

## Environmental assessment for predicting groundwater degradation of “Rey” municipality

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### Abstract:

Clean drinking water for the municipality of “Rey” with population of over one million remains a critical and serious problem. In particular, Rey’s continued water demands has caused a substantially high drop in its local groundwater level. With running this study, we can appropriately predict the quality of groundwater in Rey. In this study, we have considered presence of nitrate contaminant as the most suitable index representing groundwater contamination or pollution. For example, such index is capable of high solubility in water; has a low absorption rate; and exhibits relatively sustained compound stability. Moreover, the PMWIN software code was employed to model quality of associated aquifers. In addition, we analyzed data from Rey drinking water wells, which were collected and processed during the period of 2005 to 2012. We further evaluated: values of longitudinal and latitudinal diffusions, and absorption coefficient. A drop in the groundwater levels was measured 1.5 to 5 m for the eastern part of Rey and 5 to 11 m for the central zone of the municipality. For the western part of Rey, a drop in ground water levels in excess of 22 m were noted. In this paper, the value of Nitrate was determined and compared with standard values presented by EPA.

### 1. Introduction

In recent years, some researchers have utilized numerical methods to analyze the groundwater quality [1–4]. For instance, Mohrlök et al. as well as Bear et al. employed numerical approaches to evaluate the transport of contaminants in groundwater [5, 6]. Likewise, Abdel-Salam Haggaz [7] applied a finite element solute transport model (CSU/GWTRAN) to a vertical cross-section in the Nile Valley of Egypt. Similarly, Domenco and Schwartz [8] have demonstrated the theoretical basis for the equation describing solute transport, which further provided a conceptual framework for analysis and modeling physical solute transport processes in groundwater.

The GIS system was used to analyze and comprehend the quality of groundwater and also to characterize the most vulnerable locations of contamination along the groundwater route [9]. A numerical solution is also presented by Wang et al. [10] for advection-dispersion transport equations between mobile and immobile domains.

An explanation is introduced to simulate source control with pumping wells located within the source zone [11]. Mohrlök et al. [12] analyzed experimental tracer transport in three-dimensional flow field for groundwater and subsurface remediation. Shahraiyini et al. [13] presented a comprehensive evaluation of different finite difference schemes to solve head-based and mixed forms of the Richard’s equation. The municipality of Rey remains as one of the important cities in Iran, in terms of population settlement, having over one million residents. Typically, such residents suffer from the lack of a sanitary disposal of wastewater. Furthermore, drinking water wells in Rey supplies 40 to 50 percent of the overall drinking water wherein about 60 percent of drinking water wells are located in the residential areas. Unfortunately the major parts of Rey do not employ any collection and disposal system for wastewater. Such local wells remain continuously exposed to nitrate contamination. To this end, groundwater pollution typically poses harmful risks on health and well-being of the city residents. In addition to the pollution of Rey groundwater, population growth and

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increase in water consumption rate will result in higher water demand; and hence will likely cause further drop of the groundwater level. The situation could be improved by wastewater collection system and disposal network in Rey.

## 2. Geographical Features of Rey

Geographically, the city of Rey is in south of Tehran and is located at  $35^{\circ}, 35' N$ ,  $51^{\circ}, 26' E$ . Its highest point from sea level is the plain area in the center of this city with the altitude over 1030 m. The city is further located in the southern region of Alborz mountain ranges and the natural slope is toward the south. The altitude of its "Amin Abad" region (located in its northwest) is 1000 m above sea water level, and in Kahrizak the altitude is 980 m and in Feshafouye it is up to 950 m. In addition two mountain ranges, one in the south of the city called Azad, and the other in the east of the city called Bibi Shahrbanoo represent further high points of the city. Based on the last census statistics, the city area is over 2668 square kilometers. Fig. 1 shows Rey's geo-physical location.



**Fig.1:** Rey's Map Area  
(<http://atlas.tehran.ir/Default.aspx?tabid=238>)

## 3. Groundwater Modeling

In fact, the main aim of using the mathematical model is to solve the balance equation. In general, a mathematical model can be generated based on continuum approach. In such approach, balance equations can be written for one point of the plain area, and subsequently generalized for other adjacent points. Under such condition, balance equations can be converted to a partial differential equation, wherein, each term of this equation represents a specific value of a parameter in unit surface area, unit volume or time (which themselves can include a wide range of possible values). Thereafter, unknown points for subsequent time intervals can be achieved by employing a mathematical solution. In sum, a mathematical model

represents a set of numerical values of different parameters in the balance equation [4, 14].

