Sustainable Management of Isolated Subsurface Heterogeneous Mediums: A Case Study in Tyass Area, Iraq

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Abstract:

A hydrogeologic model has been developed for rehabilitating subsurface bearing layers that isolated by no flow boundaries which preventing lateral seepage such as antic or sink lines of mountainous topology or artificial barriers.

Rehabilitation of Tyass area as a case study requires a management based upon estimating the water demand (WD), a formulation of a 2D groundwater and mitigation models of the bearing layer against high pollutants concentration and salinity.

After the model has been calibrated and verified it was used to lower the water table levels, evaluating the safe yield and recharge capacity of existing wells which were found to be 4.6 L/s.

Two scenarios have been issued for remediation and management process; the hydrologic scenario which was issued by supplying the area with a(1.5WD) of fresh water from the old reach of Hillah River, a (WD) was used to satisfy the agricultural requirements and (0.5WD) was recycled for aquifer storage mitigation by discharging it into the river shortcut. The mitigation process of the aquifer water takes a time of 240 months to reach the final pollutants concentrations of Hillah River.

The second is a hydrogeologic scenario by injecting the aquifer by the (WD) of river water and then discharging it by the existing wells to satisfy the agricultural requirements. A half mitigation time was needed to reach the final concentrations of the aquifer water storage.

The study added a water management platform of an area surrounded by anticlines or by artificial geotechnical no flow barriers.

Keywords*:* Mitigation, Geotechnical barrier, Recharge capacity, No flow boundary**.**

1. Introduction

In 21th century human will be facing a changing in quality and quantity of water cycle. Activating forces behind this challenge are industrialization, population growth and delayed awareness. Since we are living in changeable environment which are not adequately understood, hydrogeology should be disciplinary, integrative, and flexible in assessment and decisions. Undesirable consequences occasionally encountered via ecosystem contamination such groundwater bearing layers that entirely isolated by impermeable boundary and permanently exposed to sources of harmful pollution and increase in soil salinity.

Many workers try to deal with many problems in this context, among them; David (1996) who divided a diverted water from a source into three parts depending on what happened to it. First, water will evaporate to the atmosphere. Second, Water goes to surface and subsurface and may be reused again. Third water may be polluted and the pollutants are concentrated to level that cannot be reused and should be got rid of it by sink.

Gema et al (2013) developed a participatory integrated assessment model corresponding to crop model, economic model and participatory Bayesian network in Spain. The model allowed to test different management, climate changes and assessing the impacts of these methodologies on natural crops, farms and water resources. Their model has permitted stakeholder participation, complying with a requirement of current European water laws.

Simons et al (2015) summarized the categorizing basin hydrological flows and its applicability to reuse water and selection the existing indicators developed for assessing water reuse and it impacts. It is concluded that although a number of reuse and recoverable flow methods have been developed a number of essential aspects of water reuse are left out, as well a proven methodology for obtaining a quantitative information was inadequate and future study should focuses on spatiotemporal tracking of recoverable water withdrawal and examine water user dependency to water policy makers.

Yangpeng et al (2016) used a life cycle assessment to evaluate a) multiple product-service levels, b) multiple associated uncertainties and transfer them decision-making process, c) water allocation for minimizing life-cycle environment impacts. The method was proven to be an effective in generating water supply schemes under uncertainties in north China.

Currently, a groundwater ecosystem rehabilitation of an area surrounded and isolated by a no-flow boundary penetrating the full depth of a bearing layer was adopted.

2. Purposes of Study

Adoption of sustainable water resources management to rehabilitate and survive an isolated subsurface environment by using major strategic steps:

1- Lowering of water table levels by a groundwater model.
2- Issuing a specified management platform for isolated subsurface water bearing layer.

3. Case Study and Problem Presentation

A case study of isolated unconfined bearing layer of 2508 donams for Tyass area in the middle of Iraq was undertaken. In recent few decades, authorities constructed a shortcut for Hillah River which causing with old one a circular water boundary surrounding the entire area resulting in soil water logging and swamps. To solve this drawback, it was planned to bound the area by an impermeable vertical geotechnical barrier penetrating the full depth of (4.25m) the bearing layer to prevent horizontal seepage toward the aquifer. Consequently the problem was exaggerated via swamping of ground surface, soil water logging, soil salinity rise, difficulty in drainage and irrigation activities, and environmental unbalance which forced the population immigrating their lands.

An optimum management for the aquatic wealth is required to rebalancing such environmental category.

A problem was arisen after constructing a new shortcut on Al Hilla River which letting the flow be more activated in the shortcut rather than in the old reach resulting in lowering of water heads and preventing water reaching the intake of local streams namely as; Kids, Khamisya, Awadel and Zabbar Streams Fig. 1.

