MODEL SIMULATION

5 MODEL SIMULATION

In this chapter details of calibration, validation of groundwater model for the study area and use of the validated model for predictive simulation to evaluate the impact of the implementation of future salinity control structures on artificial recharge are described.

5. 1 Calibration of Groundwater Model

The ultimate purpose of the model is to predict changes in water levels in the aquifer caused by changes in stresses on the system. Before the model can be used for prediction, it must be calibrated, that is, water levels simulated by the model, when the stress regime of the past is imposed on it, must match measured water levels at any chosen time (ORG, 1982).

The process of model calibration is a complex one. An important part of any groundwater modeling exercise is the model calibration process. Calibration is a process wherein certain parameters of the model are varied (altered) within physically reasonable bounds in a systematic fashion in order to improve/achieve the best overall agreement between the simulated and observed groundwater levels. The main parameter adjusted during model calibration is hydraulic conductivity/transmissivity.

The objective of this calibration procedure is to minimize difference between the observed data and calculated values. Usually, the model is considered calibrated when it represents historical data within some acceptable level of accuracy. The level of acceptability is, of course, determined subjectively. Even when the match to historical data is good, the model may still fail to predict future responses accurately, especially under a newer or more extended set of stresses than were experienced during the calibration period (Delleur, 1999). Many problems always arise during the calibration phase and generally relate to inadequate and/or inaccurate data (ORG, 1993).

Usually model calibration proceeds in two sequential phases, firstly, there is steady state calibration, and, secondly, transient calibration. Model calibration can be performed to steady state or transient data sets.

Steady state calibration involves matching simulated groundwater levels with those observed under steady state or dynamic equilibrium conditions. During steady state calibration, non time varying parameters are altered within physically reasonable bounds in order to improve the agreement between the simulated and observed groundwater levels. The main parameters adjusted during steady state calibration are the hydraulic conductivity/ transmissivity. These parameters are varied within physically reasonable bounds. Aquifer recharge and abstraction is not normally varied during steady state calibration (Wallingford, 1995).

In some hydrogeologic settings it may be inappropriate to assume steady state conditions owing to large seasonal fluctuations in the water levels, or a steady state data set may not be available. In this case, the model may be calibrated to transient conditions. The most common type of transient calibration begins the simulation from the calibrated steady-state solution. The model is then calibrated to a time series of water level changes caused by pumping. The initial conditions are set arbitrarily and the model is run until the solution hits the calibration targets. It is assumed that the effect of the initial conditions do not influences the solution.

There are basically two ways of finding model parameters to achieve calibration, i. e. of solving the inverse problem:

(1) Manual trial-and-error adjustment of parameters and

(2) Automated parameter estimation. (Anderson, 1992)

A general rule which must be taken into account during model calibration is that the conditions which exist during calibration should be similar to those which will exist during the predictive simulations. Transient calibration should be carried out over a period similar in length to that proposed for the predictive simulations (Wallingford, 1995).

GMS provides a suit of options for model calibration including calibration targets and plots of calibration statistics'. Both point and flux observations are supported. GMS also supports automated parameter estimation.

5.1.1 Automated Parameter Estimation

In many cases, calibration can be achieved much more rapidly with an inverse model. GMS contains an interface to inverse model: PEST. An inverse model is an internal process or an external utility that automates the parameter estimation process. The inverse model systematically adjusts user-defined set of input parameters until the difference between the computed and observed values.

Transient-state model calibration was attempted. Out of all the input parameters, the hydraulic conductivity value is the only poorly known one, as less pumping tests in unconfined aquifer have been carried out in the study area. Based on these data it was decided to vary hydraulic conductivity of unconfined aquifer in order to get a good match of the computed and observed heads.

The automated parameter estimation process by which calibration of the transient model was achieved by PEST as inverse model contained in GMS 6.0. Zonal approach for parameterization was used. This involves indentifying polygonal zones of hydraulic conductivity, marking the zones as parameters and assigning a starting value for each zone.

The PEST process will then adjust the hydraulic conductivity values assigned to the zones as it attempts to minimize the residual error between computed vs. observed heads.

5.1.2 Period of Calibration Simulation

In the present study, data were available for the periods June 1997 to June1999. For this period water table elevation, rainfall and river stage data were available. Therefore, the Groundwater model was calibrated using the data of the period June1997 to June 1999(732 days).

5.1.3 Input Parameters for Calibration

Condition- Transient
Calibration interval or target is selected = 1m. (The interval or target represents the estimated error (±) in the observed value. Calibration is achieved when the error is within the estimated error interval of observed value.
The confidence selected is 95 % (The confidence value represents the confidence in the error estimate)

Maximum number of iterations limited to twenty in the interest of time.

Anisotropy Horizontal =1

Anisotropy vertical =3

Porosity =30 %

Specific storage S_s =0.00001 m^{-1}

The specific yield of wells s_y for each zone given is as shown in table 4.2 and specific yield zones are shown in figure 4.13

River conductances given to the upper, middle and lower arc of river are 50, 60 and 20 per unit length respectively. It is as shown in section 4.11 of chapter 4.

Daily Mahi river water level's given to model for the period June1997 to June 1999 (732 days) are as shown in Annexure 1 and graph 4.1 to 4.2 (Note: River water levels at Kavi/Sea is considered same as at Dhuvaran)

Starting heads given to the model (pre-monsoon 1997) is as shown in table 4.3 (Reduced Water Levels of wells) and in figure 4.16

Observation points (active) for calibration are as shown in table 5.2(Initially 23 observation wells considered and finally 17 0bservation wells kept active)

Reduced water levels of wells for pre monsoon and post monsoon for calibration period given to the model are as shown in table 4.3.

Transient heads (head dependent flow) on boundary point's pre monsoon and post monsoon for calibration period given to the model are as shown in table 4.7

Taluka wise transient net recharges monsoon and non monsoon for the calibration period given to the model are as shown in table 4.6 and the detail dates and time of Vadodara taluka is shown below (table 5.1) and similarly recharges given to all talukas.

Taluka: Vadodara

Table 5.1 Detail Dates and Time for Net Recharge of Vadodara taluka for Calibration

Sr. No.	Date and time	Recharge rate in m/day
1	6/14/1997 12:00:00 AM	-0.0003772
2	6/15/1997 12:00:00 AM	0.0015403
3	10/14/1997 12:00:00 AM	0.0015403
4	10/15/1997 12:00:00 AM	-0.0003772
5	6/14/1998 12:00:00 AM	-0.0003772
6	6/15/1998 12:00:00 AM	0.0014921
7	10/14/1998 12:00:00 AM	0.0014921
8	10/15/1998 12:00:00 AM	-0.0003783
9	6/14/1999 12:00:00 AM	-0.0003783

Times and Time Steps for the Stress Periods (For Transient Calibration)

Time steps and stress periods in transient calibration given to model are as shown in table 5.3.

The starting horizontal permeability Hk of wells for each zone in unconfined aquifer given to model are as shown in table 4.1 and horizontal permeability zones are shown in figure 4.13

The range of horizontal permeability given to model is 5 to 50 m/day for the calibration.

Table 5.2 Observation Points for Model Calibration

Taluka	Village	Obs.Point	X Latitude	Y Longitude	Pre monsoon 1997 RWL in m from m.s.l.
Khambhat	Kansari	KR-23	256803.69	2471326.90	9.77
Jambusar	Kavi	NCCA-48	256865.3	2456700.75	0.69
Khambhat	Bhuvel	KR-21	264060.8125	2468621.00	3.98
Khambhat	Gudel	KR-25	244895.8125	2478585.00	14.4
Petlad	Danteli	KR-70	268272.9	2482068.61	13.30
Khambhat	Kanisha	KR-20	261564.14	2477128.29	11.76
Khambhat	Haripura	KR-22	270508.31	2463701.40	4.58
Borsad	Borsad	KR-19	283767.25	2479632.25	27.40
Borsad	Bhadran	KR-17	283689.9063	2474095.00	20.02
Borsad	Gajna	KR-18	283803.5625	2465232.25	-2.8
Anklav	Anklav	KR-16	294427.55	2475901.85	19.60
Anand	Vasad	KR-07	303395.9375	2488507.50	31.62
Anand	Sarsa	KR-06	301609.5625	2494433.75	27.97
Padra	Dabka	NCCA-44	289541.875	2461919.50	6.16
Padra	Masar Road	BD-34	287036.875	2450600.50	2.99
Vadodara	Dashrath	BD-05	309398.6563	2477047.00	17.62
Jambusar	Sarod	NCCA-47	280030.9063	2453555.00	0.39

5.1.4 Setting up the Stress Periods

The date/time format is used to display time values such as the time step values when post-processing. We want the stress periods to match the times where our input data in map module changes. For example, the value for recharge changes at different dates. Therefore, we need to make sure that we have stress periods that start at those times and at the time corresponding to changes in the net recharge schedules(Environmental Modeling Research Laboratory, 2005) The times and time steps for the stress periods used in transient calibration is shown in the table 5.3. The number of stress periods used is 18.

Table 5.3 Times and Time Steps for the Stress Periods (For Transient Calibration)

Stress periods	Start(date and time)	Time step(days)	Num. of time steps	Total days
1	6/13/1997 12:00:00 AM	1	1	1
2	6/14/1997 12:00:00 AM	1	1	1
3	6/15/1997 12:00:00 AM	1	4	4
4	6/19/1997 12:00:00 AM	2	1	2
5	6/21/1997 12:00:00 AM	3	1	3
6	6/24/1997 12:00:00 AM	5	1	5
7	6/29/1997 12:00:00 AM	7	1	7
8	7/6/1997 12:00:00 AM	10	1	10
9	7/16/1997 12:00:00 AM	10	9	90
10	10/14/1997 12:00:00 AM	1	1	1
11	10/15/1997 12:00:00 AM	1	2	2
12	10/17/1997 12:00:00 AM	10	24	240
13	6/14/1998 12:00:00 AM	1	1	1
14	6/15/1998 12:00:00 AM	1	1	1
15	6/16/1998 12:00:00 AM	10	12	120
16	10/14/1998 12:00:00 AM	1	1	1
17	10/15/1998 12:00:00 AM	1	2	2
18	10/17/1998 12:00:00 AM	10	24	240
End	6/14/1999 12:00:00 AM End	1	1	1
	Total			732

5.1.5 Results of Calibration

Manual trial and error method can be used to iteratively adjust model parameters until the model computed values match the field observed values to an acceptable level of agreement. The level of acceptability is, of course, determined subjectively. Because a large number of interrelated factors affect the output trial and error adjustment may become a highly subjective and inefficient procedure. It is not uncommon to make numerous trial and error simulations before an acceptable calibration is achieved. So, more time is required in trial and error method. Solution obtained by this method may not be an optimal solution.

Calibration is really a way of solving the inverse problem. Automated parameter estimation techniques improve the efficiency of model calibration and calculate the best fit. Calibration can be achieved much more rapidly with an inverse model. GMS contains an interface to inverse model: PEST. The PEST interface in GMS can be used to perform automated parameter estimation for MODFLOW. An inverse model is an internal process or an external utility that automates the parameter estimation process. The inverse model systematically adjusts a used- defined set of input parameters until the difference between the computed and observed values is minimized.

With the above data as input, the inverse model PEST was run to calibrate transient condition through several iterations adjusting horizontal permeability values until a good match achieved between computed and observed heads.

The model is calibrated. The computed horizontal permeability Hk of wells for each zone in unconfined aquifer are as shown in table 5.4.

In conceptual model number of zones considered for horizontal permeability and specific yield are considered 23 which may be adequate to represent the variation in aquifer characteristics in the study area.

Table-5.4 Computed Horizontal permeability 'HK' of wells

Zone Id	Taluka	Village	Well No.	X Latitude	Y Longitude	Hk m/day
552	Anand	Bedva	KR-08	298338.2188	2495240.50	28.86
553	Anand	Sarsa	KR-06	301609.5625	2494433.75	50
771	Anand	Vasad	KR-07	303395.9375	2488507.50	50
881	Savli	Anjesar	NCCA-14	311864.938	2486740.50	9.6857
551	Borsad	Borsad	KR-19	283767.25	2479632.25	5.1637
115	Petlad	Danteli	KR-70	268272.9	2482068.61	5
882	Savli	Manjusar	BD-48	313994.4063	2483237.25	36.144
661	Anklav	Anklav	KR-16	294427.55	2475901.85	43.497
114	Khambhat	Kanisha	KR-20	261564.14	2477128.29	32.56
772	Vadodara	Sokhda	BD-06	311648.4375	2480807.00	7.3208
111	Khambhat	Gudel	KR-25	244895.8125	2478585.00	49.572
773	Vadodara	Dashrath	BD-05	309398.6563	2477047.00	41.485
112	Khambhat	Kansari	KR-23	256803.69	2471326.90	22.077
332	Borsad	Bhadran	KR-17	283689.9063	2474095.00	5.9989
221	Khambhat	Bhuvel	KR-21	264060.8125	2468621.00	22.322
222	Khambhat	Haripura	KR-22	270508.31	2463701.40	15.74
662	Padra	Jaspur	NCCA-43	299932.24	2465442.61	49.503
334	Padra	Dabka	NCCA-44	289541.875	2461919.50	16.478
333	Borsad	Gajna	KR-18	283803.5625	2465232.25	8.9196
113	Jambusar	Kavi	NCCA-48	256865.3	2456700.75	32.193
335	Padra	Karankuva	NCCA-45	291753.25	245608.25	5
331	Jambusar	Sarod	BR-14	280113.4375	2453554.00	50
441	Padra	Masar Road	BD-34	287036.875	2450600.50	11.18

The calibration of model is carried out using data from the period June 1997 to June 1999 and the horizontal permeability is found to be in the range of 5 to 50 m/day.

