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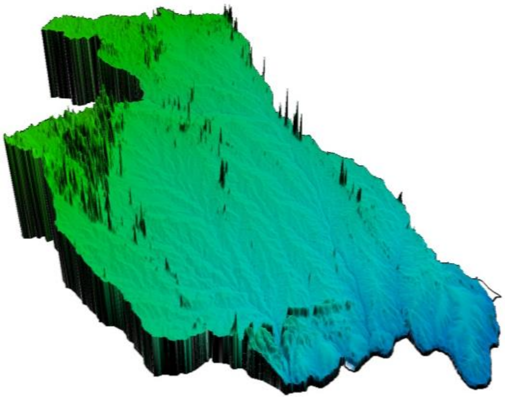
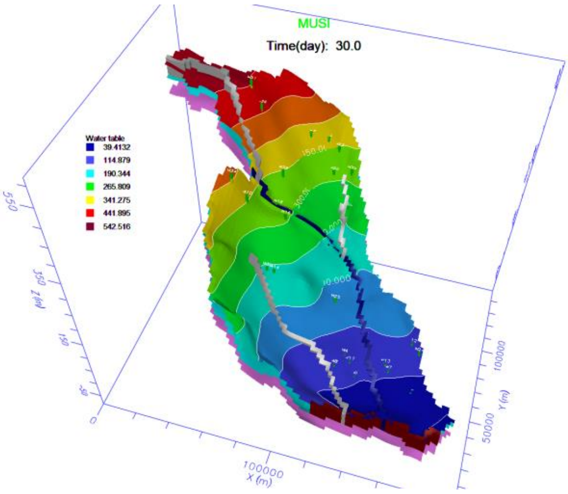
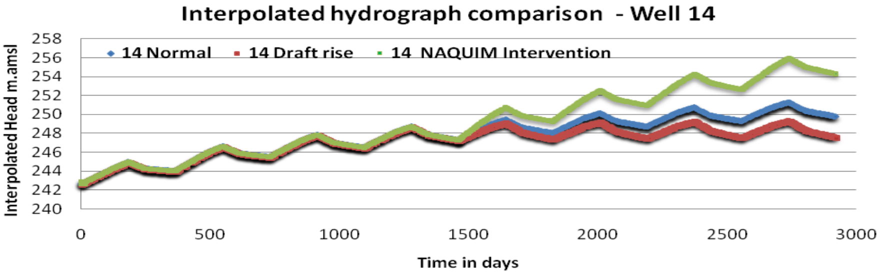
जल संसाधन नदी विकास एवम् गंगा संरक्षण मंत्रालय
केंद्रीय भूमिजल बोर्ड

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION

REPORT ON
Ground Water Modelling Studies
Lower Musi sub-basin, Telangana State







CENTRAL GROUND WATER BOARD
SOUTHERN REGION
HYDERABAD
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Report on Ground Water Modelling Studies
Lower Musi sub-basin, Telangana State

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1.0 Introduction

Ground water resources are under continuous stress to meet the increasing demands of rising population, industrial and agriculture growth. For sustainable management of ground water resources understanding of ground water system is must and it is done through aquifer mapping studies by CGWB. For long term management of ground water resources, the components influencing the aquifer system like temporal changes in climate, irrigation, domestic supply etc, needs to be analyzed along with the aquifer system. Ground water mathematical modeling as a tool can integrate all spatial along with temporal variations in the aquifer system and helps in understanding aquifer response both in space and time.

In the current study the basic data and ground water management aspects proposed under aquifer mapping studies (NAQUIM) are utilized for preparation of conceptual model and numerical model by using MODFLOW. Simulation of the model done for various time periods including prediction model with NAQUIM interventions to study the impact of proposed ground water management plans.

2.0 Objectives:

- To conceptualize and construct hydrogeological model for improved understanding of the natural groundwater flow system.
- To simulate regional groundwater flow in 3D.
- Impact on the aquifer system due to various hydrological stresses.
- To develop scenarios based on future development for response of the aquifers to stress condition.
- For efficient and sustainable management of the aquifer system.
- To understand the impact of proposed NAQUIM interventions by means of prediction model.

3.0 Study Area:

The study area, Lower Musi Basin covers an area of 12770 km^2, overlies parts of Nalgonda, Yadadri Bhuvanagiri, Suryapet, Jangaon, Rangareddy and Medchal Malkajgiri districts, Telangana State. It is located between North longitudes of 78° 24' 13" to 80°05'45" and East Latitudes of 16° 36' 34" to 17° 53' 34". The Musi river traverses through the central part of the study area, River Krishna flows through the southern boundary, (***Fig-3.1***) Administratively the study area comprises 61 mandals with 1089 Villages and Hydrologically divided into 60 watersheds. Hilly areas with high topographic gradient occupy 430 Sq.km in the western parts, thus making the mapable area to 12340 Sq.km.

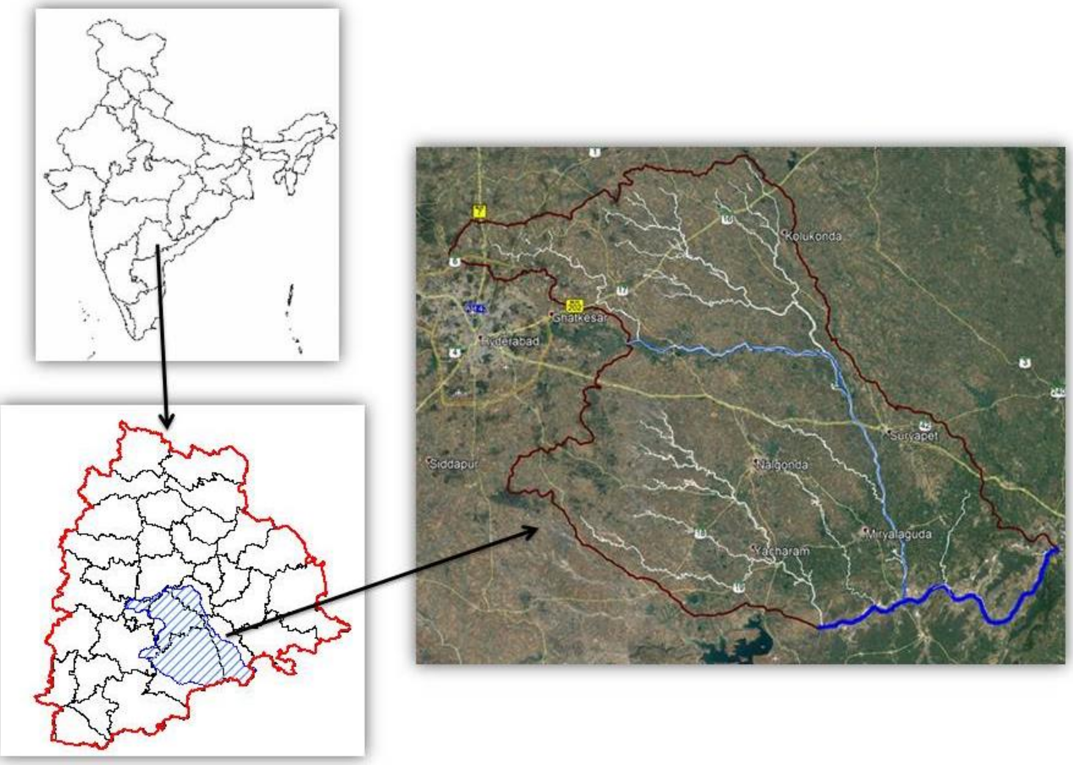


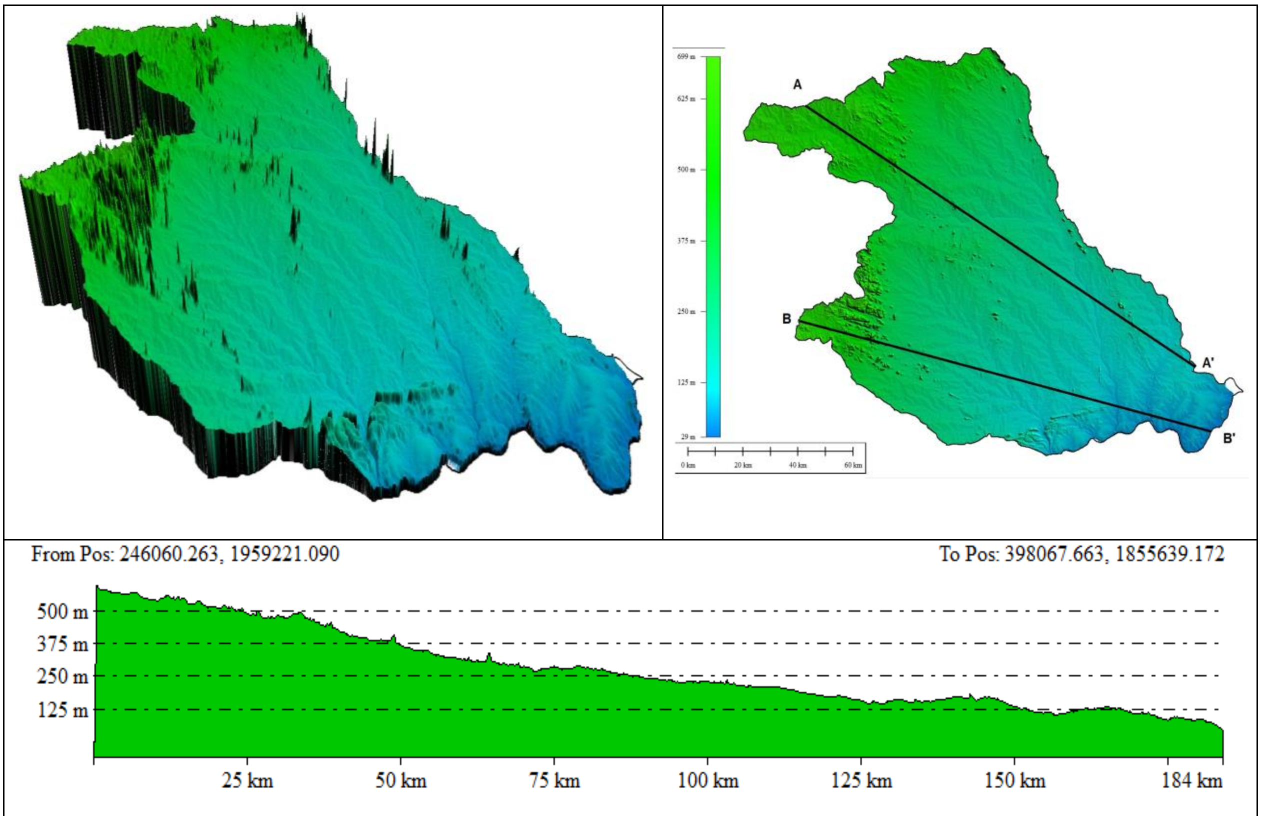
Fig-3.1: Base map of Lower Musi sub-basin, Telangana State

3.1 Topography :

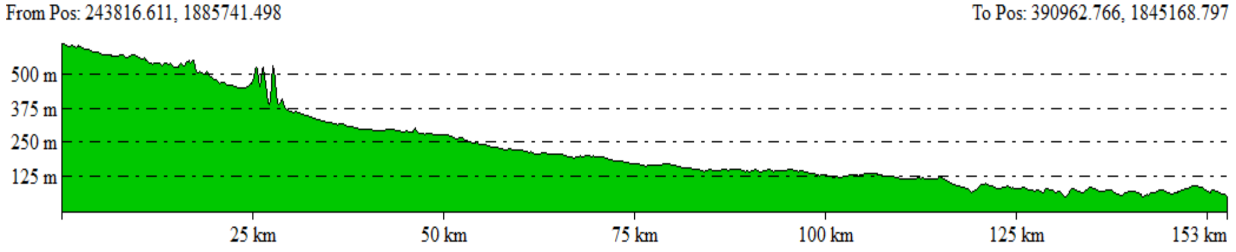
Topographic elevation range From 19 to 613 m.amsl, sloping towards southeast from northwest (***Fig-3.2***). Average topographic gradient ~ 3.5 m/Km, Slope in the area varies from gentle slope to steep slope. Western and northwest parts of the area have hilly terrains with steep slope where as the surface elevations are low and the slope is gentle to flat in southern part.

A–A' Section: This section shows Northwest-Southeast surface elevation profile from north part, it shows general decrease in the elevation from NW to SE. Flat with lower elevations is noticed in SE.

B–B' Section: This section shows Northwest-Southeast surface elevation profile from southern part, it shows steep variation in the elevation in NW and becomes gentler in SE. Flat with lower elevations is noticed in SE.



A-A1 Section



B-B1 Section

Fig-3.2: Elevation Map of Lower Musi sub-basin, Telangana State

3.2 Rainfall:

The area experiences semi-arid and tropical climate with annual precipitation varying from 581-914 mm (average: 752) and increases from south to north and west to east. The south-west monsoon contributes 74 % and north-east contributes 19% of rainfall.

3.3 Drainage:

The drainage is controlled by lineaments trending NW-SE, E-W, NE-SW and N-S directions and are drained by many streams with rivulets having dendritic, sub-dendritic to parallel drainage pattern The area is drained by Musi River which flows E-W and NNW to SSE direction, it is a tributary to Krishna River. Krishna River flows along the southern border of the study area (***Fig. 3.3***). High drainage density is observed in NW and West part and low density along the river Musi in the study area. Network of canals exist in the southern part of the area for irrigation purpose, originating from Nagarjunasagar reservoir.

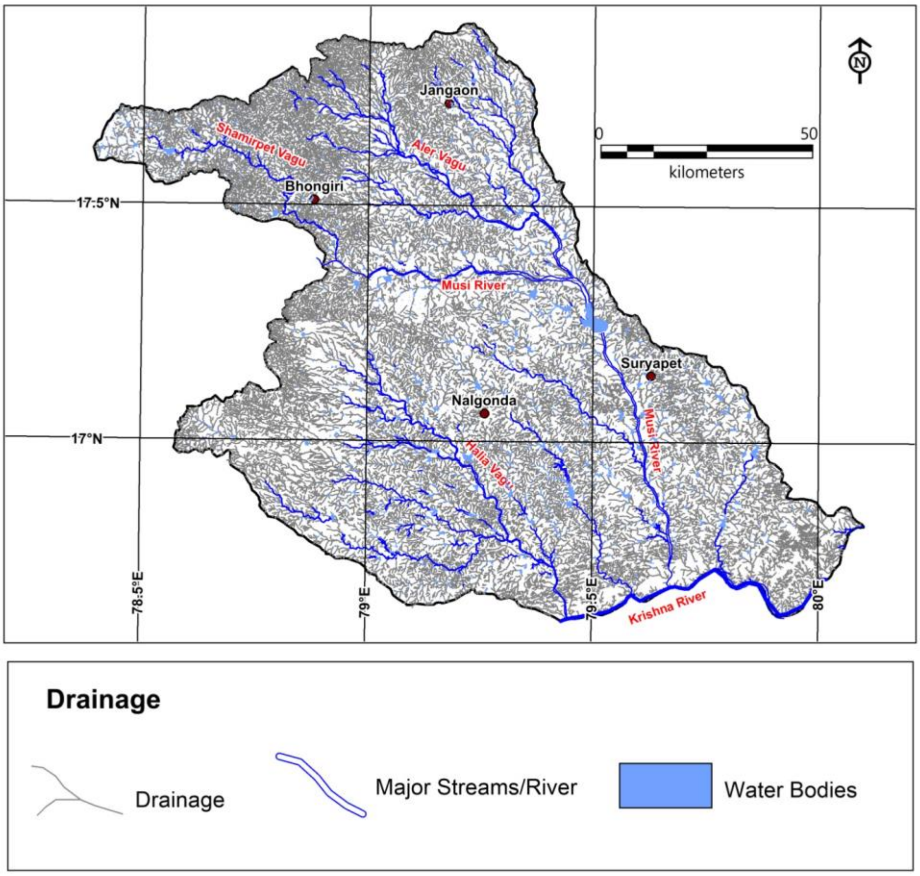


Fig-3.3: Drainage, Lower Musi sub-basin, Telangana State

3.4 Geomorphology & Land Use Pattern

The geomorphological units observed in the area are classified as, Denudational Hill, Inselberg, Pediment (PD), Pediment Inselberg Complex, Dyke Ridge, Pediplain Shallow and Pediplain Moderate. Pediplains are the major landform covering about 9169 km2 (72%) area. Pediments associated with Residual hills and intermontane valleys seen mostly in northwestern and western parts. Dissected palteaus mostly seen inn the southern parts of the area. (***Fig.3.4***).The land use pattern in the study area indicates that the area is mostly agrarian, main area is under khariff cultivation (45% area) and double crop area is 34%. Most of the double crop area is in the canal command area located in the southern part of the study area (***Fig-3.5***).

