Ass. Univ. Bull. Environ. Res. Vol. 16 No. 2 October 2013

AUCES

GROUNDWATER MANAGEMENT USING MODFLOW MODEL IN JERASH CATCHMENT AREA/JORDAN

***RAKAD A. TA'ANY, **AREEJ Al-ARABIYAT, ***JIHAD MAHAMEED AND ****JARRAH Al – ZU'BI4**

**Department of Water Resources and Environmental Management, Faculty of Agricultural Technology, Al-Balqa' Applied University, As Salt19117Jordan.*
***Ministry of Agriculture – Department of Water Harvesting.*
****Ministry of Water and Irrigation– Department of Groundwater Modeling.*
*****Manager of (Aqua Arab Countries Water Utilities Association) Project.*

*, Mobile: rakad.ayed@yahoo.comRakad A. Ta'any (*Corresponding Author): e-mail: +962776361225 Fax: +96253530469.*

ABSTRACT:

This study deals with the evaluation and management of groundwater using MODFLOW Model in Jerash Catchment area. The area is a part of Amman-Zarqa basin, (the most important basin in Jordan) that suffers from acute water shortage. This catchment covers an area of about 51 km2 and is inhabited by 61,500 people. Groundwater in the area is subjected to heavy abstraction and water quality deterioration due to urbanization over the recharge areas. The upper Cretaceous rocks are the most abundant rocks exposed in the area; they overlie the Lower Cretaceous rocks. Kurnub Group outcrops in the southern and western parts of Jerash, Na`ur formation outcrops in most parts of the study area except the southern part while the other formations of Ajloun Group outcrop in the northern part of the area. Two aquifers have been chosen to be studied, Na'ur and Kurnub, because that most wells in the study area are pumping from those layers and many springs issue from them. The presen study aims to calculate the groundwater budget, understanding groundwater behavior and proposing best management to sustain this water source. Modflow was used to build a groundwater

flow model to simulate the behavior of the flow system. The model showed that, the total amount of leakage into the lower aquifer is about 23 MCM/yr. On the other hand, 21 MCM/yr. flow out as a lateral flow and natural spring discharge. Moreover about 2.3 MCM/yr. flow into the aquifer (K) layer as lateral flow in addition to the vertical recharge from the upper layer and more than 25 MCM/yr. flow out the aquifer as lateral flow and springs discharge.

Keywords: Modflow, Management, groundwater, aquifer, Jerash, deterioration.

INTRODUCTION

Jordan falls in a region that suffers from water scarcity and shortage. It covers an area of about 90.000 km2 with more than 71% of the land area receives an annual average rainfall of less than100 mm. Rainfall distribution varies with location annual rainfall ranges from more than 600 mm in the northwest of Jordan at Ajloun areas to less than 50 mm in the eastern part of southern desert, (JICA and MWI, 2001). The catchment area is characterized by high population intensities with population of 165,000 inhabitants or about 3.5% of the Jordan population and net increase of 1.8 %. Jerash city lacks of adequate infrastructure and the population is characterized by low income and a mediocre quality of life,(Abdulla et al., 2006).

The study area lies in the lower part of (Amman-Zarqa Basin), which is the most important basin in Jordan because it is one of the transitional areas between high lands in the west and desert in the east. This is not only reflected in the climatological changes from wet to dry but also in different land use patterns and in large changes of habitat. While, the western hilly areas are relatively densely populated, the southeast of the basin is fully desert and almost without population and more than 60% of the population of Jordan about 3,720,000 inhabitants, (DOS, 2003) lie within the basin. According to the international weather classification, the climate of this area is of semi-arid

conditions except of some wet years precipitation exceeds 1000 mm.

The current study is based on MODFLOW (Modular Three-Dimensional Groundwater Flow) model was applied to study water balance (in terms of water quantity) in Jerash catchment area. This model is the most widely used program in the world for simulating groundwater flow. MODFLOW works on many different computer systems and can be applied as a one dimensional, two-dimensional, or full three-dimensional model.

The modular program design of MODFLOW allows new simulation features to be added with relative ease. A wide variety of programs is available to read output from MODFLOW and graphically present model results in ways that are easily understood.

Description of the study area:

The study area lies in the most important and the biggest groundwater basin in Jordan, which supplies the cities of Amman, Zarqa and its surrounding areas. Jerash catchment area has an area of 51 km² located in the northwestern part of the highlands of Amman-Zarqa basin and extends between coordinates (225-236) E and (180-195) N according to Palestine Grids. It is bounded by Irbid city from the north, Suweileh from the south, Mafraq from the east, and Ajloun city from the west, Figure 1. There are three main settlements in the catchment area, among these, Jerash city that is one of the best-preserved Roman cities in the Middle East. There are 61,500 inhabitants in the catchment area with a high growing rate, placing additional constrains on the stressed water supply.

MATERIALS AND METHODS:

The general slope of the catchment area is from North to South with longer axis oriented NW-SE direction. Elevations range from 1096m above the sea level (a.s.l) at (Tall Marqab) to about 400m below King Talal Dam. The average elevation of the catchment area is about 748 m (a.s.l.). Several wadis draining the catchment area,e.g(Wadi Jerash, Wadi Souf, Wadi Tawahin, Wadi El-Gadir, Wadi Uweimir, Wadi El-Riyash, Wadi Nahia, Wadi Amama, Wadi Safar, and Wadi Jadi. All of these wadies drain from north to south, that is, from the highland areas to the lowlands of the Jordan Valley.