The figure 5.1 indicates that there is a very good match between the computed and observed heads in most of wells of the study area under calibration.

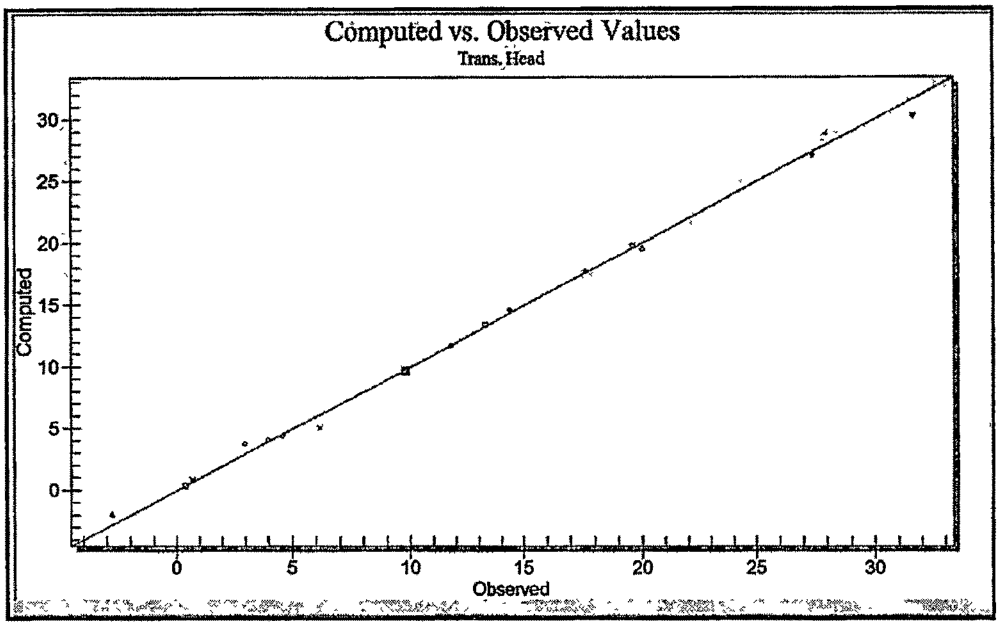
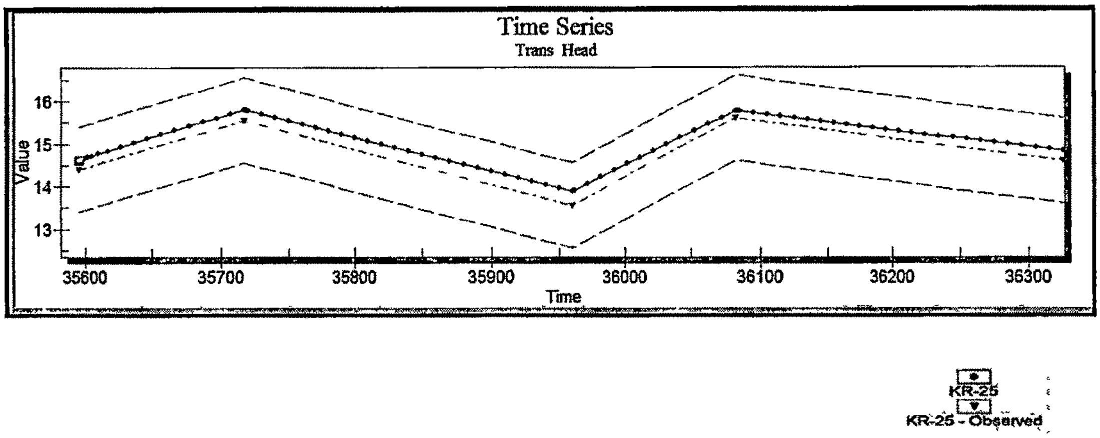


Figure 5.1 Comparisons of Computed and Observed Groundwater Heads (m) Under Calibration.

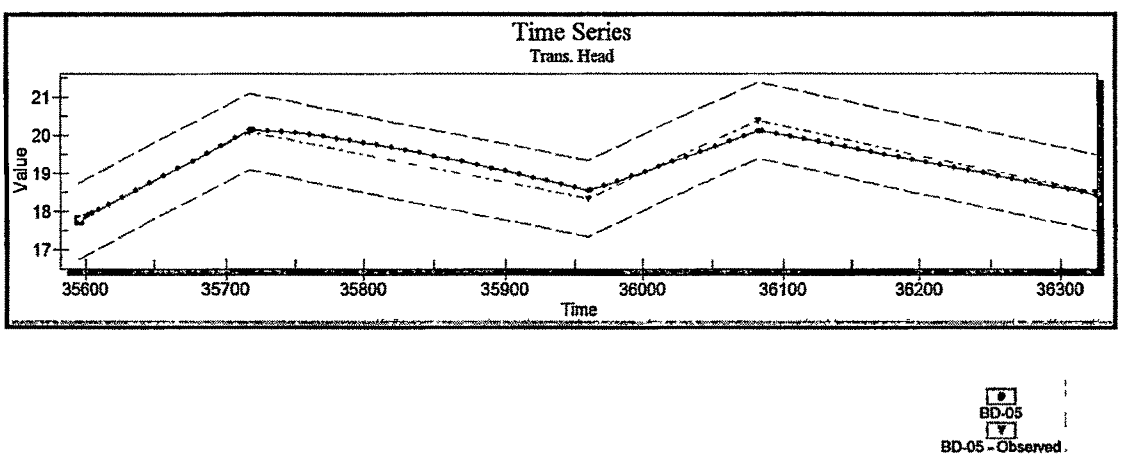
The figure 5.2 (a) and (b) show temporal variation of groundwater table elevation at wells KR- 25 and BD- 05 under calibration.

The mean error, mean absolute error and root mean squared error under calibration are as follows.

Calibration Criterion	Error in m
Mean Error (ME)	0.085
Mean Absolute Error (MAE)	1.137
Root Mean Squared (RMS) Error	1.472



(a)



(b)

Figure 5.2 Temporal Variation of Groundwater Table Elevation at Wells KR-25 and BD-05 Under Calibration.

5.2 Validation of Groundwater Model

The goal of validation is to demonstrate that the model is capable of simulating some historical hydrologic event for which field data are available. For example, one might attempt to simulate drawdown during pumping test or water level declines during a drought. Generally, some additional refinement of parameters will be necessary during validation (Wang, 1982)

Owing to uncertainties in the calibration, the set of parameter values used in the calibrated model may not accurately represent field values. Consequently, the calibrated parameters may not accurately represent the system under a different set of boundary conditions or hydrologic stresses. Model verification will help establish greater confidence in calibration (Anderson, 1992).

Once a model has been calibrated, it should be verified against an entirely independent set of data. Verification is carried out to confirm that a calibrated model and all the parameters contained therein, remains valid under different, but physically similar, conditions to those for which it was calibrated.

The calibrated model should be used to simulate the revised conditions and the results compared with the observations. This process will verify the acceptability of the model calibration. If there is poor agreement between the predicted groundwater levels and those in the verification data set the model should be re-calibrated. This re-calibration should not include the verification data. Once re-calibration has been completed a second verification exercise should be carried out (Wallingford, 1995).

5.2.1 Period of Validation Simulation

In present study, the calibrated Model was validated using the data of the period June2003 to June 2005(733 days).

5.2.2 Input Parameters for Validation

Condition- Transient

Porosity =30 %

Specific storage S_s =0.00001 m^{-1}

The specific yield of wells s_y for each zone given is as shown in table 4.2. Specific yield zones are shown in figure 4.13

River conductances given to the upper, middle and lower arc of river are 50, 60 and 20 per unit length respectively. It is as shown in section 4.11 of chapter 4.

Daily Mahi river water level's given to model for the period June2003 to June 2005(733 days) are as shown in Annexure 1 and graph 4.3 to 4.4. (Note: River water levels at Kavi/Sea is considered same as at Dhuvaran)

Starting heads given to the model (pre-monsoon 2003) is as shown in table 4.3 (Reduced Water Levels of wells).

Reduced water levels of wells for pre monsoon and post monsoon for validation period given to the model are as shown in table 4.3

Transient heads (head dependent flow) on boundary point's pre monsoon and post monsoon for validation period given to the model are as shown in table 4.7

Taluka wise transient net recharges monsoon and non monsoon for the validation period given to the model are as shown in table 4.6 and the detail dates and time of Vadodara taluka is shown below (table5.5) and similarly recharges given to all talukas.

Taluka: Vadodara

Table 5.5 Detail Dates and Time for Net Recharge of Vadodara taluka for Validation

Sr. No.	Date and time	Recharge rate in m/day
1	6/14/2003 12:00:00 AM	-0.0004723
2	6/15/2003 12:00:00 AM	0.001638
3	10/14/2003 12:00:00 AM	0.001638
4	10/15/2003 12:00:00 AM	-0.0004723
5	6/14/2004 12:00:00 AM	-0.0004723
6	6/15/2004 12:00:00 AM	0.0011575
7	10/14/2004 12:00:00 AM	0.0011575
8	10/15/2004 12:00:00 AM	-0.0005296
9	6/14/2005 12:00:00 AM	-0.0005296

Times And Time Steps for the Stress Periods (For Validation), time steps and stress periods in validation given to model are as shown in table 5.6.

The computed horizontal permeability Hk of wells for each zone in unconfined aquifer from calibration of model given to model are as shown in table 5.4 and horizontal permeability zones are shown in figure 4.13

5.2.3 Setting up the Stress Periods

The times and time steps for the stress periods used in validation is shown in the table 5. 6 The number of stress periods used is18.

Table 5.6 Times and Time Steps for the Stress Periods (For Validation)

Stress periods	Start(date and time)	Time step(days)	Num. of time steps	Total days
1	6/13/2003 12:00:00 AM	1	1	1
2	6/14/2003 12:00:00 AM	1	1	1
3	6/15/2003 12:00:00 AM	1	4	4
4	6/19/2003 12:00:00 AM	2	1	2
5	6/21/2003 12:00:00 AM	3	1	3
6	6/24/2003 12:00:00 AM	5	1	5
7	6/29/2003 12:00:00 AM	7	1	7
8	7/6/2003 12:00:00 AM	10	1	10
9	7/16/2003 12:00:00 AM	10	9	90
10	10/14/2003 12:00:00 AM	1	1	1
11	10/15/2003 12:00:00 AM	1	2	2
12	10/17/2003 12:00:00 AM	10.042	24	241
13	6/14/2004 12:00:00 AM	1	1	1
14	6/15/2004 12:00:00 AM	1	1	1
15	6/16/2004 12:00:00 AM	10	12	120
16	10/14/2004 12:00:00 AM	1	1	1
17	10/15/2004 12:00:00 AM	1	2	2
18	10/17/2004 12:00:00 AM	10	24	240
End	6/14/2005 12:00:00 AM	1	1	1
	Total			733

5.2.4 Results of Validation

With the above data as input, the model was run forward in MODFLOW to validate in transient condition. The figure 5.3 indicates that there is a very good match between the computed and observed heads in most of wells of the study area under validation.

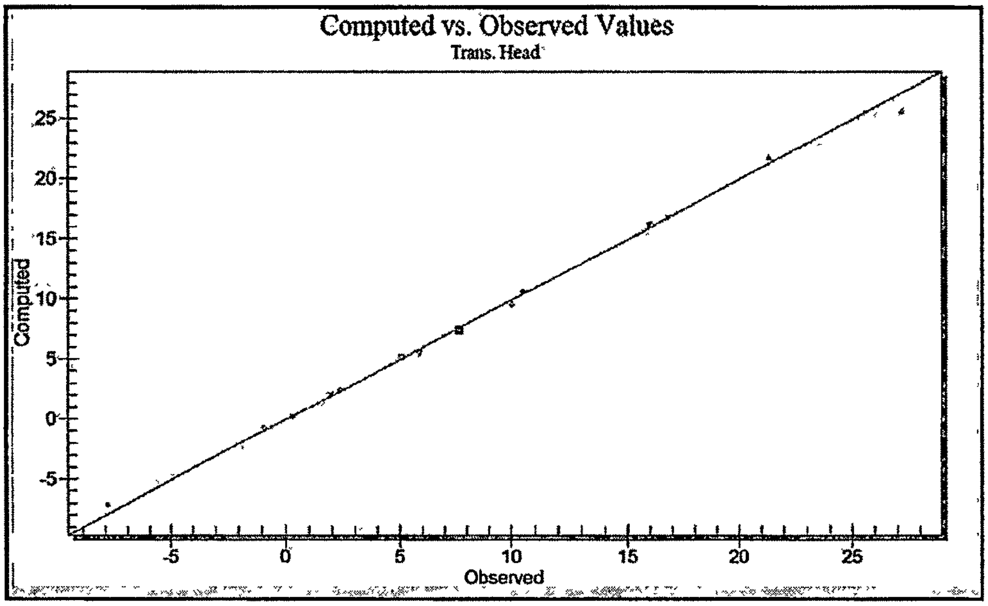
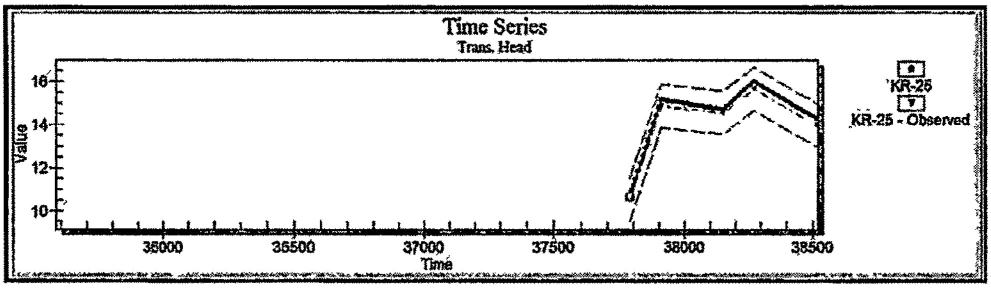
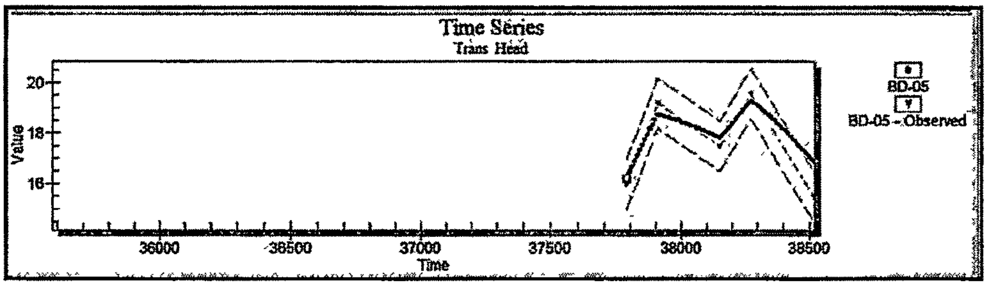


Figure 5.3 Comparison of computed and observed groundwater heads (m) under validation.