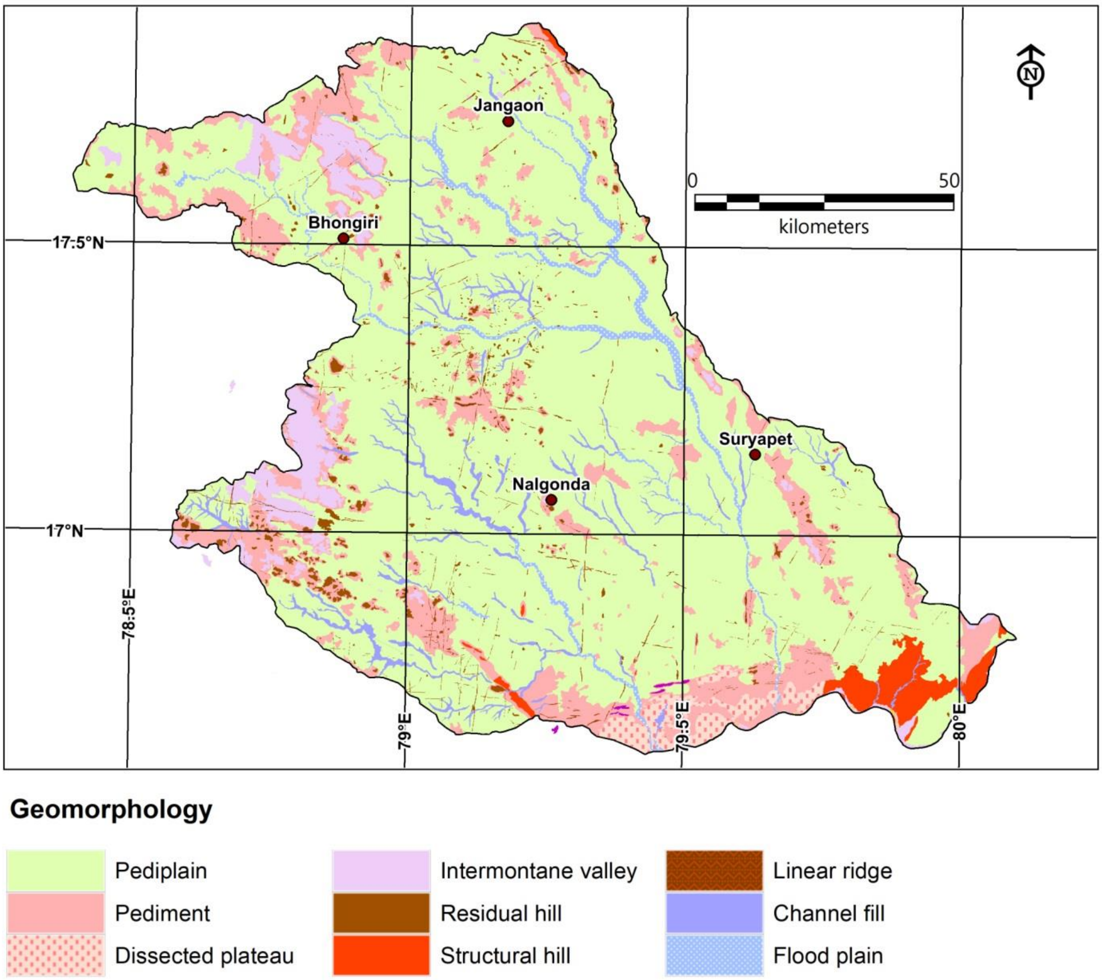


Fig-3.4: Geomorphology, Lower Musi sub-basin, Telangana State

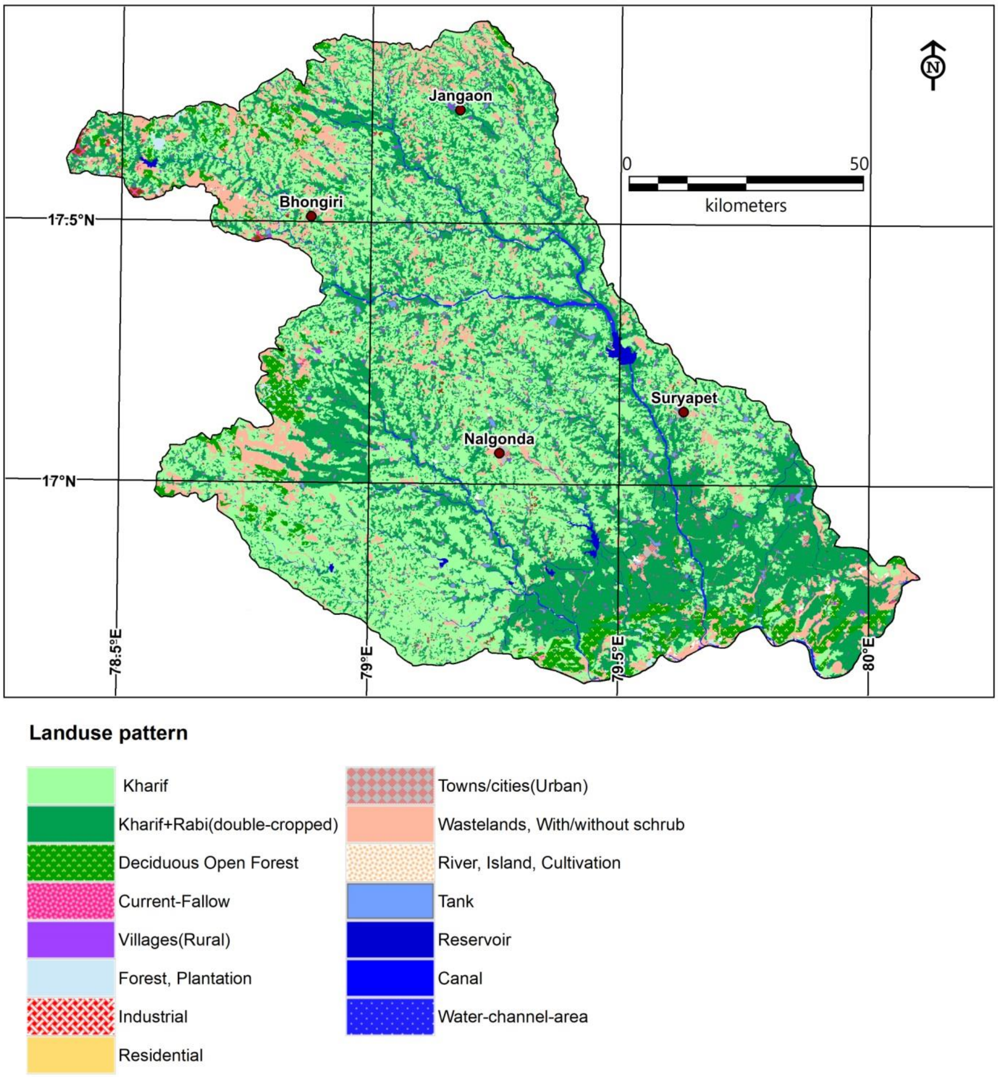


Fig-3.5:Landuse map, Lower Musi sub-basin, Telangana State

3.5 Hydrogeology & Aquifer Disposition

Geologically the area is covered with crystalline rocks (Granites and Gneisses-Banded Gneissic complex-BGC) with basic intrusive rock (Dolerite and Gabbro's) at places. Sedimentary formations, which include limestone, shale, quartzite and dolomite, occupy southern part of the area. The unconsolidated deposits comprising alluvial sands, clay, occur in isolated narrow patches along the Musi river, Halia river and major streams. The principal aquifers in the area are granites and gneisses and the occurrence and movement of ground water in these rocks is controlled by the degree of interconnection of secondary pores/voids developed by fracturing and weathering.

3.6 Ground Water Exploration:

To understand the hydrogeological characteristics of the area exploratory drilling data of CGWB wells are analysed. In the area 92 exploratory wells (EW) data available in the depth range of 32 to 200 m for determination of hydraulic properties of the aquifers . Out of 92 EW with hydraulic data, Aqifer-1 data is available for 30 wells and Aquifer-II data available for 62 wells. In the Aquifer-I, the zones encountered varies from 4 to 41 m.bgl with Ground water yields up to 2.5 lps and Transmissivity vary from 1 to 53 m^2/day. In the Aquifer-II, the fractures encountered varies from 30 to 198 m.bgl with Ground water yields upto 7 lps and Transmissivity vary from 1 to 440 m^2/day.

3.7 Ground Water Occurrence

Ground water occurs under unconfined and semi-confined conditions and flows downward from the weathered zone into the fracture zone. The main aquifers constitute the weathered zone at the top, followed by a discrete anisotropic fractured/fissured zone at the bottom, generally extending down to 200 m depth. The storage in granitic rocks is primarily confined to the weathered zone and its overexploitation, mainly for irrigation purposes, has resulted in desaturation of weathered zone at many places. At present, extraction is mainly through boreholes of 60-90 m depth, with yield between <0.1 and 7 litres/second (lps). ~97% of fractures occur within 100 m depth.

Section-A-A' (NW-SE): The section drawn along the NW-SE parts of Musi sub basin covering distance of ~120 kms. It depicts almost uniform weathered zone thickness in most part except in central part (***Fig.3.6***). The thickness of fractured zone is uniform in central parts of the section while it is more in NW parts than the SE parts of the section.

Section-D-D' (NW-SE): The section drawn along the NW-SE parts of Halia sub basin, covering a distance of ~100 kms. It depicts uniform weathered zone thickness all along the section. The fracture thickness is more in central and northern parts in comparison to southern parts (***Fig3.7***).

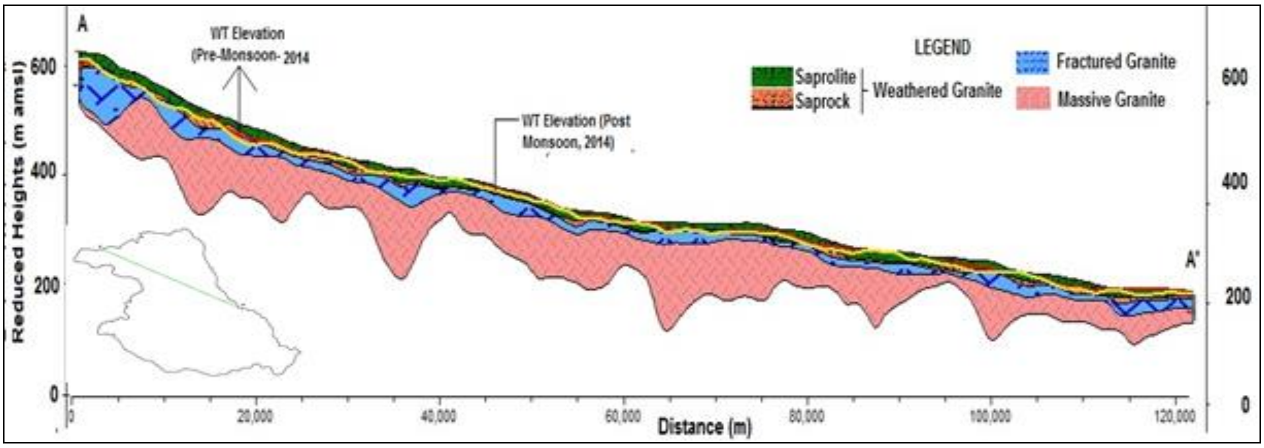
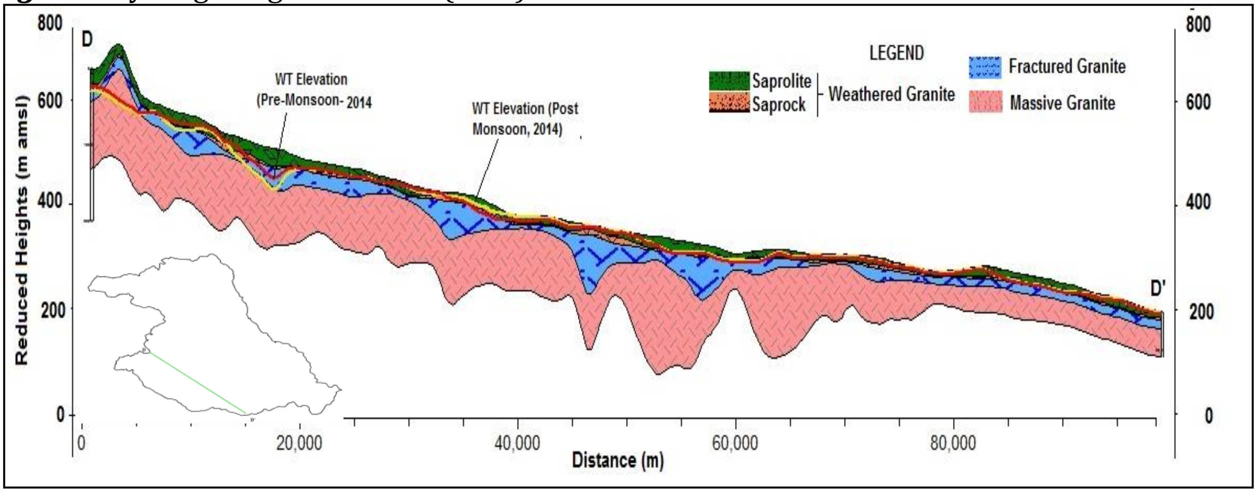


*Fig-3.6:*Hydrogeological section (A-A')

Fig-3.7: Hydrogeological section (D-D')



3.8 Depth to Water Level:

The depth to water levels during pre-monsoon (May) ranges from 1.98 m.bgl to a maximum of 51.98 m.bgl with an average of 12.03 m.bgl. The depth to water levels during post-monsoon (November) ranges from 0.42m.bgl to a maximum of 40.24 m.bgl with an average of 8.76 m.bgl. The water level fluctuation between pre-monsoon and post-monsoon ranges in between -6.21m. (fall) and 17.23 m (Rise).

Deep water levels (> 20 m.bgl) are seen in northern, western and west central part of the area, whereas shallow water levels (< 5m.bgl) are seen in the southern part of the area, mostly in the canal command area (***Fig.3.8a-b***).

The water-table elevation ranges from 62-557 and 68-598 meter above mean sea level (m amsl) during pre-monsoon and post-monsoon season respectively and general ground flow is towards River Krishna i.e from NW to SE (***Fig.3.8c-d***).

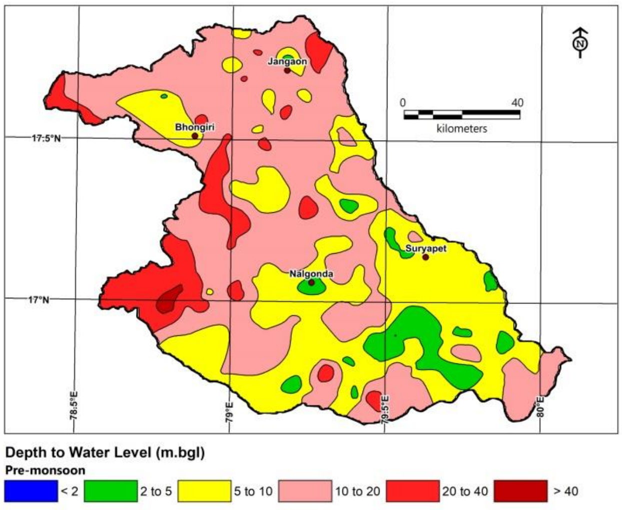


Fig-3.8a: Depth to Water Level - Premonsoon

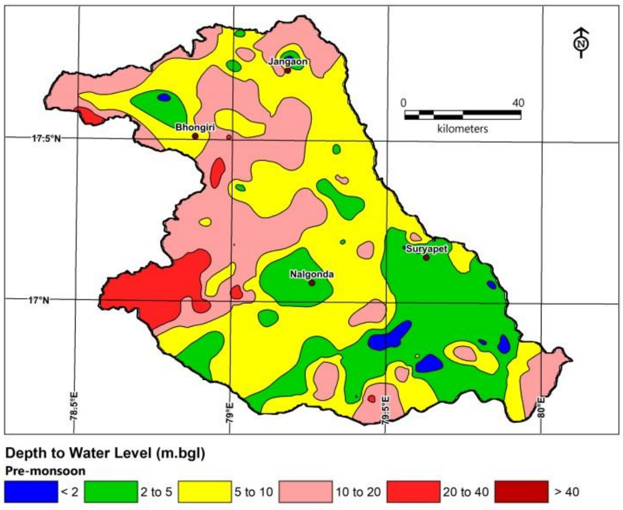


Fig-3.8b: Depth to Water Level - Postmonsoon

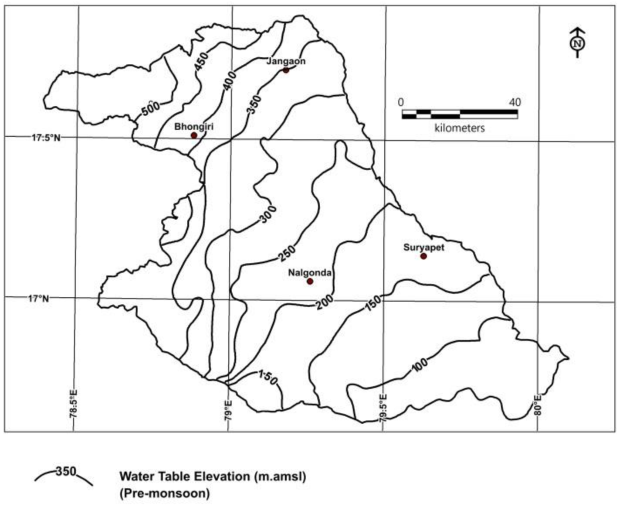


Fig-3.8c: Water Table Elevation, Premonsoon

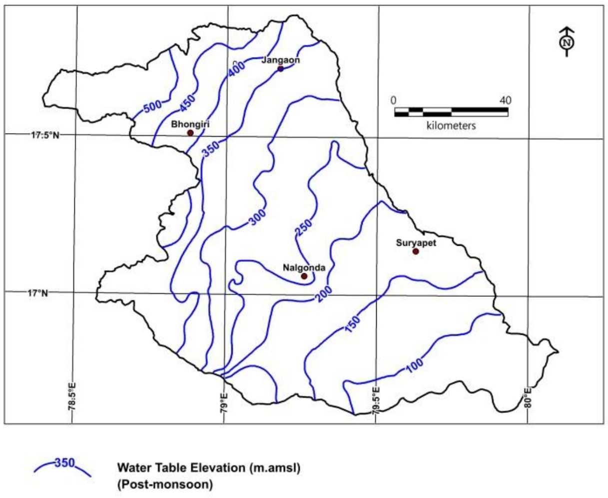


Fig-3.8d: Water Table Elevation, Postmonsoon

3.9 Ground Water Resources:

As per 2017 GEC report, the annual extractable ground water recharge of the area is 1441 MCM , annual extraction for all uses is 1053 MCM and net annual ground water potential available for future irrigation needs is 371 MCM. Stage of ground water development is 73%,Mandal wise varies from 23-122%.66% of the area is non-command and 34% command. The stage of ground water development in command area is 45% and in non-command area it is 79%.

The requirement of ground water for the irrigation is very high in non-command area. 89% of annual extraction is because of irrigation needs. The ground water extraction rate in command area is 0.05 MCM/Sq.km and Non-command area it is 0.075 MCM/Sq.km.

4.0 Conceptual Model :

The conceptual model which describe numerical model is a simplified description of aquifer system. The conceptual model deals with the following parameters.

1. Descriptions of the hydrogeologic framework and hydraulic properties of the media.
2. Descriptions of the spatial and temporal characteristics of the model boundaries.
3. Estimation of inflows, outflows, and fluxes across model boundaries.
4. Approaches used to estimate the components of the steady-state water budget.
5. Groundwater flow paths, flow velocities, and the possible effects of transient influences on groundwater flow directions.

Simplifications by means of spatial and temporal averaging of aquifer inflows and outflows across model boundaries, flow through the unsaturated zone to the water-table boundary are mostly performed in the conceptual model. These simplifications largely prevent simulating localized physical features, hydrologic processes, and uneven distribution of inflows and outflows across model boundaries, but are appropriate for modeling the geographically large areas.

4.1 Hydrogeological frame work

4.1.1 Aquifer Geometry

Granites are characterized by insignificant primary porosity and permeability. However, fracturing and weathering impart secondary porosity and permeability to a varying extent. The vertical profile of hard rock is divided into three major units namely Weathered, Fissured/Fractured layer and the massive/basement rock. The weathered zone is clayey, sand rich material, derived from prolonged insitu weathering of bedrock, varying up to few tens of meters thickness.

The fissured layer is generally characterized by fresh hard rock with dense horizontal fissuring in the first few meters. The fresh unfissured basement is permeable only locally, where tectonic fractures/shears are present. The densities of fractures with depth in most of the geological contexts are diminishing. The Exploratory drilling data, Geophysical data and well inventory data were used to bring out the lateral and vertical disposition of the aquifer system in the area.

