GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES,
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CENTRAL GROUND WATER BOARD

Brief Report on Ground Water Modelling Studies in Central Godavari Delta, East Godavari District, Andhra Pradesh

SOUTHERN REGION
HYDERABAD
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1.0 Introduction

Large scale groundwater exploitation has resulted continuous groundwater level decline and depleted groundwater storage in many parts of the Country. For proper management of groundwater resource for long-term economic development, irrigation and domestic water supply, it is imperative to understand groundwater resources availability and limitations, and to use groundwater models for the allocation of resources and assess impacts.

As a part of enhancing skills of officers of CGWB and 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:

- To Know how to create a groundwater model following the procedures of building a groundwater model: definition of model objectives, construction of hydrogeological conceptual models, design of numerical models, preparation of model inputs, model calibration and model application.
- Be familiar with the most popular groundwater model codes: MODFLOW, PMPATH, and a graphical user interface PM8.
- Be able to apply groundwater models for analysis of groundwater flow systems and water budget; and evaluation of groundwater development scenarios.

3.0 Back Ground 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, Central Godavari Delta, East Godavari District, Andhra Pradesh covering an area of 923 Sq.kms had chosen as a case study from AP. 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. The presentation of the area and model was made at CHQ, CGWB during the month of June, 2018. The details of the same in the form of report are prepared for submission to CHQ, CGWB/NHP.

3.1 Study Area:

Central Godavari Delta (CGD), covering 923 km^2 area in East Godavari district, Andhra Pradesh State is located between North longitudes of 16° 23' 58" to 16° 56' 07" and East Latitudes of 81° 44' 45" to 82° 18' 04" covered in parts of Survey of India Toposheets No. 65 H/9, H/13 and H/14. The area is bounded by Dawaleshwaram Barrage in the north, Vasishta Godavari in the west, Gauthami Godavari in east and Bay of Bengal on the south (fig-1). The elevation map of the area is shown in Fig-2. The study area comprising of 12 mandals encompassing 137 Villages. As per 2011 census, the population is about 3.5 lakhs with a growth rate of about 6%. The Salient features of the area are provided in Table-2.

Table-2 salient features of Central Godavari Delta, East Godavari District

S. No.	Item		Salient feature
1	Geographical Area	:	923 Sq.kms
2	Toposheets No.	:	65 H/9, H/13 and H/14
3	Co-ordinates	:	NL 16° 23' 58" to 16° 56' 07" EL 81° 44' 45" to 82° 18' 04"
4	Elevations	:	Min 1 m amsl (South) Max 19 m amsl (North)
5	Slope	:	Towards South
6	Major Soils	:	Deltaic Soils (Sandy & Sandy Clay Loam)
7	Major Land use	:	Agriculture (Double crop area)
8	Irrigation		Mainly by Surface water
9	Major Crops	:	Paddy , Sugarcane, Coconut and Banana
10	Drainage	:	River Godavari
11	Normal Rainfall	:	840 mm
12	Geomporphology	:	Deltaic plain
13	Geology/Principal Aquifers	:	Alluvium
14	Major aquifers	:	3 Aquifers ~1 m to 20 m Aquifer-1 (Un confined) 23-55 m Aquifer-2 (Confined)

			77-120 m Aquifer-3 (Confined)	
15	GW Abstraction Structures	:	Dug Wells/Tube well / Filter Point	
16	Stage of GW Development	:	16%	
17	Transmissivity/ Storativity	:	Aquifer-1 (T/S): 351 m^2/day/2.0X10^{-3} Aquifer-2 (T/S): 352 m^2/day /7.62X10^{-3} Aquifer-3 (T/S): 246 m^2/day /0.0107.	
18	Hydraulic conductivity	:	Aquifer-1 : 17.55 m/day Aquifer-2 : 11 m/day Aquifer-3 : 5.5 m/day.	
19	Depth to water levels (m bgl)	:	The average water level: 2.06 m bgl.	
			Pre Monsoon: 0.26 to 6.9 m bgl	Post Monsoon: 2 to 4 m.