The figure 5.4 (a) and (b) show temporal variation of groundwater table elevation at wells KR-25 and BD-05 under validation.



(a)



(b)

Figure 5.4 Temporal variation of groundwater table elevation at wells KR-25 and BD-05 under validation.

5.3 Predictive Groundwater Modeling

Groundwater models are usually prepared for two reasons, firstly to assist in developing an understanding of the groundwater system and secondly to predict the future behavior of the aquifer system under changed conditions (Rushton, 2003).

In a predictive simulation, the parameters determined during calibration and verification is used to predict the response of the system to future events. Once a calibration of a model is satisfactory, the model can be used for predictive simulation (Anderson, 1992).

Some environmental problems require predicting the system response many years. An important task in predictive modeling is to determine the length of time for which the model will accurately predict the future. The modeler must consider the extent to which the model has been validated.

Faust et al. 1981, Suggest that a predictive simulation not to be extended into the future more than twice the period for which calibration data are available, but this may not be possible if regulations require longer simulations.

Predictive simulation provides the information regarding response of the aquifer to a variety of scenarios of possible management options such as effects of number, location and spacing of wells, rates of pumping and artificial recharge, and rate of movement of leachate from hazardous wastes dumps, sanitary landfills and other sources of pollution etc. (Sarma, 2008). The outputs provide the appropriate basis for the decision making process for the optimal management of the aquifer on a sustainable basis. This process obviates the need for expensive and long term field studies and experiments.

The reliability of the predictive simulation is based on the conceptual model, information and reliability of the inputs, the parameters of the model accuracy of calibration and a clear understanding of the assumptions and limitations of the model. The confidence to be placed in model predictions depends largely on the results of the calibration, sensitivity analysis and verification tests.

Uncertainty in a predictive simulation arises from uncertainty in the calibrated model and inability to estimate accurate values for the magnitude and timing of future stresses. Two major pitfalls are involved in making predictions uncertainty in the calibrated model and uncertainty about future hydrologic stresses. Each of these requires a different type of sensitivity analysis.

It should be kept in mind that calibration of a model is done with respect to a set of observations of field data and conditions prevailing in the field. There may be changes in the conditions during the simulation. Hence use of models for predictive simulation must be done with caution and clear understanding of the conditions under calibration and simulation.

Even though the set of calibrated parameters may give close agreement during calibration and verification the model may not accurately reflect system behavior when the model is stressed in some new way. Furthermore, many predictive simulations require guesses the likelihood and magnitude of future hydrologic or human-regulated events such as future recharge events or pumping rates. Because such information is known only with uncertainty, new errors are introduced into the simulation.

Even with a well calibrated model, if the prediction is based on inadequate data and over simplifications, errors and uncertainties occur in the model predictions. Other type of the error associated with numerical model is data errors. Data errors are the result of inadequate or incorrect data being used in the model study. Data errors are difficult to assess since true description of the aquifer is never known. Unreliable predictions have also occurred due to the failure to use appropriate values for assumed future stresses. Predictive simulations should be planned and assessed by a group of people with a range of expertise to ensure that the best estimates of future stresses are included.

5.3.1 Period of Predictive Simulation

In present study, the validated Model was used for predictive groundwater modeling to study the impacts of existing and future weir on artificial groundwater recharge for the period June 2005 to June 2007(732 days).

5.3.2 Operational Runs

It is required to know the future behavior of the groundwater system in response to the applied hydrologic stresses. When the research was initiated there was a proposal to build a weir near Sindhrot. Sindhrot weir near Sindhrot village was constructed in the year 2007.The people on the downstream demand another weir to be constructed at Badalpur.

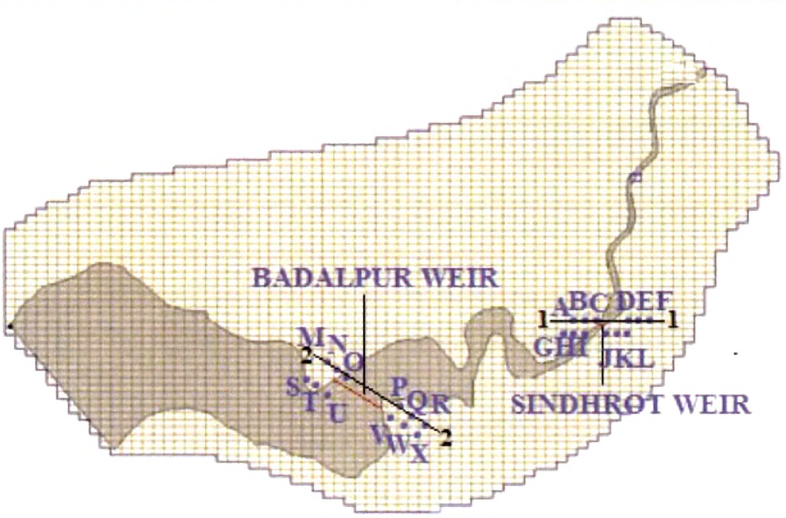
So here following three scenarios are conducted to study the impacts of existing and future weir on artificial groundwater recharge in the Mahi estuarine area.

Scenario A-Without Weir

Scenario B-With Sindhrot Weir

Scenario C-With Sindhrot and Badalpur Weir

Weir is represented in model by giving very low permeability of aquifer ($1*10^{-6}$ m/day) along the weir location. The top elevation of weir is given as RL 8.5 m considering high tide level as RL 6.95 m at weir location. The full reservoir level is kept as 8.0 m by giving river stage data input in the upstream of weir. The Sindhrot weir is having length about 540 m, average river bed RL is 6 m and deepest river bed RL is 3.51. The Badalpur weir is about 41.66 km downstream of Sindhrot weir. The Badalpur weir is having more length about 7 km, average river bed RL is 3.5 m and deepest river bed RL 0.97. The locations of imaginary observation wells for Sindhrot and Badalpur weir are shown in figure 5.5



A,B,C,D,E,F,G,H,I,J,K,L,O,P,Q,R,S,T,U,V,W and X are Imaginary Observation Wells.

Figure 5.5 Locations of Imaginary Observation Wells for Sindhrot and Badalpur Weir

5.3.3 Input Parameters for Predictive Simulation

Condition- Transient

Porosity =30 %

Specific storage S_s =0.00001 m^{-1}

The specific yield of wells s_y for each zone given is as shown in table 4.2 and specific Yield zones are shown in figure 4.13

River conductances given to the upper, middle and lower arc of river are 50, 60 and 20 per unit length respectively. It is as shown in section 4.11 of chapter 4.

Daily Mahi river water level's given to model for the period June 2005 to June 2007(732 days) are as shown in Annexure 1 and graph 4.5 to 4.6. (Note: River water levels at Kavi/Sea is considered same as at Dhuvaran)

Stating heads given to the model (pre-monsoon 2005) is as shown in table 4.3 (Reduced Water Levels of wells).

Transient heads (head dependent flow) on boundary point's pre monsoon and post monsoon for Predictive Simulations period given to the model are as shown in table 4.7

Taluka wise transient net recharges monsoon and non monsoon for the Predictive Simulations period given to the model are as shown in table 4.6 and the detail dates and time of Vadodara taluka is shown below (table5.7) and similarly recharges given to all talukas.

Taluka: Vadodara

Table 5.7 Detail Dates and Time for Net Recharge of Vadodara Taluka for Predictive Simulation

Sr. No.	Date and time	Recharge rate in m/day
1	6/14/2005 12:00:00 AM	-0.0005870
2	6/15/2005 12:00:00 AM	0.0016081
3	10/14/2005 12:00:00 AM	0.0016081
4	10/15/2005 12:00:00 AM	-0.0005870
5	6/14/2006 12:00:00 AM	-0.0005870
6	6/15/2006 12:00:00 AM	0.0013517
7	10/14/2006 12:00:00 AM	0.0013517
8	10/15/2006 12:00:00 AM	-0.0006444
9	6/14/2007 12:00:00 AM	-0.0006444

Times and Time Steps for the Stress Periods (For Predictive Simulations), time steps and stress periods in validation given to model are as shown in table 5.8

The computed horizontal permeability Hk of wells for each zone in unconfined aquifer from calibration of model given to model are as shown in table 5.4 and horizontal permeability zones are shown in figure 4.13

5.3.4 The Stress Periods

The times and time steps for the stress periods used in Predictive simulations is shown in the table 5.8. The number of stress periods used is18.

Table 5.8 Times and Time Steps for the Stress Periods (For Predictive Simulations)

Stress periods	Start(date and time)	Time step(days)	Num. of time steps	Total days
1	6/13/2005 12:00:00 AM	1	1	1
2	6/14/2005 12:00:00 AM	1	1	1
3	6/15/2005 12:00:00 AM	1	4	4
4	6/19/2005 12:00:00 AM	2	1	2
5	6/21/2005 12:00:00 AM	3	1	3
6	6/24/2005 12:00:00 AM	5	1	5
7	6/29/2005 12:00:00 AM	7	1	7
8	7/6/2005 12:00:00 AM	10	1	10
9	7/16/2005 12:00:00 AM	10	9	90
10	10/14/2005 12:00:00 AM	1	1	1
11	10/15/2005 12:00:00 AM	1	2	2
12	10/17/2005 12:00:00 AM	10	24	240
13	6/14/2006 12:00:00 AM	1	1	1
14	6/15/2006 12:00:00 AM	1	1	1
15	6/16/2006 12:00:00 AM	10	12	120
16	10/14/2006 12:00:00 AM	1	1	1
17	10/15/2006 12:00:00 AM	1	2	2
18	10/17/2006 12:00:00 AM	10	24	240
End	6/14/2007 12:00:00 AM	1	1	1
	Total			732

5.3.5 Results of Prediction Scenarios

With the above data as input, the model was run forward in MODFLOW for all the above three scenarios and results obtained are analyzed. The RWL of water table at different locations for respective scenarios are shown in table 5.9. To study the artificial recharge scenario, nature of water mound development graphs for Sindhrot weir and Badalpur weir on different dates are plotted. They are shown in figures 5.6 to 5.15. To study the effect at same point time series curves are plotted at A, B, C, D, E, F, M, N, O, P,Q and R surrounding locations of weirs. They are shown in figures 5.16 to 5.27.

Based on this predicted water table conditions of groundwater model operation under Scenario A-Without Weir, Scenario B-With Sindhrot Weir and Scenario C-With Sindhrot and Badalpur Weir, the water table contours (meters), post-monsoon and pre-monsoon respectively for years 2006 - 2007 are shown in Figures 5.28 to 5.33.