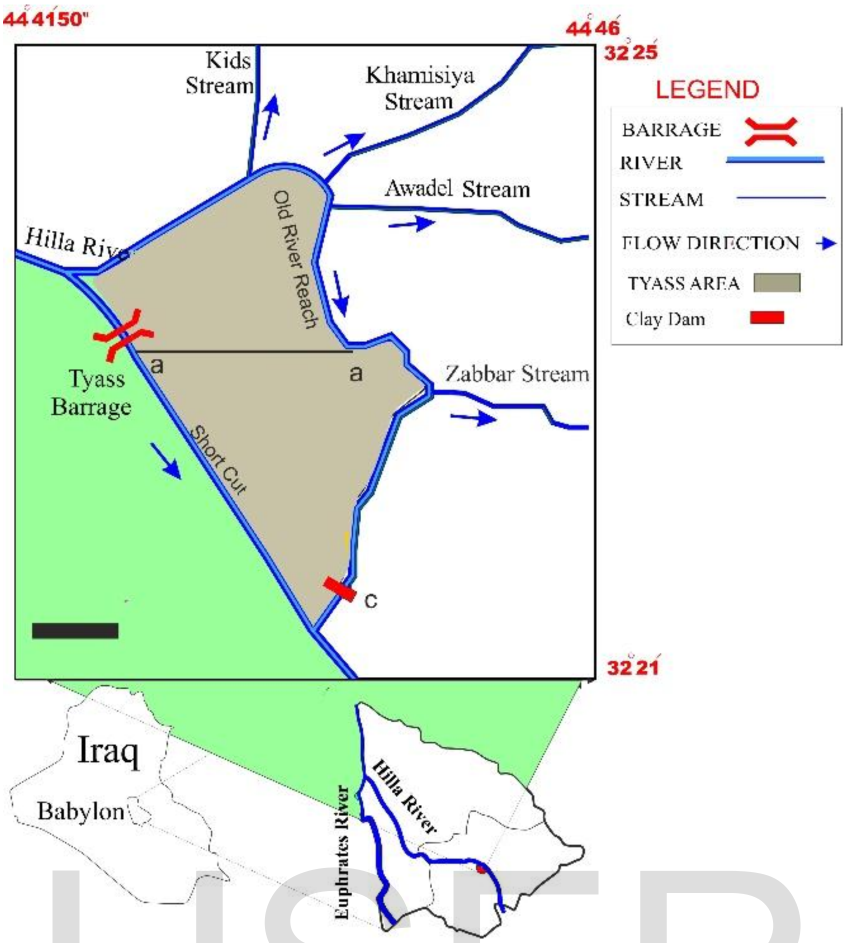


Fig. 1 Location Map of Tyass Area

In order to provide the streams with their necessary water allocations, Tyass Barrage on the shortcut and an earth dike at point (C) are constructed for lifting water heads at the intakes of the local streams. This consequently issued a problem of soil water logging and swamping the area to level sometime exceeding 0.8m above ground surface by a lateral seepage (interflow) from Hilla River as shown in section (a-a) of Fig. 2.

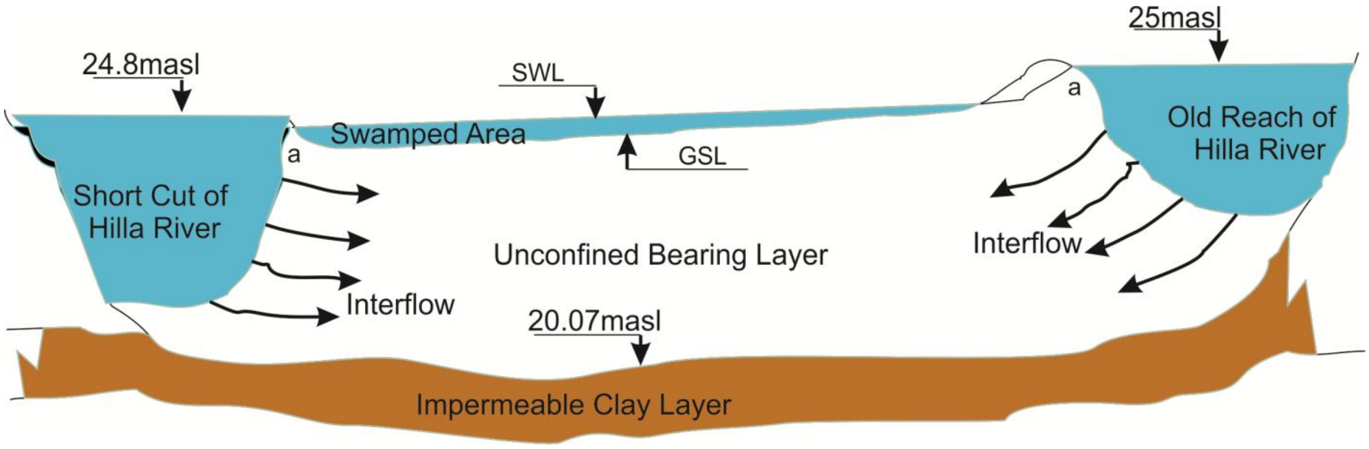
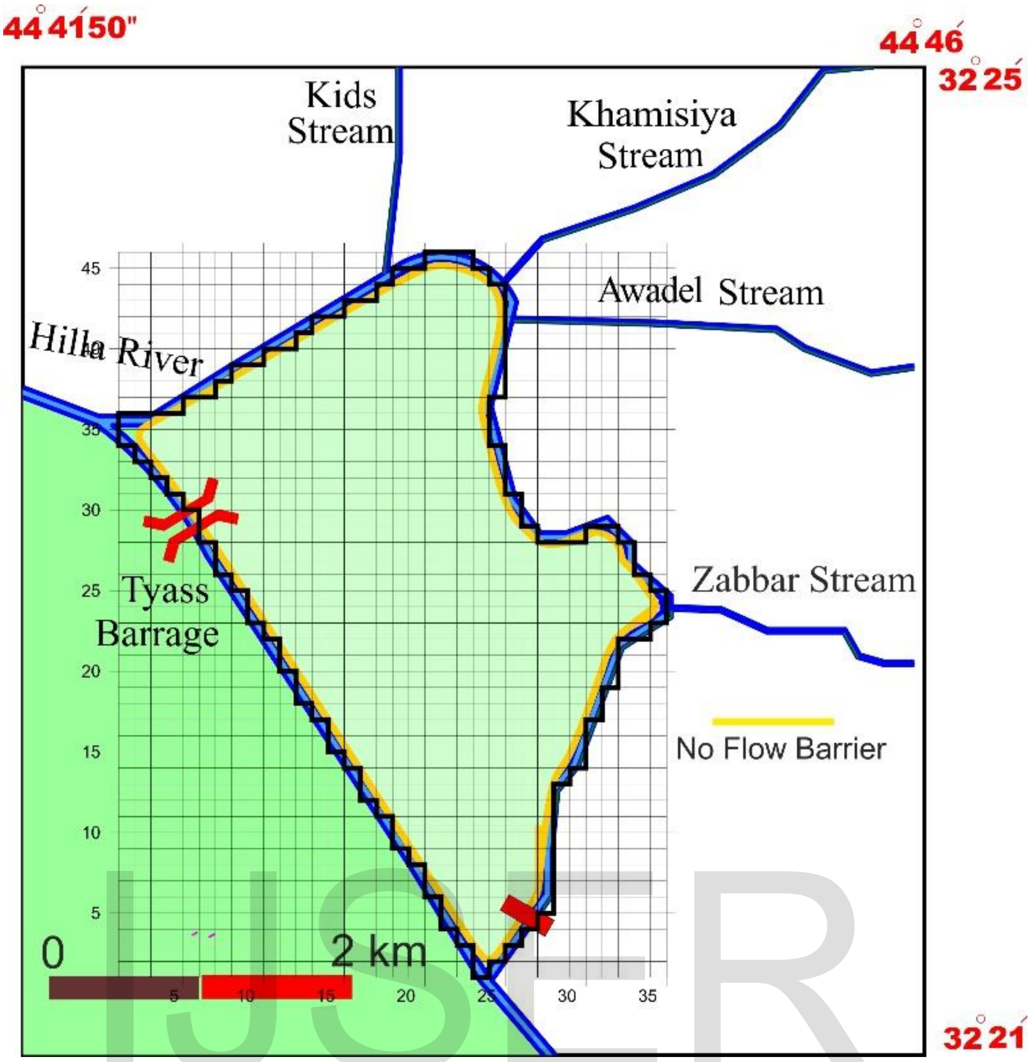


Fig. 2 Lateral Seepage into Tyass Water Bearing Layer (Section a-a)

Unfortunately, a vertical impermeable barriers penetrates the full depth (4.25m) of the unconfined aquifer was planned to surrounding the area (Figs. 3a & 3b) to prevent lateral seepage intrusion.



