CHAPTER 6

GROUND WATER SIMULATION MODEL FOR THE CANAL COMMAND AREA

6.1. Introduction

Ground water simulation model was developed for the study area. Ground flow equation needs proper boundary conditions, aquifer parameters to simulate real study area. Observed ground water levels at different locations are used to calibrate and validate the model.

6.2-Ground water simulation using ,Visual mudflow

A groundwater model, Visual MODFLOW is used to predict the effects of hydrological changes (like groundwater abstraction or irrigation developments) on the behaviour of ground water table that simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method (McDonald and Harbaug). Ground water flow equation

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \qquad 6.1$$

Where

Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

W is a volumetric flux per unit volume representing sources and/or sinks of water, with W<0.0 for flow out of the ground-water system, and W>0.0 for flow in (T-1);

Ss is the specific storage of the porous material (L-1); and

t is time (T).

Equation 6.1, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

The Ground-Water Flow Process solves equation 6.1 using the finite-difference method in which the groundwater flow system is divided into a grid of cells .For each cell, there is a single point, called a node, at which head is calculated.

The finite difference form of the partial differential in a discredited aquifer domain (represented using rows, columns and layers) is:

$$CR_{i,j-\frac{1}{2},k}\left(h^m_{i,j-1,k} - h^m_{i,j,k}\right) + CR_{i,j+\frac{1}{2},k}\left(h^m_{i,j+1,k} - h^m_{i,j,k}\right) +$$
$$CC_{i-\frac{1}{2},j,k}\left(h^m_{i-1,j,k} - h^m_{i,j,k}\right) + CC_{i+\frac{1}{2},j,k}\left(h^m_{i+1,j,k} - h^m_{i,j,k}\right) +$$
$$CV_{i,j,k-\frac{1}{2}}\left(h^m_{i,j,k-1} - h^m_{i,j,k}\right) + CV_{i,j,k+\frac{1}{2}}\left(h^m_{i,j,k+1} - h^m_{i,j,k}\right) +$$

Where $P_{i,j,k}\, h^m_{i,j,k} + Q_{i,j,k} = SS_{i,j,k}\left(\Delta r_j \Delta c_i \Delta v_k\right) \frac{h^m_{i,j,k} - h^{m-1}_{i,j,k}}{t^m - t^{m-1}}$

$h_{i,j,k}^{m}$ is the hydraulic head at cell i,j,k at time step m

CV, CR and CC are the hydraulic conductance, or branch conductance between node i,j,k and a neighboring node

$P_{i,j,k}$ is the sum of coefficients of head from source and sink terms

$Q_{i,j,k}$ is the sum of constants from source and sink terms, where $Q_{i,j,k} < 0.0$ is flow out of the groundwater system (such as pumping) and $Q_{i,j,k} > 0.0$ is flow in (such as injection)

$SS_{i,j,k}$ is the specific storage

$\Delta r_j \Delta c_i \Delta v_k$ are the dimensions of cell i,j,k, which, when multiplied, represent the volume of the cell; and

t^{m} is the time at time step m

6.3. Model Inputs: The inputs to the model are:

6.3.1. Hydrological inputs:

The hydrological inputs consist of hydrological data like rainfall, evapotranspiration and surface runoff, which determine the recharge. These inputs may vary in both time and space.

6.3.2. Operational inputs:

The operational inputs concern human interferences with the water management like irrigation, drainage, pumping from wells, water table control and the operation of retention or infiltration basins, which are often of a hydrological nature. These inputs may also vary in time and space.

6.3.3. Boundary and initial conditions:

Boundary conditions can be related to levels of the water table, artesian pressures, and hydraulic head along the boundaries of the model on the one hand (the head conditions), or to groundwater inflows and outflows along the boundaries of the model on the other hand (the flow conditions). They may also include quality aspects of the water like salinity.

In MODFLOW's River package the Conductance for the River boundary condition in each grid cell is calculated using the following formula:

$$\$COND = \frac{\$RCHLNG \cdot \$WIDTH \cdot \$K \cdot \$UCTOCOND}{\$RBTHICK}$$

Where

$COND = Riverbed Conductance [L2/T]

$RCHLNG = Reach length of the river in each grid cell [L]

$RBWIDTH = Riverbed width in each grid cell [L]

$RBTHICK = Riverbed thickness in each grid cell [L]

$K = Riverbed vertical hydraulic conductivity [L/T]

$UCTOCOND = Unit conversion factor

The reach length ($RCHLNG) of the river in each grid cell is determined from the line used to digitize the river location in the model. The riverbed width ($RBWIDTH), riverbed thickness ($RBTHICK), and riverbed hydraulic conductivity ($K) are user-defined parameters. The unit conversion factor ($UCTOCOND) is used to convert the hydraulic conductivity value from conductivity units to conductance units.

In MODFLOW's Drain Package is designed to simulate the effects of features such as agricultural drains, which remove water from the aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or elevation. The Drain package assumes the drain has no effect if the head in the aquifer falls below the fixed head of the drain. The drain package is also used for the study area to simulate its impact .The Conductance value per unit length/area of the Drain grid cells is as follows

$COND = $RCHLNG · $LCOND

Where

$COND: is the Conductance

$RCHLNG: is the reach length of the drain in each grid cell

$LCOND: is the Conductance per unit length of the drain in each grid cell

The initial conditions refer to initial values of elements that may increase or decrease in the course of the time inside the model domain and they cover largely the same phenomena as the boundary conditions do. The initial head and boundary conditions may vary from place to place. The boundary conditions may be kept either constant or be made variable in time.

6.3.4. Parameters:

The parameters usually concern the geometry of and distances in the domain to be modelled and those physical properties of the aquifer that are more or less constant with time but that may be variable in space. Important parameters are the topography, thicknesses of soil / rock layers and their horizontal/vertical hydraulic conductivity (permeability for water), aquifer transmissivity and resistance, aquifer porosity and storage coefficient, as well as the capillarity of the unsaturated zone.

6.4. Model development:

The groundwater model presented in this report relates to the upper, unconfined aquifer only, as it is considered separate from deeper aquifers. The X axis of the developed modeling frame work in MODFLOW lies between latitude 602950m to 660139 m while Y axis of lies between longitude of 2859775 m and 2901713 m. The modeling framework area is 239839 ha or 2398.39 sq km (57.189 km*41.938 km) as shown in Figure 6.1. The model area of 57.189km*41.938 km has been divided in 400 columns and 300 rows that are in the grid size of 143 m *140 m.

