Sustainable Use of Water Resources for Jafer Basin (South of Jordan) Using Mathematical Modeling and GIS Tools

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ABSTRACT

Mathematical models and GIS are good tools to study, evaluate and manage groundwater resources in a sustainable way. Groundwater flow model was setup to conceptualize the understanding of groundwater resources in Jafer basin (South of Jordan), in order to simulate the current groundwater system and provide predictive scenarios to better manage water resources. The specific objectives of this study are to: develop a three-dimensional groundwater flow model for Jafer basin using MODFLOW code for the Upper Cretaceous Aquifer System, determine the sustainability for Jafer basin, investigate different scenarios of groundwater management of Jafer basin including variation of abstraction and determine the effects of increasing natural recharge by adding 3 recharge dams.

Ten predictive scenarios were conducted in this study. Scenarios 1 to 3 are similar and indicate that regional drawdown at Al-Muhammadiyah Well-field will be greater than 110 m by 2040. Dynamic well losses may increase the actual well drawdown higher than 150 m. Scenario 6 indicates that small amounts of artificial recharge will not lessen the drawdown at Al-Muhammadiyah Well-field. Scenarios 7, 8, 9 and 10 indicate that lowering the abstraction at Eshidiya and Al-Muhammadiyah Well-fields will not decrease the overall drawdown by 2040.Scenarios 4 and 5, increasing annual abstraction by 1.5 and 2 times, will be unsustainable.

It is highly recommended that the current levels of abstraction from Al-Muhammadiyah Well-field are not sustainable. Continuation of agricultural activities in Jafer basin for the long term at current or elevated abstraction levels would require an alternative water source, such as accessing the deep sandstone aquifer. Thus, mathematical modeling (groundwater flow model) is an effective tool and technique in Jordan to understand and exploit groundwater resources in a sustainable way.

KEYWORDS: Groundwater, Mathematical modeling, Jafer basin, Calibration, Steady state, Sensitivity analysis, Water budget.

INTRODUCTION

Groundwater is the most reliable source of water supply in Jordan. The agricultural development in Jordan started in the early 1970s and nowadays around 55% of the total abstraction is taping water from groundwater basins. Groundwater Jafer basin is considered one of the most important basins in Jordan.

Many studies evidenced an overexploitation of the shallow aquifer during the past two decades, which caused a general water level decline and water quality degradation in Jafer basin.

Groundwater modeling is an effective tool to understand the groundwater flow system and manage groundwater resources. The development and use of
groundwater models have started in Jordan since the 1970s, including most of the flow models.

Jafer surface basin, which is one of the large surface water basins in Jordan, is located in the southern part of the central Jordan plain and lies to the east of the western highlands (Figure 1), bordered by Sirhan basin to the east, Wadi Araba and Red Sea basins to the west and south and Wadi Al-Mujib and Wadi Al-Hasa basins to the north. Jafer basin has an area of about 12,364 km², or about 15% of the area of Jordan, most of which is classified as arid desert with an average annual rainfall of less than 50 mm (Ministry of Water and Irrigation (MWI), 2015).

The basin displays a classic centripetal drainage pattern with all wadies draining from the encircling highlands to the central Al-Jafer playa which is the largest concave in Jordan. The basin area lies at elevations between 850 m in Al-Jafer playa and 1750 m in the western highlands.

Al-Muhammadiyah Well-field (fodder project) has been developed in 2010 in the north western area of the basin to sustain a growth of fodder to support local sheep raising farmers. Consequently, Jafer basin has been over-abstracted and new abstractions have induced a stronger imbalance in the water budget and a higher regional drawdown affecting the aquifers under stress.

METHODOLOGY

Geomorphic Setting
Jafer basin is a large internally draining catchment area in southern Jordan. It has an EW extension of around 150 km and an NS extension reaching 100 km. During previous climatic events, this basin was a freshwater lake although there is little evidence of standing water during the Mid Holocene, possibly due to wind-induced deflation (Davies, 2005).

