Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.9, No.11, 2017

www.iiste.org

Groundwater Recharge from Wala Dam Reservoir in Jordan

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Abstract

A simulation model is presented to investigate the interaction between the surface water reservoir behind Wala dam in Jordan and the groundwater aquifer in the area. MODFLOW software with RES package is used with the available measured data to calibrate the aquifer parameters (transmissivity, specific storage, specific yield, and vertical hydraulic conductivity of the reservoir bed). Steady and transient verification processes will be conducted. Two scenarios are studied to predict the quantity of groundwater that can be pumped from Heedan wells to Amman. This study will show the benefit of natural recharge from surface water to groundwater and the rate of pumping water to Amman can be raised to five times the rate before the dam construction.

1. Introduction

Wala dam was constructed as one of two main dams (Mujib and Wala), to store flood flow in Mujib basin in Jordan. The main objective of the dam was to impound floodwater in order to recharge the Wadi Sir aquifer under the dam reservoir area. The dam is located about 40 km south of Amman and 26 km to the east of the Dead Sea, and its catchment area 1770 km^2. The reservoir capacity is 9.3 MCM and surface area 0.86 km^2 at full reservoir level. The aquifer considered in the present study extends 10 km upstream of the dam and 10 km downstream including Heedan springs, and 5 km on each side of the Wadi Al Wala stream.

A comprehensive study of the Mujib-Wala basin was carried out by JICA 1990, hydrogeology of the basin and suitable dam sites were discussed. Nidal Haddadin 1992 presented hydrological simulation of Wadi Wala stream flow and developed rainfall intensity-duration-frequency curves for the area, the curves are useful for the runoff estimation at different return periods and for reassessment of Wala dam reservoir capacity. Hasan Bader 1992 studied the hydrological and hydrochemistry of the area located between Wadi Mugib and Wadi Zerqa Mai'n and concluded that the transmissivity of Wadi A Sir aquifer in the area ranges between 9.7 m^2/day and 47600 m^2/day with an average of 3236 m^2/day.

Seepage losses from Wala dam reservoir was investigated by the consulting company in its technical reporte submitted to Jordan Valley Authority 1995. The reservoir floor seepage was estimated to be vertically negligible into the underlying aquifer. The assessments were based on the available information before the dam construction. The study was carried out with the simple application of Darcy law in one direction. Steady state condition was assumed, which is virtually impossible to attain. The study assumed that the majority of the seepage from the reservoir takes place horizontally through the abutments and returns to Wadi Wala downstream from the dam. The seepage water should be collected and pumped through recharge wells into the aquifer under the dam.

The regional groundwater system of the dam area comprises two aquifers separated by an aquiclude. The upper aquifer (tafilah member Bb1) is unconfined,and the lower aquifer (A7b) is confined beneath the dam site and outcrops downstream the Kings highway bridge and discharge at Heedan springs. There is no firm study on the significance of the vertical leakage from the dam reservoir into the lower confined aquifer (wadi As Sir aquifer).
The present work investigate the potential for increasing available groundwater resources by aquifer recharge from Wala dam surface water reservoir and ascertain the effect of recharge on the flow from Heedan springs and assess their potential as a water supply.

2. Wala Dam Reservoir Area

2.1 Topography

The study area forms part of the highlands located between the plateau like hills to the east, and the Jordan valley to the west. The topography of the study area varies in altitude from a minimum height about 420 m a.s.l in Wadi Wala in the southwest, to a maximum height about 827 m a.s.l to the east of Madaba. The major drainage system in the area is Wadi Wala which runs westward and empties into the Dead Sea. The main tributaries are Wadi Zafran, Wadi Al-Halg and Wadi Shabik, which are linked with the main wadi , Wade Heedan. The topography map of the dam reservoir area is shown in figure 1.