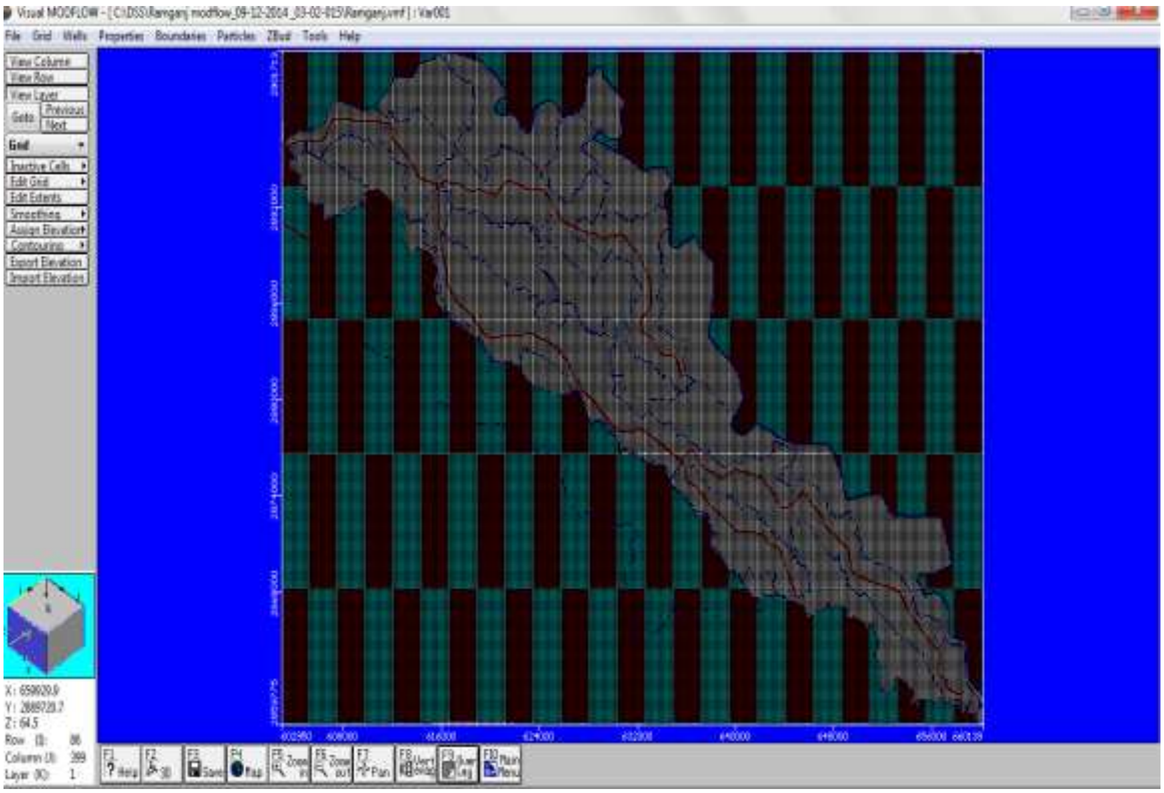

Figure 6.1.Developed Model for Study Area

The parameters usually concern the geometry of and distances in the domain to be modelled and those physical properties of the aquifer that are more or less constant with time but that may be variable in space. Important parameters are the topography, thicknesses of soil / rock layers and their horizontal/vertical hydraulic conductivity (permeability for water), aquifer transmissivity and resistance, aquifer porosity and storage coefficient, as well as the capillarity of the unsaturated zone

6.4.1. Topography:

The topography of the model area based on SRTM (Shuttle Radar Topographic Mission)90 M resolution data predicts that the levels in the model area varies from 68 to 110 m in the decreasing order from west to east as well as from north to south.

6.4.2. Layers

A single layer model is developed to represent the unconfined aquifer which extends in the Sub-Basin area, at an average depth of 50 m. The aquifer is comprised of an alternating litho logy of silty, very fine to fine sand and clay which are non-continuous over the scale of the sub-basin. The aquifer is underlain by a clay layer of the order of 20 to 40 m in thickness.

6.4.3. Hydraulic Conductivity

With reference to the various available reports and strata charts from State Tube well drilling logs, the aquifer material was found to be more or less fine sand and thus a value of 15 m/day has been found to be appropriate to the conditions, the estimated recharge and prevailing water levels. The value was varied to 10, 20 and 30m/d and is in conformance with the Central Ground Water Board (CGWB) norms.

6.4.4. Specific Yield

The average value of 0.15 has been adopted as per recommendation of CGWB for various grains sized alluvial material in the Groundwater estimation committee norms-97.In the sensitivity testing, testing was carried out for 0.10 and 0.20 to cover the range of grain size most commonly observed in the State Tube well logs.

6.4.5. Aquifer Thickness

From the CGWB (Central Groundwater Board) report of 1996, the upper aquifer in Jaunpur, Sultanpur and Pratapgarh districts of the study area was stated to an average thickness of 50 metres. Review of State Tubewell logs and hydrogeological reports for each district showed that it is very difficult to define the unconfined (or phreatic) aquifer. This is because the alluvium consists of multiple inter-fingering layers of sand, silt and clay that are semi-continuous in the study area. However there does appear to be a consistent layer of clay about 20 m to 30 m thick. In this groundwater modelling, we have focused on the interaction between the shallow phreatic aquifer and surface water (rivers, drains, soil moisture and recharge). Therefore, the model output of concern is the depth to groundwater level and the water balance between surface water and shallow groundwater. Deeper aquifers are of little consequence in this analysis as they do not significantly interchange with the unconfined aquifer in the study area.

6.4.6. Timeframes

The model has been run using seasonal inputs for the monsoon and non monsoon periods. The model used a three year time frame that is from 15th June 2011 to 14 th June 2014, to compare predicted groundwater levels with the observed water levels.

6.4.7. Boundary Conditions

Consideration of the boundary conditions of a groundwater model is one of the most important aspects in conceptualizing the model. Using a correct judgement means that the boundaries have no undue effect on the predicted water levels and flows. Sub Basin has external “no-flow” boundary conditions on the general assumption that the sub-basin surface water catchment is coincident with the groundwater sub-basin. On the northern side of the Gomti River and the southern side of Balrampur River, the catchment divides are taken at the sub-basin boundaries with “no-flow” conditions. These two boundaries meet on the south-eastern corner at the confluence of the two rivers.