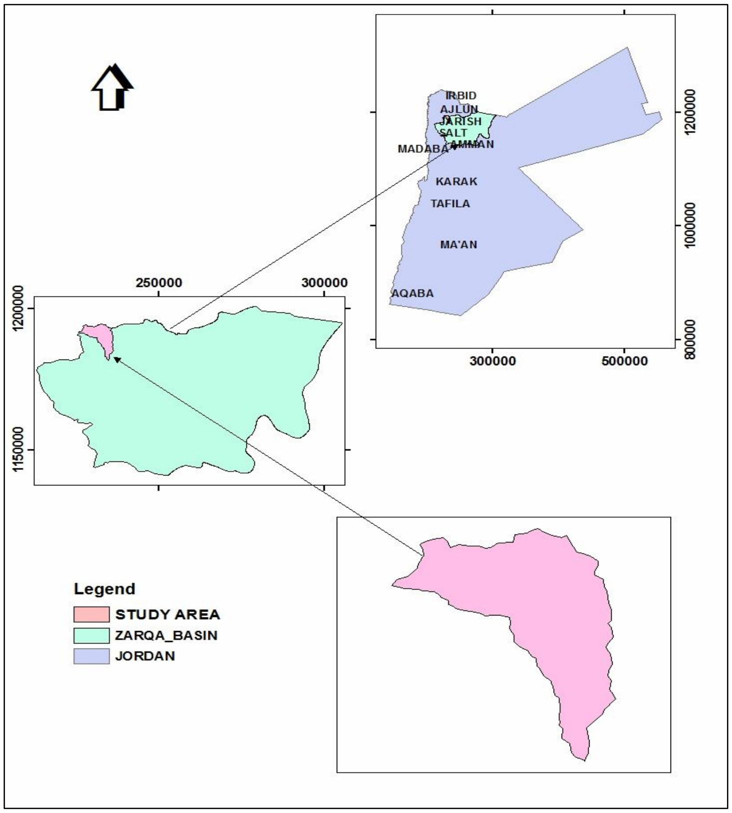

Figure .1: Location map for the study area (after Hammouri and El-Naqa,2008) Geology

The area is covered by sedimentary rocks of Lower and Upper Cretaceous. These sediments are composed of sand-stones, limestone, marls, dolomitic lime-stone, marly limestone and shales, Fig-ure 2. Generally, Cretaceous rocks in Jordan are mainly subdivided into two main sequences; Lower and Upper Cre-taceous rocks. Lower Cretaceous rocks, which are locally known as Kurnub, and Upper Cretaceous rocks are further subdivided into Ajlun and Balqa Groups.Ajlun Grouprepresents all the marine sediments of Cenomanian-Turonian age and consists of carbonate rocks, limestone, dolomite, marl, shale, chalk and sometime sandstone.Ajloun Grouprepresents all the marine sedi-ments of Cenomanian-Turonian age and consists of carbonate rocks; limestone,

dolomite, marl, shale, chalk and sometime sandstone.

Hydrogeology:

The hydrogeology of the study area is controlled by the geological structures, which effect on the piezometry, movement and occurrence of groundwater. It has been found that the dominant factor in determining the potentially water-bearing area is the permeability and the secondary the porosity both of which are directly related to the structure (MacDonald, 1965).

Groundwater occurs mostly in the fractured and cavernous limestone, fractured chert, sandstone voids and wadi fill deposits. In this study, groundwater mostly extracted from wells and springs in three aquifer systems. The extracted water represents the main water for domestic and irrigation purposes.

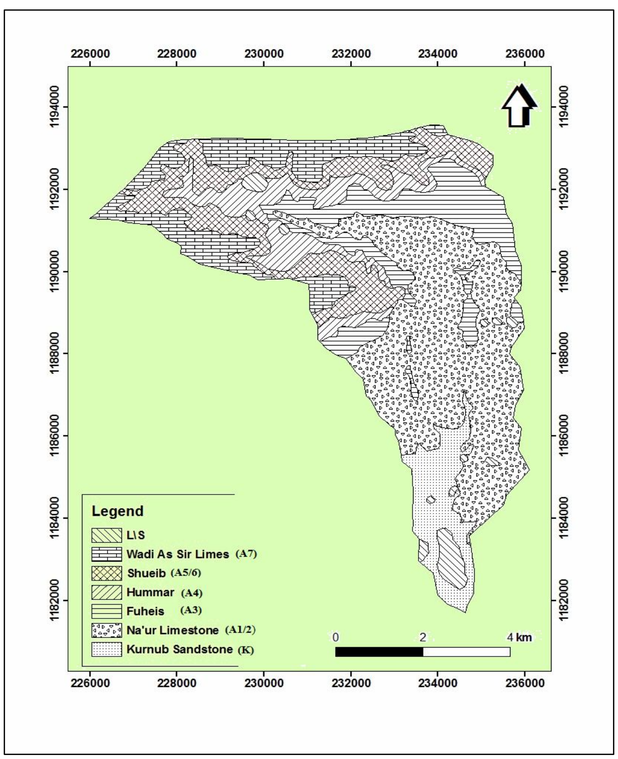

Figure. 2: Geological map of the study area (after Jubeh and Al- Hasani, 2004)

Aquifer Systems:

The aquifer systems in Jerash catchment area are subdividedinto:

a. Lower Cretaceous aquifer complex (Kurnub sandstone (K).

b. Upper Cretaceous aquifer complex.

The Lower Cretaceous Aquifer Complex:

Kurnub sandstone is a regional aquifer in Jordan (JICA and MWI, 2001). Kurnub sandstone aquifer system consists of massive, white and varicolored sandstone reach a maximum thickness of about 300 m (Bender, 1974). It outcrops along the Suweileh structure in Balqa valley north of upper Amman –Zarqa basin, and it is encountered at depths of about 480 m south of Amman, and 530 m near Zarqa. Furthermore, the aquifer outcrops in the study area, south of Jerash to the west along the slope of Zarqa River Valley.