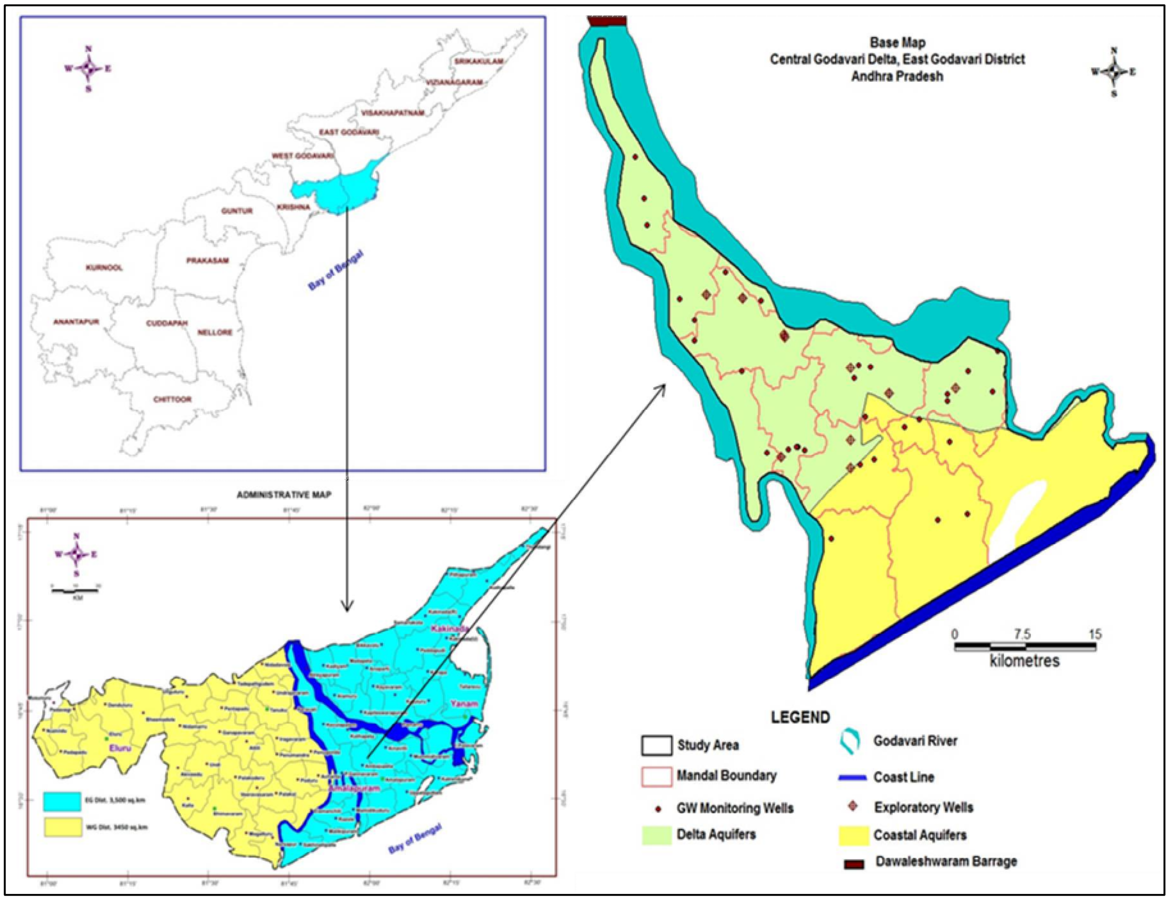


Fig-1: Base map of Central Godavari Delta, East Godavari District, AP

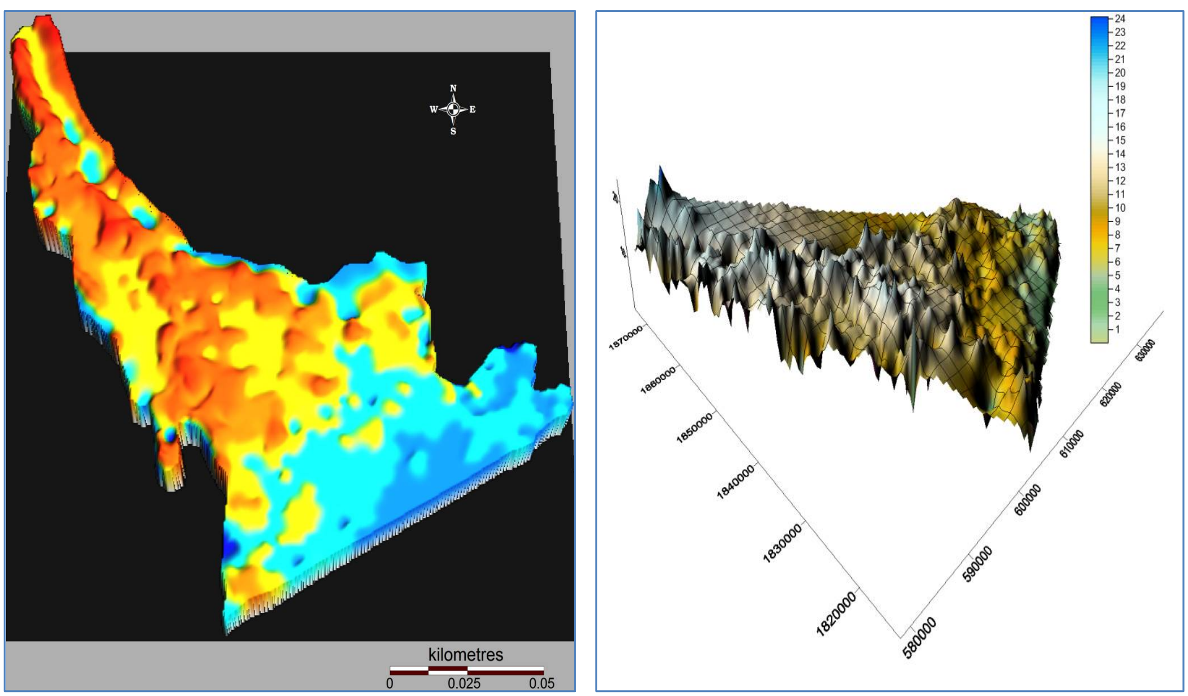


Fig-2: Elevation Map of Central Godavari Delta, EG District, AP

3.2 Rainfall:

The normal annual rainfall in the area is varying from 1130 to 1359 mm. The study of long term rainfall pattern shows that the long term normal is 1146 mm and 53% of the years the area received normal rainfall and 19 % of years the area received excess rainfall where as the remaining 28% of the years received deficit rainfall. The long term trend analysis of rainfall indicates that the rainfall has an increasing trend of 1.142 mm/year.

3.3 Drainage:

The area is drained by Godavari River which flows NNW to SE direction. The Godavari River enters East Godavari district in Devipatnam mandal and flows along the western boundary of the district. At South of Rajahmundry i.e., the northern tip of the present study area, the river splits into two viz. Vasishta Godavari in the west and Gowthami Godavari in the east. These two distributaries are forming the boundaries for the present study area **(Fig. 1)**. Further, Vasishta Godavari branches near P. Gannavaram into Vainateya Godavari which debouches into Bay of Bengal at Vodala Revu where as the Vashishta Godavari debouches into the sea at Pallepalem near Antarvedi.

3.4 Geomorphology & Land Use Pattern

The area is occupied by deltaic and coastal plains. The altitude varies from 5 to 20 m amsl. The main land forms of the study area are Channel bars, Channel islands, Cut off meanders, Deltaic palins, Meander scars, Natural levees, Oxbow lakes and Palaeo channels. The land use pattern in the study area indicates that the area is mostly agrarian. The area has the distributory network of the river Godavari. The Godavari Central Delta Irrigation Project is catering the irrigation needs of the study area both in Kharif and Rabi seasons.

3.5 Hydrogeology & Aquifer Disposition

Geologically, the area is underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. In the northernmost of the area alluvium is followed by sandstones. The sandstones formations are not exposed in the area but encountered at 40 m depth in a borehole drilled by CGWB at Vaddiparru in the northern part of the area. The general geological succession of the area is shown in Table-3.

Table – 3: General Geological Succession of the Study Area

Era/Period	Age	Series/Stage	Lithology
Quaternary	Recent to Sub-Recent	Recent	Alluvium
Mio-Pliocene	Mio-Pliocene	Rajahmundry Formation	Sand Stones

3.6 Ground Water Occurrence:

Ground water occurs in unconfined, semi-confined and confined conditions depending on the availability of impervious beds. Based on the available hydro geological data a panel diagram showing the aquifer disposition and aquifer parameters was prepared for the study area which is presented as Fig-3 & 4. The perusal of the data indicates that there are multi aquifers in the area with intervening thick clay beds. These sand beds which act as aquifers and there are three distinct beds which behave as regional aquifers. Thin beds and pinched beds are neglected in making out the regional aquifer system. The first aquifer which is present up to a maximum of 20 m below MSL is un-confined where as the other aquifers are confined. The quality of ground water from deeper aquifers is inferior when compared with top un-confined aquifer. The disposition of aquifers in the area is as given below in Table - 4.

Table – 4: Disposition of aquifers in the Study Area

S.No	Aquifer	Lithology	Type	From	To
1	1	Sand	Un Confined	Ground level	20 m bmsl
2	2	Sand	Confined	23 m bmsl	55 m bmsl
3	3	Sand	Confined	77 m bmsl	120 m bmsl