The two rivers are represented in the model using the river package. The landmark bed elevations were used to define the bed of the river through linear interpolation. Figure 6.2. shows the river boundary conditions. The stages of the rivers were averaged to be constant at an average depth of 4 metres for monsoon period of 153 days starting from 15th June to 15th Oct and 2 m for non monsoon period from 16th Oct to 14th June for Gomti River and similarly for Balrampur river on the other side an average depth of 3 metres for monsoon period of 153 days from 15th June to 15th Oct and 1.5 m for non monsoon period from 16th Oct to 14th June. The bed layer was assumed as 0.5 m thick (M) and with a vertical hydraulic conductivity (K) of 1.5 m/day. Hydraulic conductance (C) was calculated within the model as follows:

(C = $\frac{KxLxW}{M}$), where L = length of the river in each cell (m).

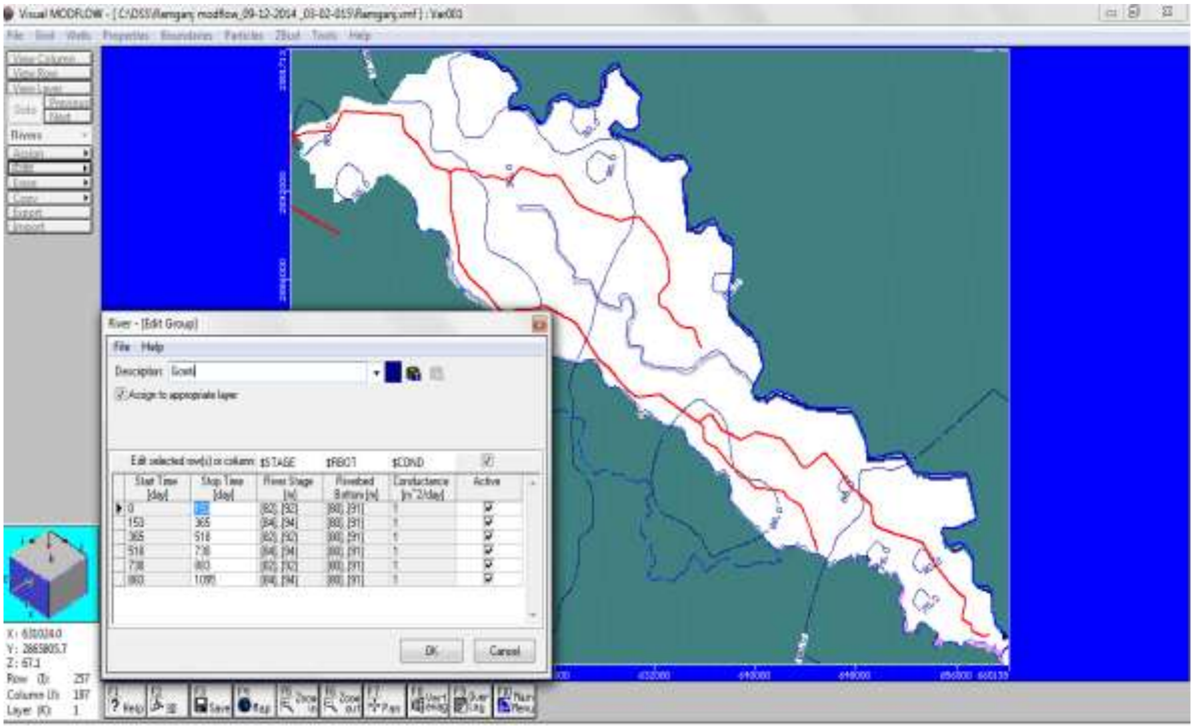

Figure 6.2.River boundary condition

6.4.8. Drains

Pili drain lying between Gomti and Balrampur rivers is also being used for the surplus run off in the of distributaries command. Since the flow data for different periods of the drain is not available, hence an average depth of flow for the entire periods has been assumed depending on field enquiry, as shown in Figure 6.3.