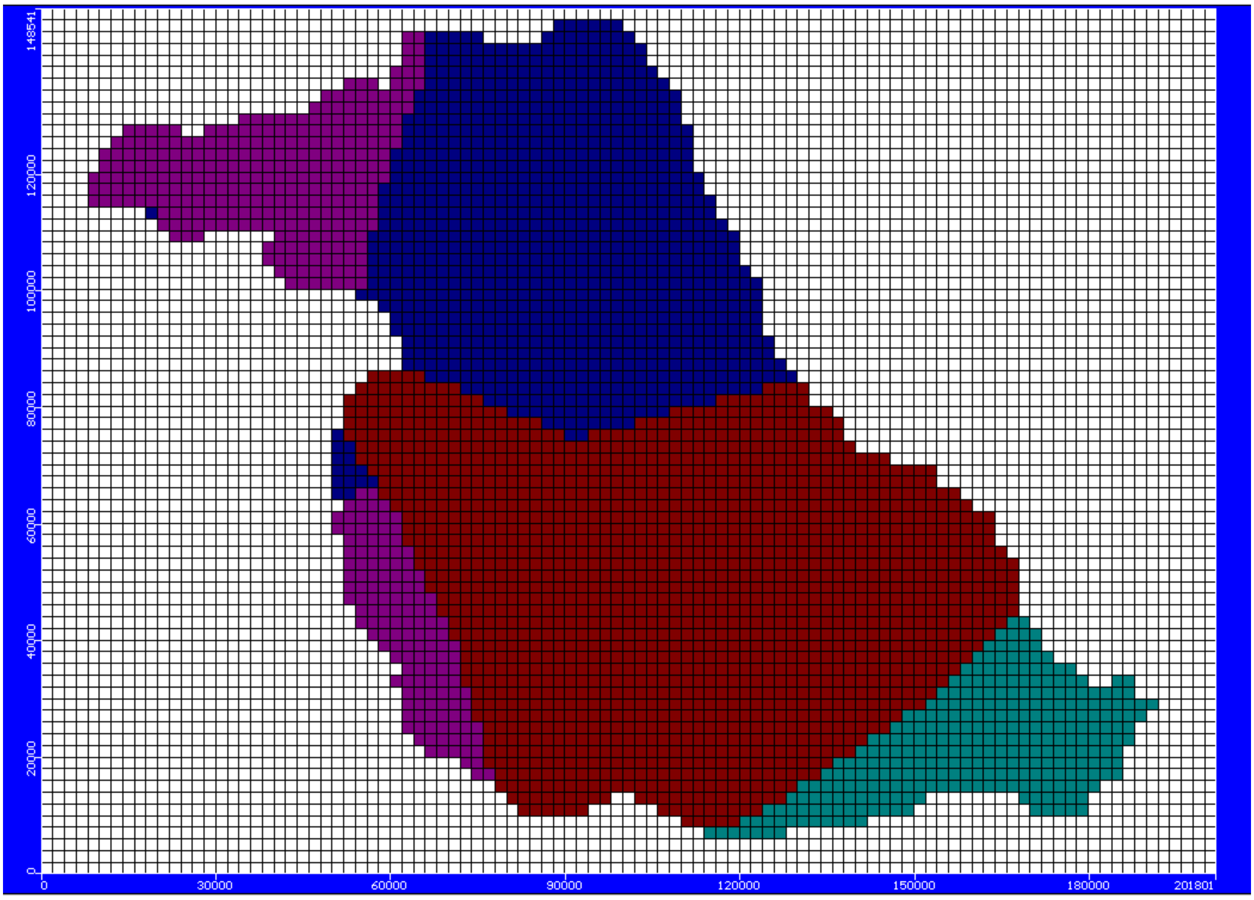
Conceptualization of 3-D hydrogeological model was carried out by using representative 92 hydrogeological data points and calibrated for elevations with Shuttle Radar Topography Mission (SRTM) data. The Aquifers are characterized into Aquifer-1 and Aquifer-2 based on their occurrences vertically from the ground surface. Aquifer-1 comprises weathered granite and the horizontal fissured layer. Aquifer-2 comprises the fresh unfissured basement where the tectonic fractures occur, it is considered upto the depth of deepest fracture below the weathered zone/layer. A two layer model was chosen over a single layer model to account for the change in aquifer properties. The top weathered layer contains the water table and is of variable thickness ranging from 10 -30 m bgl. followed by fractured layer with variable thickness ranging from 30 to 190 m.bgl

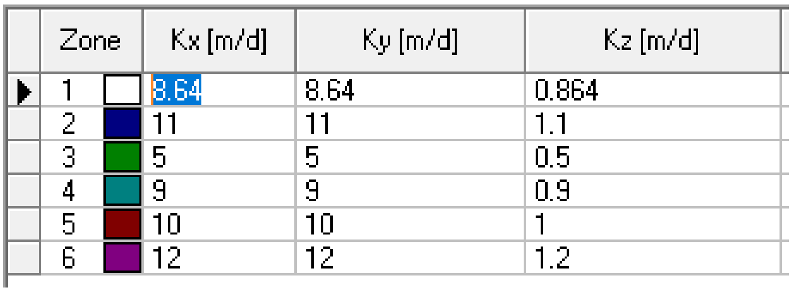
Aquifer-1: The 1st aquifer which is considered down to 32 m, wherever it is shallow has gone dry in significant part of the area due to over-exploitation. The thickness of aquifer-1 is shallow (< 10 m) in central part and in south eastern part, moderate (10-20 m) in north-western and south-eastern part and deep (>20 m) in isolated locations in the northern parts. In major part of the area the water levels are in the range of 10-20 and 5-10 m.bgl during pre and post-monsoon season respectively. The yield of bore wells varies from < 1-10 litres per second (lps) with transmissivity (*T*) between 1-630 m^2/day (average: 32) and specific yield (*Sy*) is about 1-3 % (average: 1.1 %).

Aquifer-2: The ground water is extracted mainly through bore wells of 60 to 100 m depth from 2nd aquifer (32 to 198 m). Fractures in the range of 30-60 m depth are more predominant followed by 60-100 m depth, deep fractures in the range of 100-150 and >150 m occur in north-western and western part. In this aquifer, majority of water levels are in the range of 20-30 and 5-10 mbgl during pre and post-monsoon season respectively. The yield of bore wells varies from 0.1 to 7lps (avg 1.9 lps), transmissivity varies from 1-927 m^2/day (average 58) and storativity of 1×10^{-4} to 0.06.

4.1.2 Aquifer Parameters :

Transmissivity (T) and storage coefficient (S) values are the two parameters which define the physical framework of an aquifer and control the movement and storage of groundwater. The various aquifer parameters, such as hydraulic conductivity and specific yield/specific storage, estimated using exploration data assigned to layers. The hydraulic conductivity values assigned to the model range between 4 to 12 m/day. A specific yield of 0.015 was applied uniformly to entire top layer. Hydraulic conductivity distributed zone wise to top layer and uniformly to second layer ***Fig-4.1***.





	Zone		Kx [m/d]	Ky [m/d]	Kz [m/d]
▶	1	⬜	8.64	8.64	0.864
	2	🟦	11	11	1.1
	3	🟩	5	5	0.5
	4	🟩	9	9	0.9
	5	🟥	10	10	1
	6	🟪	12	12	1.2

Fig-4.1: Hydraulic Conductivity, Lower Musi sub-basin, Telangana State

4.2 Conceptual Model Boundary conditions and Fluxes

4.2.1 Boundary Conditions

Model domain is represented by boundary conditions, set of boundary conditions represent the system’s relationship with the surrounding area. The southern boundary representing by Krishna River is assigned constant head boundary. The

Musi River flowing through the study area has been assigned with river package. River head and river bed bottom elevations were assigned to appropriate grids. The river head and bed bottom elevations at the initial and final point of Musi river are 377 & 375.5 m.amsl. and 65 & 64 m.amsl, respectively (***Fig-4.2)***. River bed conductance varies between 8 to 12 m/day. Three major streams namely Shamirpet vagu, Yeshwantapur vagu and Halia vagu are assigned with Drain package. Entire boundary of the model area is considered as no flow boundary except the southern part along Krishna river where constant head boundary assigned (***Fig-4.3)***.

Musi River (River Package)

Length of the River ; 144 km

	River head elevation (m.amsl)	River bottom (m.amsl)	Width (m.)
Starting point	377	375.5	120
End point	65	64	150

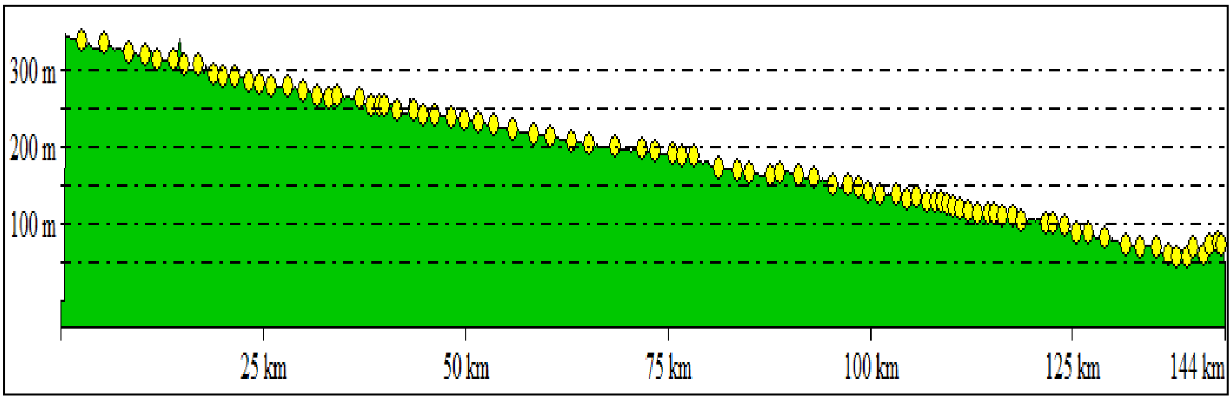


Fig-4.2: Musi River profile

Krishna River (Constant Head package)*:*

	Start time head	Stop time head
Starting point	114	114
End point	58.5	58.5

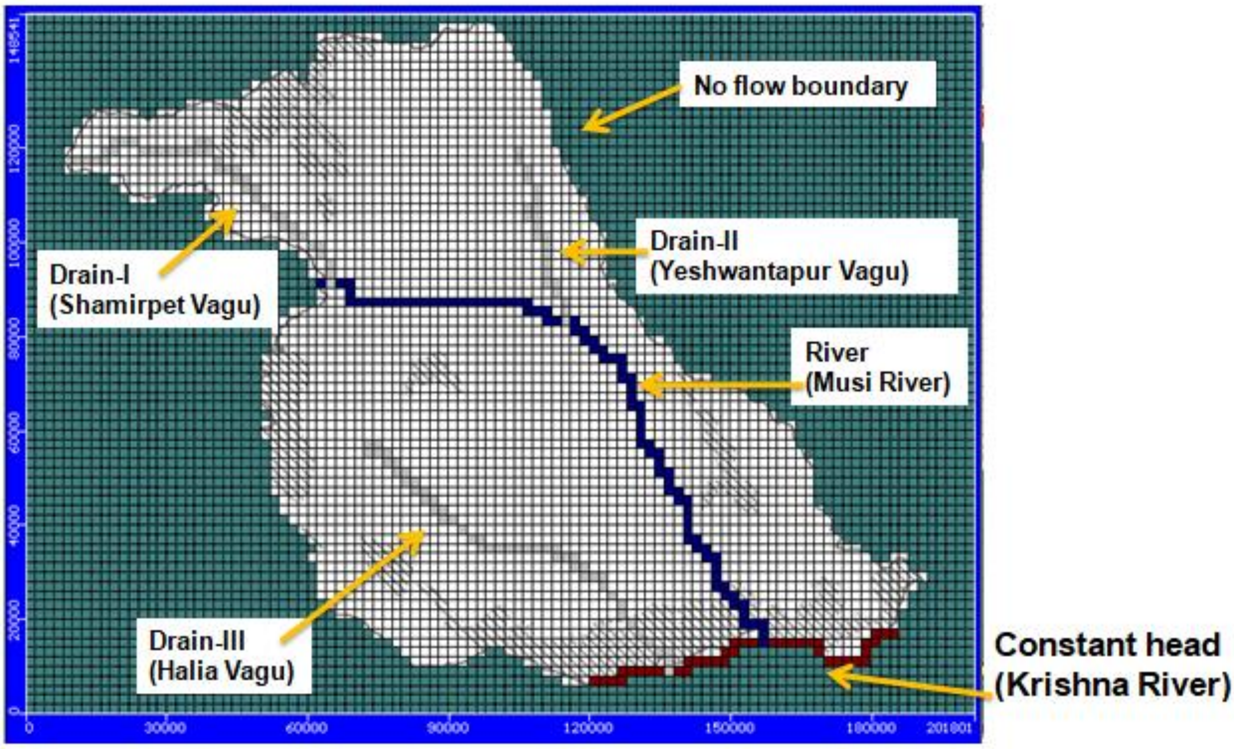


Fig-4.3: Boundary conditions map, Lower Musi sub-basin, Telangana State

4.2.2 Ground Water Flux

4.2.2.1 Ground water Recharge :

Recharge from rainfall, irrigation return flow, water bodies and canal seepage was estimated using Groundwater Estimation Committee (GEC 1997) methodology. The estimation of recharge done for monsoon and non-monsoon periods. The estimated values were applied to the respective grids in the model using recharge boundaries. The grid wise recharge are grouped into 6 zones and assigned zone wise (**Fig-4.4**).

Zones	**Recharge rate from 0 to 180 days (m/day)**
I	0.00055
II	0.0004
III	0.0004
IV	0.0004
V	0.00035

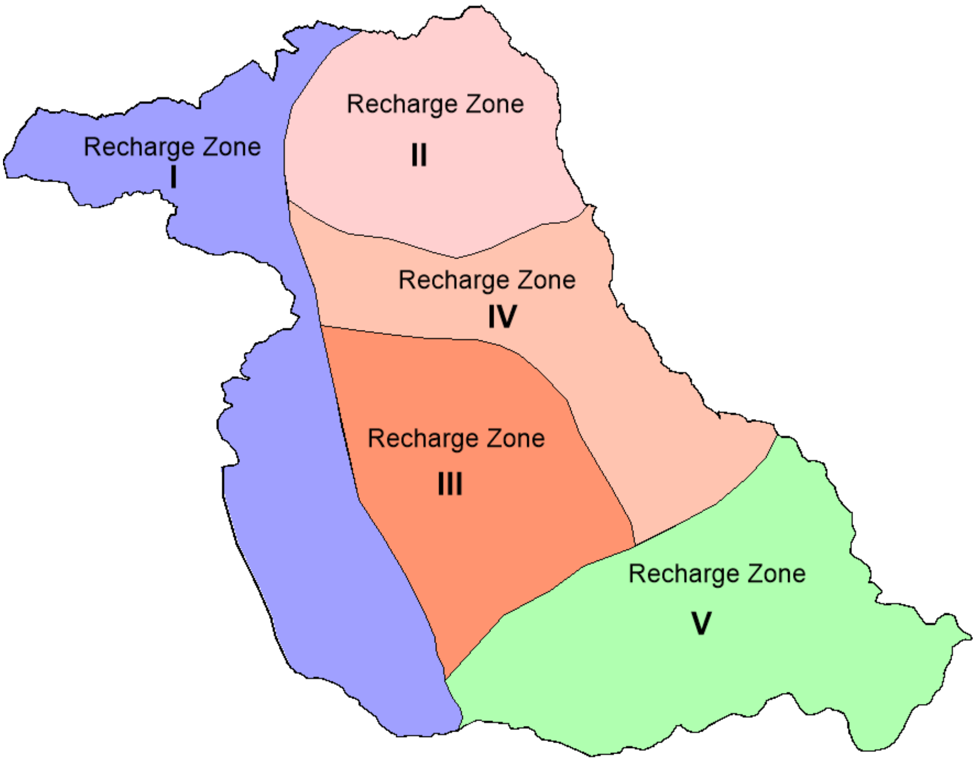


Fig-4.4: Ground Water Recharge Zones, Lower Musi sub-basin, Telangana State

4.2.2.2 Ground water Draft: The ground water draft estimated using Groundwater Estimation Committee (GEC 1997) methodology. The draft of groundwater in the study area is mainly through pumping from bore wells for the purpose of Domestic, Agriculture and Industrial. Annual draft for irrigation purpose is estimated based on the total number of bore wells and average annual unit draft. The unit draft is calculated based on amount of water pumped from wells, number of pumping hours and total number of pumping days in a year. The estimated draft values were applied as pumping wells to the respective grids in the model using well package. Monthly pumping rates assigned to each grid ***Fig-4.5***.

Groundwater uses	**Annual Groundwater Draft (mcm/year)**
Irrigation	940
Domestic & Industry	113
Total	1053

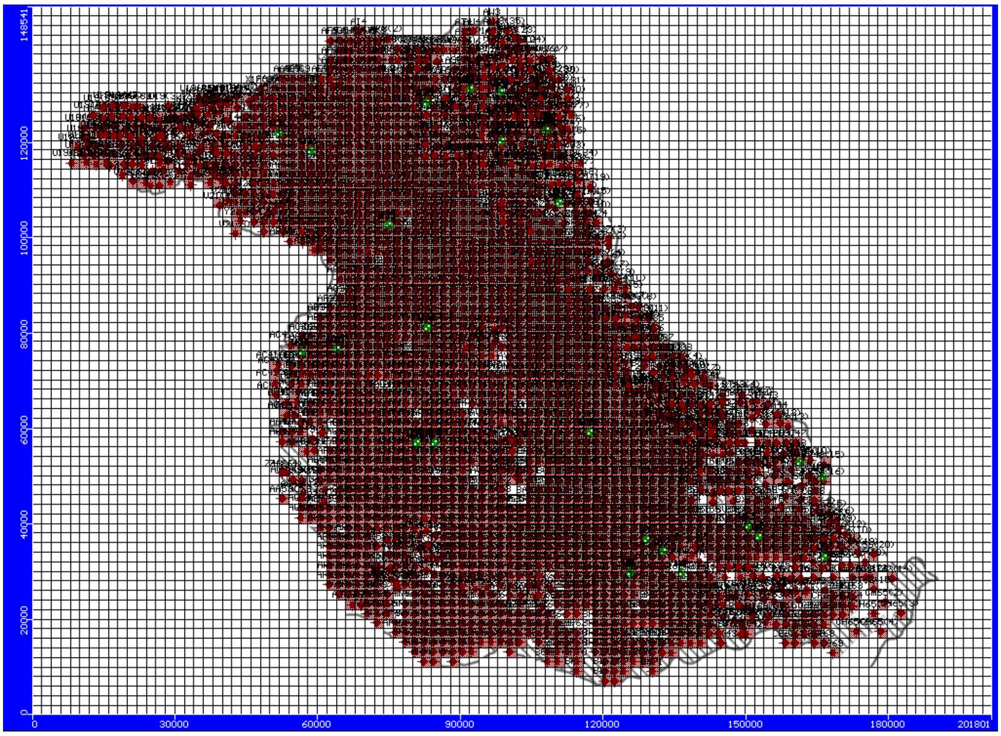


Fig-4.5 **:** Pumping well distribution, Lower Musi sub-basin, Telangana State

5.0 Numerical Model

The numerical model was developed based on the conceptual ground water flow model, various steps involved in the development of the model are

1. Selecting the governing equation(s) of groundwater flow constituting the mathematical model and the computer program to solve the mathematical model numerically.
2. Translating the conceptual model to numerical model by defining the system geometry, discretizing the spatial and temporal domains, designing a spatial grid, selecting time steps and stress periods, and formulating boundary conditions.
3. Finalizing the physical properties and hydrologic measurements of aquifer condition such as water levels/heads and inflow-out flow of the aquifer.

The numerical model subsequently calibrated, where model parameters and boundary conditions were adjusted based on an objective criteria of the match between simulated and observed heads and flows.

Groundwater flow was simulated with MODFLOW-2000, a computer program that simulates three-dimensional groundwater flow through a porous medium using a numerical finite-difference method for solving the governing equations for steady (time invariant) and transient (time variable) flow.

The numeric model is assumed to meet the governing equation by assuming,

(1) Water in the aquifer is fresh water within a narrow range of temperature and fluid-density and viscosity variations are negligible.

(2) Flow through the fractured parts of the aquifer can be represented as flow through an equivalent porous medium.

(3) Hydrogeologic units constituting the aquifer are sub-horizontal, therefore, vertical hydraulic conductivity can be simulated perpendicular to the nearly horizontal hydrogeologic units.

5.1 Model Descritization

Spatial discretization is defined in terms of layers, rows, and columns that result in discrete rectilinear volumes called cells. This three-dimensional array of cells is known as the model grid.

For transient models, time is divided into discrete intervals called stress periods and time steps. Stress periods represent intervals over which specified flows in and out of the aquifer are constant.

Uniform model grid spacing was used because (1) most groundwater transport models compatible with MODFLOW-2000 require uniform grids over the transport simulation domain, and (2) numerical accuracy is better for regular grids.

The Lower Musi sub-basin is drainage divide region, traversed by Musi river and bounded by river Krishna in the southern side. The aquifer model in Lower Musi sub-basin consists of 74 rows and 101 columns. The model has two layers with a uniform grid of 2000m x 2000m. Two layers are interconnected through vertical conductivity and water level is same for both layers.

5.2 Temporal Discretization

Inflows and out flows in to aquifer system in the area vary due to changes in climate, seasonal changes, stream flows and water use. The transient flow model simulates ground water flow in the aquifers for four water years from June 2014 to May 2018. Temporal discretization done based on the timing and duration of irrigation water use, as irrigation draft accounts for > 80% of the total draft in the area.

Seasonal changes in water levels of 1 to 20 m. observed in the area due to ground water withdrawal for irrigation, with water levels rising from June to November due to monsoon recharge and falling from December to May due to non-monsoon withdrawal. Stress periods are descretized into 3 temporal zones for each year, monsoon stress from June to September, Post-monsoon stress from October to January and non-monsoon stress from February to May.

Stress periods	Duration
Monsoon	June to September
Post-Monsoon	October to January
Non-monsoon	February to May

5.3 Model Calibration

Model calibration is an iterative process of adjusting the 3-D distribution of aquifer properties, boundary conditions to improve the match between simulation results and observations. Monitored field hydraulic heads from the observation wells distributed spatially and temporally are applied for calibrating the model. The calibration of the numerical models in the study area done by evaluating observed hydraulic heads, defining discrete zones with uniform aquifer properties in the model and adjusting these zones and aquifer property values to obtain best match between observed and simulated hydraulic heads. The aquifer properties were manually adjusted by trial and error method.

5.4 Calibration observations

Steady state calibration observations and transient calibration are reflected by hydraulic heads at each cell and mass water balance of the aquifer system. 26 observation wells in the model area with water level data were used in model calibration ***Fig-5.1***.

