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DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION

CENTRAL GROUND WATER BOARD

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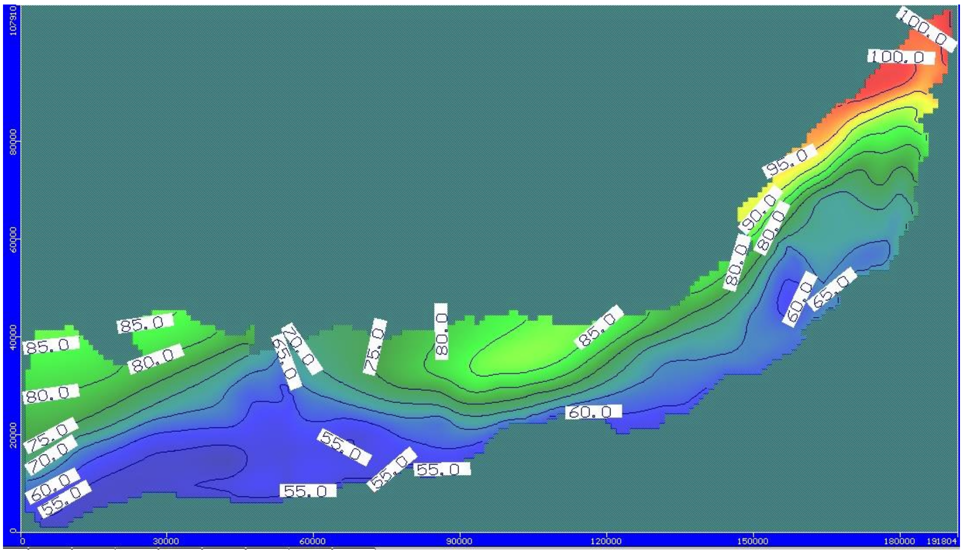
GROUND WATER FLOW MODELLING REPORT ON NORTHERN PART of BRAHMAPUTRA BASIN, ASSAM

AAP (2018-2019)



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गुवाहाटी GUWAHATI
सितंबर September 2021

REPORT ON

GROUND WATER FLOW MODELLING in PARTS of NORTHERN BRAHMAPUTRA BASIN (parts of Sonitpur and Lakhimpur districts), ASSAM
(AAP 2018-19)

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GROUND WATER FLOW MODELLING IN PARTS of NORTHERN BANK of BRAHAMAPUTRA BASIN, ASSAM (AAP 2018-19)

1.0 Regional Ground Water Flow Modelling

Groundwater is an important resource so it must be managed prudently. However, there are several difficulties associated with understanding a groundwater system. Its invisibility and highly heterogeneity nature has made it very difficult to accurately characterize the media in which the groundwater is stored. One way of improving our understanding of these highly complex systems is to build and experiment with models which replicate them. A model is a simplified representation of the complex natural world. For example, a road map is a kind of model (Wang and Anderson, 1982); it depicts a complex network of roads in a simplified manner for purposes of navigation. Similarly, a conceptual model of a groundwater system simplifies and summarizes what is known about the hydrogeology in the form of written text, flow charts, cross sections, block diagrams, and tables. A conceptual model is an expression of the past and current state of the system based on field information from the site, and knowledge available from similar sites. A more powerful groundwater model is one that quantitatively represents heads in space and time in a simplified representation of the complex hydrogeologic conditions in the subsurface. Broadly speaking, groundwater models can be divided into physical (laboratory) models and mathematical models. There are two principle drivers behind most modeling exercises. First, to gain an understanding of why a system behaves as it does and second to predict future behaviour (Fetter, 1988; Anderson and Woessner, 2002). Anderson and Woessner (2002) add a third dimension as a tool to provide solution and regulatory guidelines for improvements and corrective measures. Models can help the designer to understand a system's behaviour through the iterative process by which the model is modified until the results generated match field results. It is important to clearly establish the purpose of the model.