It is dominated by eastern gently sloping topography and numerous playa lakes that are characterized by flat topped surface of clays, mud and salt. In total, playas cover an area of 40% of the Jordan eastern desert. The number and size of these playas and their deposits are, therefore, clearly indicative of moist past environments. The most notable of these playas is Al-Jafer playa, which is located in the southeastern region of the Jordan Plateau.

Figure (2) illustrates the 3D Terrain Model of Jafer basin that manifests the drainage pattern among the catchment. Elevation at the center of the playa is about 850 m above sea level and about 1030 m above sea level at the northern boundary of the depression. The northern boundary is witnessing slope retreat. The slopes are dissected by a number of ephemeral streams that cut through the older Cretaceous and Tertiary marine sedimentary sequences. The northern boundary of the basin is divided into three hilly ranges. These hilly ranges are generally of moderate slopes and rolling hills, except on the retreating slopes facing the Jafer depression and along the ephemeral streams that feed into the depression. The surface sediments covering the area consist of desert pavement on the non-active surfaces. The wadies and wadi outflows consist of coarse grained fluvial sediments and sediment outwashes that appear as the ephemeral streams enter into the depression.

Drainage Pattern
Jafer basin displays a classic centripetal drainage pattern with all wadies draining from the encircling
highlands to the central Al-Jafer playa, the largest concave in Jordan.

The wadies in the southwestern highlands are characteristically narrow and moderately incised, while wadies are flat in the eastern part of the Basin, where the elevation is about 900 m. All the wadies in the upstream reaches drain flushing floods to the central playa.

Geological Setting

The stratigraphic sequence of greatest significance is of the Late Cretaceous and Tertiary that are exposed on the hilly areas on the northern margin of the Basin, as opposed to the Pleistocene and Holocene sediments in the center of the depression.

The campanian to Maastrichtian Al-Hisa phosphorite formation crops out to the north of the study area and fragments from it are found in the alluvium of the area (42 m thick). Al-Hisa phosphorite formation is overlain by the Maastrichtian Muwaqqar Chalk Marl formation (MMC) with a thickness of about 27m. Eocene Umm Rijam Chert Limestone formation (URC) which overlies Muwaqqar Chalk Marl formation has been reported to be about 40 m thick.

The geologic map of Jafer basin is modified from various geologic maps covering the basin and the south of Jordan (Bender 1968 and 1974; BEICIP, 1975; several geologic maps of scale 1:50,000 prepared by the Natural Resources Authority of Jordan during 1996-2006, as well as the BGR Report, 2001).
Hydrogeology of Jafer Basin

Generally, the groundwater aquifers of Jordan are divided into three main hydraulic complexes (Rimawi et al., 1992); the Deep Sandstone Aquifer Complex, the Upper Cretaceous Aquifer Complex and the Shallow Aquifer Complex. The Upper Cretaceous Aquifer Complex and the Shallow Aquifer Complex constitute the primary source of water for domestic and industrial uses in the region. The recharge to these aquifers takes place either from the elevated areas to the east, north and west sides or due to local surface water infiltrations. The local drainage system is typically characterized by a centripetal pattern with all wadies draining to the central of Al-Jafer playa from the encircling highlands (Davies, 2005). A simplified hydrogeological map of Jafer basin is presented in Figure (3). The thickness of sedimentary succession varies between 2000 m and 3000 m on the top of the Basement complex (Bender, 1974; Humphreys, 1984).

Aquifer System

The aquifer systems in the study area have been recognized in argillaceous, arenaceous and/ or carbonate rocks of the Cambrian to Paleogene age, such as Disi, Kurnub, lower Ajlun (A1-6), Amman-Wadi Es-Sir (B2/A7) and Rijam (B4) (Howard Humphry Consultants, 1984). In this study, attention was focused on the aquifers in the Ajlun and Belqa Groups, such as A1-6, B2/A7 and B4/B5. The groundwater resources are available within three successive aquifer systems.