### 3.1. Basic Equations Governing Groundwater Flow

In order to form the basic equations in one aquifer system, one can consider a representative elementary volume (REV) for the aquifer. Next, one can write the continuity equation and merge it with momentum equation. Subsequently, by considering the conservation principle of mass, changes equal to input minus output, (which in our scenario represents the basic equation of obtaining groundwater flow), [15, 16]. In the steady state, we assume that changes over time equal to zero, therefore:

$$\frac{\partial}{\partial x}(T_{xx} \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(T_{yy} \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(T_{zz} \frac{\partial h}{\partial z}) = 0 \quad (1)$$

Where 'h' is the hydraulic potential of the aquifer, 'x, y and z' are the directions and 'T=T<sub>ij</sub>' is the aquifer transmissivity coefficient tensor. Assuming that  $T_{xx} = T_{yy} = T_{zz}$ , the above equation in an isotropic environment changes to:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \quad (2)$$

Obviously, system boundary conditions should be considered. Likewise, type of its connection to the objective aquifer and also boundary conditions in an underground system should be noted.

### 3.2. Solution of Groundwater in Unsteady State (Transient State)

The main equation of underground water in unsteady state can be represented as:

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = \frac{S}{T} \frac{\partial h}{\partial t} \pm \frac{R}{T} \quad (3)$$

Where 's' represents the storage coefficient, 'T' is the aquifer transmissivity coefficient, 'R' is the recharge or discharge of the aquifer, and 't' is time. If we approximate changes of the water level over time with the following difference, then:

$$\frac{\partial h}{\partial t} = \frac{h_{i,j}^{k+1} - h_{i,j}^k}{\Delta t} \quad (4)$$

Wherein 'k' represents the time step. Underground water equation in transient state after differentiation is as follows [17 - 23]:

$$\frac{h_{i-1,j}^{k+1} - 2h_{i,j}^{k+1} + h_{i+1,j}^{k+1}}{(\Delta x)^2} + \frac{h_{i,j}^{k+1} - 2h_{i,j}^{k+1} + h_{i,j}^{k+1}}{(\Delta y)^2} = \frac{S}{T} \frac{h_{i,j}^{k+1} - h_{i,j}^k}{\Delta t} \pm \frac{R}{T} \quad (5)$$

### 3.3. Transmission of Pollution in Ground Water

Contaminants may be transmitted in groundwater due to three factors, namely: Advection resulting from ground water current, diffusion resulting from molecular diffusion, and mechanical mixing and retardation process resulting from adsorption [3, 6]. Mathematical equation of pollution transmission process is in the following format:

$$\frac{\partial}{\partial x_i} \left[ D_{ij} \frac{\partial C}{\partial x_j} \right] - \frac{\partial}{\partial x_i} (C V_i) - \frac{C' W'}{n} = R \frac{\partial C}{\partial t} \quad (6)$$

$$V_i = - \frac{K_{ij}}{n} \frac{\partial h}{\partial x_j} \quad (7)$$

$$R = \left[ 1 + \frac{P_b K_d}{n} \right] \quad (8)$$

Wherein: 'C' is the concentration of the pollutant, 'x<sub>i</sub>' is Cartesian coordinate, 'D<sub>ij</sub>' is diffusion coefficient, 'K<sub>ij</sub>' is hydraulic conductivity, 'n' is effective porosity, 'C'' is the concentration of inflow and outflow, 'R' is retardation coefficient, 'W'' is the value of inflow and outflow, and 'V<sub>i</sub>' is the real velocity of flow in x<sub>i</sub> direction, and 'K<sub>d</sub>' is the absorption coefficient. In case of homogeneous and isotropic soil, unsteady flow and the average velocity of porous media of 'V', transmission can be represented by: [16]

$$D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial y^2} - V \frac{\partial C}{\partial x} = R \frac{\partial C}{\partial t} \quad (9)$$

Wherein, 'D<sub>L</sub>' is longitudinal dispersion coefficient, and 'D<sub>T</sub>' is the transversal dispersion coefficient.

Advection: Pollutants are transmitted in groundwater according to Darcy's law. Based on this law, the value of transmitted current from point '1' to point '2' is proportional to head loss and is inversely proportional to the length of flow path as below:

$$V = \frac{Q}{nA} = - \frac{K}{n} \frac{h_2 - h_1}{L} \quad (10)$$

Therefore only when the transmission of the current is remarkable, pollutant won't be moved with groundwater with similar rate, and the concentration of the pollutant won't reduce in the flow path.

Dispersion: Dispersion occurs as the result of two following procedures. a) Molecular Dispersion: This

procedure occurs due to the movement and motion of ionic or molecular components of pollutants in the direction of concentration. To this end, quality components move from high concentration zones to lower concentration zones and when such difference is higher, the rate of dispersion increases accordingly. Based on Fick's law, molecular dispersion is defined as follows [17 - 21]:

$$F = -D_f \frac{\partial C}{\partial x} \quad (11)$$

In this equation, parameters are defined as follows: 'F' is the mass flux per unit area per unit time, 'D<sub>f</sub>' is dispersion coefficient, 'C' is concentration of the pollutant, and '∂C/∂x' is the gradient of the concentration.