Table 5.9 RWL of Water Table in m at Different Locations

(From Predictive Simulations)

Location /Date	14/6/2005			15/10/2005			16/6/2006		
	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir
A	3.11	3.12	3.13	4.83	4.93	4.94	4.4	4.8	4.8
B	2.94	2.94	2.96	4 79	5.03	5.05	4.47	4.89	4.9
C	2.83	2.83	2.85	4.95	5 48	5.48	4.7	5.4	5.35
D	2.66	2.64	2.65	5.13	5.5	5.49	4.43	5.2	5.18
E	2.67	2.66	2.66	4.91	5	4.99	4.18	4.45	4.47
F	2.95	2.94	2.95	5.19	5.22	5.2	4.57	4.7	4.67
M	2.19		2.21	2.6		3.31	2.08		2.6
N	2.04		2 06	2.32		3	1.92		2.55
O	1.97		2	2.46		3.1	2.23		2.8
P	1.32		1.37	1.82		2.77	1.58		2.2
Q	1.33		1.39	1.63		2.35	1.23		1.85
R	1.4		1.47	1.95		2.6	1.4		1.92

Location /Date	16/10/2006			15/6/2007		
	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir
A	5.6	6.1	6.12	5	5.74	5.77
B	5.7	6.52	6.47	5.07	6.13	6.12
C	5.92	7.11	6.9	5.2	6.6	6.53
D	5.87	6.93	6.66	4.65	5.77	5.69
E	5.64	6.1	6.02	4.74	5.34	5.27
F	6.1	6.28	6.25	5.22	5.71	5.67
M	2.45		2.9	1.88		2.35
N	2.3		3.15	1.89		2.85
O	2.75		3.4	2.4		3.15
P	2		2.65	1.65		2.35
Q	1.66		2.75	1.25		2.2
R	2		3.1	1.5		2.75

Location /Date	14/6/2005			15/10/2005			16/6/2006		
	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir
G	3.19	3.21	3.22	4.76	4.81	4.82	4.24	4.48	4.57
H	2.97	2.99	3	4.65	4.8	4 84	4.28	4.7	4.72
I	2.79	2.81	2.81	5	5.69	5.84	4.6	5.28	5.43
J	2.41	2.4	2.39	4.75	5 4	5.45	4.15	5	5.1
K	2.305	2.3	2.29	4.69	4 9	4.93	4 1	4.67	4.67
L	2.23	2.23	2.22	4.38	4.45	4 48	4.01	4.26	4.25
S	1.75		1.74	2.4		3 1	1.9		2 42
T	1.5		1.45	2.11		2.8	1.7		2.3
U	1.36		1.32	2.08		2 78	1.82		2.45
V	1.2		1.21	1 7		2.6	1.5		2.15
W	1.31		1.35	1.6		2 3	1.2		1.8
X	1.38		1 4	1.9		2 5	1.35		1.85

Location /Date	16/10/2006			15/6/2007		
	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir	Without Weir	With Sindhrot Weir	With Sindhrot & Badalpur weir
G	5.35	5.71	5.82	4.76	5.35	5.52
H	5.41	6.12	6.2	4.82	5.78	5.93
I	5.8	7.1	7.2	5.05	6.5	6.7
J	5.5	6.7	6.58	4.6	5.5	5.47
K	5.4	6	5.9	4.33	5.03	4.96
L	5.9	6.31	6.22	4.29	4.85	4.78
S	2.3		2.7	1.74		2.25
T	2.1		2.95	1.75		2.7
U	2.32		3	1.98		2.8
V	2		2.55	1 6		2.3
W	1.6		2.35	1.2		2.1
X	1.9		3	1.4		2.6

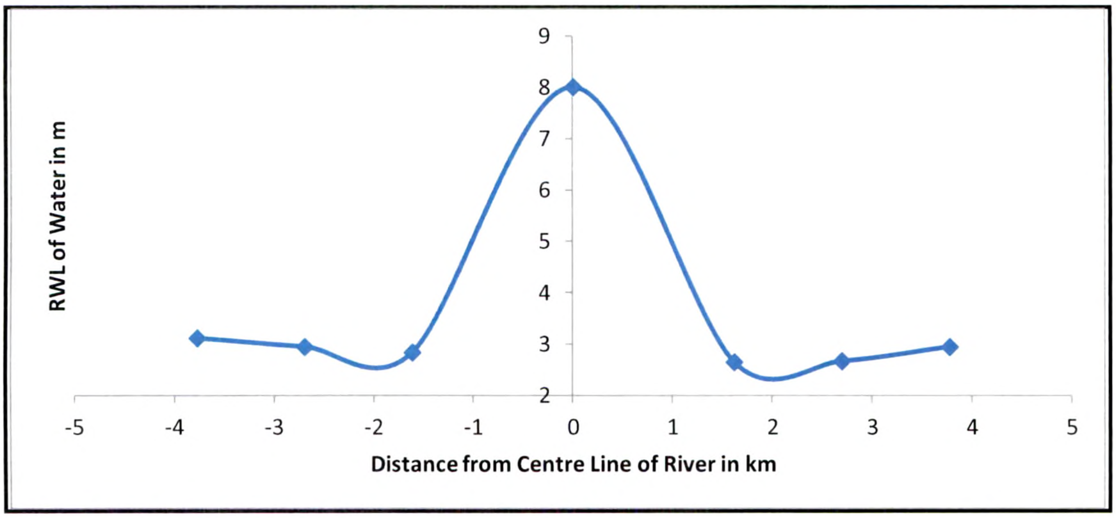


Figure 5.6 Water Mound Development for Sindhrot Weir at Section 1-1 on Date 14/6/2005

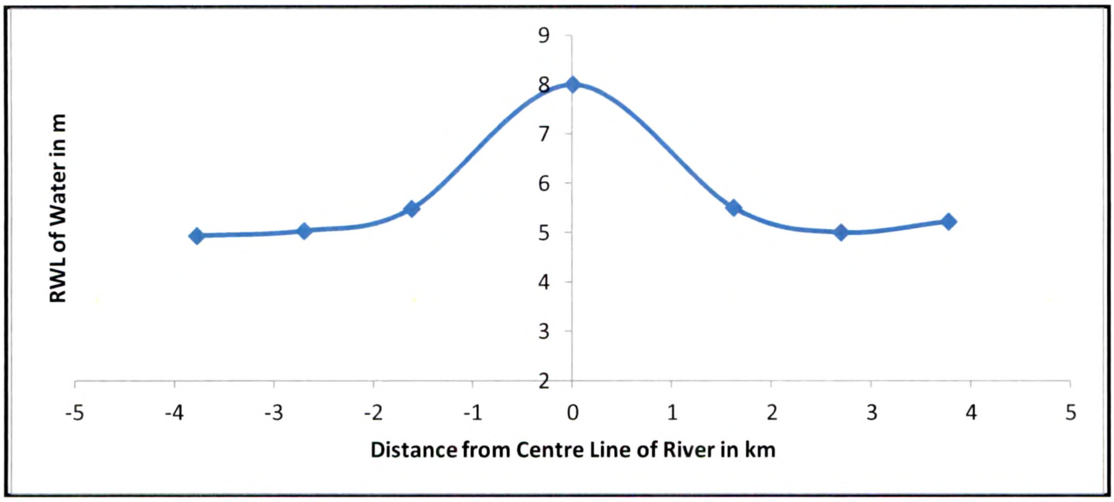


Figure 5.7 Water Mound Development for Sindhrot Weir at Section 1-1 on Date 15/10/2005

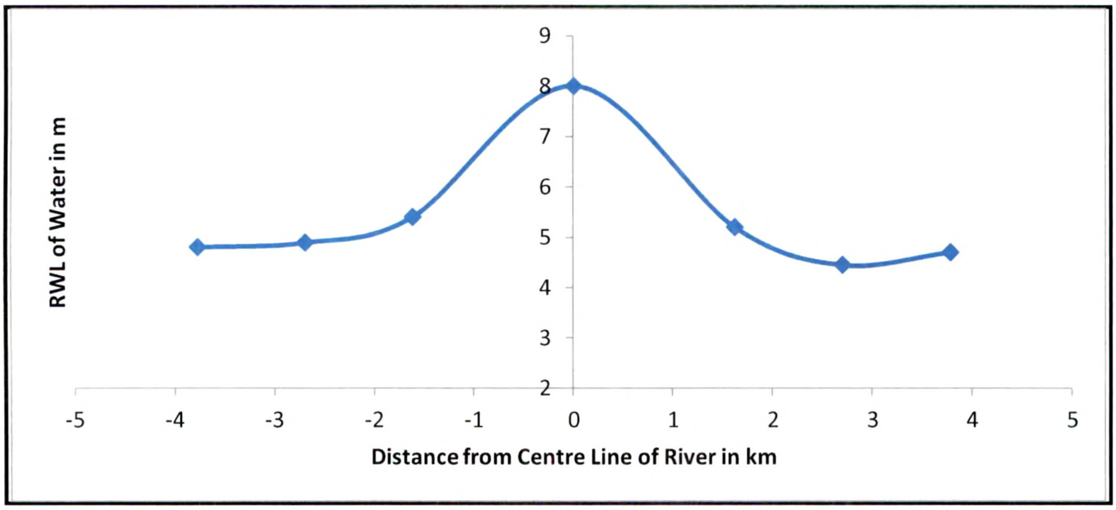


Figure 5.8 Water Mound Development for Sindhrot Weir at Section 1-1 on Date 16/6/2006

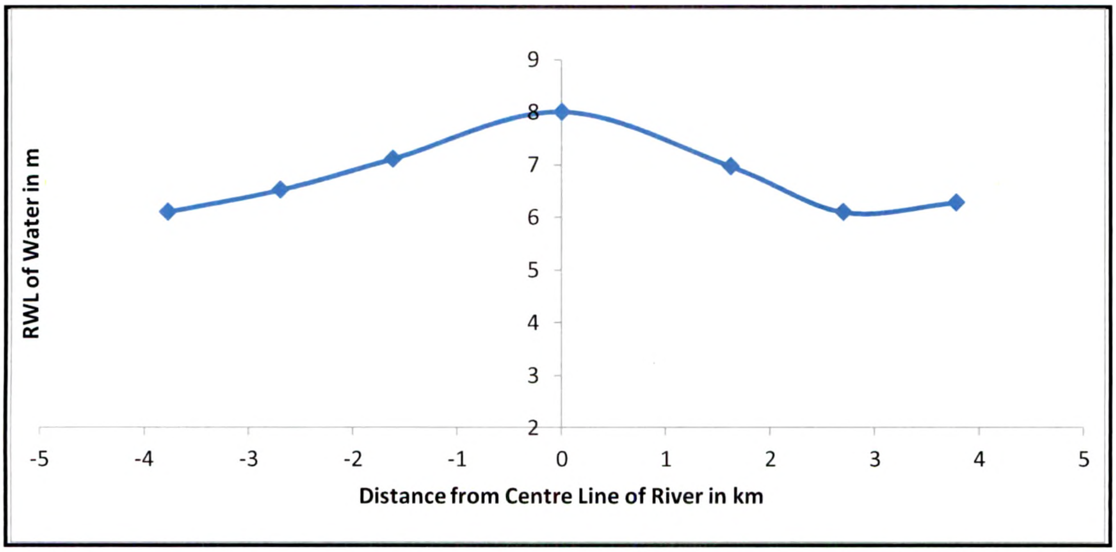


Figure 5.9 Water Mound Development for Sindhrot Weir at Section 1-1 on Date 16/10/2006

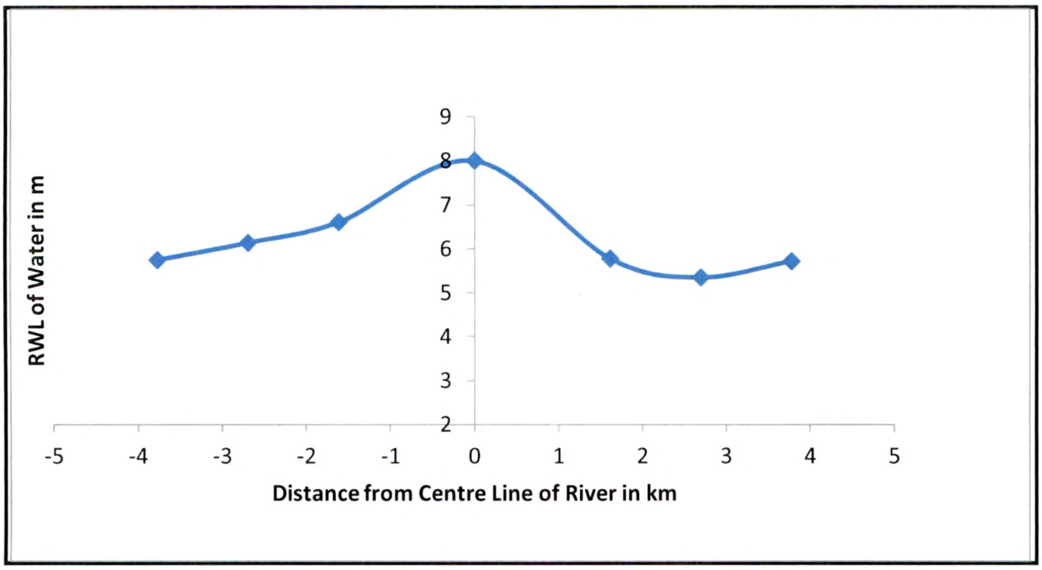


Figure 5.10 Water Mound Development for Sindhrot Weir at Section 1-1 on Date 15/7/2007

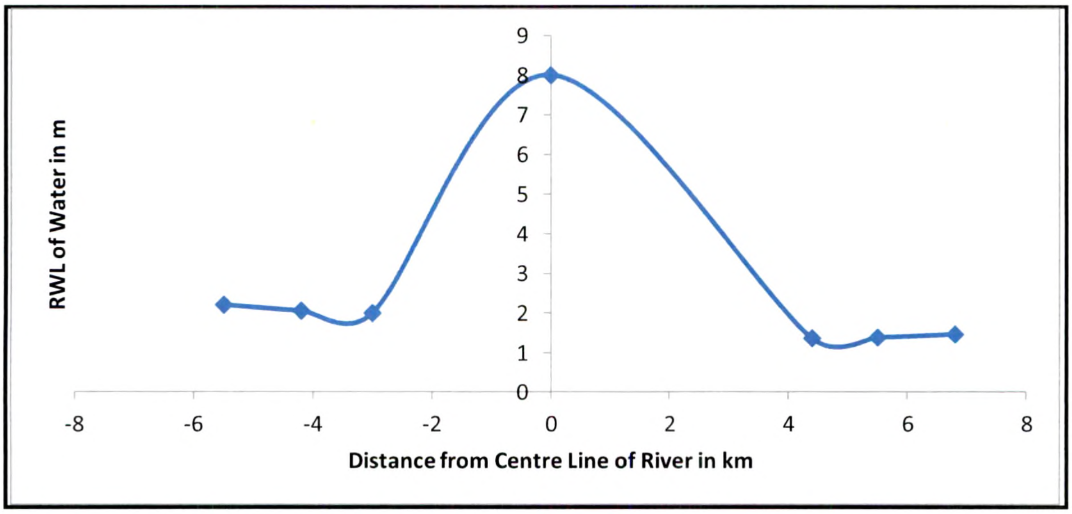


Figure 5.11 Water Mound Development for Badalpur Weir at Section 2-2 on Date 14/6/2005