4.
5.

Fig. 3a Plain View of a No Flow Barrier and Meshes Discretization

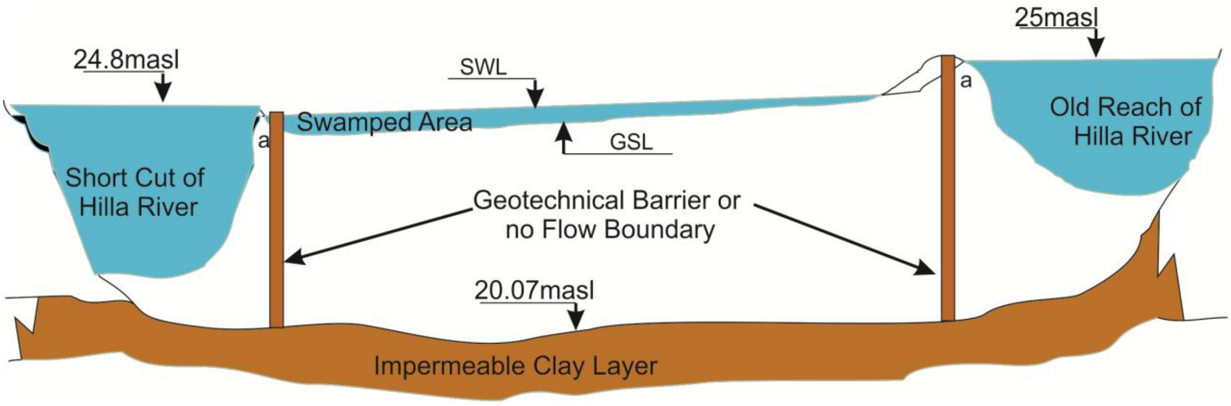


Fig. (3b) Impervious Barrier at Section a-a

Geology

The area is covered with Quaternary unconsolidated deposits which is usually consist of finer grained than the underlying pebbly sandstone AL Siddiki (1978). Quaternary deposits are represented by Flood Plain sediments of the Euphrates River. These deposits comprehend clay, silt and sand with deposits of gypsum in addition to depression fill sediments, these deposits accumulated as a result of the floods of the Euphrates River, consisting generally of fine sand layers, silt and silt loam, Parsons (1957). In general, recent sediments within the area are consisting of a succession of layers of mud, sand and shale with a little amount of gravels in deeper layers AL- Jubouri (2003).

5. Mathematical Modeling and simulation Technique

Analytical solutions of 1, 2 and 3D partial differential equations for non-steady of groundwater flow in heterogeneous anisotropic aquifer, have not yet been derived for certain initial and boundary conditions**.** Correspondingly, a numerical solutions based on a finite difference or finite element approaches have been proved to be sophisticated tools to deal with heterogeneous anisotropic large scales problems. A finite difference approach has been chosen to be developed for the simulation of groundwater flow category.

a. Mesh design

Mathematical modeling of groundwater was initialized by superimposing a square paper over a map of the modeled area and then the domain is discretized into suitable number of grids. In this way the domain is discretized into a number of columns (NC = 36) and a number of rows (NR = 46) as shown in Fig. 3a. In the current modeling, a square meshes of dimensions of (100 m*100 m) were chosen.

b. Computer simulation programing

A modified copy to the simulation program of Pricket and Lonngquist (1971) was used.

c. Error term

Error term is the most important parameter in the simulation program since it justifies the accuracy of the simulated groundwater levels. Briefly, the small error term, the high result accuracy. Anyway, Pricket and Lonngquist (1971) undertaken the error term in details, further explanations are unnecessarily. Anyway Fig. 4 presents the summation of errors per a single iteration (< 0.01) and iteration number versus time of a selected pumping well within the area.

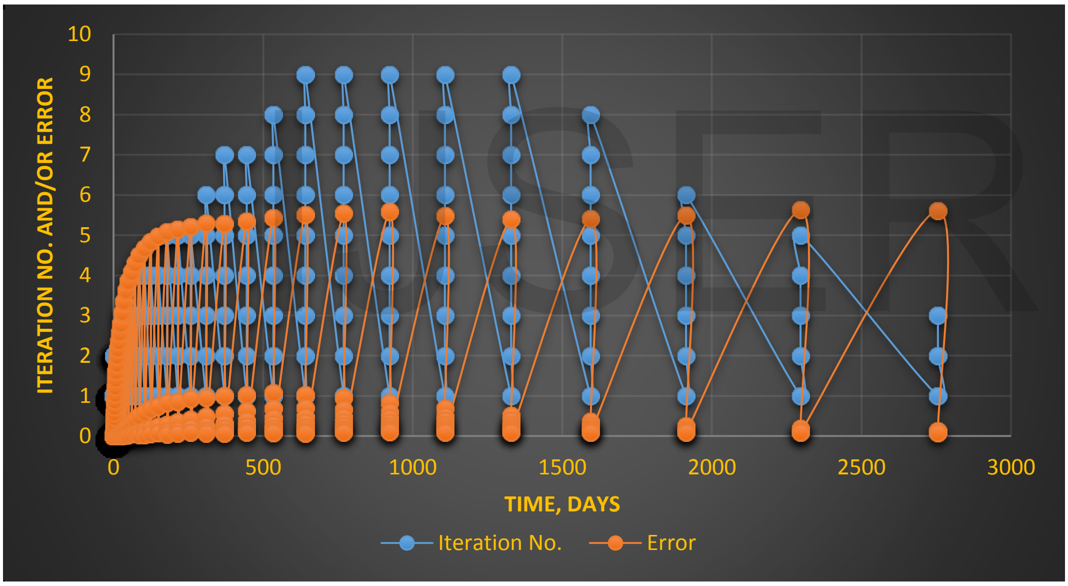


Fig.4 Iteration No. & Error Sum Versus Time

d. Aquifer properties

Aquifer properties are the major effective parameters in groundwater modeling. A pumping well was drilled in the grid of (20, 28) to evaluate the static water level, bed level, geologic stratification, transmissivity and the error term. More pumping tests were obstructed by swamps. A recovery pumping test analysis was carried out and the transmissivity was calculated Fig. 5. David and Sunada (1984).

