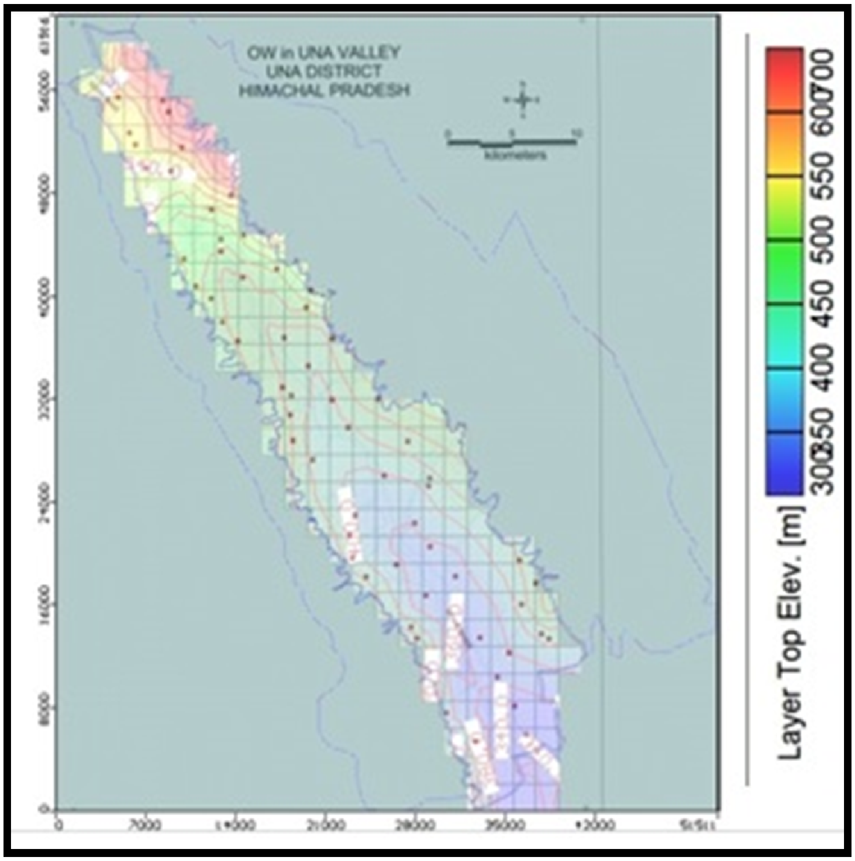
Report on

Ground Water Modelling Studies in Una Valley District Una, Himachal Pradesh



by

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Brief Report on
Ground Water Modelling Studies in Una Valley
District Una, Himachal Pradesh

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1.0 Introduction

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.

As a part of enhancing skills of officers of Central Ground Water Board (CGWB) and State Ground Water Departments (SGWD) in ground water domain and to provide required skills and know how on ground water flow modeling, National Project Monitoring Unit (NPMU), NHP, New Delhi had been arranged a tailor made 4 week's training course on Ground Water Modelling for Officers of CGWB and SGWD at IHE, Delft, The Netharlands from 14.03.2018 to 06.04.2018. The time schedule is the course is as follows.

Table-1: Time Schedule of the Training at IHE, Delft

Date	***Activities***	***Place***
14/03/2018	Arrival	**Delft**
15/03/2018	Introduction to IHE, Discussion of the course programme Lecture of theory of groundwater flow	IHE
16/03/2018	Lecture and exercise of theory of groundwater flow	IHE
17/03/2018	*Weekend*	
18/03/2018	*Weekend*	
19/03/2018	Lecture and exercise of finite difference method	IHE
20/03/2018	Lecture of MODFLOW packages, Exercise of MODFLOW model	IHE
21/03/2018	Lecture of MODFLOW packages, Exercise of MODFLOW model	IHE
22/03/2018	Lecture of modelling procedures, Exercise of MODFLOW model	IHE
23/03/2018	Lecture of modelling procedures, Exercise of MODFLOW model	IHE
24/03/2018	*Weekend*	
25/03/2018	*Weekend*	
26/03/2018	Exercise groundwater modelling: hypothetical case	IHE
27/03/2018	Exercise groundwater modelling: hypothetical case	IHE
28/03/2018	Preparation of Indian case studies	IHE
29/03/2018	Field visit	Eijkelkamp
30/03/2018	Easter Holiday	IHE
31/03/2018	*Weekend*	IHE
01/04/2018	*Weekend*	IHE
02/04/2018	Easter Holiday	IHE
03/04/2018	Indian case study: numerical model set-up	IHE
04/04/2018	Indian case study: Model inputs	IHE
05/04/2018	Indian case study: Steady state model	IHE
06/04/2018	Indian case study: Transient model Course evaluation and awarding certificates	IHE
07/04/2018	Departure participants/ *weekend*	IHE

2.0 Objectives

Numerical three-dimensional groundwater flow model was developed for the Una valley, District Una, Himachal Pradesh with the following objectives:

- To simulate regional groundwater flow to identify the distribution of heads,
- Impact on the aquifer system due to various hydrological stresses.
- To develop few scenarios for proper understanding of the aquifer system.
- For Efficient and sustainable management of the aquifer system.

3.0 Background Information

As a part of the program, CHQ, CGWB/NHP had mandated the participants to choose one area from the respective States to simulate ground water model in the training program under Indian Case Study. Accordingly District Una covering an area of 1542 Sq.kms had chosen as a case study from Himachal Pradesh. All the relevant data sets are collected, compiled and attempt had been made to simulate ground water model in Steady and Transient States during the last week of the training program at IHE, Delft.

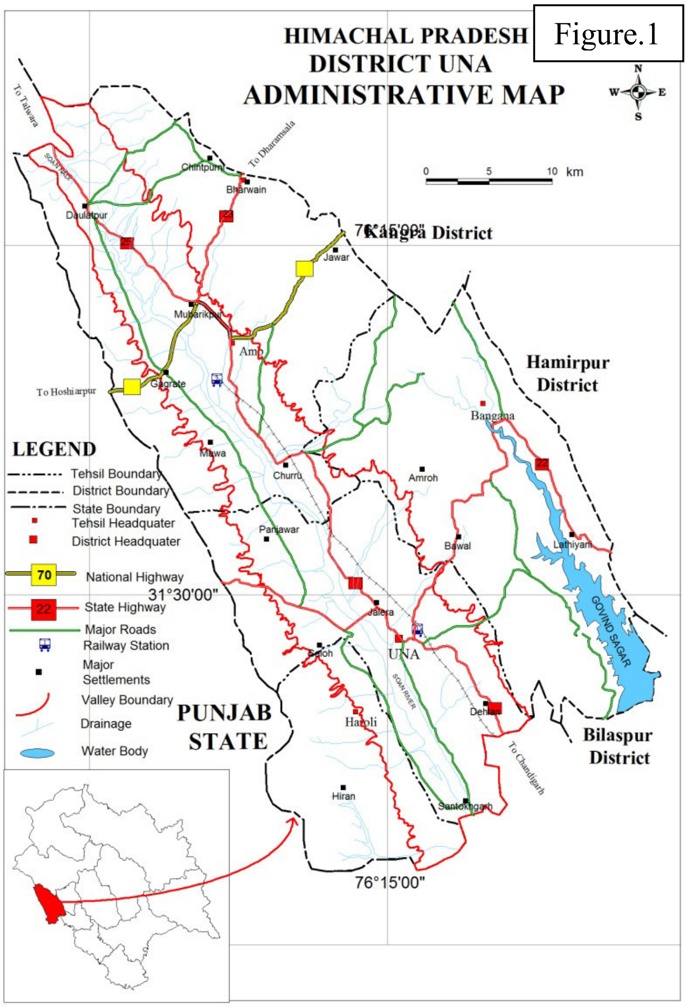


Figure.1

The study area is characterized by the Siwalik formation of Tertiary age with narrow longitudinal tectonic valley i.e. Una valley (Fig. 1) covering an area of 577 sq.km. The Una valley extends from Daulatpur to Santokhgarh and beyond the northern border of Dun-Syncline in the area is a thrust plane called Soan Thrust.

The model simulates groundwater flow over an area of **1542 sq.km** which is divided into cells with grid lines in x and y directions. 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 January 2013 to December 2017. 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, it is found that this aquifer system is stable at this pumping rate. The transient model was run until the year 2022 to forecast the dynamic groundwater flow under various scenarios of over pumping and less recharge. The model predicts the behavior of this aquifer system under various hydrological stress conditions.

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 2. The two sets of data are the physical framework and hydrological stresses.