Groundwater Flow Pattern of the Main Aquifers in the Basin

Figure (4) illustrates the groundwater flow pattern of the main aquifers B2-A7 as modified from previous studies and the water information system of the MWI.

Two periods were considered in the study to prepare those flow pattern maps to be used in the model; during the 1980s and at present (2005-2013). Figure (4) illustrates the groundwater flow pattern of the B2-A7 aquifers during the 1980s.
Figure (3): Hydrogeological map of Jafer basin

Figure (4): Groundwater flow pattern of B2-A7 aquifers during the 1980s
Model Design

The hydrogeological conceptual system was reviewed in respect to the consistency of the model design with the set-up of the boundary conditions, configuration and distribution of the model parameters, as tabulated below.

GIS and Remote Sensing Data

Shape files at Palestine 1923 belt coordinate system were prepared. These layers include the following:

i. Boundaries of the basin; surface and ground boundaries.
ii. Distribution of rainfall stations and wells.
iii. New modified isohyetal map.
v. Geological contacts and development of a new simplified geological map for the basin and the surrounding area.
vi. Major geological structure framework.
vii. Hydrogeological map.
viii. Hydrological and hydrogeological required layers: abstraction, boreholes, saturated thickness of aquifers, isohyetal maps, transmissivity layers, etc.
ix. Isopach maps for the aquifers.
x. Drainage pattern image.
xi. Landsat TM image of the Basin.
xii. Topographic contour map at 20 m and 50 m intervals.
xiii. 3D Digital elevation model.

Hydrogeological Conceptual Model

The creation of a mathematical groundwater model requires conceptualization of the geological/hydrogeological framework into a viable equivalent digitally represented groundwater flow model. This requires good understanding of the aquifer system characteristic hydraulics and geometry to effectively define the model boundary conditions. Model data has been collected from the Ministry of Water and Irrigation as well as from previous studies, which included well inventory, review of the existing pumping tests and those to be conducted under drilling and testing programmes, in order to reliably define the transmissivity and storage coefficients of the aquifer layers.

The model grid configuration has been defined to incorporate details of intensive groundwater usage and demand. As the Kurnub and Rum aquifers have not been used except a few exploration wells, the conceptual groundwater model of Jafer basin shown in Figure (5) incorporates only the upper aquifer system.

The model system, mainly consisting of limestone, is recharged by precipitation from the topographically highs such as Al-Shaubak area (north-west) and discharges into the central and eastern parts of the basin as well as throughflow of these aquifers. Estimates of recharge, groundwater abstraction and outflow from the aquifer systems from previous studies allow an estimate of the groundwater balance. This may be enhanced using lump parameter estimation tools, such as a water balance model and flow net analysis. This information will guide the modeler in the understanding of the reliability of the model output.

The justifications for the conceptual model are as follows:

1. Abstraction in Jafer basin is mainly from the Upper Cretaceous Complex.
2. The principal aquifers in Jafer basin are the B4/B5 and B2/A7 aquifers.
3. Another potential aquifer is A4 within the A1-A6 system; however, further review of existing data is necessary to establish whether there is sufficient information for modeling.
4. A1-A6 are largely confined at the base. Therefore, it is valid to assume that interaction below this layer can be separated from the deep aquifer complex.

Model Boundary Conditions

An important step in model design is to select the proper boundary conditions, as these have a significant influence on how the model runs as well as on the
resultant output (Al-Mahamid, 2005). Boundary conditions express the way how the model interacts within its domain; i.e., water fluxes or known values of model parameters, such as the piezometric head (Bear and Verruijt, 1992).

The boundary conditions of the current study have been conceptualized to ensure proper running of the flow model for the B4/B5 aquifer; north-east, south and south-west (physical boundaries-geological outcropping areas) are considered no-flow boundaries. However, some parts at Jafer basin outflow have been considered as constant head boundaries and as specified head boundaries in order to calculate cross-flow boundary into the eastern part of the model. The eastern boundary represents the constant head boundary type, where the 850 m water level contour is represented as a constant head.

