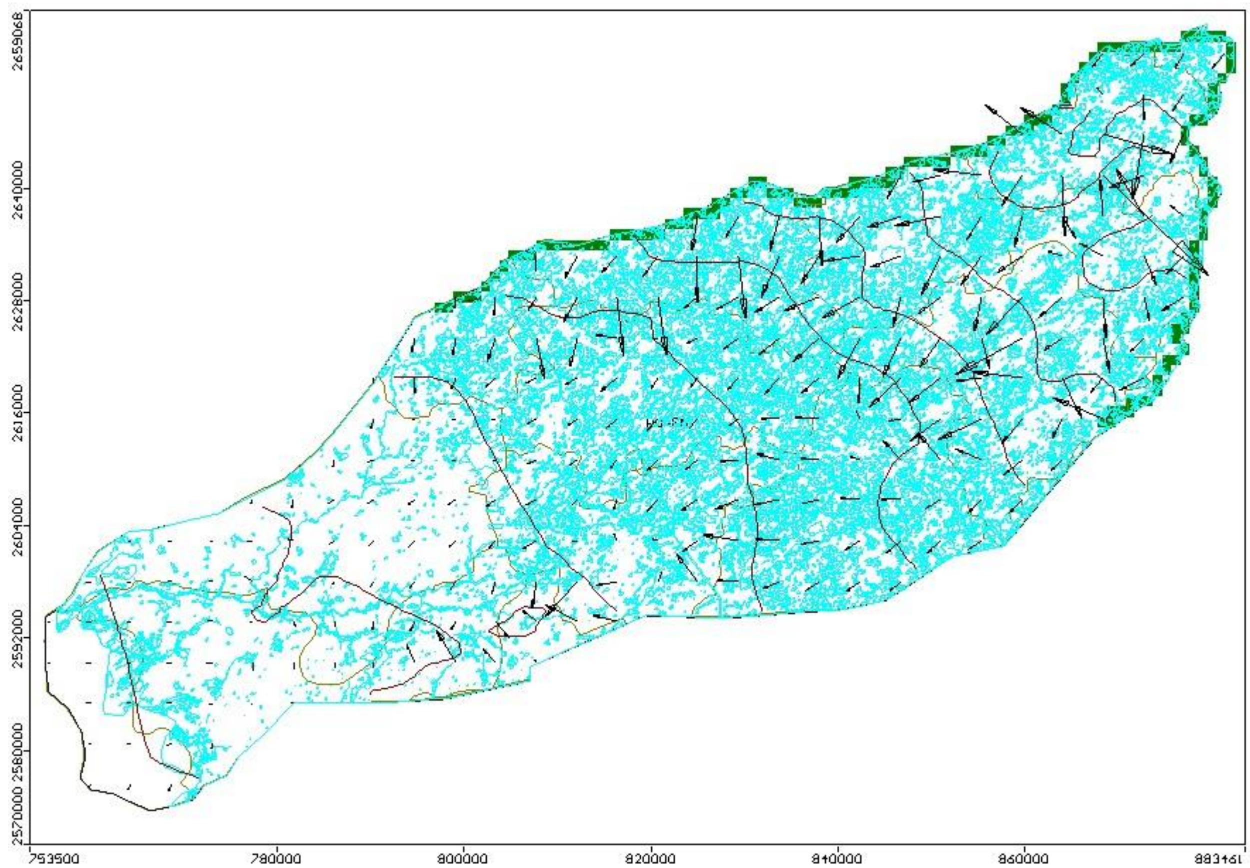
Report on

Aquifer Parameter Establishment through Numerical Groundwater model for Rupen Basin, North Gujarat

(AAP 2018-19)



By

A. K. Sinha, Assistant Hydrogeologist

Dr. A. K. Jain, Scientist-D

Central Ground Water Board

West Central Region

Ahmedabad

May 2019

REGIONAL GROUNDWATER FLOW

GENERAL

Three-dimensional mathematical models of regional groundwater flow are beneficial to the management of groundwater resources as they allow the approximation of the components of hydrological processes and provide a mechanistic description of the flow of water in an aquifer. Such a modeling study was carried out in Rupen Basin, North Gujarat, India. The study area is characterized by alluvium aquifer system with very heavy abstraction of groundwater for agricultural purposes. The model simulates groundwater flow over an area of **about 4706 square kilometers** with 74rows, 127 columns, with single vertical layer on the regional model. The detailed study area is divided into rows and columns with a size of 1.0 sq.km grids (Figure.1). The model was simulated in steady and transient state condition using the finite-difference approximation of three-dimensional partial differential equation of groundwater flow in this aquifer from May 2007 to November 2010. The model was calibrated for steady and transient state conditions. There was a reasonable match between the computed and observed heads. Based on the modelling results, the aquifer parameters of this aquifer system is established.

Modelling objectives

Numerical three-dimensional groundwater flow model was developed for the Rupen Basin,North Gujarat area, India with the following objectives,

- to simulate regional groundwater flow to identify the distribution of heads,
- to establish the aquifer parameters of the area

MODEL INPUT PARAMETERS

The model was developed by incorporating geologic data, measured and inferred hydrologic data. Two sets of data are required for the development of a groundwater model as given in Table 1. The two sets of data are the physical framework and hydrological stresses.

Table 1 Data required in developing a numerical model

Physical framework	**Hydrological stresses**
Aquifer geometry Type of aquifer Aquifer thickness and lateral extent Aquifer characteristics	Groundwater abstraction and recharge Solute concentration Aquifer stress

Groundwater flow equation

Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, and described by the partial-differential equation given by Rushton and Redshaw (1979) was used to model the groundwater flow in this study

$$\frac{\delta}{\delta x}\ K_{xx}\frac{\delta h}{\delta x} + \frac{\delta}{\delta y}\ K_{yy}\frac{\delta h}{\delta y} + \frac{\delta}{\delta z}\ K_{zz}\frac{\delta h}{\delta z} - W = S_s\ \frac{\delta h}{\delta t}$$

Where,

K_{xx}, K_{yy}, K_{zz}	-	components of the hydraulic conductivity tensor
h	-	potentiometric head
W	-	source or sink term,
S_s	-	specific storage
t	-	time

MODELLING PROTOCOL

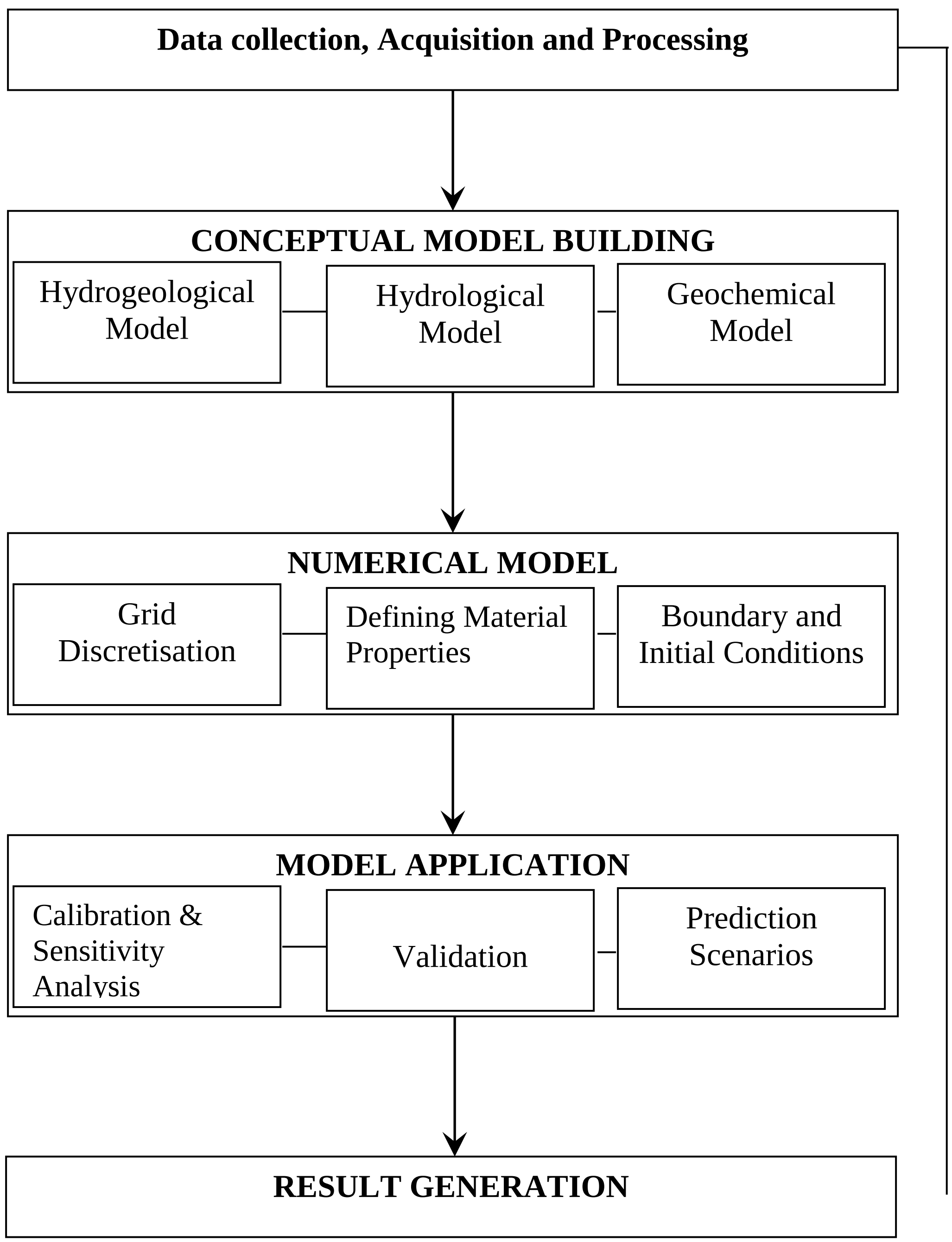
The modelling protocol used in this study for the construction of a numerical model involves the following steps:

- Data collection, acquisition and processing of primary data
- Conceptual model building
- Numerical model building
- Model application
- Result generation.

These steps are given in a form of a flowchart (flowchart1).

COMPUTER CODE

The computer software program MODFLOW (McDonald and Harbaugh 1998) developed by the United States Geological Survey (USGS) was used for the present study. The computer program uses the finite-difference technique and block-centered formulation to solve the groundwater flow equation for the three-dimensional steady and transient flow in heterogeneous media. The pre and post processor, **Visual Modflow version 4.6 of 2014** was used to give input data and process the model output. Modelling studies were carried out in the hydrogeological modeling cell of the West Central Region, Central Ground Water Board, Ahmedabad.



