Studying of performance of the under construction drainage system in shiraz plain

Ahmad Reza Karimipour[1] , Golnoosh Banitaleby[2] , Iman karimipour[3] , Mehdi Ahmadi[1]

1. Instructor of civil and hydraulic structure, Ardal training center , Islamic Azad University, Shahrekord Branch , Shahrekord , Iran (corresponding Auther) Ahmadrezakarimipour@yahoo.com

1. Instructor, Shahrekord Branch (Ardal center), Islamic Azad University, Department of Mechanic Engineering, mehdiahmadi81@gmail.com

2. M.Sc. Student of Soil physics and conservation, Agriculture Faculty, Shahrekord University, Iran, golnoosh.banitalebi@gmil.com

3. M.Sc.Student of Solid Mechanics, Mechanical Engineering Department, Faculty of Engineering, Yazd University, Iran, iman.karimipour@gmail.com

Abstract: Shiraz plain, covering an area of roughly 300 km^2 and having an average altitude of 1500 meters, is located in Fars province, in the South of Iran, in a climatologically arid and semi-arid region. Due to the problems emanated from elevated water level in parts of Shiraz plain, some drainage system constructions have been implemented with different purposes, the most significant of which are drawing down the water table in South East Shiraz and transferring water to Sarvestan plain. These projects were studied and initiated by Fars Regional Water Organization in 1993 and they are at operational stages nowadays. In the present study, after investigating the factors affecting elevated groundwater level in Shiraz plain and Shiraz city and examining such prevention techniques as the use of a drainage system, the effects of the aforementioned projects on averting water table rise in Shiraz plain in the future were simulated via PMWIN Model. After calibration and validation of the model, the required parameters were determined and groundwater level in the plain with and without the drainage system was simulated for four different cases. The results of all cases indicated that although lowering the elevated groundwater level project at South East of the plain and Shiraz urban sewage collection system were both being carried out simultaneously, in most parts of the study area, groundwater levels did not go down to the expected extent (10 meters), and hence, Khatoon drainage alone cannot solve the elevated water table problem. There is, accordingly, a need for more drainage lines in the plain.

[A. R. Karimipour, G. Banitaleby, I .Karimipour, M. Ahmadi. **Studying of performance of the under construction drainage system in shiraz plain.** *Life Sci J* 2012;9(3):954-966]. (ISSN: 1097-8135). **http://www.lifesciencesite.com**. 137

Keywords: Ground water, Shiraz plain, Drainage system, PMWIN, Modeling, Effective parameters

1.Introduction

In general, ground water resources do play a significant role in meeting the water demands in an area. Thus their evaluation, simulation, and management are vitally important. Shiraz plain, in particular, is facing elevated groundwater level problem in its southeastern region due to phenomena like increasing population, conversion of farmlands and gardens into residential areas, and destruction of old aqueducts that used to drain the plain. To overcome this problem, construction of three drainage aqueducts in the plain has been underway since 2003. So far, more than half of one of these aqueducts, with a rough length of 15 km, has been constructed. Examining the effectiveness of this drainage system, and predicting its function in the future necessitate more research in this area.

Many studies in the field of ground water flow simulation have been conducted. The following sketch makes a mention of just a few of these studies: the study of simulating groundwater flow in multi-aquifer systems with analytical and numerical Dupuit models by Bakker (1999), modeling ground and surface water interactions using Dupuit approximation by Anderson (2005), and the reconstruction of ground water parameters from head in an unconfined aquifer by Yan et al, (2007). Finite difference method for simulation of different aquifers has also been employed by different researchers. Projects such as numerical modeling of ground water resource management options in Kuwait by Mukhopadhyay et al. (1994), development and application of a comprehensive simulation model to evaluate impacts of watershed structures and irrigation water use on stream flow and ground water by Ramireddygari(2000) and studying Bajgah plain ground water situation using the finite difference three dimensional modular MODFLOW model by Rezaei and Mousavi are among the examples of such projects [4-6].

The application of MODFLOW model as a modular three dimensional finite difference model to predict behavior groundwater has undergone noticeable developments during in more recent years. Such studies as using sensitivity analysis to assist parameter zonation in groundwater flow model by Jiao (1996), modeling stream aquifer seepage in an alluvial aquifer by Osman et al. (2002), and modeling water balance in Rio Turbio aquifer, Mexico by Johannes (2004) are instances of these research projects [7-9]. Other research studies that have been conducted in this field are for example MODFlOW equipped with a new method for the accurate simulation of axisymmetric flow by Samani et al. (2004), fully conservative coupling of HEC – RAS with MODFlOW to simulate stream – aquifer interactions in a drainage basin by Rodriguez et al. (2008), and a comparison of groundwater fluxes computed with MODFlOW and a mixing model using Deuterium: Application to the Eastern Nevada test site and vicinity by Rosemary et al. (2008).

In the present study, however, the use of drainage system for dropping groundwater table of the Shiraz plain has been evaluated. For this purpose, at first Shiraz plain aquifer hydraulic behavior was modeled using PMWIN model, the core of which is formed on the basis of MODFLOW software. In this model, the performance of a recently constructed drainage system in the plain was modeled and parameters affecting hydraulic behavior of the aquifer were analyzed. Measured rainfall and evaporation rates in the plain, water recharge and discharge rates through the aqueducts and the Khoshk and Chenarrahdar Rivers, the amount of water discharged from water wells, as well as recharge rate due to returned wastewater were all considered in the model. Plain hydrodynamic coefficients were estimated by calibrating the model, and sensitivity analysis of the model was performed for four important parameters. In the end, groundwater level in the plain with and without the drainage system was simulated for four different cases.

2. Introducing Shiraz Plain

Shiraz plain is stretched from north to Babakoohi and Kaftarak mountains, from northwest to Derak mountain, from south to Sabzpooshan and Soltanabad mountains and from west and southwest to Polfasa mountain and

Maharloo lake. The area of this plain is roughly 300 Km^2 and its location is shown in Figure 1. Studies have shown that the Shiraz alluvium plain is layered, and clay layers are located between the aquifers. The alluvial sedimentation does not have a uniform thickness and sandy layers are located between silt and clay layers. Also Geophysical explorations indicate that Shiraz plain aquifer goes down as far as 200 m deep, and at depth below that if there is an aquifer layer at all, it does not have a good quality [13]. Furthermore, the alluvium structure in the west plain is mainly coarse grain and it turns to fine grain near Maharloo lake.

Based on these studies, Shiraz plain groundwater is divided into two aquifers, namely surface groundwater and deep groundwater. Surface groundwater goes down to a water table to the depth of 40 m, while deep groundwater is ranges from about 40 m of depth to 200 m.