Fick's law is considered for chemical materials easily dissolved in water. As such, a smaller coefficient should be considered when this law is used for the porosity of soil, because ions pass longer paths among the soil particles and are adsorbed by the soil particles. Using the above equation, apparent dispersion is calculated as follows:

$$D^* = W.D_f \quad (12)$$

Which 'W' is an empirical coefficient and is lower than '1'. Perkins and Johnston proposed 0.707 for 'W'. In 1979, Bear proposed 0.67 for 'W'. b) Mechanical Dispersion: This process is the result of velocity variation among the pores of the soil. The velocity of the current is higher in the central part of the pores in comparison with other points. Therefore, pollution is dispersed in various directions. This dispersion occurs in both longitudinal and transversal directions [22]. According to Bach Mat and Bear (1964), mechanical mixing is a combination of the dispersion (which itself is a function of seepage rate) and which can be defined as follows:

$$D_{11} = a_L.V \quad (13)$$

$$D_{22} = a_T.v \quad (14)$$

wherein 'D<sub>11</sub>' is longitudinal mechanical mixing relevant to dispersion, 'D<sub>22</sub>' is transversal mechanical mixing relevant to dispersion, 'a<sub>L</sub>' is the longitudinal dispersion, 'a<sub>T</sub>' is the transversal dispersion and 'V' is the average linear velocity of water in the pores. Finally the coefficient of hydrodynamic dispersion can be represented as:

$$D_L = D_{11} + D_f = a_L.V + D^* \quad (15)$$

$$D_T = D_{22} + D_f = a_T.V + D^* \quad (16)$$

The longitudinal and transversal coefficients of dispersion are characteristics of soil pores. These values are obtained using experimental works. Accordingly, when the



dispersion procedure is also considered in the transport equation of pollutants, prediction of pollutant motion seems to be more logical and also closer to reality.

Retardation Process: Retardation process in the transport of pollution in groundwater is due to the absorption mechanism – wherein such procedure occurs for both organic and inorganic particles. Retardation coefficient using dispersion coefficient, absorption and characteristics of soil pores can be calculated by Eq. (8) [19, 23].

#### 4. Conceptual Model and Data Preparations

The main objective of modeling the aquifer is natural simulation of aquifer using a series of mathematical relations and further achieving required results for managing the aquifer. In case of simulating an aquifer and adapting it with natural conditions, we can easily consider the influences of exploiting the aquifer by changing the location, time and value of picking. In other words, a groundwater model represents a simplified form of a real system of groundwater that approximately presents a correlation between hydrodynamic action and reaction of a system [4]. First step after selecting the objective is to prepare the conceptual model of aquifer system. In this procedure, the usual complexities of aquifer are simplified and observed data are analyzed as we can evaluate the system easier and faster. The aquifer of Rey is assumed to be an unconfined and one-layer aquifer. In the surrounding of Rey, 86 Piezometers were considered during 2005 to 2012.

Hydrodynamic coefficients of Rey aquifer were not precisely distinguished. Regarding large area of Rey, in order to determine the hydrodynamic coefficients of the aquifer, we should run several pumping tests. Number of pumping tests of Rey are not adequate and with these numbers, we cannot determine the hydrodynamic coefficients of the aquifer accurately. Schematic diagram of Fig. 2 represents the physical condition of this system.



Fig.2: Schematic of aquifer pollution by surficial pollutants

Rey aquifer is assumed to be unconfined and one-layer. The result of considering about 100 well logs available in Rey aquifer and also the results of other previous models for Rey plain verifies this fact. Fig. 3. Shows the nitrate observation wells and the surrounding of Rey aquifer.

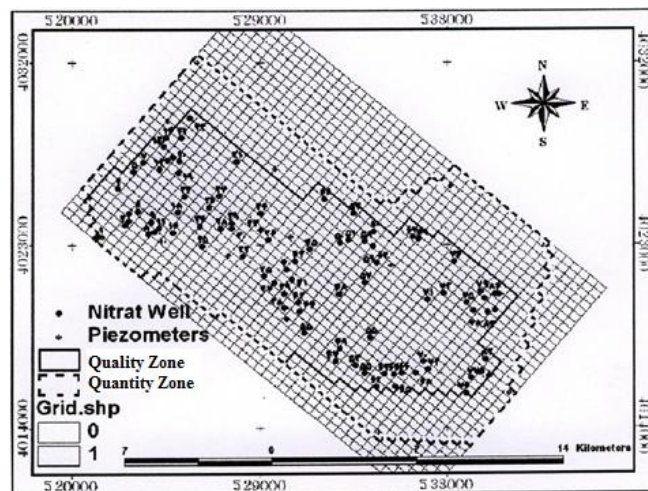


Fig.3: Nitrate observation wells and the range of quantitative and qualitative model for Rey

