pi\Delta s}\log\{\frac{t}{t'}\}$ (2)

Where
t: t_{pump} + t' is the time since pumping started, in (min) and t': recovery time is the time since pumping stopped in (min).
The specific yield can be determined approximately by the following Eq. (3):

$S_y= \frac{bwt}{1000}$ (3)

where
S_y: specific yield (unit less).
b_{wt}: corrected saturated thickness.
The specific capacity can be determined by the following Eq. (4)

$$SC = \frac{Q}{S} \quad (4)$$

Where:
SC = specific capacity, in m^2 /day,
Q = discharge, in m^3 /day,
S = drawdown, in meter), where specific capacity was calculated by dividing the maximum pumping rate at the end of the test by the observed drawdown.
The obtained data were depicted in Excel 2016 using drawing sections to determine the hydrogeological characteristics of the groundwater aquifer.

4. Results and Discussion

The main geological units in the study area include Anah, Euphrates, Fatha Formations and Quaternary deposits. The study area recognized the Euphrates formation as a water-bearing formation, which forms the principal reservoir of water produced in the study area, and is categorized as an unconfined aquifer. Hydrogeological conditions are influenced by geological, morphological, climatological, and hydrological factors; the extent to which they are felt varies greatly from place to place.

The defining feature of geological formations and their aquifers in the eastern area of the Western desert and the northern region of Al-Anbar governorate is in hydraulic connections among sequenced geological formations, where groundwater moves of deeper water-bearing layers into lesser depth via groundwater flow in an easterly direction [6,18].

The groundwater flow map (Figure 6), showed that the direction of groundwater flow is toward the Euphrates River and the depth of water in the aquifer is greatest at the western edge of the area and decreases gradually as one travels eastward across the basin. The anticline, transverse fault, and vertical fault (Figure 4) all affect groundwater flow, since the western plunging anticline split the groundwater flow path in northeastern, southern, and southeastern directions. Groundwater from the right limb of the plunging anticline combines with groundwater from the left side of the transverse fault and the Abu-Jir sub-surface fault in the southern half of the basin, creating several springs; as shown in Figure (4; B) [18]. Groundwater aquifers in the region represented by the Dammam, Anah, Euphrates, and Fatah formations are uniquely impacted by faults and folds, which either enlarge or contract the cracks and cavities that store and convey groundwater [10].

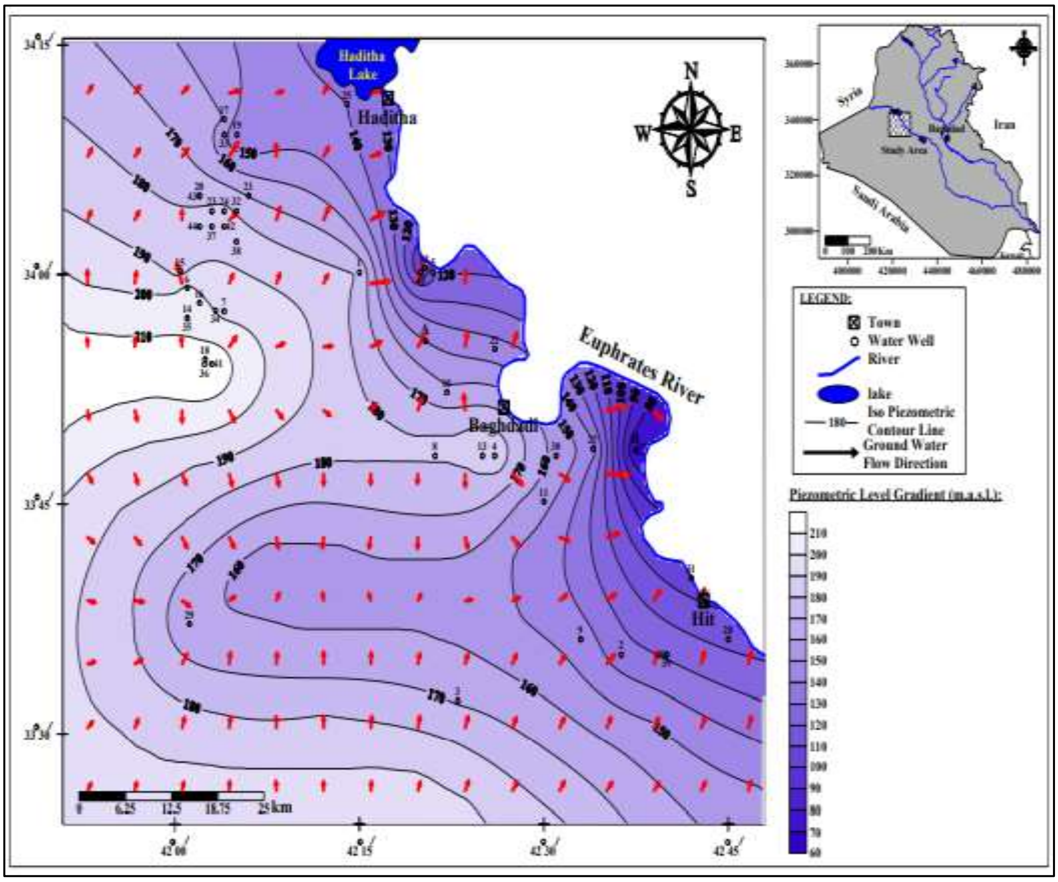


Figure 6: Groundwater flow direction in the study Area [6]