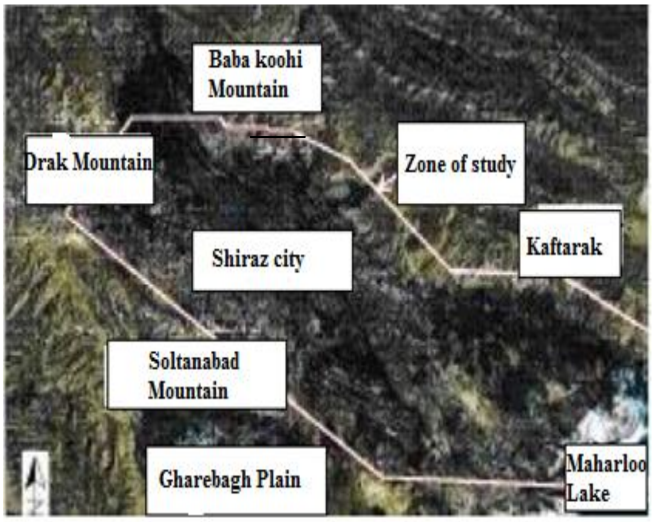
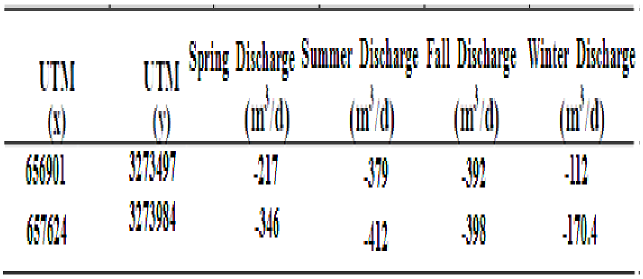


Figure 1. Shiraz Plain and the Area of study

In the range of the study area, there are 35 active observation wells and 35 active piezometric wells. During the implementation of Khatoon drainage, 12 piezometric wells surrounding the drain have been created for reading water levels. In this study, monthly fluctuation statistics of water tables of 41 rings of wells were collected and used. There are also a number of 425 rings of operating wells of surface groundwater in zone of the study that are mostly used for agricultural purposes. In Table 1 the seasonal operating of flow from two rings of wells is shown.

Table 1. Characteristics of Two Operating Wells in the Shiraz Plain



UTM (x)	UTM (y)	Spring Discharge (m^3/d)	Summer Discharge (m^3/d)	Fall Discharge (m^3/d)	Winter Discharge (m^3/d)
656901	3273497	-217	-379	-392	-112
657624	3273984	-346	-412	-398	-170.4

3. Simulation of Shiraz Plain Aquifer and Appropriation of Parameters to the Model

Shiraz plain aquifer network consists of 15500 cells and contains 100 rows and 155 columns and each cell is divided into the dimensions of 200*200 meters. Active cells in the model were symbolized with 1 and inactive cells with 0 and fixed–head cells with -1. The study area is mostly surrounded by elevations; hence, only 32 cells from the western boundary and 63 cells from the southeast boundary were at hydraulic exchange with areas outside the study area. In terms of general eastward groundwater flow, the active cells located in the western boundary are the cells receiving groundwater flow from outside of boundary, and are called GHB cells in the model.

Active cells located in the southeastern boundary are the cells discharging outflow outside the zone and are called discharge cells. Illustration of gridding of Shiraz plain aquifer and grid cells are shown in Figure 2.

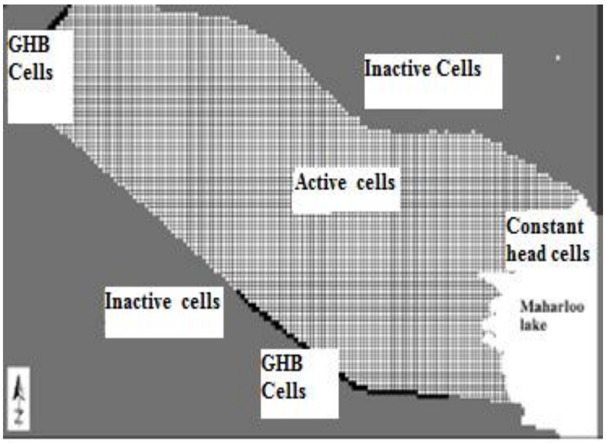


Figure 2. Gridding System of Shiraz Plain Aquifer and Its Grid Cells

The modeling of Shiraz plain is performed (in the case of transient) within a three-month period. To solve the differential equation, each time period was divided into three one-month-period phases. Total simulation period lasted more than 42 months (from March 2005 to November 2008). The data obtained from the first 30 months were used for the model calibration and for determination of model hydrodynamic coefficients, while the data from the following 400 days were used for validation and model sensitivity analysis.

To determine the initial values of specific storage and hydraulic conductance, the measurements carried out on the hydraulic conductivity and specific yield in 11 different wells in the plain area were used. The results of their distribution in the plain are shown in Figure 3 and Figure 4, respectively.

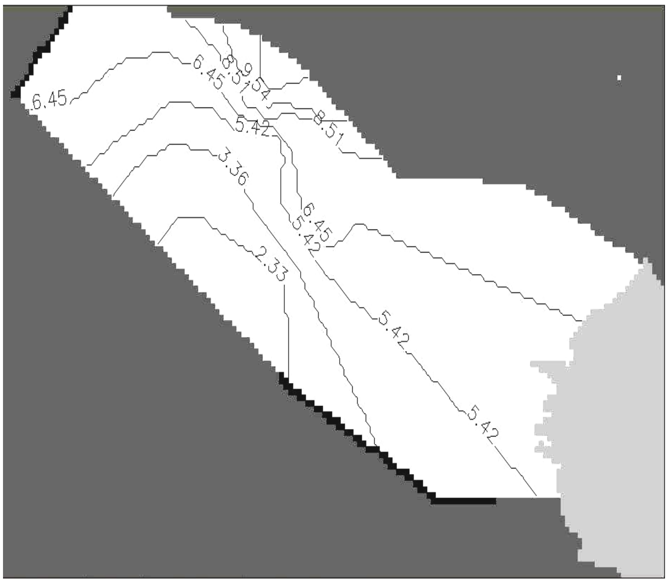


Figure 3. Distribution of the Initial Values of Hydraulic Conductivity (m/d) in Different Zones of the Plain

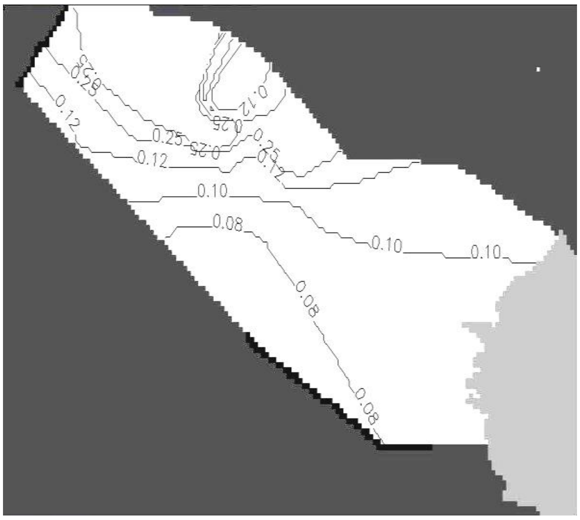


Figure 4. Distribution of the Initial Values of Specific Yield in Different Zones of the Plain

The level of the impervious layer of the bottom of the aquifer was obtained from existing maps, and through interpolation, the figures for that layer were obtained at 200 m distances in the whole plain (Figure 5). The same procedure was exercised for the data obtained from the elevation points of the plain and the topographic map of the plain at 200 m distances was prepared (Figure 6).