In the current modeling, according to the area of Rey and available data and statistics, a rectangular grid having a length of 500 m and width of 375 m is considered. As such, a grid with 37 rows and 45 columns in 'x' and 'y' directions respectively, and 1665 cells is considered. The number of active cells are 1219. The rotation of model grid is one of the specific modeling conditions which is emphasized in this study. Hence, lineation range of Rey, geology of the area, elongation of the plain and model of current system are used (with angle of 35 degree in clockwise direction with North). Typically, the initial condition of the model is the fluctuation of groundwater level in that year. In addition, time step depends on data and information available. According to the piezometric data of the region, the maximum height of water level typically occurs in April and the minimum occurs in September. Thus, a full year is divided into two six-month periods, wherein a total of 14 six-month periods is obtained from April 2005 to April 2012. Quality models are evaluated for the second six-month of 2005. As initial assumption for qualitative model range, average of 25 percent as irrigation return flow in the first six-month, and average of 50 percent in the second six-month, are considered. Coefficient of 60 percent for water return from drinking in the first six-month and coefficient of 88 percent for the second six-month of the year are considered. Based on the modeling data of Rey for 2002, feeding coefficient resulted from rainfall in the first six-month is 0.104 and in the second six-month is 0.243 [5]. During the calibration step of model, this data and also discharges of the wells will be modified.

## 5. Evaluation and Estimation of Nitrate Transport Value from Absorptive Wells into Groundwater

Quality model consists of developing a program or computer code, or selecting the appropriate software code. The code used in this research is MT3D [20, 22]. Nitrogen existing in soil can generally be reduced in three ways, including volatilization of ammonium, denitrification; and soil absorption. On average, 55% of nitrogen entering the soil is removed before reaching groundwater. Stability of nitrate in the environment is high, as it could remain in the environment for about 50 years. Schematic figure of nitrate conversions and other cyclic processes are illustrated in Fig. 4 [24]. Infants below six months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill and, if untreated, may ultimately die. Related symptoms can include shortness of breath and blue baby syndrome. The maximum contaminant level goals (MCLG) for nitrate is 10 mg/L or 10 ppm. EPA has set this level of protection based on the best available knowledge to prevent potential health problems.

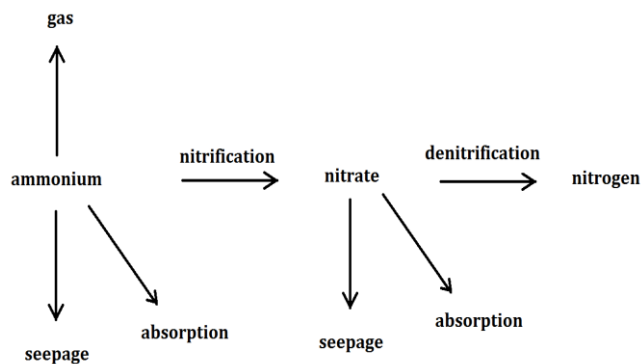


Fig.4: Schematic figure of Nitrogen conversion

As illustrated in Fig 5, absorption of chemicals in soil represents one of the reactions of chemicals in soil. It is noticed that the estimation of absorption coefficient of chemicals requires a comprehensive study. Notwithstanding, due to the loss of data for absorption coefficient of the area, several literature reviews are used. For instance, for urea, such value can equal to 0.24  $cm^3/gr$  and for ammonium 2.8  $cm^3/gr$  can be assumed. Due to the high solubility of nitrate in water, this coefficient is small and around zero [6]. After calibrating the model, the absorption coefficient of Rey is set to: 0.00001

## 6. Rey Aquifer Quality Condition

With few exceptions, typically each drinking water well has seasonal data of nitrate measuring. Among drinking water wells, about 86 wells with adequate data were selected as observation wells for nitrate. Years of evaluation are from 2005 to 2012. Since the variation of quality variables in groundwater is rare and quality data for each year only for few months is available, thus from

average of six months; September of each year when the water level is at highest and lowest level; is used for evaluation and calibration of the model. Fig. 6 shows the comparison of representative hydrographs for Rey aquifer.

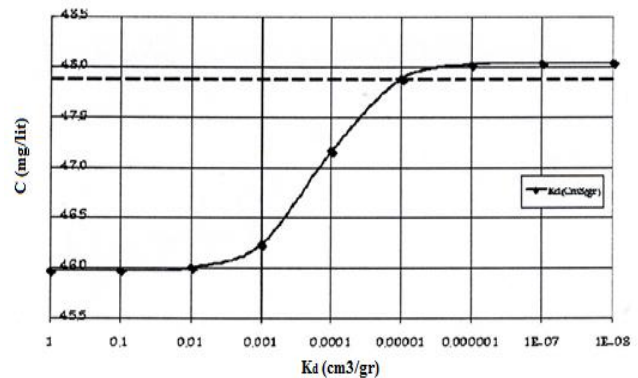


Fig.5: The value of model sensitivity to absorption coefficient for second six-month of 2005