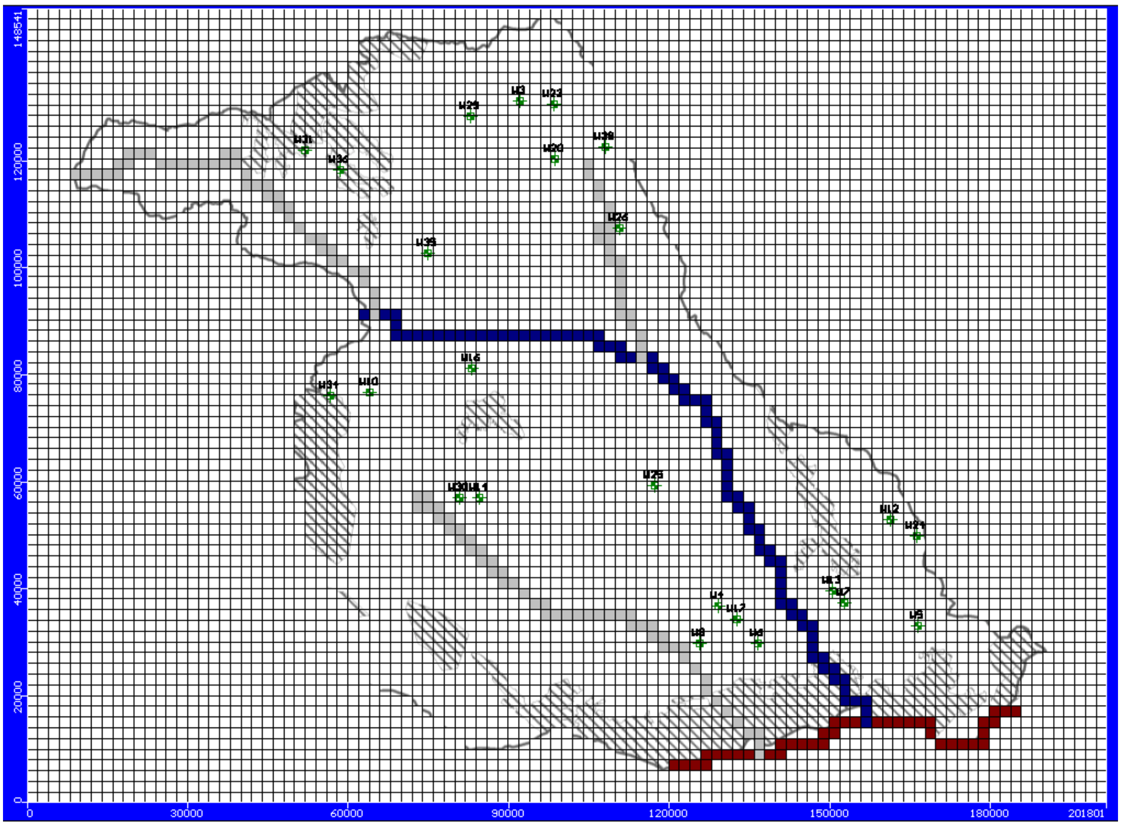
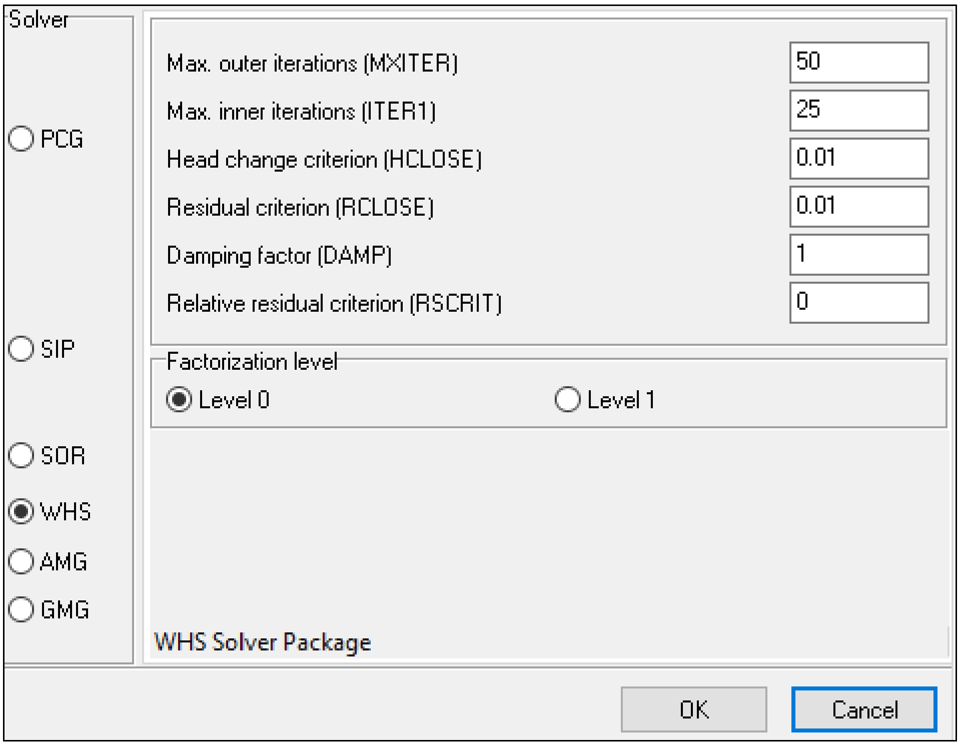


Fig-5.1 **:** Head observation wells, Lower Musi sub-basin, Telangana State

5.5 Steady state Calibration

The groundwater flow model constructed for computation of hydraulic head distribution was calibrated using 26 head observations from 26 locations, the initial water levels of 2014 was used as the steady state observations.The Steady state time unit is 30 days (1 month) and simulation time was specified as 30 days. The groundwater head in the model was computed using Visual MODFLOW. Water Hydrogeological Software (WHS) solver package of MODFLOW has been used for groundwater flow computation. WHS package checked the maximum change in the solution at every cell after completion of each iteration. If the maximum change in the solution is below the set of convergence tolerance (0.01 m), the solution converge and the solver stops, otherwise, new iteration starts. The groundwater flow model converged successfully after 50 iterations. A trial and error calibration technique has been used. The flow model was calibrated by adjusting parameters like permeability, recharge, river stage within a narrow range of values until the best fit was obtained between the observed heads and simulated heads ***Fig-5.2-5.6***.



Solver

○ PCG

○ SIP

○ SOR

● WHS

○ AMG

○ GMG

Max. outer iterations (MXITER) 50

Max. inner iterations (ITER1) 25

Head change criterion (HCLOSE) 0.01

Residual criterion (RCLOSE) 0.01

Damping factor (DAMP) 1

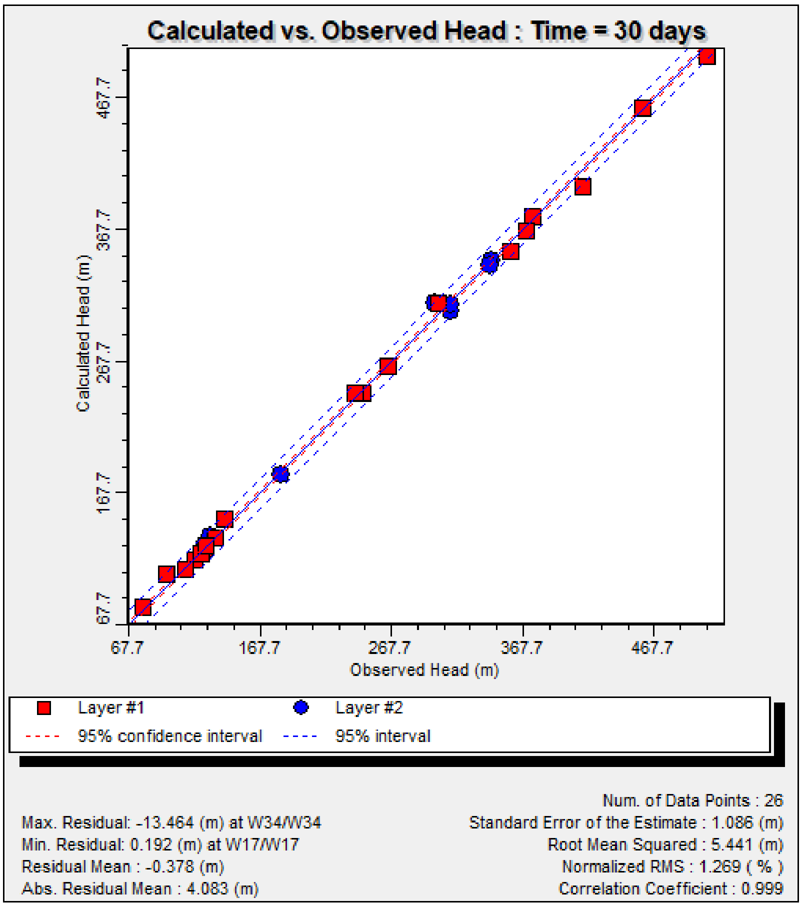
Relative residual criterion (RSCRIT) 0

Factorization level

● Level 0 ○ Level 1

WHS Solver Package

Fig-5.2 : Solver settings



```
                                                        Num. of Data Points : 26
Max. Residual: -13.464 (m) at W34/W34      Standard Error of the Estimate : 1.086 (m)
Min. Residual: 0.192 (m) at W17/W17                 Root Mean Squared : 5.441 (m)
Residual Mean : -0.378 (m)                          Normalized RMS : 1.269 ( % )
Abs. Residual Mean : 4.083 (m)                  Correlation Coefficient : 0.999
```

Fig-5.3 : Calculated vs. Observed Head Steady state Calibration

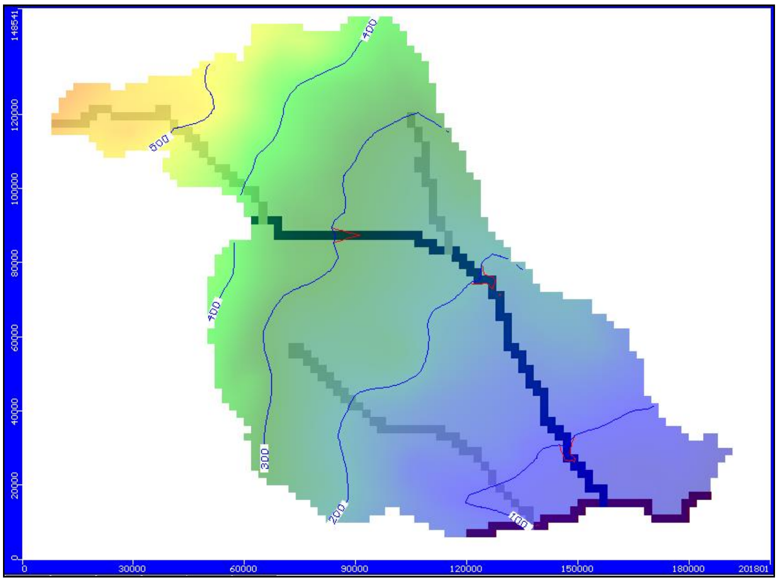
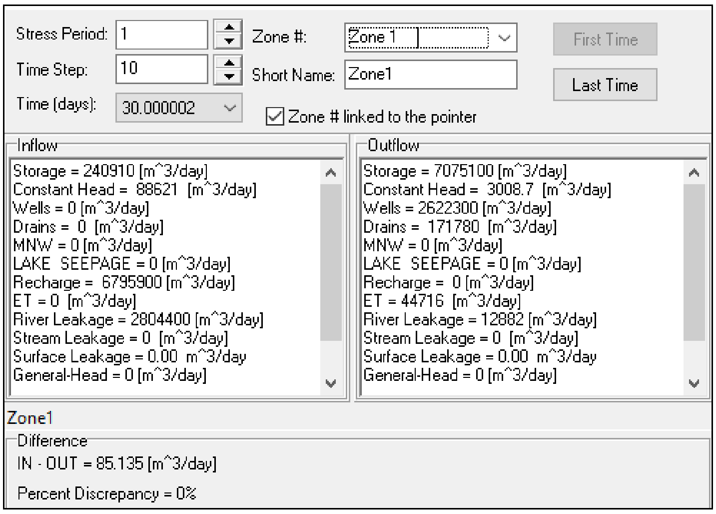


Fig-5.4 : Simulated hydraulic head after 30days, Steady state Calibration



Stress Period: 1
Time Step: 10
Time (days): 30.000002
Zone #: Zone 1
Short Name: Zone1
☑ Zone # linked to the pointer

Inflow

```
Storage = 240910 [m^3/day]
Constant Head =  88621  [m^3/day]
Wells = 0 [m^3/day]
Drains =  0  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  6795900 [m^3/day]
ET = 0  [m^3/day]
River Leakage = 2804400 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

Outflow

```
Storage = 7075100 [m^3/day]
Constant Head =  3008.7  [m^3/day]
Wells = 2622300 [m^3/day]
Drains =  171780  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 44716  [m^3/day]
River Leakage = 12882 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

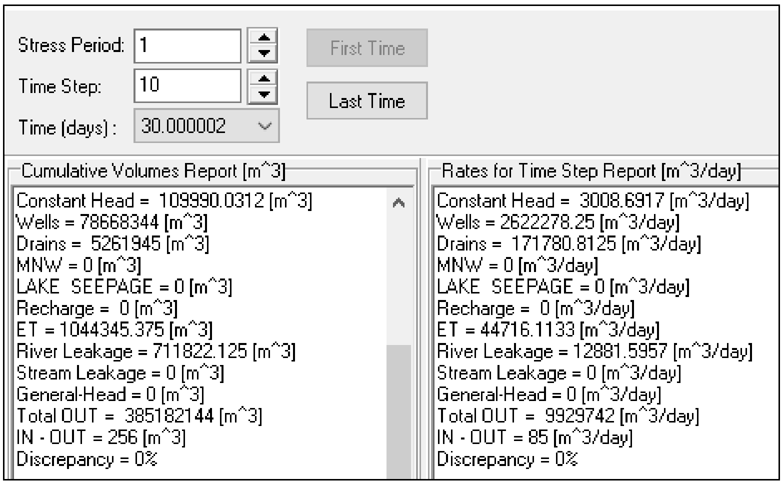
Zone1

Difference

IN - OUT = 85.135 [m^3/day]

Percent Discrepancy = 0%

Fig-5.5 : Zone Budget - Steady state Calibration



Stress Period: 1
Time Step: 10
Time (days) : 30.000002

Cumulative Volumes Report [m^3]

```
Constant Head =  109990.0312 [m^3]
Wells = 78668344 [m^3]
Drains =  5261945 [m^3]
MNW = 0 [m^3]
LAKE  SEEPAGE = 0 [m^3]
Recharge =  0 [m^3]
ET = 1044345.375 [m^3]
River Leakage = 711822.125 [m^3]
Stream Leakage = 0 [m^3]
General-Head = 0 [m^3]
Total OUT =  385182144 [m^3]
IN - OUT = 256 [m^3]
Discrepancy = 0%
```

Rates for Time Step Report [m^3/day]

```
Constant Head =  3008.6917 [m^3/day]
Wells = 2622278.25 [m^3/day]
Drains =  171780.8125 [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 44716.1133 [m^3/day]
River Leakage = 12881.5957 [m^3/day]
Stream Leakage = 0 [m^3/day]
General-Head = 0 [m^3/day]
Total OUT =  9929742 [m^3/day]
IN - OUT = 85 [m^3/day]
Discrepancy = 0%
```

Fig-5.6 : Mass Balance-Flow Steady state Calibration

5.6 Transient Calibration

Transient flow model was calibrated for 4 years period (2014 to 2018). Modeling ground water flow evaluates the relation between transient stresses and temporal changes in hydraulic heads and ground water flow directions. The initial water levels of 217 observation wells for 2014 was used as initial heads. Model was calibrated using 26 head observations from 26 locations. Transient model results included simulated hydraulic head and flux for each active cell in the model area. The groundwater flow model was run for 48 stress periods with 10 time steps each and model converged successfully after 50 iterations ***(Fig-5.7-5.10)***. Comparison of observed and simulated heads shows that general altitude of the water table is well simulated in the model. Individual hydrographs are shown in ***Fig-5.10a to j*** with simulated and observed head.

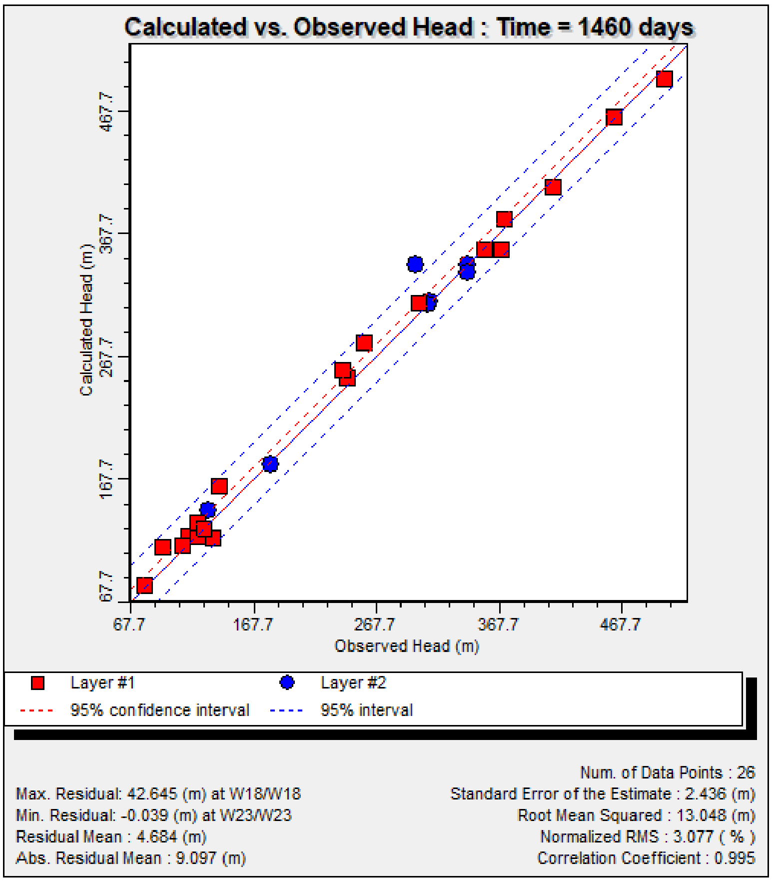


Fig-5.7 : Calculated vs. Observed Head Transient Calibration

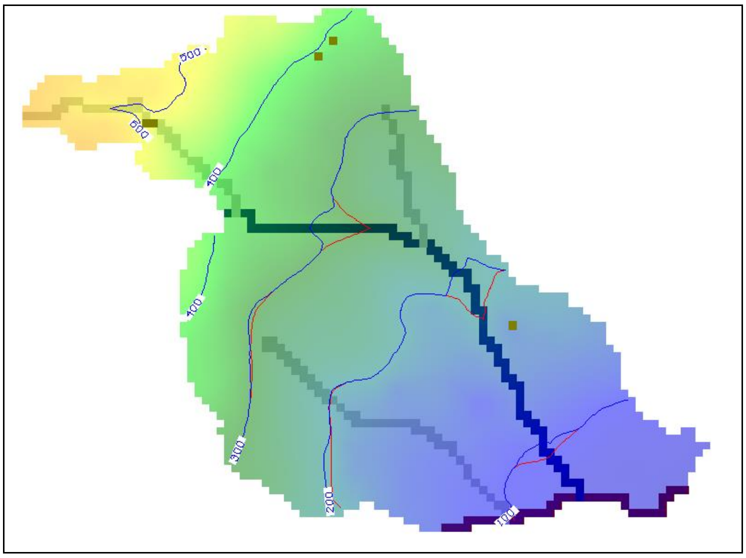
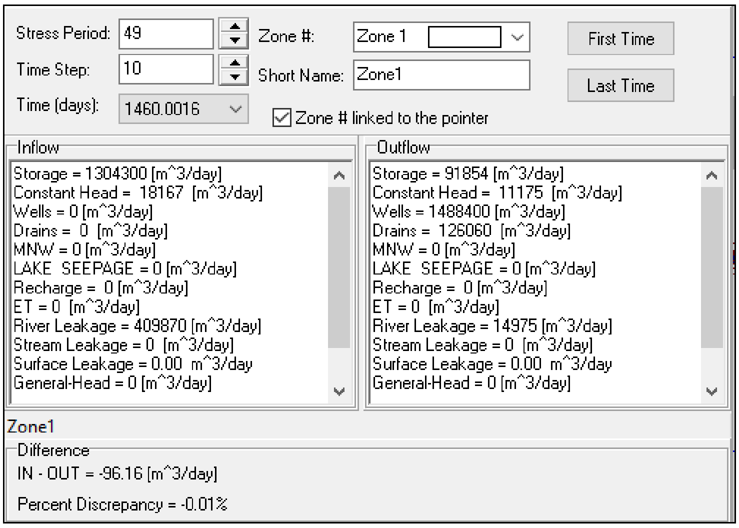