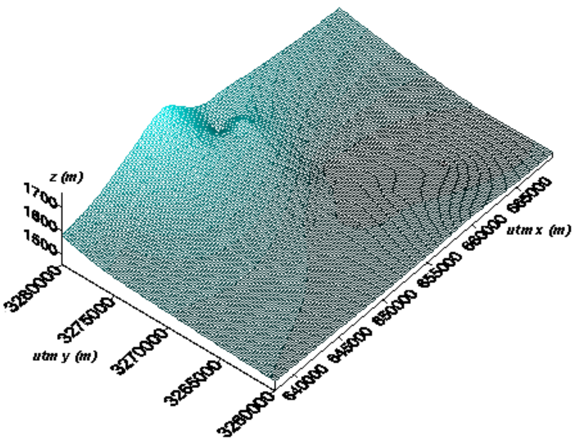


Figure 5. The Level of the Impervious Layer of the Bottom of the Aquifer

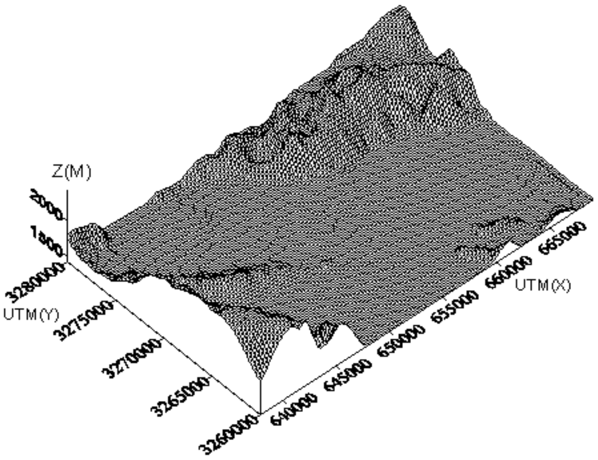


Figure 6. Topographic Map of the Shiraz Plain.

By subtracting the values of the impervious layer level of the bottom of the aquifer from the ground level, the thickness cells in the model was determined and then imported into the software. To determine the evapotranspiration of the model, the statistical data from Shiraz airport evaporation station were used.

3.1- Recharge Resources

One of the groundwater recharge resources is infiltration of precipitation. To calculate the infiltration result of atmospheric precipitations at each time step, the values of primary losses and runoff were reduced from the monthly precipitation average. According to the previous studies, the first 1.6 mm of the precipitation was subtracted for reasons of initial losses, and then to determine the amount of runoff, the division of the plain in terms of population of different zones (Figure 7) and runoff coefficient for each region were used (Table 2).

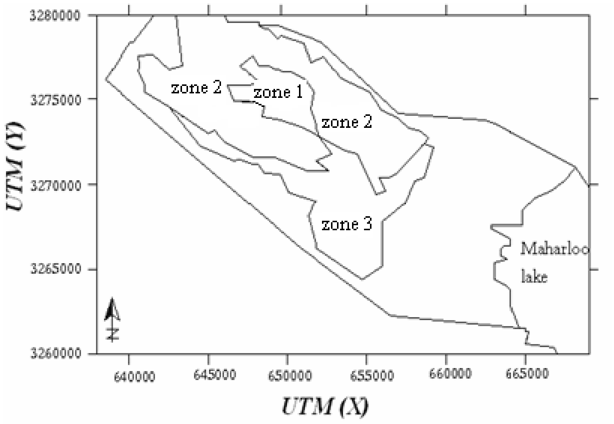


Figure 7. Division of the Plain in Terms of Three Population Zones

Table 2. Runoff Coefficient of the Triple Zones

	Triple zones	Run off coefficient
1	compressed	0.65-0.75
2	average density	0.5-0.6
3	Few density	0.35-0.4

Another groundwater recharge resources is the return of backwater to the groundwater. According to the research and predication done by the Housing and Urbanization Department of Fars Province, the amount of monthly water consumption and monthly produced waste water at each region of the plain was proven to be attributed to the population density in that area. Therefore, using the population density classification (Figure 7) and wastewater per capita production, the amount of produced wastewater in each time step was calculated. Table 3 depicts the amounts of minimum, average and maximum consumption of water per capita and waste water per capita production from 2001 to 2011.

Table 3. The Amounts of Consumption of Water Per Capita and Wastewater Per Capita Production from 2001 to 2011 in Shiraz [14].

Year	2001			2011		
population	1738000			2488000		
description	minimum	average	maximum	minimum	average	maximum
consumption of water of per capita(lit/day)	143	190	257	149	198	267
wastewater per capita production(lit/day)	110	147	198	122	163	220

The amount of agricultural return water to the ground water, as a percentage of the total amount of irrigation water, can usually be produced and it will be different in different months of the year. According to the past studies, [13] the monthly volume of input water to the surface ground water, due to the harvest of agricultural water from the deep ground water, is shown in the Table 4.

Table 4. The Volume of Input Water to the Surface groundwater due to the Harvest of Agricultural Water from the Deep Groundwater [15].

Time period	spring	summer	autumn	winter
volume input water (1000 M^3)	3019	3019	3019	0

3.2. Discharge Resources

One of the important sources of aquifers discharge is the water harvest of wells. To calculate the rate of water harvest, statistical data were gathered from all the wells, and the wells' depth, type of use, discharge and the number of hours of pumping in a day have been figured out [13].

Some amount of water harvested in different ways will be returned to the groundwater. The amount of water back to the groundwater is calculated and finally the amount that is actually taken out of the groundwater throughout the year and is effective in reducing the level of water table is entered into the software as GRD matrix file (due to the high multiplicity of date). The situation of these wells is shown in Figure 8.

This contains shallow wells operating in the whole region (425 wells) and the temporary pumping wells around the drainage path that are used for drying drainage drilling path (500 wells). After passing the drainage from the temporary wells, these wells become inactive with some of them only in function four hours a day.

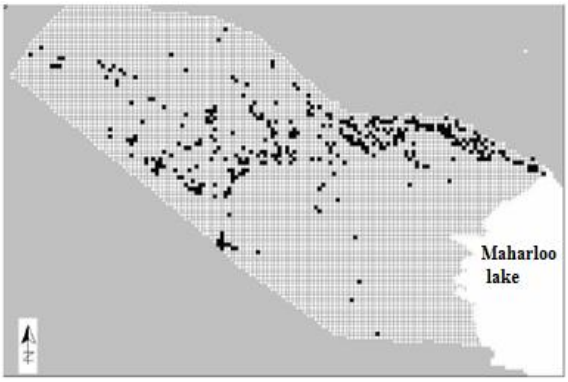


Figure 8. Exploitation Wells and the Temporary Pumping Wells around the Drainage in Shiraz Plain.

Drainage network constructed is another source of aquifer depletion. After networking the aquifer, Khatoon drainage constructed path was located in 76 cells. Figure 9 shows the situation of Khatoon drainage and the ambient rivers.

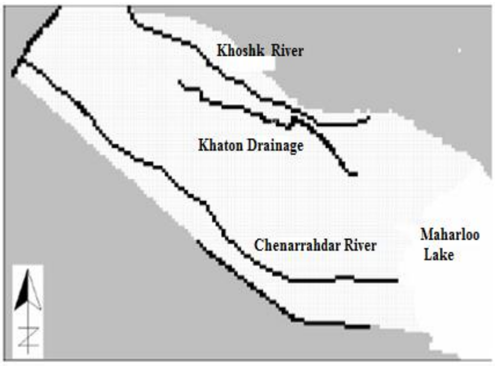


Figure 9. Khatoon Drainage and the Ambient Rivers in the Model

To calculate the flow entered into the drain for each of cells, the equations 1 and 2 were used which are similar Darcy’s Law, and their parameters were calculated for all 76 cells.

$$Q_D = C_D (h/d)^2 \qquad h > d \tag{1}$$

$$Q_D = 0 \qquad h < d \tag{2}$$

Here CD is Drain hydraulic conductance and it depends on the material characteristics of the drain and environmental conditions and (h) is the hydraulic head in a drain–cell. D is the elevation of the drain.