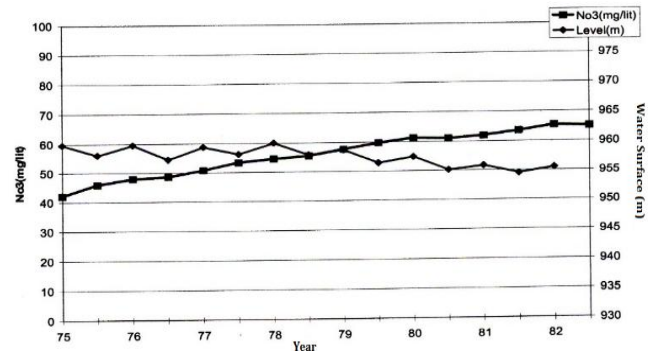


Fig.6: Comparison of representative hydrographs of Rey aquifer

Average concentration of nitrate in aquifer increases annually. Additionally, the variation of aquifer nitrate concentration does not depend on level of groundwater. In other words, dry and wet periods do not have any influence on increase or decrease of nitrate in aquifer. According to this graph, 3 mg/lit is added annually to the average value of nitrate concentration in aquifer. The average value of nitrate concentration in 2012 was about 65 mg/lit which is about 1.5 times more than drinking water standard. The maximum allowable of nitrate in aquifer is 45 mg/lit based on drinking water standard.

## 7. Steady State Model Calibration

Quality modeling includes developing a program or computer code or could be based on the selection of a suitable computing code. Code used in this study is (Processing Modflow 5/3) PMWIN 5/3 [14, 17]. This program was originally developed for a remediation project at a disposal site in the coastal region of Northern Germany [25]. It follows MODFLOW and MT3DMS codes, which are widely used by researchers to simulate groundwater flow and solute fate [26]-[32]. Calibration is the process of

modifying the input parameters to a groundwater model until the output from the model matches an observed set of data. In our model, initial attempts were made to run calibration via a direct method only. But according to the limited time of project, high volume of work, the calibration was ultimately performed by both direct method (trial and error) and reverse method PEST. The result of calibration of the model in permanent regime is the hydraulic conductivity of the aquifer (K).

To calibrate the hydraulic conductivity, we truly require the steady state modeling. In this step, we have to consider a beginning for modeling in which the aquifer remains in an ideal condition. The method used in this study is the virtual piezometer method. According to the observed data of piezometric wells of the area, isopiestic observation map of the area is prepared. Using this map, the observation water level for all points of the model is distinguished; thus all points of the model can be chosen as virtual piezometers by this map. Then we can optionally select 100 or 140 points in the model and then record the water levels of these points along with coordinate locations of those points. Thus these points are chosen as virtual piezometers. The model is calibrated by inserting data from virtual piezometers, which finally results in more accurate operation. Fig. 7 illustrates the water level of 135 virtual piezometers in Rey.

## 8. Transient Model Calibration

The result of model calibration in unsteady regime is the storability of aquifer (S). Because the sedimentary environment of the area is conical toward the river surrounding, (and also the conical sedimentary is consisted of fine and coarse particles), the storage coefficient is calibrated with a uniform distribution from the border of highlands toward the low-lying areas in the range of 5.5 to 6 percent. The periods of modeling in unsteady state regime is the same as steady state regime.

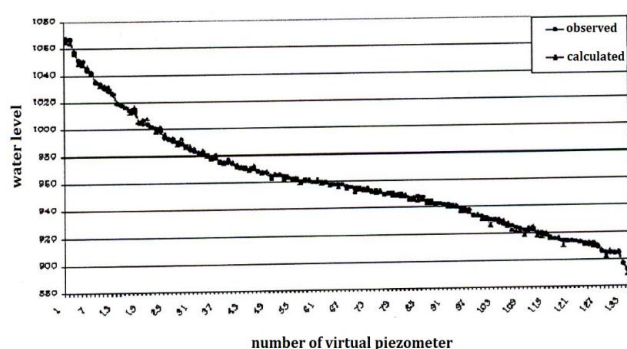


Fig.7: Water level in virtual piezometers

## 9. Calibration of Simulating Model

Generally in quality modeling of aquifer, parameters which are effective and are calibrated in dispersion procedure are absorption coefficient, dispersion length, ratio of horizontal dispersion to dispersion length, and also

ratio of vertical dispersion to dispersion length [15, 33]. All such parameters should generally be gained from experimental studies. In this research, due to the lack of experimental data, parameters were achieved from trial and error. In order to calibrating the model, first initial values are specified to the above-mentioned parameters; next the model is run for six months and then the simulated values are compared with measured values. Such procedure continues to reach the best adaptation. Since the second half of 2005 is considered for calibration of quality parameters, years except 2005 are used to verify the model. Calibrated parameters of the model are shown in Table 1.