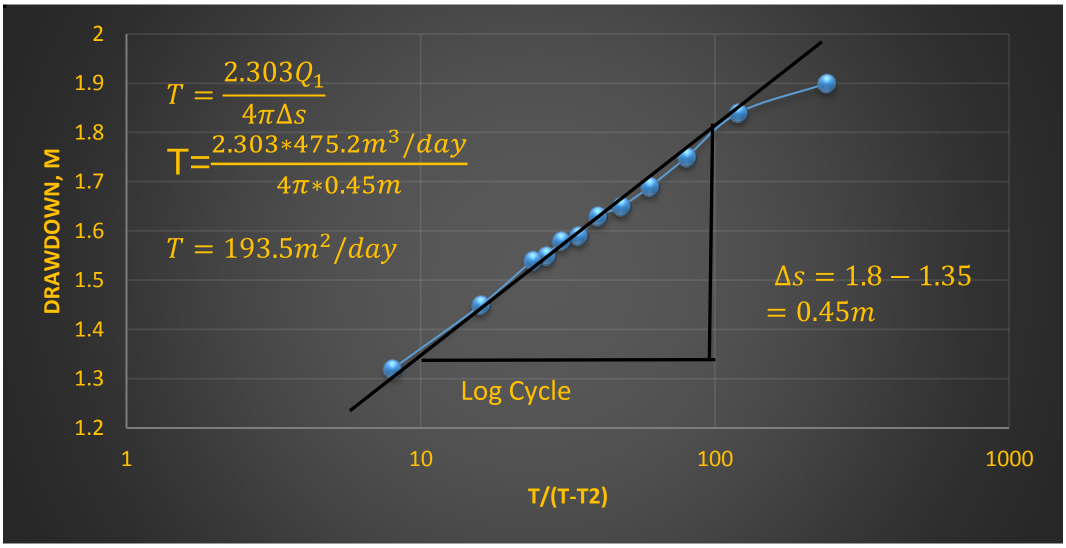


Fig.5 Recovery Pumping Test Analysis

Since no piezometric well was drilled in the area, therefore a specific storage was assumed to be (0.2) for geologic formations similar to Tyass aquifer as outlined by Todd (1980). This value was adjusted during the model calibration.

e. Aquifer geometry

Briefly, it is found that the average aquifer bottom level is (20 m above sea level) whereas the natural groundwater levels is presented in Fig. 6.

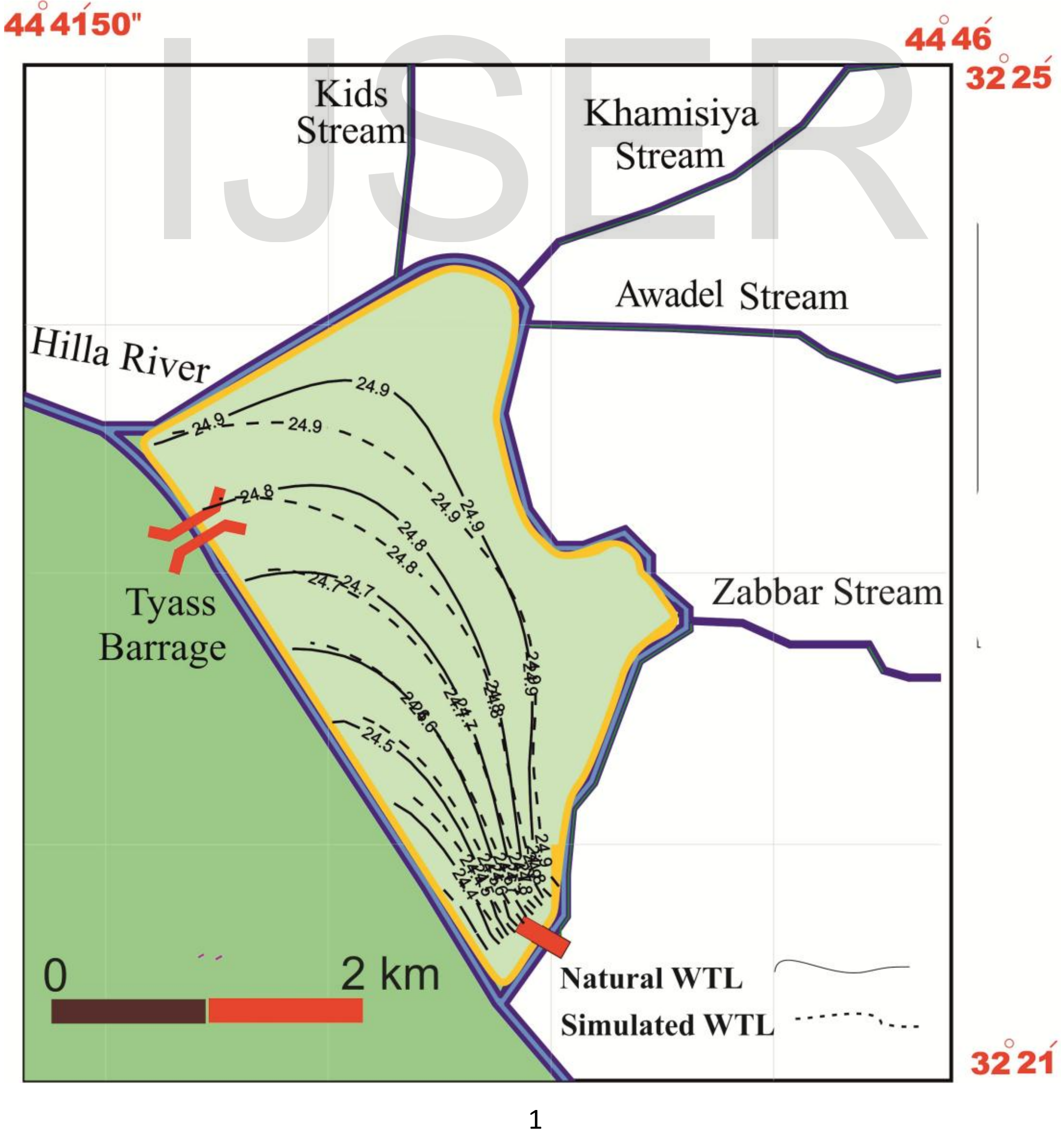


Fig. 6 Natural & Simulated Groundwater Levels

F. Aquifer recharge

Naturally, the local field measurements showed that most infiltrated water reaching the unconfined aquifer is mainly come from irrigation water. It average values were measured by double ring infiltrometer to be (2mm/day). This value was included in the model defaults and input data files.