Equation 2 is ensures that in case the discharge to the drain will be zero when the hydraulic head is lower than or equal to the drain elevation.

And the amount of hydraulic head for each cell, $h_{i,j,k}$ in each time step was determined by the software. Based on current measurements [16] the value of 20 m^2/day was considered as the initial estimation for the coefficient of CD and based on that, the simulation was conducted and then this coefficient was optimized in the calibration stage.

3.3- Determining Initial Conditions

The initial conditions are the most important parameters for solving partial differential equations in the ground water and the calculations should begin with these condition considered. Because the model simulation started in 2005, statistical data from the water table since march 2005, as the initial transient conditions, was given to the model. Figure 10 shown the initial water table level of march 2005 in the model cells. As expected, the water table shows the general flow of direction from the west to east in the plain.

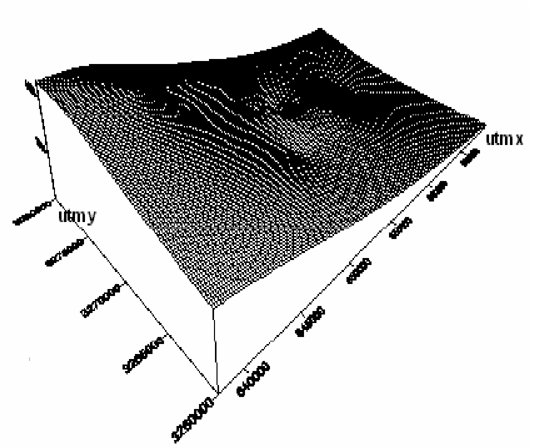


Figure 10. Initial Water Table Level in March 2005

4. Model Calibration

The result of the first implementation of the model (before calibration) as the calculated water table level was compared with observatory water table level in nine wells and is shown in Figure 11.

As is clear, the calculated values in most wells are higher than the observed values and the variance obtained is higher than 19 m^2.

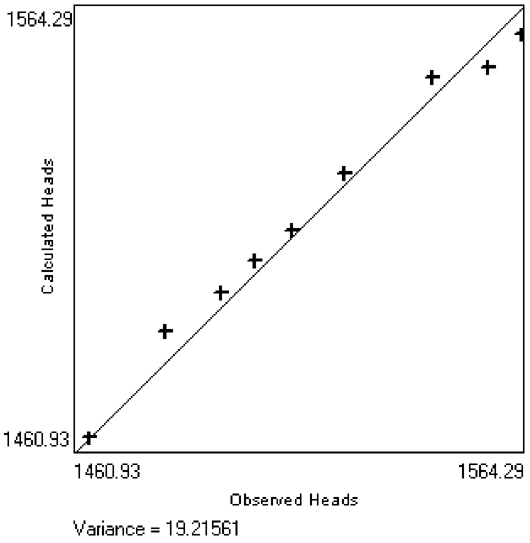


Figure 11. The Comparison of Calculated Water Table Level Values and the Observed Values before Calibration.

Since the aquifer hydrodynamic coefficients had different values (due to the geological context of the region and the heterogeneous aquifer in the different parts of the plain), the area under focus was divided into several smaller areas on the basis of the texture in order to determine the hydraulic conductivity coefficient and specific yield. With implementation of sequential model for the different amounts of these coefficients, the model was calibrated in such a way that the best correspondence between observed water table level and the calculated water table levels in the wells could be obtained.

Figures 12 and 13 respectively illustrate the hydraulic conductivity and specific yield zoning after model calibration.

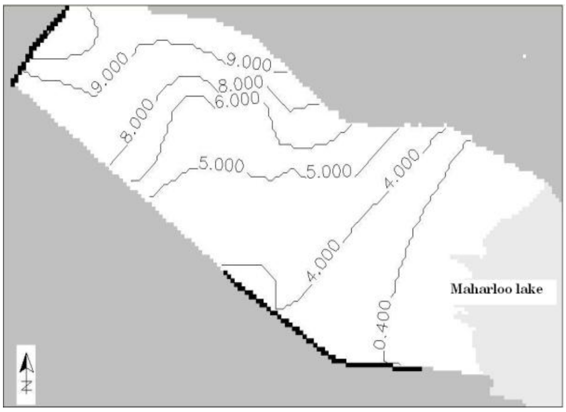


Figure 12. Hydraulic Conductivity of Zoning in the Plain after Calibration.

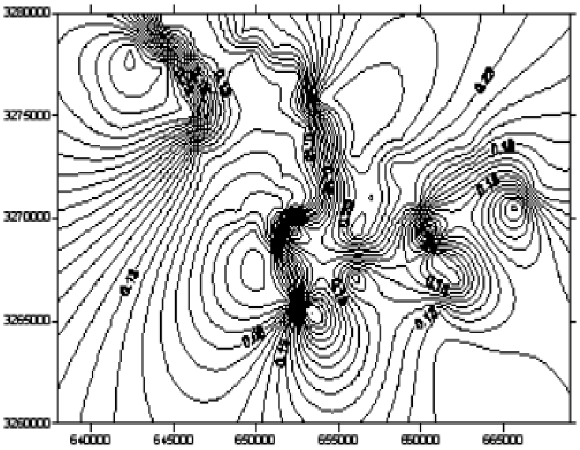


Figure 13. Specific Yield of Zoning Diagram after Calibrating the Model.

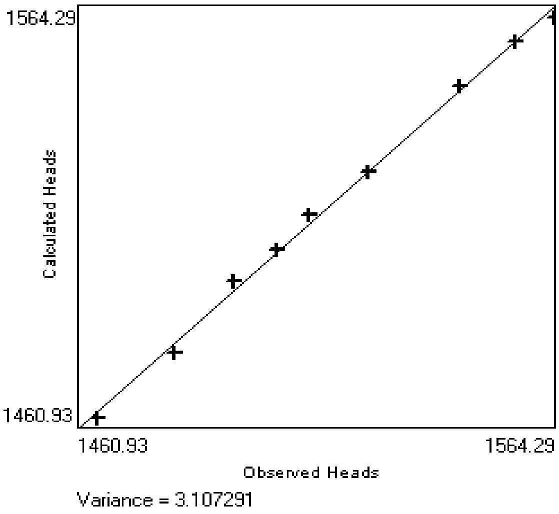
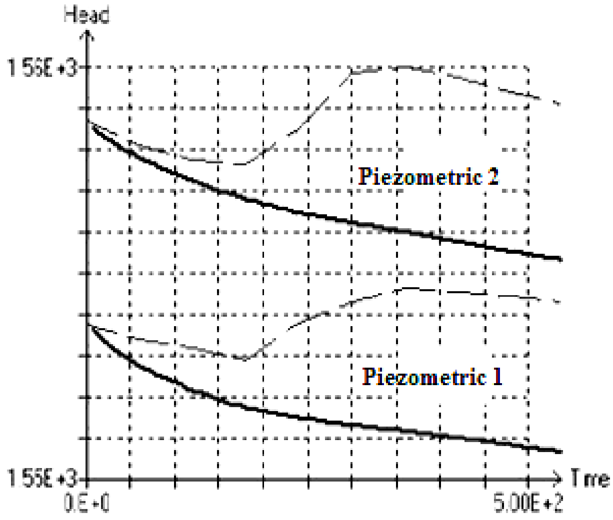


Figure 14. The Scatter Diagram after Calibration.