Six wells were selected for pumping test operations (Figure 7, Table 1) with six observation wells (Figure 8) for monitoring the water level drop as a result of pumping.

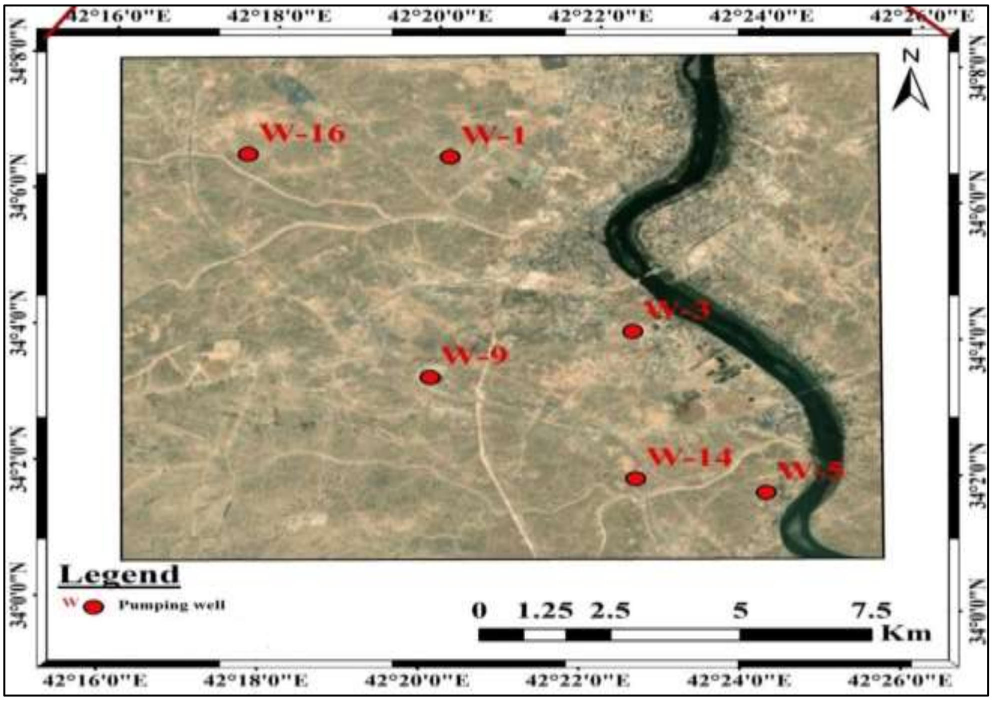


Figure 7 : Selected wells for pumping test

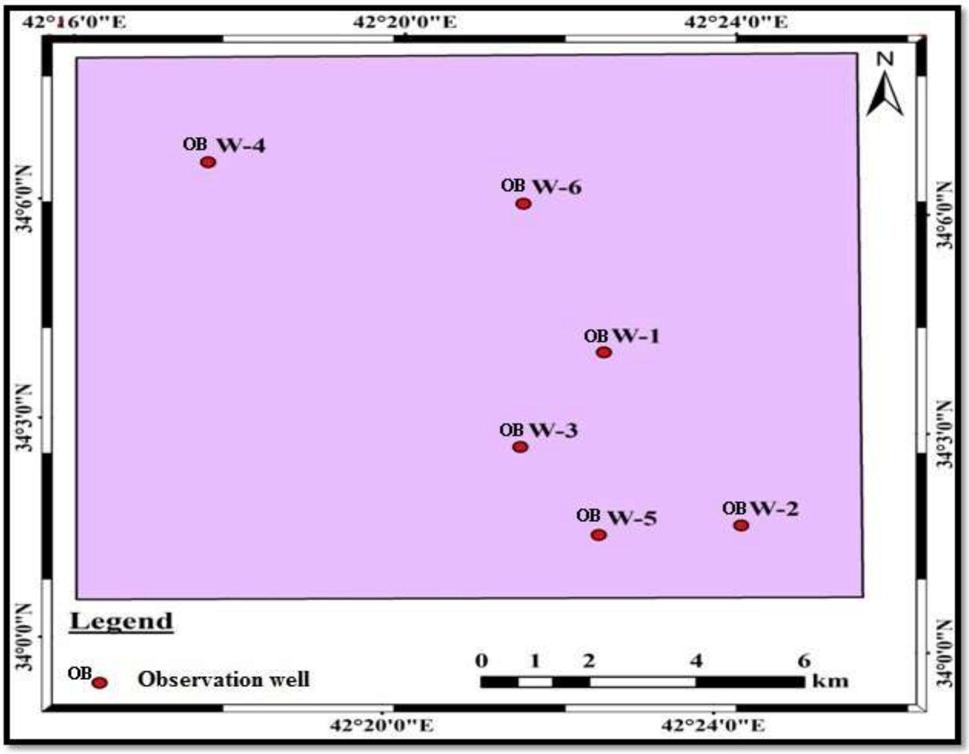


Figure 8: Location of observation wells

Table 1: Pumping wells data in the study area.

Well no.	Longitude	Latitude	Depth of well (m)	Elevation (m a.s.l.)	Depth of water (m)	S.W.L (m a.s.l.)
W1	E 42˚20' 11"	N 34˚ 06' 33"	80	137	55	82
W3	E 42˚22' 32"	N 34˚ 04' 02"	100	125	79	46
W5	E 42˚24' 16"	N 34˚ 01' 42"	55	111	31	80
W9	E 42˚20' 02"	N 34˚ 03' 18"	95	154	65	89
W14	E 42˚22' 38"	N 34˚ 01' 52"	65	133	21	112
W16	E 42˚17' 40"	N 34˚ 06' 32"	100	162	56	106

Analysis results of pumping test

Hydraulic properties were evaluated for the Euphrates aquifer in the study area through pumping and recovery tests.

Hydraulic properties and Pumping Test (W1)

The pumping test was carried out on well (1), which is located in the northeast part of the study area in the discharge areas and penetrates partially Euphrates Formation. The well was drilled to a depth of about 80 m where the depth of the static water level was 55 m from the ground surface, with a saturated thickness of 25 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W6) was away from the production well (W1) at a distance of 10 meters, at a date (2022/3/10) with a constant discharge rate equal to 8 l/s (i.e. 691.2 m^3/day) for pumping period of 300 minutes. And then drawdown was stopped and the static water level settled at a depth of 60.92 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 300 minutes and reaches the static water level again at depth of 55 meters (Table 2)