Flowchart 1 Ground water modelling methodology (after Bear 1992)

MODEL CONCEPTUALISATION

The conceptual model of the system was arrived from the detailed study of geology, borehole lithology, geophysical resistivity survey &logs, cross section and water level fluctuations in wells. Groundwater of the study area is found to occur in the intergranular pore spaces in the recent alluvium and aeolian deposits. Groundwater is found to occur in unconfined conditions in the alluvium formation.

Boundary conditions

The study area forms a part of the Luni basin(CGWB Basin Map https://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Basins#CGWB). The boundary conditions modeled are as per the Basin boundary (Figure.2).The Northern boundary of the study area is the Banas River Basin and Souhern boundary is bounded by Sabarmati River basin. .Rupen river flows from the north eastern boundary to the South Western boundary and was modeled General head boundaryIn the North Eastern part. Except these two regions, the remaining boundary was modeled as no flow boundary as the flow from outside the boundary is negligible.

The aquifer top and bottom were derived mainly based on the lithology of boreholes and by intensive field surveys. The study area has multilayered aquifer system but the top layered is modelled. First unconfined layer comprises of the top soil and alluvial formation consisting medium to coarse sand, which is underlain by thick clay, below which aquifers occur under semiconfined/confined conditions.

GRID DESIGN

The geographic boundaries of the model grid covering 4706 km^2 of the study area were determined using the map module. The map was projected using the metric coordinates in the map module and then imported into the MODFLOW. The finite-difference grid was superimposed on the study area was constructed based on the conceptual model representing the physical properties of the groundwater system. The gird network has a constant spacing 1.0 km by 1.0 km. The model grid discretised into 4706 cells with 74 rows and 127 columns, and vertically by 1 layer **(Figure. 1).** The length of model cells is 1000 m along the east west and 1000 m along the north- south directions of the study area.

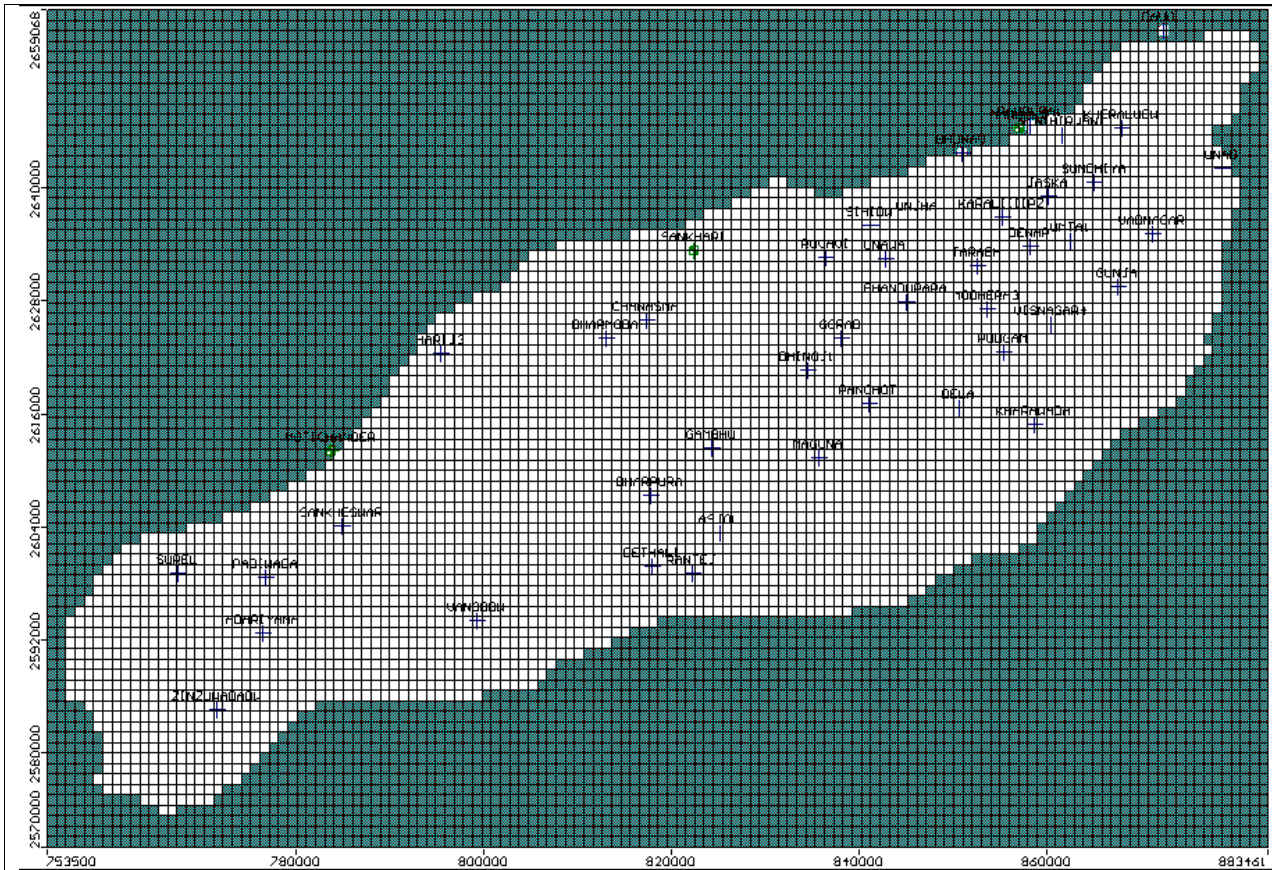


Figure.1 Discretisation of the study area

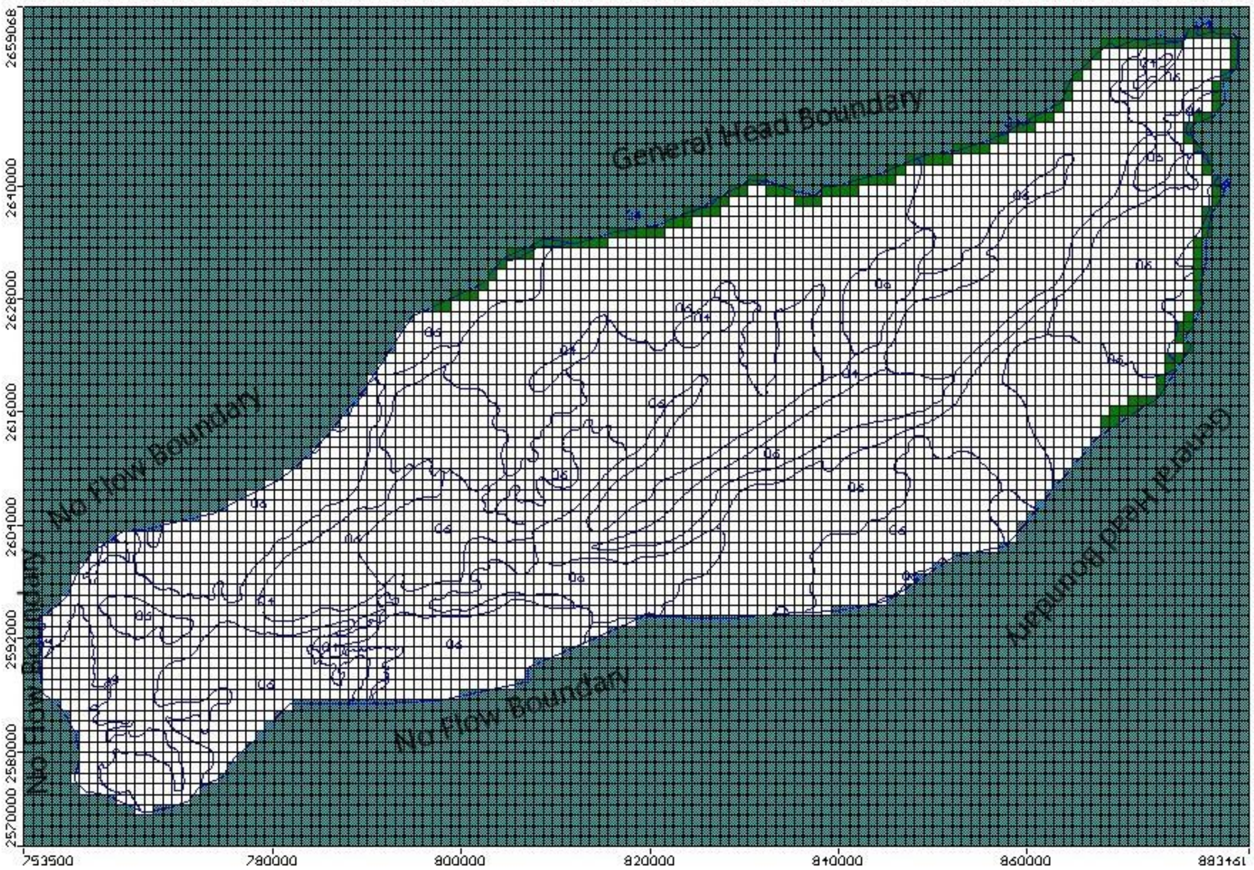


Figure.2 Boundary condition of the study area.

INPUT PARAMETERS

Initial Groundwater head

The initial groundwater head of the study area is shown in figure.3. After detailed analysis of the hydrographs, rainfall and water level fluctuation, it was decided that the groundwater head data of May 2007 represents the spatial groundwater distribution of the study area. During this period the rainfall was also normal and the groundwater fluctuation was representative of the normal year.