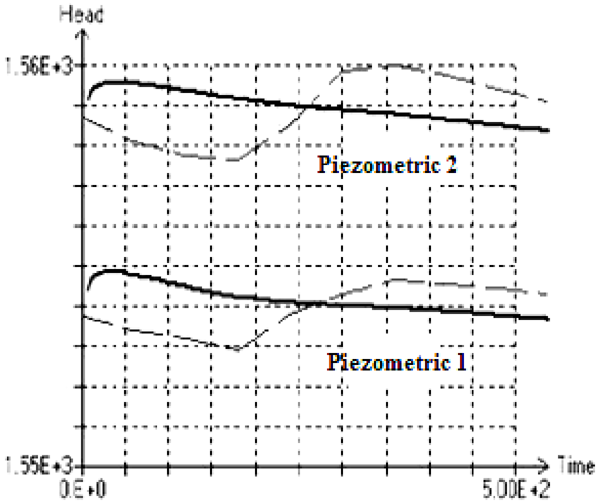
As the comparison of Figures 11 and 14 implies, the implementation calibration causes a correspondence between measurement and simulation, such that the Variance has reduced about $3m^2$.

5. Sensitivity Analysis Results

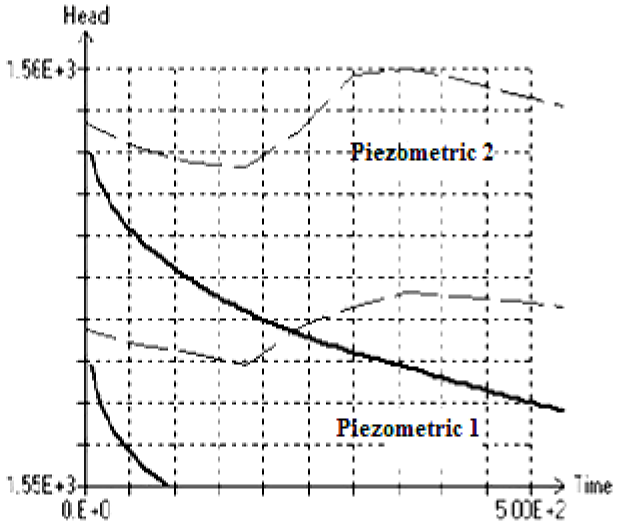
Model sensitivity analysis was performed for several parameters. For reasons of space, very briefly the effect of only four important parameters is dealt with. Aquifer Recharge resources was the first parameter that was analyzed. It was revealed that: firstly, the amount of recharge can be estimated low or high very easily. Secondly, the model is so sensitive to recharge rate that a ten-percent increase or decrease in recharge can change the water table level in some parts of the plain as deep as 7 meters. Figure 15 shows changes in calculated water table level in piezometric wells 1 and 2, caused by 10 percent increase or decrease in recharge rate.



Water Table Level in Piezometrics 1 &2



10% Increase in Recharge Rate



10% Decrease in Recharge Rate

Figure 15. Calculating Head for 10% Increase or Decrease in Recharge Rate in the First and Second Piezometric Wells

To investigate the model's sensitivity to hydraulic conductivity and specific yield parameters, each parameter was manipulated separately in the area and its effects on the water table level in the middle of the plain (piezometric well #16) and on its edge (piezometric well # 20) were studied. In this study, it was observed that hydraulic conductivity parameter, after recharge rate, has the most significant effect on the piezometric water table level.

Furthermore, As displayed in Figures 16 and 17, changing the amount of hydraulic conductivity from 6 to 0.003 m/day at piezometric wells No.16 and No. 20 has brought about changes as great as 3 meters in water table level. The model sensitivity and calculated water table level in the aquifer sides (piezometric well No.20) are more of hydraulic conductivity, which seems to be because of its effect on the recharge rate of the aquifer from this area. It is worth reminding that in all the diagrams in this article, observed water table level lines as are broken lines and calculated water table level lines are shown as bold lines.

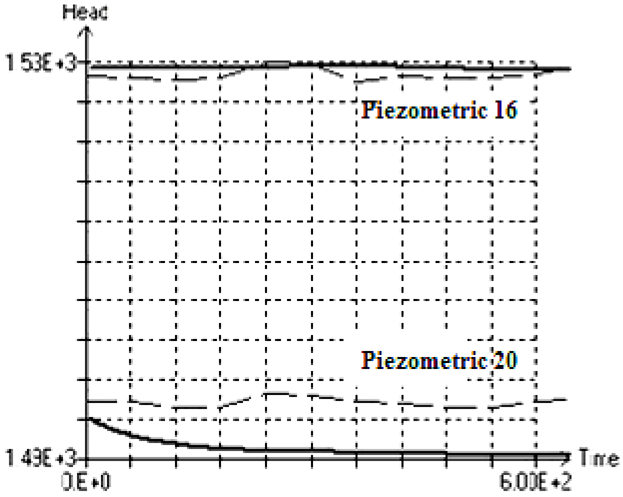


Figure 16. Piezometrics Wells 16 and 20 Water Table Level Diagram for k=6 m/day

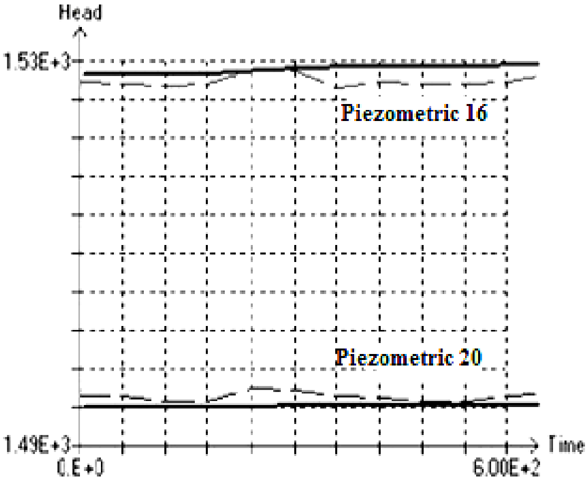


Figure 17. Piezometric Well 16 and 20 Water Table Level Diagram for k=0.003 m/day

Examination of the effect of specific yield coefficient in the model showed that this coefficient exerts more effects on the ground water seasonal fluctuations in the whole plain and as is observed in Figures 18 and 19, by changing the specific yield coefficient from 0.03 to 0.15, the amount of the estimated water table fluctuations fell drastically in the whole time period. This effect is almost equal in the middle area (piezometric well No.6) and in the edges (piezometric wells No.18 and No.9).

Therefore, it can generally be concluded that the fluctuations amplitude of ground water depended on specific yield coefficient such that on the local areas where specific yield coefficient is less, fluctuation amplitude of water level will be higher.