Table 2: Pumping test and recovery test data for well no. 1

Pumping test field data (W1)

Name of Well: (W1). Date: 10 / 3 / 2022

Longitude: 42˚01′32″ E Latitude: 34˚22′33″ N

Distance between P and Ob. (10) m. SWL: 55 m

Elevation: 137m. a.s.l. Q = 691.2 m^3/day

Production well diameter (12) inch. Observation well diameter (8) inch.

Saturated thickness (b) = 25 m

Time (min)	Pumping test water level (m)	Recovery test water level (m)	Time (min)	Pumping test water level (m)	Recovery test water level (m)
1	55.06	60.60	40	58.73	55.94
2	55.30	60.35	50	59.09	55.76
3	55.60	60.03	60	59.37	55.60
4	55.66	59.70	80	59.83	55.45
5	55.76	59.25	100	60.20	55.36
6	55.91	58.95	120	60.43	55.24
7	56.04	58.72	140	60.59	55.19
8	56.26	58.45	160	60.73	55.12
9	56.47	58.26	180	60.8	55.07
10	56.84	57.34	200	60.85	55.05
15	57.29	56.86	240	60.89	55.03
20	57.63	56.54	260	60.91	55.02
25	57.96	56.32	280	60.92	55.01
30	58.24	56.12	300	60.92	55.00

Hydraulic Properties and Pumping Test (W3)

The pumping test was carried out on well (3), which is located in the east part of the study area in the discharge areas and penetrates partially the Euphrates Formation. The well was drilled to a depth of about 100 m where the depth of the static water level was 79 m from the ground surface, with a saturated thickness of 21 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W1) was away from the production well (W3) at a distance of 10 meters, at a date (2022/3/2) with a constant discharge rate equal to 5 l/s (i.e. 432 m^3/day) for pumping period of 120 minutes. And then drawdown was stopped and the static water level settled at a depth of 93 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 110 minutes and reaches the static water level again at depth of 79 meters (Table 3).