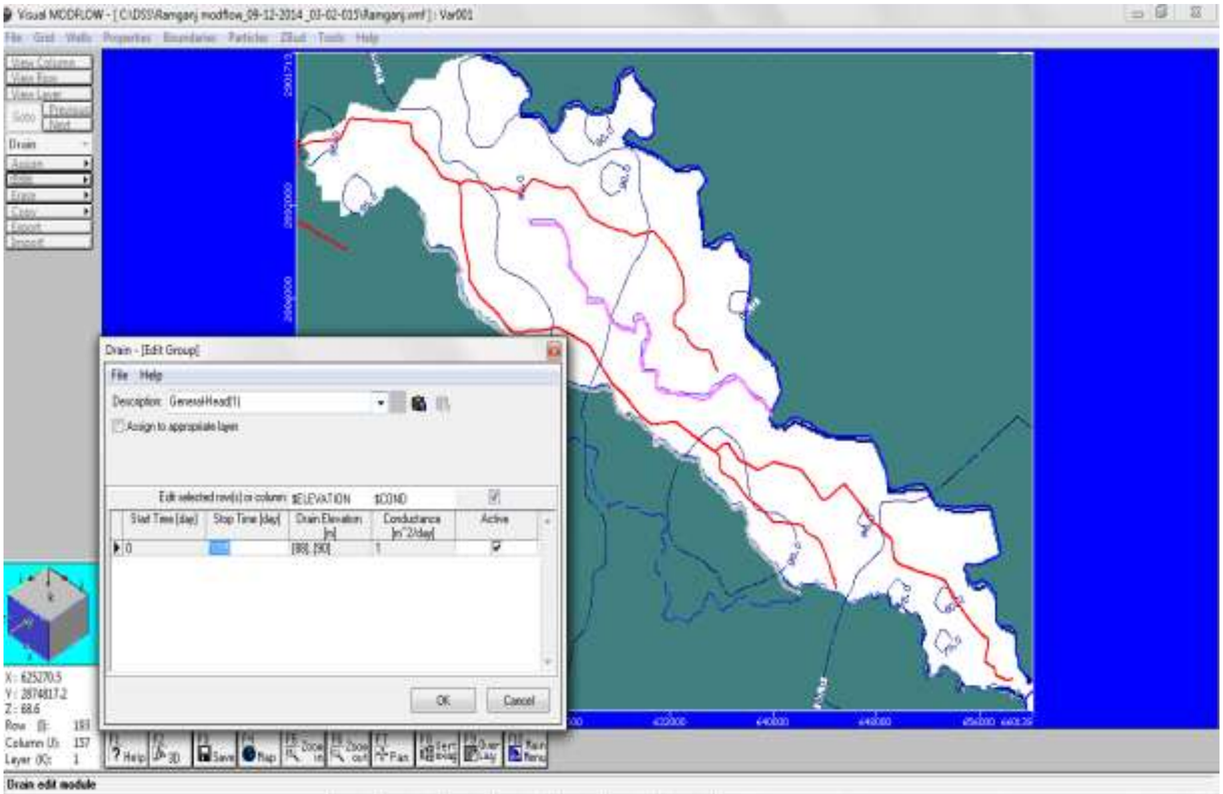

Figure 6.3.Status of drains in the Model area:

6.4.9. Initial Groundwater Levels

Initial groundwater levels of 60 monitoring wells of the study area, were collected for pre-monsoon date of 15th June 2011 from automatic groundwater level recorders. The initial water level contours generated from available data of imported file of 60 observatory well levels at GIS platform is shown in Figure 6.4.

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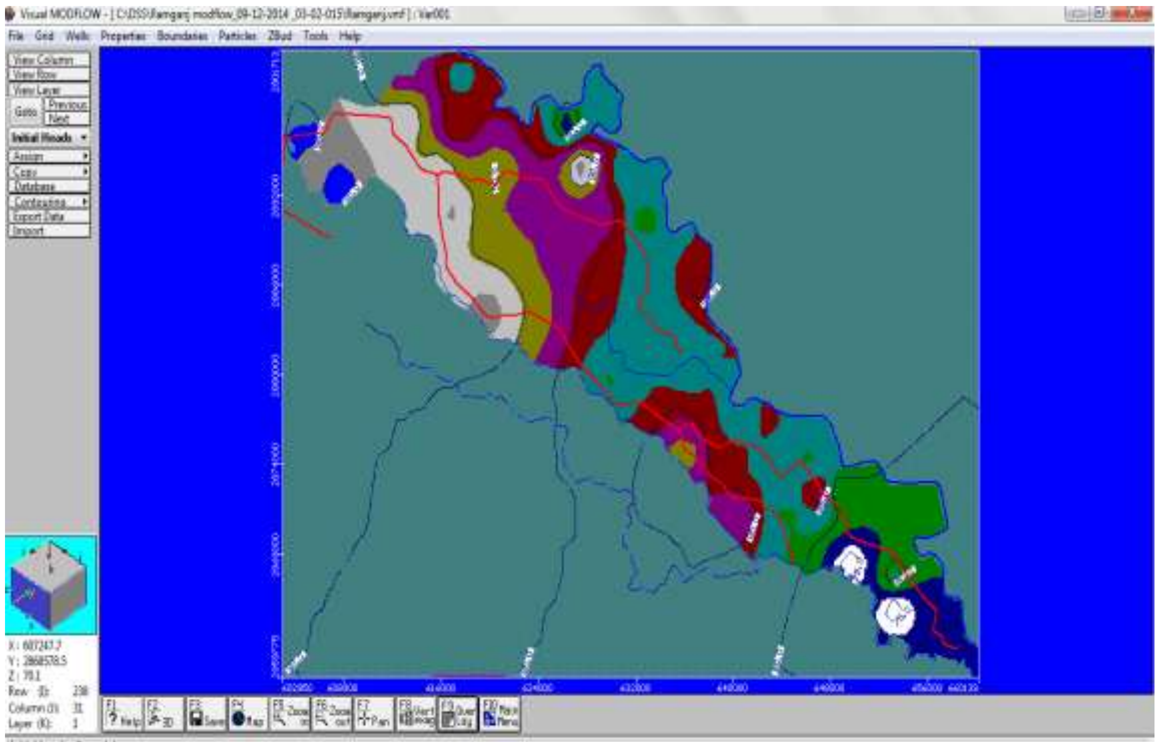


Figure 6.4. Initial groundwater levels

6.4.10. Recharge zones

Net recharge values for the model area has been calculated at block level, based on Groundwater estimation committee report 1997 for monsoon and non monsoon periods separately. Groundwater extraction from private borings has been calculated separately based on available borings and average running hours for each Rabi and Kharif periods as shown in Figure 6.5.