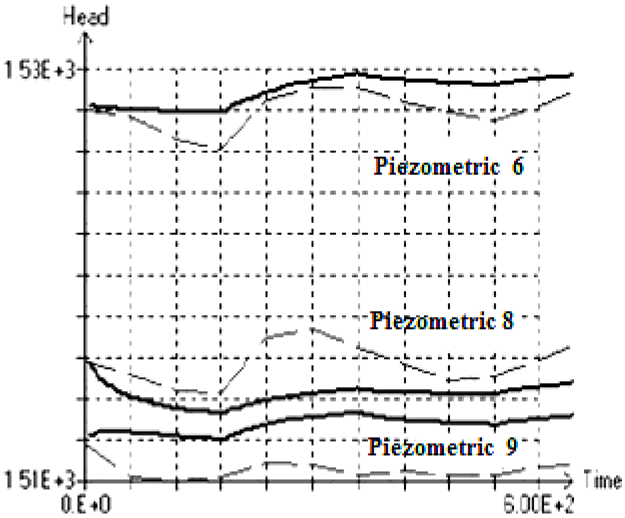


Figure 18. Estimated and Observed Water Level Diagram for k= 6 m/d and Sy=.03

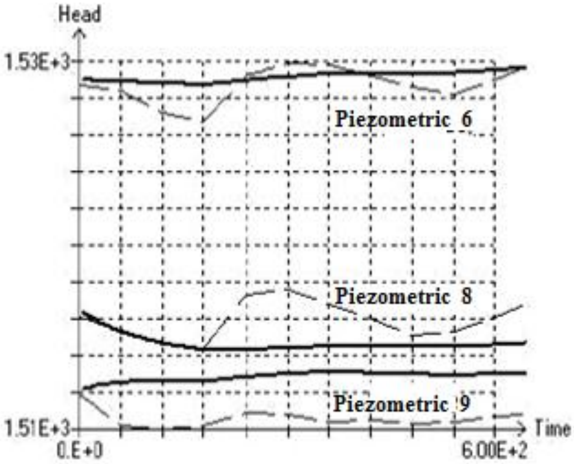


Figure 19. Estimated and Observed Water Level Diagram for k= 6 m/d and Sy= 0.15

Drain hydraulic conductance was the last parameter to which the model sensitivity was investigated. The effect of this factor on estimated water table level is shown in Figures 20 and 21. As it can be observed, increasing this coefficient by 60 times (i.e. changing drain hydraulic conductance from 0.05 to 3) brings about an insignificant change only at piezometric well No. 31 that is very close to the drain, not in two other piezometric wells.

Therefore, it could be concluded that the effect of drain hydraulic conductance is only limited to drain influence radius and it does not affect the whole model.

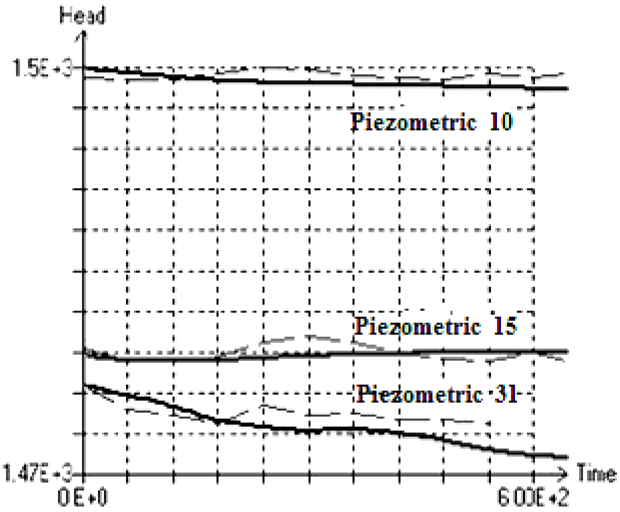


Figure 20. Estimated and Observed Water Level Diagram for k= 4 m/d Sy=0.03 , cD=0.05 m2/d

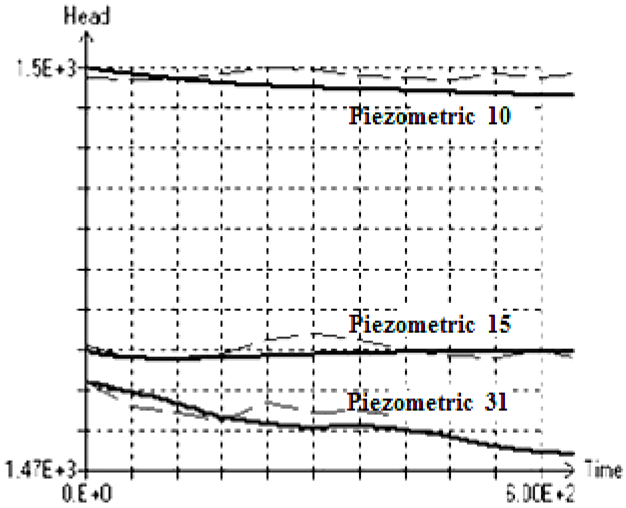


Figure 21. Estimated and Observed Water Level Diagram for k= 4 m/d Sy=0.03 , cD=3 m2/d

5. Validation

The information obtained from September 2006 to September 2007 were used for validation. The stresses placed on the aquifer were regarded as they wer for the previous procedures. The results of validation have been presented in Figure 22, which shows a good fit between estimated and observed values.

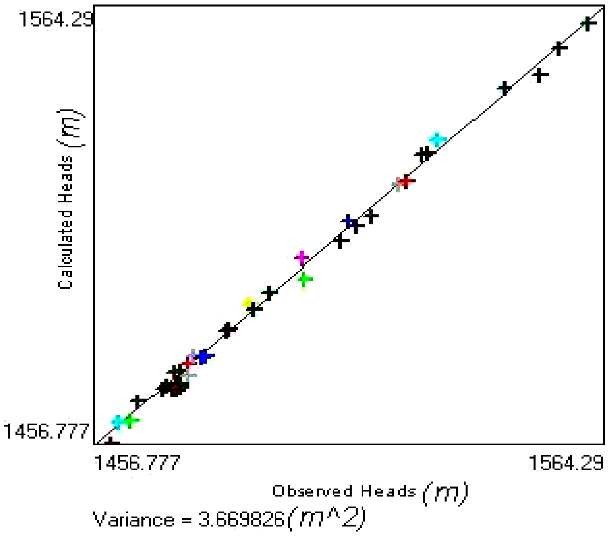


Figure 22. The Scatter Diagram and Comparison of Estimated and Observed Heads

6. The Results of Drainage System Performance

After model calibration, validation and specification of all the required parameters, the status of ground water level of the Shiraz plain was simulated at the end of performance of drainage in different scenarios. Scenarios considered in this case are as follows:

The first case: Regarding the development of the city towards Kaftarak, and the conversion of agricultural lands to residential areas, in this case agricultural pumping wells in the range of Kaftarak were off and the ground water status of the shiraz plain were studied with and without drainage system.

The second case: In this case, the model results were also considered with and without drainage system.

The third case: The performance of drainages and status of ground water level in drought conditions were studied.

The fourth case: The performance of drainages and status of ground water level at the end of the implementation of drainage in wet conditions were studied.