Fig-5.8: Simulated hydraulic head after 1465 days, Transient Calibration



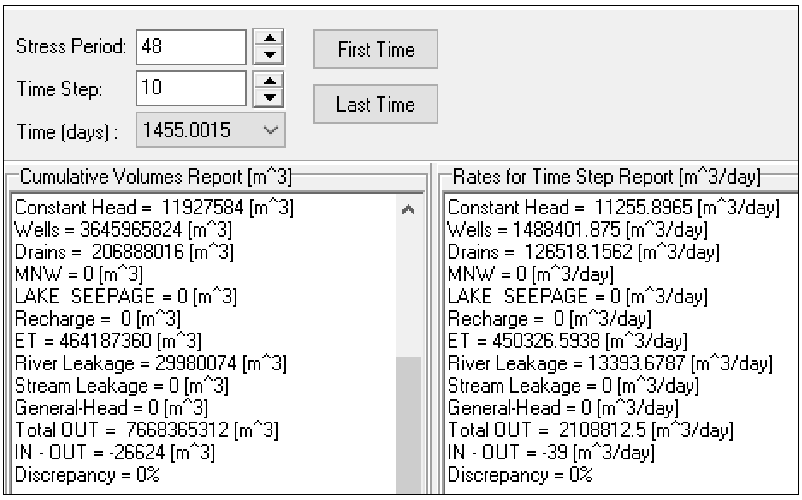
```
Stress Period: 49
Time Step: 10
Time (days): 1460.0016
Zone #: Zone 1
Short Name: Zone1
☑ Zone # linked to the pointer

Inflow
Storage = 1304300 [m^3/day]
Constant Head = 18167 [m^3/day]
Wells = 0 [m^3/day]
Drains = 0 [m^3/day]
MNW = 0 [m^3/day]
LAKE SEEPAGE = 0 [m^3/day]
Recharge = 0 [m^3/day]
ET = 0 [m^3/day]
River Leakage = 409870 [m^3/day]
Stream Leakage = 0 [m^3/day]
Surface Leakage = 0.00 m^3/day
General-Head = 0 [m^3/day]

Outflow
Storage = 91854 [m^3/day]
Constant Head = 11175 [m^3/day]
Wells = 1488400 [m^3/day]
Drains = 126060 [m^3/day]
MNW = 0 [m^3/day]
LAKE SEEPAGE = 0 [m^3/day]
Recharge = 0 [m^3/day]
ET = 0 [m^3/day]
River Leakage = 14975 [m^3/day]
Stream Leakage = 0 [m^3/day]
Surface Leakage = 0.00 m^3/day
General-Head = 0 [m^3/day]

Zone1
Difference
IN - OUT = -96.16 [m^3/day]
Percent Discrepancy = -0.01%
```

Fig-5.9 : Zone Budget Output-Flow transient Calibration



```
Stress Period: 48
Time Step: 10
Time (days) : 1455.0015

Cumulative Volumes Report [m^3]
Constant Head = 11927584 [m^3]
Wells = 3645965824 [m^3]
Drains = 206888016 [m^3]
MNW = 0 [m^3]
LAKE SEEPAGE = 0 [m^3]
Recharge = 0 [m^3]
ET = 464187360 [m^3]
River Leakage = 29980074 [m^3]
Stream Leakage = 0 [m^3]
General-Head = 0 [m^3]
Total OUT = 7668365312 [m^3]
IN - OUT = -26624 [m^3]
Discrepancy = 0%

Rates for Time Step Report [m^3/day]
Constant Head = 11255.8965 [m^3/day]
Wells = 1488401.875 [m^3/day]
Drains = 126518.1562 [m^3/day]
MNW = 0 [m^3/day]
LAKE SEEPAGE = 0 [m^3/day]
Recharge = 0 [m^3/day]
ET = 450326.5938 [m^3/day]
River Leakage = 13393.6787 [m^3/day]
Stream Leakage = 0 [m^3/day]
General-Head = 0 [m^3/day]
Total OUT = 2108812.5 [m^3/day]
IN - OUT = -39 [m^3/day]
Discrepancy = 0%
```