Table 2. Data required in developing a numerical model

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

i. Ground water 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

ii. Modelling Protocol

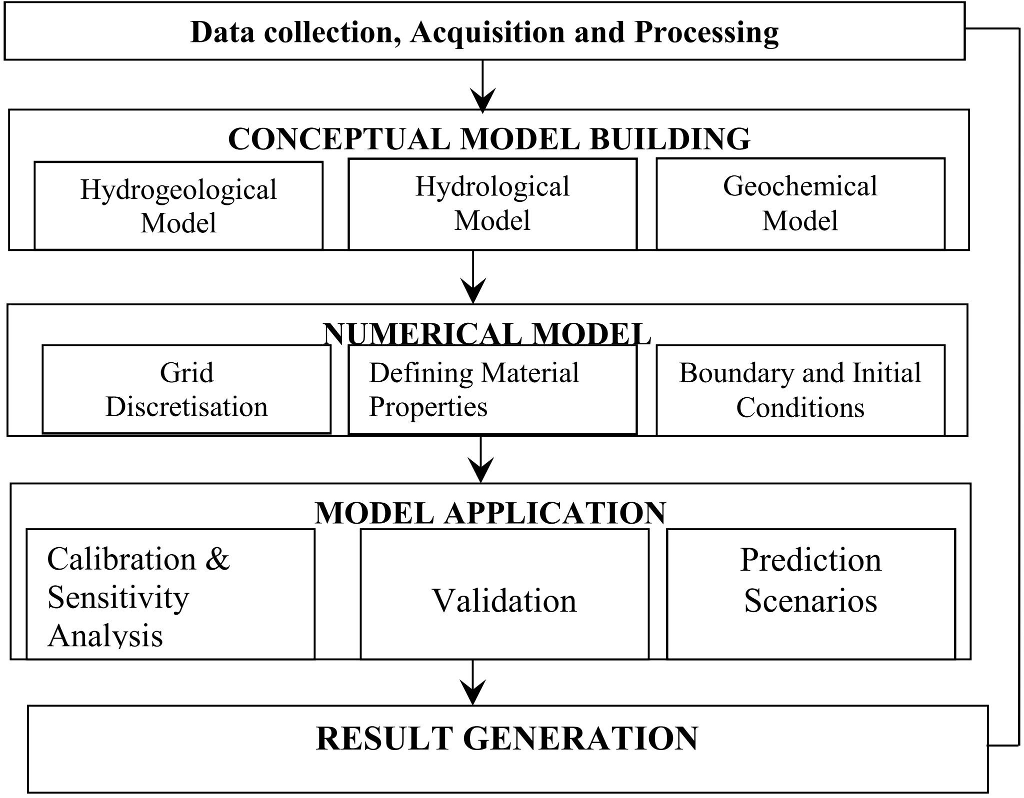
The modelling protocol used in this study for the construction of a numerical model involves the following steps:

- 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).

iii. 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.



Flowchart 1 Groundwater modelling methodology (after Bear 1992)

4.0 Model Conceptualization

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 alluvial formation in the valley area and surrounded by Siwalik formation. Groundwater is found to occur in unconfined conditions in the alluvial formation.

i. Grid Design

The geographic boundaries of the model grid covering 1542 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 2.0 km by 2.0 km. The model gird discretised into 841 cells with 29rows and 29 columns, and vertically by 1 layer **(Figure. 1).** The length of model cells is 2000 m along the east west and 2000 m along the north- south directions of the study area.

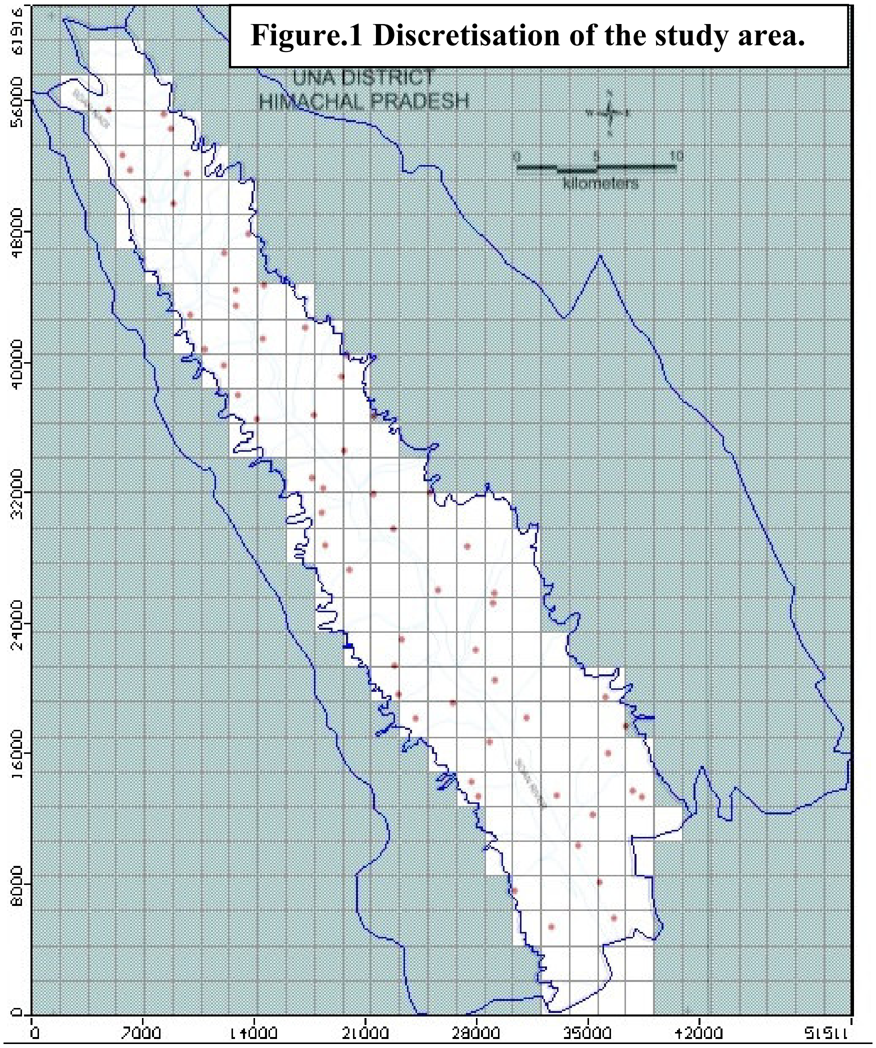


Figure.1 Discretisation of the study area.

ii. Boundary conditions

The study area forms a part of the Satluj River basin. The boundary conditions modeled are as per the watershed boundary (Figure.2).The western boundary of the study area is the Beet area of Siwalik formation and Eastern boundary is also falls under Siwalik formation of outer Himalayas. These boundaries are modeled as No Flow Boundaries as the flow from outside the boundary is negligible. In the middle of the Valley the Swan river flows from the north-western boundary to the south-eastern boundary and modeled as River Boundary. The inward entry and outward flow at the north-western and southeastern boundaries are modeled as General Head Boundary.