The Kurnub sandstone aquifer is described as a semi-confined aquifer under–laying the carbonate aquifers and separated from them by the marls and shales of (Nau'r Formation) with a thickness of about 100 m. The recharge to this aquifer is limited due to small outcrop area and to the leakage from the overlying carbonate aquifers; and was estimated to be about 4.5 MCM as local recharge (WAJ, 1989). Along Wadi Jerash catchment area, there is only two springs issuing from the Kurnub sandstone aquifer, these are Ain Jebarta and Bisas El-Neil springs.

There are many wells drilled by Water Authority penetrating the Kurnub sandstone aquifer in the study area. Figure (3), shows piezometry and structure contour map base of Kurnub aquifer it can be concluded that at the southwestern part of the study area has a base of less than 350 m. On the other hand, in the northeast it was found more than 600 m explains the movement of water from north and south to the middle of the aquifer.

In general, the transmissivity of this aquifer ranges between 3.0-1700 m2/d and the Hydraulic conductivity ranges between (1-2.6) m/d while the storage coefficient ranges between 0.001-0.10, (JICA and MWI, 2000).

The Upper Cretaceous Aquifer Complex:

This aquifer complex consists of Ajlun and Balqa groups. The age ranges from Upper Cretaceous to Lower Tertiary. The Ajlun Group forms the main aquifer system in the study area and the water bearing formations are mainly limestone, dolomitic limestone, and marlstone of the Ajlun Group.

The Upper Cretaceous Aquifer Complex:

This aquifer complex consists of Ajlun and Balqa groups. The age ranges from Upper Cretaceous to Lower Tertiary. The Ajlun Group forms the main aquifer system in the study area and the water bearing formations are mainly limestone, dolomitic limestone, and marlstone of the Ajlun Group.

Data Collection:

All data available related to geological, hydrogeological, hydrological and other related environmental data documented in technical reports, papers, journals or other references were collected in order to confirm the data collected and to compile the missing data.

Data Evaluation:

All physical data collected from the Ministry of Water and Irrigation were checked and evaluated by field surveying and statistical handling.

GIS Database:

All relevant data were tabulated (attributes) and were used to create the shape files under ESRI-GIS software to cover the geological, hydrogeological and hydrological aspects in the study area. Structured contour maps, drainage boundary, groundwater flow systems and the topographic map was digitized and converted into shape files (themes). Formation thickness, saturation thickness and depth to water levels were calculated.

Groundwater Model:

Generally, steps for any groundwater modeling cover the following items: conceptual model, code selection, model design, calibration, verification, sensitivity analysis and prediction.

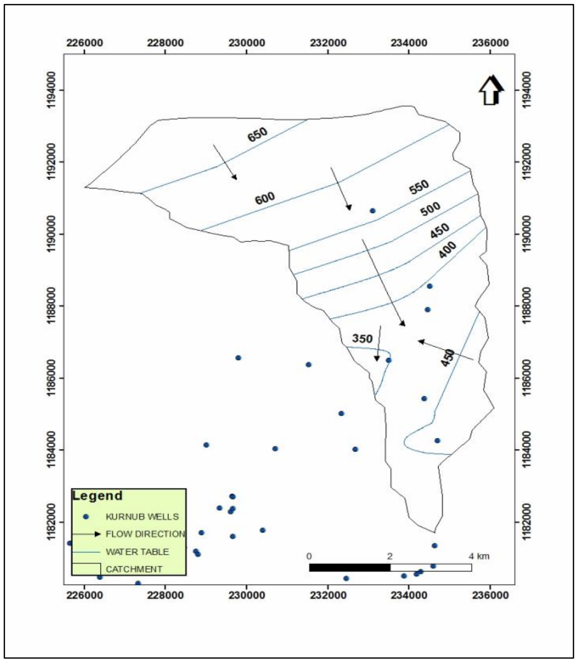

Figure 3: Piezometry and structure contour map base of Kurnub aquifer

Conceptual Model:

It consists of a set of assumptions that minimize the complicated real system to simplified view to reach the model objectives. Generally, it contains the hydro-stratigraphic units, water budget, flow system and data needed to assign values. Based on the data compilation and interpretation of topographic, geological and hydrogeological situation, the conceptual model of Jerash catchment area was developed.

Modeling Software:

Processing Modflow Pro (PMWIN Pro) software version 7.0.13 is a three-dimensional groundwater flow software based on finite difference approach. This software was used to simulate the groundwater flow system and the effects of groundwater abstraction on the groundwater systems in Jerash catchment area. PMWIN Pro is an enhanced version of Processing Modflow for Windows, supported MODFLOW- 2000 and several codes of useful modeling tools and comes with a professional graphical user-interface.

Model Design:

Processing Modflow Pro (PMWIN) is based on the block-centered finite difference approach for modeling design. The block-centered grid considered that the flux boundaries are located at the edge of the block. In the block-centered finite difference approach, an aquifer system is represented by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells) as shown in Figure 4. The nodal grid represents the framework of all numerical model calculations. Thus, the hydro-stratigraphic units and the thickness of each model cell can be specified in terms of layers, rows and columns.

According to the conceptual model and other related data, the model design was established. In order to reach the main aims of this study, the model design contained the upper, middle and lower layers. In addition, the mesh size (250 m by 250 m) of the model reflects the actual hydraulic response and to eliminate the superposition of drawdown in the same cell as much as possible. Model parameter values were assigned into the model by three methods: Cell-by-Cell, Polygon and Vector Trans methods. The first two methods was a part of the model software and the Vector Tans method is a part of GIS software.