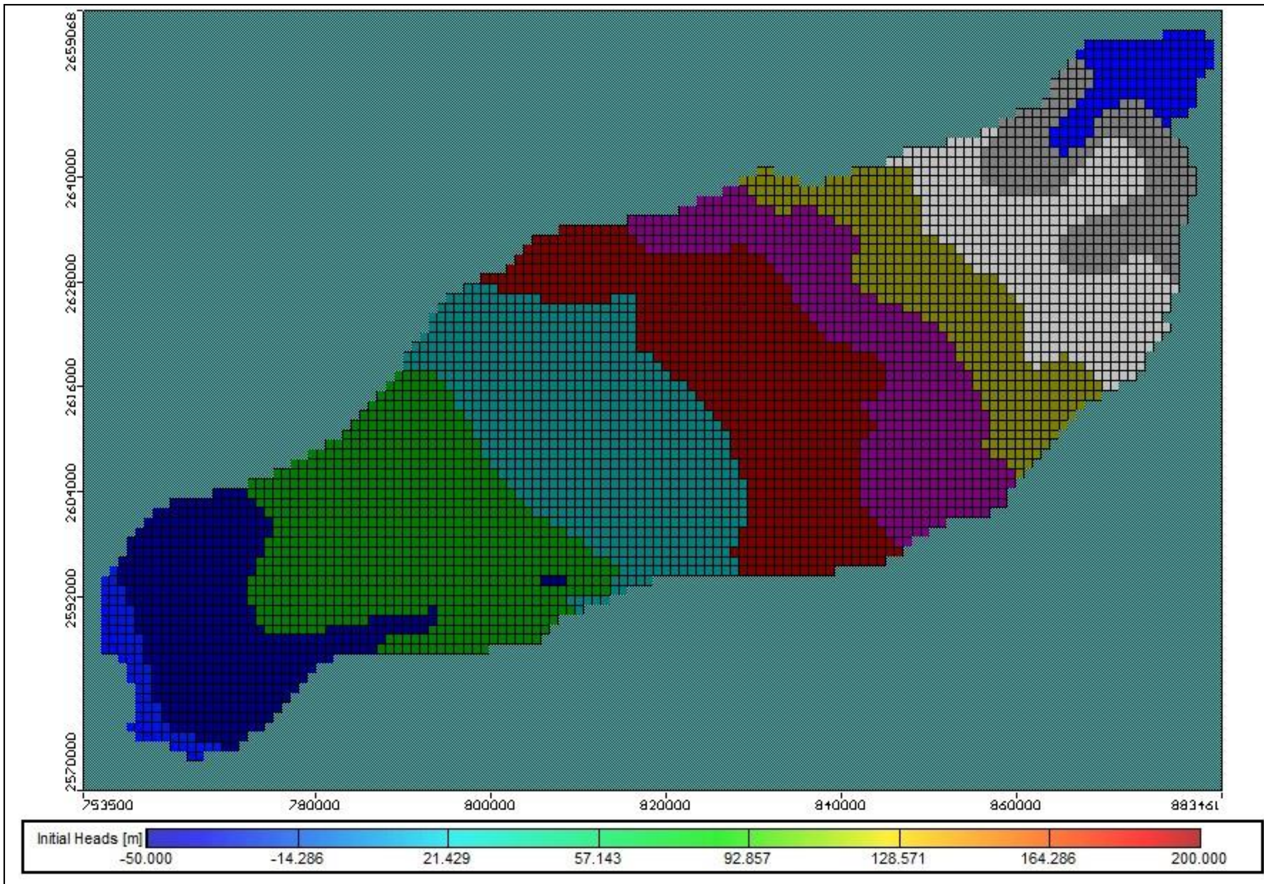


Figure.3 Initial groundwater head of the study area during May 2007

Aquifer Geometry

The aquifer geometry includes defining the aquifer topand bottom of Ist layer for all the cells (Figure 3a & b). They were mainly derived from the subsurface characterization using the lithologs, resistivity data and geological field work. These values were extrapolated for the entire area considering the lithological variations and field study of well sections. The Ist layer is characterized by Loose alluvial formation with a maximum thickness of 90m and is underlained by thick clay formation.

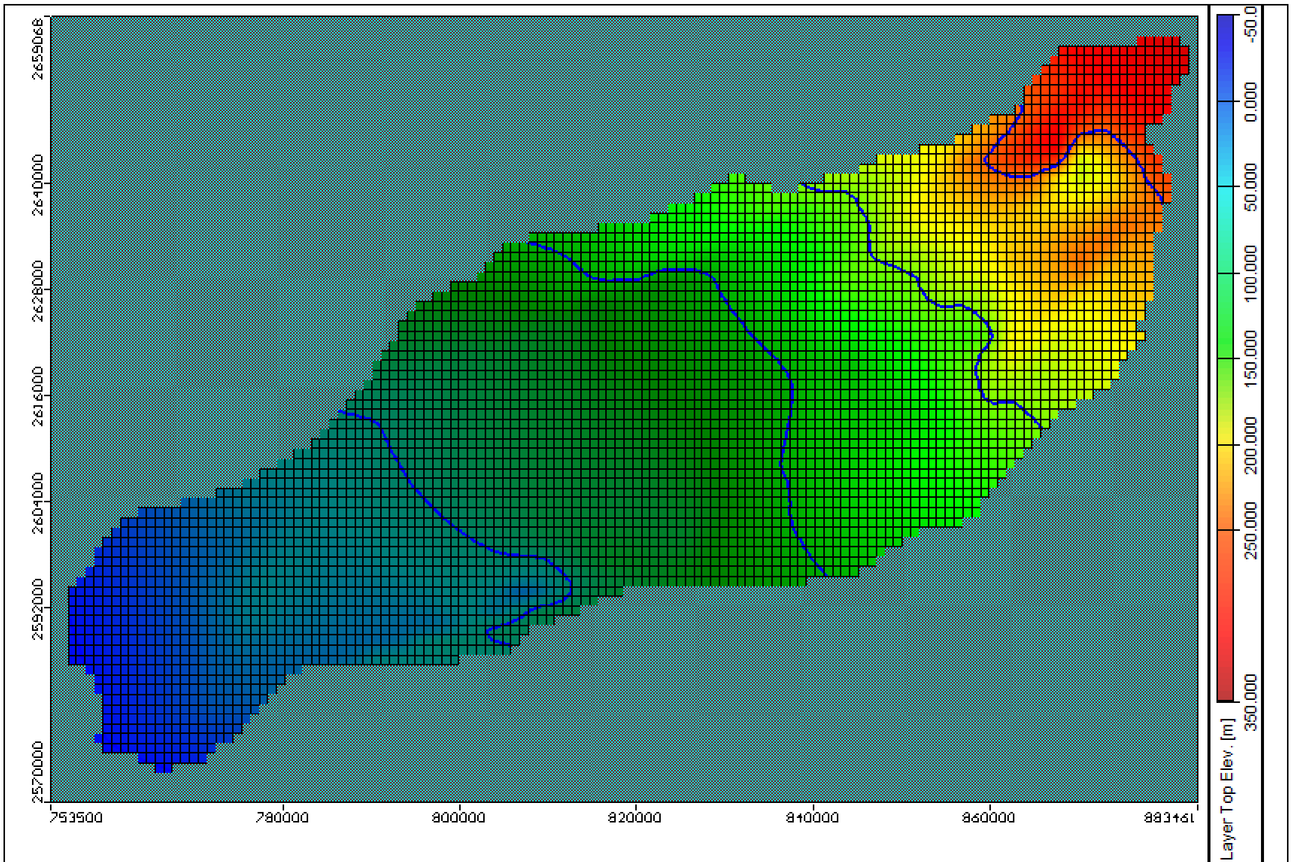


Figure 3a Top elevation of the study area

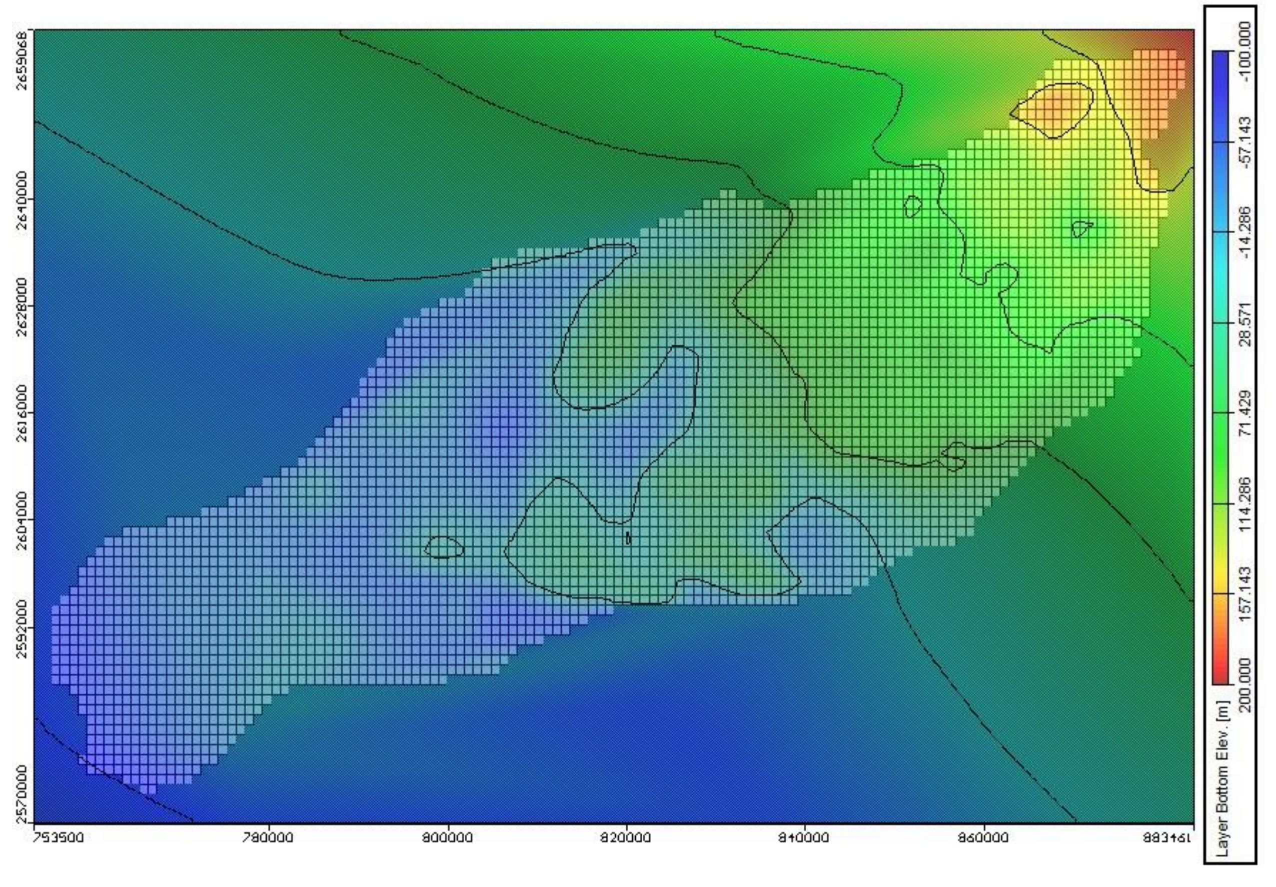
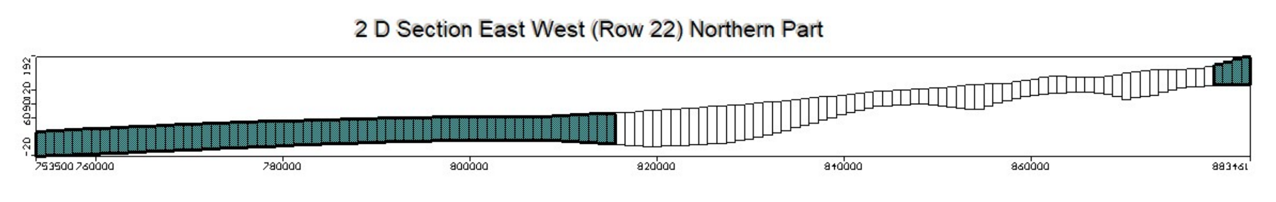
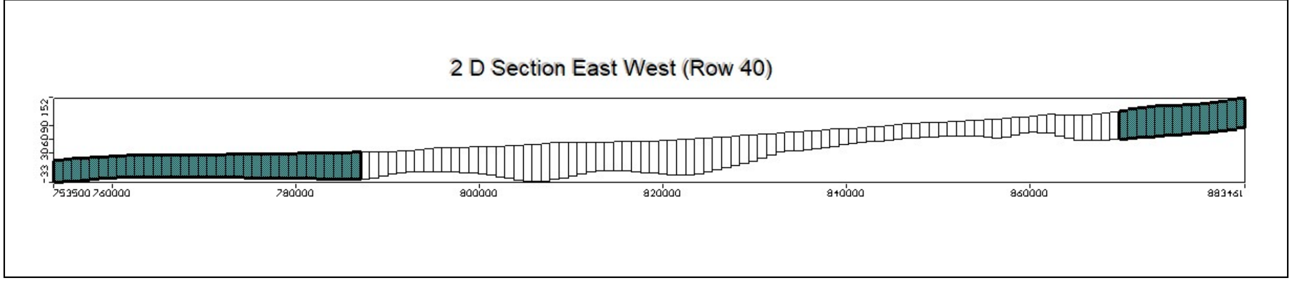


