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INTEGRATED APPLICATION OF (MODFLOW) AND (WEAP) MODEL IN NINEVEH PROVINCE

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ABSTRACT

The province of Nineveh is considered one of the areas that began affected by the waves of drought, so it became necessary to find additional water resources. Consequently, groundwater is considered a good candidate to bridge the gap between water supply and demand. The current study included the construction of a conceptual groundwater model, then this model is converted to a numerical model by means of (MODFLOW) and after a proper calibration of the model it was linked to a surface water model using (WEAP) tool to reduce the shortages in supply of different water requirements. It was noted that when relying on groundwater as an extra resource to the surface water resource, there is an substantial improvement in the reliabilities of meeting the various demands. Additionally, the simulation results revealed that the possibility of adding groundwater as a dependable resource is helping to meet the requirements and to substitute the future shortages of water. The main contribution of the present research is unifying the surface water system with groundwater system in such a way that could be use them interchangeably whenever it is necessary. The proposed mechanism could predict the states of supply and demand through virtual scenarios which could be of a great help in development of preparedness and proactive plans to face future challenges in issue of water supply.

KEYWORDS: WEAP, GMS, MODFLOW, LinkKitchen

1. INTRODUCTION

There is an increasing awareness about the current and future climate change and its direct impact on the availability of water resources in many parts of the world. This motivated people to start looking for alternative sources for water and try to determine optimal policies for the water resources management. The significance of this is particularly seen in areas that are currently suffering water shortage problems and increasing in population which have led to a remark decrease in the available amount of surface water .One of these alternative sources is groundwater. Groundwater can be used to meet different water requirements (depending on its quality) at critical times of the year.

The province of Nineveh is considered one of the areas that began affected by the waves of drought [1], so it became necessary to find additional water resources. Consequently, groundwater is considered a good candidate to bridge the gap between water supply and demand. However, it needs further studies and researches of its availability and distribution from both qualitive and quantitive points of view. The reliability studies in using the two sorts of water in an integrated manner is also essential to ensure the sustainability of supplies.

The determination of the model forms and methods which integrates the use of surface water and groundwater in to maximize the net benefits accrued from water resources systems is a crucial step toward any successful management plan. Through the analysis of the consequences result from scenarios of water flow decrease in the Tigris River, [2] shows the need of finding additional resources to prepare for these conditions if occurred in the future and substitutes the shortfall in water quantities, especially those related to the civilian requirements. The groundwater in the province of Nineveh has not been used in a sustainable manner.

Recently groundwater simulation models have been used extensively to study the movement of groundwater [3]. In this regard, Kim and Sultan [4] proposed a simulation model to simulate aquifer called Nbean in Egypt and tried to find the effect of irrigation and drainage operations on groundwater using (MODFLOW). They showed that a good plan should be prepared in order to provide the right level of water for agriculture to avoid the phenomena of dry wells and waterlogging.

Kumar et. al. [5] simulated the groundwater flow in the western side of the River Yamuna in India using (Visual- MODFLOW). The study showed that the continue to pump the same amount of groundwater will lead to the deterioration of groundwater state in the future and extensive reduction in the steady state level of water. Yang et. al. [6] developed a three-dimensional simulation model of groundwater in the city Tonkoulo in China using a conceptual model in which the aquifer was divided into three classes according to layers type. It was aimed to find the hydrological parameters. Results revealed that the output of the model are closely correlated to the actual measured parameters. Thus the recommendations of the implementation of conceptual models to predict the state of groundwater level under different scenario of demand were quite justified. Richie [7] proposed a conceptual model of groundwater in the salty basin in USA. Preparation of three-dimensional model has been accomplished using finite differences method by means of (GMS-6.5) along with (MODFLOW) model. It is used for a long-term plan to identify possible amounts of pumping from the aquifer. Also Zare and Koch [8] studied the groundwater movement during the construction of the Kafushan Dam in Iran by building a (MODFLOW) model to simulate groundwater using (GMS-6.5) system. Hadded developed et. al. [9] developed a model for decision support system (DSS) for the management of groundwater in the Zeus tank in Tunisia linking the two models (WEAP-MODFLOW) to assist groundwater using the method of conceptual model. The surface system water has been built using the tool (WEAP) with adopted scenarios extending up to the year (2030). It turned out through the analysis of the results that it is possible to avoid the shortage of water in the future through the construction of water treatment plants, as well as relying on the withdrawals from the aquifer Zeus to substitute the shortfall in supply.

The current study included the construction of a conceptual groundwater model for specific areas in the province of Nineveh. The (MODFLOW) model is linked with the model (WEAP) as presented by [1] to maintain and observe the impact of groundwater use on a regular basis and integrated with surface water to reduce the shortages in supply of different requirements. This work is a step towards realizing how to build an integrated water management including surface and groundwater. One of the most important contribution of the current research work is that it is considered the first attempt in this important aspect in Nineveh according to the knowledge of the authors.