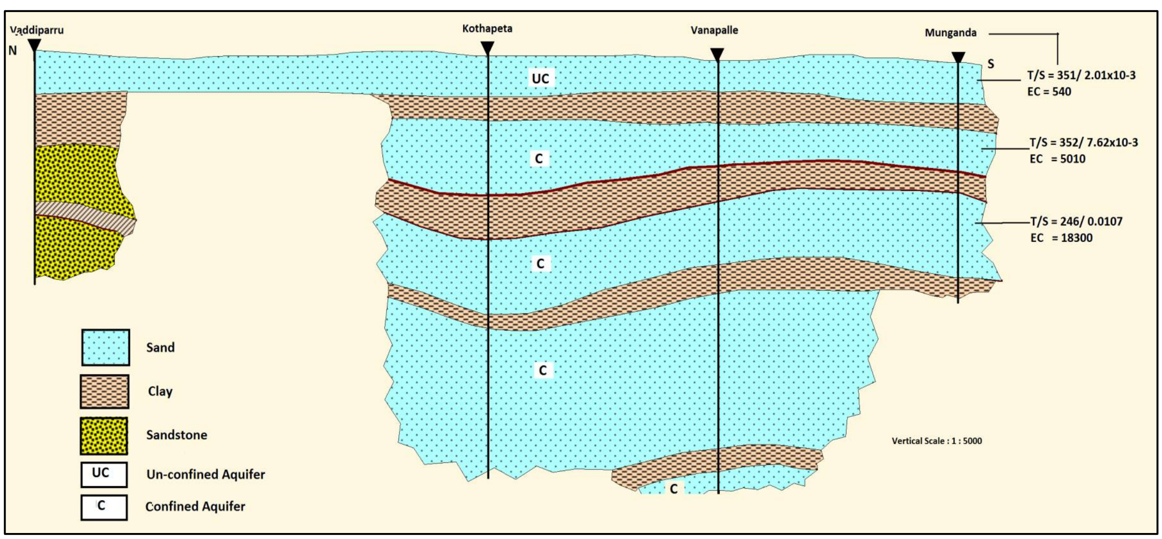


Fig-3: Disposition of Aquifers in the Study Area & Storage Parameters

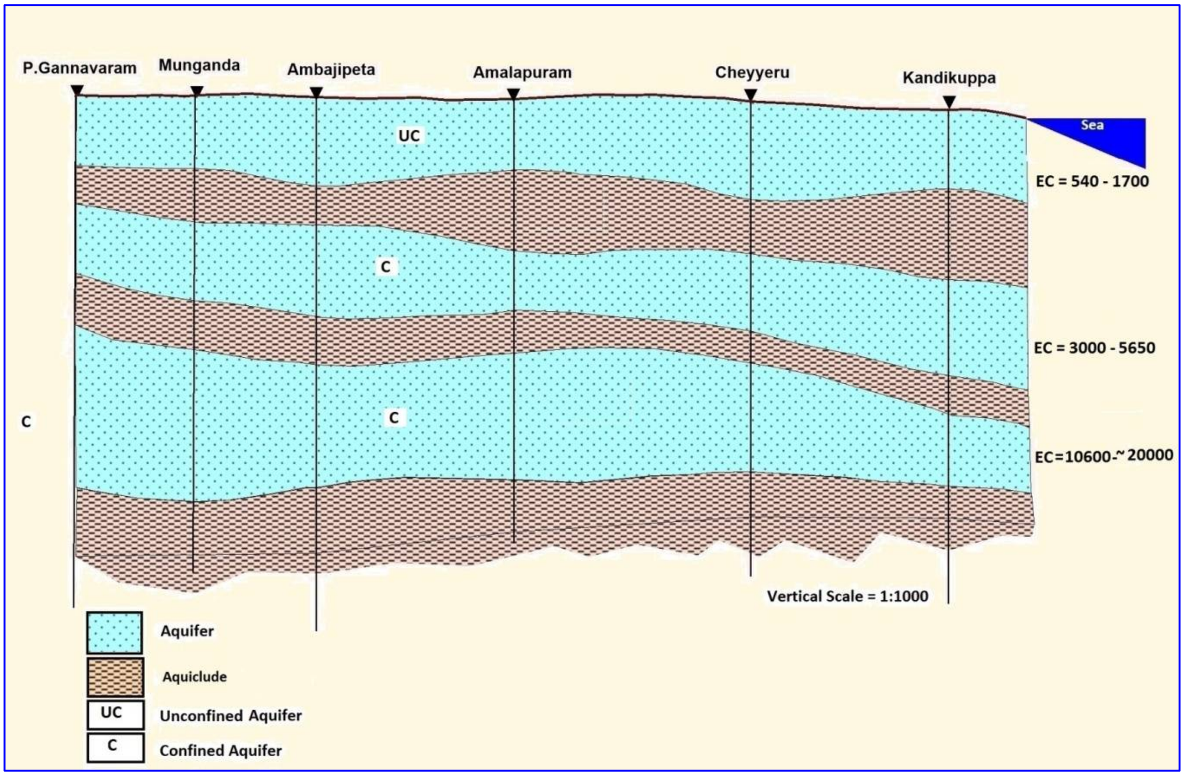


Fig-4: Disposition of Aquifers in the Study Area and EC

CGWB, SUO, Visakhapatnam studied the area in depth by establishing 50 key observation wells in the area, all of which are tapping the unconfined aquifer. Due to non availability of abundant number of wells tapping the deeper aquifers, most of the study was restricted to the unconfined aquifer only. From the exploratory wells drilled earlier by CGWB, it is identified that the quality of ground water in the deeper aquifers is Saline. The existence of three distinct aquifers within 120 m bgl is established from the well field constructed up to a depth of 120 m bgl, during GW exploration by CGWB in the area. The first aquifer is under unconfined conditions where as the other two aquifers are confined in nature. The ground water in the deeper aquifers is not being tapped as the quality of this water is saline.

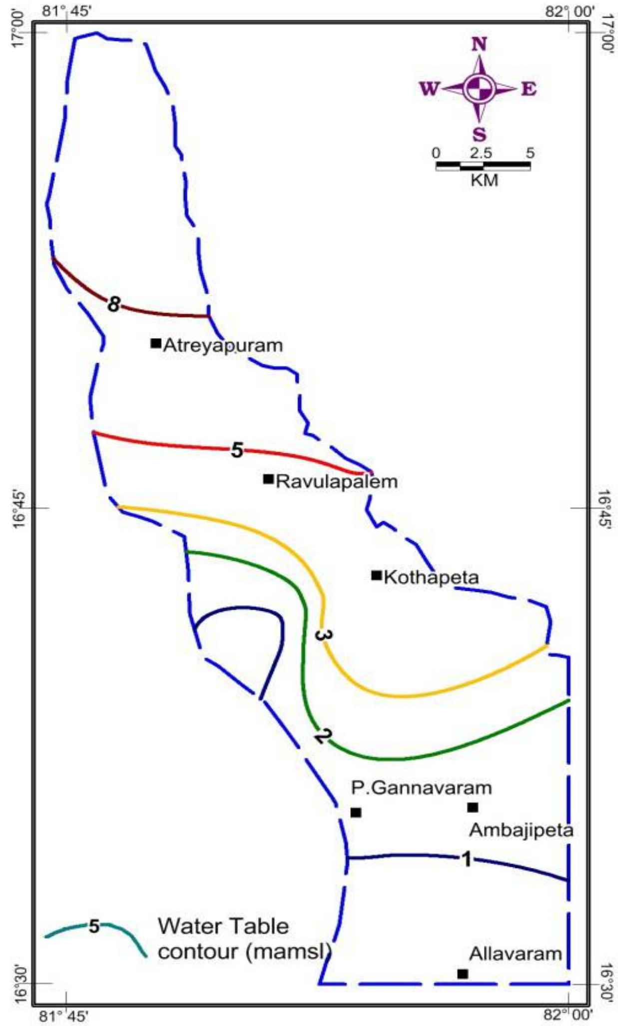
3.7 Depth to Water Level:

The depth to water levels during pre-monsoon (May) ranges from 0.35 m bgl to a maximum of 9.11 m bgl. The depth to water levels during post-monsoon (November) ranges from 0.26 m bgl to a maximum of 6.9 m bgl.

The average water level of the area is 2.90 m bgl.

In the northern part of the area, the depth to water level ranges in between 4 and 6 m bgl, whereas in the southern part of the area it ranges in between 2 and 4 m bgl.

The water level fluctuation between pre-monsoon and post-monsoon water levels ranges in between 0.02 m and 2.49 m. The fluctuation map reveals that the entire area shows rise of < 2 m in water level.



The Central Ground Water Board is monitoring the long-term behavior of water levels with respect to time through existing 5 National Ground Water Monitoring Wells in the study area. The trend analysis indicates that, overall the water levels are slightly rising during both the pre and post monsoon seasons. The water table elevation ranges between < 2 m amsl in the southern part of the area and >8 m amsl in the northern part of the area. The general ground water flow direction is towards southeast.

3.8 Hydrochemistry:

The temperature of shallow ground water is controlled a large extent by the atmospheric temperature. The range of temperature in the study area is from 28° C to 31° C. The ground water temperature is lower than atmospheric temperature. The pH values of ground water in the study area are ranging in general between 7.5 and 8.8 indicating that water is alkaline. In the study area, EC ranges from 750 to 3000 micro siemens/cm at 25°C. The chloride is less than 250 mg/l. The fluoride content in the ground water of the study area is < 1 mg/l. The results of samples were plotted on Piper's Trilinear diagram and on modified piper diagram for Geochemical classification of waters. From the figures it is evident that majority of ground water is Na K – HCO3 type followed by Na K – Cl SO4 type.

3.9 Ground Water Resources:

Being a part of the Command of Godavari Irrigation System, the requirement of ground water for the irrigation is limited in the study area and when required is met through dug wells and filter points. The main device for lifting of ground water for irrigation purposes is driven by electrical motor and by diesel engines to a small extent. The stage of ground water development in the area is 6%. The entire area is categorized as safe.

4.0 Ground Water Modelling:

Ground Water flow modelling is a tool for studying the groundwater behaviour under spatio-temporal variations of input and output stresses. Usually, generic numerical solution is implemented in computer models. The numerical model/solution is based on the finite difference or finite element methods. One of popular models is MODFLOW (McDonald and Harbaugh, 1988), which is based on the finite difference method was developed by US Geological Survey. The MODFLOW is an algorithm of compatible codes based on finite difference solutions for 3-D flow through porous medium. Many graphic user interfaces have been developed for MODFLOW to facilitate the model creation, model inputs and visualization of the model results.

Groundwater modelling is an iterative process. Models are only approximations of reality, but not reality itself. Assumptions and even simplifications are necessary in the modelling because of the complexity of hydrogeological formations on the one hand and the lack of sufficient field data on the other hand. Therefore, groundwater modelling is not only a science but also an art. The art of modelling can only be learned from practicing how to apply models.

4.1 Simulation of groundwater flow model

A Ground water model simulates groundwater flow indirectly by means of governing equations thought to represent the physical process that occur in the system, together with equations that heads or flows along the boundaries of the model. They require use of partial differential equations. Although MODFLOW is freely available, all graphic interfaces are commercial. One of cheaper popular interfaces is PMWIN (Chiang and Kinzelbach, 2001). PMWIN is used for development of Numerical conceptual model for simulation of groundwater flow for Central Godavari Delta. It consists of number of packages for assigning boundary conditions such as constant head, drains, rivers, recharge, wells, hydraulic conductivity, Evapotranspiration, vertical leakance *etc*.

4.2 Model Conceptualization and Numerical Model Development:

The steps followed in creation of numerical model are design of the model grid, Specification of the aquifer geometry, Input of the parameters, Simulation of the natural groundwater flow and Simulation of the dynamic response of the aquifer to external stresses.

5.0 Ground water Model Simulation in Central Godavari Delta

The Central Godavari Delta had been selected for these hands on ground water modelling study during the training program at IHE, Delft. A three layer model was conceptualized.