Figure 3b Bottom elevation of the Ist layer of the study area

Figure 3d.Model section along East-West are given below:





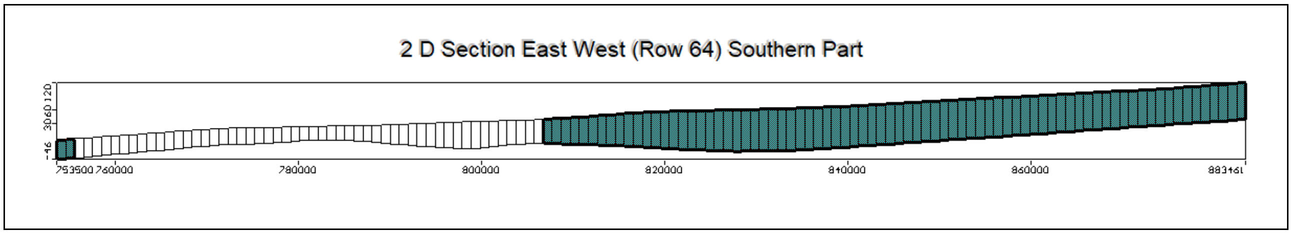
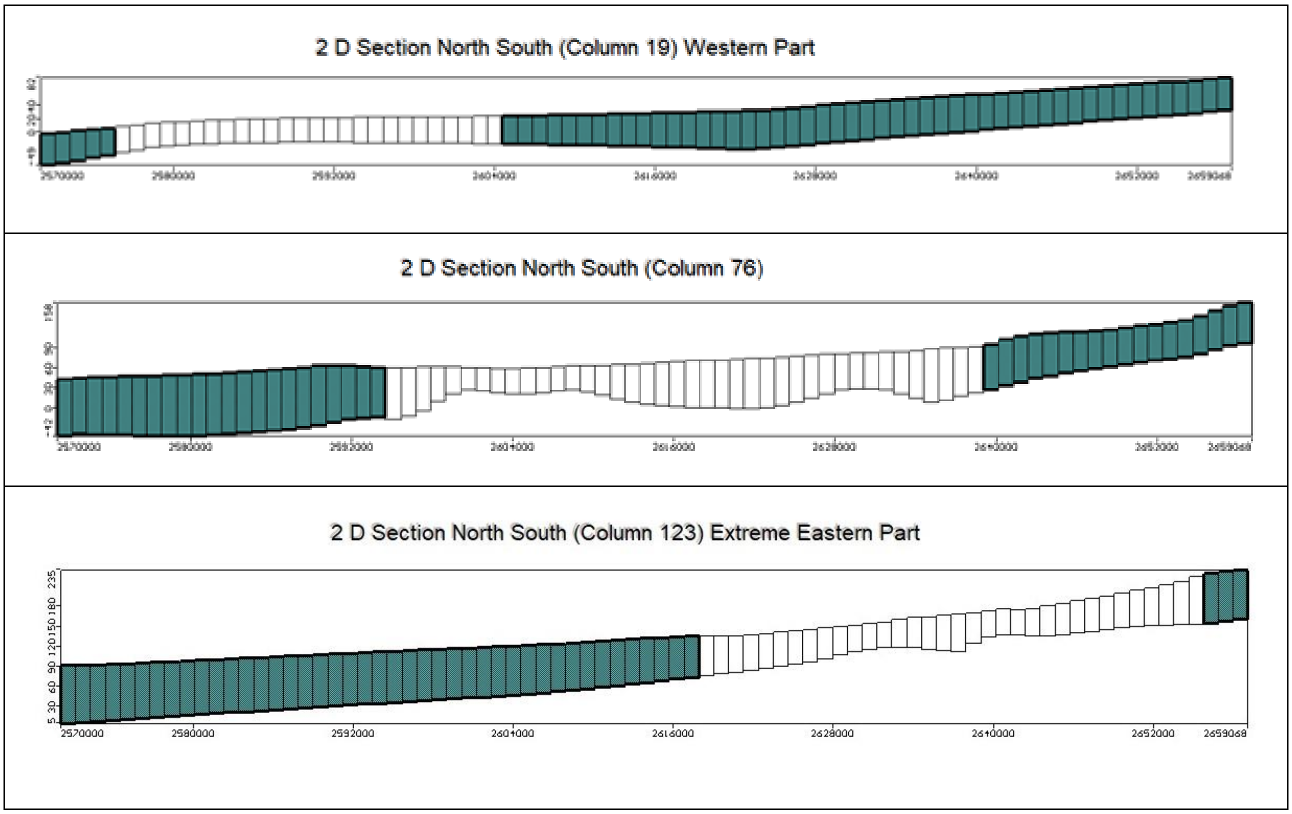


Figure 3e Section along North-South direction



Aquifer characteristics

The aquifer properties such as horizontal hydraulic conductivity, Specific yield and storativity (figure 4a & b) used in the model was derived from 67pumping tests results and is given in the Table 2. The data of the pumping test is enclosed in table-2a.

Table.2 Summary of the Pumping test results

Formation	Hydraulic conductivity (k in m/day)	Specific Yield (%)	Storativity
Sand medium to coarse	0.8-65.3	0.00397-0.0.104	0.000073-0.0003

Table.2a Details of the Pumping test results

Sl. No.	**District**	**Taluka**	**Village**	**Transmissivity (m^2/Day)**	**K (m/Day)**	**Sp.yield/ Storativity (S)**
1	Banaskantha	Vadgam	Vadgam	346	12.8	0.0003
2	Banaskantha	Vadgam	Mahi III	39	1.7	0.0001161
3	Patan	Chanasma	Karora TW-2	471	13.9	
4	Patan	Patan	Kamliwara TW-1	239	6.3	0.000073
5	Patan	Patan	Khimiyana	28	0.8	
6	Mahesana	Kadi	Jadavpura	78	11.1	0.0001
7	Mahesana	Vadnagar	Vadnagar DW I	30.8	15.6	0.009
8	Mahesana	Vadnagar	Vadnagar DW II	13.4	2.59	0.0263
9	Mahesana	Visnagar	Umta DW	29.6	12.8	0.00478
10	Mahesana	Kheralu	Chansol DW	24.1	18.2	0.0127
11	Mahesana	Vadnagar	Chopa DW	4.97	1.47	0.0276
12	Mahesana	Vadnagar	Aspa DW	6.62	3.98	0.104
13	Mahesana	Visnagar	Kada DW	31.4	6.65	0.0841
14	Mahesana	Satlasana	Satlasana DW	17.9	8.88	0.0123
15	Mahesana	Visnagar	Kansa DW	63.9	65.3	0.00567
16	Mahesana	Kheralu	Kheralu 2 DW	35.9	18.5	0.00397