Table 3: Pumping test and recovery test for well no. 3

Pumping test field data (W3)

Name of Well: (W3).   Date: 2 / 3   / 2022
Longitude: 42˚20′00″ E   Latitude: 34˚04′30″ N
Distance between P and Ob. (10) m.   SWL: 79 m
Elevation: 125 m. a.s.l.   Q = 432 m^3/day
Production well diameter (12) inch.   Observation well diameter (8) inch.
Saturated thickness (b) = 21 m

Time (min)	Pumping test water level (m)	Recovery test water level (m)	Time (min)	Pumping test water level (m)	Recovery test water level (m)
1	83.00	89.00	30	92.30	**79.70**
2	85.00	88.00	35	92.50	**79.40**
3	86.00	87.00	40	92.70	**79.30**
4	87.00	86.00	45	92.80	**79.20**
5	88.00	85.00	50	92.90	**79.10**
6	88.50	84.80	55	93.00	**79.50**
7	88.90	84.10	60	93.00	**79.30**
8	89.00	83.40	70	93.00	**79.10**
9	89.40	83.10	80	93.00	**79.00**
10	9090.00244	82.00	90	93.00	**79.00**
15	91.00	81.00	100	93.00	**79.00**
20	91.50	80.50	110	93.00	**79.00**
25	92.00	80.00	120	93.00	**79.00**

Hydraulic Properties and Pumping Test (W5)

The pumping test was carried out on well (5), which is located in the east part of the study area in the discharge areas and penetrates partially the Euphrates Formation. The well was drilled to a depth of about 55 m where the depth of the static water level was 31 m from the ground surface, with a saturated thickness of 24 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W2) was away from the production well (W2) at a distance of 12 meters, at a date (2022/3/2) with a constant discharge rate equal to 4 l/s (i.e. 345.6 m^3/day) for pumping period of 210 minutes. And then drawdown was stopped and the static water level settled at a depth of 36.85 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 200 minutes and reaches the static water level again at depth of 31 meters (Table 4).

Table 4: Pumping test and recovery test for well no. 5

Pumping test field data (W5)

Name of Well: (W5). Date: 2 / 3 / 2022
Longitude: 42˚24′16″ E Latitude: 34˚01′42″ N
Distance between P and Ob. (12) m. SWL: 31m.
Elevation: 111 m. a.s.l. Q = 345.6 m^3/day
Production well diameter (12) inch. Observation well diameter (8) inch.
Saturated thickness (b) = 24 m

Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)	Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)
1	33.00	36.42	45	35.20	**33.09**
2	33.90	36.14	50	35.44	**32.88**
3	33.14	35.95	55	35.70	**32.66**
4	33.21	35.76	60	36.04	**33.32**
5	33.30	35.47	70	36.25	**31.94**
6	33.35	35.29	80	36.40	**31.67**
7	33.48	35.15	90	36.54	**31.46**
8	33.55	35.03	100	36.66	**31.19**
9	33.61	34.92	110	36.71	**31.07**
10	33.70	34.82	120	36.77	**31.05**
15	33.92	34.24	135	36.78	**31.03**
20	34.22	33.94	150	36.81	**31.01**
25	34.40	33.82	165	36.83	**31.00**
30	34.58	33.72	180	36.85	**31.00**
35	34.75	33.65	210	36.85	**31.00**
40	34.91	33.38			

Hydraulic properties and Pumping Test (W9)

The pumping test was carried out on the well (9), which is located in the western part of the study area in the discharge areas and penetrates partially the Euphrates Formation. The well was drilled to a depth of about 95 m where the depth of the static water level was 65 m from the ground surface, with a saturated thickness of 25 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W3) was away from the production well (W9) at a distance of 15 meters, at a date (2022/3/7) with a constant discharge rate equal to 7 l/s (i.e. 604.8 m^3/day) for pumping period of 120 minutes. And then drawdown was stopped and the static water level settled at a depth of 70 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 120 minutes and reaches the static water level again at depth of 65 meters (Table 5).

Table 5: Pumping test and recovery test data for well no. 9

Pumping test field data (W9)

Name of Well: (W9). Date: 7 / 3 / 2022

Longitude: 42˚17′17″ E Latitude: 34˚03′43″ N

Distance between P and Ob. (15) m. SWL: 65m.

Elevation: 154 m. a.s.l. Q = 604.8 m^3/day

Production well diameter (12) inch. Observation well diameter (8) inch.

Saturated thickness (b) = 25 m

Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)	Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)
1	67.00	68.00	30	69.90	**65.10**
2	67.80	67.00	35	69.95	**65.00**
3	68.00	66.70	40	70.00	**65.00**
4	68.30	66.50	45	70.00	**65.00**
5	68.55	66.10	50	70.00	**65.00**
6	68.70	66.00	55	70.00	**65.00**
7	68.85	65.90	60	70.00	**65.00**
8	69.00	65.80	70	70.00	**65.00**
9	69.20	65.65	80	70.00	**65.00**
10	69.40	65.50	90	70.00	**65.00**
15	69.60	65.40	100	70.00	**65.00**
20	69.70	65.30	110	70.00	**65.00**
25	69.80	65.20	120	70.00	**65.00**

Hydraulic properties and Pumping Test (W14)

The pumping test was carried out on the well (14), which is located in the southeast part of the study area in the discharge areas and penetrates partially the Euphrates Formation. The well was drilled to a depth of about 65 m where the depth of the static water level was 21 m from the ground surface, with a saturated thickness of 44 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W5) was away from the production well (W14) at a distance of 16 meters, at a date (2022/3/9) with a constant discharge rate equal to 6 l/s (i.e. 518.4 m^3/day) for pumping period of 180 minutes. And then drawdown was stopped and the static water level settled at a depth of 29 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 180 minutes and reaches the static water level again at depth of 21 meters (Table 6).