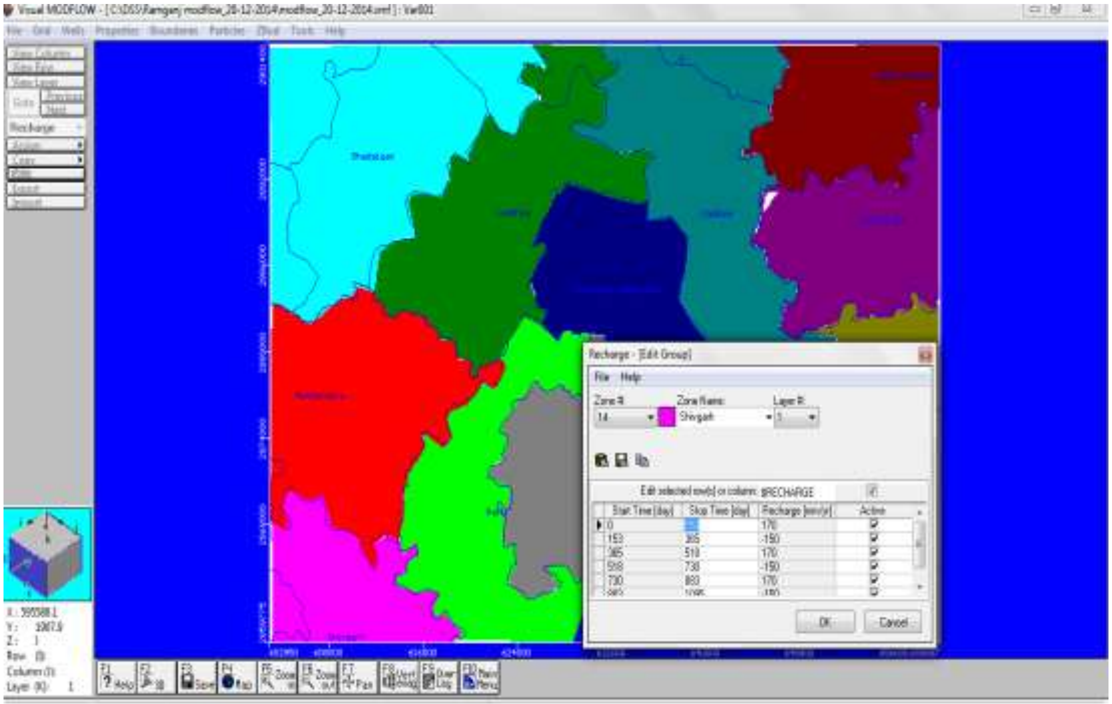


Figure 6.5. Recharge zones at Block level in groundwater model

6.4.11. Observatory wells

Groundwater levels for 11 monitoring wells, for which data for the complete three years was available, has been used for comparison with the model run results as shown in Figure 6.6.

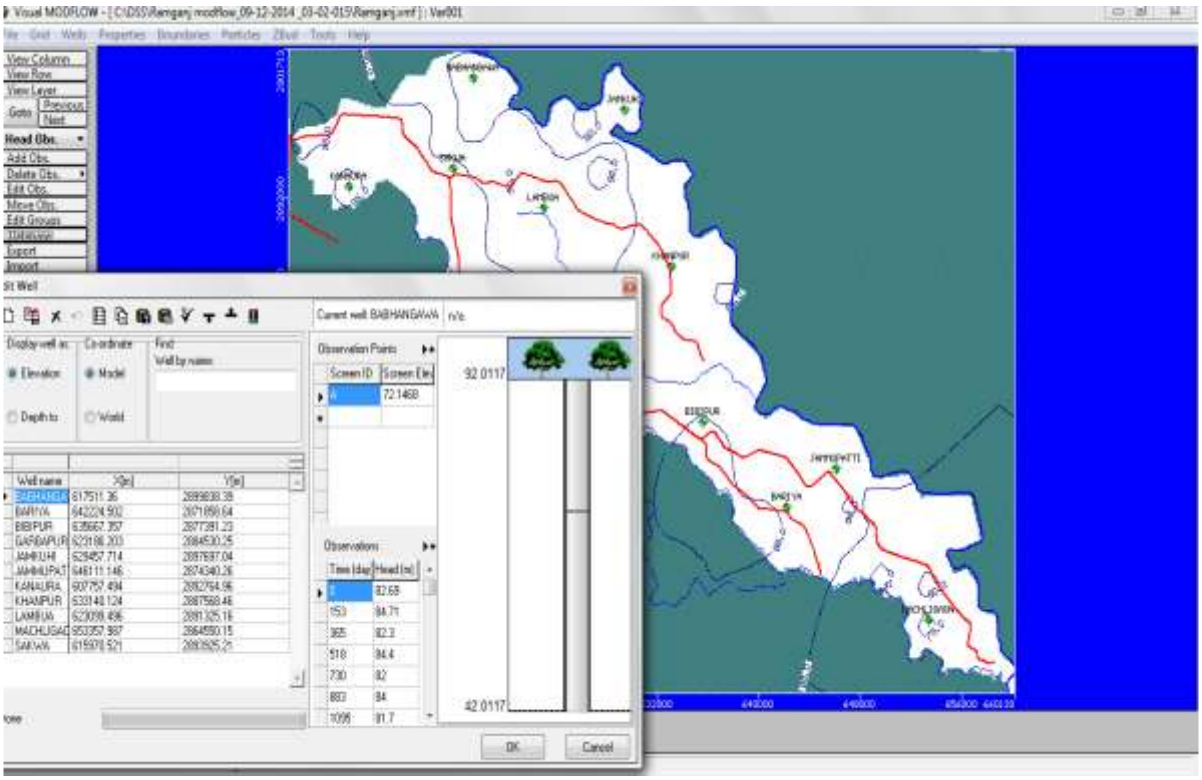


Figure 6.6. Monitoring wells used for water level calibration

6.5. Ground water simulation runs

6.5.1. Groundwater Simulation Model Calibration

Developed model was run for a period of three years staring from 15th of June 2011.The thickness of the upper unconfined layer is taken as 50 m (meter) for the modelling purposes based on bore logs, as groundwater extraction is mainly limited to upper strata being used by shallow borings for irrigation purposes. The values aquifer parameters such as specific yield=0.15%, hydraulic conductivity =15m per day in X and Y directions and 1.5 m per day in the Z direction are taken based on bore logs and pump test results. The net recharge applied at block level was calculated outside the model domain based on Groundwater estimation committee report 1997 norms. Following observations may be made from the model runs:

(i) For the net recharge values calculated at block level as per Groundwater Estimation Committee norm 1997, with the current cropping intensity of 163.1% and prevailing irrigation practises, the model run output shows a correlation coefficient of 0.94 to 0.92 between the observed and predicted groundwater levels at the different stages of running period of three year.

(ii) Spatial variation in groundwater levels for the study area shown in figure 6.7. predicts that with the current irrigation practices for the present cropping intensity of 163.1% as per Table 6.1, the groundwater levels depletion in the wells selected in non command and tail canal command areas is between 0.5m to 1.0m per year and in the head canal commands, where the canal density is good, it is showing a rise in groundwater levels between 0.5 m to 1.0 m per year. Field visit confirms that the areas adjacent to canals, where canal water is easily accessible, are experiencing the problem of water logging whereas non command and tail of canal command areas are facing the problem of depletion in groundwater levels, thereby increasing the energy cost through diesel driven private borings.