Table.1: Calibration parameters of quality model of Rey

1	TRPT (ratio of horizontal dispersion to length of distribution)
0.1	TRPV (ratio of vertical dispersion to length of distribution)
0	DMCOEF (effective molecular dispersion coefficient)
0.00001	KD (absorption coefficient)
50	longitudinal dispersivity

## 10. Error Distribution

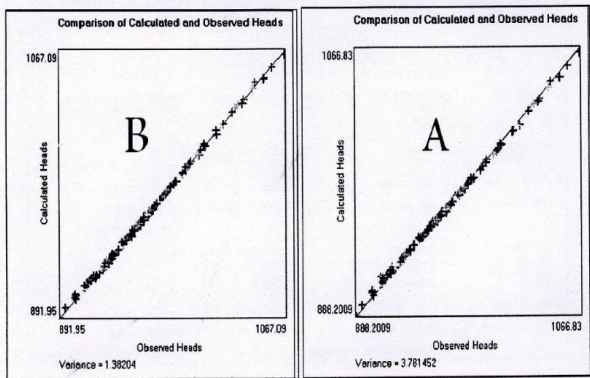
In order to prepare the water level map for the area and to further compare the results of the model with actual values, 135 virtual piezometers are used. In the literature of mathematical models, this selection is introduced as determination of objective calibration. One hundred percent adaptation with these objectives seems to be impossible and also does not satisfy the validity of the model. Stated differently, model contains some errors and these errors should be distributed in a predetermined manner. Meanwhile one model calibrated 100 percent may not be comply with conceptual models and cannot predict truly [18]. Scatter-diagram (scatter curve) shows the comparison of modeled and observed values and in fact indicates a type of error comparison of results of the model. Fig. 8 represents the verification results in calibration period in unsteady regime. Fig. 9 illustrates the scatter-diagram of evaluated values and modeled ones in second six-month for quality model of Rey aquifer- which is acceptable according to the field collected data.

## 11. Analysis of Parameter Sensitivity

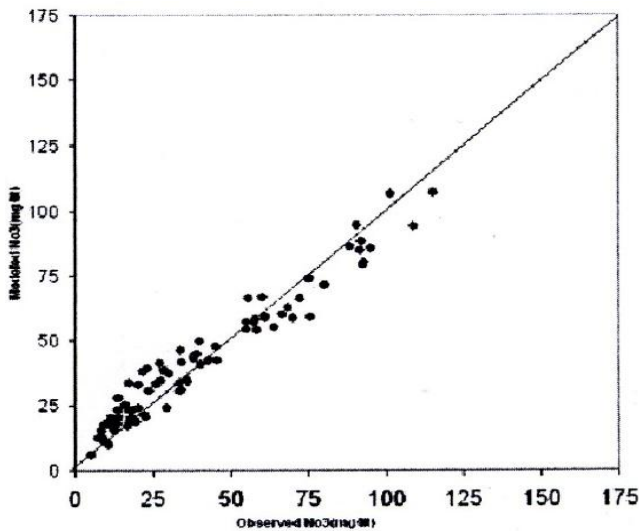
The main objective of sensitivity analysis is to show the reaction of quality model of aquifer with respect to the variation of an uncertain input parameter [34, 35]. Model response can be high or too low for variation of input parameters. Rey aquifer current model shows sensitivity to the variation of hydraulic conductivities, hydrological stresses, boundary conditions and variation of saturated



layer thickness. Quality model of Rey groundwater is sensitive to the absorption coefficient, input and output of nitrate concentration in the aquifer, and sensitivity of the model to longitudinal dispersion coefficient. Additionally soil particle density is low.



**Fig.8:** Scatter of observed and modeled values in unsteady regime  
A: first six-month of 2005, B: second six-month of 2005



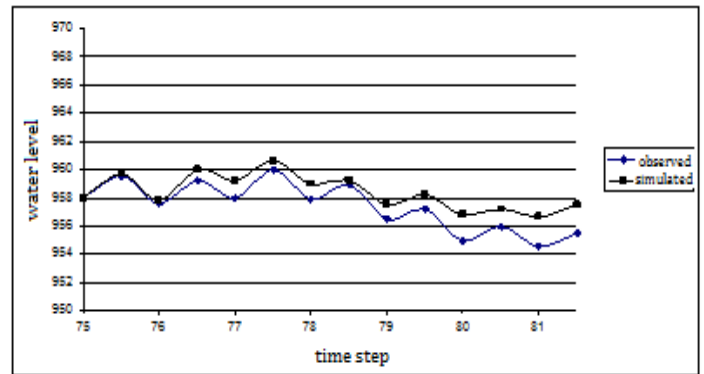
**Fig. 9.** Consideration of evaluated and modeled scattered values in second six month