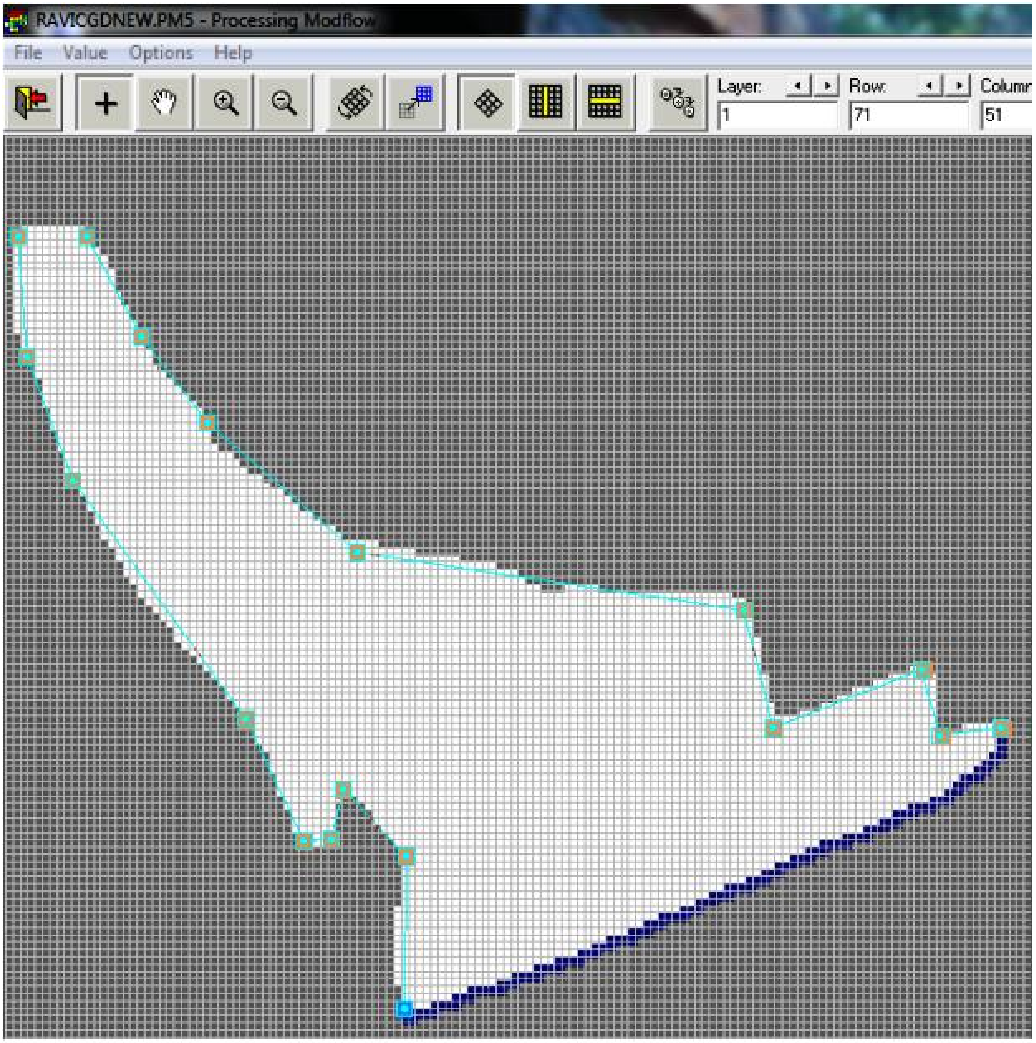


Fig- 5: Discretization of Central Godvari Delta in PM8 Software

The Coast Line in the south is taken as Constant Head boundaries and River as boundary in the east and west parts of the study area through which the water is allowed to leave the system or water can enter from in to the system depending on the difference between the heads. The total thickness of the conceptual model is 60 m bgl. The general ground water flow is towards the south i.e Coast line. The details of conceptualization of model is provided in the table

Table- 5: Details of Model Conceptualization

No. of Layers Conceptualized	:	03
Grid Size	:	500*500 m
No. of Rows	:	132
No. of Columns	:	140
Type and Thickness of 1st layer	:	Unconfined & 20 m
Type and Thickness of 2nd Layer	:	Aquitard & 10 m
Type and Thickness of 3rd Layer	:	Confined & 30 m

Layer	Type	Horizontal Anisotropy	Vertical Anisotropy	Transmissivity
1	1: Unconfined	1	VK	Calculated
2	3: Confined/Unconfined (Transmissivity varies)	1	VK	Calculated
3	3: Confined/Unconfined (Transmissivity varies)	1	VK	Calculated

5.1 Steady State

5.1.1 Construction of Steady State Natural Model:

Under the natural conditions, groundwater is usually in a steady state. The long-term average recharge equals the long-term average discharge. Groundwater level distribution and water budget of the steady natural groundwater flow provide references for assessing the impact of abstraction. The calculated groundwater levels provide the initial conditions for transient groundwater modelling.

The model area 923 Sq.kms is divided into 132 rows and 140 columns of 500 * 500 m grid size (Figure-5). Three model layers represent 2 aquifers and 1 aquitard. The first model layer represents the top unconfined aquifer up to 20 m depth and the other model layers are confined. The first row of the first model layer represents the Constant head boundary. The last row of all model layers represents the coastal line as the constant head boundary.

The top elevation of the first model layer is the land surface elevation (Figure-6). A grid file is created from and CSV file consisting of Easting, Northing and elevation and is exported into the model through PMWIN field interpolator to interpolate surface elevation on model grid. The top and bottom elevations of other model layers are 10 m and 20 m respectively. The elevation of the top layer is extracted from DEM.

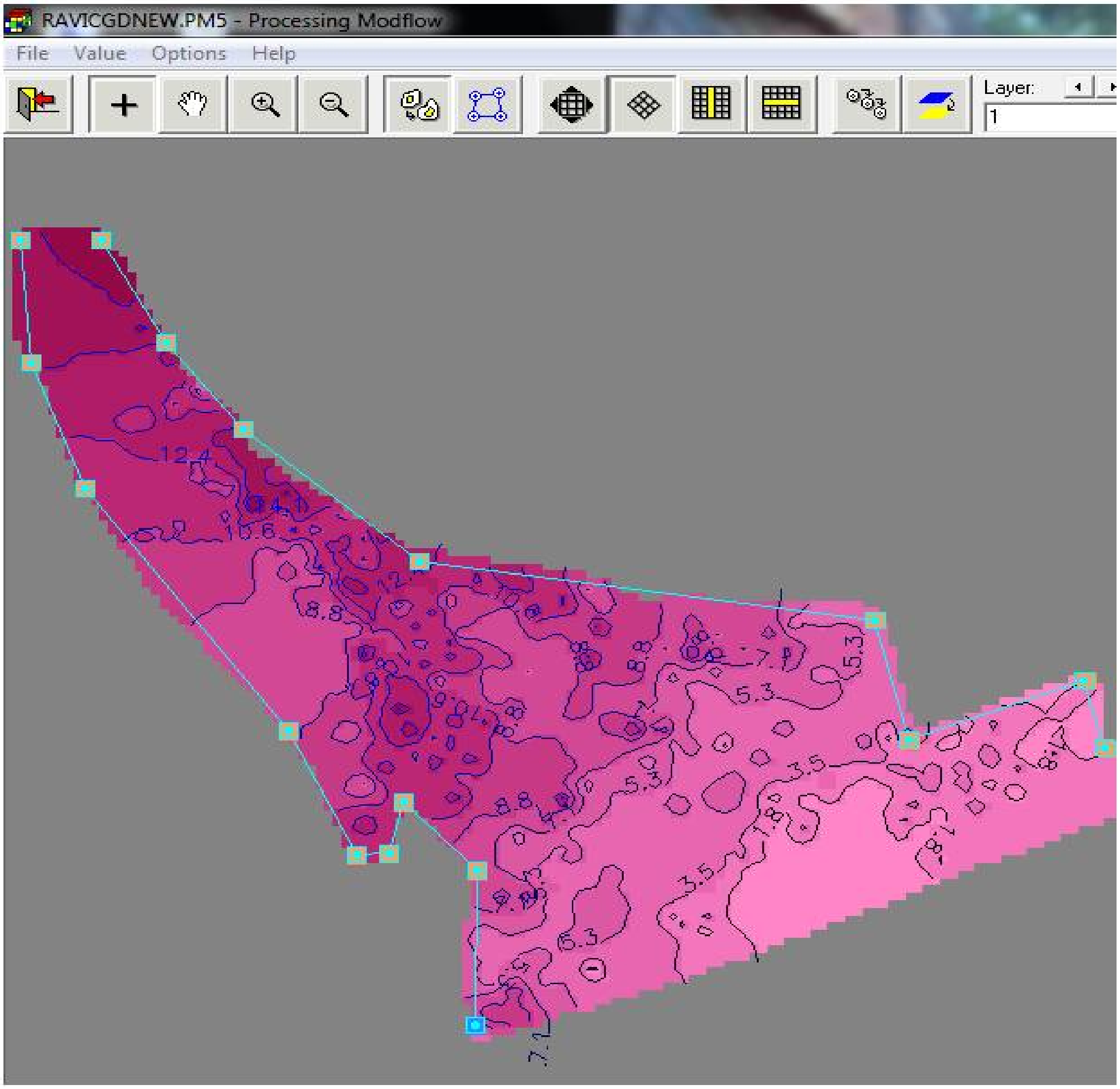


Fig-6: Surface elevation as Initial Hydraulic Heads for Steady State Simulation

5.1.2 Model parameters

The time unit is day and simulation time was specified as one day. The daily water balance will be calculated by the model. The initial groundwater heads can be surface elevation of top layer for all model layers since the steady state model does not require the initial heads. They are used only as initial values for iterative solution. However, the initial heads at the last row (Coast line) of the southern boundary of the study area of all model layers was specified as zero, which will be used as the value of constant head boundary.