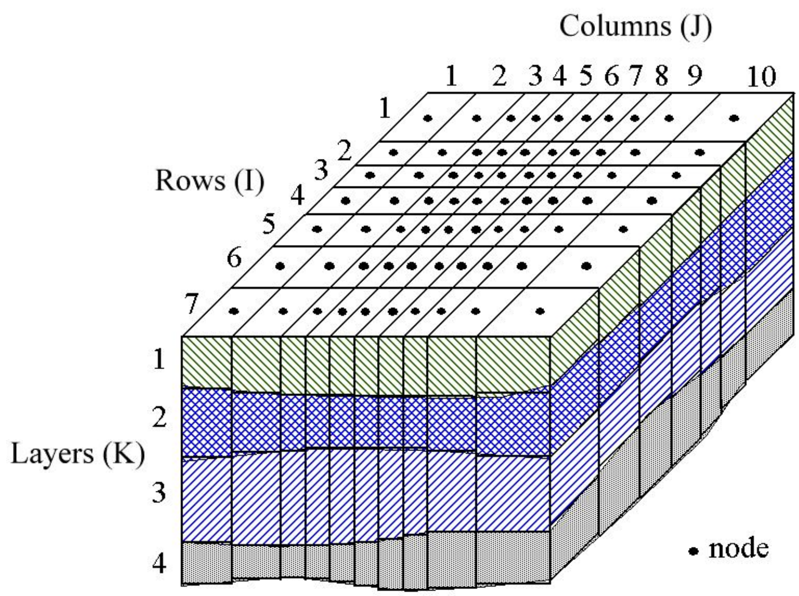

Figure.4: Spatial discretization of an aquifer system and the cell insides

Boundary Conditions:

According to the modeling guide prepared by Middlemis (2000), three types of hydrogeological boundaries are dominant in the groundwater system:

a. Specified head boundaries (Dirichlet conditions).

At least one point in a modeled domain to insure that there is a uniqueness of the solution.

b. Flow boundaries (Neumann conditions)

This type of boundary means that the (flux) across the boundary is given. A special case of this boundary is the impervious boundary where the flux is zero.

c. Head-dependent flow boundaries (Cauchy or mixed boundary conditions)

Linear combination of head and flux at boundary where the flux across the boundary is calculated given a boundary head value.

Assigning Parameter Values:

The geometry of the aquifer systems was assigned in the model domain. First, topographic map and structural maps of all layers were digitized. Second, transformation polylines to points then assign to the model as ASCII file. Then, the thematic maps (vector graphics) were imported into the model by using Cad Reader (DXF format) so that all of input data could be checked. Processing Modflow Pro (PMWIN) has three methods for specifying parameter values:

Cell-by-cell (since the elevation of the base of a hydrogeological unit has a different value in each cell, the data needed to enter into the model cell by cell), Polygon (when the elevation of the base of a hydrogeological unit is homogeneous) and Polyline method. These methods were applied for few data at certain locations. Hydrogeological parameters were assigned in the model domain by the following method: First, the horizontal hydraulic conductivities were assigned in the model domain as initial values based on the pumping tests analysis results. Second, by using Field Interpolator (Gridding method-Kriging) filling all cells in the model domain where pumping tests were not available.

Theoretical Background of the Mathematical Model:

However, the dominant flow equations of the groundwater system should be related to continuity and Darcy’s law. Generally, continuity requests the conservation of water mass (outflow-inflow = change in storage) and Darcy's law (Fetter, 1988) states that the specific

flow rate (filter velocity) is proportional to the negative head gradient in the isotropic porous medium.

Model Calibration:

Steady state calibration was performed by comparison piezometric heads of the Upper and Lower aquifers (initial states) and the calculated hydraulic heads of the model results. Calibration of the steady state in the upper aquifer (A1/2) was based on the water-table map, which represents the groundwater situation in the aquifer. The same methodology was applied for the Lower aquifer.

Sensitivity Analysis:

To minimize the uncertainty in the estimation of aquifer parameters, sensitivity analysis was conducted in this study. In addition, the sensitivity analysis was conducted in this study to test the effect on the model domain if one parameter is changed whereas all other parameters are kept constant. Sensitivity analysis was applied for steady and non-steady states in the upper and lower aquifers.

Results and Discussion:

Model Design:

There are two types of finite difference grids:

the block-centered grid where flux boundaries are located at the edge of the block and the mesh-centered grid where the flux boundaries coincide with a node. The Processing Modflow Pro (PMWIN) is based on the block-centered finite difference approach. In the block-centered finite difference approach, an aquifer system is represented by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells). The nodal grid represents the framework of all numerical model calculations. The hydro-stratigraphic units and the thickness of each model cell can be specified in terms of layers, rows and columns, (Harbaugh, 2005).Based on the conceptual mode and other relevant hydrogeological data, the model design for Jerash catchment area has been built up in order to cover an area of about 51 km2 and to assure the objectives of this thesis with the following properties:

- Number of square cells: 3,840 for two layers.

- Mesh size: 250 m by 250 m.

The mesh size of the model 250 m by 250 m was chosen as it is obvious that the study area is quietly small. Seven hundred and ninety two square cells are active and used for model calculations in the upper layer (A1/2) and 803 active cells in the lower aquifer (K).