As a part of AAP 2018-19, the ground water flow modelling of 5709 sq. km of Northern Brahmaputra (parts of Sonitpur and Lakimpur districts) was taken up. The steady state and transient models were developed to evaluate the regional effects or changes in ground water resources associated with increased water demands and development. The model is developed and calibrated on the basis of hydrogeological data generated and collected during various previous studies, Aquifer Mapping Studies in Sonitpur and Lakhimpur districts, Integrated hydrogeological, hydrological and geophysical data include the water levels of shallow and deeper zones along with the information of aquifers in terms of their depth ranges and thickness, lithological information and hydraulic properties. The unconsolidated unconfined aquifer of the parts of Northern Brahmaputra basin in northeastern India is utilized for micro irrigation but still there is heavy scope for development. NAQUIM studies in these districts have proposed for more utilization of groundwater for irrigation. To evaluate likely groundwater resource impacts over the coming years, a regional groundwater flow model for the basin was developed.

1.1 Objective

The objective of the study is to –

i. Understand the aquifer dynamics and to assess the ground water potential.
ii. Design the predictive scenario of groundwater regime in case the present ground water budget pattern continues.
iii. Optimization of ground water development for sustainability of aquifers.
iv. Model the ground water flow system.

1.2 Introduction of Study Area

Study Area (parts of Sonitpur and Lakhimpur districts) is located in between Arunachal Himalayas in the north and the Brahmaputra river in the south. Subansiri river is taken as the Eastern boundary and a small tributary to the Brahmaputra has been taken as the western boundary. Isolated Archaean inliers are found in the south from Biswanath to Singri. The extension of Archaean basement from southern inliers up to the Siwalik ridges in the north is established by the magnetic and gravity surveys by the Oil and Natural Gas Commission (Viswanathan, et.al., 1972). The alluvial sediments were deposited over the basement. The coarsest sediments, i.e., the traction load fraction of the south flowing rivers emerge from Arunachal Himalayas were deposited over piedmont surface. The finer materials were deposited in nearly the flat terrain towards the south. Presence of boulders in isolated places in the south may indicative of its provenance lies towards the south, i.e., the Archaean inliers or inselbergs.

Geomorphologically, the area can be classified mainly into four divisions: structural hills, piedmont zone, alluvial plan and flood plain. Piedmont zone is in the north eastern part of the study area. The piedmont zone is gravel dominated while alluvial plain and the flood plain are mixture of sand, gravel and clay in varying proportions. The alluvial flood plain consists of younger and older alluvial deposits. Older alluvial aquifer is found towards north in the piedmont zone. The alluvial aquifer is characterized by coarse grained materials ranging in size from gravel to boulder. Boulder zones are encountered in the area close to piedmont and some areas in the south near ancient Bhareli river and also near Archaean inliers, like Halleshwar, Na Pam, Panch-Mile, Jamuguri and Biswanath. Aquifer in the area is generally sand dominated mixed with gravel and at places pebble down to a depth 150m, below which clay content increases. Six clay layers are found to present in the sub-surface. Thickness of clay layers ranges from 5 to 60m. Maximum thickness of clay layers are found in the west central and north western parts of the district. However, clay in the subsurface are very localized. Grey colour clay bands struck at various depths in the southern wells which are missing towards the north. Down to a depth of 100m clay appears as lenses. However, beyond 100m clay is dominated in the western part the district or right bank of Jia Bhareli river. Sonitpurdistrict area has saucer shaped topography. In the northern part there is Arunachal Himalayas and towards south the Brahmaputra River. The Brahmaputra River bed is elevated after 1950's great earthquake. Water logging problem of the area can be related with this changing physiography.

Groundwater is present under unconfined condition in the area. Water level trends from observation wells and piezometers from the study area reveal that shortterm rainfall only improves soil moisture and serves farmers, but only adequate rainfall over long duration can replenish groundwater. Thesurface elevation map is represented in Fig.1.