The Horizantal hydraulic conductivity was specified as 60 m/day and Vertical Hydraulic conductivity as 1/10th of the horizontal hydraulic conductivity i.e., 6.5 m/day. Once all model inputs are made, MODFLOW was run to calculate groundwater levels in all model Layers in steady state. The output control option was checked to include groundwater head, flow and drawdowns. The model run for Steady State simulation successfully and mudflow generated ground water contour map is visualized and provided in the Fig-7.

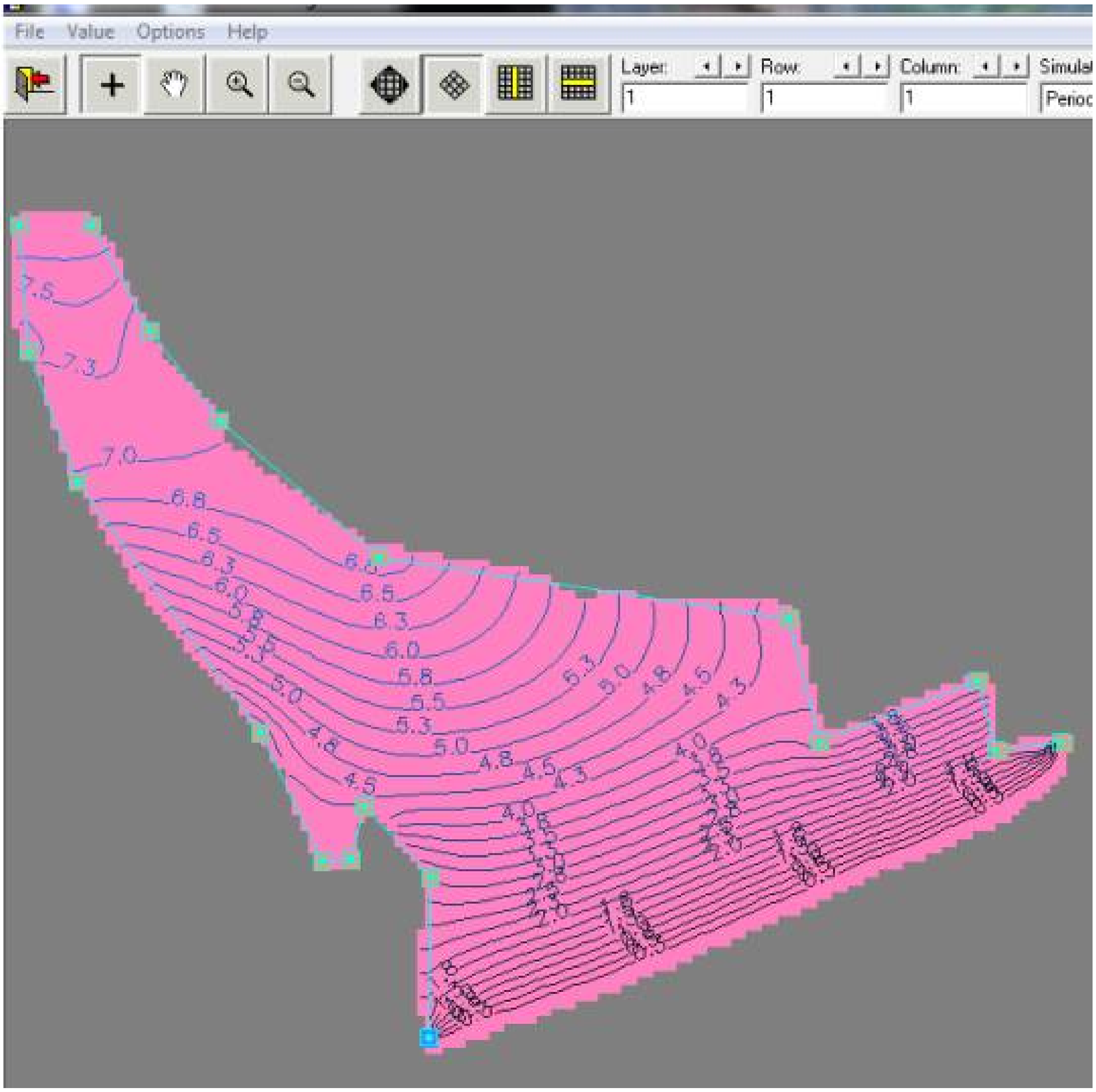


Fig-7: Ground Water Contours/Calculated ground water heads (Modflow Simulated)

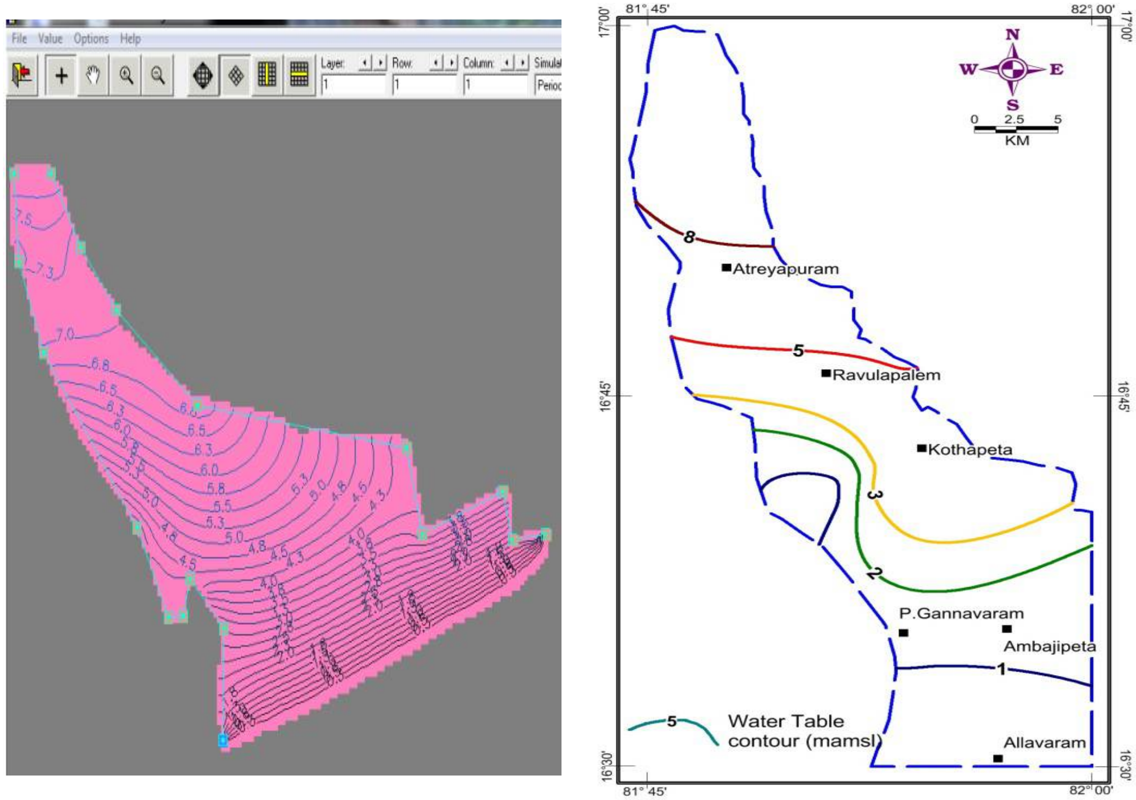


Fig-8: Calculated vs Natural ground water levels in the Study area

****
*   TIME STEP   1 OF STRESS PERIOD   1
****

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
CONSTANT HEAD	0.0000000E+00	2.5614964E+04	-2.5614965E+04
WELLS	0.0000000E+00	0.0000000E+00	0.0000000E+00
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	2.4370000E+04	0.0000000E+00	2.4370000E+04
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	1.4366089E+04	1.3121179E+04	1.2449102E+03
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
RESERV. LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
SUM	3.8736090E+04	3.8736145E+04	-5.4687500E-02
DISCREPANCY [%]	0.00		

Table-6: Water budget of Steady State Flow simulation

5.1.3 Construction of a steady development model

To understand how does the groundwater system response to the abstraction rates of the study area a steady state ground water development model is constructed by assigning the abstraction rates. In order to assess the changes of the groundwater levels caused by abstraction, the calculated groundwater levels from steady state natural model are used as initial heads in the development model. The well package of MODFLOW is used to simulate abstraction rates. The study area consisting of 11 mandals and the mandal wise abstraction rates from GEC 2013 is used with polygon input method in the PMWIN 8 software.

