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Integrated Groundwater Management for Great Man-Made River Project in Libya

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Abstract

Groundwater is a vital resource of freshwater, and necessary for all aspects of life. It is estimated that over one billion people on earth do not have access to clean water supply. This research will study the future groundwater situations in the well field area of Great Man-Made River Project in Libya (GRMMP), which is located in the south west of Libya. The research will introduce the real situation after the arrival of water from the Great Man-Made River (GMMRP), phase-II, to the coastal area; groundwater was the main source of water to both agricultural and municipal consumptions for the country. Three scenarios will be carried using Groundwater Vistas software (GV), which runs of the MODFLOW and MODOFIC packages to make simulation and optimization respectively of that area. Three case studies will be carrying out of the area, East Jabel Hasauna well field (EJH). With the huge rate of pumping which planning to reach 2 million cubic meters per day, the results expected to be different and has some effect on groundwater budget. This paper is introducing the first scenario is simulated the East EJH which have 153 abstraction wells, the scenario have five stage related to long-term changing of groundwater table. The first three have shown clear changing of water table 8 m, 11.93 m, 14.43 m respectively, with constant abstraction rate of 5184 cubic meter per day. While the results of the last two stages were too close to third stage which 14.44 m.

Keywords: Groundwater Management, Man-Mad River, Jabal Hasauna

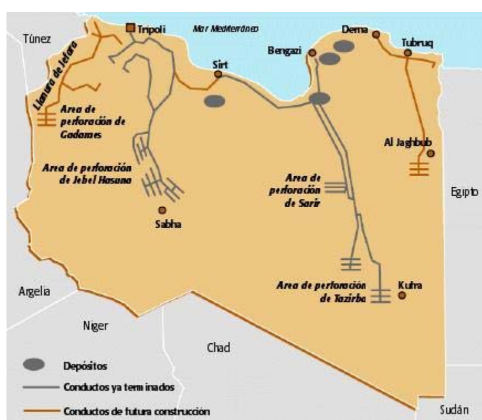
1. Introduction

Groundwater is vital to many nations. Worldwide some 2000 million people, innumerable farmers and many industrial premises depend on it for their water supply. Accelerated development over the past few decades has resulted in great social and economic benefits, by providing low-cost, drought-reliable and (mainly) high-quality water supplies for both the urban and rural population and for irrigation of (potentially high-value) crops. Libya is considered as one of those countries which suffer from limited water resources availability because most parts of the country are either semi-arid or arid and the driest regions of the world, with yearly average rainfall ranging from just ten millimeters to 500 mm. Just five per cent of the entire area of Libya exceeds 100 mm annually. Evaporation rates are also high, ranging from 1,700 mm in the north to 6,000 mm in the south, (IMB, 1980). Under such conditions, surface water development is not a sustainable option, thus putting immense pressures on ground water resources. Much of the ground water is used in irrigated agriculture, which represents 80% of total consumption (Alghariani, 2002).

Libyan government has been entrusted with the implementation and operation of the worlds largest pre-stressed concrete pipe project The Great Man Made River Project (GMMRP), which, since its conception in 1984 has grown to include almost 4,000 km of mainly 4 meter diameter pre stressed concrete cylinder pipe (PCCP). Eventually over 6.0 million cubic meters of water will be conveyed every day from well fields deep in the Sahara desert to the population centers that are concentrated on the northern coastal strip. Graet Man-Mad River Project is totally depend on the abstraction of groundwater basins to supply the water, and the majority of this water was collected between 38,000 and 14,000 years ago, though some pockets are only 7,000 years old. The project has some of five phases Figure 1 which the current and future conveyances include

- Sarir-Sirt,Tazerbo Benghazi System SSTB.
- Jabal Hasaouna-Jefar System.
- Gadabiya/Sedada System.
- The Gedammes/Zwara System.
- Kufra/Tazerbo System Jagboub/Tobruk System

Figure 1: Great Man-Made River Project Phases



The second phase of the Great Man Made River Project involves conveying two million cubic meters of water from well fields at East Jabal Hasouna and North East Jabal Hasaouna to Tarhouna and Tripoli. Three hundred and four production wells at the East Jabal Hasouna well field will produce 1.4 m cubic meters of water per day(area of study), and 153 production wells at North East Jabal Hasaouna will produce a total of 0.6 million cubic meters per day. The conveyance pipeline consists of 895 kilometers of 4.0 and 3.6 meter diameter pipes with pressure ratings varying from six to twenty six bars. Conveyance pump stations are located at each of the EJH and NEJH well fields in order to convey the water downstream of a regulating reservoir at Fezzan, (GMMRP).