Fig-5.10 : Mass Balance-Flow transient Calibration

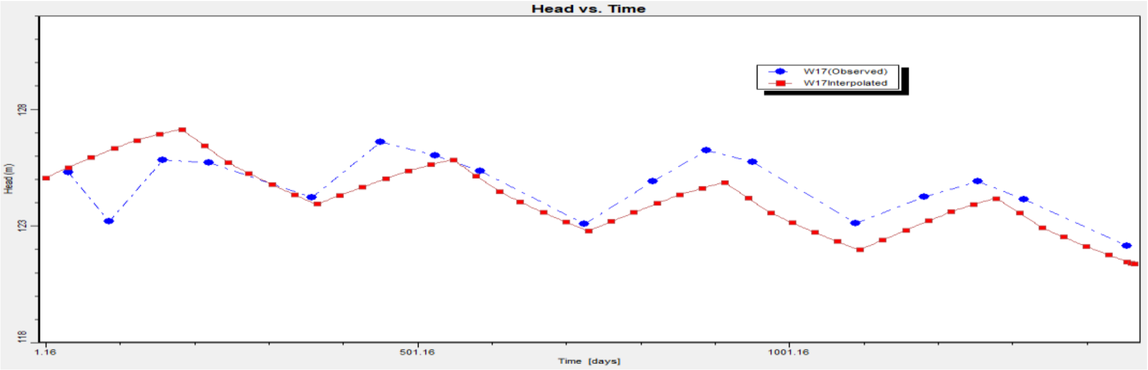


Fig-5.10(a): Well no. W17

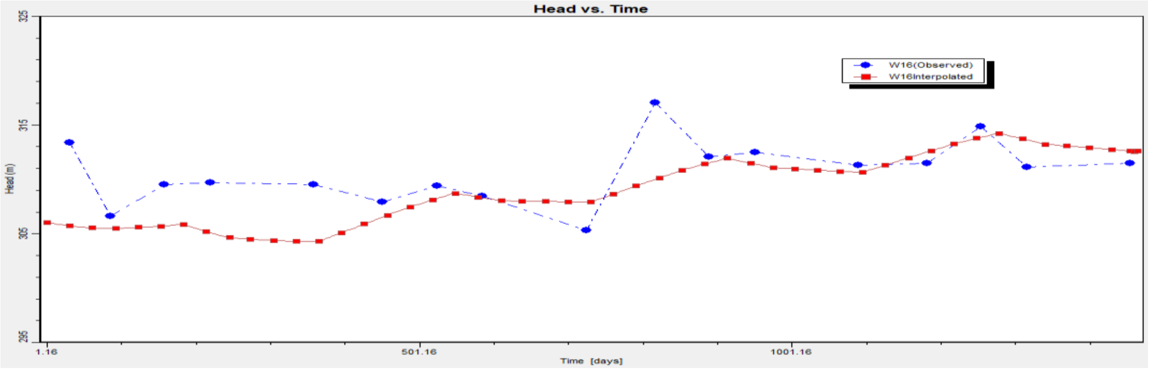


Fig-5.10(b): Well no. W16

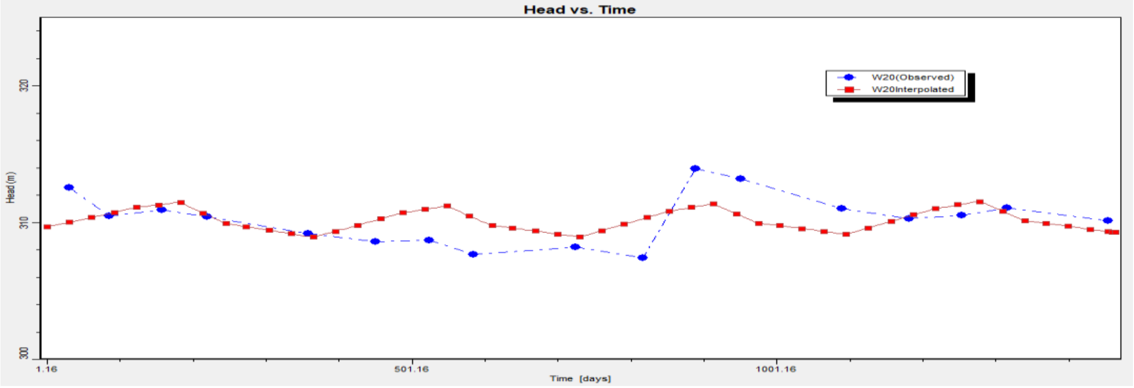


Fig-5.10(c): Well no. W20

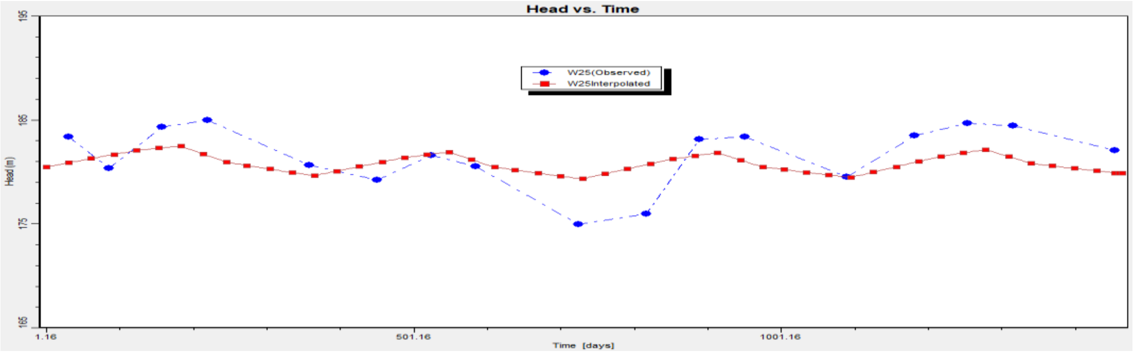


Fig-5.10(d): Well no. W25

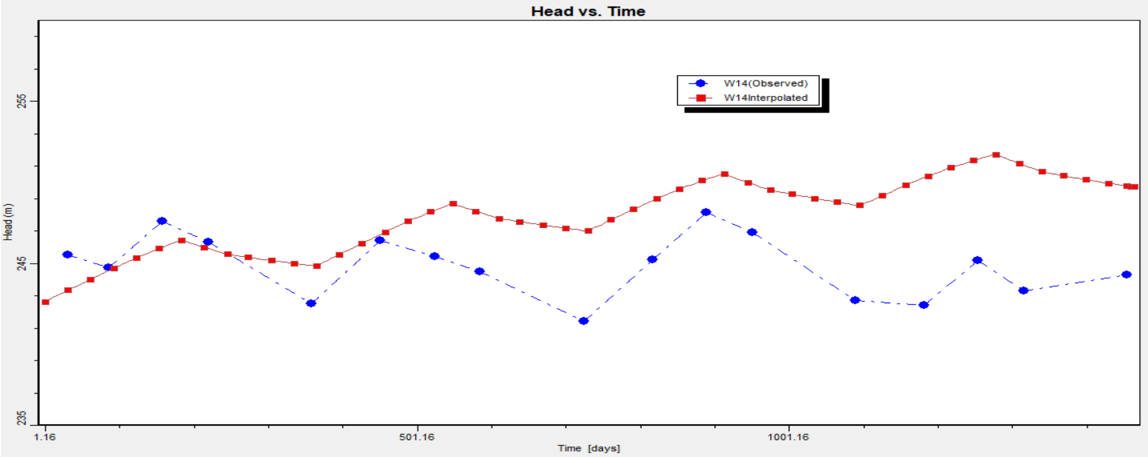


Fig-5.10(e): Well no. W14

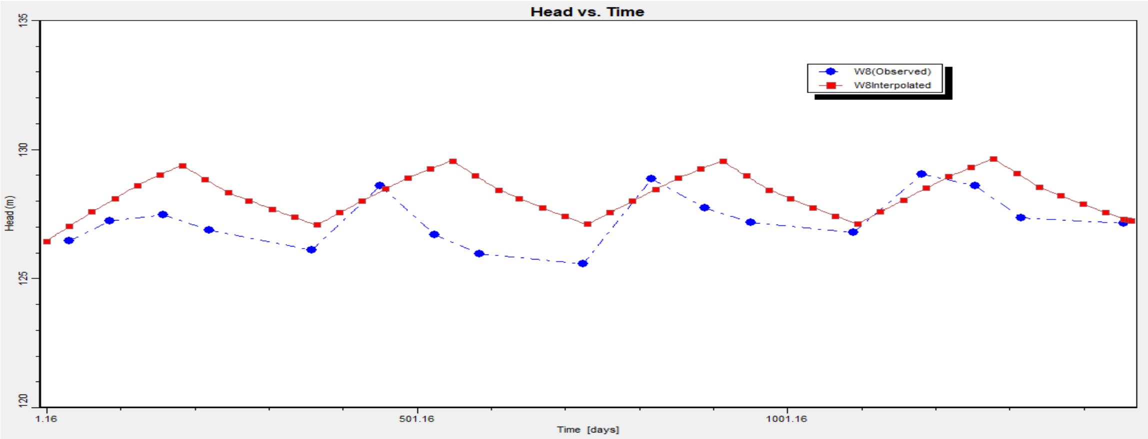


Fig-5.10(f): Well no. W8

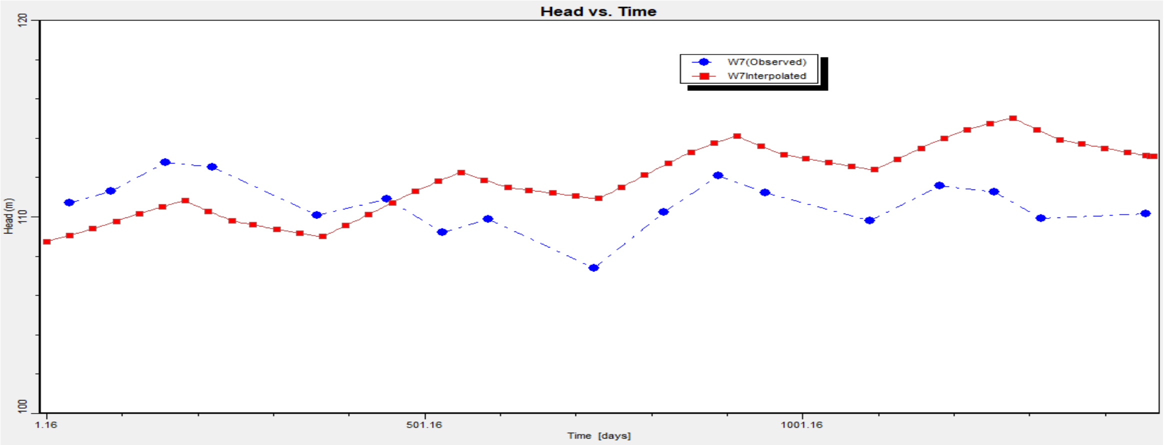


Fig-5.10(g): Well no. W7

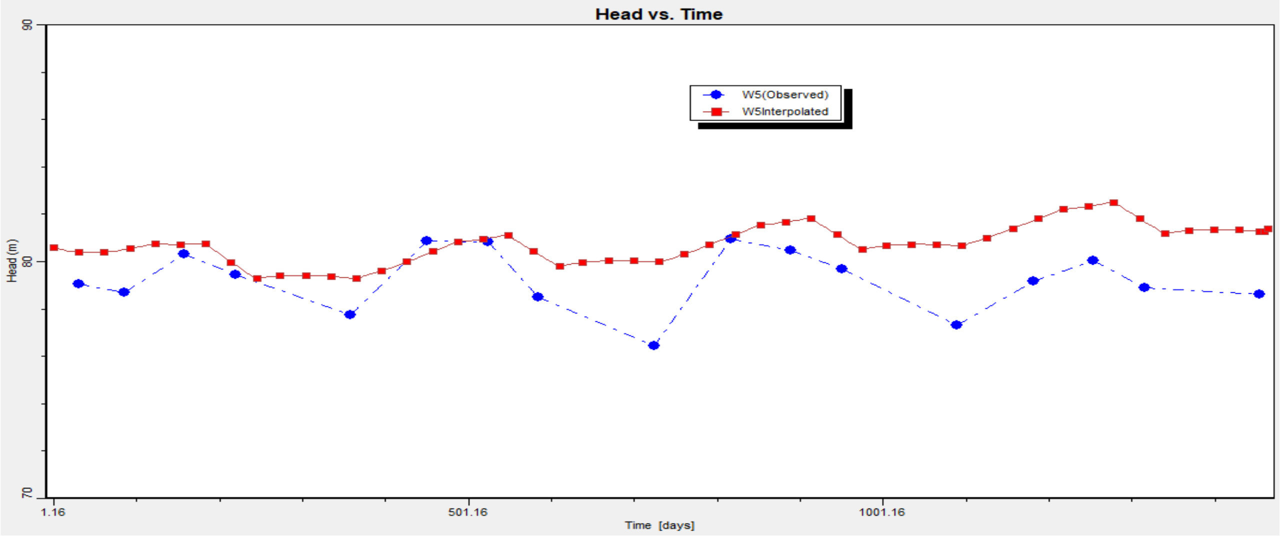


Fig-5.10(h): Well no. W5

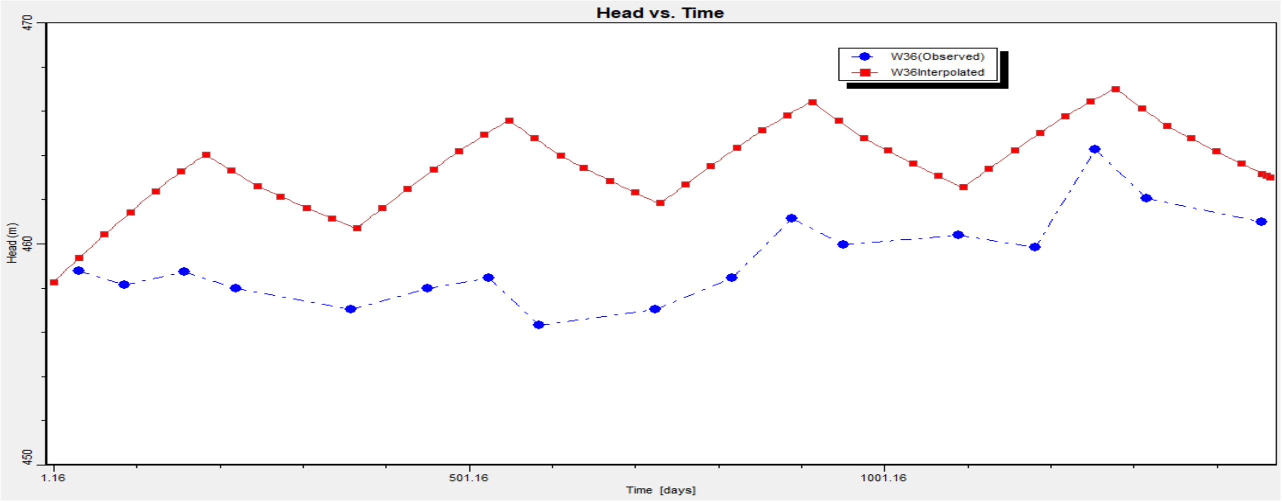


Fig-5.10(i): Well no. W36

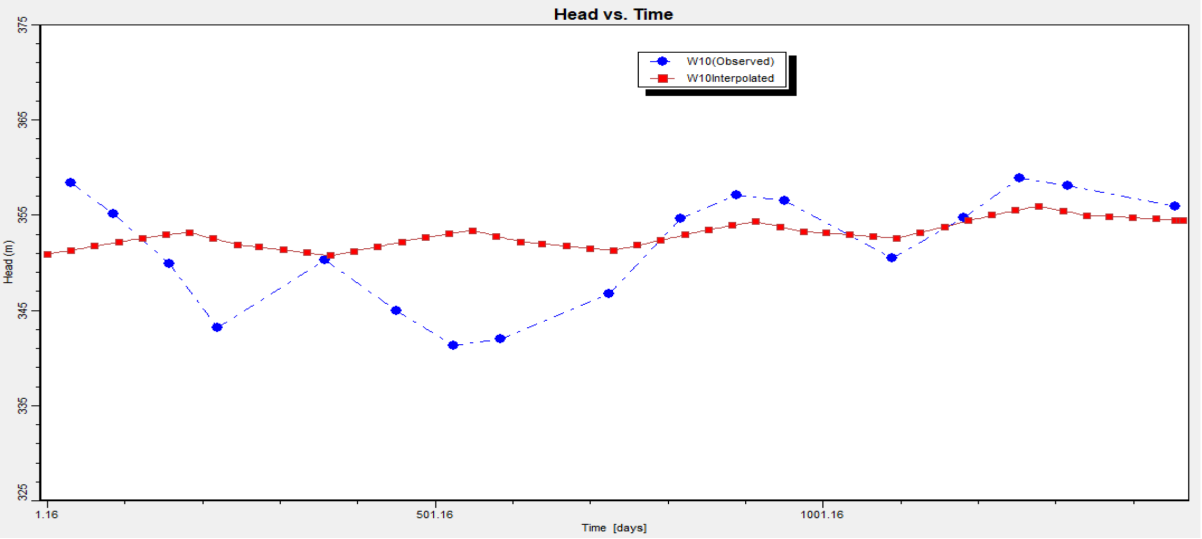
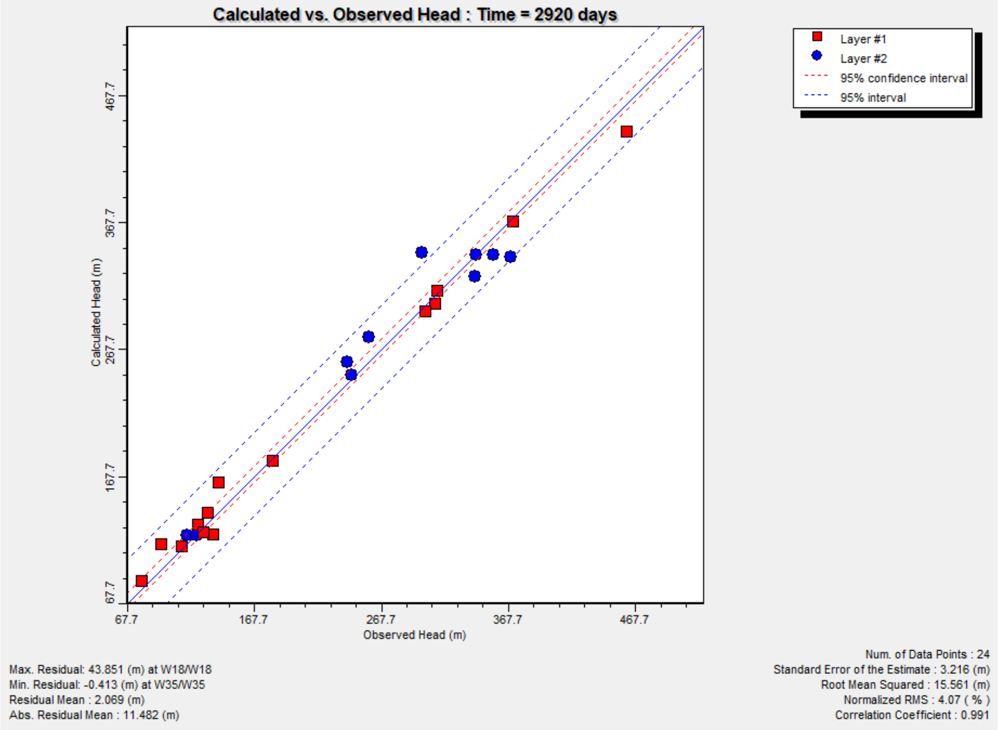


Fig-5.10(j): Well no. W10

6.0: Prediction Model

6.1 Prediction model –I (extension of existing conditions)

Transient flow model was calibrated for 8 years period 4 years for existing transient flow model (2014 to 2018) and 4 years prediction model (2019 to 2022). All the model parameters used in the study state calibration remains constant for prediction model including boundary conditions. The transient flow model data of ground water flux, recharge and withdrawal of ground water are extended without any change for prediction model period (2019-2022). The initial water levels of 217 observation wells for 2014 was used as initial heads. Model was calibrated using 26 head observations from 26 locations. The groundwater flow model was run for 97 stress periods with 10 time steps each and model converged successfully after 50 iterations ***(Fig-6.1-6.3)***.



Max. Residual: 43.851 (m) at W18/W18
Min. Residual: -0.413 (m) at W35/W35
Residual Mean : 2.069 (m)
Abs. Residual Mean : 11.482 (m)

Num. of Data Points : 24
Standard Error of the Estimate : 3.216 (m)
Root Mean Squared : 15.561 (m)
Normalized RMS : 4.07 (%)
Correlation Coefficient : 0.991

Fig-6.1 : Calibration plot with normal conditions

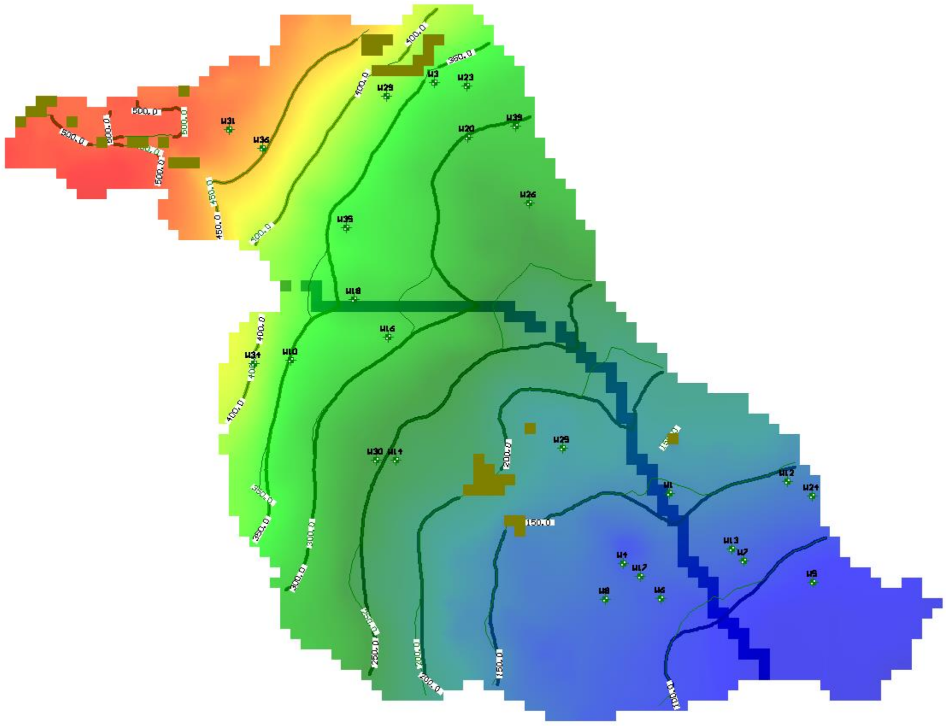
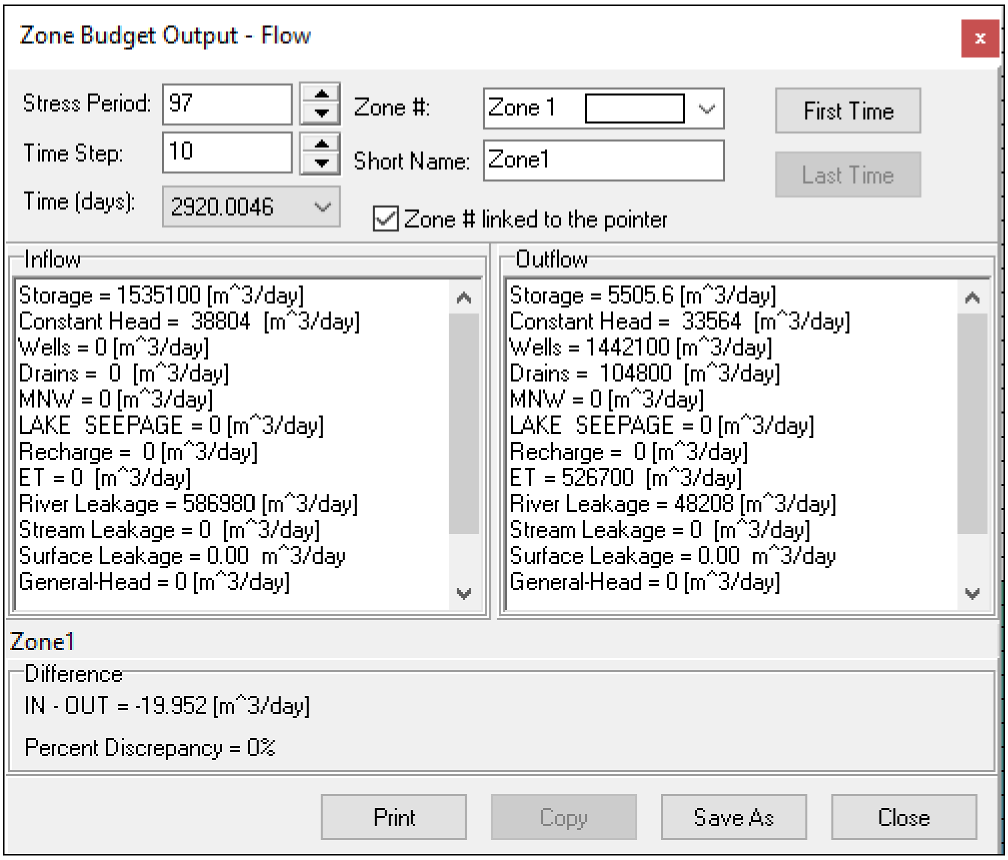


Fig-6.2 : Simulated hydraulic head after 2920 days with normal conditions


Zone Budget Output - Flow

Stress Period: 97

Time Step: 10

Time (days): 2920.0046

Zone #: Zone 1

Short Name: Zone1

☑ Zone # linked to the pointer

Inflow

Storage = 1535100 [m^3/day]
Constant Head = 38804 [m^3/day]
Wells = 0 [m^3/day]
Drains = 0 [m^3/day]
MNW = 0 [m^3/day]
LAKE SEEPAGE = 0 [m^3/day]
Recharge = 0 [m^3/day]
ET = 0 [m^3/day]
River Leakage = 586980 [m^3/day]
Stream Leakage = 0 [m^3/day]
Surface Leakage = 0.00 m^3/day
General-Head = 0 [m^3/day]

Outflow

Storage = 5505.6 [m^3/day]
Constant Head = 33564 [m^3/day]
Wells = 1442100 [m^3/day]
Drains = 104800 [m^3/day]
MNW = 0 [m^3/day]
LAKE SEEPAGE = 0 [m^3/day]
Recharge = 0 [m^3/day]
ET = 526700 [m^3/day]
River Leakage = 48208 [m^3/day]
Stream Leakage = 0 [m^3/day]
Surface Leakage = 0.00 m^3/day
General-Head = 0 [m^3/day]

Zone1

Difference

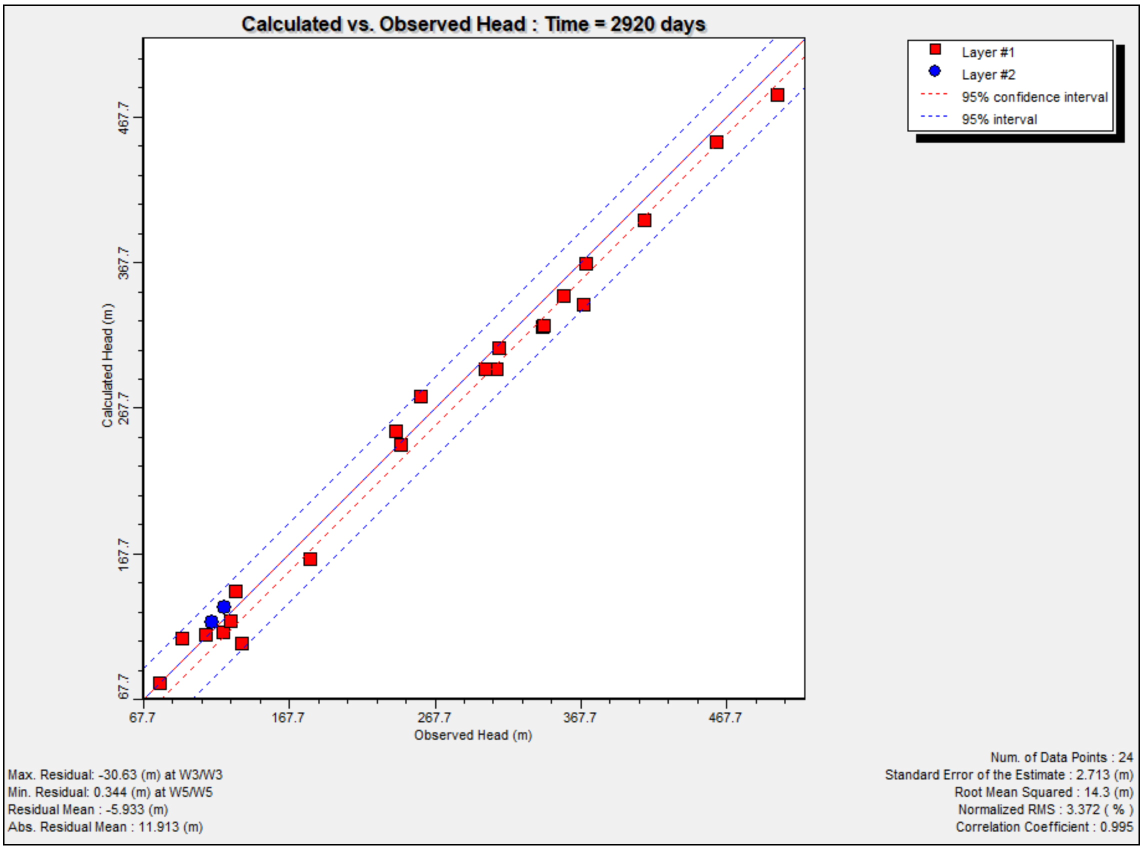
IN - OUT = -19.952 [m^3/day]

Percent Discrepancy = 0%

Fig-6.3 : Zone budget with normal conditions

6.2 Prediction model –II (Increase in irrigation draft @ 15%)

Transient flow model was calibrated for 8 years period 4 years for existing transient flow model (2014 to 2018) and 4 years prediction model (2019 to 2022).All the model parameters used in the study state calibration remains constant for prediction model including boundary conditions and recharge to ground water. The ground water withdrawal assumed to increase by 15% every year to the exiting withdrawal and assigned to the prediction model period(2019-2022).The initial water levels of 217 observation wells for 2014 was used as initial heads. Model was calibrated using 26 head observations from 26 locations. The groundwater flow model was run for 97 stress periods with 10 time steps each and model converged successfully after 50 iterations ***(Fig-6.4-6.6)***.



```
Max. Residual: -30.63 (m) at W3/W3
Min. Residual: 0.344 (m) at W5/W5
Residual Mean : -5.933 (m)
Abs. Residual Mean : 11.913 (m)
```

```
Num. of Data Points : 24
Standard Error of the Estimate : 2.713 (m)
Root Mean Squared : 14.3 (m)
Normalized RMS : 3.372 ( % )
Correlation Coefficient : 0.995
```

Fig-6.4 : Calibration plot with Increase in irrigation draft

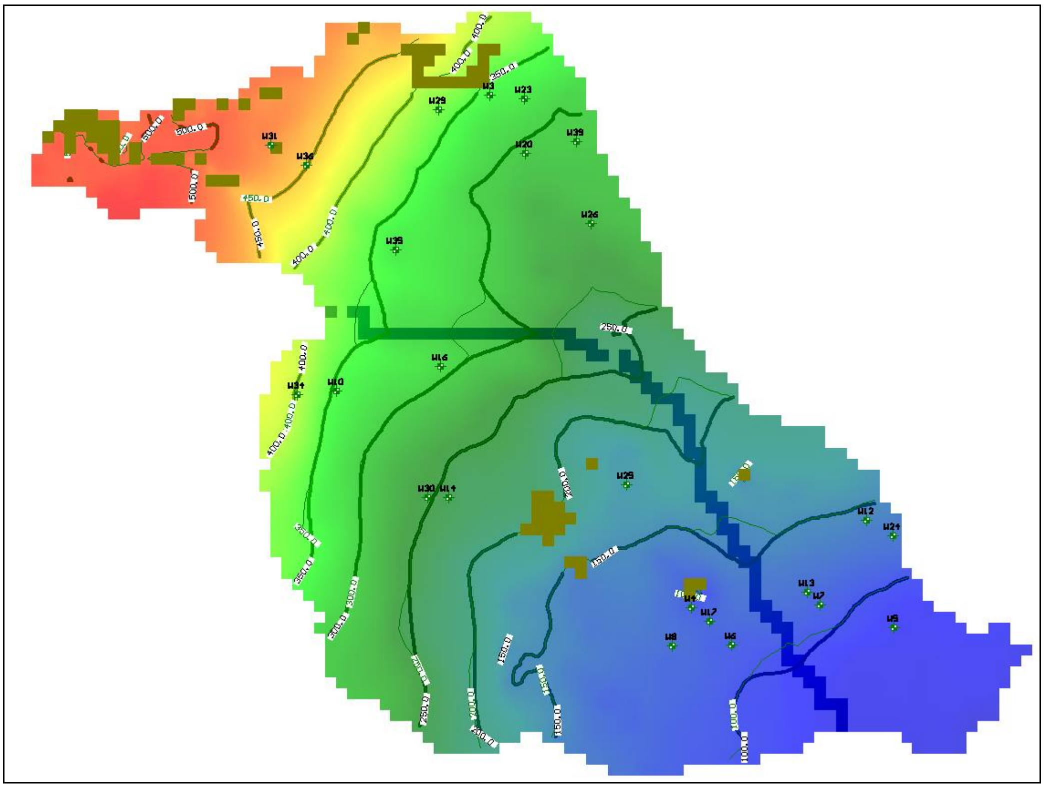
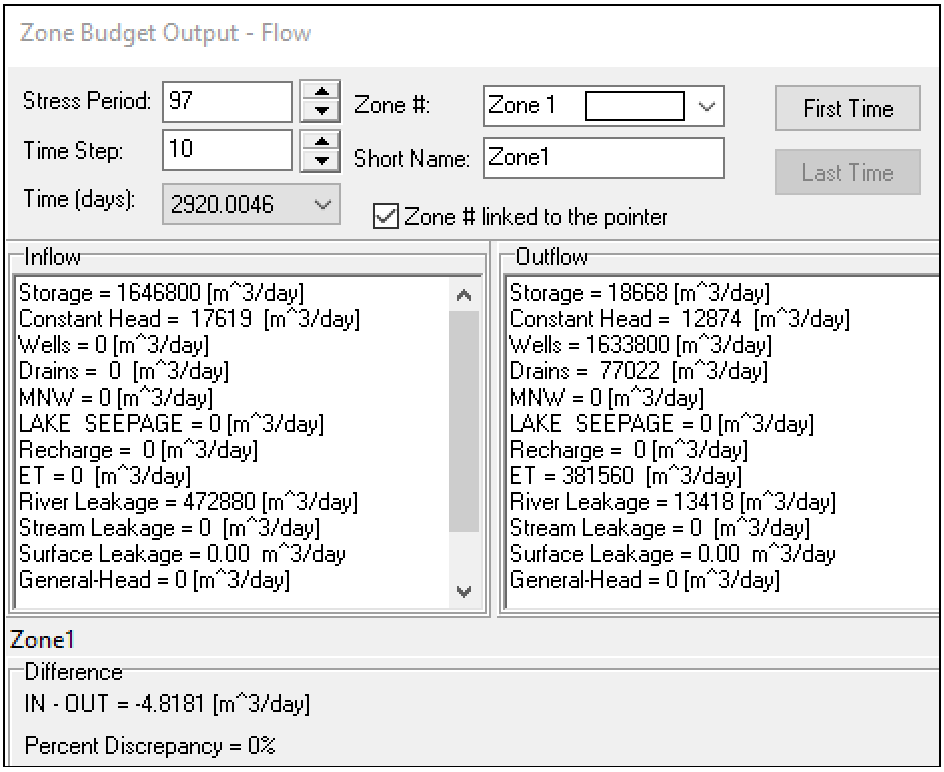


Fig-6.5 : Simulated *hydraulic head* after 2920 days with increase in irrigation draft



Stress Period: 97

Time Step: 10

Time (days): 2920.0046

Zone #: Zone 1

Short Name: Zone1

☑ Zone # linked to the pointer

Inflow

```
Storage = 1646800 [m^3/day]
Constant Head =  17619  [m^3/day]
Wells = 0 [m^3/day]
Drains =  0  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 0  [m^3/day]
River Leakage = 472880 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

Outflow

```
Storage = 18668 [m^3/day]
Constant Head =  12874  [m^3/day]
Wells = 1633800 [m^3/day]
Drains =  77022  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 381560  [m^3/day]
River Leakage = 13418 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

Zone1

Difference

IN - OUT = -4.8181 [m^3/day]

Percent Discrepancy = 0%

Fig-6.6 : Zone budget with increase in irrigation draft

6.3 Prediction model –III (Impact of NAQUIM intervention)

Various ground water management interventions were proposed under aquifer mapping studies (NAQUIM) in the study area. The impacts of these interventions are simulated by applying the year wise additional ground water recharge to the aquifers.