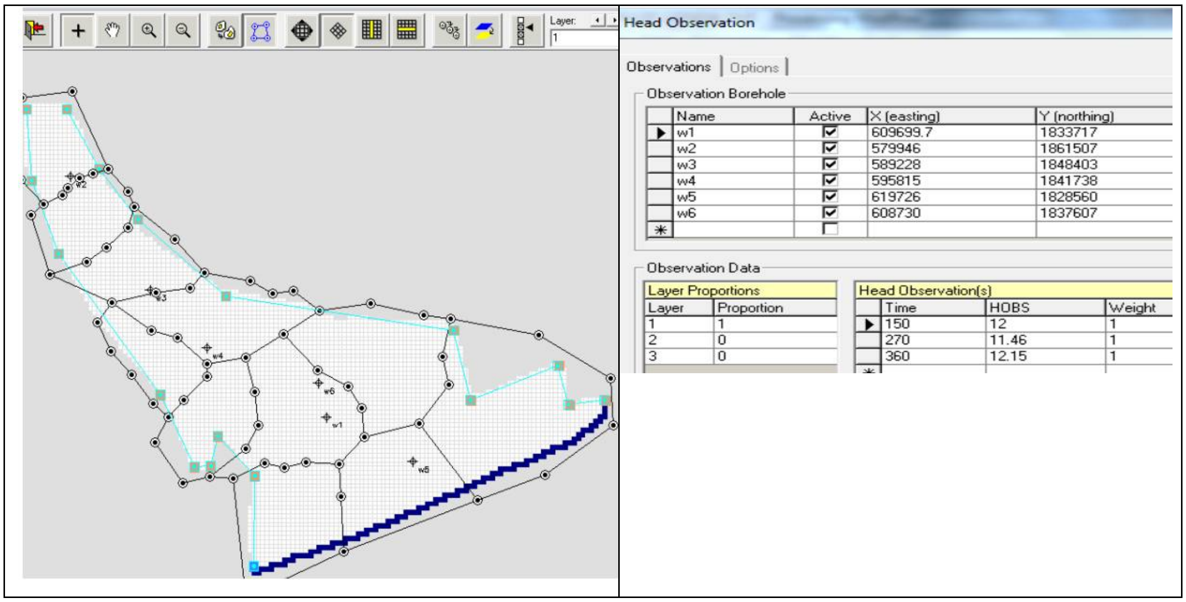


Fig-9: -Mandal wise GW abstraction Rates and head observation wells

Mandal	**Draft (MCM)**	**Draft (MCM)/day**	**Area (Sq.kms)**	**Draft/Area**	**Cell (500x500)**	**m3/d**
AINAVILLI	7.27	-0.0199178	62	0.117258	29314.51613	80
ALLAVARAM	5.15	-0.0141096	103	0.05	12500	34
AMALAPURAM	4.5	-0.0123288	80	0.05625	14062.5	39
AMBAJIPETA	10.62	-0.0290959	52	0.204231	51057.69231	140
ATREYAPURAM	8.51	-0.0233151	61.26	0.138916	34729.02383	95
KATRENIKONDA	0.76	-0.0020822	166	0.004578	1144.578313	3
KOTHAPETA	6.71	-0.0183836	77	0.087143	21785.71429	60
MUMMIDIVARAM	1.32	-0.0036164	80	0.0165	4125	11
P GANNAVARAM	1.98	-0.0054247	45	0.044	11000	30
RAVULAPALEM	6.48	-0.0177534	46	0.14087	35217.3913	96
UPPALAGUPTAM	0.55	-0.0015068	120	0.004583	1145.833333	3

Table-7: Mandal Wise Ground water Abstraction

The values of Effective Porosity, Recharge and Head Observations/WLs of Post Monsoon (Unconfined Aquifers) have been assigned to the model (Fig-). The model is run again to simulate the impact of the abstraction. The contour map of groundwater levels in the in the first layer is shown in Figure-10.

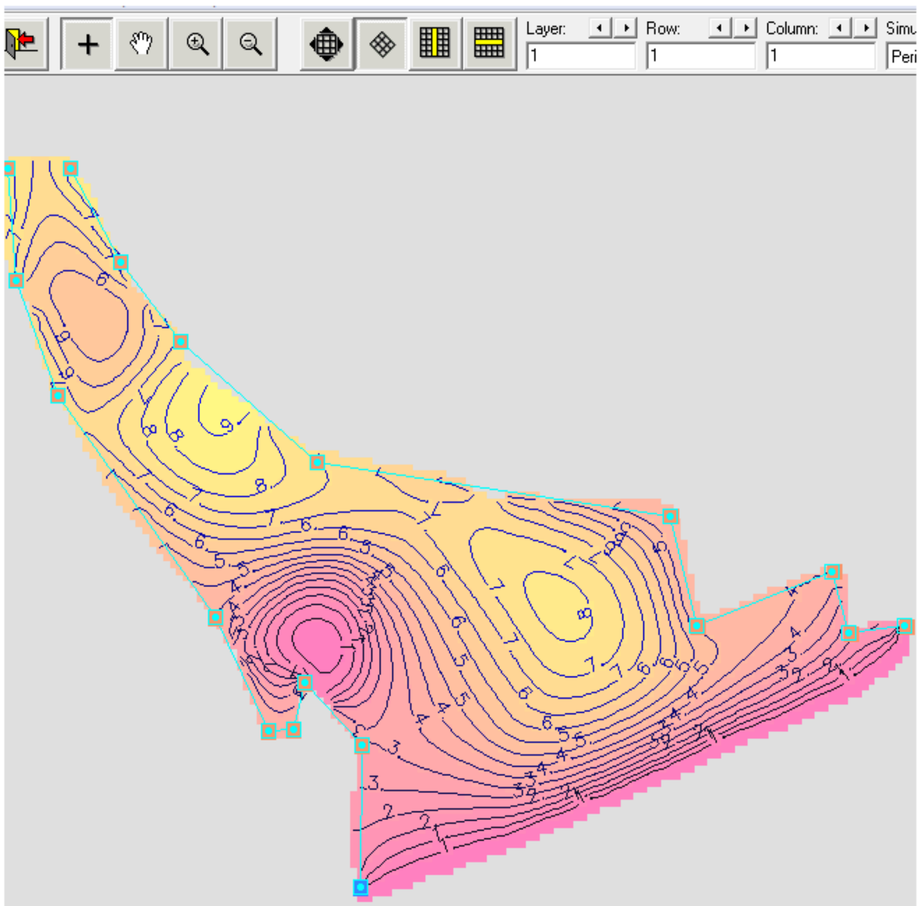


Fig- 10: Hydraulic Heads in Steady development Model

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
CONSTANT HEAD	0.0000000E+00	4.6863230E+04	-4.6863230E+04
WELLS	0.0000000E+00	1.5796051E+05	-1.5796052E+05
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	1.9496000E+05	0.0000000E+00	1.9496000E+05
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	4.9899461E+04	4.0035640E+04	9.8638213E+03
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
RESERV. LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
SUM	2.4485945E+05	2.4485938E+05	7.8125000E-02
DISCREPANCY [%]	0.00		