Table 6: Pumping test and recovery test for well no 14

Pumping test field data (W14)

Name of Well: (W14). Date: 9 / 3 / 2022

Longitude: 42˚24′16″ E Latitude: 34˚01′42″ N

Distance between P and Ob. (16) m. SWL: 21m.

Elevation: 133 m. a.s.l. Q =518.4 m^3/day

Production well diameter (12) inch. Observation well diameter (8) inch.

Saturated thickness (b) = 44 m

Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)	Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)
1	23.11	28.87	40	27.84	24.41
2	23.71	28.54	45	27.93	24.29
3	24.09	28.27	50	28.00	24.03
4	24.48	27.90	55	28.07	23.78
5	24.73	27.64	60	28.14	23.43
6	24.96	27.32	70	28.31	23.06
7	25.18	27.14	80	28.44	22.41
8	25.41	27.34	90	28.67	23.63
9	25.60	27.17	100	28.82	23.04
10	25.87	26.99	110	28.91	22.51
15	26.63	26.53	120	29.09	21.90
20	27.07	26.09	135	29.12	21.06
25	27.32	25.56	150	29.05	21.00
30	27.51	25.06	165	29.00	21.00
35	27.71	24.77	180	29.00	21.00

Hydraulic properties and Pumping Test (W16)

The pumping test was carried out on the well (16), which is located in the northwest part of the study area in the discharge areas and penetrates partially the Euphrates Formation. The well was drilled to a depth of about 100 m where the depth of the static water level was 56 m from the ground surface, with a saturated thickness of 44 m. A pumping test was carried out at the pumping well, where the observation well (Ob. W4) was away from the production well (W16) at a distance of 13 meters, at a date (2022/3/8) with a constant discharge rate equal to 5.5 l/s (i.e. 475.2 m^3/day) for pumping period of 180 minutes. And then drawdown was stopped and the static water level settled at a depth of 67 m from the land surface, which represents the hydrodynamic level at discharge above. After the pump has been shut down, the water levels in the well will start to rise and directly followed by a process of recovery test that lasted for a period of 180 minutes and reaches the static water level again at depth of 56 meters (Table 7).

Table 7: Pumping test and recovery test data for well no.16

Pumping test field data (W16)

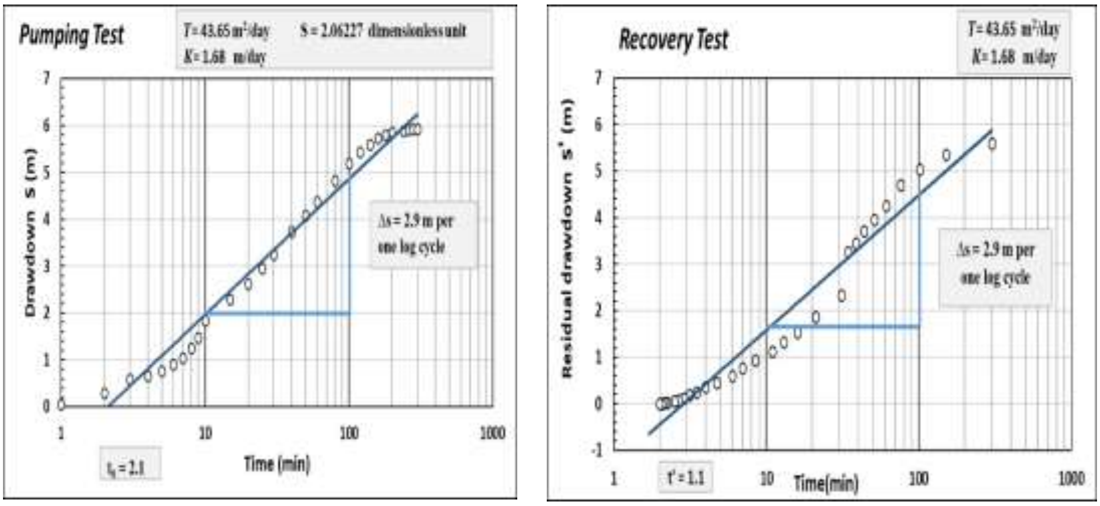
Name of Well: (W16). Date: 8 / 3 / 2022
Longitude: 42˚18′58″ E Latitude: 34˚04′14″ N
Distance between P and Ob. (13) m. SWL: 56m.
Elevation: 162m. a.s.l. Q = 475.2 m^3/day
Production well diameter (12) inch. Observation well diameter (8) inch.
Saturated thickness (b) = 44 m

Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)	Time (min)	Pumping test Water Level (m)	Recovery test Water Level (m)
1	60.00	64.00	40	66.85	56.10
2	60.70	63.80	45	66.90	56.00
3	61.45	63.40	50	67.00	56.00
4	62.20	63.10	55	67.00	56.00
5	63.00	62.00	60	67.00	56.00
6	63.30	61.85	70	67.00	56.00
7	63.85	61.65	80	67.00	56.00
8	64.20	61.45	90	67.00	56.00
9	64.65	61.20	100	67.00	56.00
10	65.00	60.00	110	67.00	56.00
15	66.00	58.00	120	67.00	56.00
20	66.40	57.00	135	67.00	56.00
25	66.70	56.50	150	67.00	56.00
30	66.75	56.30	165	67.00	56.00
35	66.80	56.20	180	67.00	56.00

Table (8) displayed the computed hydraulic characteristics of the groundwater aquifer at study area, whilst Figures (9-14) depict (Cooper_Jacob, and Theis Recovery) for the six wells designs.

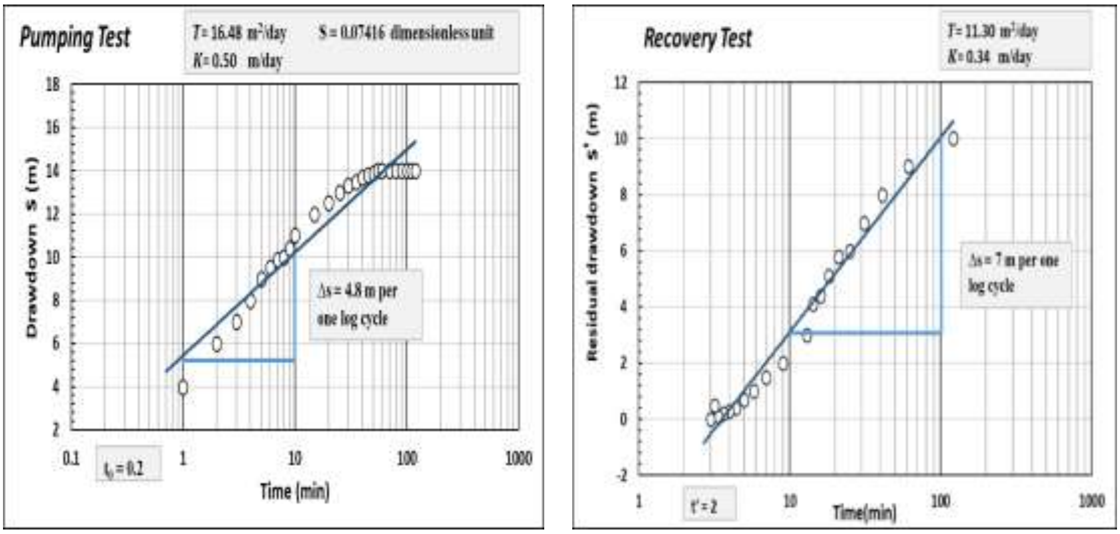
Table 8: Hydraulics parameters of Euphrates aquifer in the study area

Well	Pumping Test		Recovery Test		average T (m^2/day) Av.	average K (m/day) Av.	Sy	Sc (m^2/day)
	T (m^2/day)	K (m/day)	T (m^2/day)	K (m/day)				
W1	43.65	1.68	43.65	1.68	43.65	1.68	2.06227	116.75
W3	16.48	0.50	11.30	0.34	13.89	0.42	0.07416	30.85
W5	30.14	1.12	26.37	0.98	28.25	1.05	0.47088	59.07
W9	79.11	3.16	73.83	2.95	76.47	3.05	0.26106	120.96
W14	31.64	1.09	21.57	0.74	26.60	0.91	0.69529	64.85
W16	27.19	0.91	16.42	0.55	21.80	0.73	0.09051	43.2