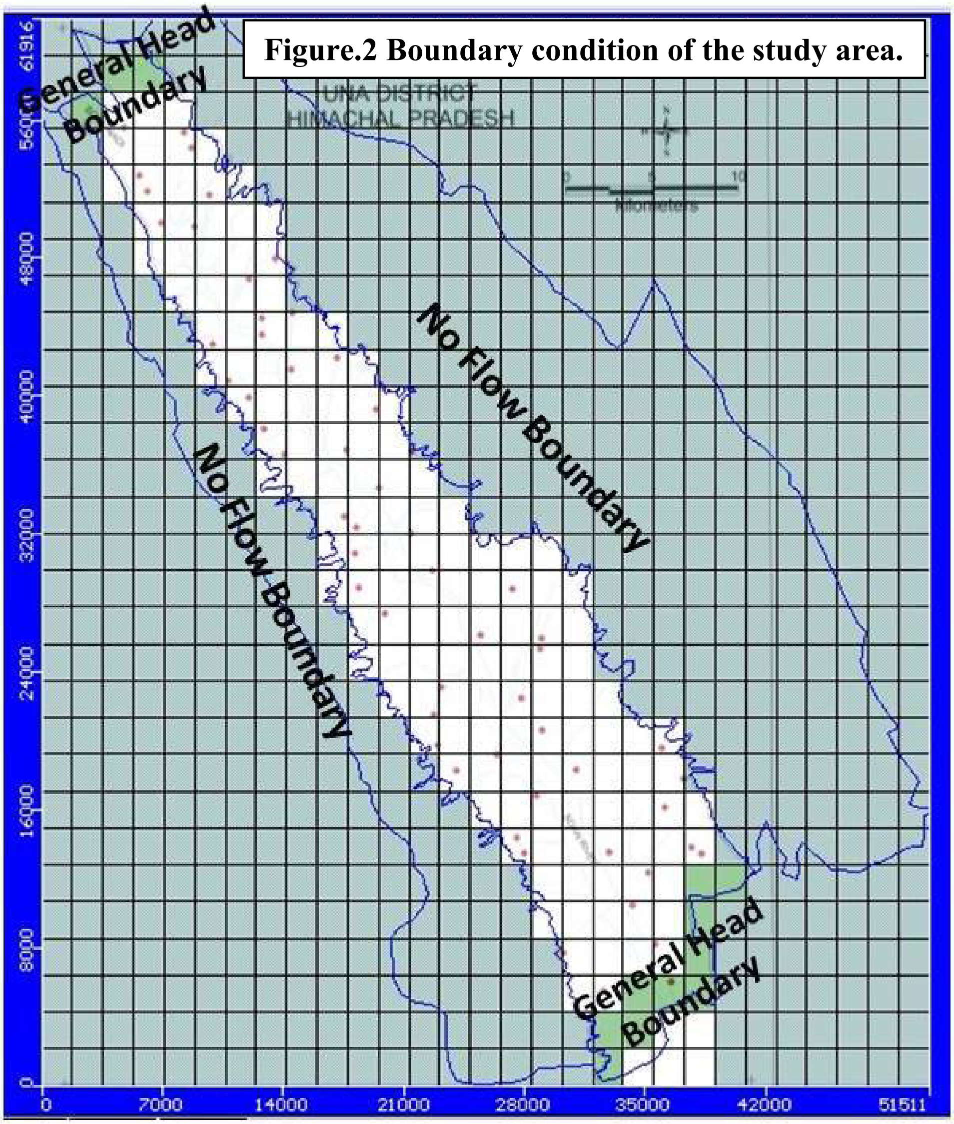


Figure.2 Boundary condition of the study area.

The aquifer top and bottom were derived mainly based on the lithology of boreholes and by intensive field surveys. The study area has been vertically divided into single aquifer system as no continuous confining layers have been observed. The unconfined layer comprises of the top soil and alluvial formation, which is underlain, by Siwalik formation, which occurs under semiconfined conditions.

iii. Input Parameters

a. 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 2013 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.

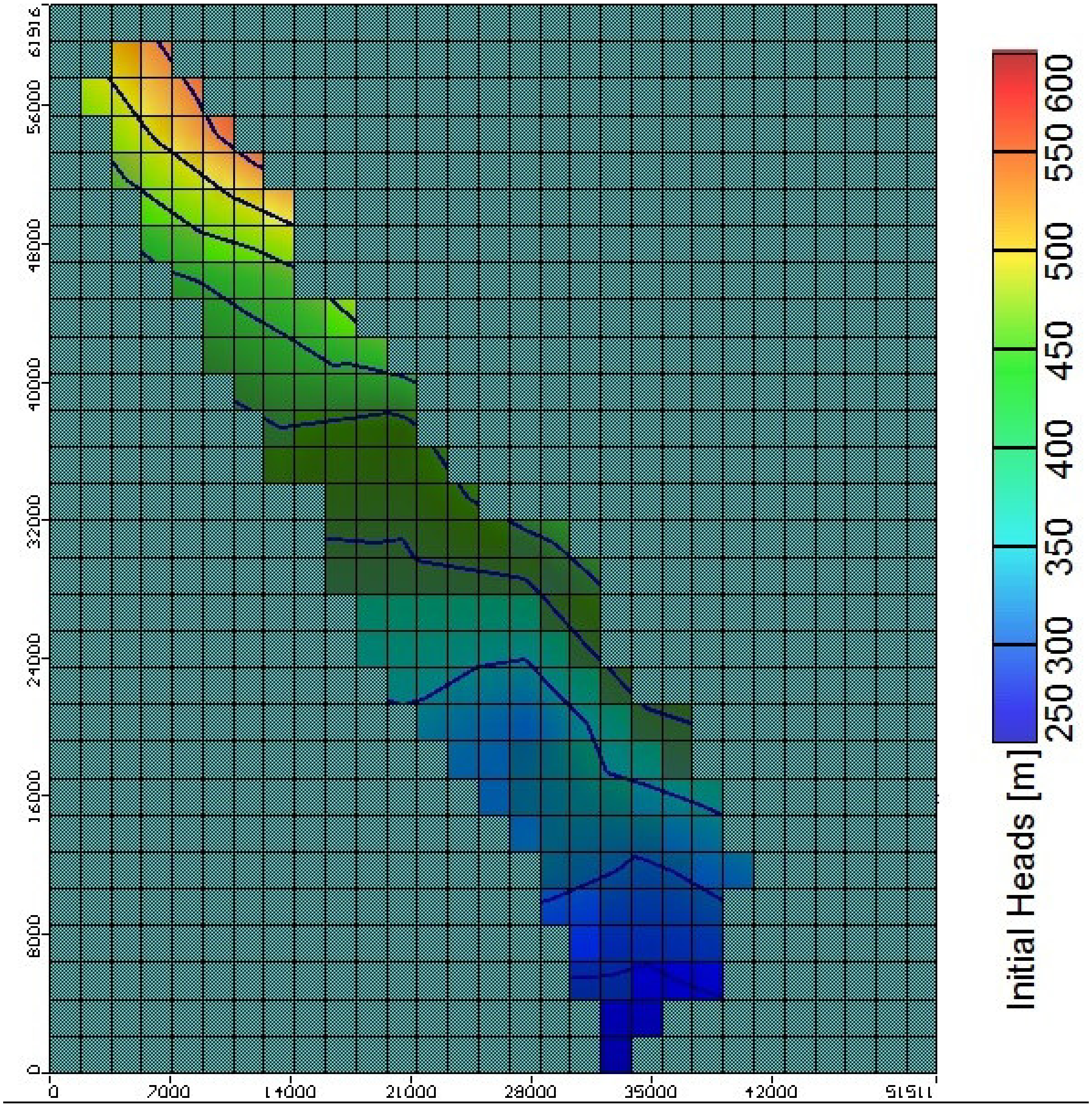


Figure 3. Initial groundwater head of the study area during May, 2013.

b. Aquifer Geometry

The aquifer geometry includes defining the aquifer top, bottom of I^{st} layer (Figure 3a & 3b). 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 alluvial formation with a maximum thickness of about 200 m and is underlained by Siwalik formation and the section west-east and north-south is given in figure 3c & 3d.