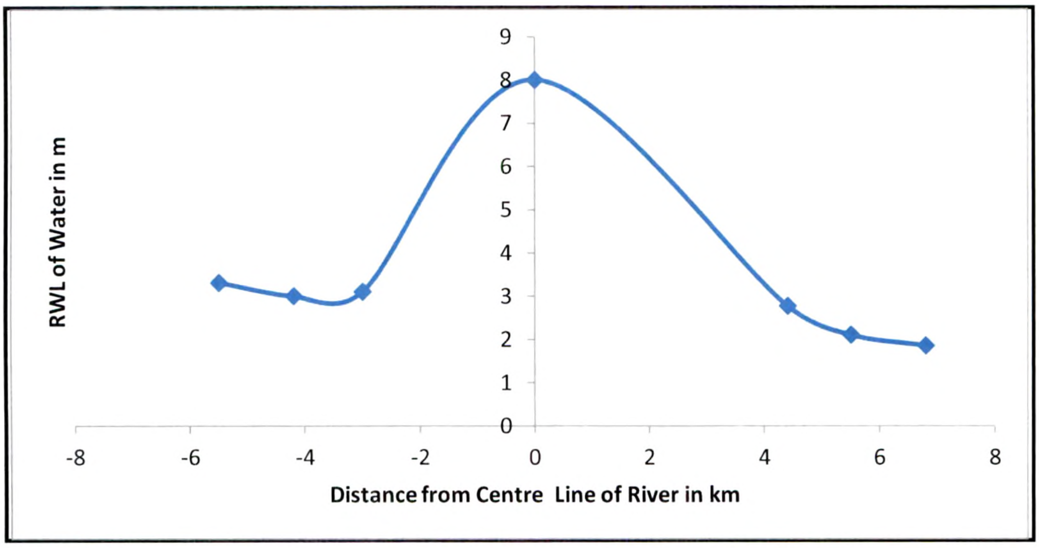


Figure 5.12Water Mound Development for Badalpur Weir at Section 2-2 on Date 15/10/2005

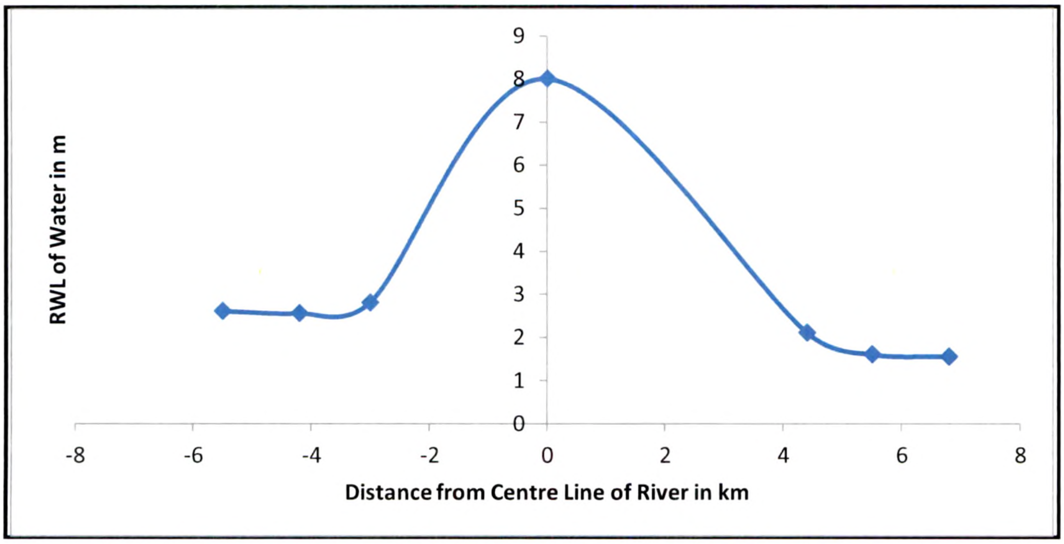


Figure 5.13Water Mound Development for Badalpur Weir at Section 2-2 on Date 16/6/2006

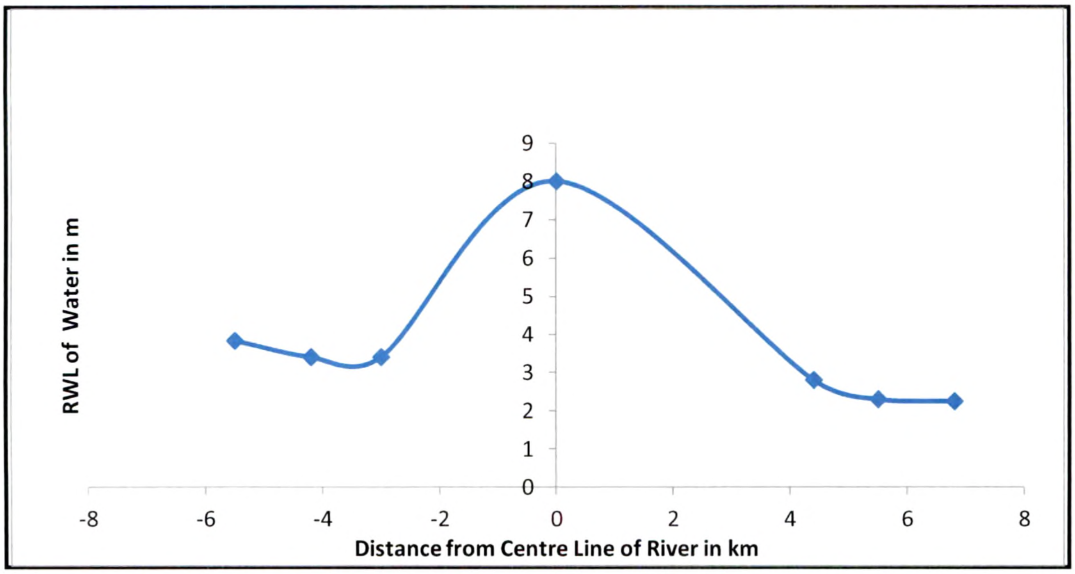


Figure 5.14 Water Mound Development for Badalpur Weir at Section 2-2 on Date 16/10/2006

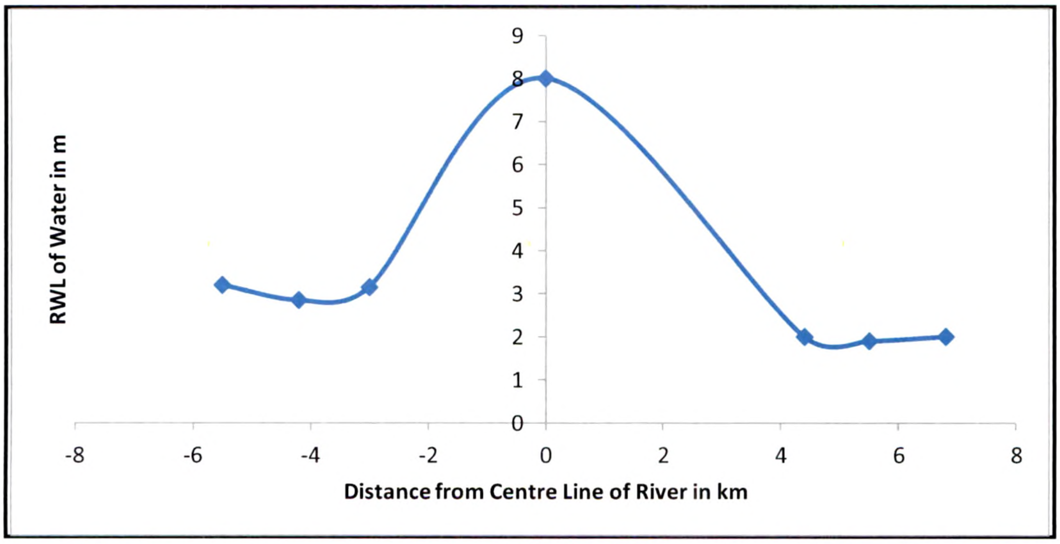


Figure 5.15 Water Mound Development for Badalpur Weir at Section 2-2 on Date 15/6/2007

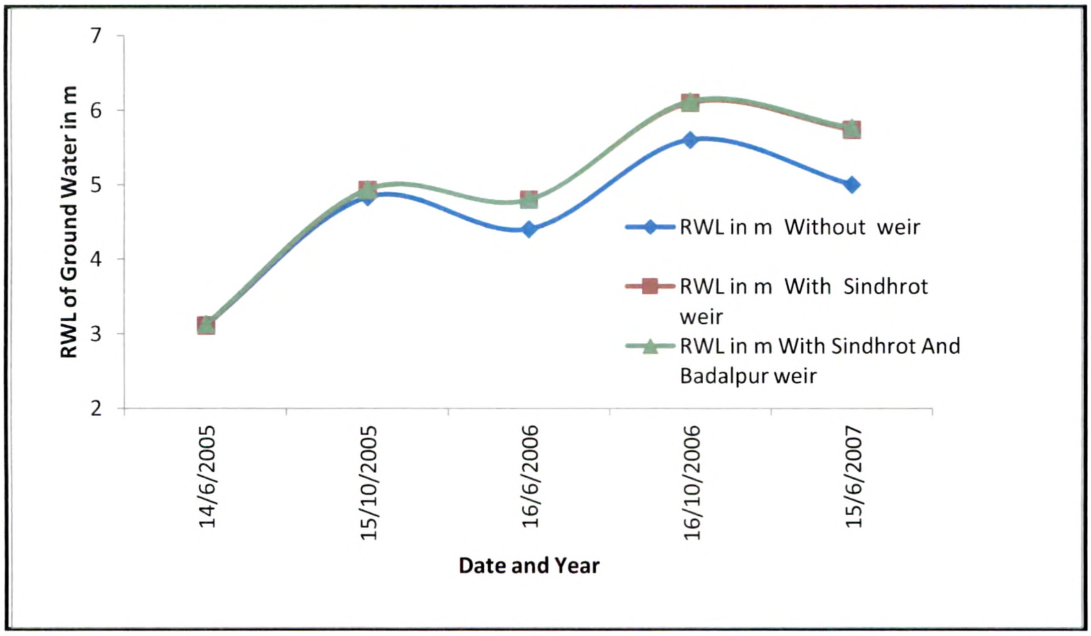


Figure 5.16 Temporal variation of groundwater table elevation at well A under predictive simulation

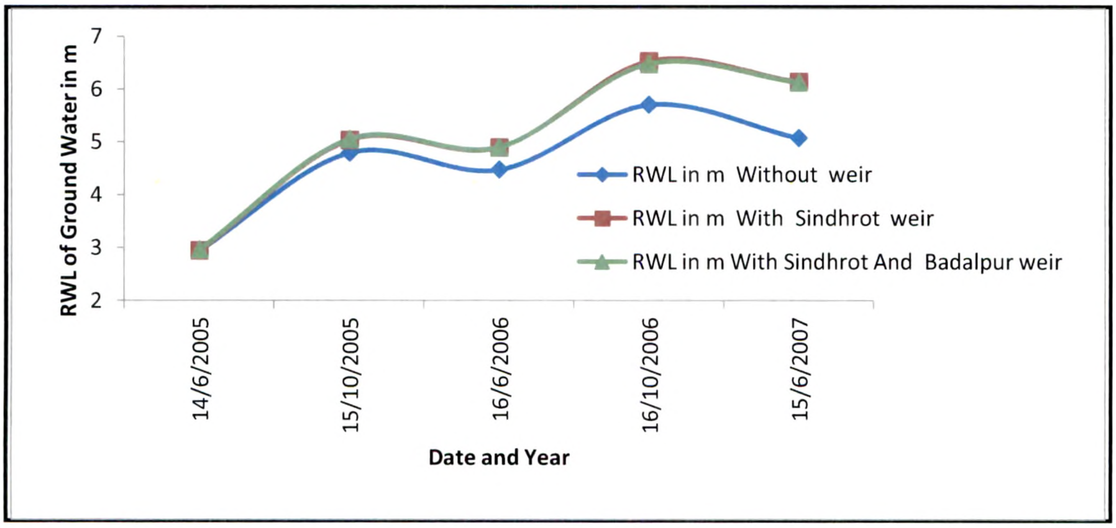


Figure 5.17 Temporal variation of groundwater table elevation at well B under predictive simulation

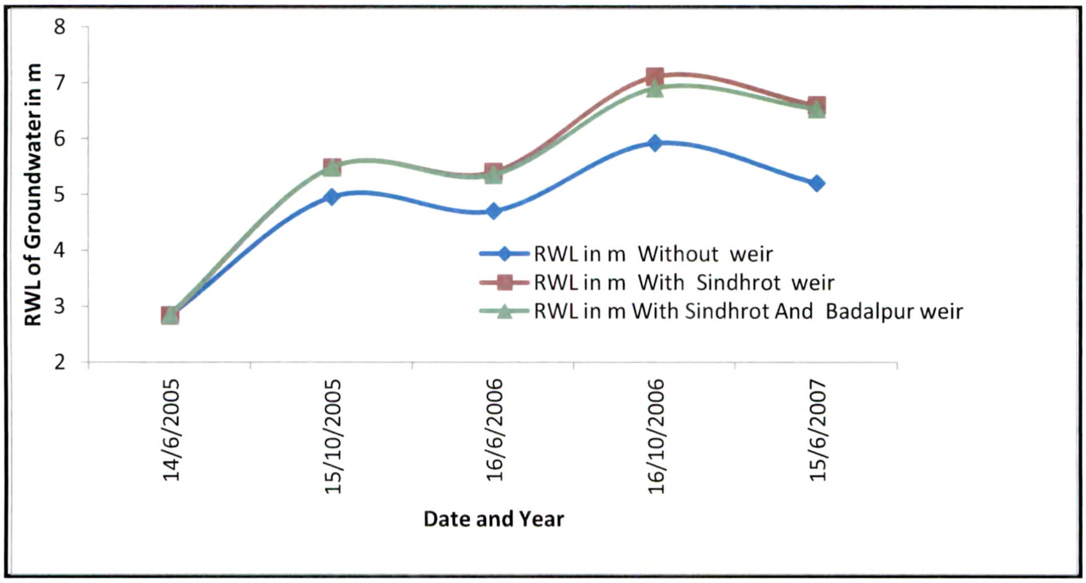


Figure 5.18 Temporal variation of groundwater table elevation at well C under predictive simulation