Transient flow model was calibrated for 8 years period 4 years for existing transient flow model (2014 to 2018) and 4 years prediction model (2019 to 2022). Except recharge to ground water all other model parameters used in the study state calibration remains constant for prediction model. The mandal wise additional recharge (***Table-6.1***) with proposed NAQUIM interventions are assigned spatially to the recharge zones as given in the ***table-6.2***. The initial water levels of 217 observation wells for 2014 was used as initial heads. Model was calibrated using 26 head observations from 26 locations. The groundwater flow model was run for 97 stress periods with 10 time steps each and model converged successfully after 50 iterations. The simulated water table elevation map with NAQUIM interventions after 2920 days is given in ***(Fig-6.7-6.9)***.

Table-6.1 : Mandal wise additional recharge with proposed NAQUIM interventions

S.No	**Mandal**	**District**	**Area (Sq.Km)**	**Additional Recharge with proposed NAQUIM interventions (MCM)**
1	Bachannapeta	Jangaon	216.017	2.41
2	Devaruppala	Jangaon	184.779	3.94
3	Gundala	Jangaon	174.296	5.06
4	Jangaon	Jangaon	196.959	4.3
5	Lingalaghanpur	Jangaon	188.163	3.9
6	Raghunathpalle	Jangaon	252.273	5.35
7	Anumula_Haliya	Nalgonda	192.511	3.13
8	Chandur	Nalgonda	211.007	5.64
9	Chinthapalle	Nalgonda	276.125	2.79
10	Chityala	Nalgonda	240.803	6.5
11	Damaracherla	Nalgonda	218.489	5.6
12	Gurrampode	Nalgonda	311.616	2.2
13	Kangal	Nalgonda	227.055	7
14	Kattangoor	Nalgonda	192.929	5.53
15	Kethepalle	Nalgonda	151.381	2
16	Marriguda	Nalgonda	229.912	4.15
17	Miryalaguda	Nalgonda	252.864	9.2
18	Munugode	Nalgonda	242.697	8.66
19	Nakrekal	Nalgonda	153.081	5
20	Nalgonda	Nalgonda	354.168	11.28

21	Nampalle	Nalgonda	281.592	4
22	Narketpalle	Nalgonda	234.454	7.27
23	Nidamanur	Nalgonda	218.209	3.82
24	Peddavura	Nalgonda	289.748	3.81
25	Saligouraram	Nalgonda	227.37	5.73
26	Thipparthi	Nalgonda	189.424	6.07
27	Thripuraram	Nalgonda	162.404	5.2
28	Vemulapalle	Nalgonda	116.32	3.48
29	Chilkur	Suryapet	108.824	3.75
30	Chivvemla	Suryapet	151.69	4.1
31	Garidepalle	Suryapet	194.741	4.45
32	Huzur nagar	Suryapet	130.156	3.51
33	Mattampalle	Suryapet	216.554	3.13
34	Mellachervu	Suryapet	152.316	5.52
35	Munagala	Suryapet	142.74	3.5
36	Neredcherla	Suryapet	123.836	7.42
37	Penpahad	Suryapet	187.164	3.13
38	Suryapet	Suryapet	215.219	7.5
39	Alair	Yadadri	166.145	4.55
40	Bhongiri	Yadadri	301.216	10.58
41	Bommalaramaram	Yadadri	166.19	5.92
42	Choutuppal	Yadadri	277.597	6.57
43	Mothkur	Yadadri	147.5	7.94
44	Narayanapur	Yadadri	246.465	6.34
45	Rajapet	Yadadri	196.976	4.9
46	Ramannapeta	Yadadri	227.051	6.17
47	Turkapalle_M	Yadadri	187.137	5.6
48	Valigonda	Yadadri	320.676	8.58
49	Yadagirigutta	Yadadri	186.922	6.1

Table-6.2 : Zone wise Recharge rate with Normal and NAQUIM interventions

Zones	Normal Recharge rate (m/day)	Recharge rate with NAQUIM interventions (m/day)
I	0.00055	0.000619
II	0.0004	0.000513
III	0.0004	0.000544
IV	0.0004	0.00055
V	0.00035	0.000464

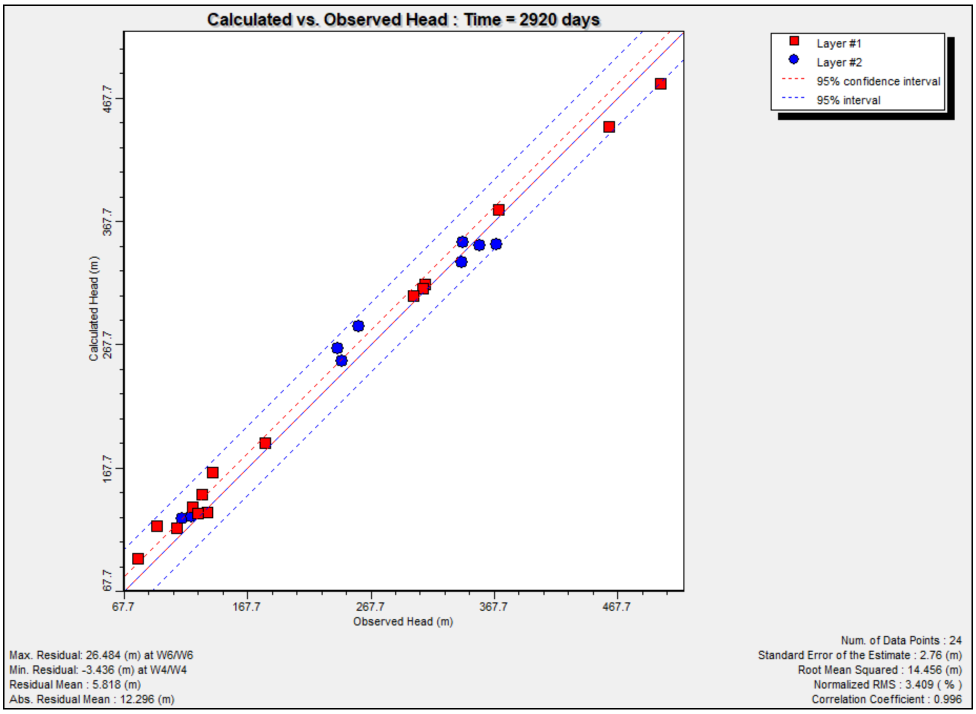


Fig-6.7 : Calibration plot with NAQUIM interventions

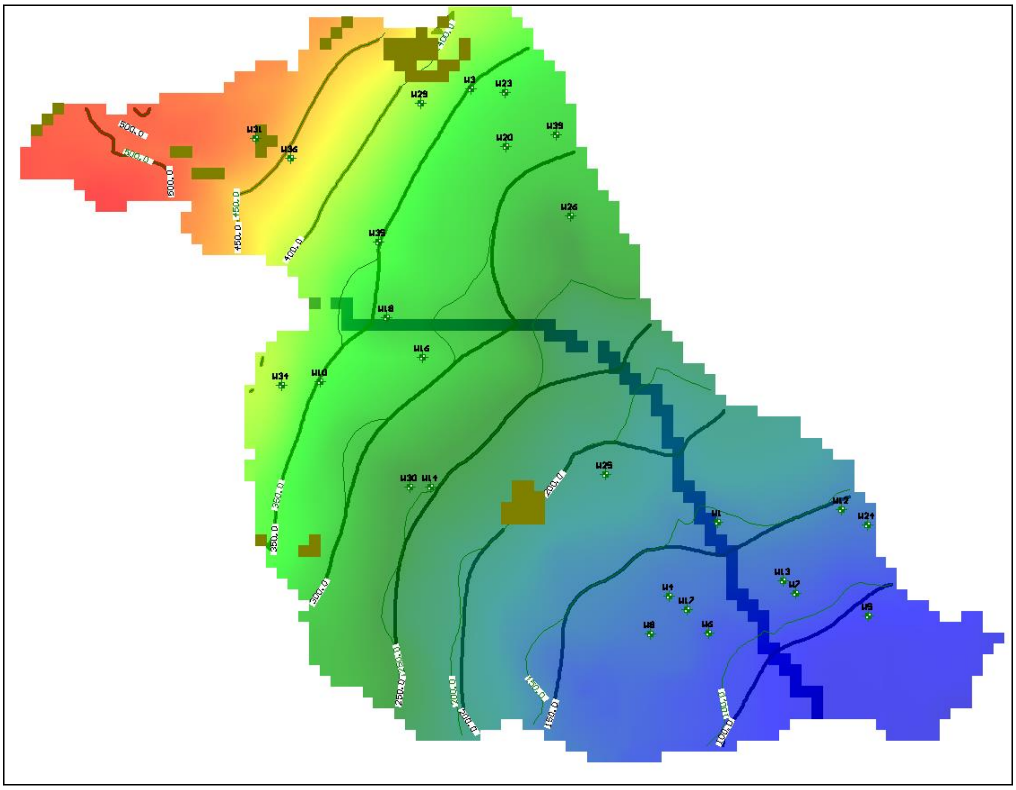
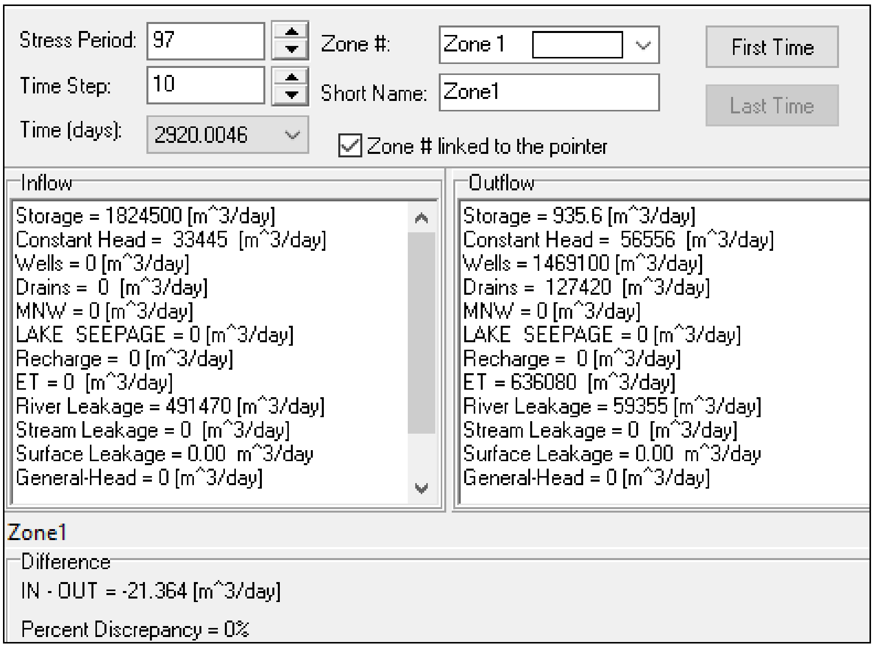


Fig-6.8 : Simulated Water table elevations after 2920 days with NAQUIM interventions



Stress Period: 97
Time Step: 10
Time (days): 2920.0046
Zone #: Zone 1
Short Name: Zone1
☑ Zone # linked to the pointer

Inflow

```
Storage = 1824500 [m^3/day]
Constant Head =  33445  [m^3/day]
Wells = 0 [m^3/day]
Drains =  0  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 0  [m^3/day]
River Leakage = 491470 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

Outflow

```
Storage = 935.6 [m^3/day]
Constant Head =  56556  [m^3/day]
Wells = 1469100 [m^3/day]
Drains =  127420  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 636080  [m^3/day]
River Leakage = 59355 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
```

Zone1

Difference

```
IN - OUT = -21.364 [m^3/day]