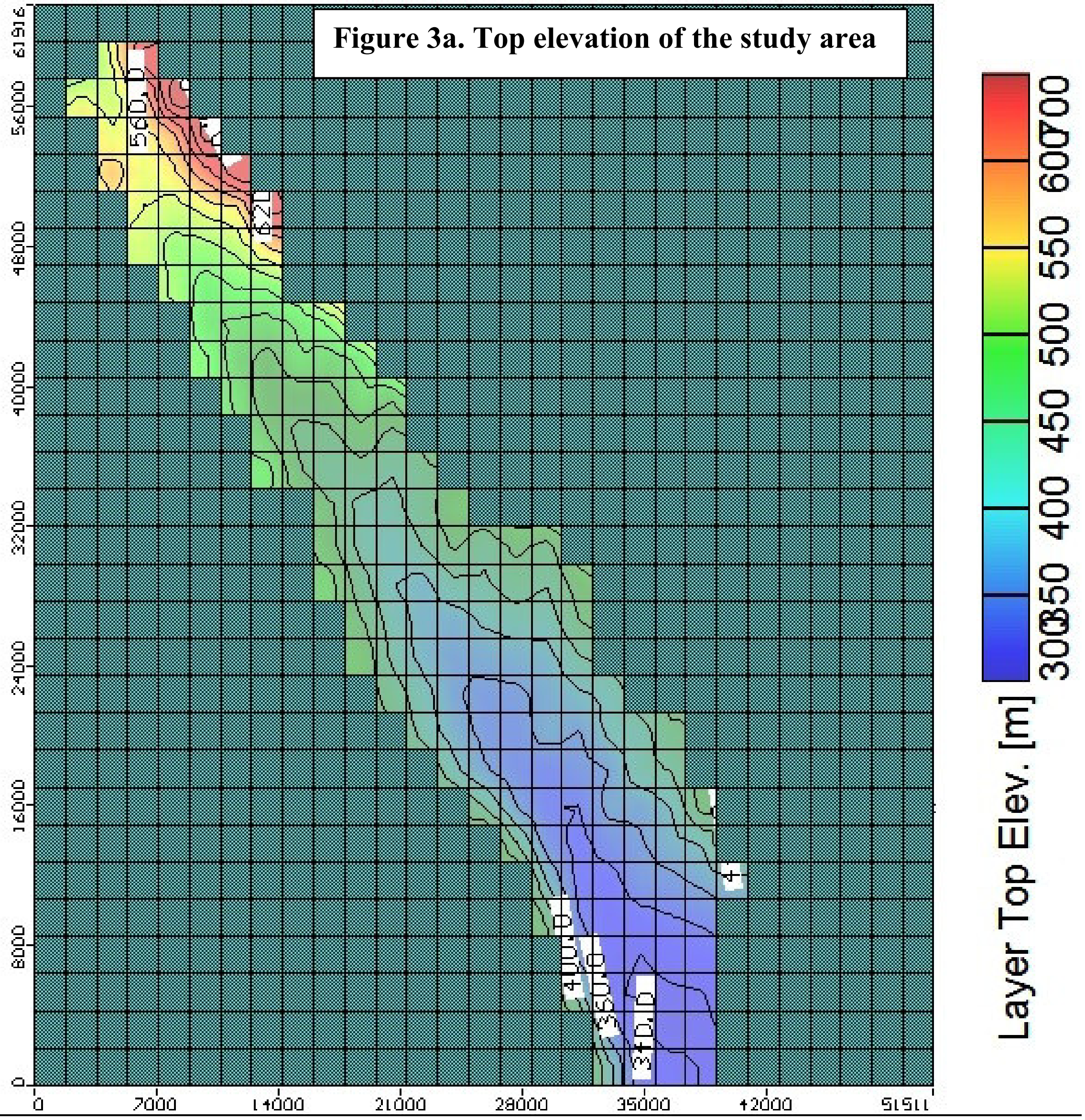


Figure 3a. Top elevation of the study area

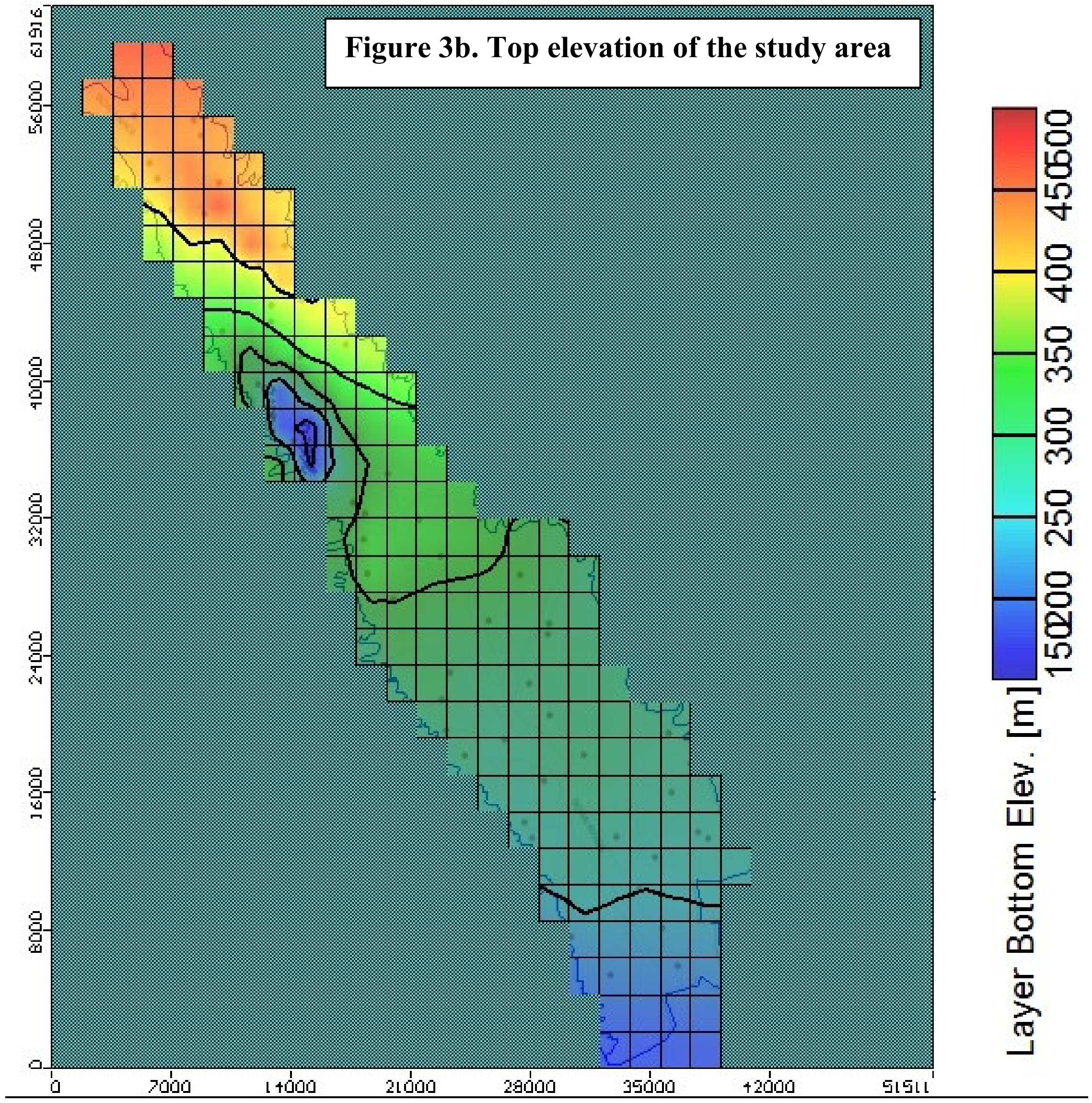


Figure 3b. Top elevation of the study area

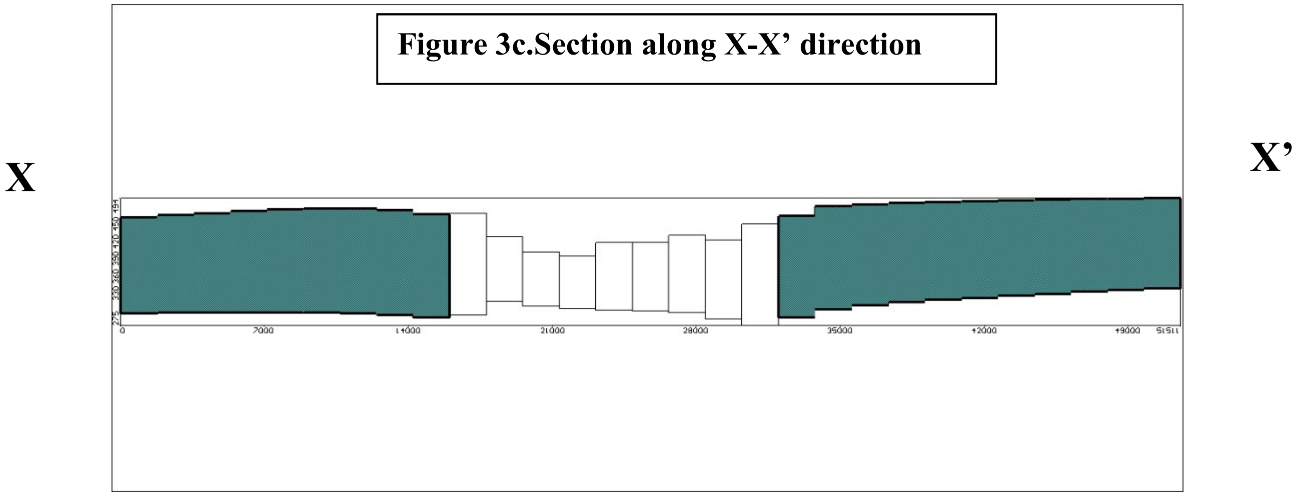
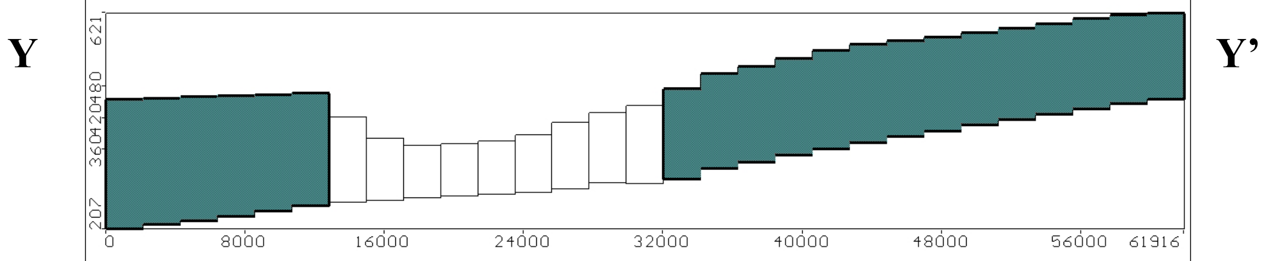