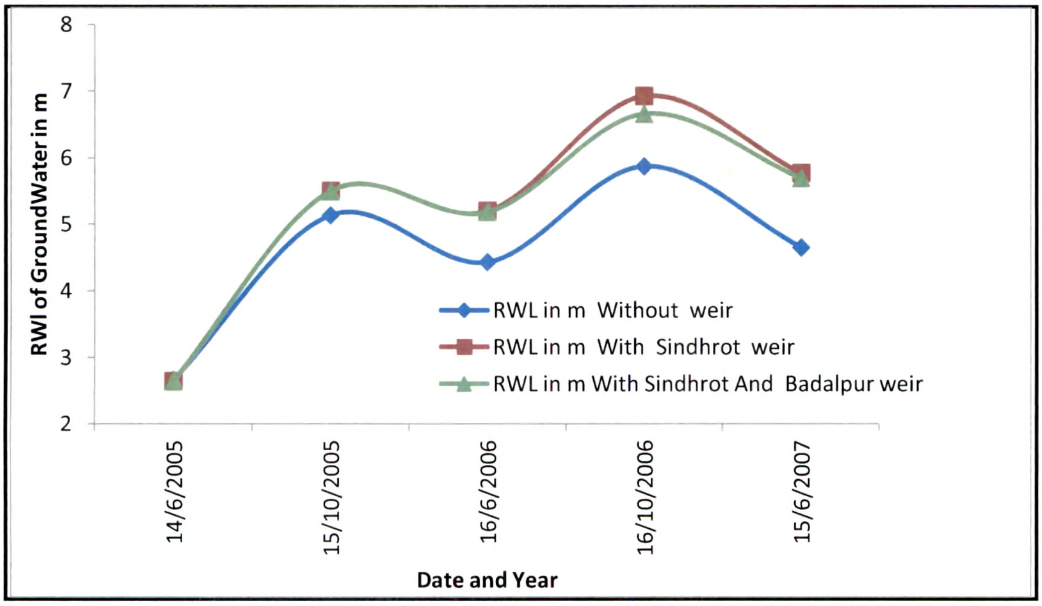


Figure 5.19 Temporal variation of groundwater table elevation at well D under predictive simulation

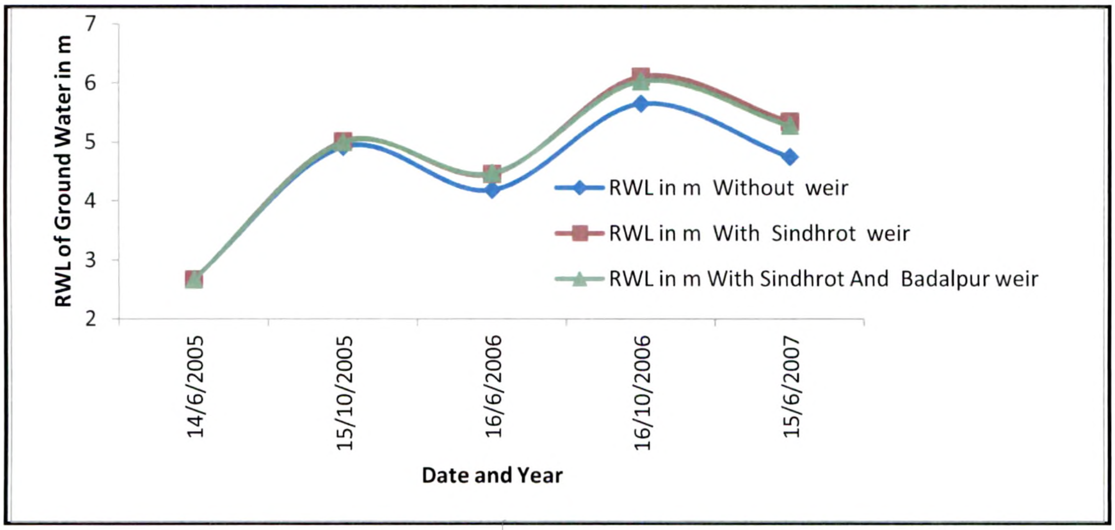


Figure 5.20 Temporal variation of groundwater table elevation at well E under predictive simulation

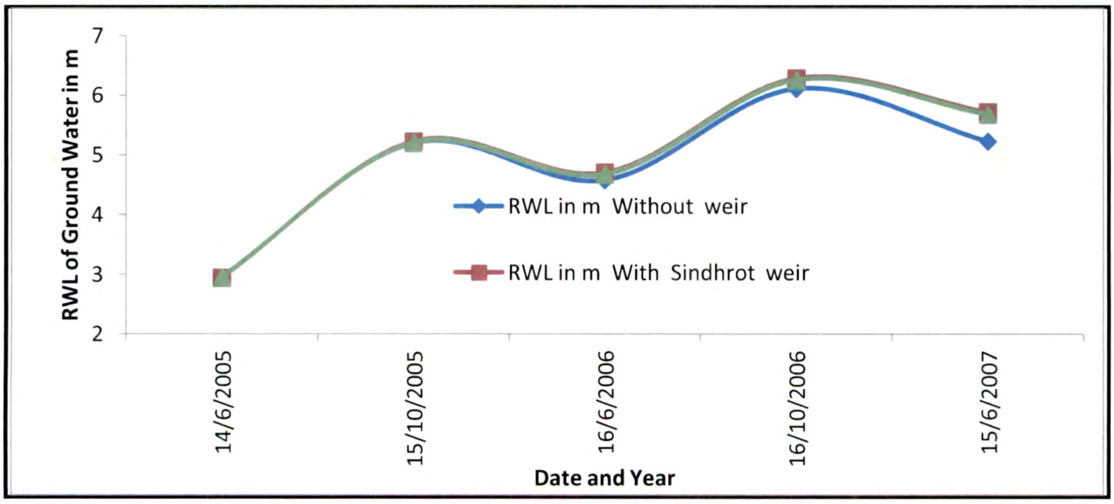


Figure 5.21 Temporal variation of groundwater table elevation at well F under predictive simulation

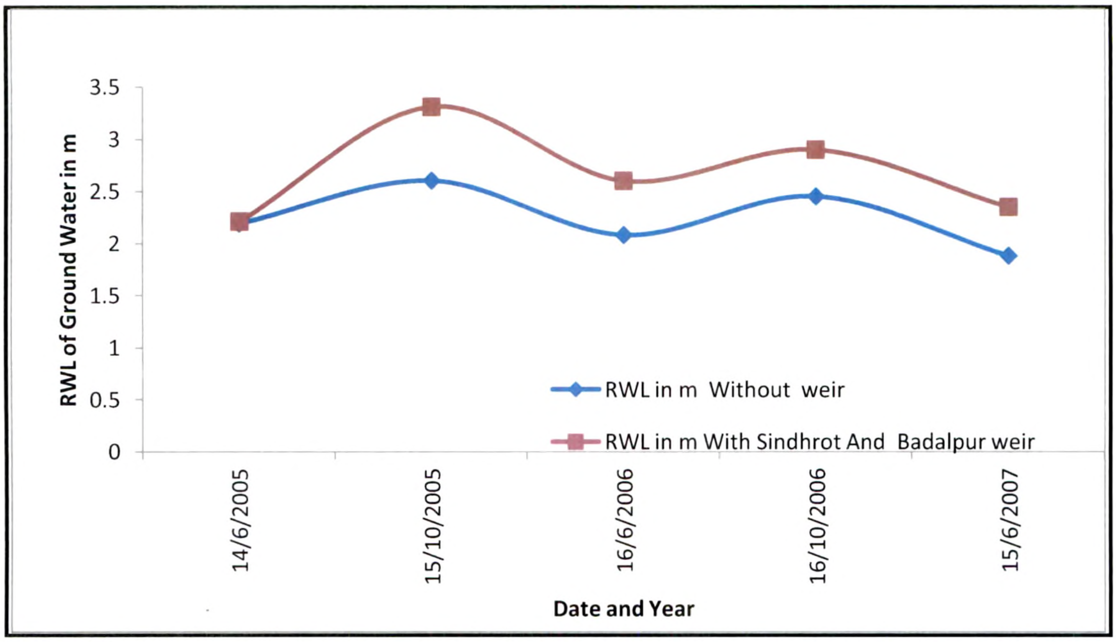


Figure 5.22 Temporal variation of groundwater table elevation at well M under predictive simulation

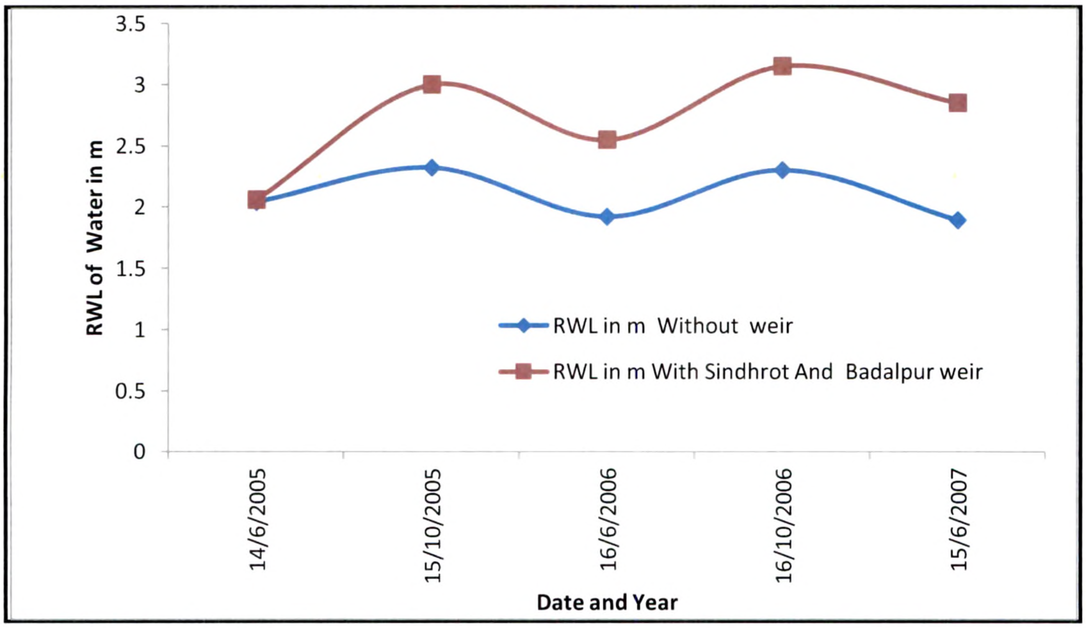


Figure 5.23 Temporal variation of groundwater table elevation at well N under predictive simulation

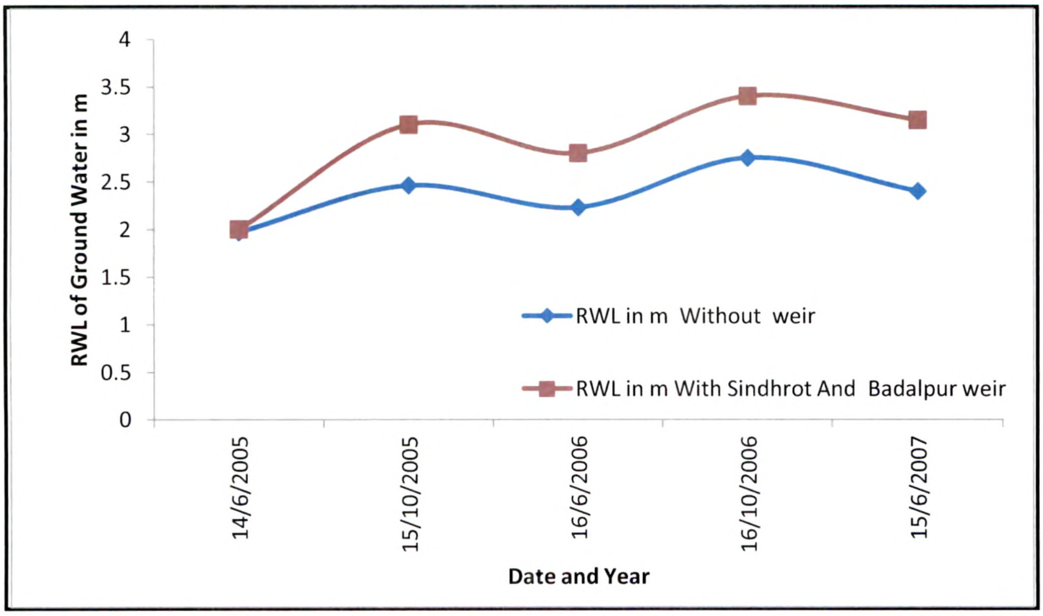


Figure 5.24 Temporal variation of groundwater table elevation at well O under predictive simulation