Boundary Conditions:

It is important to select and define boundary conditions carefully in model design because they are of great influence on the model results in every sense. Boundary conditions are constraints imposed on the model grid to represent the interface between the model calculation domain and the surrounding environment. There are three major types of boundary conditions, all of which may vary with time:

Type 1: Specified Head (First Type or Dirichlet Boundary):

The head value is specified and the model calculates the flow across the boundary to or from the model domain. This type is used for Rivers, coastlines, lakes, groundwater divides, known pumping water levels in bores and dewatering targets.

Type 2: Specified Flow (Second Type or Neumann Boundary):

The flow value isspecified and themodel calculatesthe head at theboundary. This type is used for impermeable boundary; groundwater divides or streamlines infiltration source, evaporation sink, lateral inflow or outflow and other known sink or source fluxes.

Type 3: head-dependent Flow: Boundaries (Cauchy or Mixed Boundary Conditions):

This type of boundary is a linear combination of head and flux at boundary where the flux across the boundary is calculated from given a boundary head value. The type of boundary selected should be consistent with the conceptual model and the water budget, should be located and oriented consistent with the physical features it represents. In particular, model domain boundaries

should be set far from the area of interest so that imposed stresses on the grid interior do not reach the boundaries. Alternatively, the boundary needs to be configured such that the simulated boundary effect is realistic.

Based on the boundary conditions and the groundwater flow pattern of the Upper and Lower aquifers, the boundary conditions of the current study have been built up carefully. It was assumed that the upper aquifer (A1/2) is completely covering the study area, there is a flow found in the southern part but there is no flow in the rest parts of the aquifer. On the other side, the 375 m water level contour is being used as a constant head boundary in the southern part of the model area to calculate the outflow toward south. In addition, the rest of the model area has been left as specified head boundary. Figure .5 shows the flow model boundaries of the upper aquifer (A1/2) of Jerash catchment area.

For the lower aquifer (Kurnub), the southern east border has been considered as a flow boundary. On the other hand, the 460 m water level contour was assumed to be a constant head boundary in order to calculate flow enter the model area from this side. In addition, the southwestern border of the study area is assumed as constant head boundary, the 340 m water level was taken as a constant head in order to calculate the flow towards west direction. The rest of the model area was left as specified head boundary. Figure .6 illustrates the flow boundaries of the lower aquifer (Kurnub) of Jerash catchment area.

Aquifer Units and Parameters:

Parameter values need to be assigned to the appropriate models cells, are based on the extent of the corresponding hydro-stratigraphic units, and the associated field measurements or literature estimates for the aquifer parameters. Data needed to assign into the model can be grouped into two types: Physical framework, which defines the geometry of the system including the topographic contour lines, structure contour lines of each formation and the areal extent of each hydro-stratigraphic unit. Moreover, hydrogeological parameters including water levels, fluxes, transmissivity, and specific yield are needed.

Physical Parameters:

Two aquifers have been chosen to be studied Na'ur (A1/2) and Kurnub (K), because most water tapped in the study area are from those aquifers and also many springs issue from them.

The geometry of the aquifer system was described in maps of the base flow and topography of the catchment.

The contour lines of these maps have been used for the determination of the relevant values for each model cell.

By using ArcView, the topographic map and all of structural maps of all layers were prepared for model input. In addition, the thematic maps (vector graphics) were imported into the model in the (DXF format). Some data of some locations has been entered into the model by Data Editor, which is used to assign parameter values to the model.

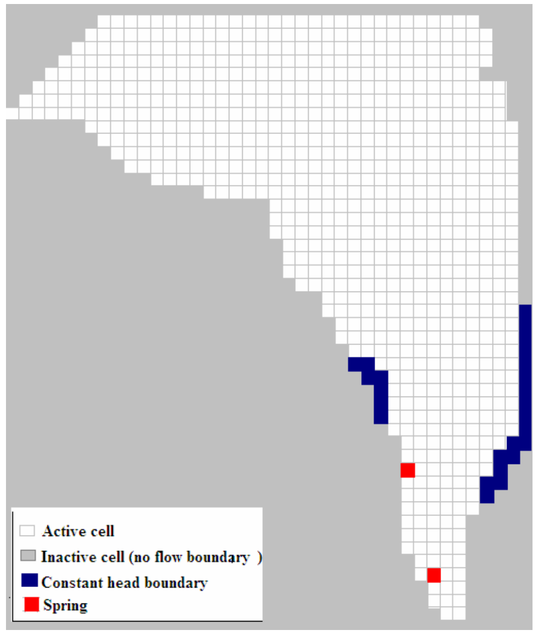

Figure .5: Groundwater flow model boundaries of the upper aquifer (A1/2)

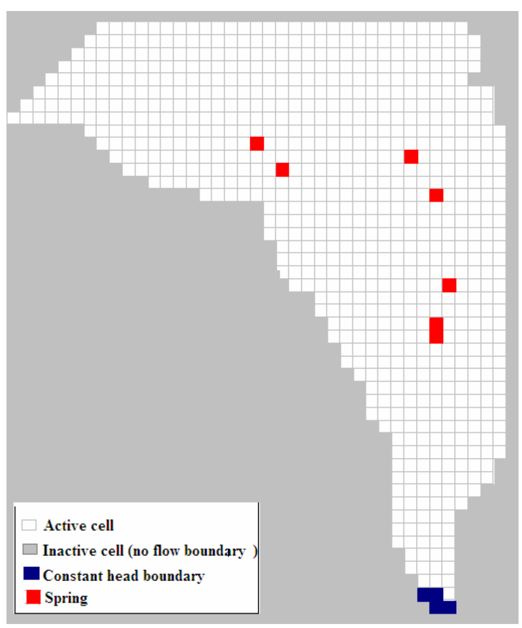

Figure .6: Groundwater flow model boundaries of the lower aquifer (K)

The Data Editor provides three methods for specifying parameter values: Cell-by-cell (since the elevation of the base of a hydrogeological unit has a different value in each cell, the data had to be entered into the model cell by cell), Polygon (when the elevation of the base of a hydrogeological unit is homogeneous) and Polyline method. The first two methods had been applied but the Polyline method was not used because there is no river or drainage system in the study area.