2. Methodology

There are many areas of hydrogeology where one needs to apply models to represent the real hydrogeologic system, to understand the flow system and predict how a flow system will behave in the future. In addition, models can be used to analyze hypothetical flow situation in order to gain generic understanding of that type of flow system (Anderson and Woessner, 1992). Numerical models must be used when there are complex boundary conditions or where the value of parameters varies within the model area (Zheng and Bennett, 1995).

Numerical modeling of groundwater has been widely used for more than four decades to evaluate groundwater resources and develop a better understanding of the flow characteristics of aquifer (Mays and Tung, 1992). It is also used to predict the impacts of various groundwater management alternatives such as the impacts of pumping and recharge, groundwater-surface water interaction, the migration of chemical contamination, saltwater intrusion, etc. in order to find the best achieve an objective, there are two basic approaches solving a numerical simulation model: the finite difference formulation and finite element formulation. In this study the finite difference formulation will be used.

The MODFLOW (modular finite difference groundwater flow model) is probably the most frequently used groundwater modeling program (Winston, 1999). MODFLOW was developed by McDonald and Harbaugh 1988. The reputation of MODFLOW comes from its power and excellent documentation. It is also applicable to most types of groundwater modeling problem and accepted by many agencies both in USA and internationally.

The Amsterdam Water Supply utility has been using MODFLOW for many years (Olsthoom, 1999). It has been used for many purposes; for example, it was used to predict the effect of any kind of changes to the water supply system, to position extraction wells and also to design deep-well recharge system. Its selection for these tasks was based on its unique advantages, such as the ability to model transient flow. It also works with graphical interfaces, such as GROUNDWATER VISTAS (Rumbaugh, 2004). Groundwater modeling system GMS, and Visual Modflow which makes it user friendly. Finally, MODFLOW incorporates automatic calibration to determine aquifer parameters for any degree of heterogeneity

3. Previous Research

MODFLOW was used to simulate groundwater flow and the impact of five pumping scenarios to estimate the safe yield of future abstraction in the upper aquifer in the Azraq basin in Jordan, based on analysis of groundwater balance. The water balance was based on infiltration formula. The infiltration represents the gross amount of water that goes into the soil during the given storm. However, not all this infiltration goes into deep percolation to recharge groundwater. Additional losses through further evapotranspiration and interflow occur, leaving the actual groundwater recharge to be lesser than the infiltration (Al-kharabsheh, 2000)

Another application of MODFLOW was carried out in Kuwait to create a calibrated modeling system to simulate the drawdown and field operation in discontinuous layering and multiple screens. The application of MODFLOW gave useful information about the hydraulic impact on historical and future groundwater abstractions (Szekely et al.,2000).

Visual MPDFLOW has been calibrated and applied by Rasheeduddin et al, (2001) in a heterogeneous and anisotropic aquifer to investigate the possible alternative methods for effective groundwater management and development in part of the sedimentary basin of eastern Saudi Arabia. The Saudi Arabian basin, which is also arid, is similar in many respects to Libyan basins, including the Murzuk.

MODFLOW has been used to simulate groundwater in a multilayer aquifer system in southwest of Egypt. Geologically, the aquifer is known as Nubian Sand Stone Aquifer system. These layers extend to Libya, Chad and Sudan. The result indicates that the problem of depth to water increasing owing the drawdown in potentiometric surfaces is becoming serious (Ebraheem, 2002).

Boronina et al. (2003) also used MODFLOW model in southern Cyprus (a semi-arid experiencing a scarcity of water resources, as in Libya), to calculate water balance and the recharge rate at the Kouris basin. The impact of groundwater extraction in the study area was predicted by the model and simulated and observed heads agree within a reasonable degree of accuracy.