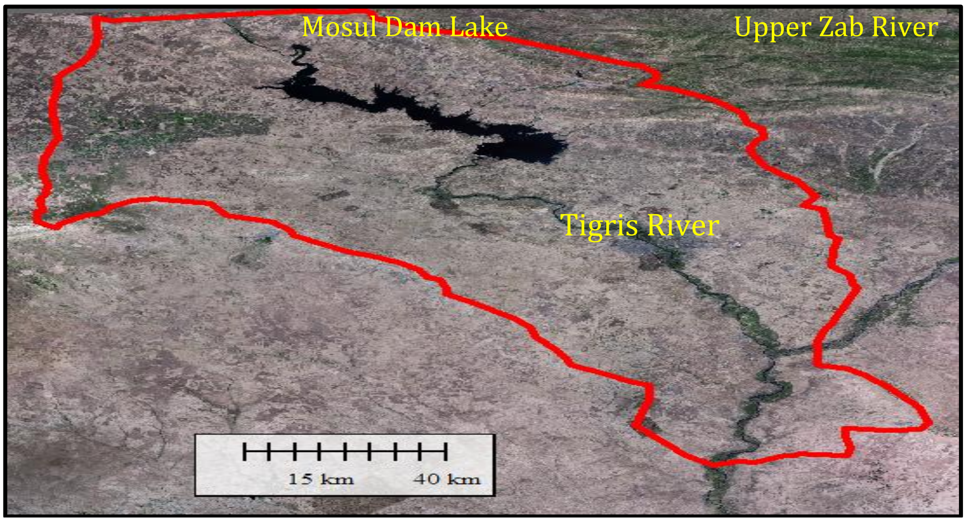


Fig. (1) :-Boundaries of groundwater aquifers in the selected area of study

2. Groundwater in the province of Nineveh

Groundwater aquifers in the province of Nineveh are formed from several configurations. The formations of limestone constitutes the main aquifer within the north-eastern and northern parts, especially Plaspi formation and the limestone formation within the Mountain of Sinjar area which is considered as important reservoirs for groundwater. Through the information and the available data during the pumping test operations in some wells drilled within this area, it is possible to identify some hydrogeological parameters and coefficients. Table-1 summarized these parameters and coefficients in different locations within the study area.

Table(1): -Characteristics of aquifers in the selected area of study around Mosul city

Location in the study area	Type of formation	Permeability coefficient (m/day)	Aquifer Productivity (m^3/day)	Static water depth (m)
North eastern &North	Plaspi	0.1-5.1	60-1487	6-108
Central& South part	Fatha	0.1-8.1	7-13320	3-65.5
Western part	Injanah	0.1-18.5	27-2970	-1.2-100
Eastern part	Bai Hassan	0.1-23.9	20-3069	1.5-118.2

3. Building (MODFLOW) model

The steps to build a model (MODFLOW) starts by creating a conceptual model then converting this model to a numerical model using (GMS). Building a conceptual model within GMS platform can be done by introducing some sort of maps representing the physical features of the groundwater system in the study area. The GMS program can identify those maps through nodes and arcs especially designed to represent the conceptual model of the area [10]. The boundaries of some sub-basins of Tigris river with total area of 9400 km^2 has been delineated to represent the boundary of the aquifer and the edges of Mosul Dam lake and the surface water level elevation and the bed level elevation of the reservoir including the water surface elevations of both Tigris and Upper Zab rivers are all fed to the model. As far as the recharge of water from precipitation to the groundwater is of concern, data from Mosul and Rashedia weather stations were used in the model. The static water elevations of the aquifers have been estimated with the aid of some existing wells within the area. Additionally, the following assumptions have been made to accomplish the conceptual model and bridge the gap exists due to lack of data.

1- The study area consists of a single layer and extends to a depth of 150 m above sea level (note that it is possible to add any information arise in the future without affecting the model performance).

2- The study area is assuming the same to its counterpart from the boundaries of the sub-basins of the Tigris River inside the province (the direction of flow is usually towards the low areas).

3- There is no flow outward from the study area and no outward flow from outside towards the inside (reservoir kind is of no flow boundary).

4- The coefficient of the vertical conductivity is one-third the value of the horizontal conductivity.[11]

5- The groundwater reservoirs in the study have been divided into four divisions to determine the characteristics of the soil (water conductivity and the ability of soil to conserve water) (K, Ss), according to the details given in Table-1, these divisions are shown in fig. (2).