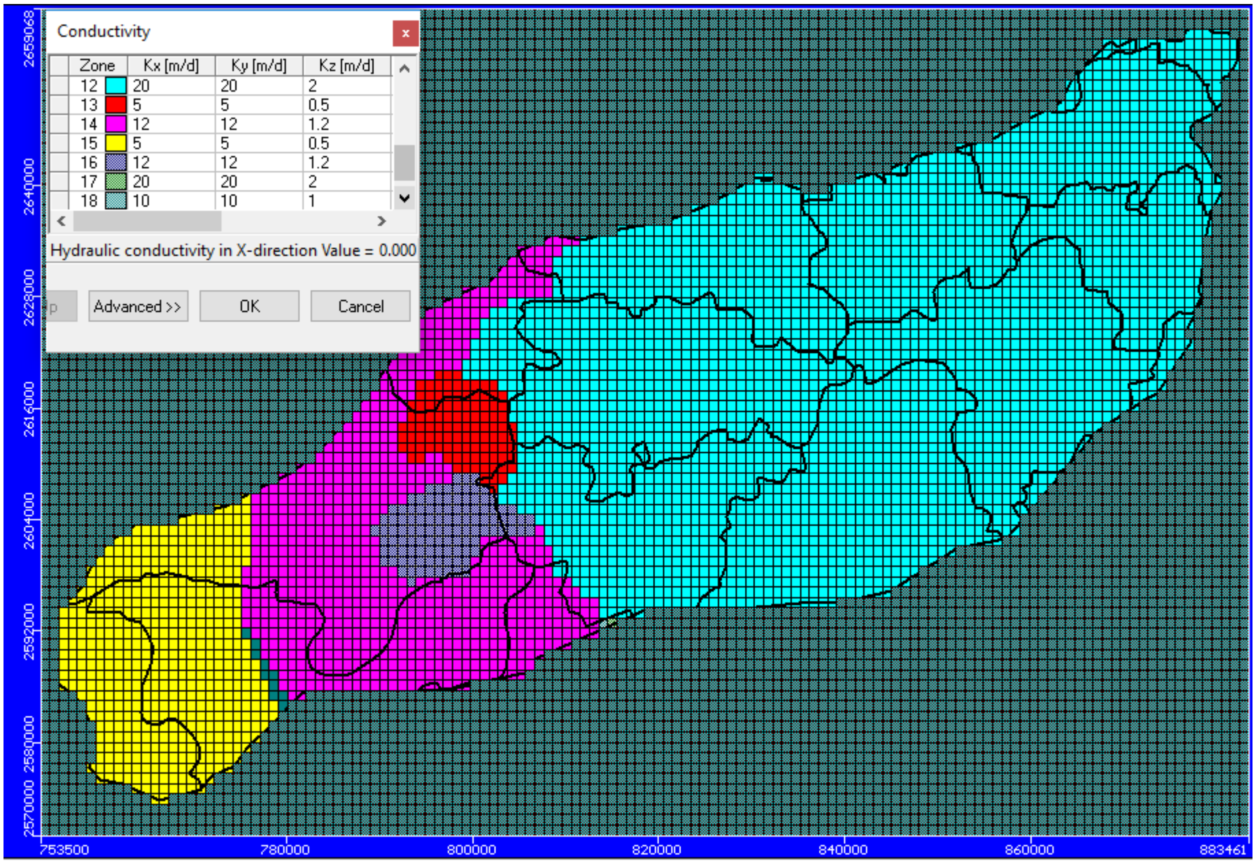


Figure.4a Hydraulic Conductivity values for Aquifer

Groundwater Abstraction

The groundwater of the study area is abstracted for irrigation, drinking water supply and domestic purposes. Agriculture activity of the study area is mainly dependant on groundwater resource. The Landuse and landcover map was prepared to demarcate the area under cultivation. Information on the number of wells (open and shallow Tubewells) available in the study area was collected from the department of economics & Statistics and also from the electricity board. The draft data was finally used from GWRE 2013. The domestic and drinking water requirement of the study area was calculated based on population. The ground water draft details are given in Table 3. In the model input the draft was distributed to the cell by creating pumping well in each talukas as per the draft data (figure-5a &b)

Table.3 Groundwater draft details (As per GWRE 2013)

Sl. No.	Taluka	Basin Area (sq km)	No.of Grids	Taluka_Area	Total GW Draft (mcm/year)	Model area factor	Basin Area Total GW Draft (mcm/year)
1	Kheralu	277.27	277	333	106.25	0.83	88.52
2	Vijapur	35.26	35	562	155.13	0.06	9.74
3	Chanasma	486.70	487	487	60.78	1.00	60.78
4	Dasada	495.85	496	1669	18.61	0.30	5.53
5	Mandal	72.00	72	479	33.83	0.15	5.09
6	Vadgam	11.17	11	559	143.41	0.02	2.87
7	Mahesana	509.76	510	799	267.45	0.64	170.63
8	Unjha	296.21	296	318	67.03	0.93	62.50
9	Becharaji	404.42	404	412	72.32	0.98	71.02
10	Satlasana	40.94	41	290	59.38	0.14	8.39
11	Vadnagar	226.40	226	321	98.96	0.71	69.86
12	Harij	176.63	177	401	38.15	0.44	16.82
13	Sidhpur	7.77	8	358	86.57	0.02	1.88
14	Rann of Kachchh	188.46	188	188	0	1.00	0.00
15	Visnagar	479.15	479	490	134.99	0.98	132.03
16	Patan	339.92	340	769	318.76	0.44	140.99
17	Sami	658.38	658	1586	38.15	0.42	15.84

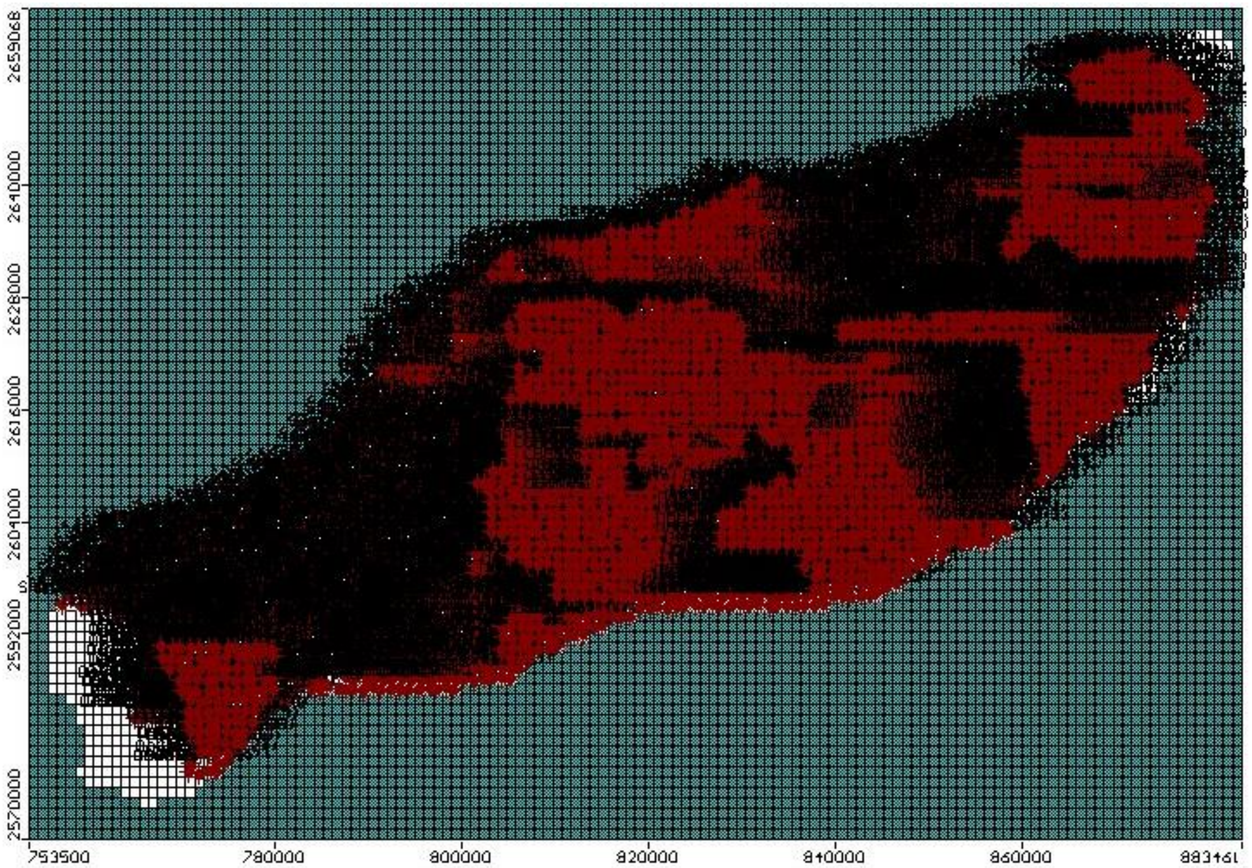


Figure 5a. Distribution of pumping wells

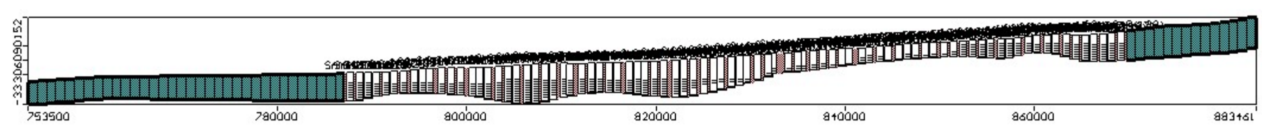


Figure.5b . Sectional view of the pumping wells (Row 40)

Groundwater Recharge

The recharge of the study area aquifer varies considerably due to differences in landuse pattern, soil type, geology, topography and relief. The recharge to the aquifer system is from rainfall and return flow from irrigation. Rainfall is the principal source of groundwater recharge. The rainfall hydrograph were studied to understand the recharge pattern in the study area The entire portion of the study area is geologically covered by Alluvium. The infiltration capacity of formation ranges from 0 – 12 % (Groundwater resources estimation committee report, 1997). 10% of long term average annual rainfall is applied uniformly during the monsoon period i.e. from June to September, for the rest period 10% of this recharge is applied in the model. The recharge zones of the study area is shown in figure.6