Figure 3c.Section along X-X' direction

Figure 3d.Section along Y-Y’ direction

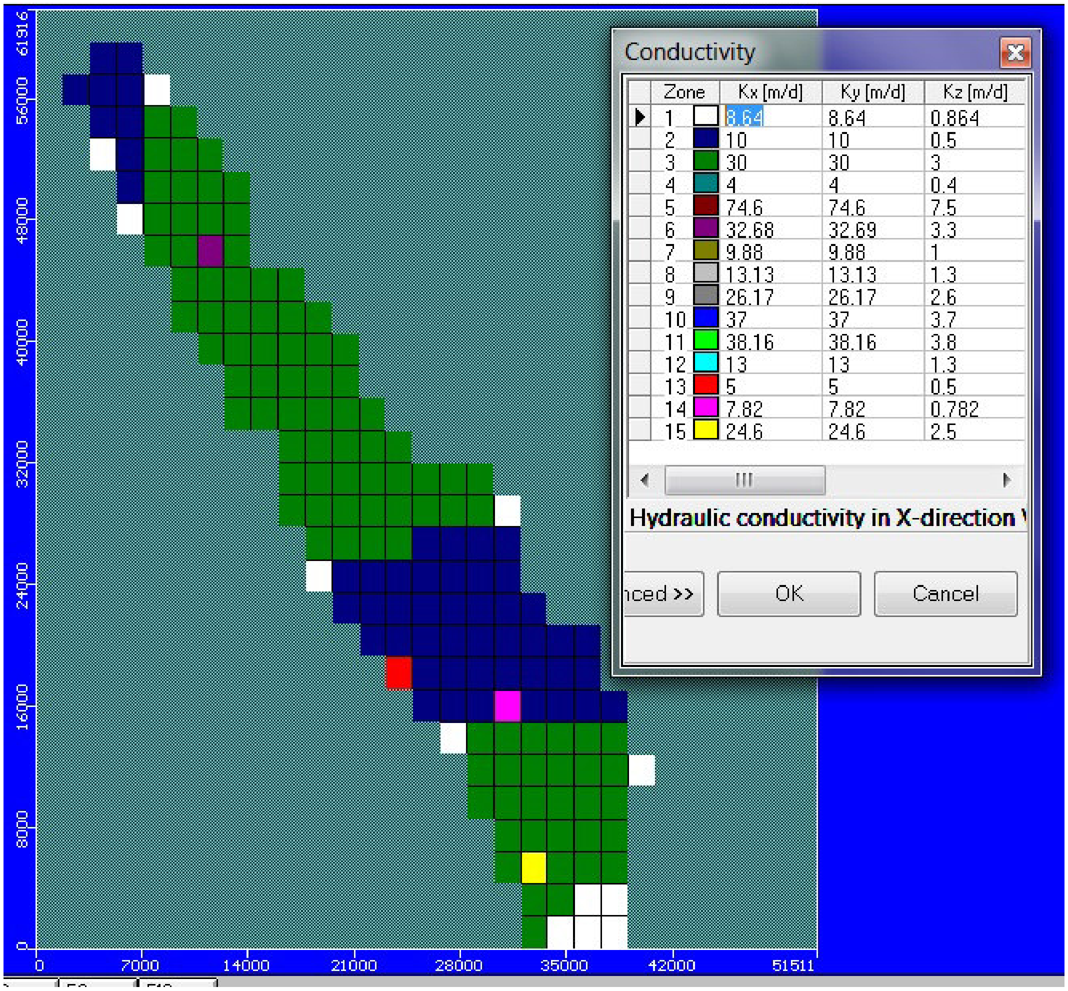


c. Aquifer characteristics

The aquifer properties such as horizontal hydraulic conductivity, Specific yield and storativity (figure 4a & b) used in the model was derived from 15 pumping tests results and is given in the Table 2.

Table.2 Summary of the Pumping test results

S No.	Station/village	Y Co-ordinate	X Co-ordinate	Transmissivity T (m2/day)	Aquifer Thickness B (m)	Hydraulic conductivity K (m/day)
1	Tatehra	31.62585	76.09573	1099.13	42	26.17
2	Tahliwal	31.3555	76.2747	959.41	39	24.60
3	Samurkalan	31.51145	76.287	89.03	42	2.12
4	Nagnauli	31.5541	76.133	312.15	24	13.01
5	Mahadeyiyan	31.4722	76.1942	149.91	30	5.00
6	Lower Bhanjal	31.70833	76.0625	1177	36	32.69
7	KVK Rampur	31.4555	76.26056	179.84	23	7.82
8	Kailash Nagar	31.75417	76.0434	1342.82	18	74.60
9	Jadla	31.5772	76.1187	648.7	17	38.16
10	Goindpur Banehra	31.74861	76.04583	353.95	35	10.11
11	Dhamandari	31.57278	76.2561	374.77	34	11.02
12	Daulatpur	31.788	75.9986	67.979	18	3.78
13	Chalan	31.67278	76.06028	512.22	39	13.13
14	Ambota Nagnath	31.67917	76.04361	656.06	33	19.88
15	Amb	31.61175	76.1108	1147.16	31	37.01



Conductivity

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1 ⬜	8.64	8.64	0.864
2 🟦	10	10	0.5
3 🟩	30	30	3
4 🟦	4	4	0.4
5 🟥	74.6	74.6	7.5
6 🟪	32.68	32.69	3.3
7 🟨	9.88	9.88	1
8 ⬜	13.13	13.13	1.3
9 ⬛	26.17	26.17	2.6
10 🟦	37	37	3.7
11 🟩	38.16	38.16	3.8
12 🟦	13	13	1.3
13 🟥	5	5	0.5
14 🟪	7.82	7.82	0.782
15 🟨	24.6	24.6	2.5

Hydraulic conductivity in X-direction

Figure.4a Hydraulic Conductivity values for Aquifer I

d. 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 and small region of lift irrigation system. The Landuse and landcover map was prepared to demarcate the area under cultivation. Information on the number of wells (open and borewells) available in the study area (Figure.5a& 5b) was collected from the Department Irrigation & Public Health Department, Govt. of Himachal Pradesh. The ground water draft was being calculated on the bases of **average discharge**, **pumping hrs**, **No. of borewells/dug wells** used for Irrigation, domestic and Industrial purpose in Una valley. The total ground water draft was distributed in all the cells in equal ratio due to non-availability of real data of individual wells (Table 3).

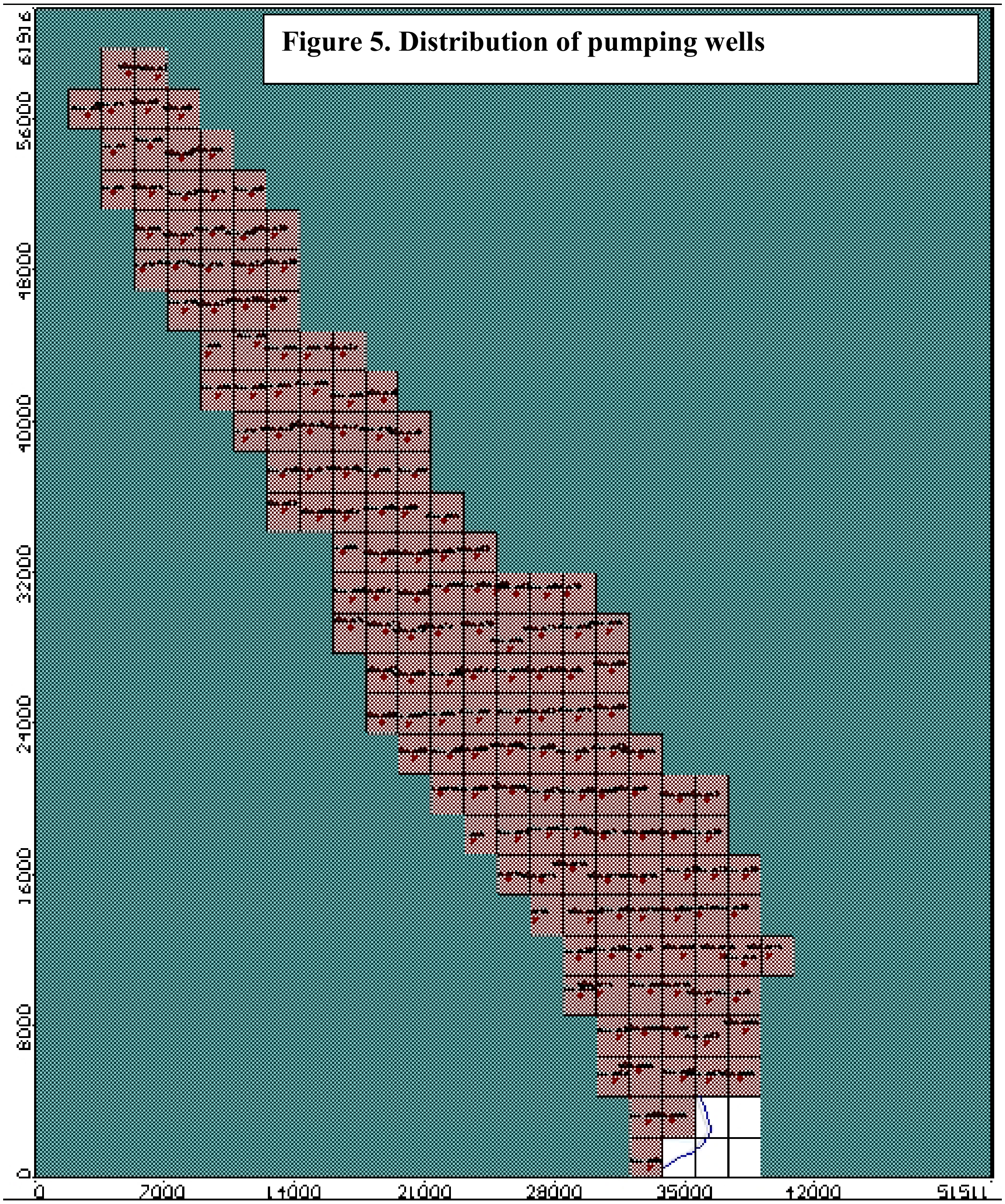
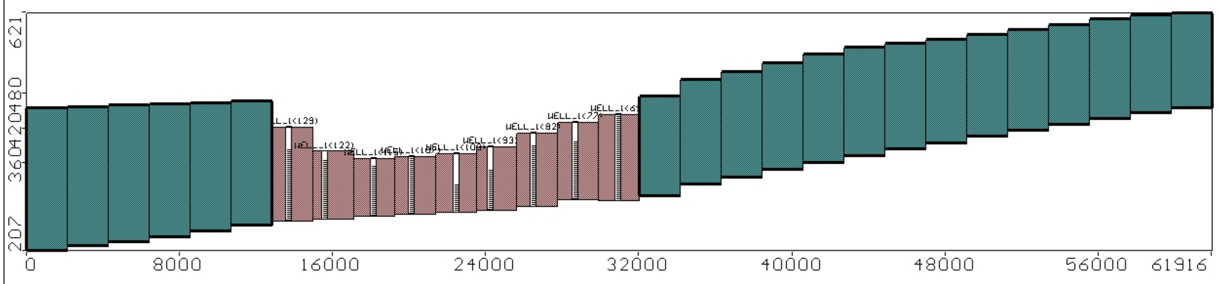