6. Model calibration and verification

The model was calibrated and verified before any environmental applications. The followings were checked.

a. Natural and simulated groundwater regime

After the model program has been run for time enough to reach a steady state condition, the simulated water table levels are compared with the natural values. The results show a matching between the natural and simulated groundwater levels of maximum difference less than 10%, Fig. 7.

b. Aquifer response to discharging and recharging effects

A pumping well of (400 m^3/day) productivity was setup in a location shown in Fig. 7 to evaluate both a safe yield (SY) and the corresponding drawdown of existing wells. The figure also presents the resulting contour maps for both groundwater levels and drawdowns.

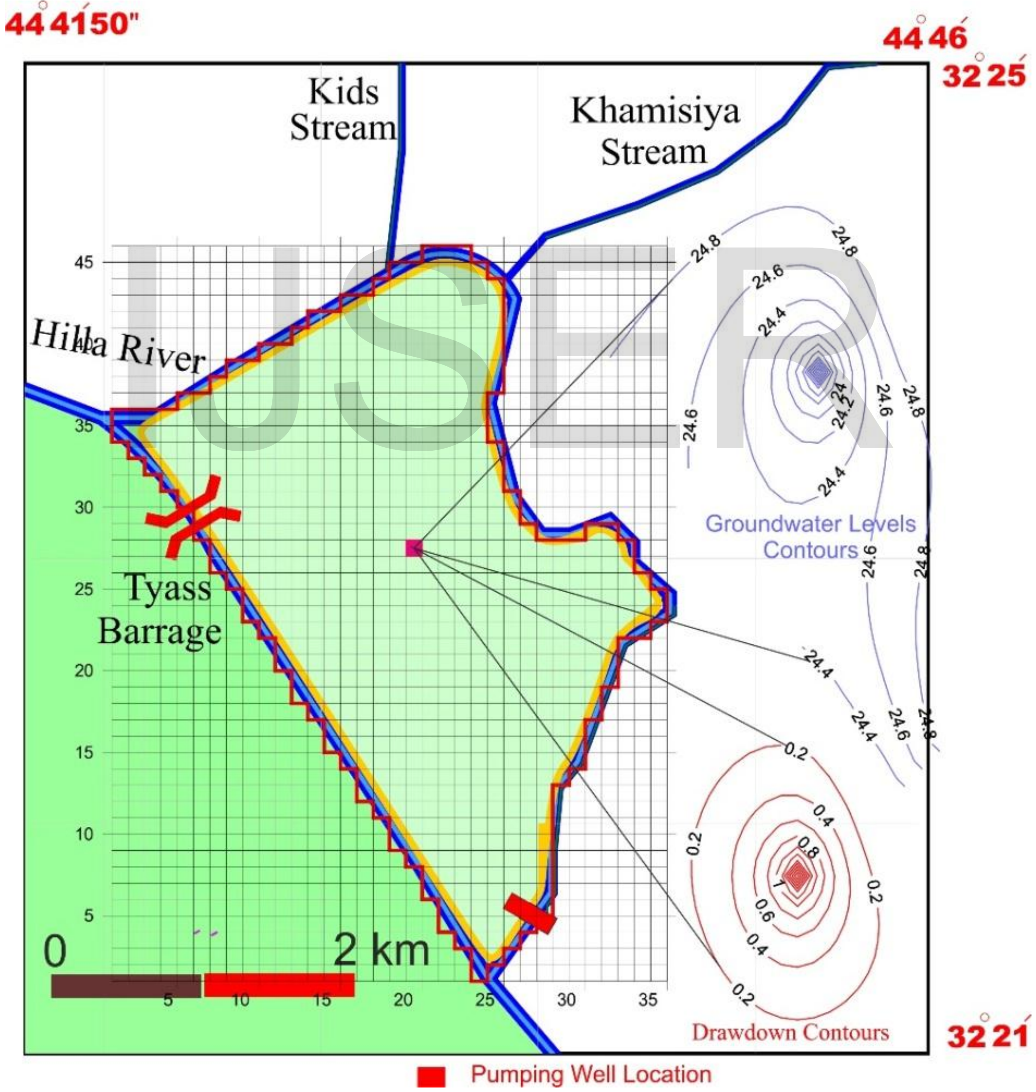


Fig. 7 Pumping Well Location, Groundwater Levels and Drawdown contours

A verification of the model indicated that;

1- (400 m^3/day) is a safe yield that can be exploited within a single nodes to produce a drawdown of (2.43m) at the center of pumping well. Section (a-a). Fig. 8 shows the resulting cone of depression at steady state condition.

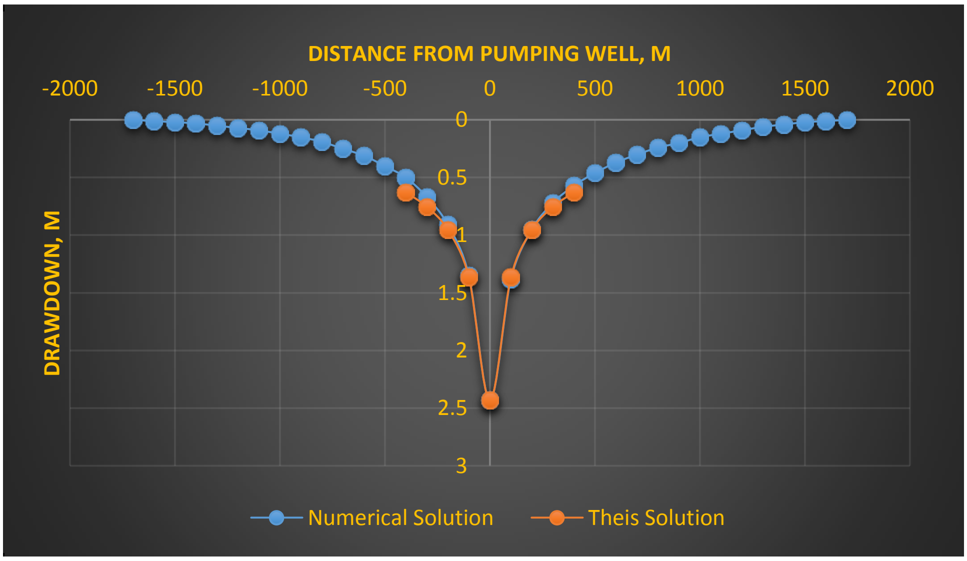


Fig. 8 Distance-Drawdown Comparison of Theis & Numerical Solutions along Section (a-a)

2- Fig. 9 presents time- drawdown variation curves at the locations of 100m south of the pumping well location respectively. The results show that the steady maximum drawdown of 1.38m has been obtained after 2755day respectively.