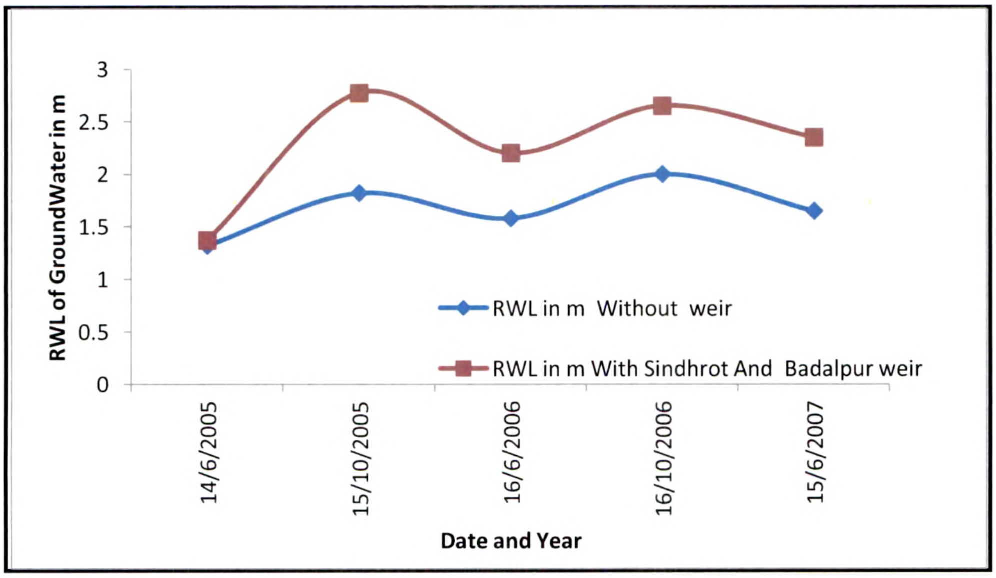


Figure 5.25 Temporal variation of groundwater table elevation at well P under predictive simulation

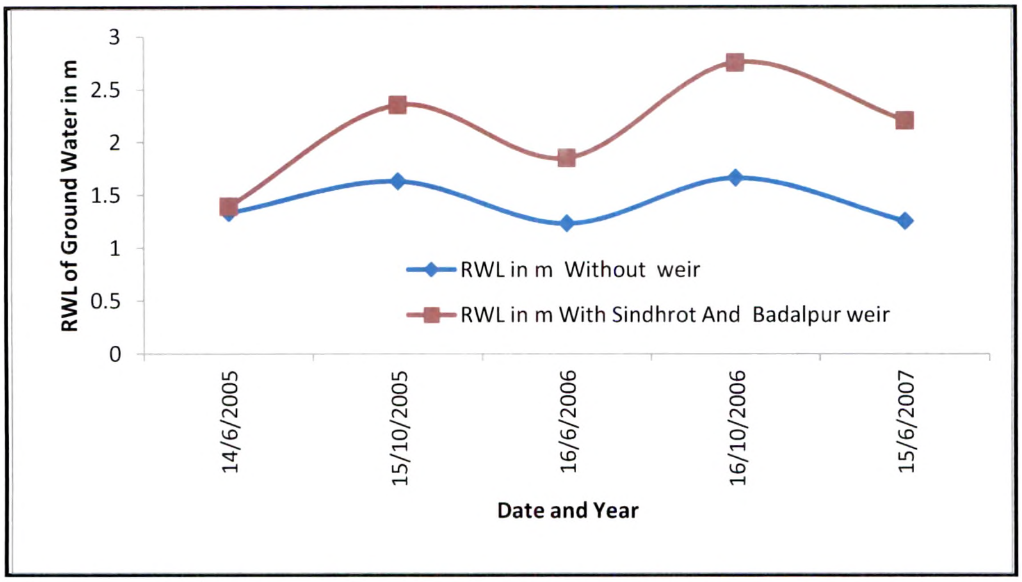


Figure 5.26Temporal variation of groundwater table elevation at well Q under predictive simulation

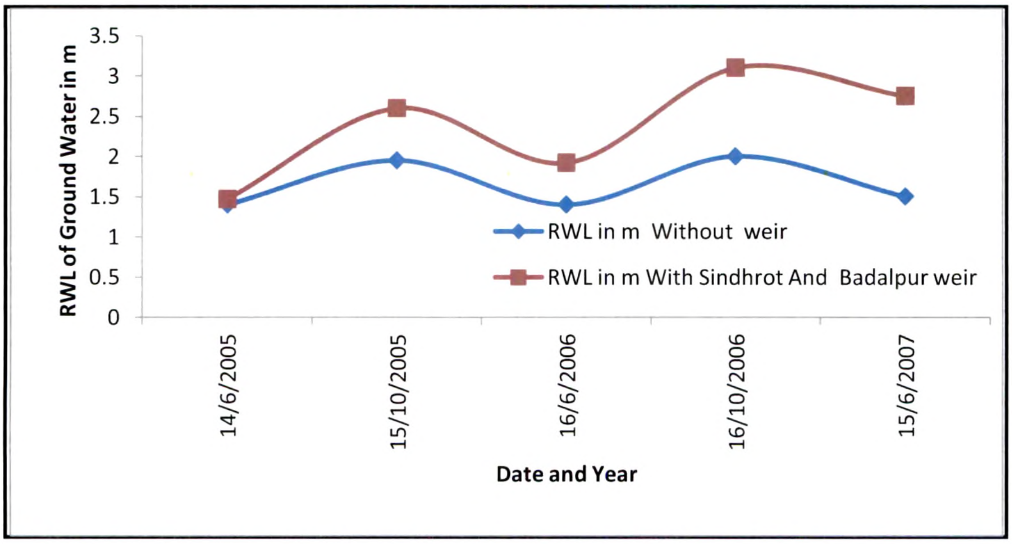


Figure 5.27Temporal variation of groundwater table elevation at well R under predictive simulation

Pre-monsoon and post-monsoon water mound nature is studied. Comparing the groundwater mound for various dates for pre-monsoon and post-monsoon conditions with Sindhrot weir at section 1-1, following observations are made.

1. The rise of 1.81, 2.09, 2.65, 2.86, 2.34 and 2.28 m for locations A, B, C, D, E, and F respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 15/10/2005 due to recharge from rainfall and ponded water on upstream of Sindhrot weir (Fig.5.6 and 5.7).
2. The rise of 1.68, 1.91, 2.57, 2.56, 1.79 and 1.76 m for locations A, B, C, D, E, and F respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 16/06/2006 due to recharge from ponded water on upstream of Sindhrot weir (Fig. 5.6 and 5.8). The rise is less compared to rise on 15/10/2005 due to no rainfall recharge and more pumping in pre-monsoon season.
3. The rise of 2.98, 3.58,4.28,4.29, 3.44 and 3.34 m for locations A, B, C, D, E, and F respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 16/10/2006 due to recharge from rainfall and ponded water on upstream of Sindhrot weir (Fig.5.6 and 5.9). The rise is more compared to rise on 15/10/2005 due to accumulated effect of recharge.
4. The rise of 2.62, 3.19, 3.77, 3.13, 2.68 and 2.77 m for locations A, B, C, D, E, and F respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 15/06/2007 due to recharge from ponded water on upstream of Sindhrot weir (Fig. 5.6 and 5.10). The rise is less compared to rise on 16/10/2006 due to no rainfall recharge and more pumping in pre-monsoon season.

Comparing the groundwater mound for various dates for pre-monsoon and post-monsoon conditions with Badalpur weir at section 2-2, following observations are made.

1. The rise of 1.1, 0.94, 1.1, 1.4, 0.96 and 1.13 m for locations M, N, O, P, Q and R respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 15/10/2005 due to recharge from rainfall and ponded water on upstream of Badalpur weir (Fig.5.11 and 5.12).
2. The rise of 0.39, 0.49, 0.80, 0.83, 0.46 and 0.45 m for locations M, N, O, P, Q and R respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 16/06/2006 due to recharge from ponded water on upstream of

Badalpur weir (Fig. 5.11 and 5.13). The rise is less compared to rise on 15/10/2005 due to no rainfall recharge and more pumping in pre-monsoon season.

3. The rise of 0.69, 1.09, 1.4, 1.28,1.36 and 1.63 m for locations M, N, O, P, Q and R respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 16/10/2006 due to recharge from rainfall and ponded water on upstream of Badalpur weir (Fig.5.11 and 5.14). The rise is more compared to rise on 15/10/2005 due to accumulated effect of recharge.
4. The rise of 0.14, 0.79, 1.15, 0.98, 0.81 and 1.28 m for locations M, N, O, P, Q and R respectively was observed in Reduced Level of groundwater table from 14/06/2005 to 15/06/2007 due to recharge from ponded water on upstream of Badalpur weir (Fig. 5.11 and 5.15). The rise is less compared to rise on 16/10/2006 due to no rainfall recharge and more pumping in pre-monsoon season.
5. The unsymmetrical behavior in the groundwater mounds along the centre line of river is reflected in Figures 5.11 to 5.15 because on right hand side irrigation return flow is adding into the groundwater in MRBC area where as in left hand side irrigation is done by groundwater pumping.

From figure 5.16 to 5.21 of temporal variation of groundwater table at locations A, B, C, D, E, and F on upstream side of Sindhrot weir it was found that the Reduced Water Levels are higher with Sindhrot weir compared to without weir. The effect of the Badalpur weir on the Reduced Water Levels at above locations, upstream of Sindhrot weir is not significant. The trends of variation in groundwater table from pre-monsoon to post-monsoon with weir and without weir are similar for all above locations.

From figure 5.22 to 5.27 of temporal variation of groundwater table at locations M, N, O, P, Q and R on upstream side of Badalpur weir it was found that the Reduced Water Levels are higher with Sindhrot and Badalpur weir compared to without weir. The trends of variation in groundwater table from pre-monsoon to post-monsoon with Sindhrot & Badalpur weir and without weir are similar for all above locations.

Area of influence is more at Badalpur weir as compared to Sindhrot weir. The Badalpur weir is about 41.66 km downstream of Sindhrot weir. Reduced water levels are found to be showing rising trend with weir compared to without weir. General groundwater flow is found from north-east to south-west direction is observed. Rise in water table below river is observed. Reduced water levels in unconfined aquifer are found to be showing rising trend with weir compared to without weir. Water levels in locations surrounding of sindhrot weir are not much affected by Badalpur weir. Increase in water table at nearby locations in two years after construction of Sindhrot weir is found to rise by 0.5 m to 1.43 m. Construction of the weir has resulted increase in the groundwater recharge due to fresh surface water seepage in the study area and also helps in reducing salinity.

The North and South boundary of the model area is considered as catchment boundary of Mahi lower basin. As the study area receives rainfall only during four months of monsoon, the observed water table contours are not found parallel to these boundaries during pre-monsoon hence the variable head boundary is considered based on observed values. The major objective of the study is to investigate the effect of recharge in the vicinity of the river. Thus the water level fluctuations at boundaries are assumed beyond area of influence for river recharge. However, the discrepancy in assumed water level and actual water level at boundary affects the inflow- outflow from boundaries in total water budget of modeled area.

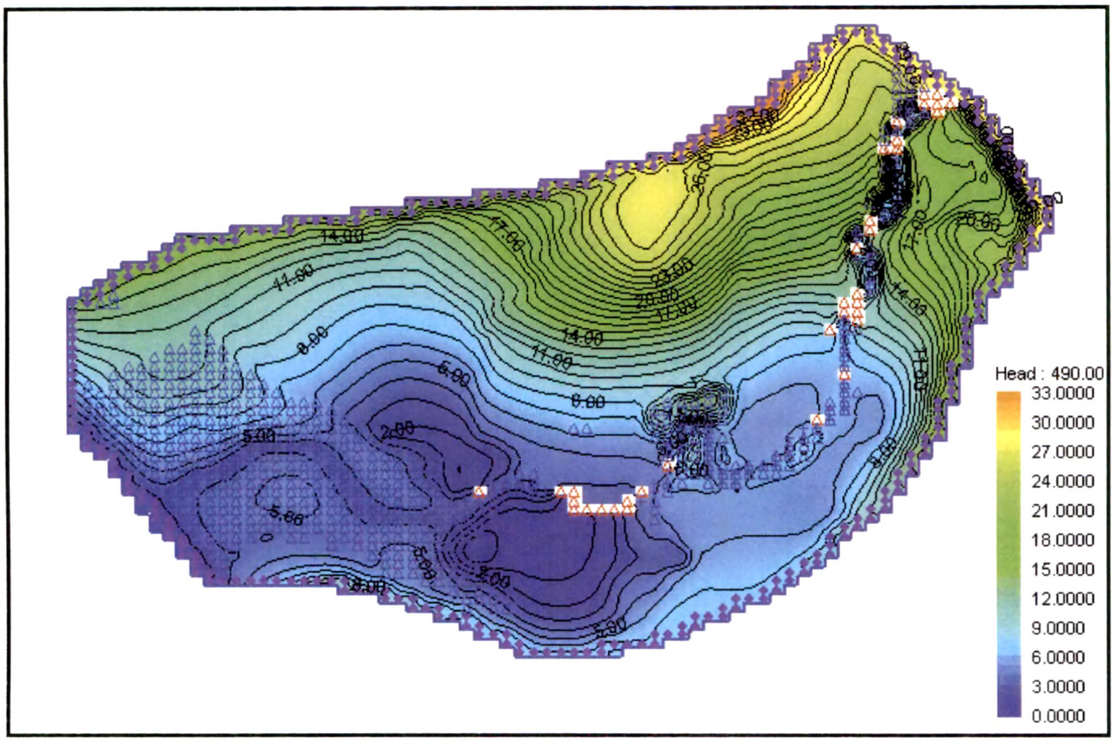


Figure 5.28 Predicted water table contours without weir 16/10/2006 (12:00 AM).