Hydrogeological Parameters:

According to the aquifer characteristics mentioned in hydrogeology section, the hydrogeological parameters had been assigned to each model layer as initial parameters. Horizontal and vertical hydraulic conductivities were assigned to each model layer. First, the horizontal hydraulic conductivities were assigned in the upper and lower aquifers. Then, by using Field Interpolator (Gridding method by Kriging) all model's cell were addressed.The values between (0.003-3) m/d of hydraulic conductivity were used for the Upper aquifer (A1/2), while the hydraulic conductivity values between (1-2.6) m/d were used for the lower aquifer. The maximum recharge was calculated using wet year data for the upper aquifer. During the calibration these values were modified to come up with the best fit between the measured and calculated head.

Model Calibration:

Model calibration of steady state was done, using comparison of the observed piezometric heads of the two aquifers with the calculated hydraulic heads, (Figure7). The calibration of Na`ur (A/2) was based on the water table map, which reflects the groundwater situation. The volume of rainfall was calculated for the wet hydrological year and found to be 44 MCM. Most parameters were considerable changing during the steady state to reach the best fit for the model, particularly the hydraulic conductivity and the recharge. According to the best matching between the observed heads and model calculated heads, (Figure 8), the catchment area can be

divided into two zones as shown in (Figure 9), the hydraulic conductivity of the northern parts was 1 m/s and it was 3m/d for the southern parts.

The calibration of the Lower aquifer (Kurnub) under steady state calibration was done based on the initial water level map of the Lower aquifer (Figure 10), the model was calibrated and the best match was reached as shown in (Figure 11). According to the matching between the observed heads and model-calculated heads, the hydraulic conductivity of the lower aquifer was about 2 m/d for the whole aquifer.Although there was best match between measured and calculated water tables and have the same water flow direction, but they were not exactly matched because the available data were not enough especially wells distribution over the study area which were used for drawing water tables. The exactly layers thicknesses were not available for the study area so the average layers thicknesses were used and this affect the accuracy of the model. In addition, water flow from other layers may affect and altered water table in the study layers.The recharge area cells were interpolated for the upper layer cells by using the Polygon input method. The value of recharge rate in the upper aquifer was 4*10-4 m/day for the southern part of the study area, while it was between 1*10-4 to 3*10-4 in the northern part for wet hydrological year, (Figure 12).

The water budget of the study area has been calculated based on the steady state calibration. Tables (1 and 2) represent the total water budget of the whole model domain in terms of inflows and outflows from or into the groundwater system (Upper and Lower aquifers). The model indicates that, the biggest amount of outflow from the Upper aquifer was about 23 MCM as leakage to the Lower aquifer and more than 21 MCM as outflow towards Zarqa River and natural spring discharge.

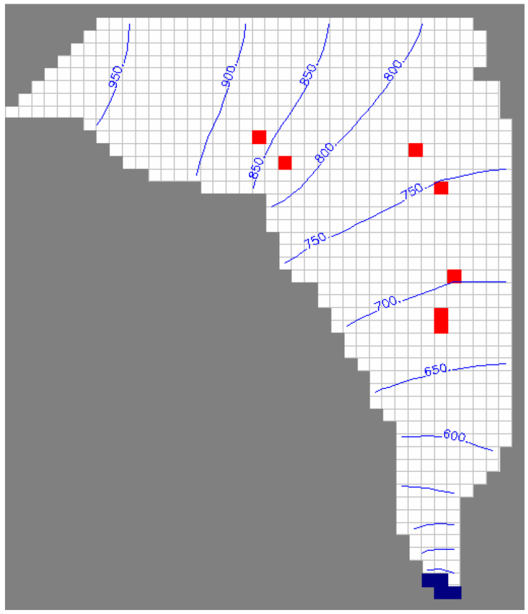

Figure .7: Calculated water table for the Upper aquifer

The amount of leakage, which is about 23 MCM from the Upper aquifer represent the majority amount of inflow into the Lower aquifer. Some inflow enters into the aquifer close from southeast, which is about 2.3 MCM. On the other side, there is about 25.1 MCM as outflow towards the southern west parts, and about 0.047 MCM as a natural spring discharge.

The difference between the inflow and the outflow in this aquifer is about 0.152 MCM.From tables (1 and 2), the total inflow that enters the model system more than 46 MCM as a rainfall and lateral flow. Taking in consideration the discharge from springs, the available water for abstraction will be around 42 MCM.

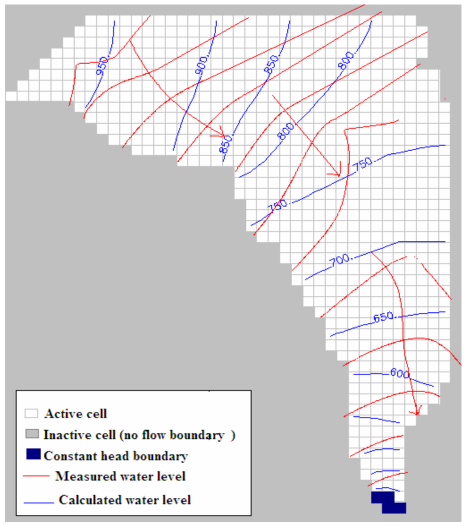

Figure .8: Matching map between the measured and calculated water table of the Upper aquifer

Sensitivity Analysis:

The main purpose of a sensitivity analysis is to quantify the effect of uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters (Al Mahamid, 2005). Sensitivity analysis was carried out in this study to test the effects on the model (head) if one parameter is changed whereas all other parameters are kept constant.