Table-8: Water Budget in Steady Development Model

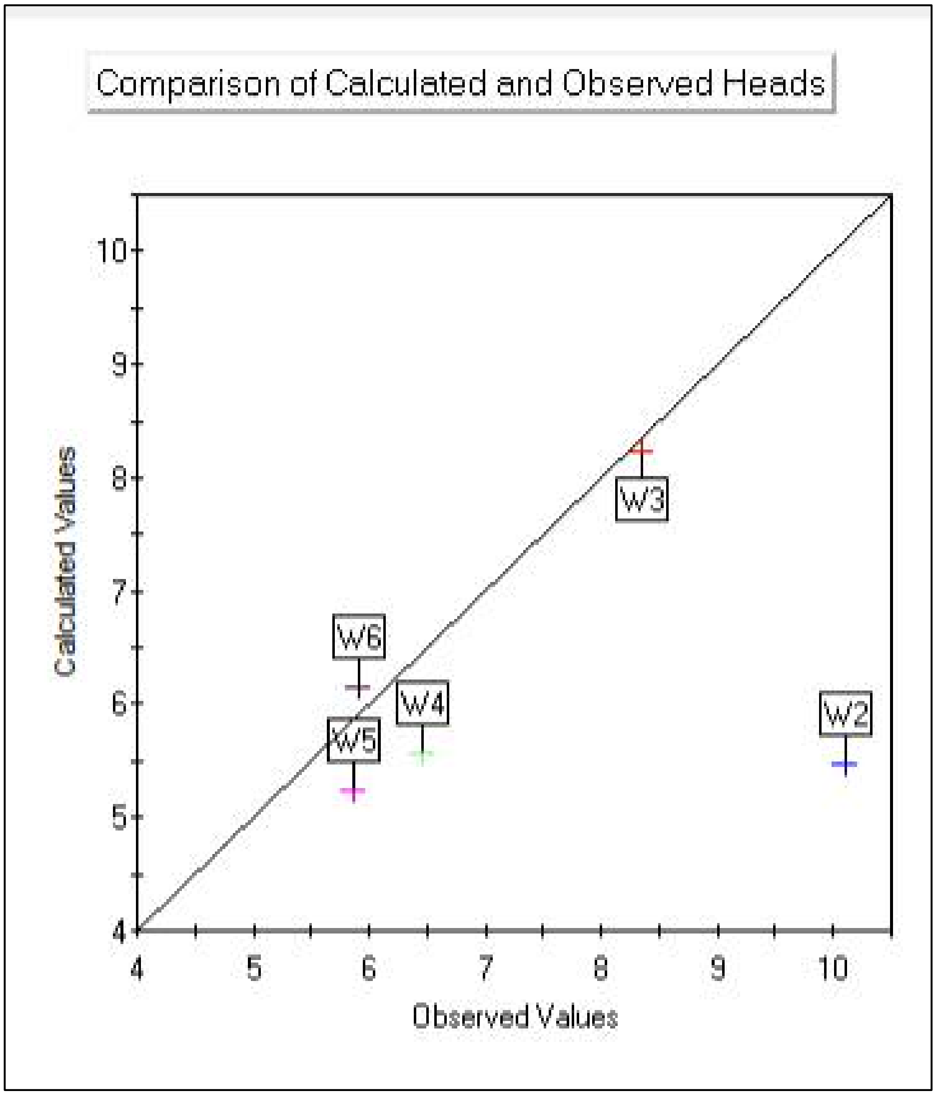


Fig-11: Comparison of Calculated and Observed Heads

5.2 Transient State:

Transient groundwater flow means that groundwater levels and flow components change with time. The transient flow may be caused by seasonal variation of recharges and/or discharges. The transition process from one steady state (natural) to another (equilibrium state with abstraction) is also transient. The magnitude of variations of groundwater flow depends on storage parameters. The transient model is used to understand the variations of groundwater levels in relation to change of recharge and storage.

5.2.1 Simulation time

For transient groundwater modelling, simulation time, stress period and time step must be defined. The stress period is a very important time parameter which dictates time-dependent model inputs. . The simulation time is the total time period of transient modelling and specified as number of stress periods. In these hands on exercise, 365 days (1 year) is used as the stress period. The stress period was divided into a number of time steps Viz., 30 days (January), 150 days (January-May), 270 days (June-September) and 365 days (October-December) for calculation of groundwater levels.

5.2.2 Initial groundwater levels

The initial conditions are very important for transient groundwater modelling since they provide initial groundwater levels as references for changes to occur. The initial groundwater levels are simulated by the steady state model. Accordingly, the calculated groundwater levels by the steady state model are used as the initial heads in this exercise.

5.2.3 Storage parameters

The storage parameters are used to calculate the change of groundwater storage because of changes in groundwater levels. These parameters are specific yield for unconfined aquifer and specific storage for confined aquifers. The storage parameter values depend on hydro geological formations. The parameter

zones are the same as for hydraulic conductivities and the storage parameters assigned to the model is shown in Table-9.

Table-9: Storage Parameters assigned to the Model

Layers		**Specific Yield**	**Storage Coefficient**
Layer1 (Aquifer-Un Confined)	:	0.40	0.0001
Layer2 (Aquitard)	:	0.20	0.00001
Layer3 (Aquifer-Confined)	:	0.25	0.0001

5.2.4 Recharge:

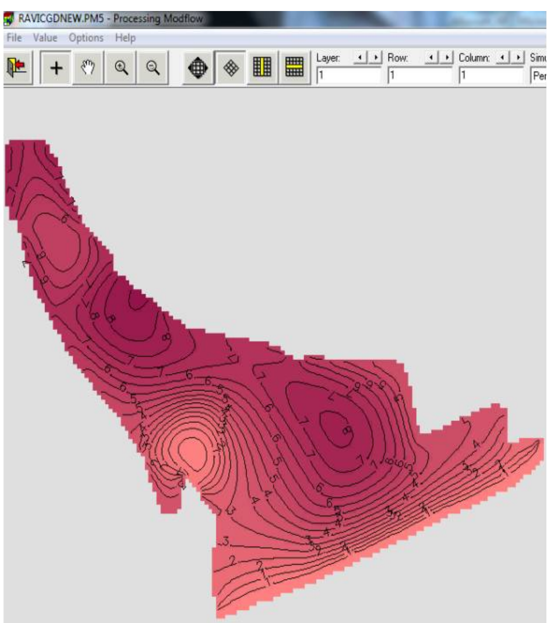
In this exercise, the recharge package is updated with the transient recharge values. The mandal wise recharge values are assigned to the model as shown in the Table-10.

Table-10: Mandal wise Recharge assigned to the Model

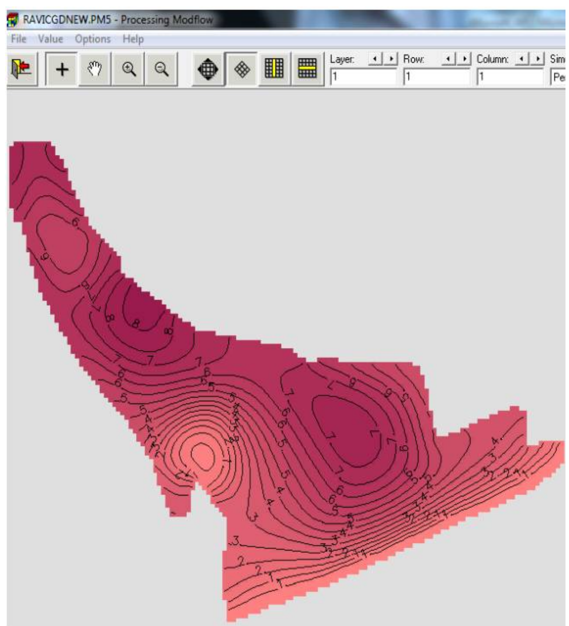
S.No.	Mandal	Recharge (m/day)	S.No.	Mandal	Recharge (m/day)
1	AINAVILLI	0.012898387	6	KATRENIKONDA	0.000503614
2	ALLAVARAM	0.0055	7	KOTHAPETA	0.009585714
3	AMALAPURAM	0.0061875	8	MUMMIDIVARAM	0.001815
4	AMBAJIPETA	0.022465385	9	P GANNAVARAM	0.00484
5	ATREYAPURAM	0.01528077	10	RAVULAPALEM	0.015495652
			11	UPPALAGUPTAM	0.000504167

5.2.5 Contour map of groundwater levels:

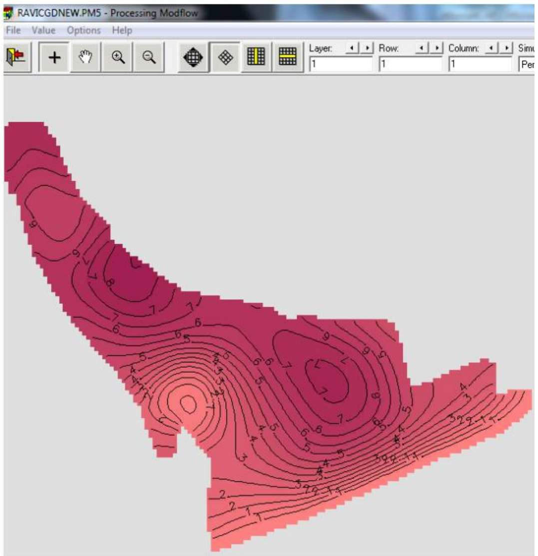
Figure 12 shows the contour map of groundwater levels in the model layer 1 at 4 stress periods Viz., 30 days, 150 dyas, 270 days and 365 days. There is no much change observed in ground water levels during the stress periods. The contour pattern is very much similar to the steady state groundwater levels (Figure-10). The comparison ofcalculated and observed ground water heads are shown in Fig-13. The drawdowns of 4 stress periods Viz., 30 days, 150 dyas, 270 days and 365 days are depicted in Fig-14.