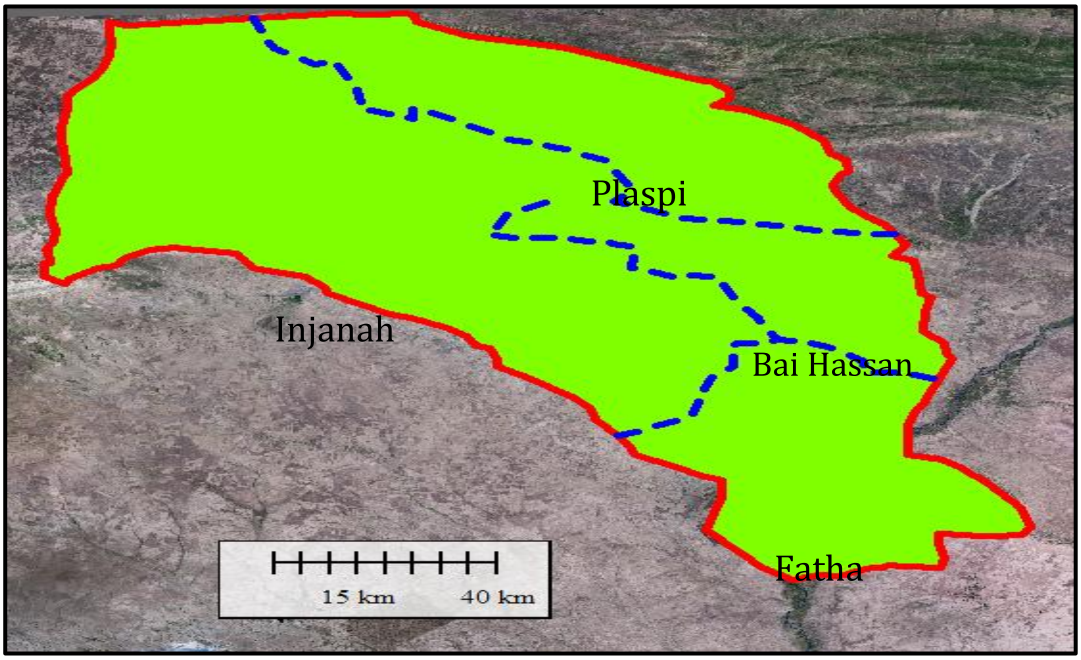


Fig. (2):- Divisions of the study area b geological formations

After completing the construction of the conceptual model shown in Figure (3), the numerical model (ModFlow) constructs a number of square grid of cells (100 * 100), so as to divide the water reservoir to three dimensional model to enable the adoption of mathematical calculation using finite difference method. It is worth mentioning that the higher the density of the network the greater the numerical model accuracy, but the time required to reach a solution will increase accordingly.

Fig. (3):- the conceptual model of the study area

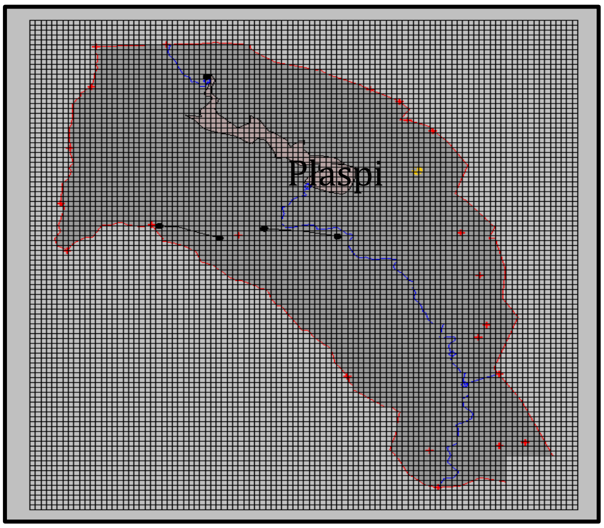
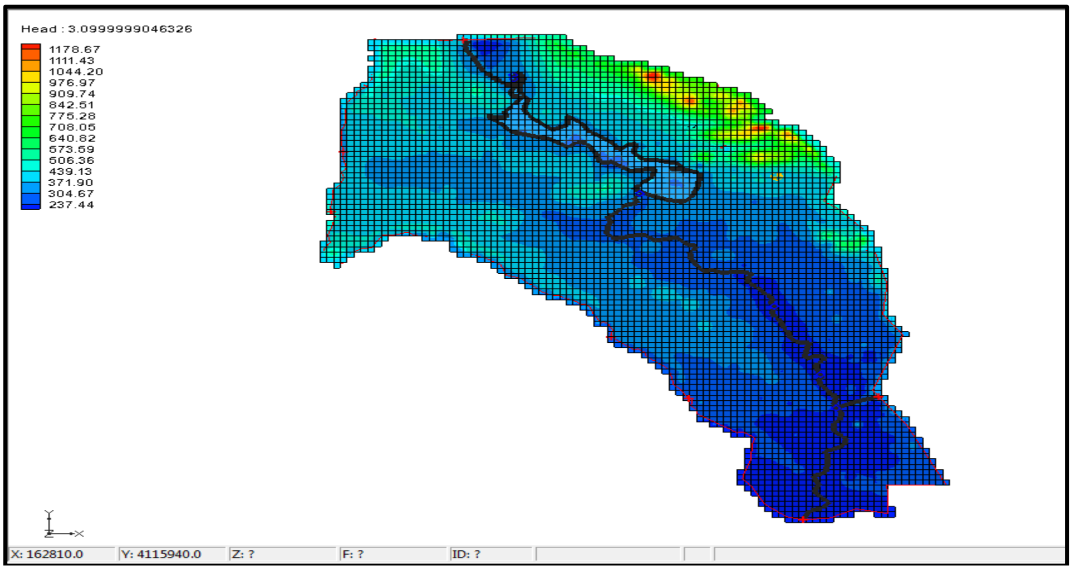


Fig. (4):- the (100*100) network built in the study area

4. calibration of the (modflow) model

The calibration of the MODFLOW for groundwater modeling was performed assuming values for conductivity and storage coefficients obtained from pumping test data in some of selected wells in the area of study. By comparing groundwater levels presented by [11] and those calculated by the numerical model and shown in Figures (5-a) and (5-b), and after a number of attempts and checks until an acceptable level of agreement between the output of the model and the hydrological steady state conditions of the selected area has been reached. Thus, it becomes possible to calculate the inflow to the aquifer and the outflow from the aquifer and the general direction of groundwater movement.