Facchi et al, (2004) applied a simulation model to the irrigation district in Northern Italy to evaluate the distribution of crop water consumption and interaction between recharge and groundwater dynamics. The simulation code is based on the coupling of two models: the groundwater flow model MODFLOW and conceptual vadose zone model (SVAT model).the models were linked within a geographical information system (GIS) as an interface. Application of the system reproduced the observed patterns of variables involved in the hydrological balance, in particular the interaction between irrigation, groundwater recharge and fluctuation of water table. However, there are some limitations in applying this system, particularly the huge amount of data for calibration and validation, which may not always be available.

Groundwater modeling has previously been applied in Murzuk basin in the Barjuj Project area using a digital model developed at the institute for Water Resources, hydrology and Agricultural Hydrulic Engineering of University of Hanover to simulate the behaviour during operation of the project and the calculate the drawdown rates of the water table. The Barjuj project extracts water from the Murzuk basin and the model was used to predict the water situation for two time horizons: 20 and 50 years. Two respective target withdrawals were considered:

- 55000000 cubic m/year for irrigating 3000ha
- 68,500,000.00 cubic m/year for irrigating 3650ha.

The results showed that the aquifer is suitable for providing the Wadi Barjuj irrigation project for both scenarios, the resulting drawdown being 38.5 m after 20 years and 46.5 m after 50 years of the project operation (IMB, 1980).

Although the Barjuj project also abstracts water from Murzuk Basin, the development is located almost in same basin with another projects such as Irawa ,Gadawa and Maknosa. it is therefore unlikely that the drawdown would have any significant effect on piezometric levels.

Pizzi and Sartori (1984) applied an Interconnected Groundwater System Simulation (IGROSS model), a special digital program designed for multi aquifer groundwater systems simulation on western Libya Aquifer System which includes Murzuk and Al Hamra system. The model was used to optimize groundwater extraction for domestic, agricultural and industrial water requirements to the year 2030. the model was applied to simulate 10 different alternative over period 1979-2030, the best one based on the smaller hydraulic head decline was selected with water level 443.30 m.s.a.l.

In another study, Pizzi et al. (2002) applied a quasi-three dimensional finite element flow model to simulate multilayered aquifer in western Libya aquifer system with vertical and lateral hydraulic interconnections. The model was calibrated in steady-state and non steady-state for period 1970-1990. it was then used to predict different alternative simulations until the year 2046 to find out the best well filed layouts and the maximum drawdown of water level to abstract 2000000.00 m3/day and 2,500,000.00 m3/day from 440 production wells. This program was linked with the computer program WATNET-4, developed by the Water Research Center (UK), to find out the best network of collector system in western Libya aquifer system. The results showed 450 m.a.s.l is last water level can be achieved.

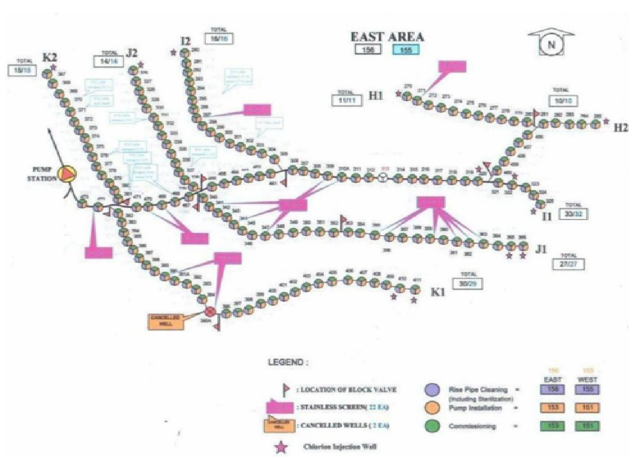
4. Data Collection and Analysis

Data of the research was collected from the well field, using high sensitive implant equipment to record the water level from different peizomitrec wells and the motion of groundwater for each abstraction well as well. Data were collected by the GMMRP Authority, it is consist of thirty two pizomiteric wells head recording, twenty two are deep wells, and ten are shallow some of them were taken on 1988 and others on 1998 till 2007. it is also consist of trasissivity of study area, aquifer storage factor, and hydraulic resistance, cross section from northeast to southwest at study area showing core resistivity and gamma ray logging, and hydraulic conductivity. Daily drawdown data for pumping wells are also available and the current value of pumping rate, the location and layout of well field area. Water requirement for crop irrigation in the area and crop consumptive use are present.