Percent Discrepancy = 0%
```

Fig-6.9 : Zone budget with NAQUIM interventions

6.4 Prediction models comparison and observations

The inflow and outflow components of the three prediction model outputs are compared to understand the impact of increased ground water draft and the impact of NAQUIM interventions. From the comparison data for inflow components given in ***table-6.3*** and out flow components given in ***table-6.4*** the following observations are made. The graphical representation of Inflow and Outflow components are given in ***Fig-6.10*** and **F*ig-6.11 .***

- The inflow to storage increased by 14 MCM with increase in ground water draft and it further increased 106 MCM with the impact of NAQUIM interventions.
- The inflow by constant head and river leakage increased with increase in ground water draft and decreased with the impact of NAQUIM interventions.
- The outflow from storage increased by 1 MCM with increase in ground water draft and decreased by 1.6 MCM with the impact of NAQUIM interventions.
- The outflow with wells increased by 66 MCM with increase in ground water draft and 10MCM with the impact of NAQUIM interventions.
- The outflow by constant head, drains, evapotranspiration and river leakage decreased with increase in ground water draft whereas out flow from these components increased and the impact of NAQUIM interventions.

  Well wise simulated combined hydrographs for three prediction models are given in ***Fig-6.10***, to ***fig-6.11(a-i)***.

Table-6.3 **:** Comparison of water budget, Inflow components

Inflow (MCM/Yr)	Normal 2920	Draft rise 2920	Change (Normal-draft Rise)	NAQUIM	Change (Normal-draft Rise)
Storage	560.3115	573.9625	13.651	665.9425	105.631
Constant Head	14.16346	14.87485	0.711385	12.20743	-1.95604
River Leakage	214.2477	237.7975	23.5498	179.3866	-34.8612

Table-6.4 **:** Comparison of water budget, outflow components

Outflow (MCM/Yr)	Normal 2920	Draft rise 2920	Change (Normal-draft Rise)	NAQUIM	Change (Normal-draft Rise)
Storage	2.009325	2.99008	0.980755	0.341494	-1.66783
Constant Head	12.25086	11.08724	-1.16362	20.64294	8.39208
Wells	526.3665	592.176	65.8095	536.2215	9.855
Drains	38.252	33.143095	-5.10891	46.5083	8.2563
ET	192.2455	170.21045	-22.0351	232.1692	39.9237
River Leakage	17.59592	17.01338	-0.58254	21.66458	4.068655

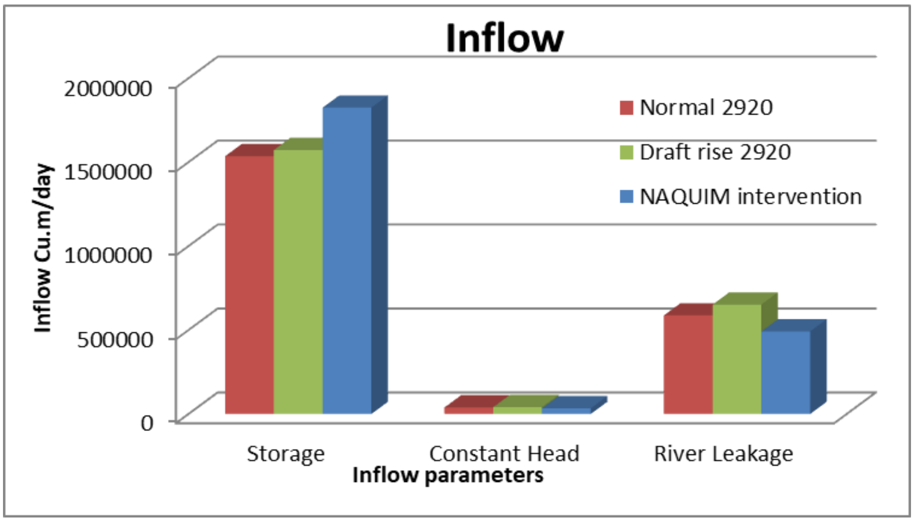


Fig-6.10 : Inflow componenets of prediction models

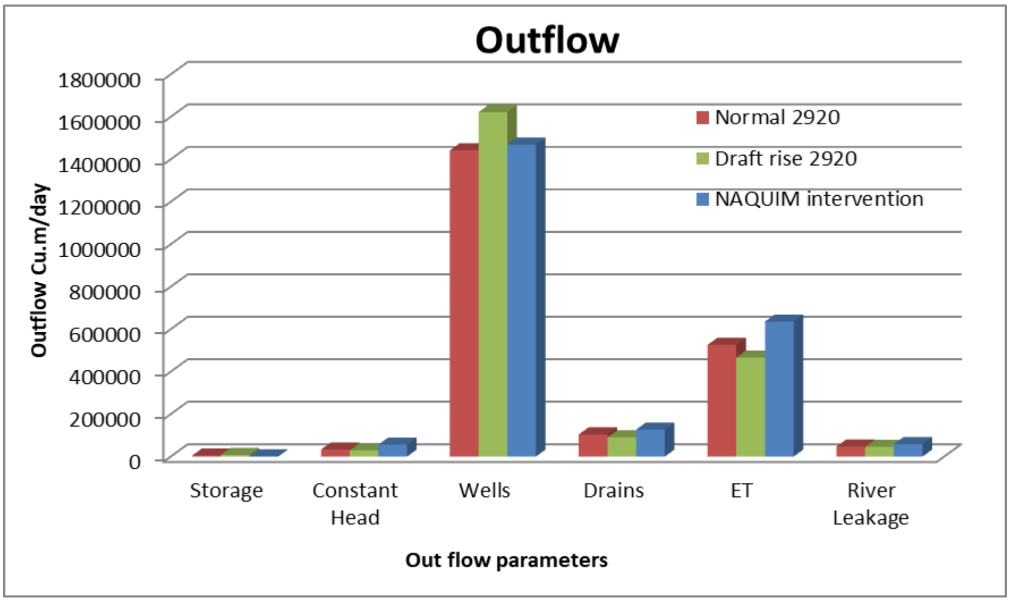


Fig-6.11 : Outflow componenets of prediction models

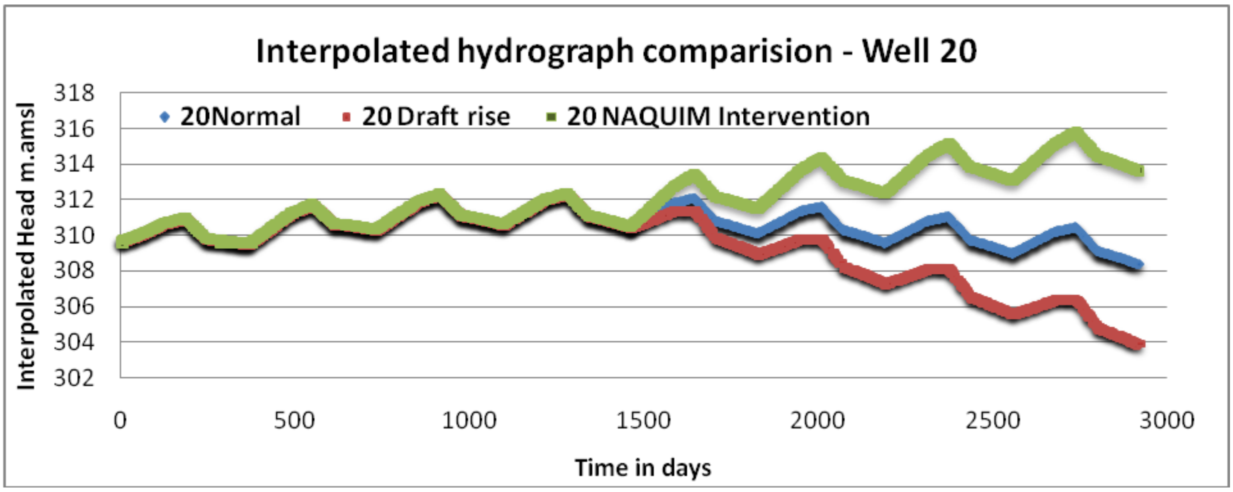


Fig-6.12(a) : Interpolated hydrograph Comparison-well 20

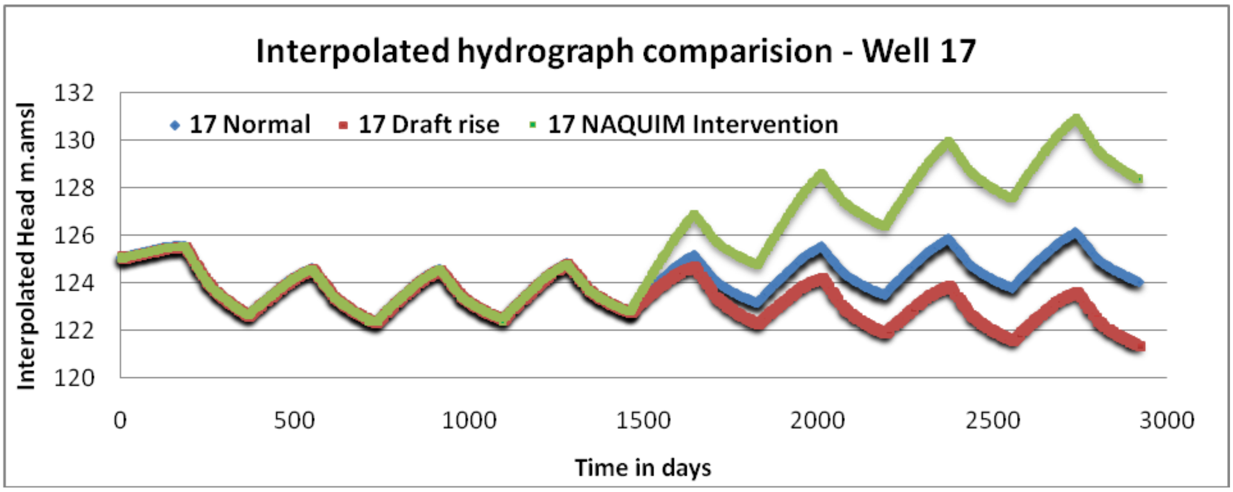


Fig-6.12(b) : Interpolated hydrograph Comparison-well 17

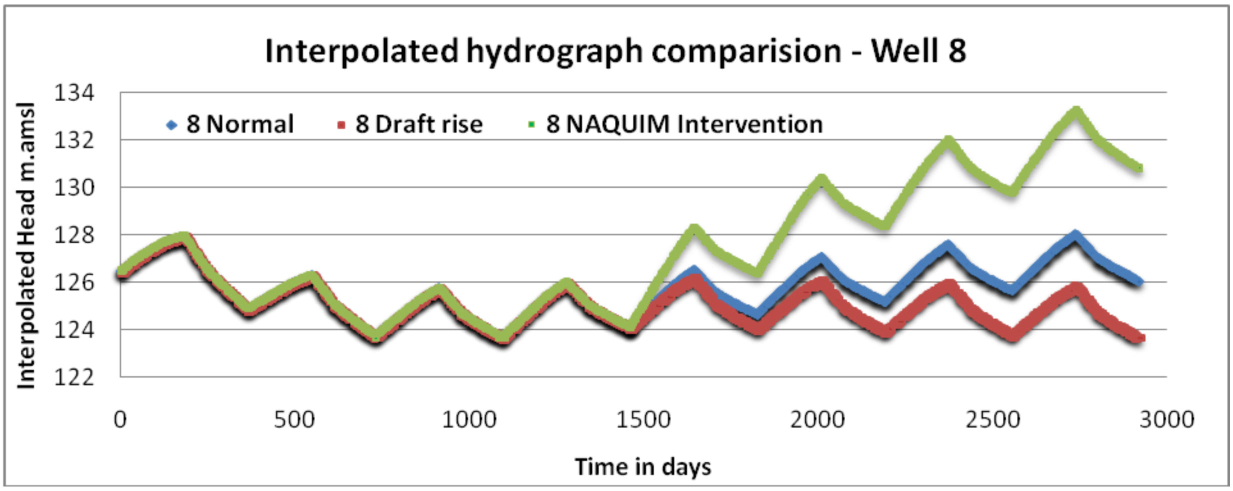


Fig-6.12(c) : Interpolated hydrograph Comparison-well 8

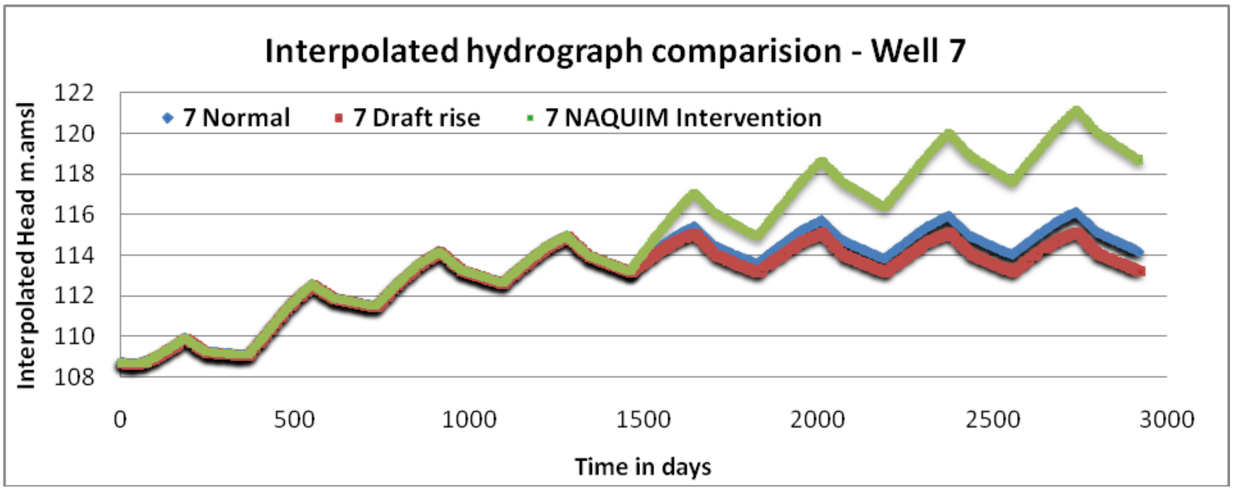


Fig-6.12(d) : Interpolated hydrograph Comparison-well 7

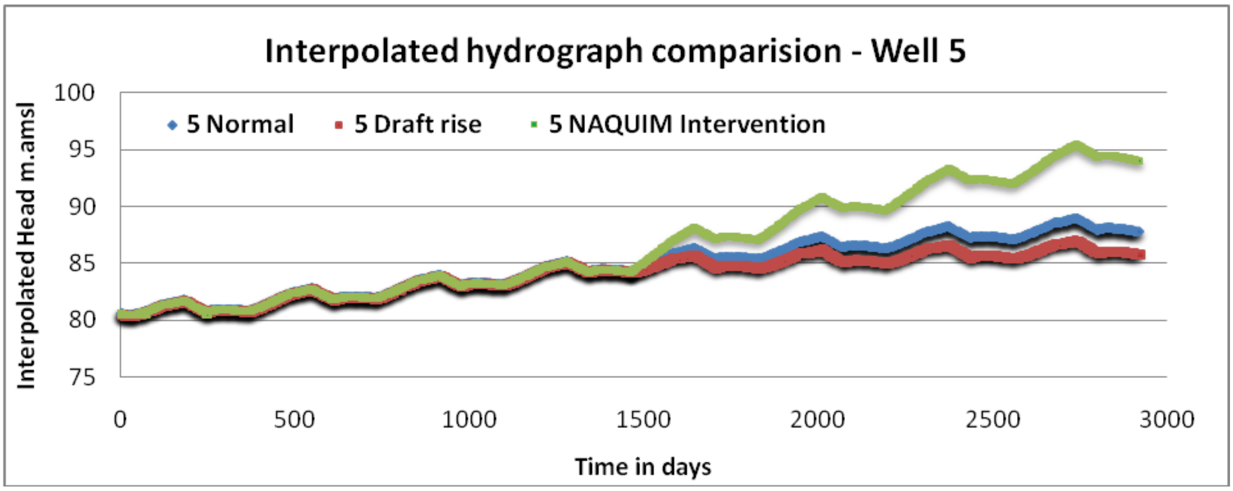


Fig-6.12(e) : Interpolated hydrograph Comparison-well 5

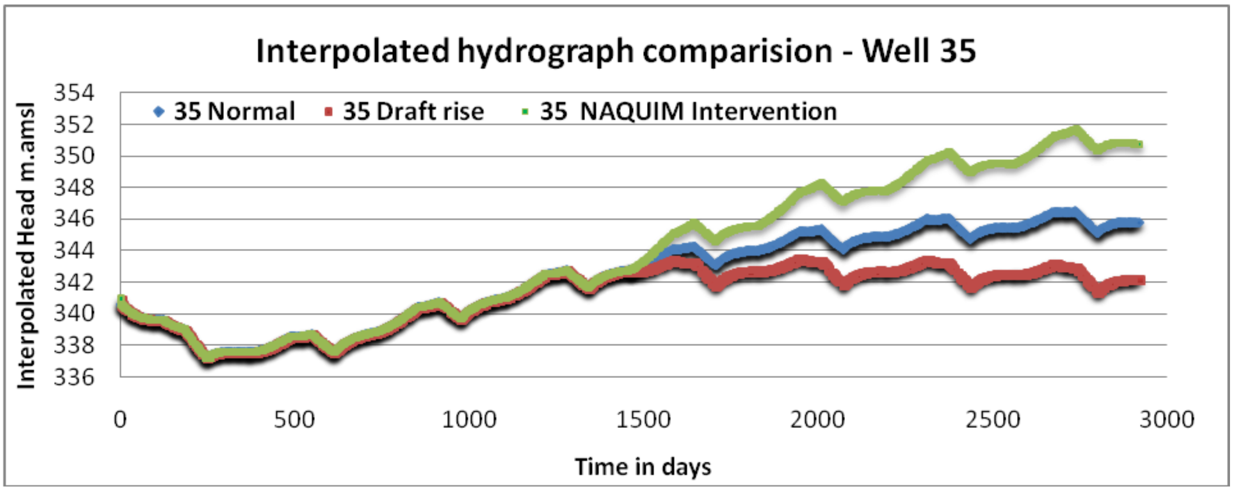


Fig-6.12(f) : Interpolated hydrograph Comparison-well 35

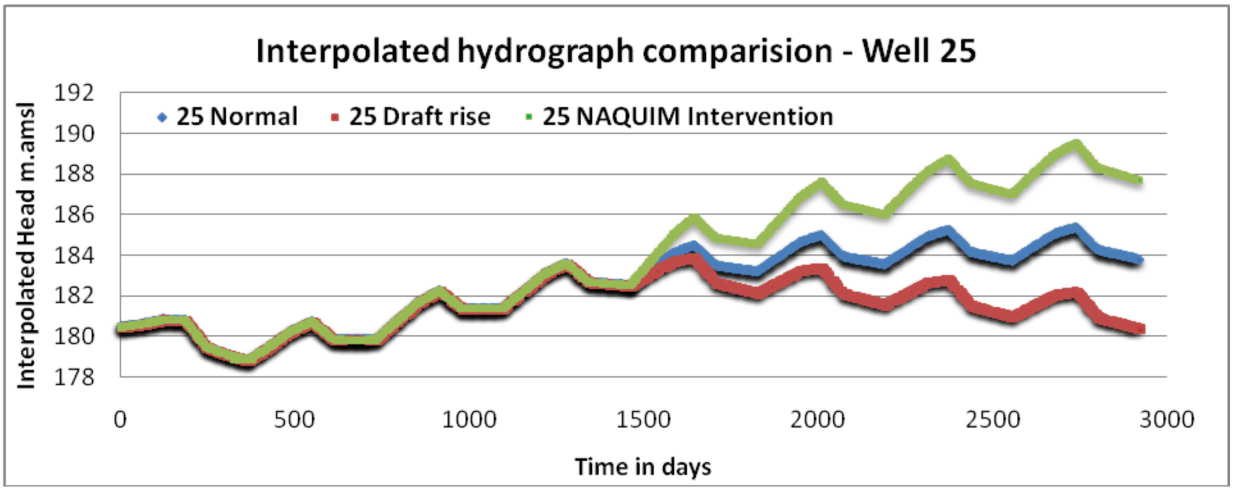


Fig-6.12(g) : Interpolated hydrograph Comparison-well 25

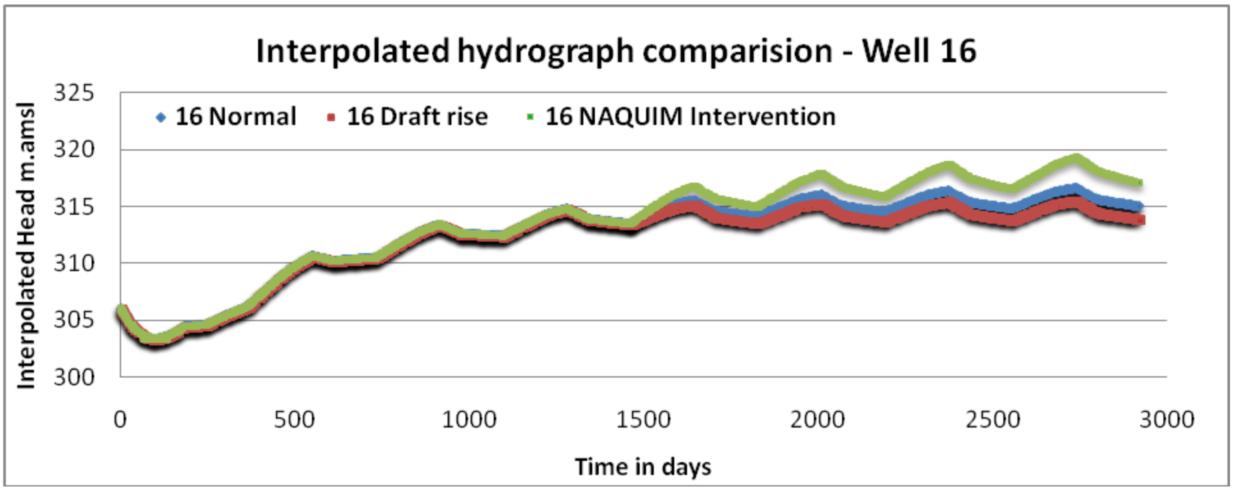


Fig-6.12(h) : Interpolated hydrograph Comparison-well 16

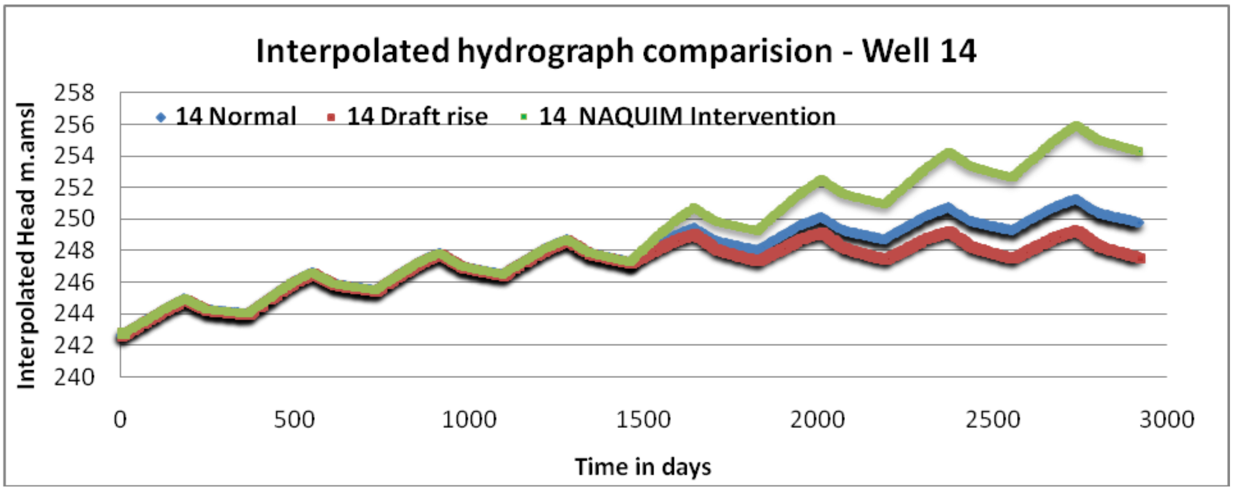


Fig-6.12(i) : Interpolated hydrograph Comparison-well 14

7.0 Conclusions

3D Ground water flow model was developed to simulate regional groundwater flow in Lower Musi Sub-basin. Conceptualized and constructed hydrogeological model for improved understanding of the natural groundwater flow system. The groundwater model was developed based on data available on exploratory wells, Rainfall, Irrigation well data for ground water draft and historical ground water level data to calibrate the model. Ground water recharge, draft and Ground water levels are used to simulate the model. Steady state and Transient models are calibrated and applied to simulate prediction models with different criteria. The impact of proposed NAQUIM interventions simulated by means of prediction model. Sequence wise conclusions are as follows.

- Conceptualization of 3-D hydrogeological model was carried out by using representative 92 hydrogeological data points and calibrated for elevations with SRTM data.
- Aquifers are characterized into Aquifer-1 and Aquifer-2 based on their occurrence vertically from the ground surface.
- A two layer model was chosen over a single layer model to account for the change in aquifer properties.
- Aquifer parameters, such as hydraulic conductivity and specific yield/specific storage, estimated using exploration data and assigned to layers.
- Boundary conditions assigned to the model domain, constant head boundary assigned to southern boundary for Krishna River , River package assigned to Musi River. Drain package assigned to three major streams namely Shamirpet vagu, Yeshwantapur vagu and Halia vagu.

- Recharge from rainfall, irrigation return flow, water bodies and canal seepage estimated using GEC 1997 methodology and applied to the respective grids in the model using recharge boundaries.
- Ground water draft estimated using GEC 1997 methodology and applied as pumping wells to the respective grids in the model using well package.
- Numerical model was developed based on the conceptual ground water flow model.
- Groundwater flow was simulated with MODFLOW-2000.
- The aquifer model is discretized by 74 rows and 101 columns with two layers with a uniform grid of 2000m x 2000m. Two layers are interconnected through vertical conductivity with same water levels.
- 26 observation wells are used for model calibration.
- The Steady state simulation time was specified as 30 days.
- The transient flow model simulates ground water flow in the aquifers for four water years from June 2014 to May 2018.
- Comparison of observed and simulated heads shows that general altitude of the water table is well simulated in the model.
- Three prediction models generated viz. i. Prediction model–I(extension of existing conditions).ii. Prediction model –II (Increase in irrigation draft @ 15%). iii Prediction model –III (Impact of NAQUIM intervention).
- Comparison of three prediction models reveal the variations and responses of inflow outflow components to changing ground water stress scenarios.