![Figure (5): Hydrogeological conceptual model of Jafer basin](image)

For the lower aquifer (B2/A7), physical and hydraulic boundaries are relatively different from those of the upper aquifer. Northern and southern parts represent no-flow boundaries. The eastern and western parts represent the constant head boundaries, whereby the 1300-1500 m water level contour represents the western boundary and about 700 m water level contour represents the eastern boundary of the study area.

Model Layers

As described above, regarding model configuration and geometry of the aquifer system for the groundwater flow modeling of Jafer basin, the basin model is a 4-layer quasi three-dimensional model consisting of 129 rows and 161 columns with a constant grid separation (grid size) of 1000 m x 1000 m.

Recharge and Discharge

Based on the isohyal map of the rainfall distribution, recharge is taken as a percentage of the average precipitation in the model area ranging between 3% and 10%.

For precipitation less than 50 mm, infiltration is assumed to be zero, whereas for precipitation more than 50 mm, the infiltration percentage was assumed to be 5%. Recharge from precipitation is specified in the model in the unit of meters per day (m/d) and the areal distribution of recharge for the B4/B5 and B2/A7 aquifers is located in the north-western part of the study area where rainfall is more than 50 mm. The total amount of inflow that is represented by areal recharge as precipitation and throughflow is about 17-20 MCM per year.
As natural inflow and natural outflow to a closed system are equivalent, the total amount of natural outflow is taken as base flow or underflow before the 1980s. This assumes that there is no other significant discharge such as groundwater abstraction, which is reasonable prior to the 1980s.

The amount of groundwater abstraction of Jafer basin has been taken from the Water Information System—Ministry of Water and Irrigation (WIS–MWI). The current total groundwater exploitation in Jafer basin is about 36.5 MCM according to 2012 statistics from the upper and lower aquifers (1.5 MCM from the upper aquifer and 35 MCM from the lower aquifer). The total water use includes 18.7 MCM for agricultural, 10.7 MCM for domestic and 7.1 MCM for industrial purposes.

**Groundwater Throughflow**

The governing equation has been based on the Darcy flow equation modified to include the field hydraulic parameters. This equation represents groundwater flow in a flow tube defined by groundwater flow lines and piezometric contours:

$$Q = K b i W;$$

where: $Q =$ volumetric groundwater flow rate (m$^3$/day). $K =$ system permeability (m/day), $b =$ thickness of the aquifer, $i =$ hydraulic gradient (dimensionless), $W =$ width of the aquifer unit. For the B2/A7 aquifer, the throughflow is estimated according to the following values:

$K = 0.6$ m/day (JICA (1990) used values between 0.6 and 1.0 m/day).

$b = 200$ m (average thickness).

$i = 0.006$ (hydraulic gradient west to east in Jafer).

$W = 80,000$ m (width of the aquifer).

$Q = 56,400$ m$^3$/d or 20.6 MCM/yr.

**Hydraulic Conductivity**

Horizontal and vertical hydraulic conductivities have been assigned in the upper and lower aquifers based on the pumping test analysis results recorded in the MWI-WIS and compiled in previous hydrogeological studies in and close to Jafer basin (Al-Kharabsheh and Al-Mahamid, 2002). Using a standard field interpolator (gridding method by Kriging), data was distributed to cells within the model area. The range of horizontal hydraulic conductivity of the upper aquifer is between $6 \times 10^{-5}$ m/s (5 m/day) and $1 \times 10^{-4}$ m/s (8 m/day). There are very high values (transmissivity $\approx 10,000 – 25,000$ m$^2$/day) found in the thicker part of the aquifer.