2.2 Hydrogeology

Wala dam region includes the following three main aquifers described below from the lower elevation to the upper (JICA 1999):

1. Upper and lower member of the Naur limestone formations aquifer (NL) A1-A2 confined between Kornub sandstone aquilude and Wadi As Sir (WSL) A7a and Shueib aquiclude (FHS) A5-A6. Thickness of the aquifer 80-115 m, specific capacity 0.01-12 m^3/hr/m, transmissivity 0.03-100 m^2/ day, and permeability $2x10^{-8}$-$3.1x10^{-8}$ m/ sec.

2. Limestone of the intermediate member of the Wadi As Sir limestone formation (WSL), A7b confined between Wadi As Sir (WSL) A7a and Shueib aquiclude (FHS) A5-A6 and Wadi Umm Ghudran (WG) B1c and B1a and Wadi As Sir aquiclude (WSL) A7c. This is the aquifer considered in the present study. Thickness is 70-130 m and average permeability $1x10^{-6}$ m/ sec.

3. Amman Silicified Limestone (ASL) B2a and AL Hisa Phoshrite Aquifer (AHP) B2b is confined between Wadi Umm Ghudran (WG) B1c and B1a and Wadi As Sir aquiclude (WSL) A7c and Muwaqqare Chalk-Marl (MCM) aquiclude B3. Thickness is 75 m.

In a consulting report submitted to Jordan Valley Authority 1995, details of the geological layers at Wala dam site are described. Figure 2 shows a geological section at Wala dam site.

2.3 Available Data

A number of wells have been used to pump groundwater from Heedan springs area to Amman and to local people for water supply and irrigation use. Total Flow record from these wells is provided by the ministry of water and irrigation in Jordan as shown in table 1.

Table 1. Annual flow from Heedan wells

Year	Pumped water, MCM
2000	10.53
2001	9.68
2002	9.96
2003	11.7
2004	12.37
2005	11.35
2006	11.93

Head measurements are available at wells Heedan2, Wala11, and Wala14. After the dam construction has been finished, head measurement was recorded at a number of wells during the period May-2002 to November-2007. All these data are used in the present work for calibration and validation processes.

3. Methodology and Model Description

The applications of MODFLOW (a modular three-dimensional finite difference groundwater model of the U.S. Geological Survey) to the description and prediction of the behavior of groundwater systems have increased significantly over the last three decades. The original version of MODFLOW-88 (McDonald and Harbaugh 1988) or MODFLOW-96 (Harbaugh and McDonald 1996a, 1996b) can simulate the effect of wells, rivers, drains, head-dependent boundaries, recharge, and evapotranspiration. In MODFLOW, an aquifer system is replaced by a descritized domain consisting of an array of nodes and associated finite difference blocks (cells). The nodal grid forms the framework of the numerical model. Hydrostratigraphic units can be represented by one or more model layers. The thickness of each model cell and the width of each column and row may vary.

The Reservoir package (Fenske et. al, 1996) in MODFLOW code is designed for cases where reservoirs are much greater in area than the area represented by individual model cells. The reservoir package is ideally suited for cases where leakage from or to reservoirs may be a significant component of flow in a groundwater system. Bed thickness of the dam reservoir equals the difference between the topography of the reservoir bed and top elevation of the Wadi As Sir formation. The hydraulic conductance of the reservoir bed is used in the present work and determined through calibration process.

The aquifer domain considered in the present work extends 10 km upstream of the dam and 10 km downstream, and 5 km on each side of the Wadi Wala stream. The domain is descitized into square cells with 200 m width. Smaller cells of 10 m width are used in the vicinity of the dam reservoir, wells and springs location. It is assumed that Wadi As Sir limesron aquifer forms one hydrological layer. The aquifer is convertible between confined and unconfined, and from the hydraulic contour map shown in figure 1, the boundary conditions imposed in the model are fixed, details are given in Alnaimat 2007. Heedan wells and Heedan springs are modeled as pumped wells with negative recharge rates.