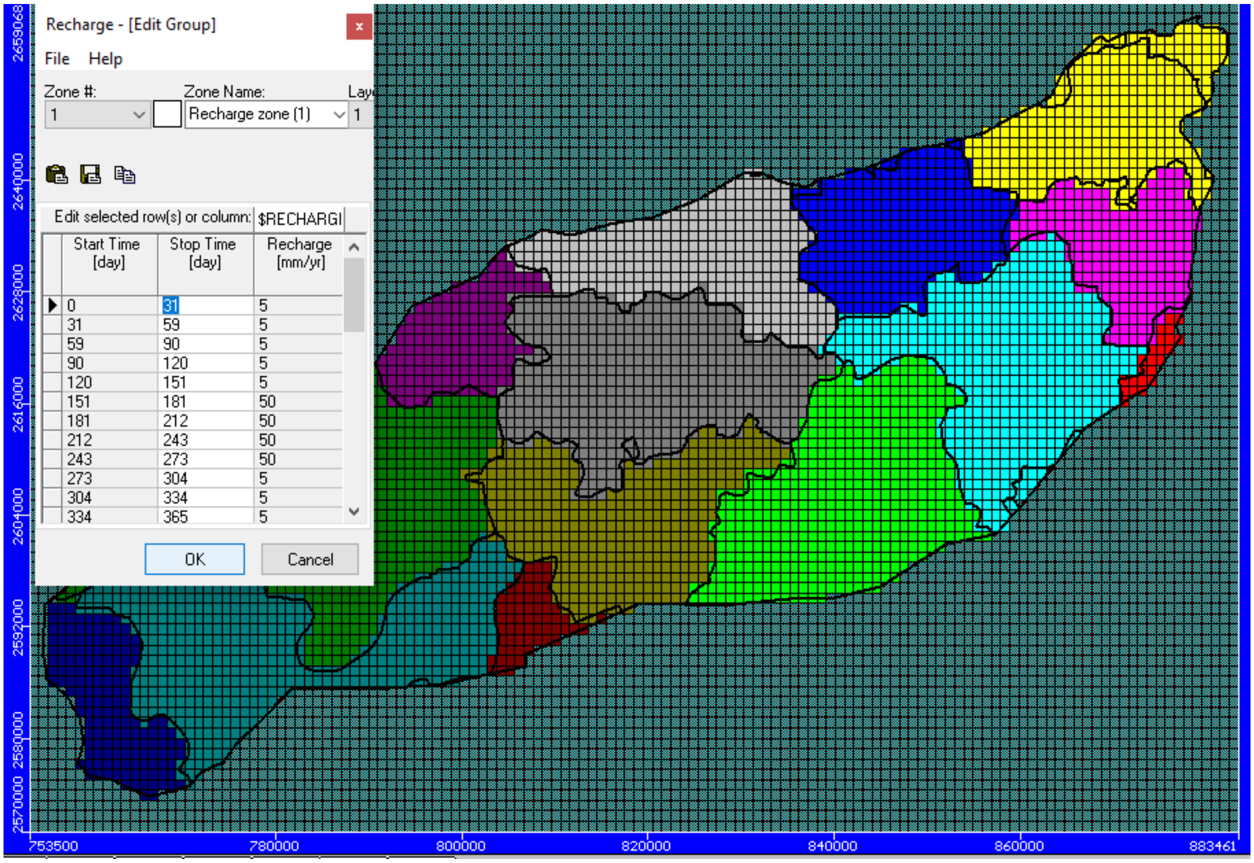
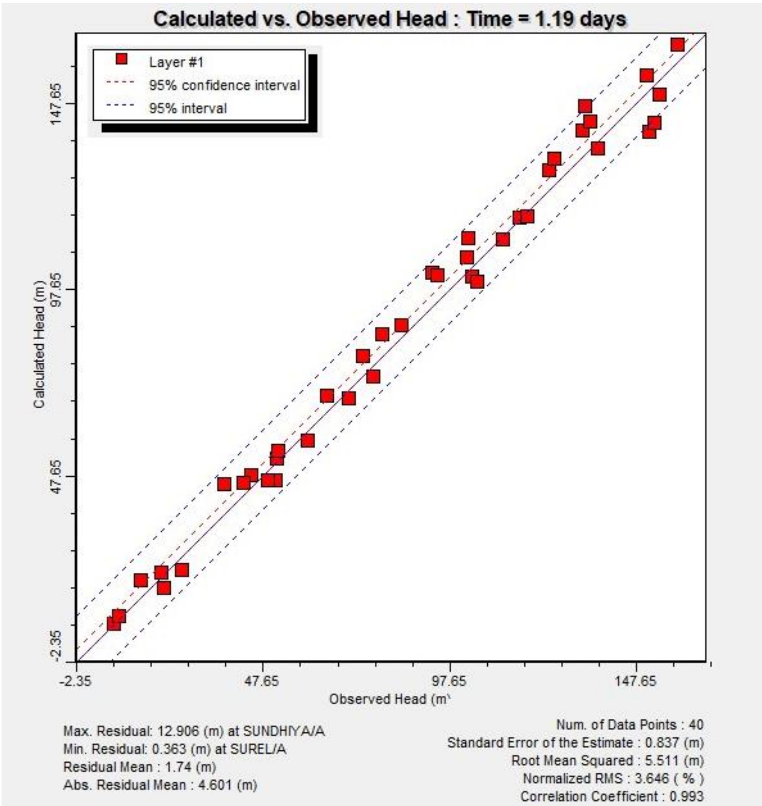


Figure-6 Recharge zones of the study area

MODEL CALIBRATION

The calibration strategy was to initially vary the best known parameters as little as possible, and vary the poorly known or unknown values the most to achieve the best overall agreement between simulated and observed. Steady state model calibration was carried out to minimize the difference between the computed and field water level condition. Steady state calibration was carried out with the water level data of May 2007 in 45 wells distributed over the study area. The area under study has lack of data related to aquifer parameters. Out of all the input parameters, the Specific yield value is the only poorly known as only 14 pumping test data were available in this area. The lithological variations in the area and borehole lithology of existing large diameter wells were studied. Based on this it was decided to vary hydraulic conductivity values upto10% of the pumping test results for layer in order to get a good match of the computed and observed heads (Fig. 8). The figure indicates that there is a very good match between the calculated and observed water heads in most of the wells of the study area. Root mean square error and the mean error were minimized through numerous trial runs.

Transient state simulation was carried out for a period of 3 years from May 2007 to May 2010 with monthly stress periods and 24 hour time step. The trial and error process by which calibration of transient model was achieved by several trials until a good match between computed and observed heads over space and time. The hydraulic conductivity values incorporated in the transient model were modified slightly from those calibrated by the steady state model. Based on the close agreement between measured and computed heads from May 2007 to May 2010 at 45 observation wells distributed throughout the aquifer, the transient models were considered to be calibrated satisfactorily. The sensitivity of the model to input parameters were tested by varying only the parameter of interest over a range of values and monitoring the response of the model by determining the root mean square error of the simulated heads compared to the measured heads.



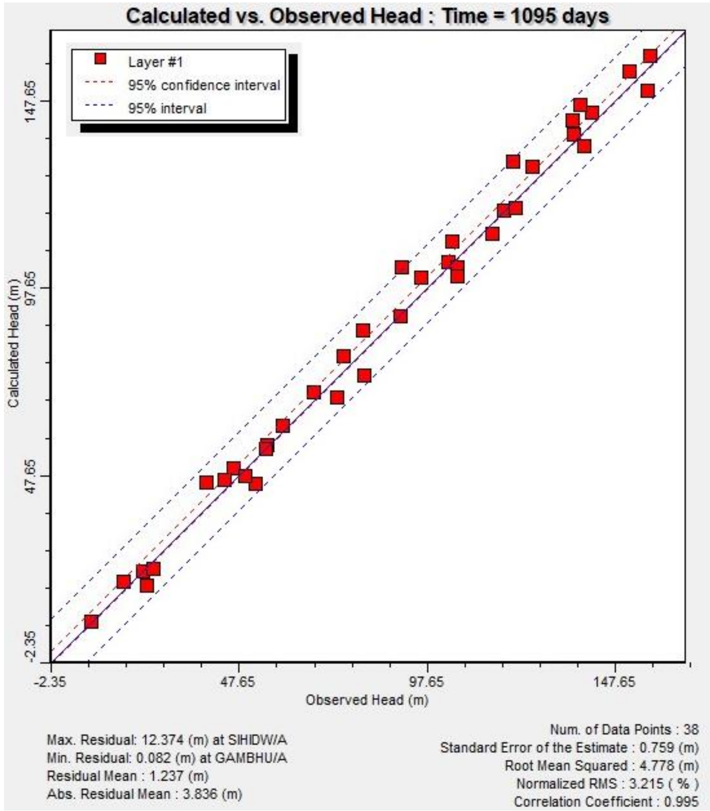


Figure-7 Comparison of computed and observed groundwater head under steady state & Transient state condition.

SIMULATION RESULTS

The model was simulated in transient condition for a period of 3 years from May 2007-May 2010. There was fairly good agreement between the computed and observed heads (Figure.11a to 11c). A study of the simulated potentiometric surface of the aquifer indicates that the highest heads are found on the Northern eastern side of the study area, which is a general reflection of the topography. During the simulation period, it is observed that few patches in the north eastern part gets dried up (**Figure**.8a & 8b). The number of dry cells gradually increases with the summer season and number of dry cells reduces with arrival of monsoon. The regional groundwater flow direction is from north east to South west .There is significant amount of ground water enters from the northern boundary from Patan, Unjha, Kheralu and Vadgam taluka located on north eastern boundary. The groundwater flow vectors for the month of May 2007 & November 2010 is given in figure.8b & 9b. The comparison of observed and computed heads in given in figure 10a to c.