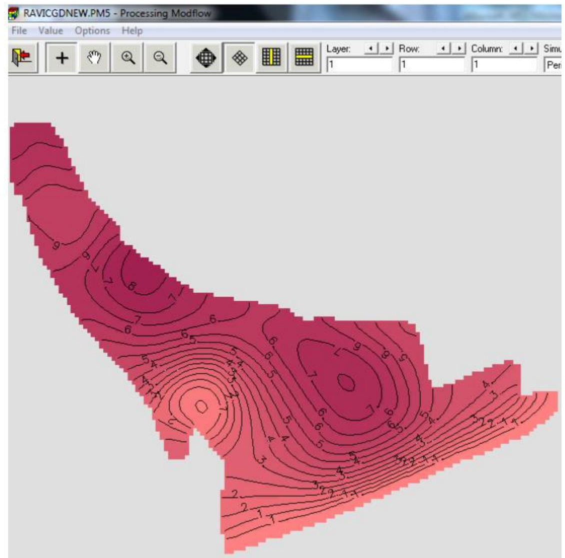
Hydraulic Heads (30 days)



Hydraulic Heads (150 Days)



Hydraulic Heads (270 days)



Hydraulic Heads (360 days)

Fig-12: Ground Water levels in the Transient State

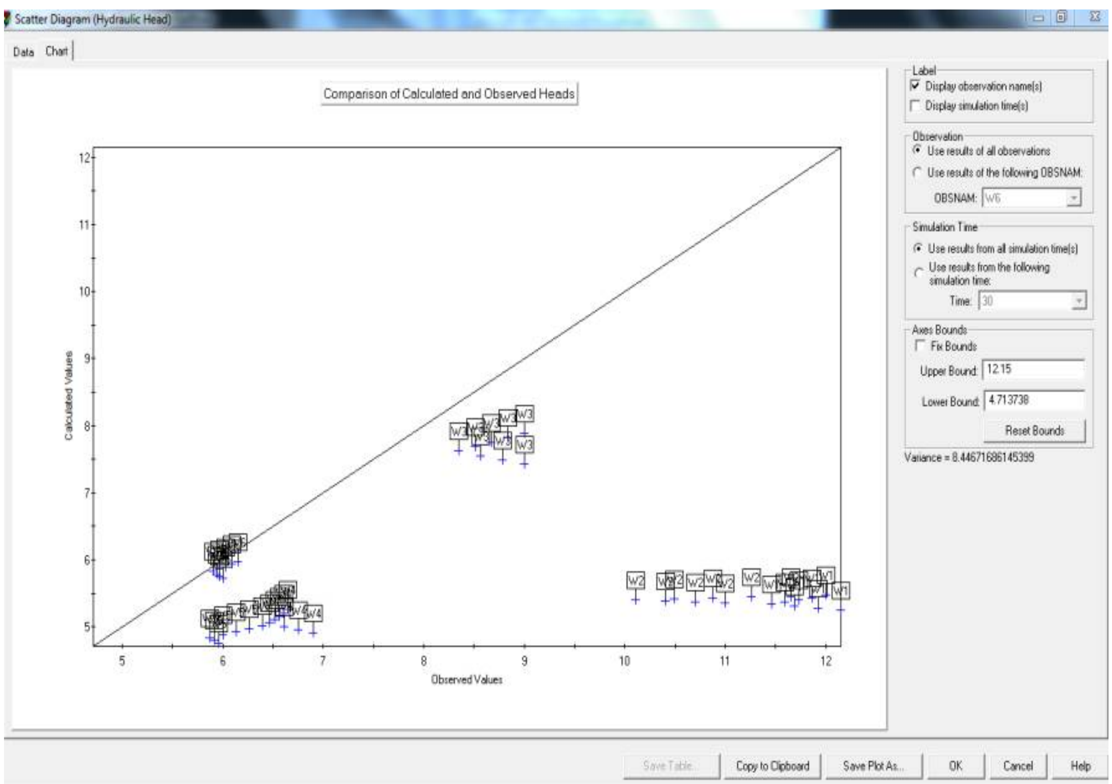
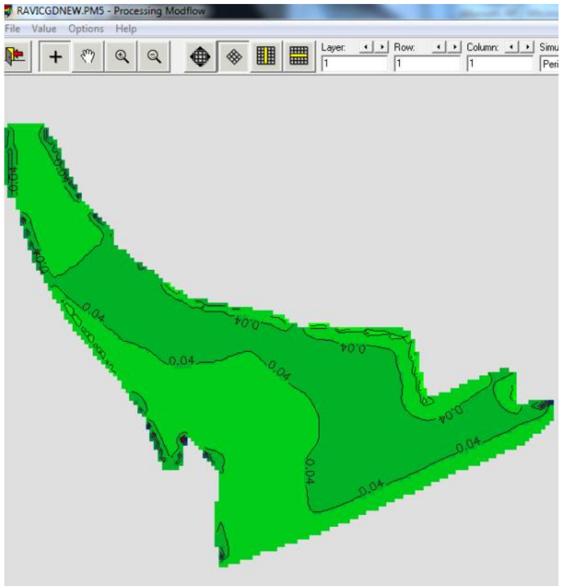
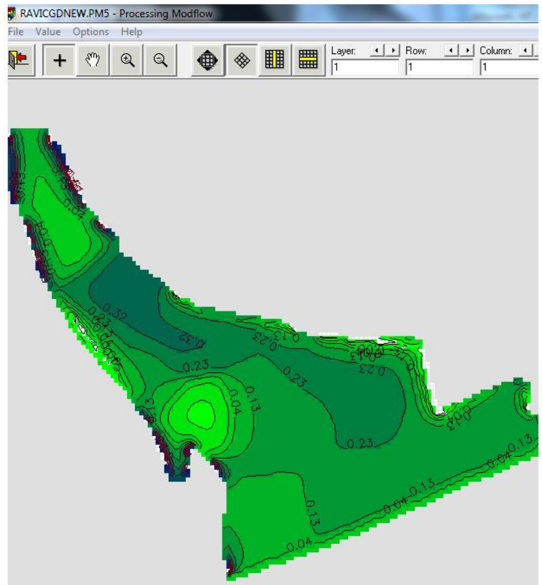


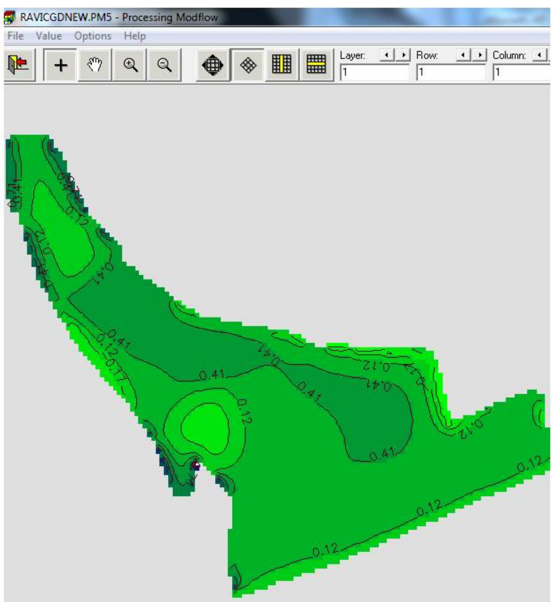
Fig-13: Comparison of Calculated and Observed Heads



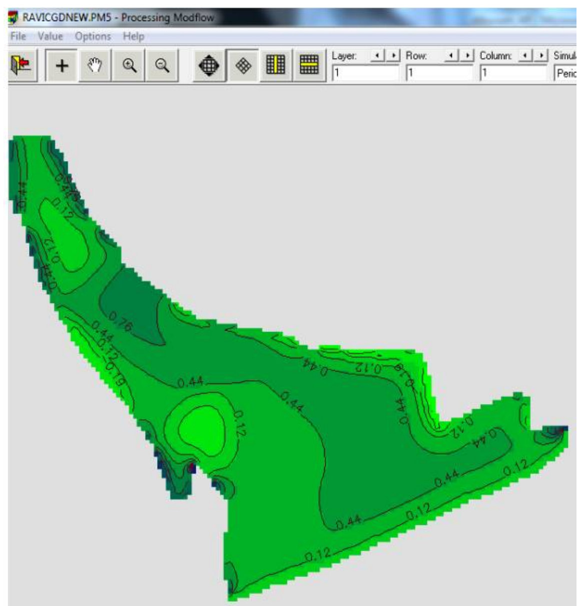
Drawdown (30 days)



Drawdown (150 days)



Drawdown (270 days)



Drawdown (360 days)

Fig-14: Drawdowns in the Transient State

5.2.6 Water budget

For transient groundwater flow, the imbalance of total recharge and discharge causes the change of groundwater storage over the time. It is observed from the water budget that the no change in the ground water heads are attributed to increased River leakance with pumping of ground water.

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	8.3787121E+06	-8.3787120E+06
CONSTANT HEAD	0.0000000E+00	5.9082814E+04	-5.9082812E+04
WELLS	0.0000000E+00	1.5796051E+05	-1.5796052E+05
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	9.2607900E+06	0.0000000E+00	9.2607900E+06
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	3.8151242E+03	6.6885319E+05	-6.6503806E+05
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00

Table-11: Water Budget in Transient State