## 12. Quality Model Verification

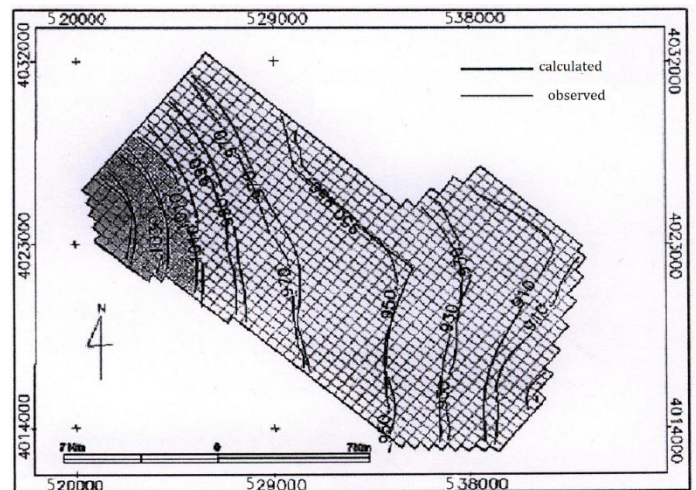
Prepared model should substantially have similar behavior to the natural reaction of the aquifer. Since the model of Rey is calibrated in steady and unsteady regimes, data of the first six-month of 2005 is treated as the initial condition of the aquifer and then by distinguishing the feeding data and discharge of aquifer until the end of 2011, the model is run. The water level achieved by model is compared with the observed water level (Fig 10) in these years to determine the accuracy of the model.

As an additional goal, we intend to predict the future water levels of seven subsequent years by using initial data for the year 2005, (the prediction of water level in April 2012). The errors of the model are transmitted

accumulatively from each step to the next one. Fig. 10 represents the calculated and observed representative hydrographs of water level in Rey aquifer. As it shown, the water level of representative hydrograph of simulated aquifer after 14 periods (7-year) is about 2 m higher than representative hydrograph water level in the aquifer. Furthermore, and as explained earlier, this happens because the error of model is transmitted accumulatively from each period to the next period.



**Fig.10:** Comparison of calculated and observed representative hydrographs of water level in the aquifer



**Fig.11:** Calculated and observed water level contour map in April 2012

Fig. 11 shows the calculated and observed water level contour map during April, 2012 in Rey aquifer and represents the accuracy of prediction of model for next seven years. As it could be seen, the pattern of simulated water level contour map follows the pattern of observed contour map which is important from modeling perspective.

## 13. Verification and Determination of Accuracy of Simulated Quality Model

To verify and determine the accuracy of the model, the initial concentration of the aquifer is assumed to be the concentration in September 2005, and model is run for a consecutive period of time. Based on the results of the model, and as time passes, corresponding predicted error increases respectively. At most, we can predict situation during next several years with this model and for more than three years, the accuracy of prediction significantly declines. Fig. 12 illustrates the accuracy of the model after two years (A, September of 2007) and the accuracy of the model after three years (B, September of 2008).

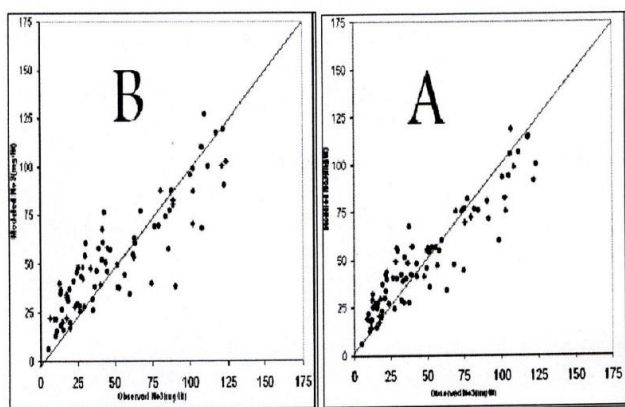


Fig.12: Scatter diagram of observed and modeled nitrate values

The most important factor contributing to error in the model is that the depth of drinking water wells in Rey area is about 100 m to 250 m. If two wells of water, one in a depth of 100m and the other in a depth of 150m are considered, the concentration of nitrate in these wells are different. Since the wastewater recharged to aquifer is collected in the surface of the aquifer and the pollution is higher on the surface of the aquifer, the pollution thus reduces. Most of the recharged water to the wells with the depth of 100 m is among the surficial parts of the aquifer with high values of pollution. Pumping wells with the depth of 150 m, from the low-lying parts of the aquifer, experiencing reduction of the pollution from such layer. In this regard, variation of the depths of wells remains the most significant important factor creating error in the model. Likewise, change in the location of drinking water wells, distance from the source of pollution, error in the quality of model and etc. could cause error in the quality model. Fig. 13 shows the map of the calculated and observed nitrate in September of 2008. This map is prepared based on the initial concentration of September in 2005 and represents the prediction of the model for next three years. As it could be seen, the accuracy of the model for central regions which possess the highest values of nitrate is low. The reason is that population in central regions is high and since these areas face the lack of collection network and wastewater transport, thus the amount of influent wastewater into the aquifer in these areas is too high.