Fig. 9 Time- Drawdown Comparison of Theis & Numerical Solutions at 100m distance beyond the (400m^3/day) Pumping Well Center

7. Groundwater Chemistry

The sustainability of groundwater category of Tyass area constantly requires to investigate the chemical composition of most effective minerals. Briefly the measured Fe, Zn, Cu, Cd, Pb, and TDS were listed in Table 1.

Table 1 Average Concentration of most Effective Ions

IONS		Aquifer Water Col.1	Hillah River Water Col.2	Max Allowable Limits Iraqi Limitations (1984) Col.3
Fe	mg/liter	0.40	0.1	0.30
Zn		3.25	1.02	3.00
Cu		1.15	0.23	1.00
Cd		0.004	0.0014	0.003
Pb		0.033	0.0021	0.01

TDS	ppm	7000	500	1200 for sensitive plants

8. Groundwater Storage Evaluation (V)

The assessment of a strategic groundwater storage requires to estimate the exact porosity (p) of a bearing layer but this is difficult in nature, however the average porosity may be estimated by the form:

$$p = \frac{G_s \gamma_w}{\gamma_d} - 1 \qquad \ldots\ldots\ldots\ldots\ (5)$$

Where G_s *is the specific gravity*, γ_w *is a unit weight of water* and γ_d is a dry unit weight of soil.

The strategic groundwater storage (V) of heterogeneous aquifer may be given by the following form:

$$V = \sum_{i=1,j=1}^{n} \left(h_{i,j} - b_{i,j}\right) p_{i,j} A_{i,j} \qquad \ldots\ldots\ldots\ldots\ldots (6)$$

Where n is a number of meshes, $h_{i,j}$ *is a water table level* , $b_{i,j}$ is a bottom level of the aquifer, $A_{i,j}$ is an area of single mesh and i, j are coordinates of a specified mesh. Corresponding to Eqs. 5 and 6, it is found that the average porosity $p = 0.32$ and aquifer groundwater storage is $10{,}608{,}000 m^3$.

9. Optimum Management of Aquatic Wealth

A management study requires to assess the following items:

a. Water resources Assessment

b. Rainfall

Table 2 includes the average monthly rainfall of 35 years historical data with annual rainfall of (116.6 mm).

Table 2 Average Monthly Rainfall in Tyass Area

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total
Rainfall, mm	4.4	20.4	27	22	14	13.3	12.3	3	0.00	0.00	0.00	0.2	116.6mm

c. Groundwater Exploitation

A safe yield of 400 m^3/day per single well is an exploitation value that was used for replenishment of Tyass bearing layer.

d. Surface Water

In spite of bounding the area by Hilla River, it has not surface water allocation. The current study is aimed to quantifying and qualifying the surface water releases that instantaneously satisfy water demands and replenish the aquifer.

e. (WD) Evaluation

To evaluate this item, plant diversity, crops coefficients and monthly evapotranspiration were estimated by Blaney- Criddle method, Israelsen and Hansen (1962) and included in Table 3.

Table 3 Crop Coefficients and Evapotranspiration

month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP

ET., mm	162	87	59	53	64	101	160	227	283	311	293	227
Barley	0.00	0.30	0.49	1.02	1.18	1.18	0.70	0.30	0.00	0.00	0.00	0.00
Berseem	0.40	0.47	0.79	1.11	1.18	1.19	1.17	1.15	0.00	0.00	0.00	0.00
Broad bean	0.00	0.50	0.50	0.51	0.92	1.19	1.15	0.00	0.00	0.00	0.00	0.00
Onion/Garlic	0.77	1.01	1.06	1.06	1.07	1.06	0.91	0.77	0.00	0.00	0.00	0.70
Wheat	0.00	0.71	0.89	1.11	1.18	1.20	0.84	0.32	0.00	0.00	0.00	0.00
Cotton	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.01	1.29	1.13	0.78	0.00
Cucumber	0.00	0.00	0.00	0.00	0.00	0.63	0.94	1.04	0.94	0.00	0.00	0.00
Eggplants	0.00	0.00	0.00	0.00	0.60	0.87	1.10	1.04	0.00	0.00	0.00	0.00
Maize(autumn)	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	1.11	1.27
Okra	0.00	0.00	0.00	0.00	0.00	0.40	0.44	0.74	1.07	1.11	1.06	0.98
Sunflower	0.00	0.00	0.00	0.00	0.00	0.37	0.87	1.21	1.04	0.45	0.00	0.00
Tomato	0.00	0.00	0.00	0.00	0.00	0.61	0.96	1.20	1.02	0.00	0.00	0.00
Watermelon	0.00	0.00	0.00	0.00	0.00	0.41	0.83	1.03	0.90	0.00	0.00	0.00
Alfalfa	0.77	1.02	0.83	0.51	0.53	0.80	0.99	1.05	0.94	0.99	0.97	1.06
Date palm	0.90	0.90	0.90	0.91	1.00	1.04	1.04	1.05	1.10	1.11	1.09	0.90
Grape	0.52	0.44	0.42	0.32	0.34	0.34	0.71	0.91	0.95	0.96	0.94	0.80

f. WD Algorithm

The WD estimation of Tyass is subjected to the following conditions:-

a- Plantation of a full area.

b- Randomly an equal areas are specified for each plant crop. The monthly WD was estimated and listed in Table 4, Col.(3), whereas the net WD Col. (4) was obtained by subtracting the average monthly rainfall.