Fi.re (5-a): The level of groundwater in the study area obtained (ModFlow) model at the beginning of simulation period

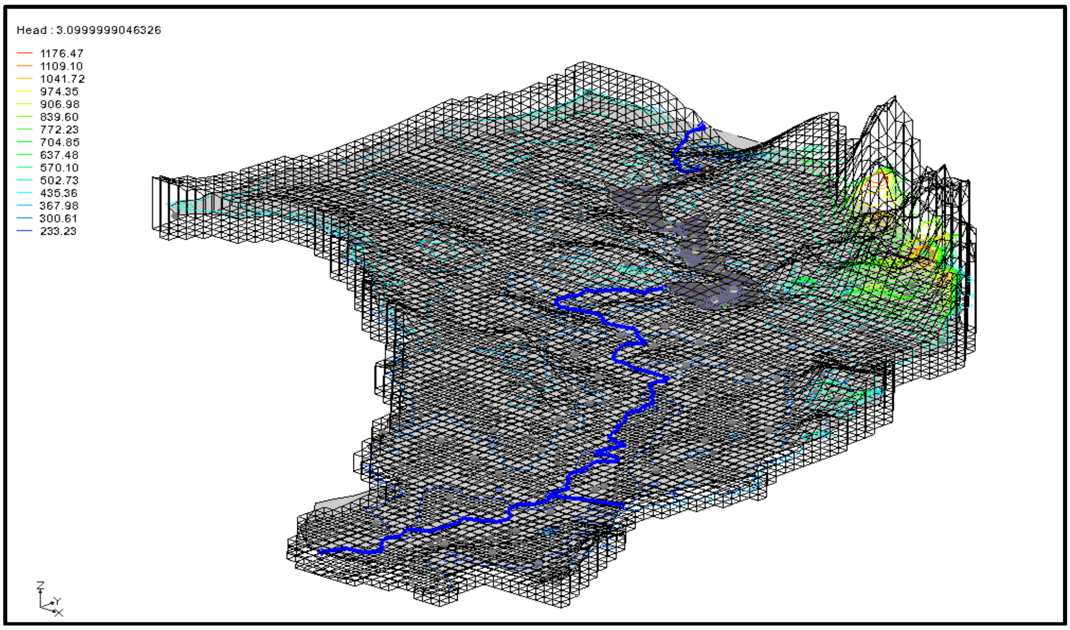


Fig. (5-b): Three-dimensional representation of groundwater levels using (MODFLOW) model at the beginning of simulation period

5. linking groundwater model with surface water model

One of the main advantages of the numerical model (MODFLOW) is the possibility of linking it with hydrological models and operating them simultaneously to observe the effect of the ongoing processes within the aquifer system (pumping from wells, recharge and water movement), as well as the ongoing operations on surface water system (precipitation, irrigation levels, surface reservoirs and others) on the level and quantity of groundwater.

In the current study, the numerical model for groundwater have been linked with the surface water using (WEAP) tool to integrate the water management. Figure (6), shows some details about the linking of these two models. However, in order to link the two models, they both should converted into the same programming language such as FORTRAN and then identifying grids with a certain number of cells in the study area such that the components of the resulting system are in common. Figure (7) shows how MODFLOW linked to WEAP.

Recently, a program called (LinkKitchen) which is designed specifically to link hydrological model WEAP with models of type MODFLOW has been introduced []. This program insures the process of operating MODFLOW within WEAP tool with the need of running MODFLOW using GMS, (see Figure 8). Thus, the groundwater levels could be controlled and the information could be exchanged between the two models in each interval of time. Any change in the surface water aspects such as reservoir level would be reflected on the groundwater level directly where these effects could be evaluated. Moreover, the availability of water can be known and the quantities to be withdrawal from groundwater can be calculated in each period of time.