The model implementation for the study area was achieved using the commercial software Groundwater Vistas Models (GV), which run the groundwater flow package to simulate the hydraulic head distribution in study area. The study area 4864 square kilometers was applied into a uniform square grid of 1000 m spacing in (GV), comprising 64 rows and 76 columns. 15 rows and 24 columns have been added in pumping field area in order to decrease the grids size. In this study aquifer boundary is chosen as General Head Boundary (GHB) around the model area. GHB has been chosen because there are no surface water bodies such as sea or river, and no flow boundary such as faults which can affect the groundwater level, GHB is generic from the head dependent boundary normally used along the edge of the model to allow groundwater to flow into or out the model under the regional gradient. After the simulation model has been set up, the GV is ready to run MODFLOW package, the results of the simulated hydraulic head.

Some of those data were used to make the simulation of the study area; the first simulation was taken for the East East Jabal Hasouna well fields, which consist of 156 production wells figure 2. The model was sitting in the software with all requirement data, and it was running for five scenarios, starting from 10 till 40 years and five years more. The scenarios that already have been analyzed are: 2007 to 2017, 2007 to 2027, 2007 to 2037, 2007 to 2047, and 2007 to 2052. These scenarios were taken to get the pizometeric condition for groundwater of study area.

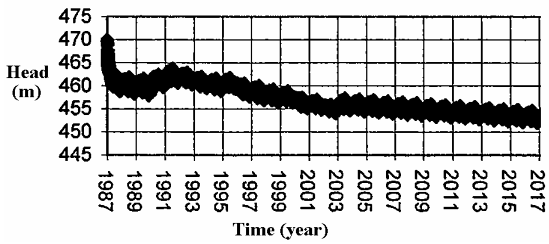
Figure 2: Pumping Wells for the Study area (East EJH)



5. Result and Discussion

The results of the first scenario had shown the continual drawdown of groundwater table for the first three stages of the simulation and for the next two periods was constant. The objective of this scenario is to assess the long-term impacts of the existing water for agriculture and human use purpose on the groundwater situation at the study area. All pumps pump at the same rate of 5184 cubic meter /day. The total amount of extracted water is 285500000 cubic meter /year divided into 128400000 cubic meters in summer and 15710000 cubic meters in winter, extracting this amount of water will cause drawdown. The drawdown versus the time plot is in figures as shown bellow. As it can be seen the oscillating nature of piezometric level trajectory has continued into the future, which expected given the differing amount of water extracted season during the summer and winter. The maximum drawdown of the first stage for the scenario 1 was 8 m which become visible on 2017 with water level 451.90 m.a.s.l after running of the MODFLOW simulation for 10 years since 2007 Figure 3, this water level was simulated from 1992 since the pumping of GMMRP started at water level 459.90 m.a.s.l.

Figure 3: Peizometric Head Distribution of scenario 1- stage 1



It seems clear that, the plot of drawdown versus time going forwarder to increase. Therefore, the model was running for an other period which was 20 years till 2027 Figure 4, in this time the value of drawdown was 11.20 m at water level of 448.70 m.a.s.l. which shown the real impact on the groundwater level. With this investigate; the model needs to run for more periods. The next two was for 30 and 40 years respectively. At year of 2037 water level was 446.80 m.a.s.l which gives 13.10 m of drawdown Figure 5, and at 2047 was 446.10 m.a.s.l with 13.8 m of drawdown Figure 6.