Table. 4 Monthly WD Algorithm & Actual Surface Water (SW) Releases

Months	**WD (m^3/month)**	**WD (m^3/s)**	**Rainfall, (m^3/s)**	**Net WD (m^3/s)**	**SW Releases (m^3/s)**	**Hydrologic Solution**	**Hydrogeologic Solution**
						Daily Discharging Rate, (m^3/day)	**Daily Discharging Rate, (m^3/day)**
	Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)	Col.7
OCT	273615.0	0.105561	0.010644	0.094917	0.142376	4100.414	8200.829
NOV	182398.2	0.07037	0.049347	0.021023	0.031535	908.1936	1816.387
DEC	135949.3	0.05245	0.065313	0	0	0	0
JAN	136039.4	0.052484	0.053218	0	0	0	0
FEB	200640.0	0.077407	0.033866	0.043541	0.065312	1880.971	3761.942
MAR	446851.1	0.172396	0.032172	0.140224	0.210336	6057.677	12115.35
APR	818235.0	0.315677	0.029753	0.285924	0.428886	12351.92	24703.83
MAY	1140411.0	0.439973	0.007257	0.432716	0.649074	18693.33	37386.66
JUN	1025831.0	0.395768	0	0.395768	0.593652	17097.18	34194.36
JUL	789737.9	0.304683	0	0.304683	0.457025	13162.31	26324.61
AUG	683175.3	0.263571	0	0.263571	0.395357	11386.27	22772.53
SEP	507936.6	0.195963	0.000484	0.195479	0.293219	8444.693	16889.39

c- **Productivity of each well = 400m^3/day**

d- $\boldsymbol{Col.(5) = Col.(4) * 1.5}$

e- $\boldsymbol{Col.(6) = Col.(4) * 0.5}$*86400

f- $\boldsymbol{Col.(7) = Col.(4) * 86400}$

10 Sustainable Theory for Hydrologic Environment

After the construction of the geotechnical barrier, the water resources system (surface & groundwater flow regimes) is completely isolated since the impermeable barrier prevents lateral GW movement moreover the water resources decision makers unspecified SW releases via the resulting bad environmental consequences. Anyhow Tyass surface and subsurface sustainability requires to consider:-

10.1 Bad Environmental Consequences

Although, the construction of Tyass Barrier prevented lateral movement of groundwater it led to a gradual drought and caused many bad environmental impacts namely as; evaporation process increases soil TDS and harmful minerals concentrations such as Fe, Cu, Pb, Zn, and Mg, which consequently lead to the absence of plant life.

10.2 Environmental Remediation

Fig. 3a shows that GW is completely swamped the area therefore before the beginning of remediation, a lowering of water levels is evitable as categorized hereinafter:-

10.2.1 Hydrologic Solution

a- Supplying the area with a 1.5 of WD, Table 4, Col. (5), by a direct SW releases from Hillah River through an irrigation canal for both WD satisfaction and bearing layer replenishment.

b- Discharging the 0.5 WD shown in Table 4, Col.(6) by discharging wells with a productivity of ($400m^3$/day) which were setup adjacent to the shortcut of Hilla River to facilitate the discharging process into the river as shown in Fig. 10. The purpose of constructing these wells is for aquifer water replenishment.

c-

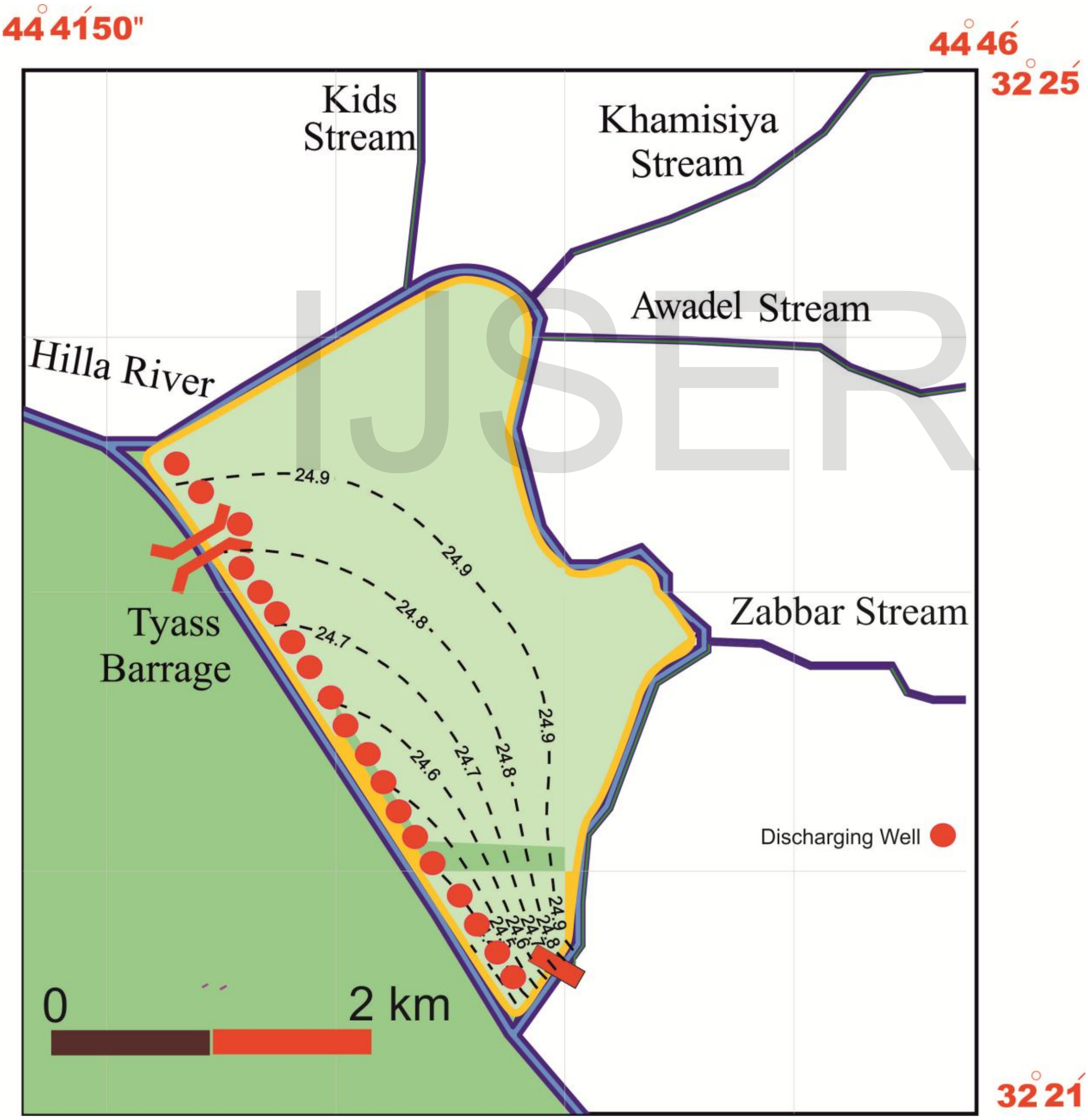


Fig. 10 Discharging Wells Distribution of Hydrologic Solution

d- Monthly Dilution

The daily releases of Col.6 were changed to monthly releases to mitigate the aquifer water storage against TDS and harmful elements of Table.1. The dilution process begins on October with monthly discharging values and initial concentrations of Table.1, Col.1 which replaced with fresh water of Hillah River with measured concentrations of Table 1, Col.2.