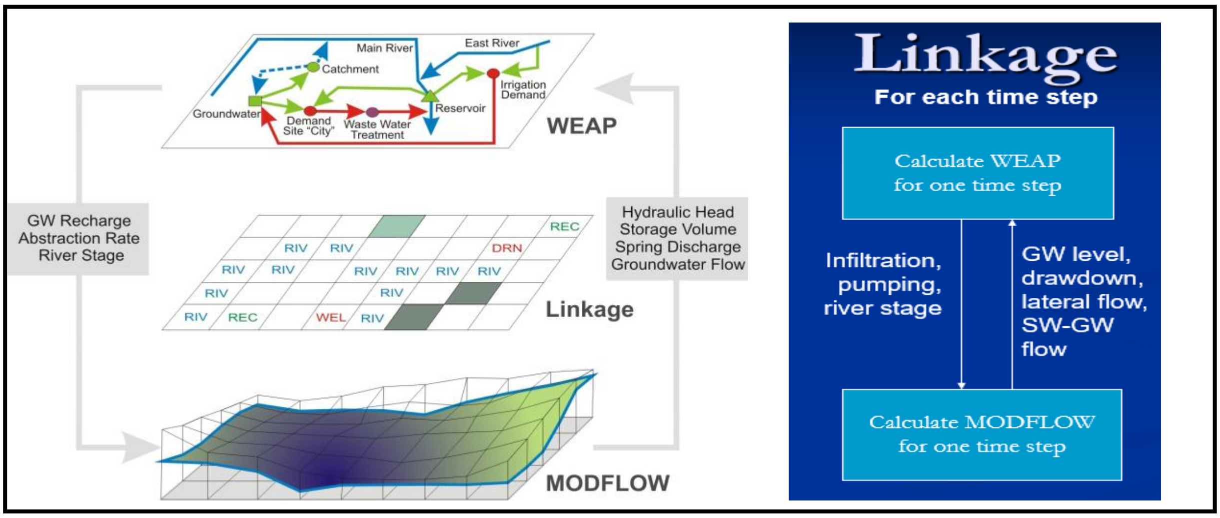


Fig.(6): Linking the two models (WEAP) and (ModFlow)