During the steady state calibration, it was found that the horizontal hydraulic conductivity and recharge rate were very sensitive in comparison with respect to other parameters.

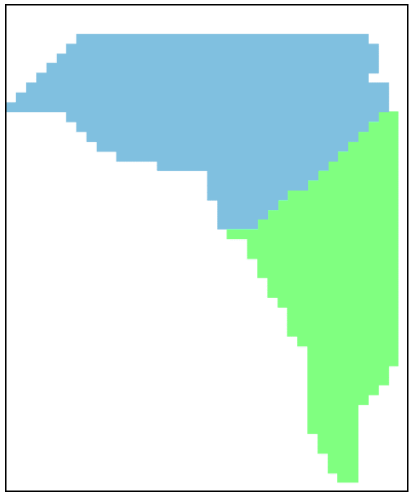

Figure .9: The hydraulic conductivity (K) zone for the upper layer

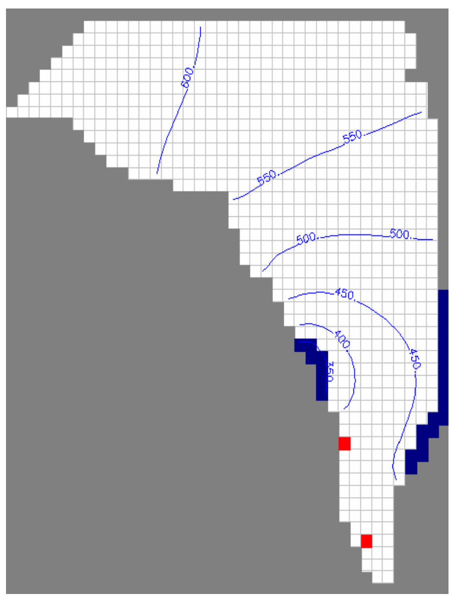

Figure .10: Calculated water table for the Lower aquifer

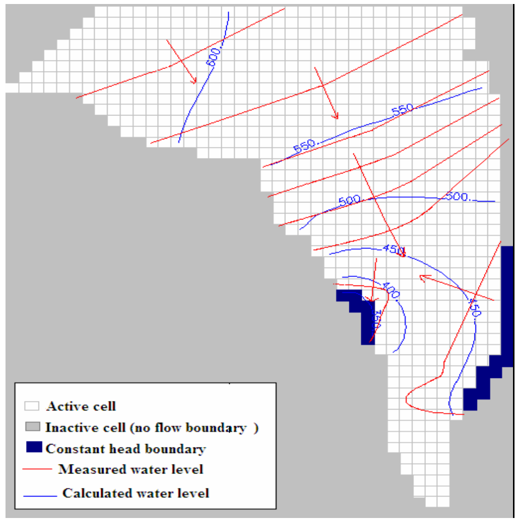

Figure .11: Matching map between measured and calculated water table of the Lower aquifer

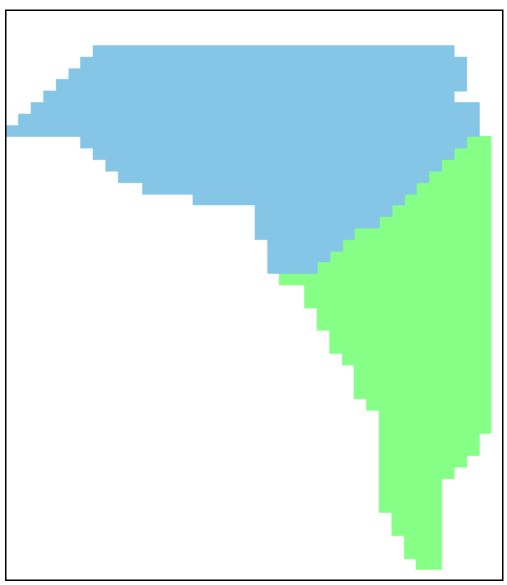

Figure .12: Recharge Zones for the upper Aquifer

Table .1: Water budget of the whole model domain for the upper aquifer (MCM/year)

Flow Term	Inflow	Outflow	(In-Out)
Constant head	0.0	17.3	-17.3
Spring	0.0	3.8	-3.8
Recharge	44	0.0	44
Leakage	0.1	23	-22.9
Total	44.1	44.1	0.0

Table .2: Water budget of the whole model domain for the lower aquifer (MCM/year)

Flow Term	Inflow	Outflow	(In-Out)
Constant head	2.3	25.1	-22.8
Spring	0.0	0.048	-0.048
Recharge	0.0	0.0	0.0
Leakage	23	0.0	23
Total	25.3	25.148	0.152

CONCLUSIONS:

The main conclusions reached from this study can be summarized as:

1. The dominant direction of the groundwater flow in the Kurnub is from north and south to the Middle West of the aquifer, while for the Nau'r Formation water flows from the northeast and the northwest to the middle -eastern part of the aquifer and from the northwest to the eastern part of the aquifer.
2. Three-dimensional groundwater flow model for (A1/2) formation and lower aquifers (K) was built and calibrated for steady state. The groundwater budget of the whole model domain was calculated. About 44 MCM/yr.

entered into the upper layer as a rainfall recharge and about 0.092 MCM/yr. and entered from the lower layer (K) as they are hydraulically connected.