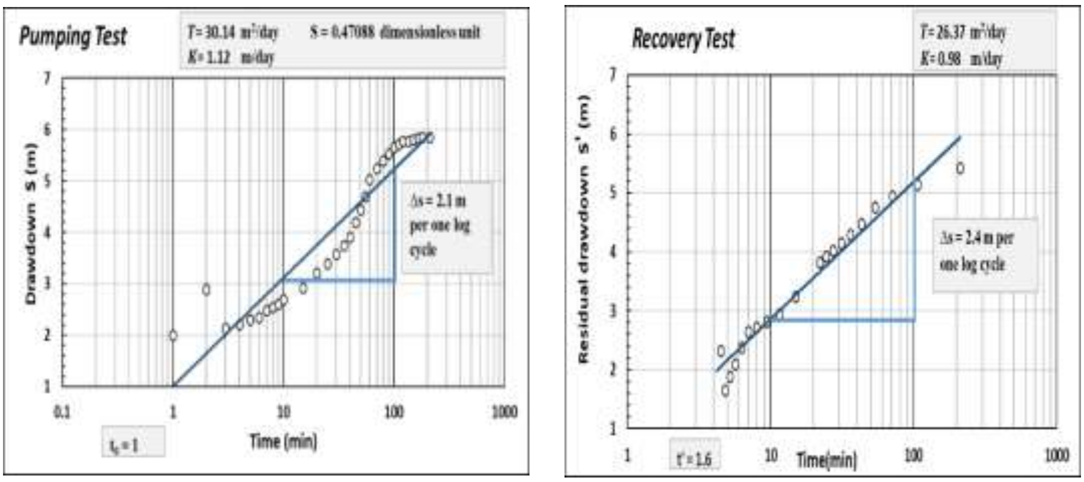
(a) **(b)**

Figure 9: Diagrams of drawdown, and water level recovery with time for well (W1) via using Cooper-Jacob 'Drawdown', and Theis 'Recovery' method.



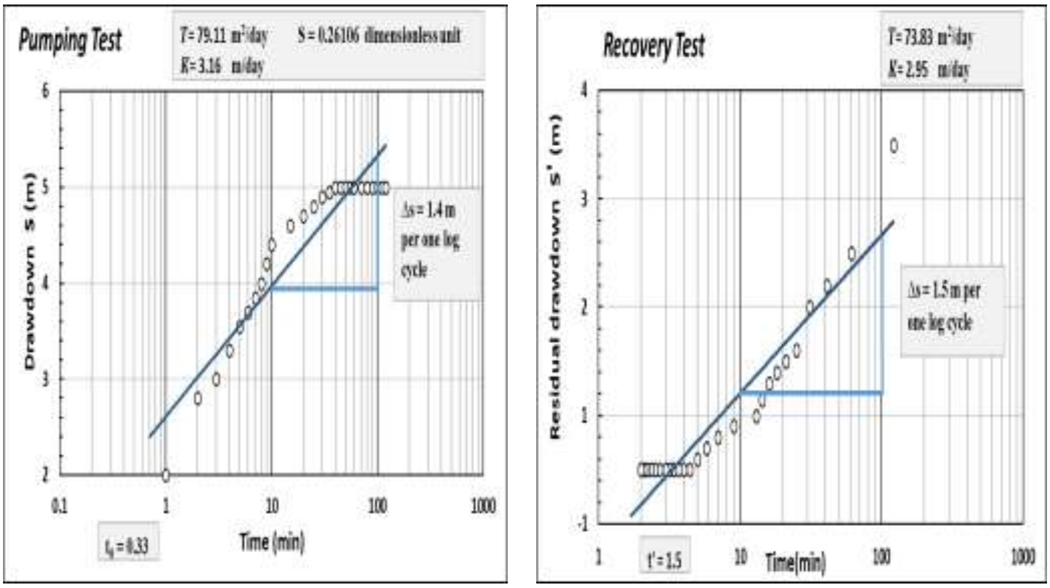
(a) **(b)**

Figure10: Graphs drawdown and water level recovery with time for well (W3) through uing Coper-Jacob [Drawdown] and Theis [Recovery] method.