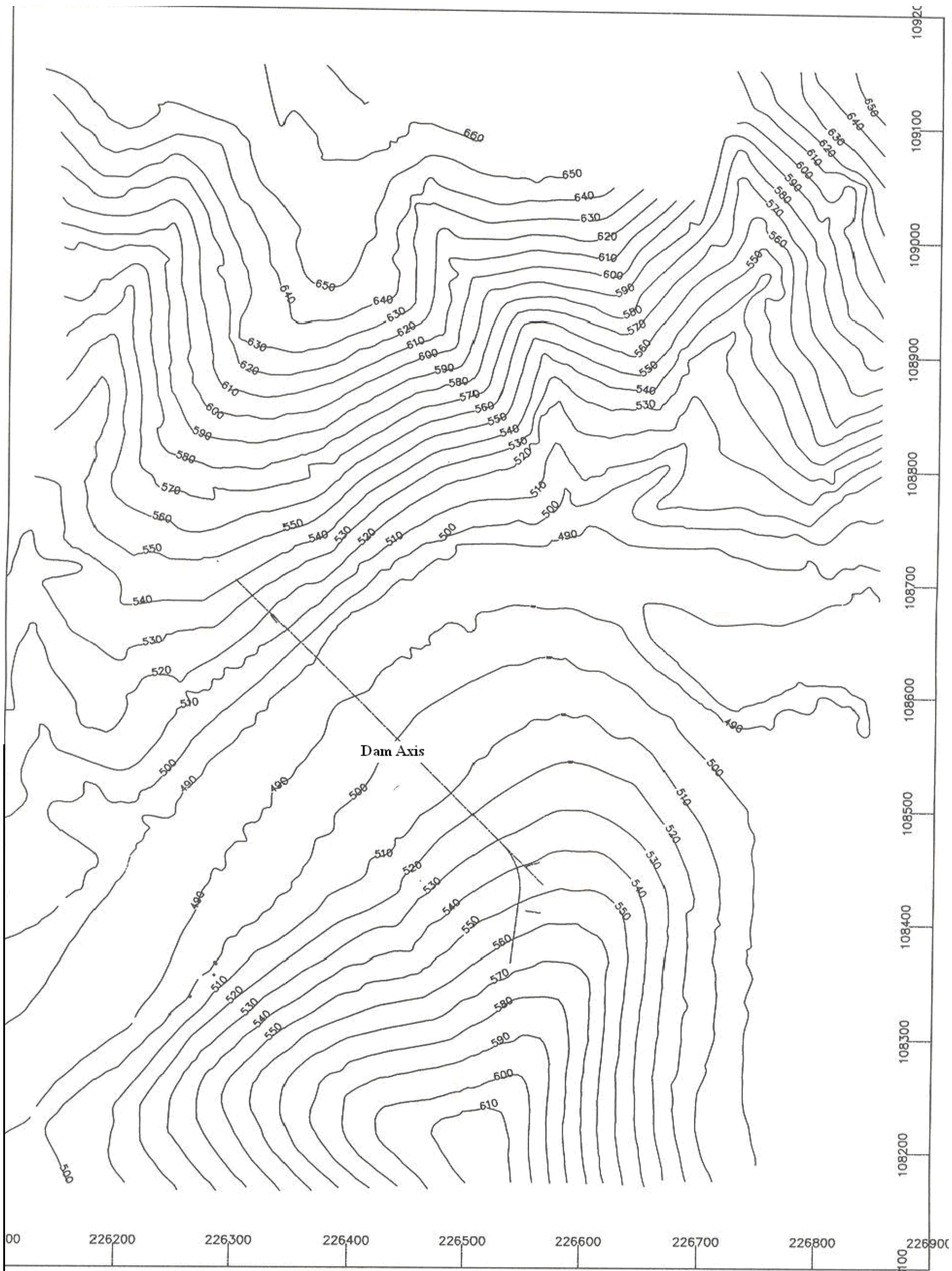

Figure 1. Topography Contour Map of the Dam Reservoir Area

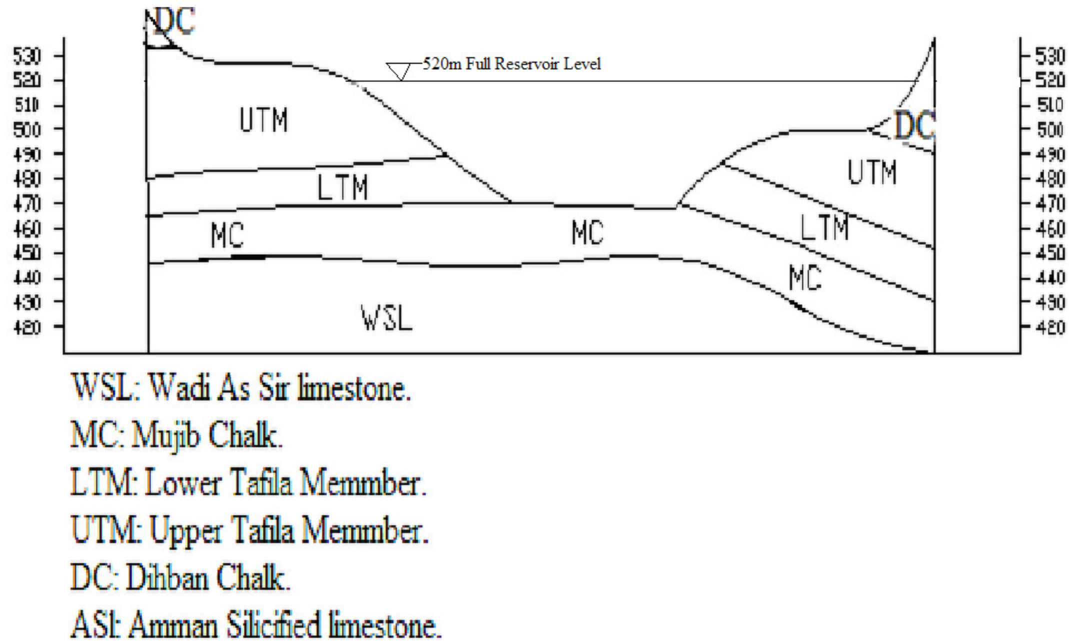

Figure 2. Geological Section at Wala Dam Reservoir

4. Results and Discussions

The transmissivity of the aquifer is determined through steady state calibration process. The aquifer is divided into five regions of different values of trensmissivity. Heedan springs are represented by ten cells and total average flow rate 1962 m^3/h in the year 1984/ 1985. Recorded head in nine observation wells in the year 1984/ 1985 are shown in table 2. The calibrated transmissivity of the aquifer is shown in figure 3. The results for steady head in the observation wells are compared with measured as shown in table 2. The contour map for steady head distribution is shown in figure 4, the flow direction is from east towards the springs site. The steady head distribution is used as an initial condition in the transient simulation.

Table 2. Simulated and observed head

Well No.	Well name	Measured value, m	Simulate value, m
1	Wala4	399.6	401.984
2	Wala5	381	369.623
3	Wala6	428.32	434.695
4	Wala12	415	414.051
5	Wala13	459.2	459.238
6	Wala14	449.78	444.879
7	Wala15	349.37	353.54
8	Wala9	339.85	333.958
9	Wala11	335.23	344.965