Table 6.1 -Showing details of Present Cropping pattern in Ramganj distributaury command area of 39861 ha as per National Informatics Centre Statistics 2011-12

Kharif	RICE_K	12585.2409	32	47%
	MAIZE_K	3456.41149	9	
	Other_Kharif	2830.84537	7	
	Kharif_Fallow	14200.5515	36	36%
Rabi	WHEAT	16953.6919	43	58%
	GRAM	2891.16975	7	
	Other_Rabi	3143.94433	8	
	Rabi-Fallow	10084.2433	25	25%
Jaid	URD_J	11.8542679	0	1%
	Other-Jaayad	212.879281	1	
	Jaayad_Fallow	32848.3157	82	
Perrinial	SUGARCANE	91.445525	0	
	Vegitation	1357.62809	3	16%
	Wasteland	5338.74949	13	
Net sown area				65%
Cropping Intensity in % of polygon area				106%
Cropping Intensity in % of Net sown area				163.1%

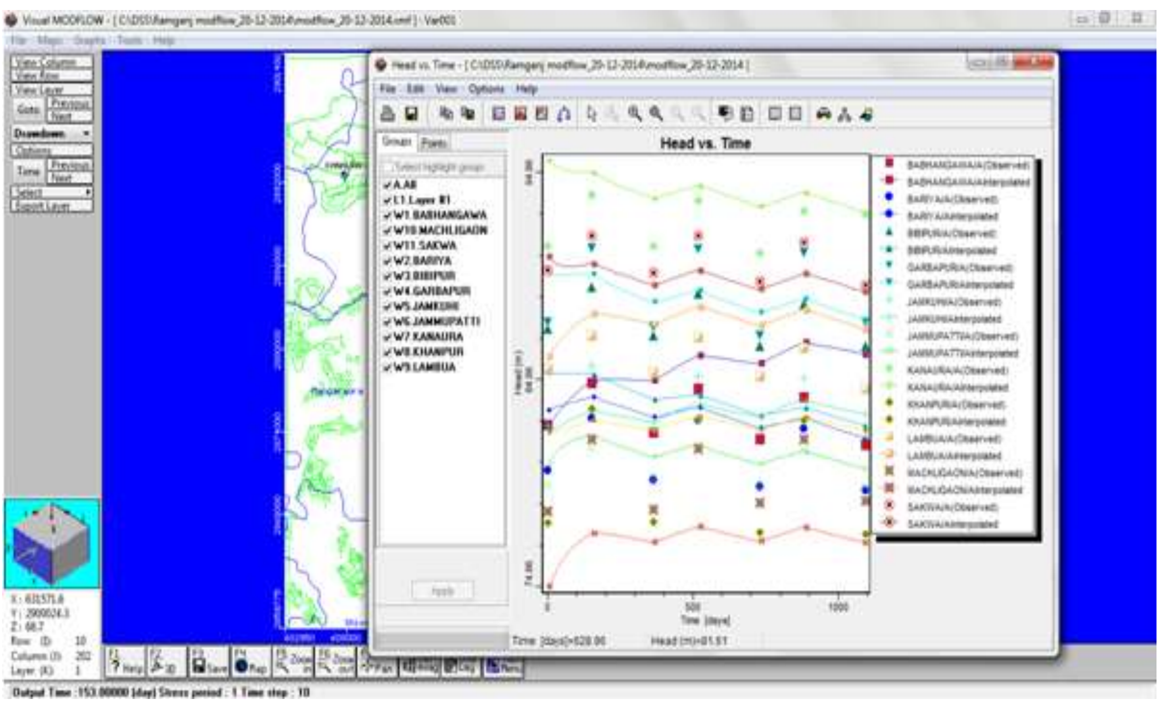


Figure 6.7.Model calibration run showing the calibrated water levels and actual water levels

6.5.2. Sensitivity Analysis

The sensitivity of the model calibration and prediction was initially assessed by varying model parameters over the potential range of values for the key parameters of hydraulic conductivity, specific yield and river leakage. Following points may be noted:

(i) The value of hydraulic conductivity is not a sensitive factor in the calculation of groundwater levels or flows as it is constrained by being in a relatively small range for fine sands. So for the whole model a single value of 15 m per day for hydraulic conductivity was adopted.

(ii) The Specific Yield varied between 0.10 and 0.20 in the short-term. Specific Yield affects the amplitude of fluctuations in groundwater levels between pre- and post-monsoon conditions. When applied over long time periods (decades), variations in Specific Yield have an impact on the size of long-term trends (rising or falling).

(iii) The model uses thickness for calculating transmissivity ($T = kb$) and thus doubling the thickness has the same resultant as doubling the hydraulic conductivity, which was effectively carried out in sensitivity runs of that parameter. Therefore, the depth of aquifer has little impact on predicted depth to groundwater.

(iv) It was found that the model predictions of depth to groundwater are sensitive to recharge. For a net increase in recharge per year the predicted groundwater levels shows an increasing trend at all the observatory well locations, while for a net decrease in recharge per year the predicted groundwater levels showed an decreasing trend at all the observatory well locations.

6.5.3 Model Predictions on Conjunctive Use Implementation

For the future predictions in the model area, the cropped area and its crop water requirement has been calculated outside the model domain for the different cropping intensities and uniform net recharge values required are calculated, to see the impact of model run on groundwater levels if conjunctive use is implied. Groundwater assessment done for districts of the study area under Groundwater estimation committee 97(GEC-97) norms is tabulated in Table 6.2. .It shows an annual recharge of 340 mm per year from all the sources, while present annual draft is only 250 mm per year for the current cropping intensity.

Table 6.2.Status of Districtwise Ground Water Resource Potential (2004, 2008 & 2012) as per GEC-97 Norms

S.	Assessment Unit (District)	Net annual Ground water Recharge/ potential (m)			Existing Gross Ground water draft for all uses (m)			Stage of Ground water development (%)		
		2004	2008	2012	2004	2008	2012	2004	2008	2012
1	Jaunpur	0.41	0.36	0.32	0.24	0.28	0.27	58.26	77.36	82.77
2	Pratapgarh	0.24	0.21	0.35	0.08	0.13	0.24	33.53	60.56	69.86
3	Sultanpur	0.41	0.38	0.35	0.19	0.28	0.24	46.09	72.77	69.94
	Average	0.35	0.32	0.34	0.17	0.23	0.25	45.96	70.23	74.19

The present cropping intensity is 106% (47% Kharif (K), 58% Rabi (R) and 1% Jaid (J)) of polygon area or 163.1% (72.3% K, 89.2% R, 1.6% Jaid) of net sown area. The Net sown area is 65% only [SMEC, 2010].Following scenarios are investigated:

(i) If conjunctive use is applied for the current cropping intensity of 106% (47% Kharif (K), 58% Rabi (R) and 1% Jaid (J)) of polygon area or 163.1% (72.3% K, 89.2% R, 1.6% Jaid) of net sown area with annual recharge 340 mm per year and ground water drafts of 250 mm per year, it will show a rising trend in ground water levels as predicted in model run, shown in Figure 6.8.