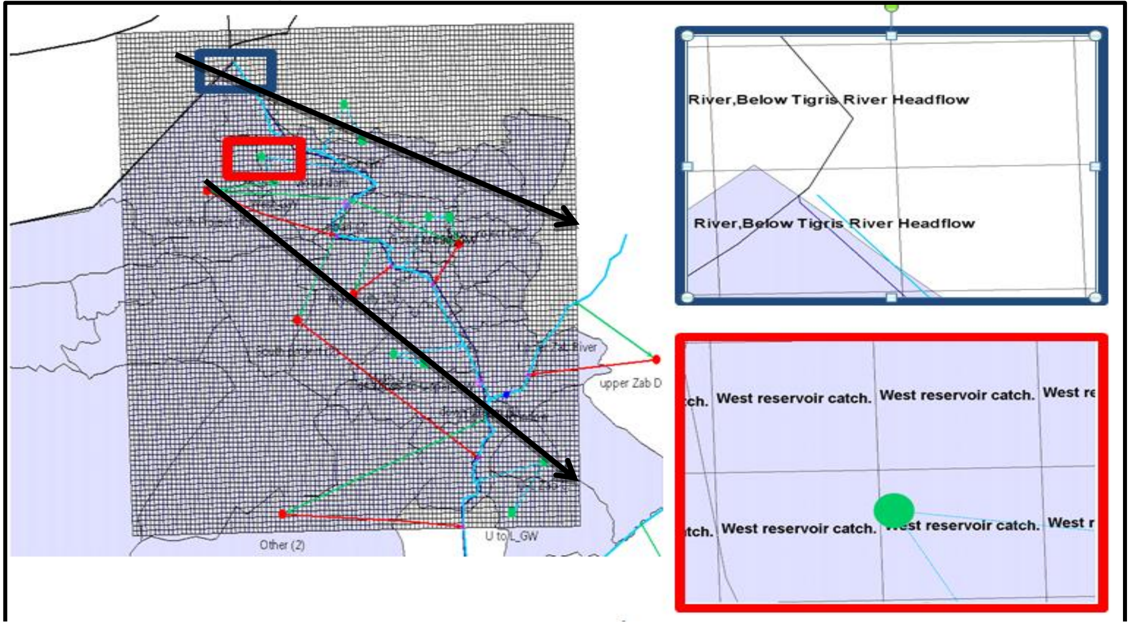


Fig.(7): Definition of network cells

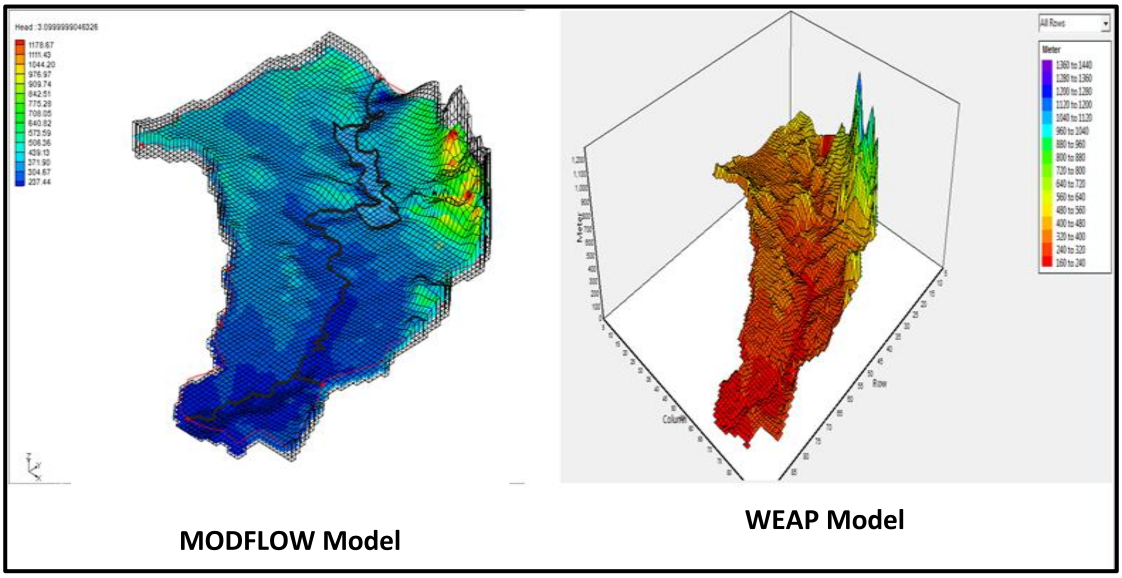


Fig.(8): Representation of the model (MODFLOW) within the (WEAP) tool

6. application of the linked system

A qualitative application of the built system in which the MODFLOW model combined within WEAP tool has been applied using a certain scenario of surface water supply [1]. In this application (Scenario 3) given by [1] is selected. This scenario was assumed that the surface water supply to be reduced to one third of its normal average and permits withdrawal of water from groundwater for the benefits of North Jazera and East Jazera irrigation projects, (see Figure 9). No water to be pumped for the benefit of South Jazera project as it laying outside the area selected for this application.

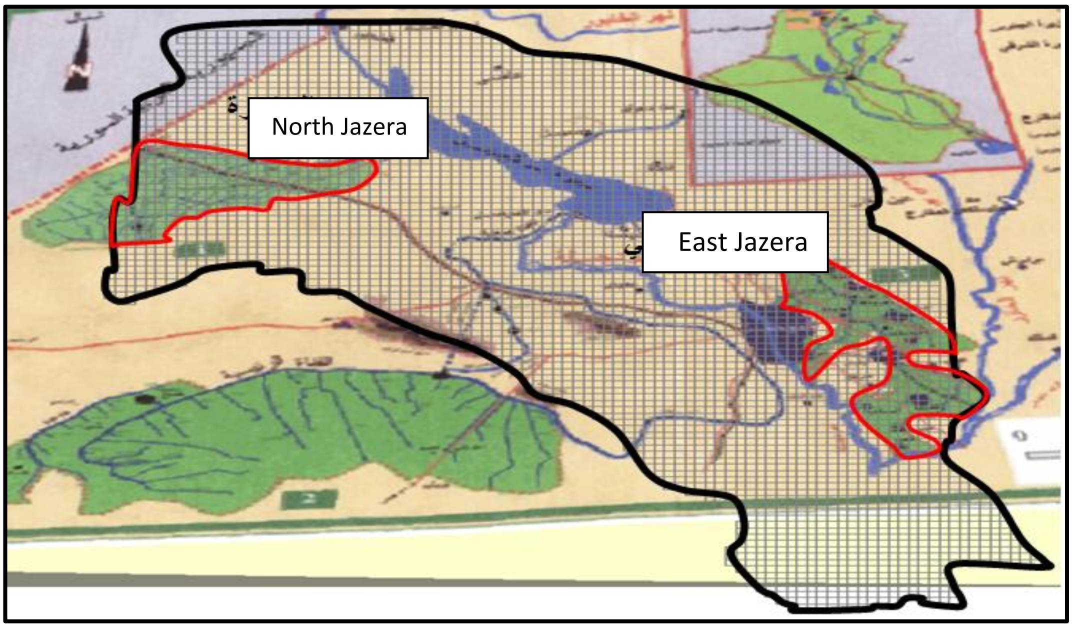


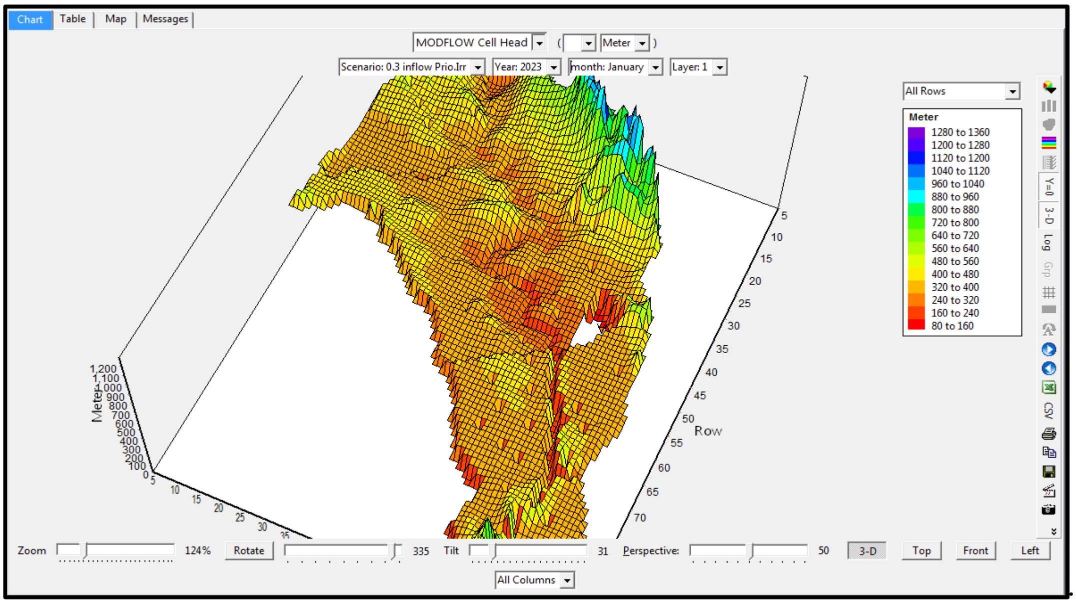
Fig. (9) :-Jazera Irrigation Projects

Pumping of water from groundwater was continued through the simulation time and the pumped quantities of water were allocated for agricultural purposes. The effects of the process were observed in terms of calculating the reliabilities of supply water for different kinds of requirements.