6.1- The Results of the First Case

Figure 23 depicts the comparison of the water table in the aquifer of the Shiraz plain with and without drainage construction. After the implementation of drainage, water table has remarkably decreased in all the plain with only a slight rise in a corner of the plain where the dormant wells of Kaftarak are located. To demonstrate the water table drawdown level, the lines in Figure 24 have been presented. As the diagram shows, the most serious reduction occurs in the northern area (the beginning of the drainage area) that is about 10 m, whereas a very low drawdown (about 0.5m) is observed at the end of the draining area near Maharloo Lake. The cause of this seems to be the change of texture of soil and its becoming fine-grained eastward, which give rise to the decrease of the radius influence of the drain as a result of the reduction of the hydraulic conductivity. Moreover, the proximity of the level drainage crossing route to the surface of the Earth has been influential in reducing the amount of drawdown in the Eastern plain. So in general, with the implementation of drainage in the case that Kaftarak pumping wells are dormant, leads to the prognosis of about 10 m drawdown at the first drainage route, and a roughly 0.5 m drawdown at the end of drainage route

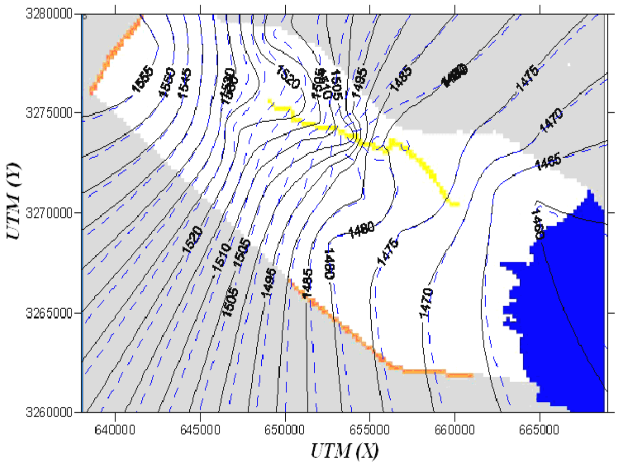


Figure 23. Comparison of Water Table in the Aquifer of the Shiraz Plain with (Bold Line) and without Drain (Broken Line)

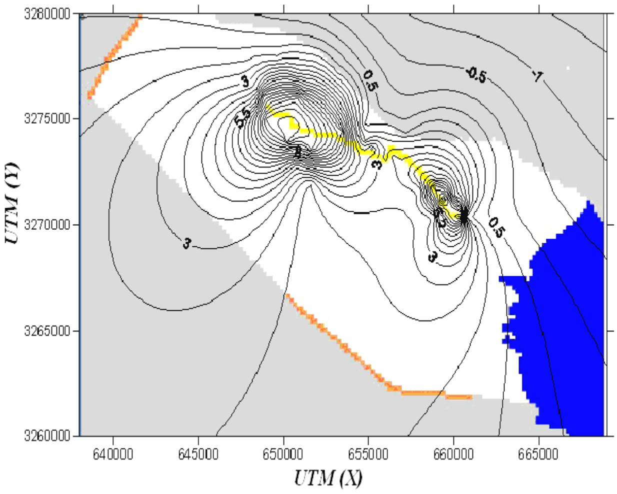


Figure 24. The Reduce Lines of Ground Water Level after the Implementation of Drainage in the First Case.

6-2- The Results of the Model in the Second Case

Figure 25 shows the reduction level lines of ground water after the implementation of the drainage and Figure 26 displays water table level in the aquifer of the Shiraz plain with and without drainage. As is shown, the ground water level in most of the plain zones drops and reduction of water table in more noticeable around the drainage (at about 6m). All in all, drawdown in this case is less than drawdown in the first case. And this seem logical due to the decreasing returned sewage entrance to the aquifer in the second case. Therefore, we can conclude that not only the simultaneous performance of drainage and sewage networks of Shiraz are not contradictory operations, but these plans are in fact complementary. It seems that the little increase (about 0.5m) in the ground water level in southern zones plain is due to water entrance from the southern boundary to the plain, which follows from the water level decrease in the plain.

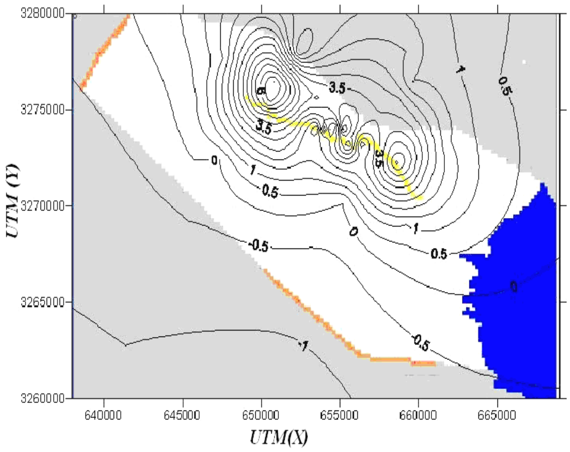


Figure 25. The Reduced depths of Ground Water Level after the Implementation of Khatoon Drainage in the Second Case.

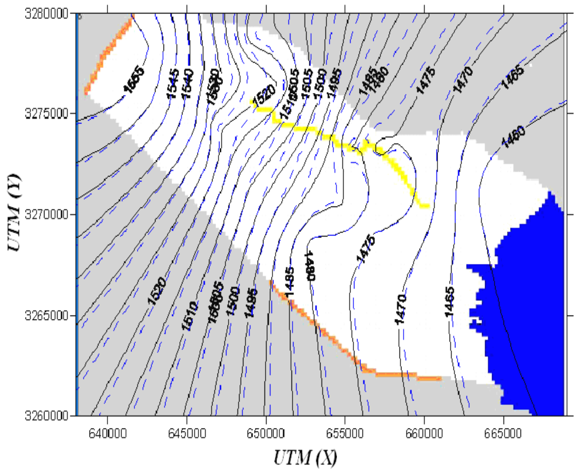


Figure 26. The Comparison of Water Table with (Bold Line) and without Drain (Broken Line.) in the Second Case

6-3- The Results of the Model in the Third Case (Drought Conditions)

Figure 27 shows the Reduced depths ground water level after the implementation of drainage in the drought case. In this case, we can see the reduced water level (at about 4m) and the reduction of the discharge passing through the drainage. This head loss in the plain is less than that in the second case, which seems to be logical due to the precipitation decrease. In this case, the decrease of the water level in the Maharloo Lake shore is observed. .

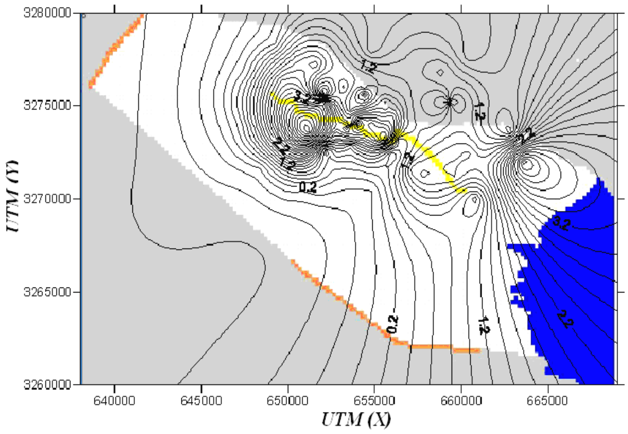


Figure 27 . The Reduced depths of Ground Water Level after the Implementation of Drainage in Third Case (drought)

6-4- The Results of the Model in the Fourth Case (Wet Conditions)

Figure 28 shows the reduced lines ground water level after the implementation of the drainage. As is observed in Figure 28, the water table drops down to 10 m. but in southern areas and near Maharloo Lake and northwest areas, the water table increases at about 2 m. This increase in water table can be justified owing to the increase of inflow during wet conditions, and it indicates the necessity of the implementation of the city drainage network.

Water balance in the different scenarios and the outflow rate of the drainages can help further evaluation of ground water hydraulic behavior in the different scenarios.