Figure 4: Peizometric Head Distribution of scenario 1- stage 2

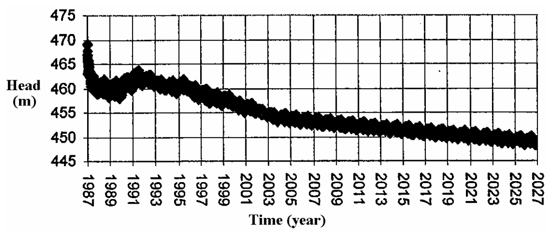


Figure 5: Peizometric Head Distribution of scenario 1- stage 3

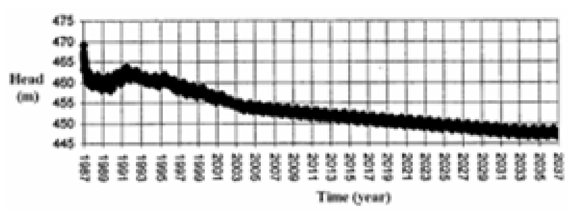
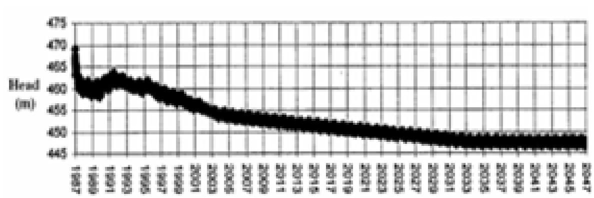
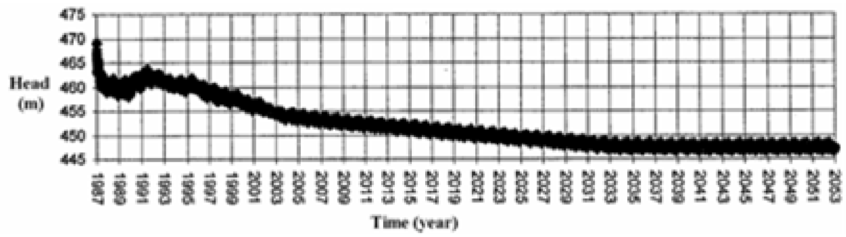


Figure 6: Peizometric Head Distribution of scenario 1- stage 4



With another stage the model was run for another six years until 2053, and the water level was at value 445.10 m.a.s.l as shown in Figure 7.

Figure 7: Peizometric Head Distribution of scenario 1- stage 5



It can be seen from the five figures that, the drawdown of groundwater level is changed with time for log term. That is caused by the increasing of the value of abstracting water; Table 1 shows the water level at each yeas of simulated stage. At the first three stages water level had changing with clear difference, while in the last two stages had small one, that can be related to the geological of Murzuq Basin, and the groundwater level has reached the general level of the whole area of the basin, with aquifer bad at level of 500 m.a.s.l. As this scenario is the first one of the study for that area, it can make an attention for groundwater sustainability.

Table 1: Water Level of Stag

years	**Water level (m.a.s.l)**				
	Stages1	**Stages2**	**Stages3**	**Stages4**	**Stages5**
2017	451.90	449.80	448.80	448.70	448.10
2027	-	448.70	447.80	447.10	447.00
2037	-	-	446.80	446.00	445.30
2047	-	-	-	446.10	445.60
2053	-	-	-	-	445.10

For the purpose of estimating the research models for hypotheses testing first, a sample of companies listed in Tehran Stock Exchange for the time period of 2001-2003 is used. Second, a sample of state companies is used. We estimate the research models with pooled data for three years, and overall 647 years-firm. Then, similarly the models are estimated for sample companies in different industrial groups. Finally, we estimate the research models using cross-sectional data for each year (2001 to 2003). We estimate the research models for the sample of state companies in the same way.

6. Conclusion

Abstracting water from a leaky-confined aquifer depresses the piezometric surface. This drop or drawdown increases as the pumping increase, unless there is a reversal through recharge. However, because of the low rainfall and high evaporation situations in study area, natural recharge is practically nonexistent. Thus the tendency is for the piezometric surface to continually depress, making it more difficult to sustain yield. The effect of the abstraction on the piezometric surface level in the observation well as shown in the figures, where it is apparent that the drawdown has consistently increased from 8 m in 2017 to 14.80 m in 2053.

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