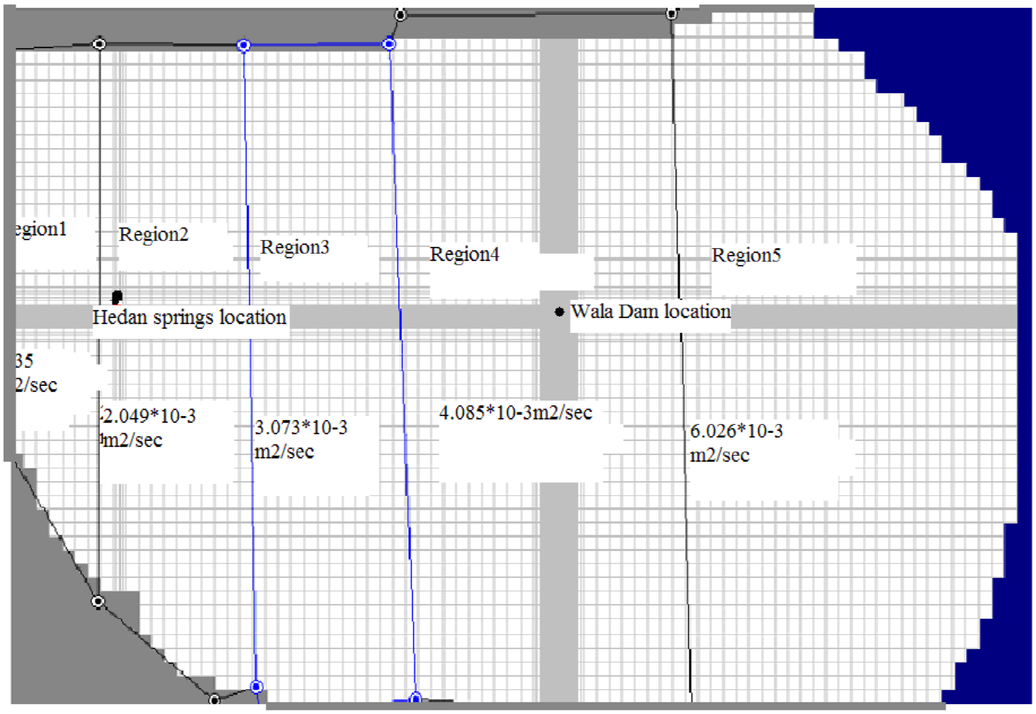

Figure 3. Transmissivity Distribution of Wadi As Sir Aquifer

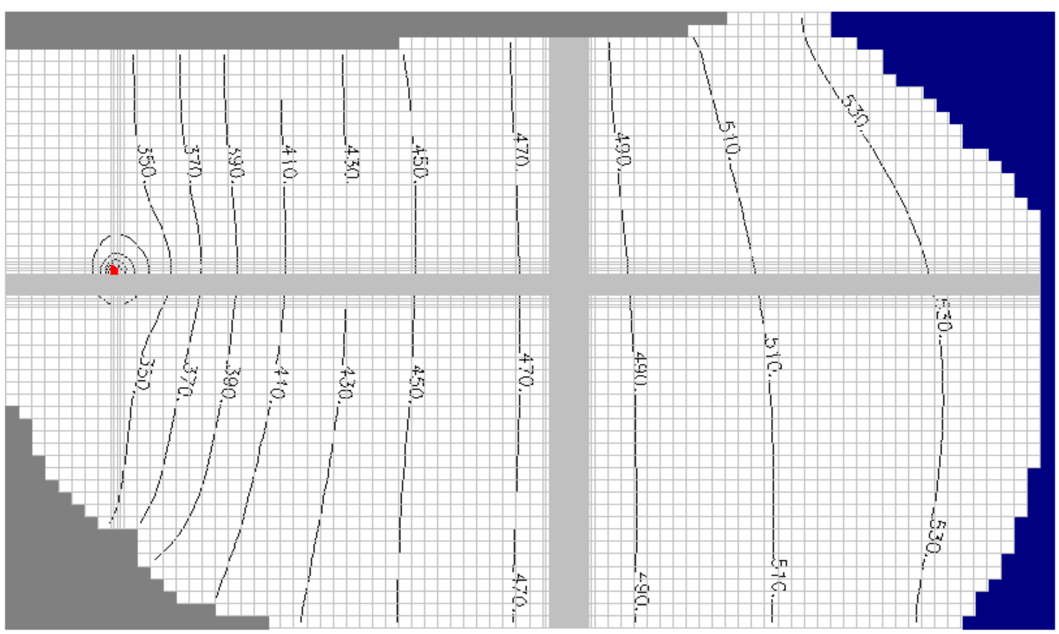

Figure 4. Head Contour Lines for Steady State Conditions

Transient simulation is carried out to determine the specific storage and specific yield of Wadi As Sir limestone aquifer, and vertical hydraulic conductivity of the reservoir bed through calibration process. Calibration is based on head record