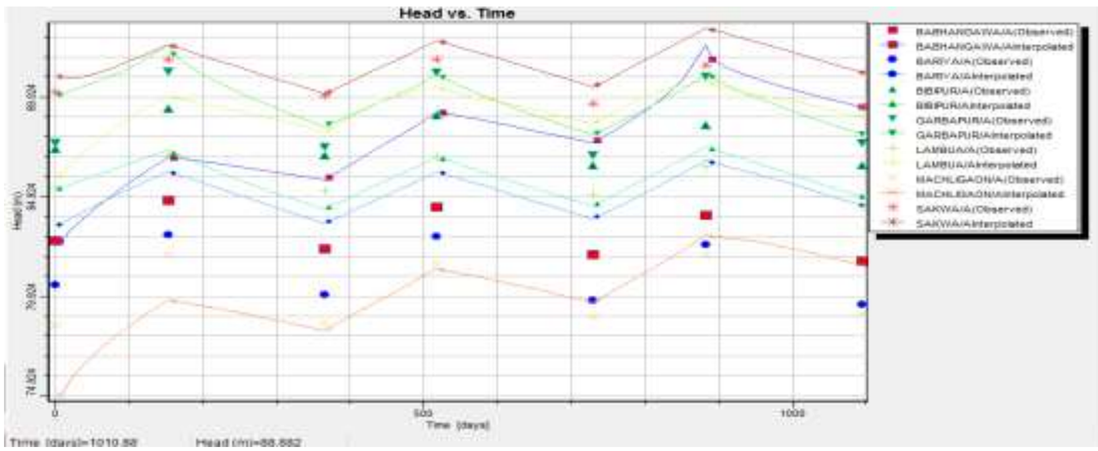


Figure 6.8. Ground water levels with current cropping intensity of 163.1%, if conjunctive use is applied

(ii) If Conjunctive use is implemented, for the proposed cropping intensity of 222% of net sown area (=163.1*34/25) by keeping net recharge value equal to zero, simulation results show that, groundwater levels will always remain sustainable, as shown in Figure 6.9.

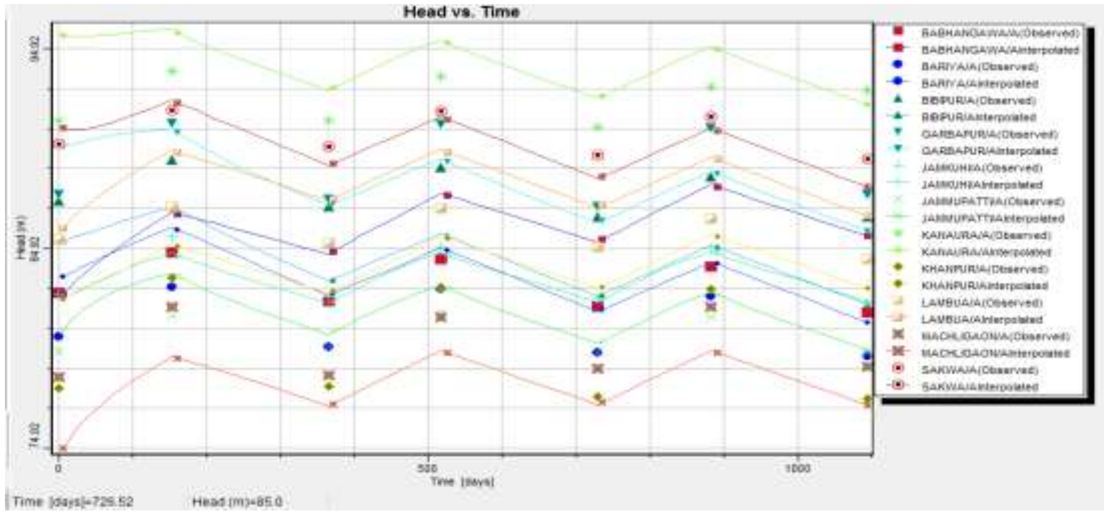
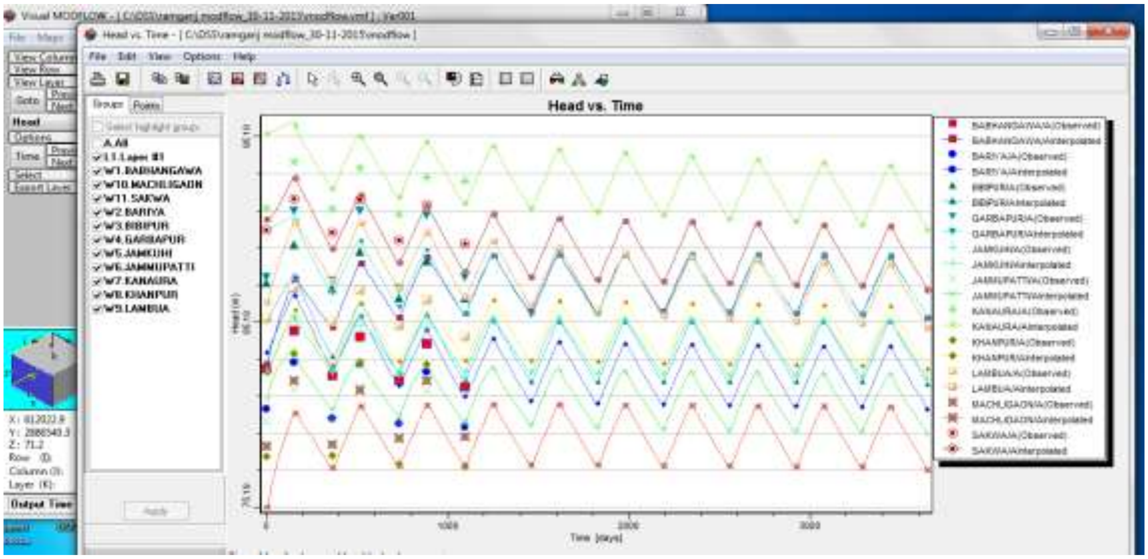


Figure 6.9. Ground water levels for proposed cropping intensity of 222%, if conjunctive use is applied

(iii) Groundwater simulation model is run with conjunctive use implementation for a period of ten years from June 2011 to June 2020.For the net recharge of 340 mm per year mainly in rainy seasons from 15th June to 15th Oct and ground water draft of 340 mm per year from 16th Oct to 14th June, shows that the ground water levels in pre monsoon and post monsoon periods will remain more or less sustainable at 222% cropping intensity as shown in Figure 6.10.