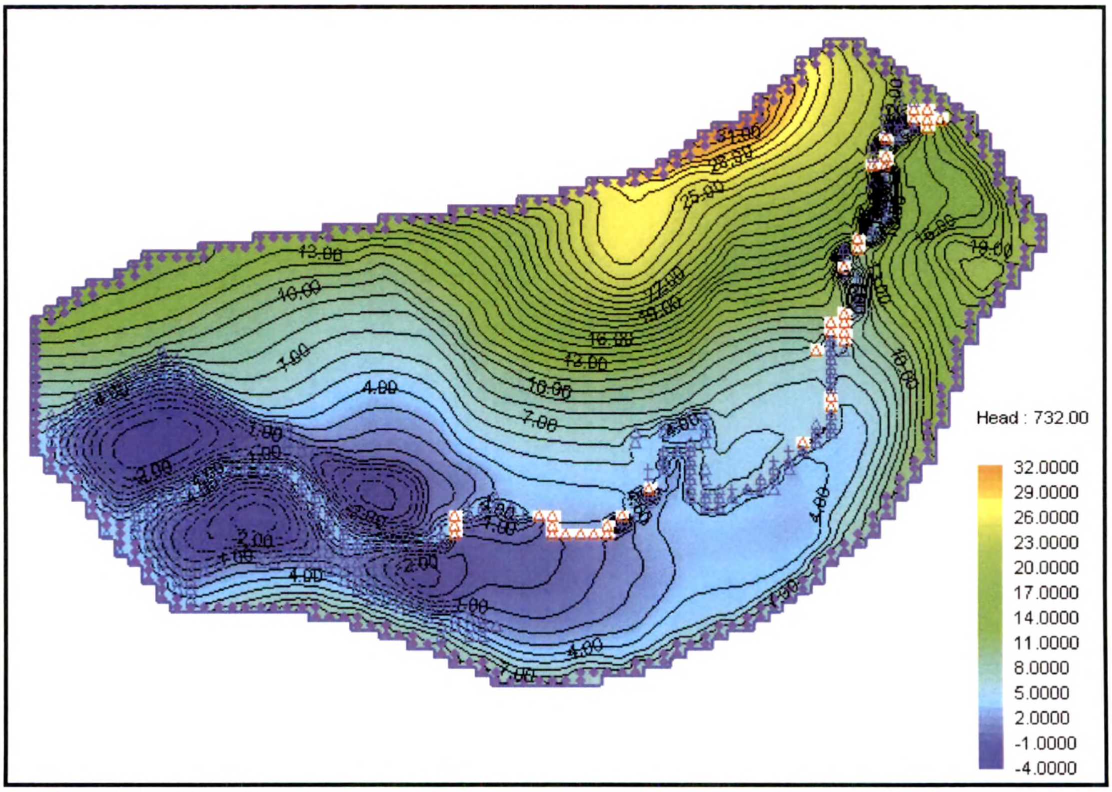


Figure 5.29 Predicted water table contours without weir 15/06/2007 (12:00 AM).

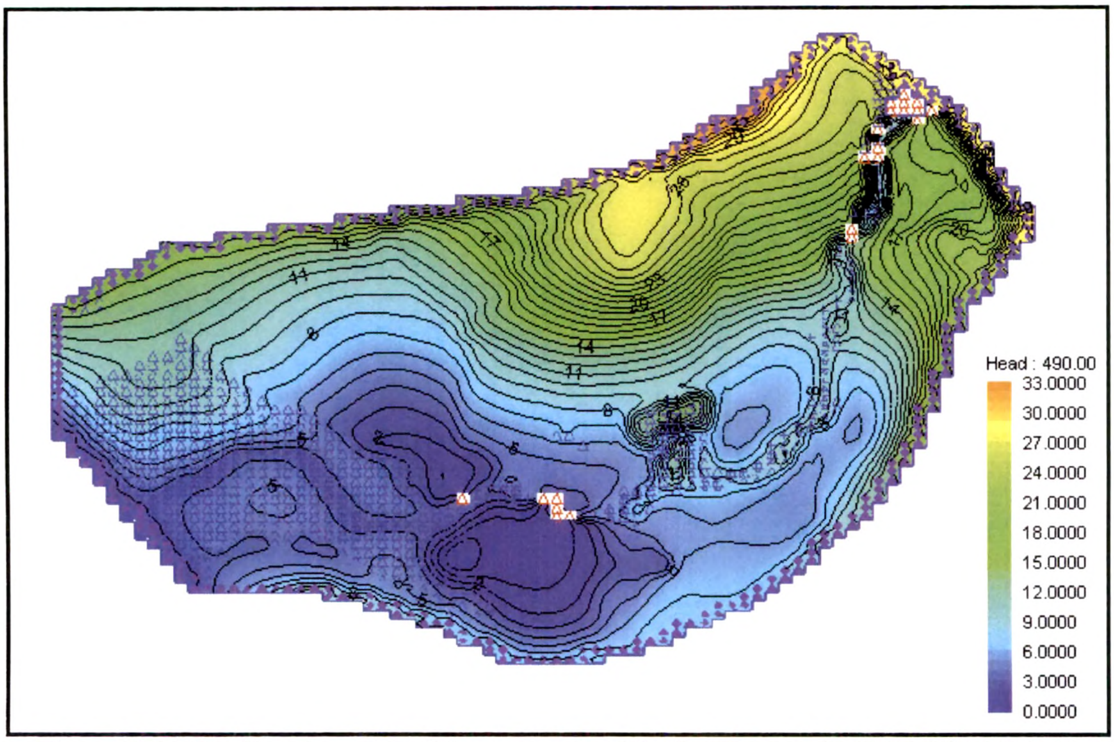


Figure 5.30 Predicted water table contours with Sindhrot weir 16/10/2006 (12:00 AM).

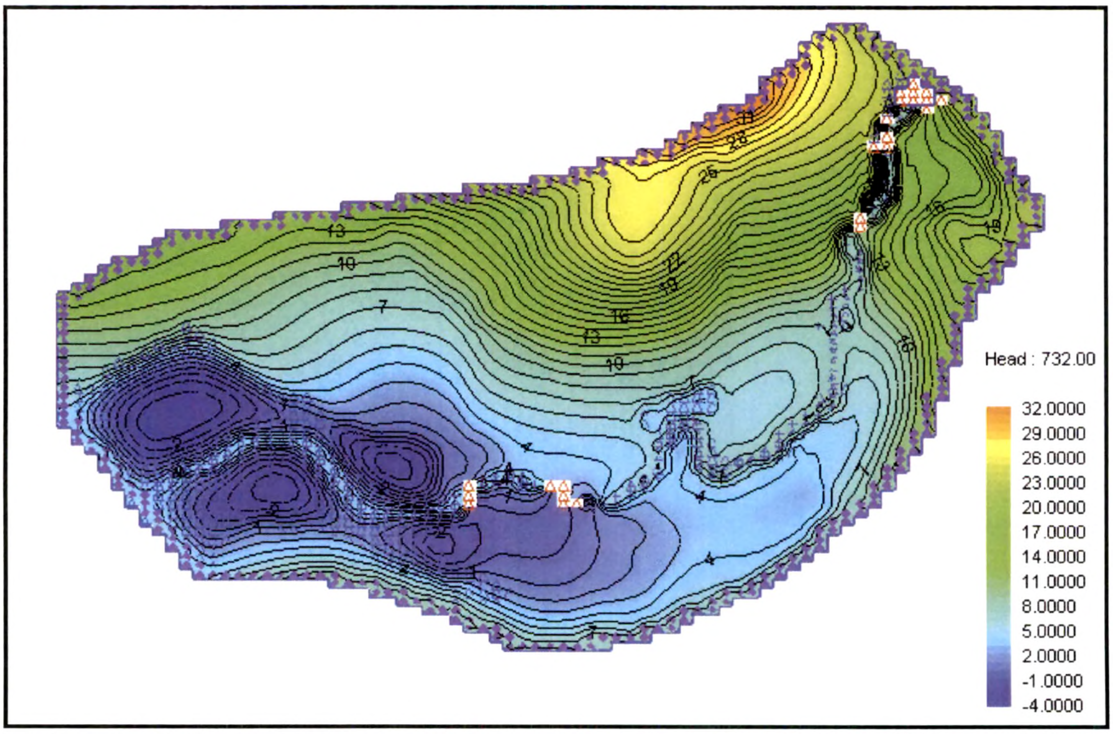


Figure 5.31 Predicted water table contours with Sindhrot weir 15/06/2007 (12:00 AM).

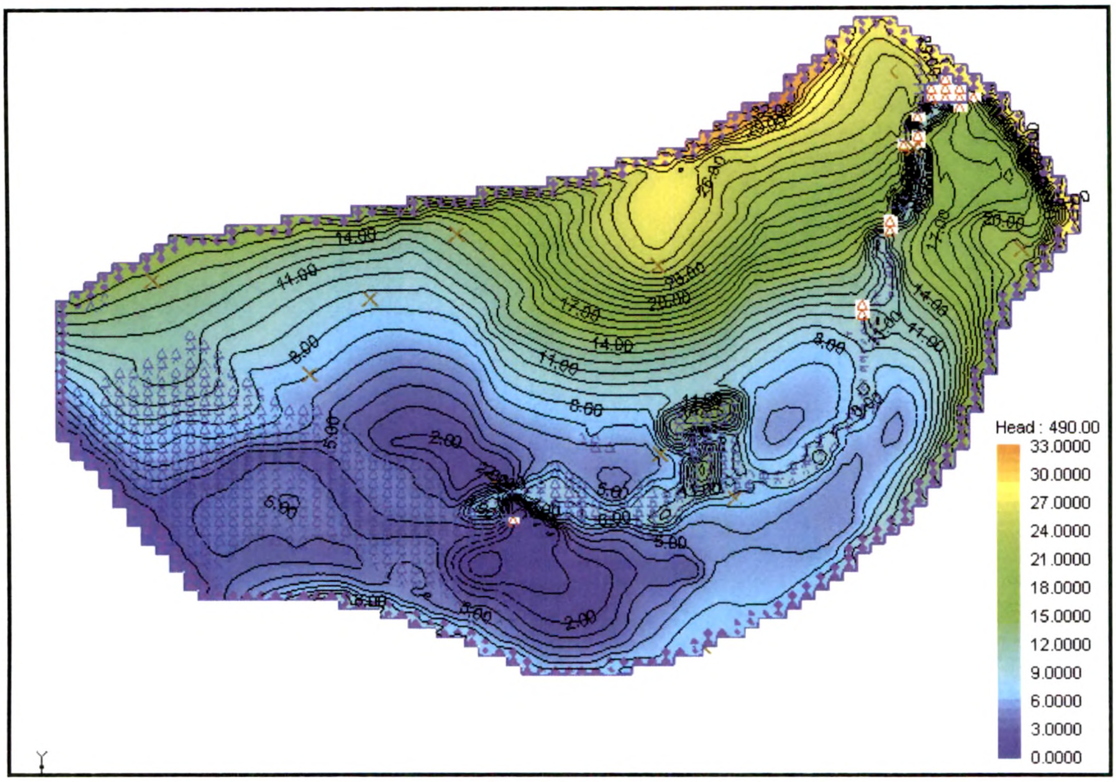


Figure 5.32 Predicted water table contours with Sindhrot & Badalpur weir 16/10/2006 (12:00 AM).

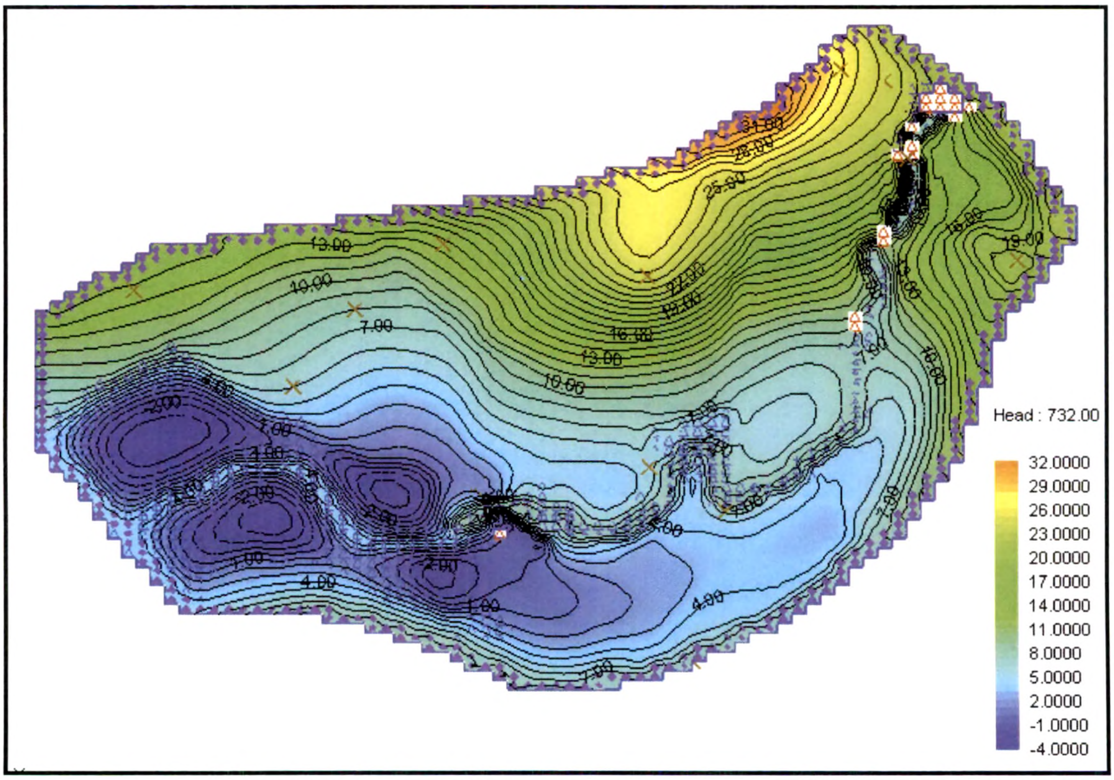


Figure 5.33 Predicted water table contours with Sindhrot & Badalpur weir 15/06/2007 (12:00 AM).