at wells Wala11 and Wala14 during the period 1986-1989. Results show that the specific storage is $1.52x10^{-5}$ m^{-1} for the confined region and specific yield 0.158 for the unconfined region. Typical comparison between simulated and observed head is shown in figure 5. The head contour map for the last time step is shown in figure 6.

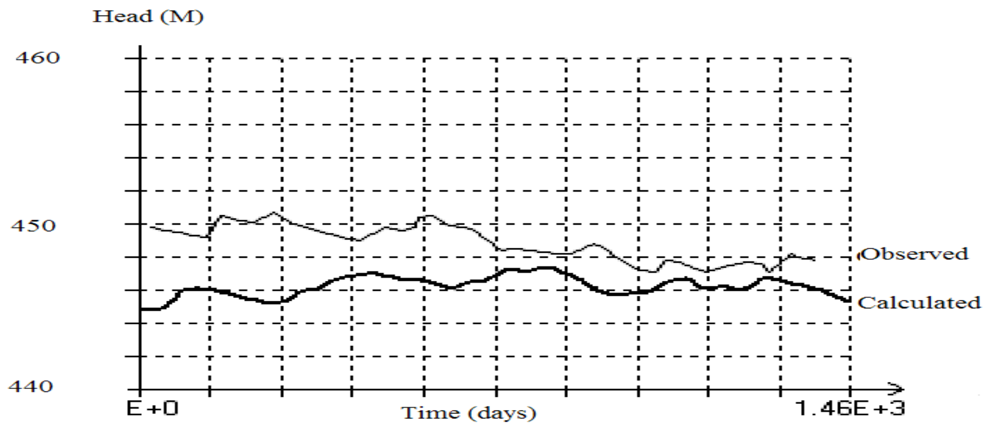

Figure 5. Comparison of Simulated with observed Head at Well14.