10.2.2 Hydrogeologic Solution

a- It was assumed to satisfy the net WD Table 4, Col.4 and Col.7 for the agricultural activities by using a SW releases to recharge the unconfined bearing layer by recharging wells drilled adjacent to the old reach of Hilllah River shown in Fig.14 to facilitate water supplying.

b- Discharging the injected water again to satisfy the WD for agricultural purposes.

c- The groundwater model and practical measurement reveals that during the recharging process of the unconfined aquifer, the groundwater level correspondingly rised as shown in Fig. 15. The figure indicates that the maximum suitable recharge is 4.6L/s which will maintain WTL at 0.25m below GSL during the recharging process.

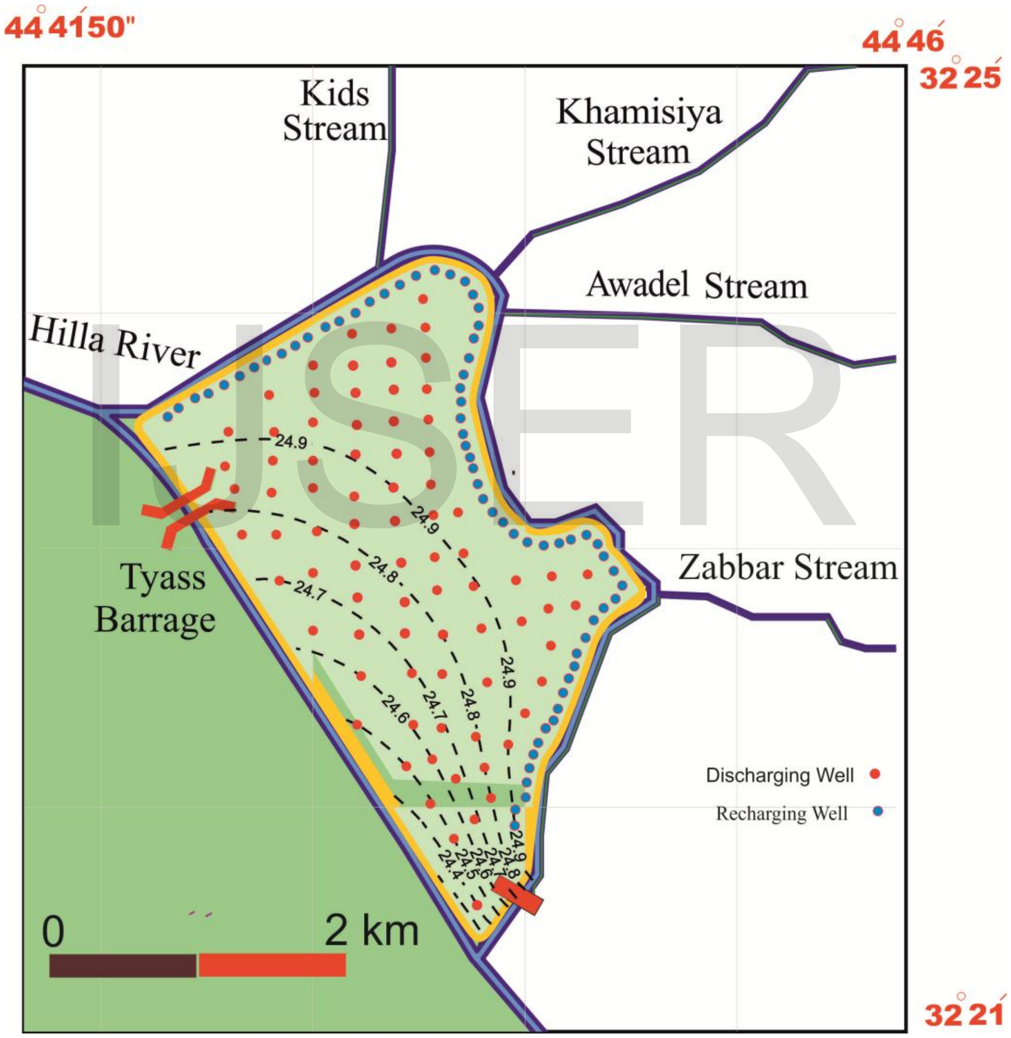


Fig. 14 Recharging and Discharging Wells Distribution of the Hydrogeologic Solution

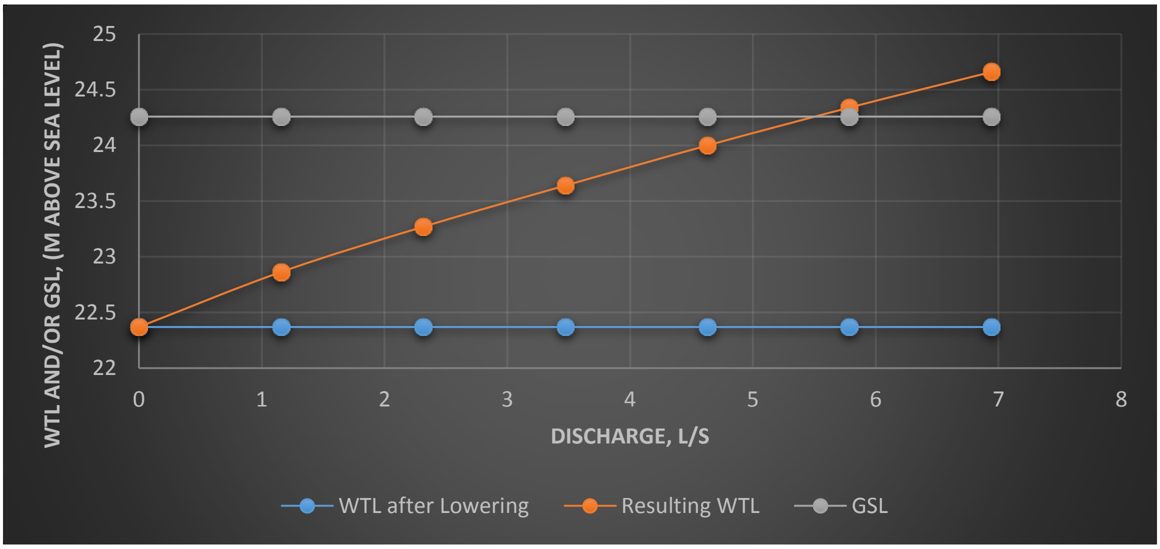


Fig 15 Groundwater level Rise corresponding to recharging process

Conclusions

1- Hydrogeologic remediation is more effective and economic solution for a land bounded by a no flow boundaries.
2- Mitigation of subsurface heterogeneous media is possible and an effective field practice.

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