For the B2/A7 aquifer, the same methodology was applied to address all cells. The value of the hydraulic conductivity of the lower aquifer was ranging between $5 \times 10^{-6}$ (0.5 m/day) and $4 \times 10^{-5}$ m/s (4 m/day) for confined and phreatic conditions, respectively. The vertical hydraulic conductivity values were kept constant for the upper aquifer and the lower aquifer at 0.5 m/day based on the previous hydrogeological and model results. However, the vertical hydraulic conductivity of the B3 aquitard that locates between the upper and lower aquifers has a significant confinement between the two aquifers. The value of the vertical hydraulic conductivity is estimated to be about $8 \times 10^{-5}$ m/day for this layer with an average thickness of 250 m. Further, the vertical hydraulic conductivity of the A1/A6 aquitard that locates between the B2/A7 and Kurnub aquifers has a significant confinement between the two aquifers. These values have been modified during the calibration process in order to reach the best fit between the measured and calculated heads of the upper B4/B5 aquifer and the B2/A7 aquifer.

**RESULTS AND DISCUSSION**

The pre/post processor called MODFLOW, developed by Chiang and Kinzelbach (2003), was used to develop the groundwater flow model of Jafer basin area by applying a three-dimensional finite difference approach. MODFLOW was used in the groundwater flow calculations.

ArcGIS was used to prepare the data input files for
the model and import them by way of shape files to MODFLOW. This software was used to create the files needed as data input to MODFLOW and graphical output in the format of *.DXF or *.PGL files. The contouring package SURFER was applied from the digitization of the structure contour from BGR, 2001 of the hydrogeological layers. Validation of these contours was conducted by comparing the well data obtained from the MWI-Water Information System (WIS).

Steady State Calibration

Model calibration of steady state for Jafer basin was carried out by comparison of observed piezometric heads of the upper and lower aquifers with the hydraulic heads calculated by the model. The calibration of the B4/B5 aquifer (limited and less potential aquifer) was based on the water table during the 1980s, which reflects the groundwater steady state conditions before significant abstraction of the aquifer occurred.

Parameter optimization was accomplished during the steady state to reach the best fit for the model due to sensitivity of the horizontal hydraulic conductivity, throughflow and recharge. The vertical hydraulic conductivity of the B3 aquitard layer was modified on a local scale to reach the optimum fit between the measured and calculated heads. The highest discrepancies were found close to the south-eastern boundaries, where the thickness of the aquifer is very thin, as well as within the proximity of the outflow of the basin along the eastern boundary. For the B4/B5 aquifer, distribution of the horizontal conductivity increases from south-east (3 m/day) to north-west (10 m/day) of the model area.

Vertical hydraulic conductivity of the B3 aquitard (between B4/B5 and B2/A7 aquifers) has a very high effect on the upward or downward leakage between the two aquifers. It was found that the vertical hydraulic conductivity of B3 aquitard was ranging from 1x10^-5 m/day to 2x10^-5 m/day. Vertical hydraulic conductivity of the A1/A6 aquitard (between B2/A7 and Kurnub aquifers) has a very high effect on the upward or downward leakage between the two aquifers. It was found that the vertical hydraulic conductivity of A1/A6 aquitard was ranging from 1x10^-4 m/day to 1x10^-3 m/day. The highest value was found at the central and western parts of the study area.

During the calibration of the B2/A7 aquifer, it was found that the horizontal hydraulic conductivity was the most sensitive parameter which was considerably changing during the steady state to reach the best match between the observed and calculated heads as shown in Figure (6). The highest discrepancy of the model was found in the western part of the model area due to the steeping of the water level contours from a recharge mound in the north-western part of the model. The horizontal conductivity of the B2/A7 aquifer ranges from 0.5 m/day in the western part of the model area to about 4 m/day in the eastern part of the model area. The distribution of horizontal hydraulic conductivity of the B2/B7 aquifer in the study area increases from west to east of the model area and has been divided into 3 zones. Therefore, calibration of the upper and lower aquifers under steady state (B4/B5 and B2/A7 aquifers) was carried out by comparison with the groundwater level which has a limited number of observation points (boreholes).