6.10- Ground water behaviour under proposed cropping intensity of 222% for a period of 10 years, if Conjunctive use is applied

(iv) Groundwater simulation model is run for conjunctive use implementation for a period of three years. The groundwater sustainable area will increase to 92% for the present cropping intensity of 163.1 % of net sown area as against the sustainable area of only 65% under current irrigation practices. Further, the groundwater depletion area will reduce from 30% to 7%, having yearly depletion of more than 0.34 m and the waterlogged area will reduce from 5% to 1%, where the rise in groundwater levels is more than 0.34 m per year as shown in Figure 6.11. and 6.12.

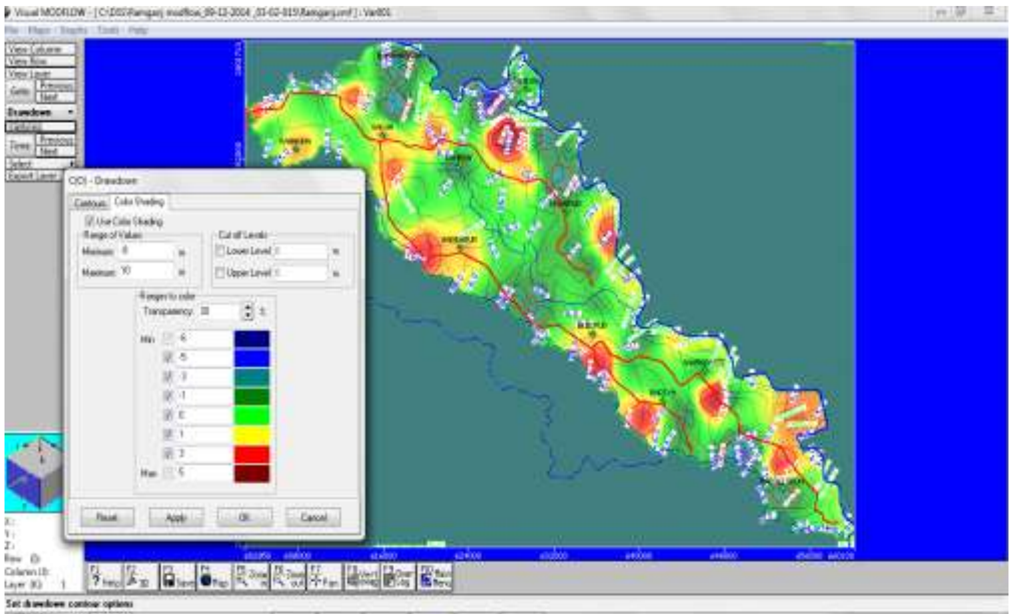


Figure 6.11. Draw down in Ground water levels during a period of 3 years under current irrigation practices for the existing cropping intensity of 163.1%

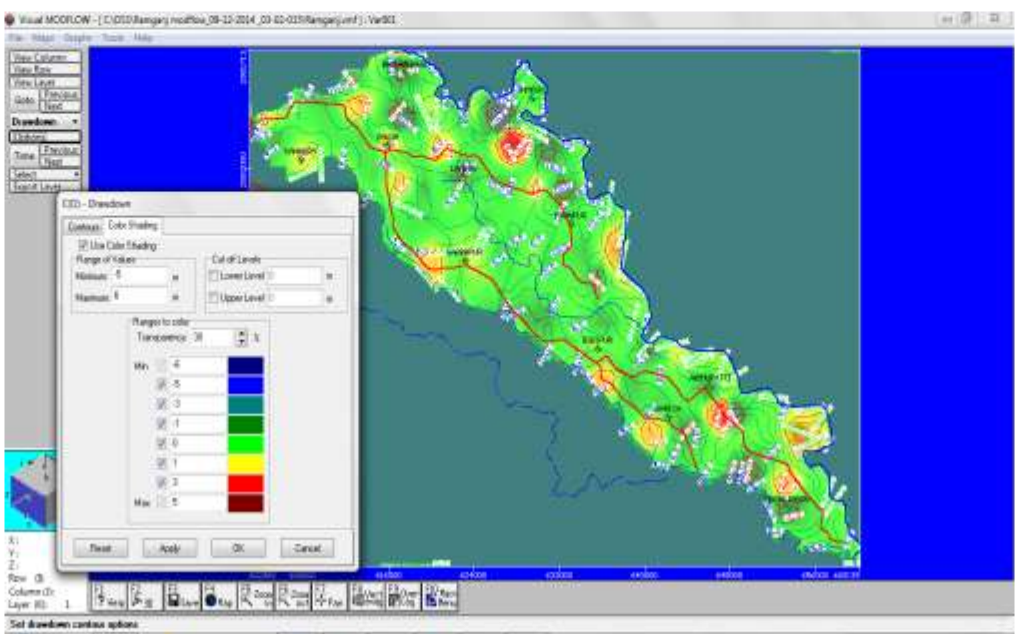


Figure 6.12. Draw down in Ground water levels under proposed cropping intensity of 222% during a period of 3 years, if Conjunctive use is implied

6.6. Summary and Conclusions

Groundwater modeling framework has been developed through Visual Modflow for Ramganj distributaries command able area, a part of Indo-Gangatic alluvial plains of Uttar Pradesh in northern India. The simulated model predicts that if conjunctive use is opted the cropping intensity may be increased to 222 percent from the existing intensity of only 163.1 percent. It also shows an overall increase in ground water sustainable area and decrease in groundwater depletion area. The sustainable area may increase to 92 percent at percent cropping intensity of 163.1, with implementation of conjunctive use, against the sustainable area of only 65 percent with existing irrigation practices. Water logged area will also reduce to 1 percent as against to present 5 percent. Groundwater withdrawal may add additional cost for lifting groundwater through electric/diesel driven private borings. However, there is saving in terms of overall additional gain in terms of bringing prevailing waterlogged and barren areas crops under cultivation, thereby increasing gross margin to farmers. At the same time simulation of model for a period of ten year from june 2011 to june 2020 shows that the ground water levels in pre monsoon and post monsoon periods will remain sustainable.