South Jazera

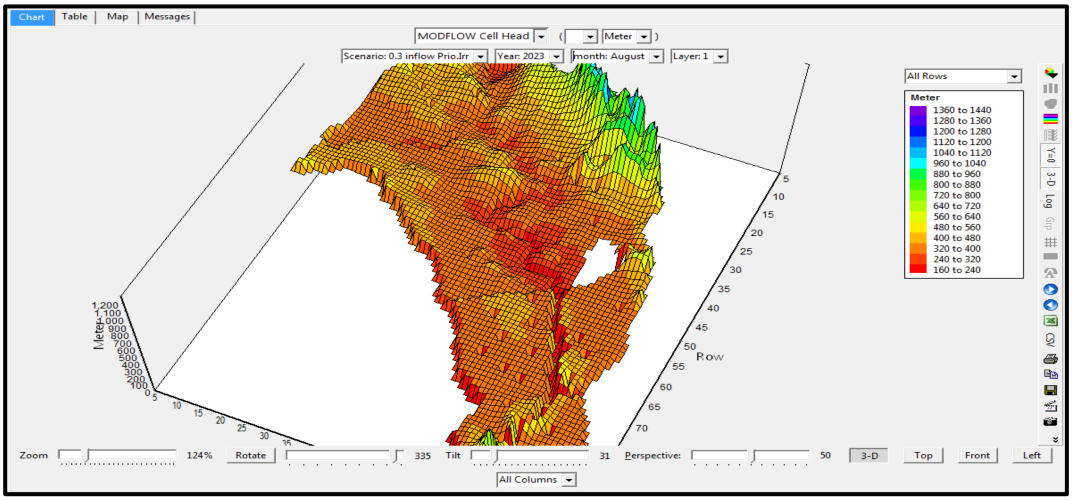
7. RESULTS AND DISCUSSION

Through the application of abovementioned Scenario and pumping water from groundwater to meet the demands for agriculture, the observation of the levels of groundwater reveals that the continuous pumping for successive years of simulation resulted in a substantial reduction in groundwater levels, and if the pumping continued further, a state of drought may be reached (the level approached the deepest point in the aquifer) as could be seen in Figures (10-a) and (10-b) respectively. The white area in the figure represents the discontinuity of the available groundwater within this level. However, the white area becomes wider in summer season as shown in Figure (10-b). The two figures also points out that the levels of groundwater are relatively high during the first quarter of the year because of the natural recharge to the groundwater though the precipitation in those months. This indicates the strength of combining the two models and how water transfers between them in an integrated manner. The decrease in groundwater elevations become very clear in summer season which highlights the need for integrated management plan. In this regard, one should apply some restrictions on the pumped quantities from groundwater and when to pause the process of pumping to allow the groundwater levels to be recovered



MODFLOW Cell Head (Meter)
Scenario: 0.3 inflow Prio.Irr
Year: 2023
month: January
Layer: 1
All Rows
All Columns

Fig. (10-a): The groundwater level in January (2023)



MODFLOW Cell Head (Meter)
Scenario: 0.3 inflow Prio.Irr
Year: 2023
month: August
Layer: 1
All Rows
All Columns

Fig. (10-b) :-the level of groundwater in August (2023)

Through the execution of scenario-3 and reviewing the results obtained over the 27 years of simulation for 25 inflow series expected in Tigris river [1], and by calculating the reliabilities of meeting the demand for civil requirements, it was found that there are some improvement in these reliabilities as shown in Figures (11-a) and (11-b), where the impacts of using the pumping from a groundwater and its effect on the provision of civil requirements are quite evident as shown clearly in red in the Figures below.