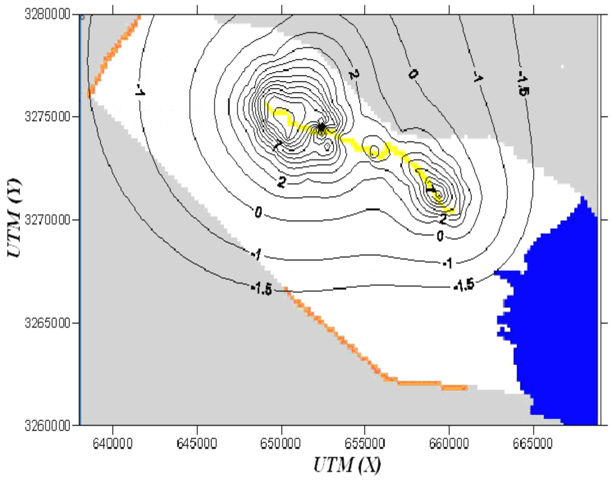


Figure 28. The Reduced depths Ground Water Level after the Implementation of the Drainage in the Fourth Case (Wet Conditions)

7. Water Balance in the Study Area

Using the water balance in the area, the rate of inflow from and outflow to the neighboring plains in the different scenarios were examined and compared. This comparison for the different scenarios is depicted in the Table 5.

Table 5. Inflow and Outflow Rate of Water in the Neighboring Plains for the Different Scenarios (m^3/d)

Senario	Inflow from Western boundary	Outflow to Gharebagh plain	Outflow to Maharloo Lake	Outflow from Drainage
1-inactive Kaftarak pumping wells	1357	-2532	-2358	33117
2-implementation sewerage network	1356	-1800	-3858	31800
3-drought	406	-1000	-1360	29748
4-wet	-80	-5761	-6297	33510

The examination of the results indicates a satisfactory performance of the drainages in all the scenarios. As expected in the state of drought (scenario 3), we observe the minimum inflow and outflow and drains of the plain; and in the state of wet (scenario 4) we observe the maximum inflow and outflow and drains of the plain.

In the wet case, the flow direction reversal occurs in the plain's western boundary and a decrease in outflow from its boundary follows (due to the increase in the plain ground water). This incident is well in harmony with the rise of water table in this scenario (Figure 28). It is worth noting that the amount of flow passing through the Khatoon drainage which was predicted by the planning consulting engineers was 86400 m^3/day. Of course, in this prediction, the main drainage of Khatoon with all the branches connected to it have been investigated, and therefore according to the aforementioned figures which are calculated by the model, we can conclude that without the implementation of sub-networks, the amount of discharge passing through the drainage would be less than half of what the designers estimated.

8. Conclusion

Ground water hydraulic flow model of the Shiraz plain with its drainages was implemented in PMWIN software. After model calibration, validation, and specification of all the required parameters, the status of ground water level was simulated at the end of the performance of drainage and in the different scenarios.

The examination of the results implies a good performance of the drainages. This was evident in all the scenarios, where the flow passing through the drainage was more than inflow and outflow of the plain. As expected in the state of drought (scenario 3), we observed the minimum inflow and outflow and drains of the plain. However, in the state of wet (scenario 4), we observe the maximum inflow and outflow and drains of the plain.

For water level to drop down to the desired depth, minor drainage lines had to be utilized; otherwise, the amount of discharge of drainage would be less than half of what the designer estimated. In this study, hydraulic behavior of the Shiraz plain aquifer was simulated using PMWIN.

The performance of recently constructed drainage system in the plain was modeled and plain hydrodynamic coefficients were estimated via calibration, and sensitivity analysis of the model was performed for four important parameters. The results indicate that the model is sensitive to recharge rate and hydraulic conductivity, respectively. This being so, a small variation in these two parameters causes a dramatic change in hydraulic head distribution in the plain. Furthermore, specific yield coefficient influences the seasonal water level fluctuations, but the aqueducts conductance coefficient only affects the aqueduct radius of influence with little effect on the overall hydraulic behavior of the plain.

9. References

[1] Bakker, M. (1999)."Simulating groundwater flow in multi-aquifer systems with analytical and numerical Dupuit models", *Journal of Hydrology*, 222, 55-64.

[2] Anderson, E.I. (2005). "Modeling ground water–surface water interactions using Dupuit approximation", *Journal of Advances in Water Resources*, 28, 315-327.

[3] Knowles, I. and Yan, A. (2007). "The reconstruction of groundwater parameters from head

in an unconfined aquifer", *Journal of Computational and Applied Mathematics*, 208, 72-81.

[4] Mukhopadhyay, A., Al-Sulaimi, J., and Barrat, M. J. (1994). “Numerical modeling of groundwater resource management options in Kuwait.” *Groundwater*, 32 (6), 917-928.

[5] Ramireddygari, S. R., Sophocleous, M. A., Koelliker, J. K., Perkins, S. P., and Govindaraju R. S. (2000).“Development and application of a comprehensive simulation model to evaluate impacts of watershedstructures and irrigation water use on stream flow and groundwater: The case of wet walnut creek watershed,Kansas, USA.” *J. of Hydrology*, 236 (3), 223-246.

[6] Rezaei, H., and Mousavi, S.A. (2003). “Study of Bajgah plain groundwater situation using the finite difference there dimensional modular Modflow model.” *Proc. of the Second National Student Conf. on Water and Soil Resources*, Shiraz University, 907-916.

[7] Jiao, J. J., and Leaner, D. N. (1996). “Using sensitivity analysis to assist parameter zonation in groundwater flow model.” *Water Resources Bulletin*, 32 (1), 75-78.

[8] Osman, Y. Z., and Bruen, M. P. (2002). “Modeling stream-aquifer seepage in an alluvial aquifer: An improved loosing- stream package for MODFLOW.” *J. of Hydrology*, 264, 69-86.

[9] Johannes, H. A. (2004). “Modeling water balance in Rio Turbio aquifer, Mexico.” M.Sc. Thesis, Wagenin Gen University, Mexico.

[10] Samani, N., Kompani-Zare, M., and Barry, D. A. (2004). “MODFLOW equipped with a new method for the accurate simulation of axisymmetric flow.” *J. of Advances in Water Resources*, 27, 31- 45.

[11] Rodriguez, L. B., Cello, P. A., Vionnet, C. A., and Goodrich, D. (2008). “Fully conservative coupling of HEC-RAS with MODFLOW to simulate stream-aquifer interactions in a drainage basin. *J. of Hydrology*, 353, 129-142.

[12] Rosemary, W. H. C., Greg, M. P., Earman, S., and Ronald, L. H. (2008). “A comparison of groundwater fluxes computed with MODFLOW and a Mixing model using deuterium: Application to the eastern Nevada test site and vicinity.” J. of Hydrology, 361, 371- 385.

[13] Fars Regional Water Orqanization. (1996). Reports on Shiraz plain studies, Shiraz.

[14] Parab consulting Eng. Co. (1993). Feasibility studies on water table drawdown in southeastern Shiraz and its transfer to Sarvestan plain, Vol. 3, Shiraz.

[15] Parab consulting Eng. Co. (1993). Feasibility studies on water table drawdown in southeastern Shiraz and its transfer to Sarvestan plain, Vol. 3, Shiraz.

[16] Kresic, N. (1997). Quantitative solution in hydrology and groundwater modeling, Lewis Pub., CRC Press,Boca Raton Inc., USA.

5/16/2012