3. **The total amount of leakage into the lower aquifer is about 23 MCM/yr. On the other hand, 21 MCM /yr. flow out as a lateral flow and natural spring discharge.**
4. **About 2.3 MCM /yr. flow entered into (K) layer as lateral flow in addition to the vertical recharge from the upper layer.**
5. **More than 25 MCM /yr. flow out the aquifer as lateral flow and springs discharge.**
6. **During the steady state calibration, it was found that, the horizontal hydraulic conductivity and recharge rate were very sensitive in comparison with respect to other parameters.**

REFERENCES:

Abdulla, F.and Al-Assa'd, T. (2006): Modeling of groundwater flow for Mujib aquifer, Jordan.Earth Syst. Sci. 115, No. 3, June 2006, p 289–297.

Al Mahamid, J. (2005): Integration of Water Resources of the Upper Aquifer in Amman-Zarqa Basin Based on Mathematical Modeling and GIS, Ph.D. Thesis, Freiberg University, Germany.

Bender, F., (1974): The geology of Jordan, contribution to the regional geology of the earth, supplementary edition of volume 7.Gebrueder Borntraeger, Berlin.

DOS – Department of Statistics (2003): Estimation of Population by Governorate. Department of Statistics, Amman, Jordan.

Fetter CW, (1988): Applied Hydrogeology, 2nd edition. Merrill publishing Company, London, p 592.

Hammouri, N. and El-Naqa, A. (2008):GIS based Hydrogeological Vulnerability Mapping of Groundwater Resources in Jerash Area – Jordan. Geofísica International 47 (2), 85-97.

Harbaugh, A. MODFLOW-2005, (2005):The U.S. Geological Survey, Geological Survey Techniques and Methods 6-A16 by Chapter 16 of Book 6. Modeling techniques, Section A. Ground Water.

JICA (Japan International cooperation Agency) and MWI (Ministry of Water and Irrigation), (2001): The study on water resources management in The Hashemite Kingdom of Jordan. Yachiyo Engineering Co., Ltd., Progress report (2). Ministry of Water and Irrigation, Jordan.

JICA (Japan International Cooperation Agency) and MWI (Ministry of Water and Irrigation), (2000): Hydrogeology of the Amman-Zarqa Basin Outline. Ministry of Water and Irrigation, Jordan.

Jubeh, N. and Al- Hasani, (2004): Hydrology and Hydrochemistry of Wadi Jerash Catchment area, Unpublished Undergraduate Project, A-Balqa` Applied University, Salt, Jordan.

McDonald, Sir, M. and Partners in Cooperation with Hunting Geological Surveys Limited, (1965): East Bank Water Resources, Vol. 5 and 6, London, Amman.

Middlemis, H. (2000): Groundwater Flow Modelling Guideline.Aquaterra Consulting Pty Ltd.

WAJ (Water Authority of Jordan), (1989): Yarmouk Basin, Resources Study Draft, Final Report, NRA, and Amman, Jordan.

Ass. Univ. Bull. Environ. Res. Vol. 16 No. 2 October 2013

تقييم وإدارة المياه الجوفية في حوض جرش باستخدام نموذج MODFLOW

*ركاد عايد طعاني، **أريج عواد العربيات، ***جهاد المحاميد، ****جراح محمود الزعبي

يعتبر حوض جرش المائي جزءً من حوض الزرقاء ومن أكثر الأحواض أهمية في الأردن. يعاني هذا الحوض من نقص حاد في المياه، فضلا عن التطور الاقتصادي والاجتماعي في المنطقة التي يقع عليها الحوض مما أدى إلى زيادة ضخ المياه الجوفية، وزيادة الفجوة بين الضخ والتغذية للحوض. إن الأهداف الرئيسة لهذه الدراسة هي حساب الموازنة المائية للمياه الجوفية، والتعرف على نظام حركة المياه، واقتراح أفضل إدارة للحفاظ على هذا المصدر المائي. لذا تمت دراسة الأوضاع الجيولوجية والهيدروجيولوجية والهيدرولوجية لمنطقة المعينة (تغطي نحو ٥١ كم٢). وقد استخدم برنامج Modflow لبناء نموذج تدفق المياه الجوفية لمحاكاة سلوك نظام التدفق، وتمت معايرة النموذج لحالة ثبات التدفق. أما الصخور المتكشفة في منطقة الدراسة فهي صخور من العصر الطباشيري العلوي، (تعلو صخور العصر الطباشيري السفلي) كما أن مجموعة الكرنب تتشكل في الأجزاء الجنوبية والغربية من جرش، بينما تتشكل صخور ناعور في معظم أنحاء منطقة الدراسة ما عدا الجزء الجنوبي. في حين أن غيرها من التشكيلات (مجموعة عجلون) فتتشكل في الجزء الشمالي من منطقة الدراسة. وقد تم اختيار اثنين من طبقات المياه الجوفية التي يتعين دراستها، (طبقتي ناعور والكرنب)، وذلك لأن معظم الآبار في المنطقة تضخ من تلك الطبقات والعديد من الينابيع أيضا تخرج منها. ويوجد أكثر من تسعة عشر بئراً ضمن حدود المسقط المائي المستخدم في الدراسة تستخدم لتزويد مدينة جرش والقرى المحلية الواقعة في منطقة وادي جرش، وهناك أيضا حوالي ثلاثة عشر ينبوعاً رئيسياً. ويتراوح متوسط الهطول المطري في منطقة الدراسة بين أقل من ٢٧٥ مم في الأجزاء الجنوبية إلى أكثر من ٦٠٠ مم في الأجزاء الشمالية من المنطقة. ولقد تم دراسة السنوات الهيدرولوجية الرطبة والمعتدلة والجافة للمنطقة في هذا البحث.