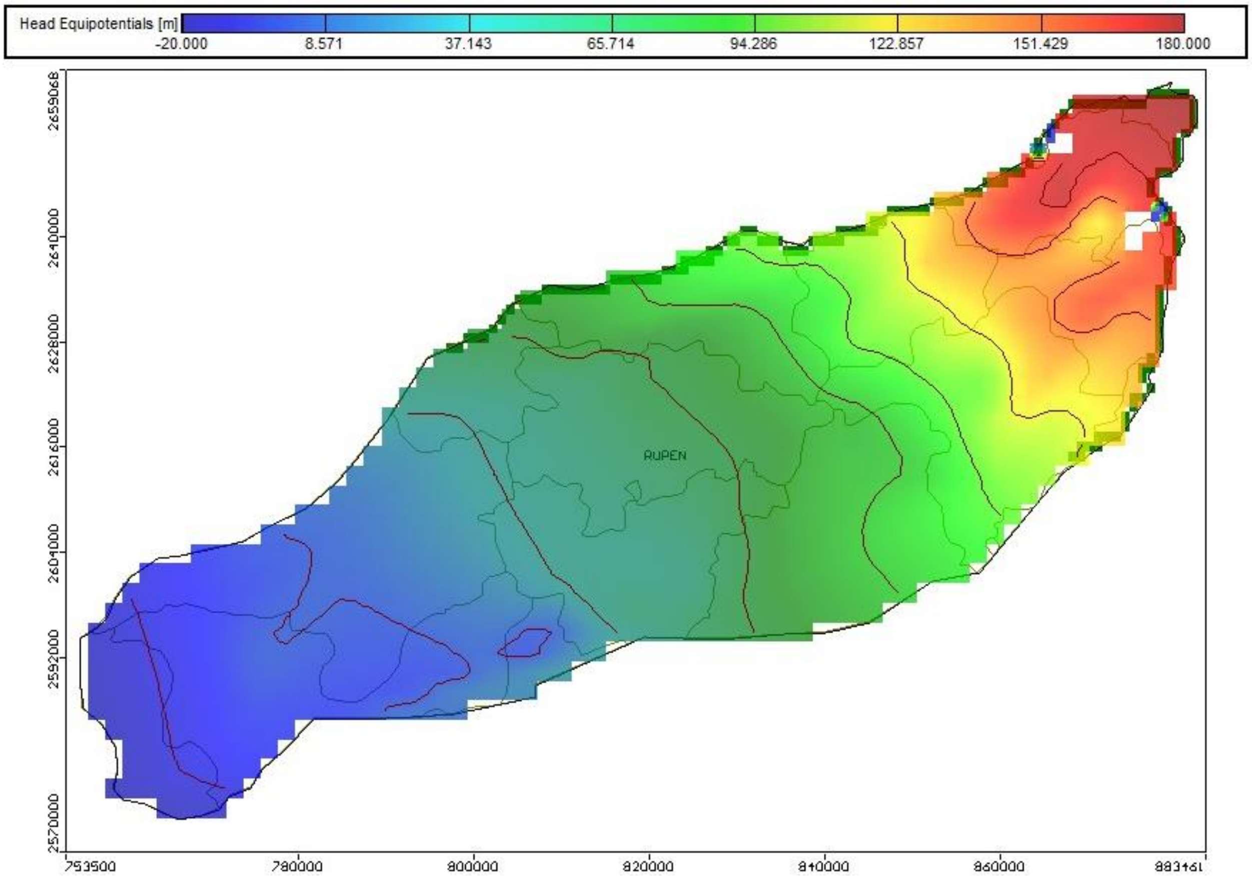


Figure.8a Simulated groundwater head during May 2007

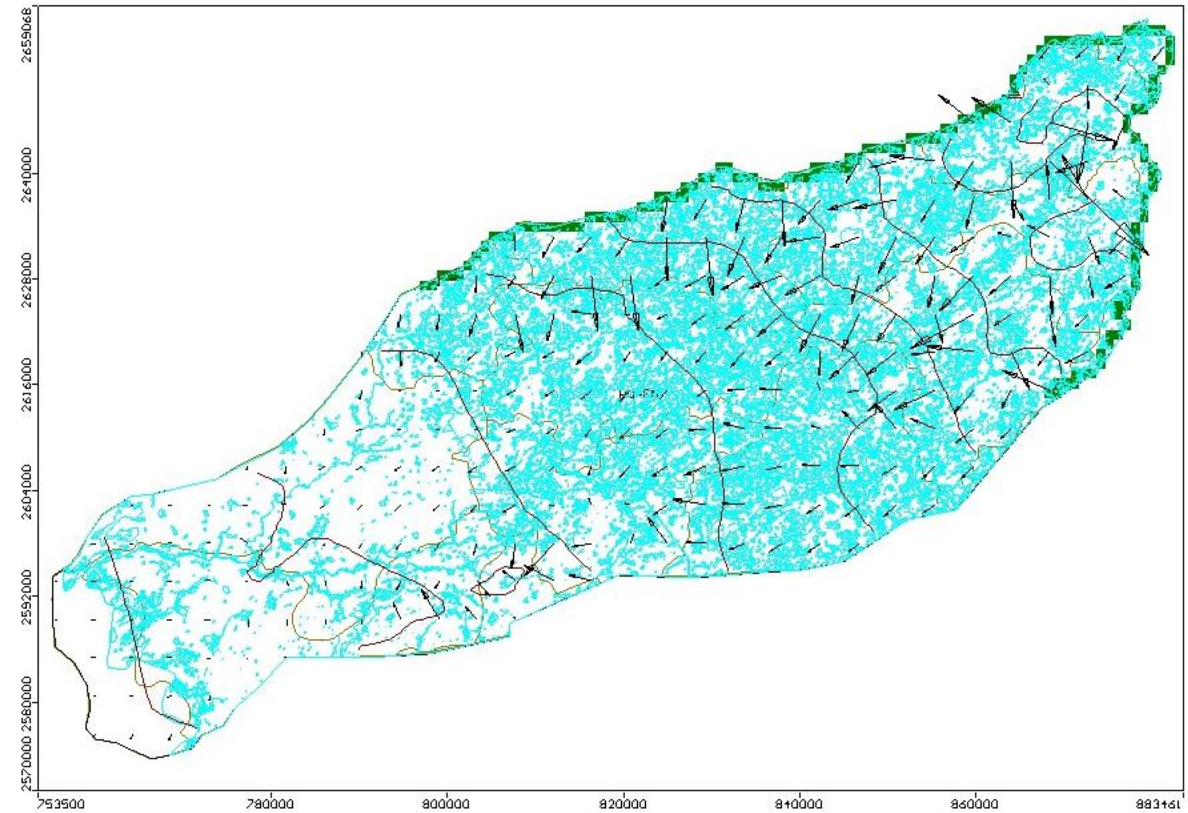


Figure-8b Groundwater flow vectors during May 2007

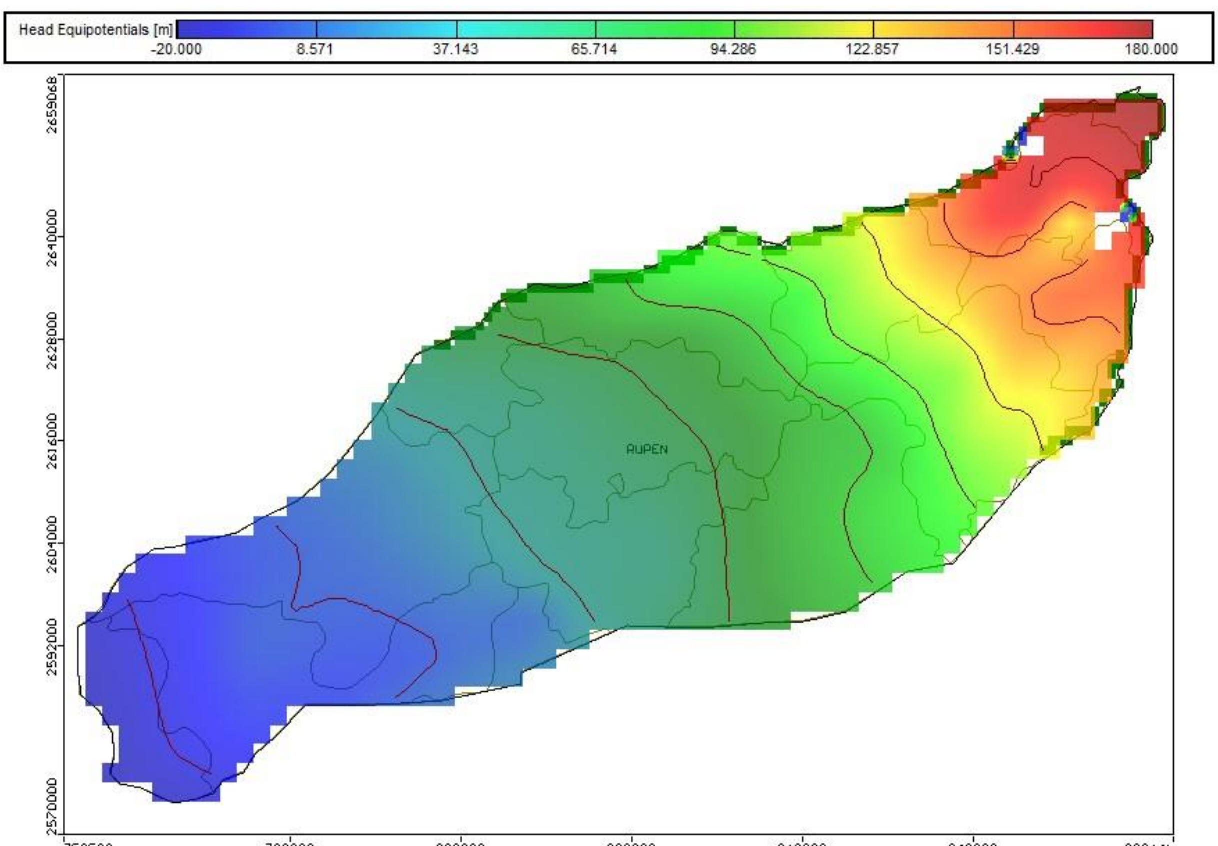


Figure.9a Simulated groundwater head during November 2009

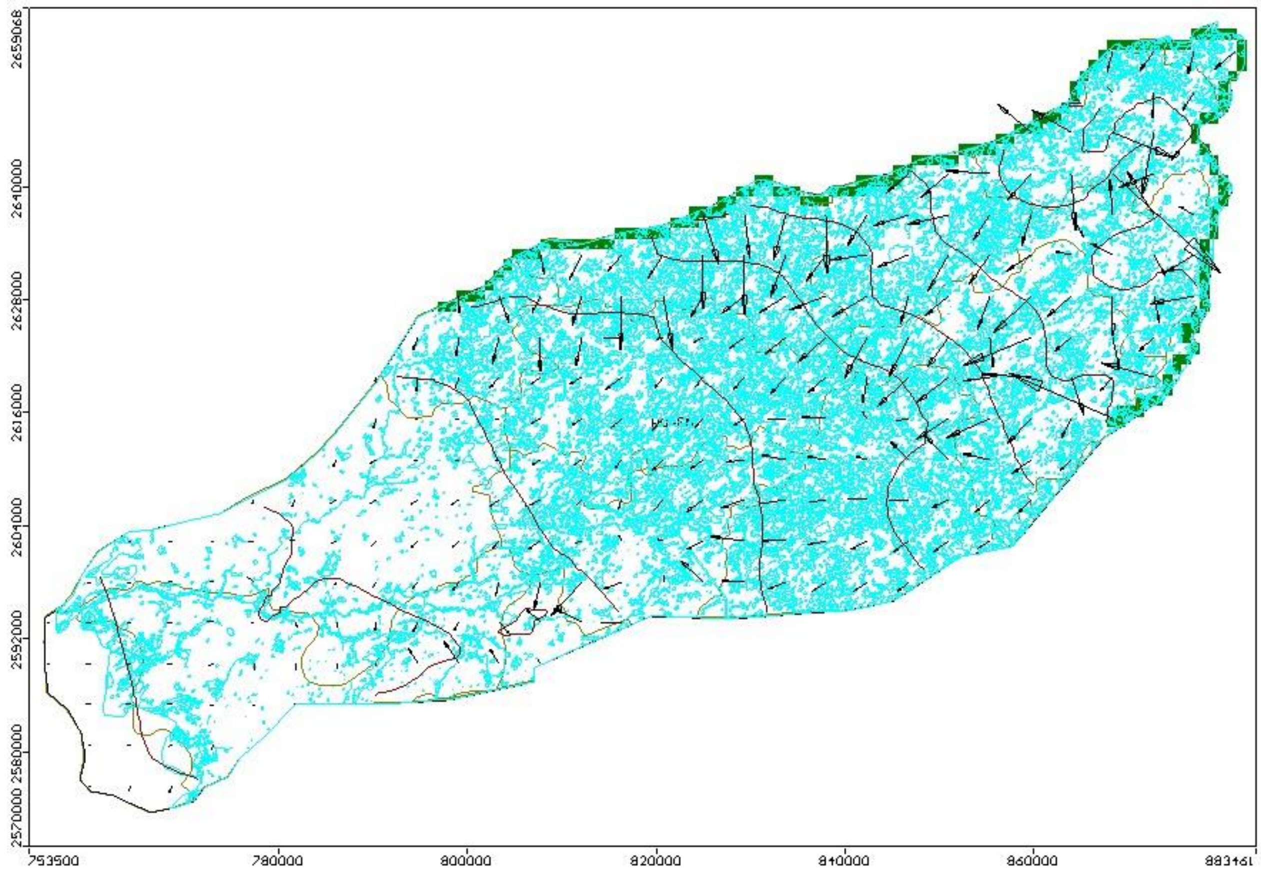


Figure 9b Groundwater flow vectors during November 2010

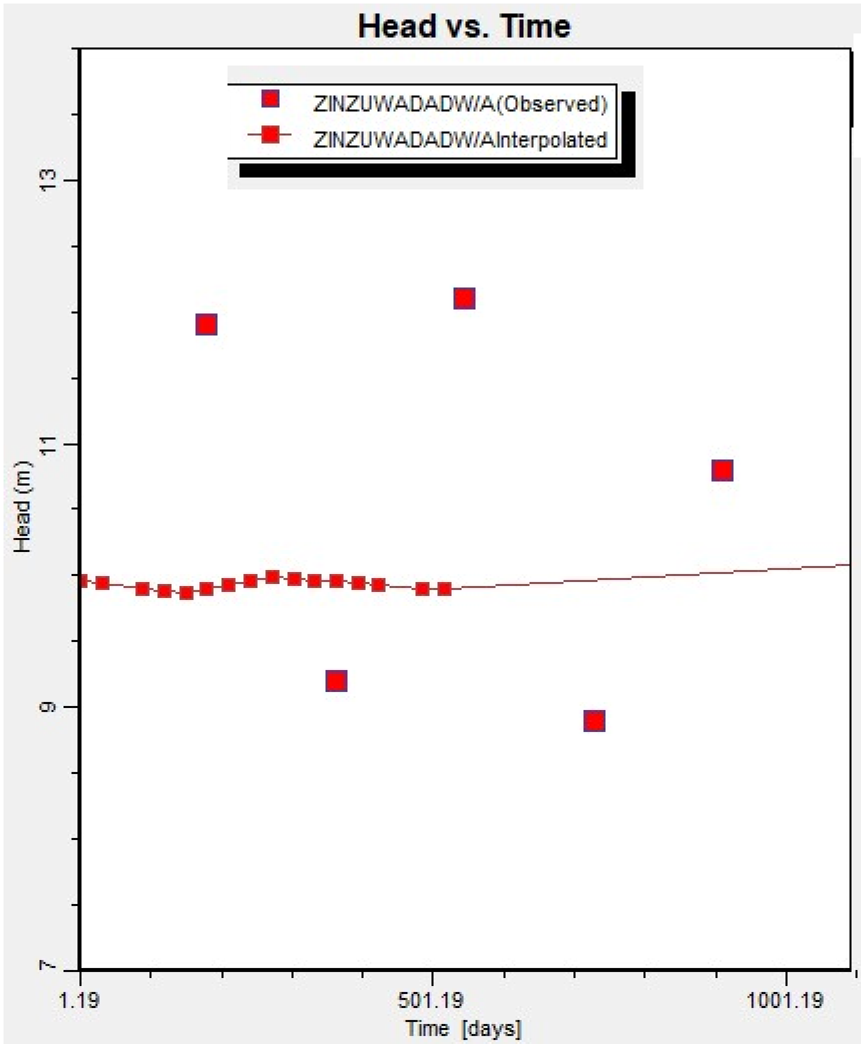


Figure.10a Times series analysis of Computed and observed head at Zinzuwada

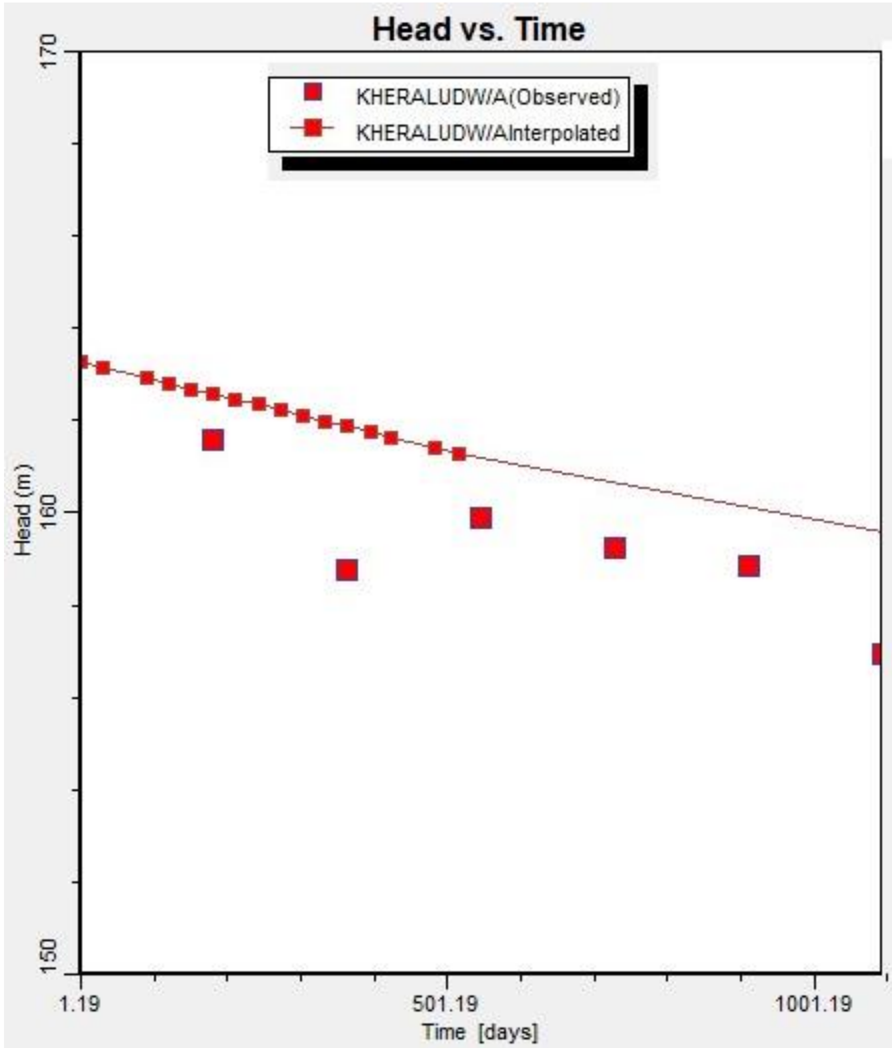


Figure.10b Times series analysis of Computed and observed head at Kheralu

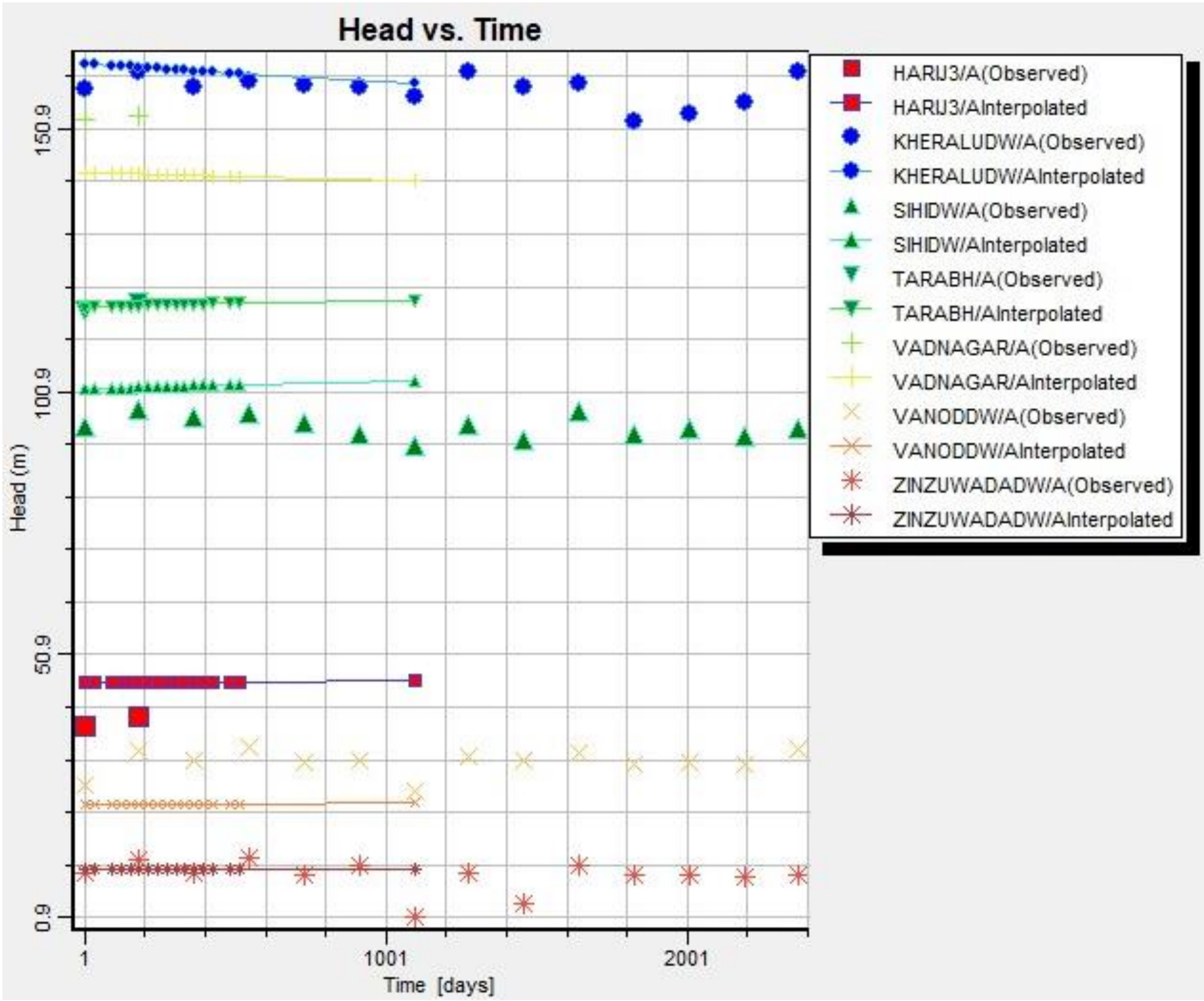


Figure.10c Times series analysis of Computed and observed heads at few selected wells in the modeling area

CONCLUSION

Single layer finite-difference flow model was used to simulate the groundwater head in Rupen basin aquifer system for a period of 3 years (May 2007-May 2010) for better understanding of the aquifer system. There was data gap for the aquifer parameters such as Transmissivity, Permeability and Specific yield. The simulated results with input of data by trial and error was able to establish the aquifer parameters of the first aquifer in the basin which is a multi layer alluvium aquifer system. The spatial groundwater head follows the topography. The groundwater water flows from the north east to south west with significant amount of ground water entering from the northern boundary which is also established by regional water table contour of the area. The ground water flow diminishes towards the south west part which has very fine sand/clayey sand as aquifer material adjoining the Rann of Kacchh. The computed groundwater head mimics the observed groundwater head in several locations.

Over all this ground water flow modeling exercise has been able to fix the aquifer parameters of the unconfined aquifer of Rupen basin.