Figure 5. Distribution of pumping wells

Table 3. Ground water draft of Una valley

Total Ground water Draft (ham)	Total Monsoon Draft (ham)	Total Non-monsoon Draft (ham)	**Total Monsoon Draft (cub meter)**	**Total Non-Monsoon Draft (cub meter)**
9559.66	3186.553333	6373.106667	**31865533**	**63731067**

Figure 5a. Sectional view of the pumping wells



e. 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, irrigation and inflow from the river and storage tanks. Rainfall is the principal source of groundwater recharge. The rainfall hydrograph were studied to understand the recharge pattern in the study area. The aquifer gets recharged and groundwater level shoots with rainfall above 40 mm. The entire portion of the study area is geologically covered by top soil and alluvial formation. Recharge from monsoon and non-monsoon season have been estimated by Rainfall Infiltration Factor Method (GEC 1997) based on based on the Rainfall Infiltration Factor method and is estimated using the following equation

Rrf = f * A *Normal rainfall in monsoon season

Where

f = rainfall infiltration factor

A = area for computation of recharge

The infiltration capacity of alluvial formation ranges from 20 - 25 % and used 22% infiltration factor for this model as (Groundwater resources estimation committee report, 2013).

5.0 Running of Model

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.

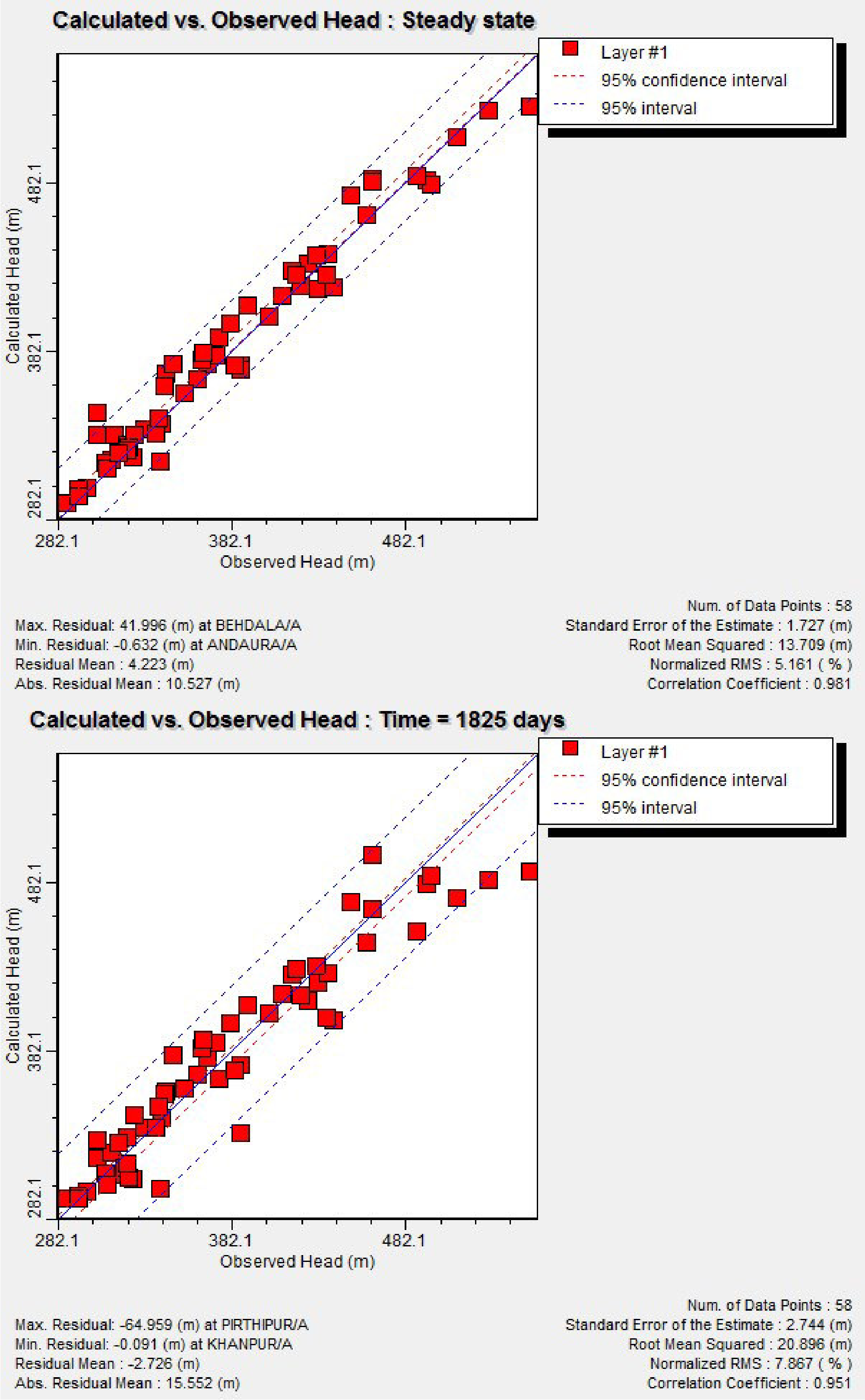
i. Steady state model:

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 2013 in 60 wells distributed over the study area. Out of all the input parameters, the Specific yield value is the only poorly known as only 15 pumping tests were available in this area. The lithological variations in the area and borehole lithology of existing wells were studied. Based on this it was decided to vary hydraulic conductivity values upto 10% of the pumping test results for layer in order to get a good match of the computed and observed heads (Figure. 6). 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.

ii. Transient State Model:

Transient state simulation was carried out for a period of 5 years from Jan 2013 to Dec 2017 with season wise stress periods during monsoon and non-monsoon for 245 days and 120 days respectively. 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 and recharge 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 Jan 2013 to Dec 2017 at 60 observation wells distributed through out the aquifer, the transient models were considered to be calibrated satisfactorily (Figure 6). 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 6. Comparison of computed and observed groundwater head under steady state & Transient state condition.