Water Budget

Tables 1 and 2 tabulate the water budget of the steady state for the whole model domain. For the B4/B5 aquifer, the areal recharge from precipitation is about 3.1 MCM that represents (4%-5% of the total precipitation). The outflow from the B4/B5 aquifer is about 6.1 MCM from constant head cells from the eastern boundary. There is a flow of 3 MCM as vertical leakage coming from the B2/A7 aquifer, but this value is highly sensitive to the vertical hydraulic conductivity of the B3 aquitard (between the B4/B5 and B2/A7 aquifers).

For the B2/A7 aquifer, the areal recharge is about 6.5 MCM. The inflow from Al-Shaubak Mount (north-west) is about 14 MCM that includes the contribution of higher infiltration of precipitation in this area. The vertical inflow (upward leakage) from the Kurnub aquifer through A1/A6 is about 6.6 MCM. The total outflow of the B2/A7
aquifer consists of 28.2 MCM as outflow along constant head cells along the eastern boundary.

Table 1. Annual water budget of the model domain for the B4/B5 aquifer (MCM)

<table>
<thead>
<tr>
<th>Flow Term</th>
<th>Inflow</th>
<th>Outflow</th>
<th>Difference (In-Out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant head</td>
<td>6.1</td>
<td>6.1</td>
<td>0</td>
</tr>
<tr>
<td>Recharge</td>
<td>3.1</td>
<td>-</td>
<td>3.1</td>
</tr>
<tr>
<td>Vertical Leakage</td>
<td>3</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Sum</td>
<td>6.1</td>
<td>6.1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Annual water budget of the model domain for the B2/A7 aquifer (MCM)

<table>
<thead>
<tr>
<th>Flow Term</th>
<th>Inflow</th>
<th>Outflow</th>
<th>Difference (In-Out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant head</td>
<td>28.2</td>
<td>-</td>
<td>-14.1</td>
</tr>
<tr>
<td>Recharge</td>
<td>6.5</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Vertical Leakage</td>
<td>3.3</td>
<td>-</td>
<td>6.6</td>
</tr>
<tr>
<td>Sum</td>
<td>31.5</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Transient State Calibration (Time-Dependent Simulation)

The calculated water levels and hydraulic parameters of the steady state calibration were used as input for the long-term simulation of the transient flow. The transient simulations were carried out to reach the present state of the water levels and to forecast long-term response of the aquifers to groundwater withdrawal till the year 2040.

The transient state of groundwater system for Jafer basin has been considered to have started at the beginning of the 1980s due to increasing groundwater abstraction. The groundwater exploitation was about 5 MCM/yr between 1980 and 1989 according to the records from the MWI. The current groundwater exploitation in Jafer basin measured by MWI in 2012 was about 36.5 MCM, including 18.7 MCM as agricultural, 10.7 MCM as domestic and 7.1 MCM as industrial usage. This value has been used for the transient simulation until 2040. The transient simulation of the groundwater flow of Jafer basin covered the period from 1980 to 2013.

Figure (6): Comparison between measured and calculated groundwater level of B2/A7 aquifer
For the calibration of the B4/B5 aquifer, three observation wells were included in the model domain to monitor fluctuations in the water level. There was sufficient monitoring well data for calibrations in the B2/A7 aquifer in the western part of the model domain from 12 observations to calibrate the simulated transient flow with actually observed water levels. However, Eshidiya and Al-Muhammadiyah well fields haven't any observation well yet. Comparing the calculated drawdown in the B2/A7 aquifer, the simulation of drawdown could be considered as being representative of the whole model area. Therefore, the accumulative drawdown for the long-term calibration (1980-2013) in the B2/A7 aquifer has been simulated. The maximum drawdown has reached 67 m by the end of 2013. Four cones of depression have been developed in the model area. The most severe one was close to Al-Muhammadiyah Well-field with a maximum drawdown of about 67m by 2013. The aquifer parameters for the transient state calibration were concerning the values of specific yield and storage coefficients. The specific yield for the B4/B5 aquifer was 5%, whereas for the B2/A7 aquifer it ranged between 2% and 5%. In addition, the B2/A7 aquifer in most parts of the model area is considered as a confined aquifer which refers to the storage coefficient or specific storage. The specific storage for the B2/A7 aquifer was between $1 \times 10^{-6}$ and $1 \times 10^{-4}$ (1/m). The maximum value of the specific storage of the B2/A7 aquifer represents the central parts of the model area, (such as: Eshidiya Well-field area), whereas the minimum value represents the western parts of the model area.