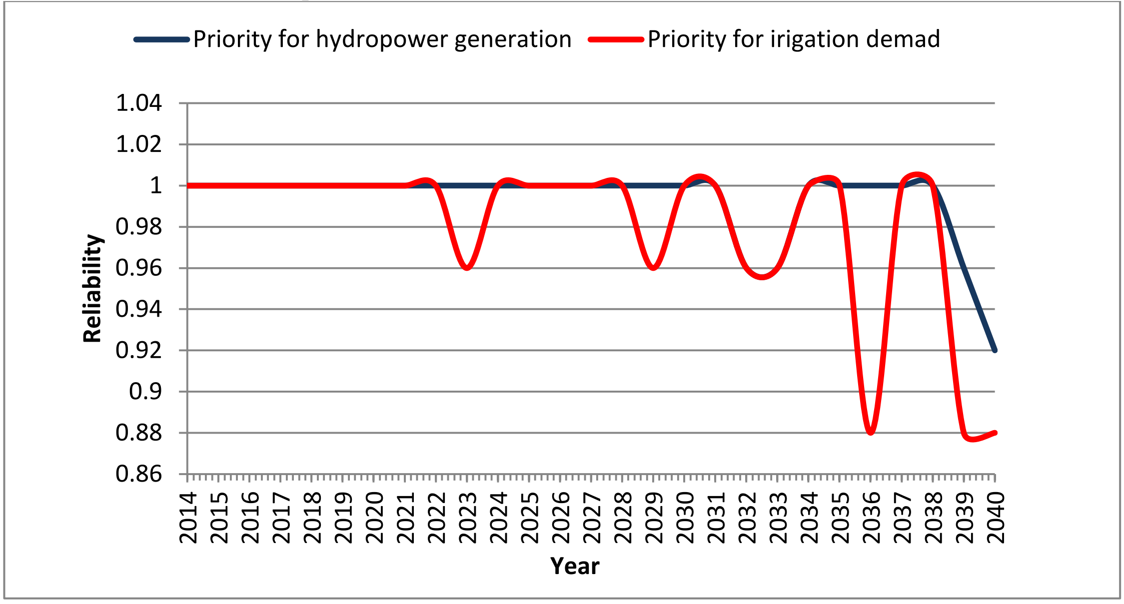


Fig. (11-a):- Reliability of supply for civilian requirements according to Senario-3 and no groundwater is considered

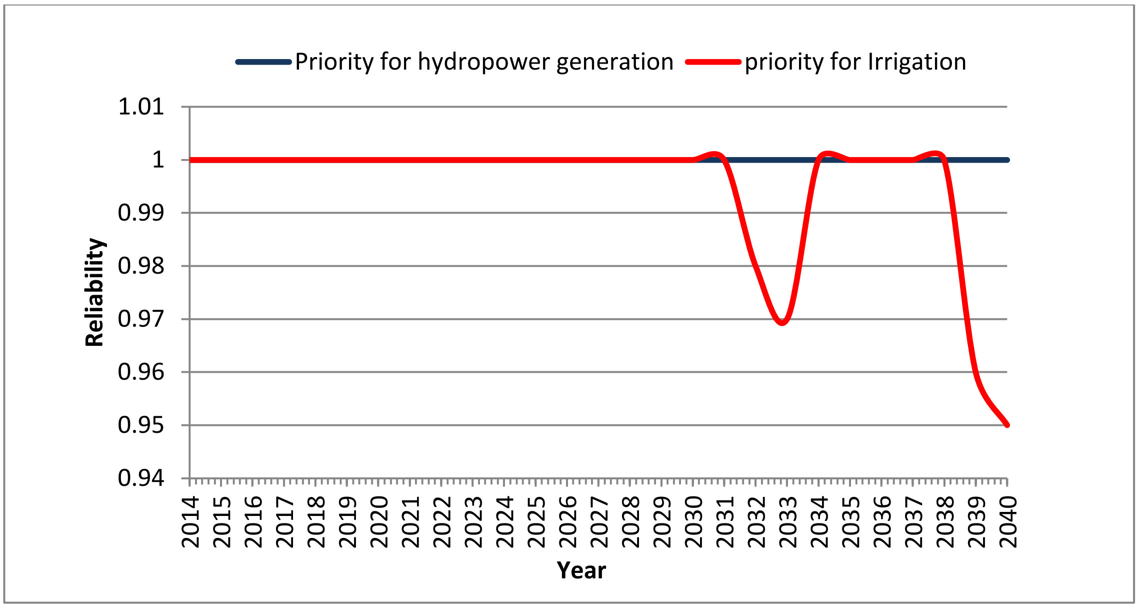


Fig. (11-b):-Reliability of water supply for civilian requirements according to Scenario-3 and groundwater is considered.

8. CONCLUSIONS

A three-dimensional model of groundwater is built for a selected areas in Nineveh province. A numerical model "MODFLOW" has been adopted with the help of conceptual model using the program (GMS). This model was converted into a numerical model and linked with the water surface model by means of (WEAP) tool. This arrangement helped in using the both water resources in an integrated manner and satisfying the different water demands requirements. This study showed that the conceptual models could represent a system of groundwater reasonably and can be applied to predict the change in groundwater levels under various scenarios of pumping. After connecting all of the surface water system using (WEAP) with groundwater using "MODFLOW" , it was possible to calculate the reliabilities of supply for various requirements after adding the groundwater resource to the whole water resource system of the selected area and start the process of pumping for the benefit of agricultural sector. The simulation results revealed that the possibility of adding groundwater resource as a dependable extra resource helping in meet the requirements and substitute the future shortages of water is clearly evident.

The main contribution of the present research is unifying the surface water system with groundwater system in such a way that can use them interchangeably whenever it is necessary.

The proposed combined system can evaluate the water resources in Nineveh province in the present time as well as in the future where it could predict the decreasing supply state and increasing demand state of water through virtual scenarios which in turns could help in development of preparedness and proactive plans to face future challenges in issue of water supply.

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