Max. Residual: 41.996 (m) at BEHDALA/A
Min. Residual: -0.632 (m) at ANDAURA/A
Residual Mean : 4.223 (m)
Abs. Residual Mean : 10.527 (m)

Num. of Data Points : 58
Standard Error of the Estimate : 1.727 (m)
Root Mean Squared : 13.709 (m)
Normalized RMS : 5.161 (%)
Correlation Coefficient : 0.981

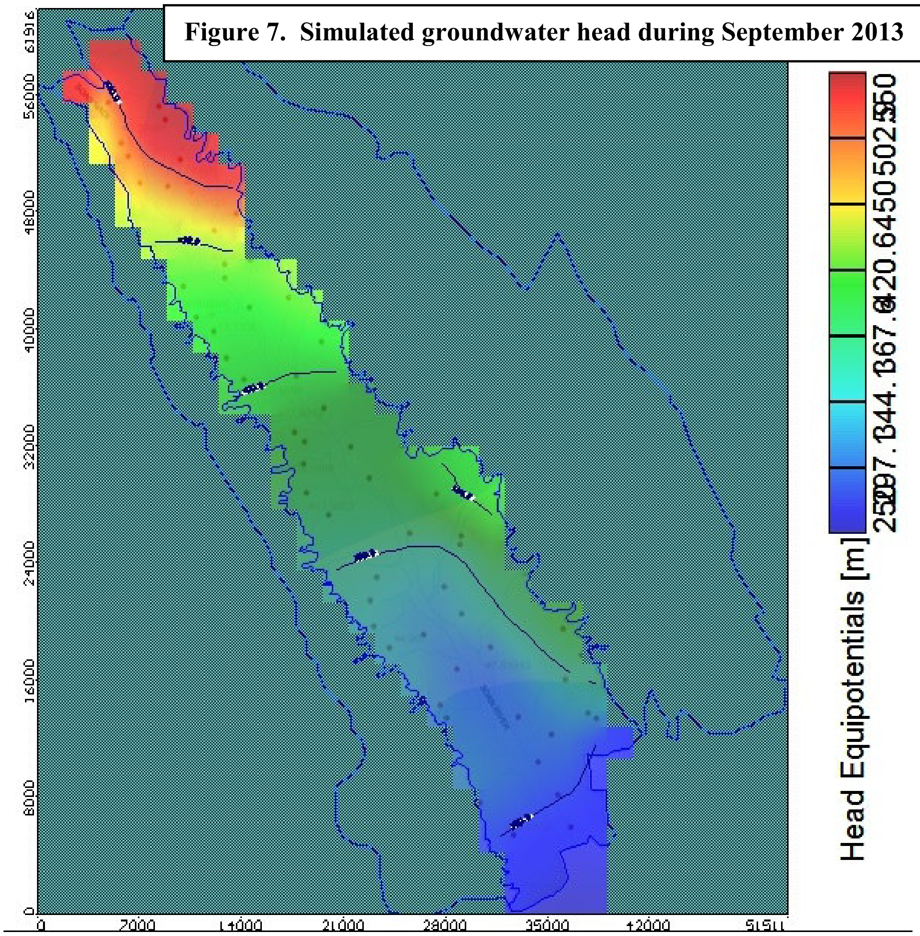
Max. Residual: -64.959 (m) at PIRTHIPUR/A
Min. Residual: -0.091 (m) at KHANPUR/A
Residual Mean : -2.726 (m)
Abs. Residual Mean : 15.552 (m)

Num. of Data Points : 58
Standard Error of the Estimate : 2.744 (m)
Root Mean Squared : 20.896 (m)
Normalized RMS : 7.867 (%)
Correlation Coefficient : 0.951

6.0 Simulation Results

The model was simulated in transient condition for a period of 5 years from January 2013 to December 2017. There was fairly good agreement between the computed and observed heads (Figure.7). A study of the simulated potentiometric surface of the aquifer indicates that the highest heads are found on the North-western side of the study area, which is a general reflection of the topography. The regional groundwater flow direction is from north-east to south-west. The groundwater flow vectors for the month of December 2012 is given in figure.8. The comparison of observed and computed heads in given in figure 9. The computed and observed heads for Daulatpur and Amb village clearly shows the match in the pattern and trends (Figure.9). The transient simulation clearly shows the matching of pattern of the groundwater head with change in time.