**Model Predictive Scenarios**

Overabstraction from wells is mostly in the B2/A7 aquifer, exacerbating the situation by lowering the water table and removing the storage of the aquifer. This will have long-term effects in both eventually directly affecting the well pumping rate as well as possibly extending the effect of the cones of depression on the other well-field areas. The model transient results will be used to predict and run ten model scenarios for Jafer basin to cover the time period between 2013 and 2040. There were 10 predictive scenarios modeled as tabulated in Table (3), which shows the assumption of each scenario and the maximum accumulated drawdown, as well as the effect on Eshidiya and Al-Muhammadiyah Well-fields. Figure (7) shows prediction accumulated drawdown after 28 years (2013-2040) of the continuous abstraction (as a current abstraction of 36.5 MCM) for the B2/A7 aquifer (main potential aquifer). Consequently, the accumulated drawdown will reach 122m by 2040. Four cones of depression will develop in Jafer basin; the most severe one is located close to Al-Muhammadiyah Well-field.

**Recommendations**

Lowering abstraction or even stopping pumping at Eshidiya does not change the high drawdown at Al-Muhammadiyah Well-field. It is highly recommended for continuation of agricultural activities in Jafer basin to access the deep sandstone aquifer below the Upper Cretaceous aquifer. The groundwater flow results convey that Al-Muhammadiyah Well-field represents the largest cone of drawdown on the groundwater level of the area of study as is clearly obvious in all model predictive scenarios. Thus, the quantity of abstracted water for irrigation must be decreased and an alternative water resource must be provided to meet the various demands in the study area.
Table 3. List of predictive model scenarios and maximum drawdown by the year 2040

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Assumption</th>
<th>Maximum Accumulated Drawdown (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Keeping the current abstraction (36.4 MCM)</td>
<td>122</td>
</tr>
<tr>
<td>2</td>
<td>Decreasing domestic supply only by 25% (10.7-8 MCM)</td>
<td>122</td>
</tr>
<tr>
<td>3</td>
<td>Decreasing domestic supply only by 50% (10.7-5.4 MCM)</td>
<td>122</td>
</tr>
<tr>
<td>4</td>
<td>Increasing current abstraction by 1.5 times (54.6 MCM)</td>
<td>183</td>
</tr>
<tr>
<td>5</td>
<td>Increasing current abstraction by 2 times (72.8 MCM)</td>
<td>240</td>
</tr>
<tr>
<td>6</td>
<td>Artificial recharge for 3 locations based on recharge dams with maximum storage of 1 MCM and actual infiltration up to 25%</td>
<td>122</td>
</tr>
<tr>
<td>7</td>
<td>Decreasing Eshidiya Well-field abstraction by 25% by the end of 2020 (5.3 MCM)</td>
<td>122</td>
</tr>
<tr>
<td>8</td>
<td>Decreasing Eshidiya Well-field abstraction by 50% by the end of 2020 (3.5 MCM)</td>
<td>122</td>
</tr>
<tr>
<td>9</td>
<td>Stopping Eshidiya Well-field abstraction by the end of 2020</td>
<td>122</td>
</tr>
<tr>
<td>10</td>
<td>Decreasing Al-Muhammadiyah Well field abstraction by 50% for agricultural production (5 MCM)</td>
<td>62</td>
</tr>
</tbody>
</table>

Figure (7): Prediction drawdown after 28 years (2013-2040) for B2/A7 aquifer, scenario no. 1
REFERENCES