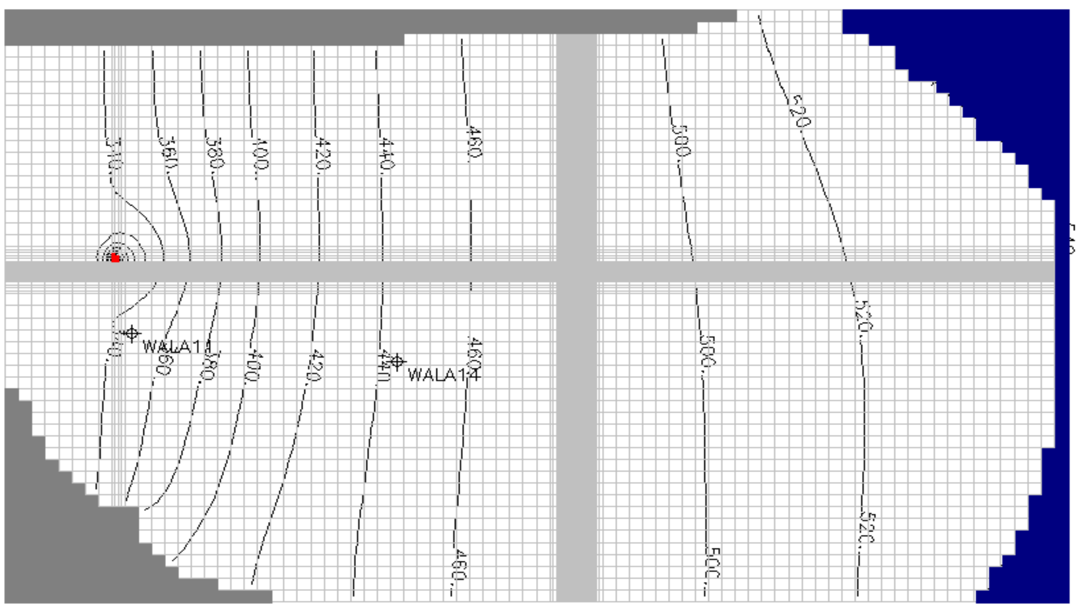

Figure 6. Head Contour Lines for the Last Time Step

The second stage of calibration considers the period after completing the dam construction. Data from seventeen wells and from reservoir water level record during the period 2002-2006 are used to determine the vertical hydraulic conductivity of the geological formation below the dam bed and to determine Heedan springs discharge. Five of the seventeen wells are pumping water to Amman, their annual discharges are recorded. Details of data are presented by Alnaimat 2007. Initial head distribution is prepared for the day 29th of October 2002 using data from the seventeen wells mentioned above. From calibration process, it is found that the vertical hydraulic conductivity is 0.252 m/ day. Typical comparison is shown in figure 7 between simulated and observed head at well OW5, the maximum difference is 4%. Water budget package in the MODFLOW is used to check the accuracy and found the difference between inflow and outflow of water is 0.02% for the aquifer system.

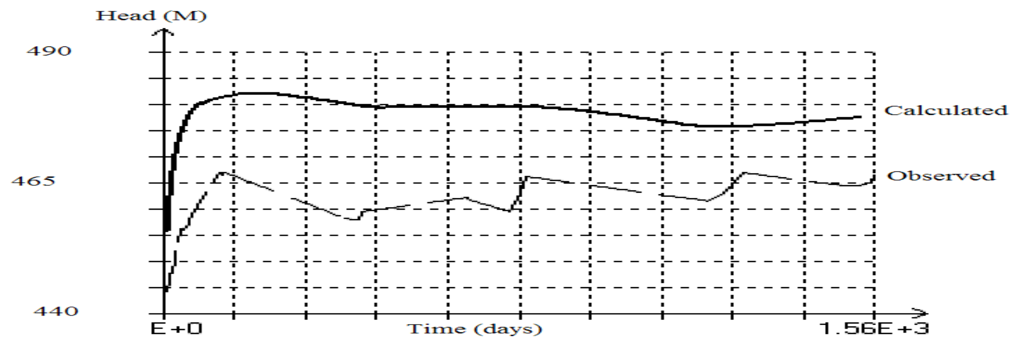

Figure 7. Comparison Between Simulated and Observed Head at OB5 Well

Scenario1

The aim of this scenario is to evaluate the benefits of the groundwater recharge from Wala dam reservoir. The initial water level in the reservoir is maximum 520 m a.m.s.l and the final water level equals 40% of the maximum. The simulation is for one year time with one day time step, and the head distribution in the aquifer returns to its steady state before the dam construction. It is found that the annual discharge from Heedan wells equals 63.9 MCM compared with 12 MCM before the dam construction. This result shows that recharge process raises Heedan wells discharge to five times.

Scenario 2

The initial and final conditions are the same as in scenario 1, but the simulation period is three years. It is found that the annual abstraction from Heedan wells is 40.3 MCM compared with 12 MCM before the dam construction.

5. Conclusions

Simulation of groundwater recharge from Wala dam reservoir has been conducted to evaluate the interaction between surface water and groundwater. Using the MODFLOW software and the available data, the aquifer parameters have been estimated by calibration process. Transmissivity varies from 30240 m^2/ day west of Heedan springs to 177 m^2/ day in the east of the springs. The specific storage of the confined part of the aquifer is 1.52 x 10^{-5} m^{-1} and the specific yield for the unconfined part is 0.158. The vertical hydraulic conductivity of the reservoir bed is 0.252 m/ day. Verification of results is accepted through good comparisons between observed and simulated heads. Model accuracy is checked by using water budget package of the MODFLOW software. Two scenarios are presented to prove the advantages from the groundwater recharge from Wala dam reservoir.

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