Figure 7. Simulated groundwater head during September 2013



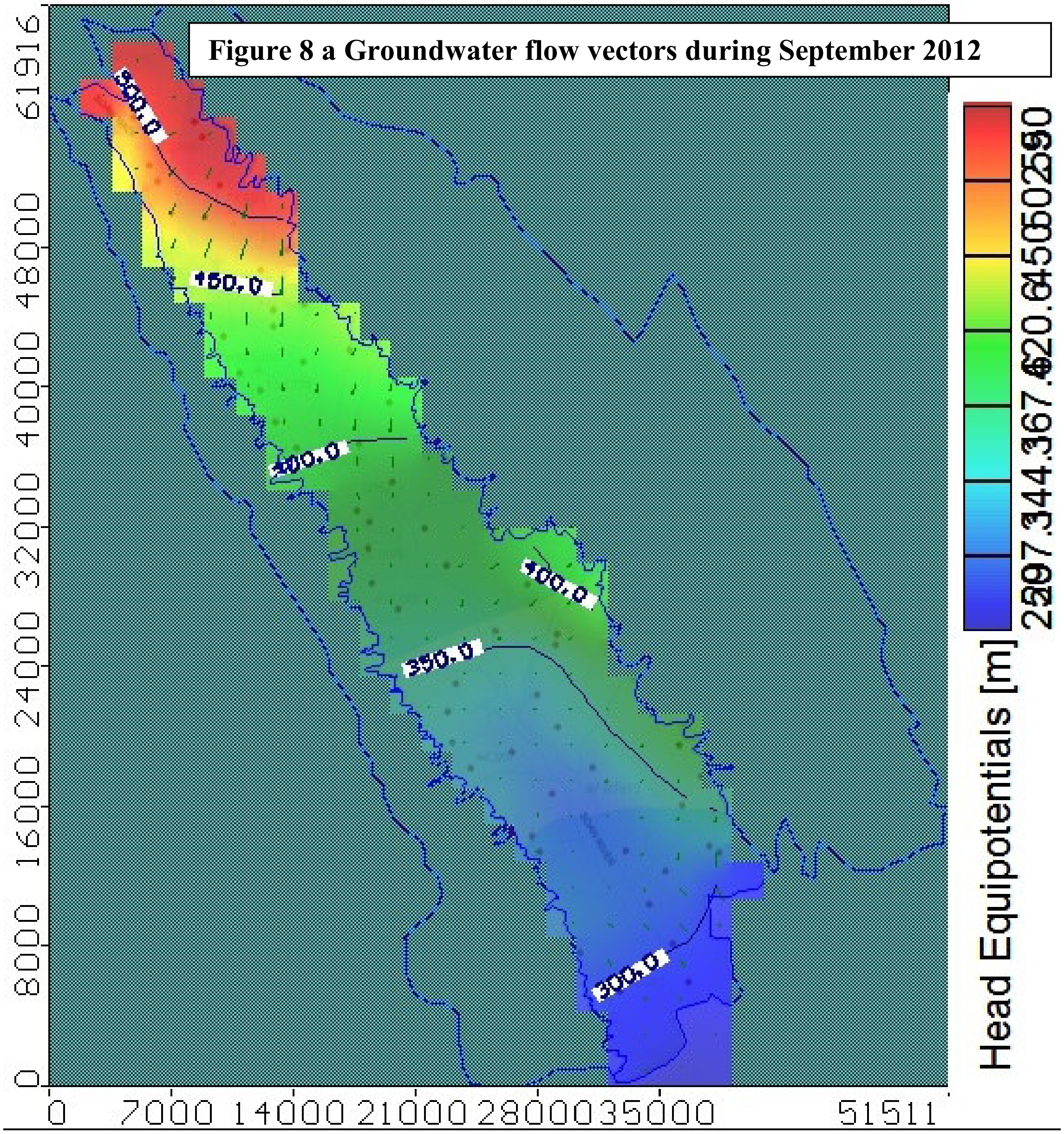


Figure 8 a Groundwater flow vectors during September 2012

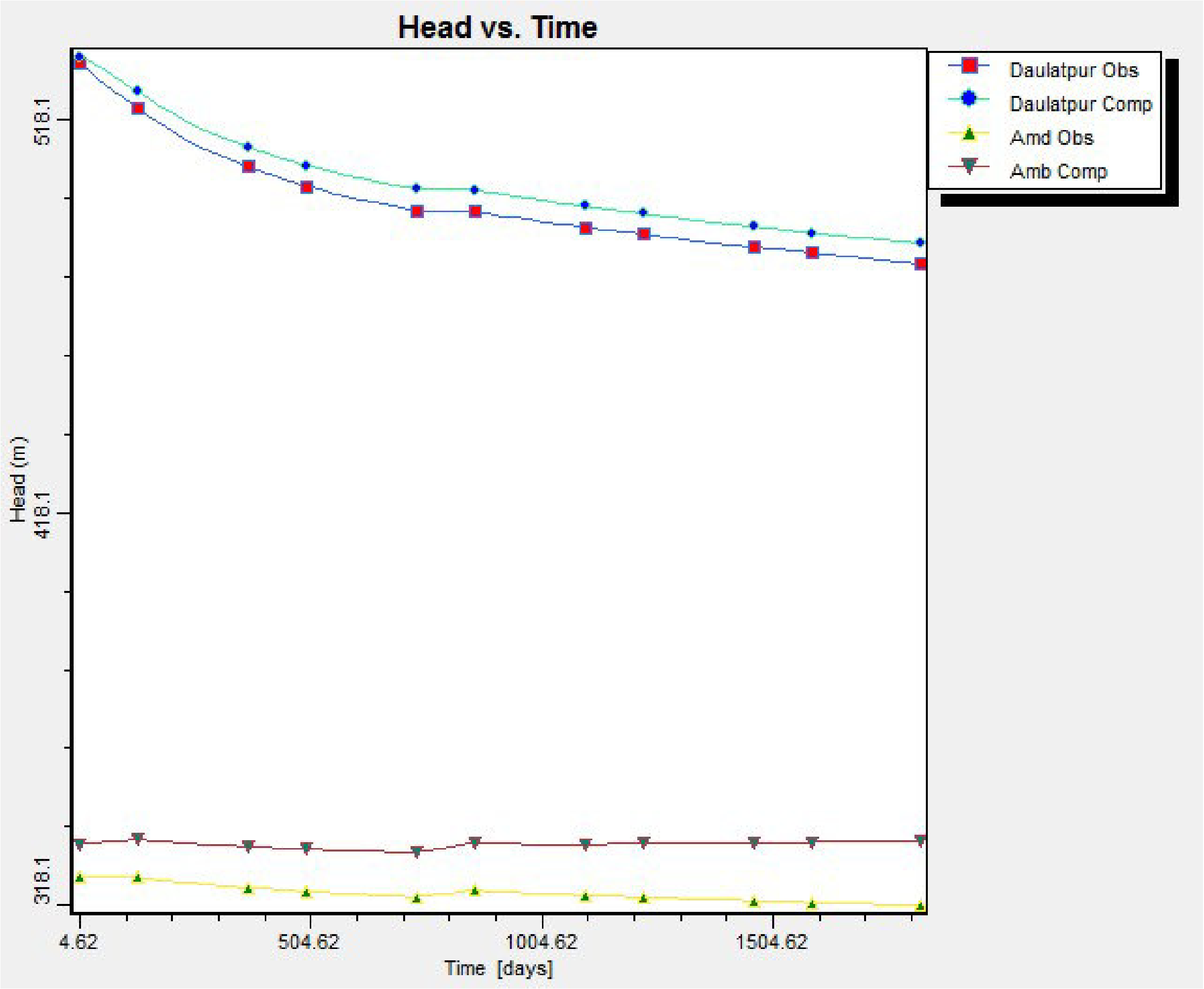


Figure.9 Times series analysis of Computed and observed at Daulatpur & Amb villages

7.0 Model Prediction

The aquifer response for different input and output fluxes was studied in order to sustainably manage the aquifer system. The model was run for a further period of 05 years from 2017 to 2022. Before commencement of this simulation, the data of normal rainfall, abstraction, and recharge was provided to the model upto 2022.

One prediction runs were planned to evolve optimal management schemes.

i. Normal rainfall condition

The model was run to predict the regional groundwater head in this area until the year 2022. For these runs the monthly average rainfall calculated from 05 years rainfall data was used. The present level of groundwater abstraction was considered for this simulation. The simulated regional groundwater head for September 2022 is shown in Figure.10. There is not much increase or decrease in water level (Figure. 10). Such observation is made in most of the locations. This clearly indicates that the model is stable under the present pumping conditions.

ii. Increase in Pumping

The model was run to predict the regional groundwater head in area until the year 2022 with 30 % increase in pumping for which the normal monsoon and non monsoon rainfall data was used. The predicted model indicates that there is uniform decline of ground water head in the aquifer of study area (Figure. 10).

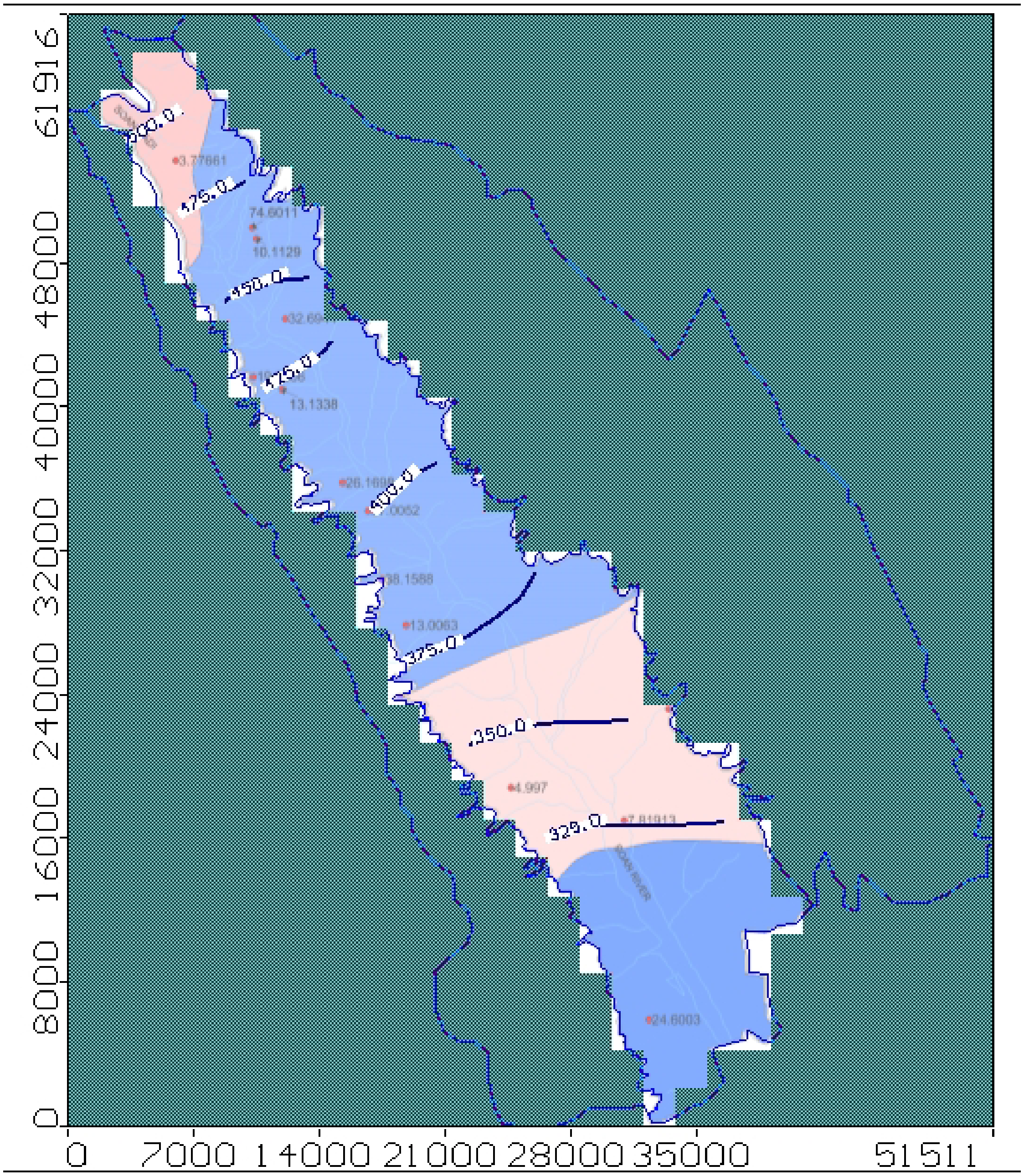


Figure. 10. Predicted groundwater head 2022 under normal present conditions.

7.0 Conclusion

Three-layered finite-difference flow model was used to simulate the groundwater head in the Una aquifer system for a period of 5 years (Jan 2013-Dec 2017) for better understanding of the aquifer system. All the data was inputted into the model and Visual Modflow Classic 4.6.0.166 was used to simulate the model. 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, it is found that this aquifer system is stable at this pumping rate. The transient model was run until the year 2022 to forecast the dynamic groundwater flow under various scenarios of over pumping and less recharge. The model predicts the behavior of this aquifer system under various hydrological stress conditions. The simulated results indicate that this aquifer system is stable under the present conditions. The spatial groundwater head follows the topography. The groundwater water flows from the north to south -south eastern. The computed groundwater head mimics the observed groundwater head in several locations. The model helps in understanding the groundwater head trend and illustrates the impact of changes in hydrological conditions, thus enables the water managers for an effective management tool.