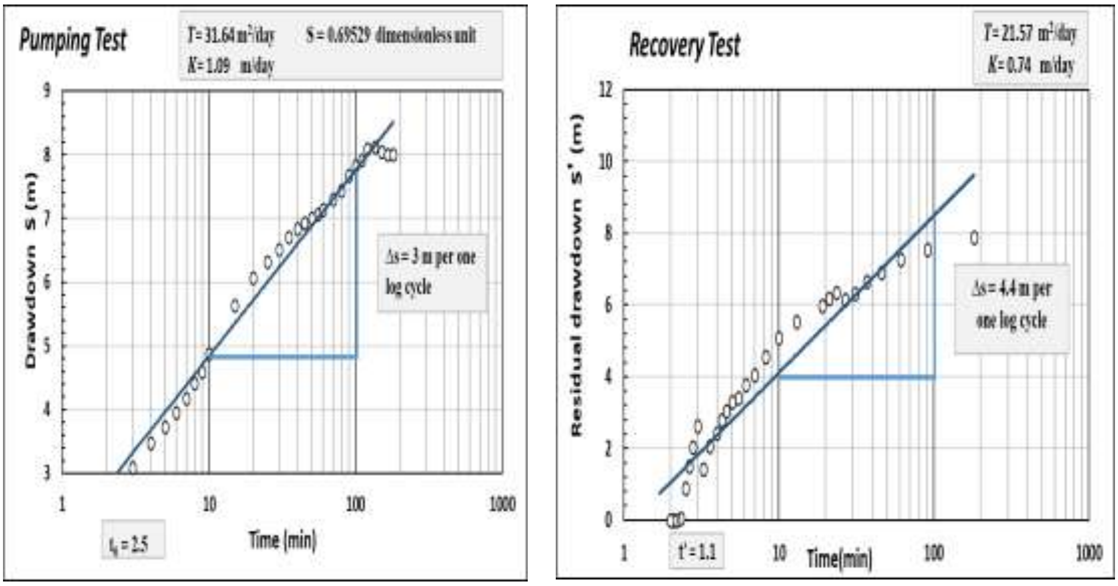
(a) **(b)**

Figure11 : Graphs, of drawdown and water level recovery with time for well (W5) by using Cooper-Jacub (Drawdown) and Theis (Recovry) method.



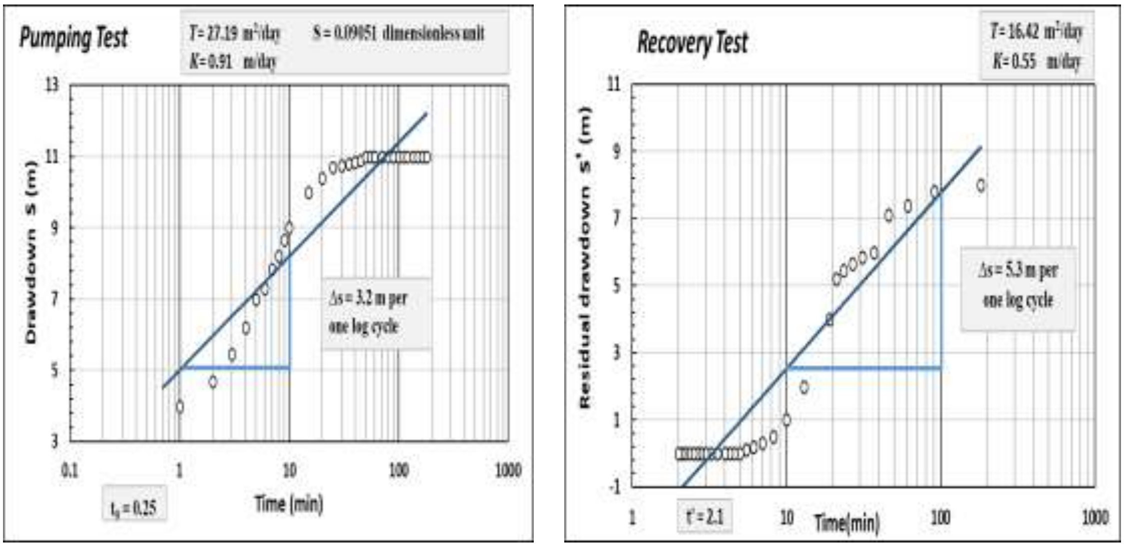
(a) **(b)**

Figure 12: Graphs of drawdown and water level recovery with time for well (W9) by using Cooper-Jacob (Drawdown) and, Theis (Recovery) method.



(a) **(b)**

Figure13: Graphs of drawdown and water level recovery with time for well (W14) by using Cooper-Jacob (Drawdown) and Theis (Recovery) method.



(a) **(b)**

Figure 14: Graphs of drawdown and water level recovery with time for the well (W16) by using Cooper-Jacob (Drawdown) and Theis (Recovery) method.

5. Conclusions

1. The results of 18 wells demonstrated that the southern part of the Haditha area contains only an unconfined aquifer represented by the Euphrates Formation.
2. The groundwater flow reveals that the water depth increases in the western part of the area and decreases progressively in the eastern part of the basin, where the regional flow trend is toward the Euphrates River.
3. Based on Cooper-Jacob and Theis recovery methods, the ranges of transmissivity and specific yield values were (13.89- 76.47m^2/day) and (0.018-0.036), respectively, using pumping test data obtained from pumping six selective wells and their attached six observation wells.
4. The variation in the values of the hydraulic properties can be attributed to the hydrogeological conditions of the Euphrates fractured aquifer which is due to variations in lithofacies, saturated thickness and the intensity of fractures and joints. In addition, the hydraulic properties are influenced by the dissolution process, where the openings in the limestone may range from microscopic original pores to large solution caverns and it's playing the main role in determining the nature and characteristics of the aquifer.

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