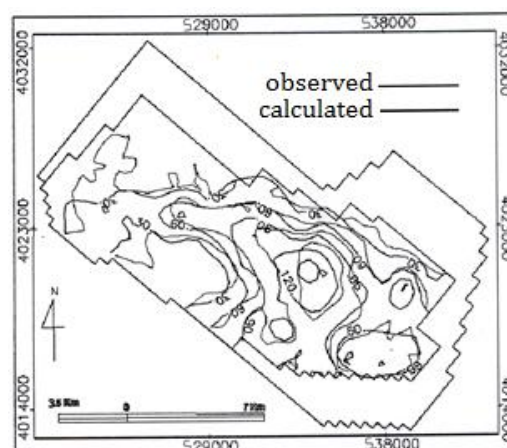


Fig.13: Calculated and observed contour maps for nitrate in September 1378 (the accuracy of the model three years later)

#### 14. Prediction of Quality Condition in Rey Aquifer for April 2018 Using the Model

In this section, quality condition in the aquifer is used to predict the water level in the aquifer until 2018. Based on the prediction of such model, if the hydrological events of 2005 to 2012 such as severe draught occurs again from 2012 to 2018, also the wastewater network of the whole city will be completed until 2011 and the number of added wells to the area is according to the prediction of water and wastewater company of Rey, on average, the groundwater level of the area until 2012 will drop about 9.5 m. Of course the loss distribution is not similar. Eastern parts of Rey faced a loss of 1.5 to 5 m of the groundwater level and central areas about 5 to 11 m. The highest drop of groundwater level can be observed in the west of Rey and around Keikavar piezometer. Due to the lack of recharge by sewage collection network, the congestion of wells and also the increase in per capita consumption and number of population, water level in west of Rey has been reduced up to 22 m. Since many of drinking water wells in Rey are located in the west of this city, the drop of groundwater level about 18 to 22 m in this area causes a significant reduction in discharge of local wells. This matter can further delay the providing of the drinking water in Rey till 2018. Similarly, severe drop of water level in the aquifer will cause a reduction of quality of aquifer in the west of Rey and probably salinization of groundwater in the area. It will also cause land subsidence in that area. To solve this problem, we should recharge the aquifer in west of Rey. One practical solution can be recharge of the aquifer by treated wastewater. In this regard, we should transfer the treated wastewater from the wastewater treatment plant into the aquifers.

#### 15. Prediction of Nitrate of Aquifer in 2016

This section of the qualitative model of aquifer is used to predict the nitrate value of aquifer for a three-year



period. In order to predict the nitrate value of aquifer, available quality parameters in the beginning of 2013 is given to the model as the initial concentration and then the simulation is done for a three-year period. Figure 13 shows the nitrate prediction for April of 2016. Increase in consumed water and consequently increase of returned wastewater into the aquifer makes the nitrate concentration to be increased. Figure 14 shows conditions with lack of sewage collection network. The recharge of wastewater remains constantly high in the central zone of the city and in the southwest of the city. Likewise the value of nitrate reduces to 30 mg/lit due to the impact of a proper sewage network wherein a gradual reduction of nitrate value will extend from west and southwest toward central zones. Southeast, east and northeast of Rey very likely will face an increase in nitrate concentration. Also, we can observe the gradual movement of maximum nitrate curve from central areas to the east and northeast - which can signify as the reduction of nitrate concentration due to the development of sewage collection network.

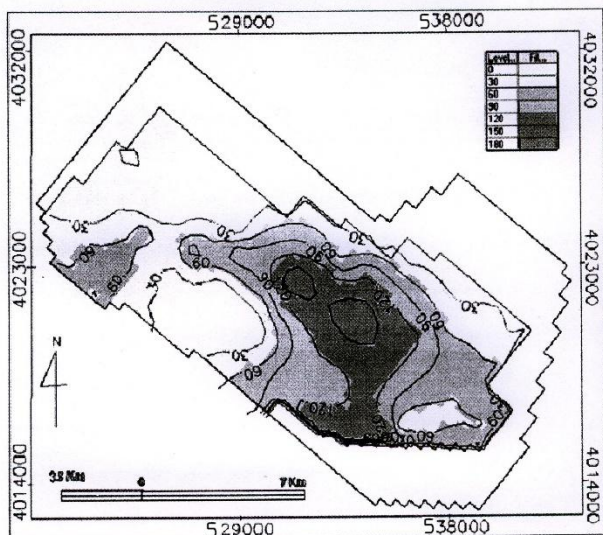


Fig.14: Nitrate map for April of 2016

## 16. Conclusion

The city of Rey with the population of 1 million faces a water crisis. Among different water resources, groundwater has a major and outstanding role in supplying municipal drinking water. Mathematical ground water model showed, when dry period occurs within 7 years from 2005 to 2012, the average groundwater depth will very likely decline by 9.5 meter. More particularly: in the eastern region the level of the groundwater depth would decrease from 1.5 to 5 meter; in the central region the groundwater level reduction can fall within a range of 5 to 11 meters; and in the western region, the groundwater level can decline more than 22 meter in some locations. Groundwater quality model showed that Rey aquifer has more than one layer. The concentration of nitrate will increase in central and eastern

regions and the concentration of nitrate can be reduced in Rey aquifer by establishing adequate sewage collection systems. By applying the groundwater model (PMWIN); it is possible to predict groundwater potential extractions for more than 10 years. In contrast, by utilizing the quality groundwater model, which is only possible to simulate for 3 years, it is shown that the errors would be increasingly mounted after 3 years.

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