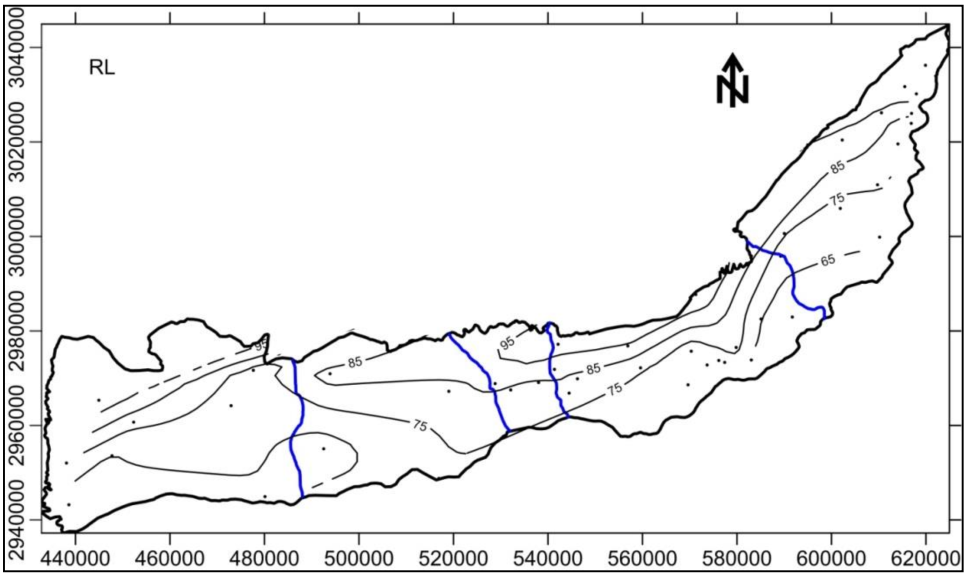

Fig 1: Surface Elevation Contour in parts of Sonitpur& Lakhimpur districts

1.3 Rainfall

The area close to the foothills receives more rainfall. The rainfall increases towards NE direction. Rainfall during dry season i.e., from November to March contributes nearly 7% to the total rainfall whereas the rainy season which commences from April and continues up to October contributes 93%. Average annual rainfall in Lakhimpur district is 2859mm and in Sonitpur district it is 1978 mm.

2.0 Geology

The model area lies in the fore deep of the Eastern Himalayas, which now constitutes the Brahmaputra Basin in Assam. Quaternary sediments of enormous thickness overlie the older rocks in all part of the district. The stratigraphy of the area is given in the table 1 and Geological map in Fig 2.

Table 1: Geological succession of the area

Age	Formation	Lithology
Quartemary	Pleistocene to Recent	Younger alluvium comprising fine to coarse grained gray coloured sand and clay with little gravel. Older alluvial sediments comprising sand, gravel, pebble with clay. Bhabar formation comprising boulder, cobble, pebble, gravel, sand with occasional impersistent clay.
Unconformity		
Tertiary	Upper Siwaliks	Sandstone, Siltstone and Claystone
Unconformity		
Pre-Cambrian/ Archaean		Gneisses, Amphibolites and Granite

The outcrops of Archaean rocks consisting of gneisses and granites with few amphibolite bands occur as small solitary hills in the southern margin of the district, mainly 8long the northern bank of Brahmaputra river in the areas of Singri, Tezpur, Bhumraguri and Biswanath. The gneisses have a regional strike of foliation in NNE-SSW direction and dipping towards west. Several sets of joints are developed giving rise to bouldery outcrop due to weathering.

The Tertiary rocks in the area are restricted to the extreme northern boundary along the foothill zones and belong to upper Siwalik Group.

The Quaternary sediments can be groupedinto two broad divisions viz., (i)Piedmont terrace deposits and Older valley All deposits extending from Pleistocene to sub-Recent and (ii) the flood plain deposits extending from Sub-Recent to Recent age.

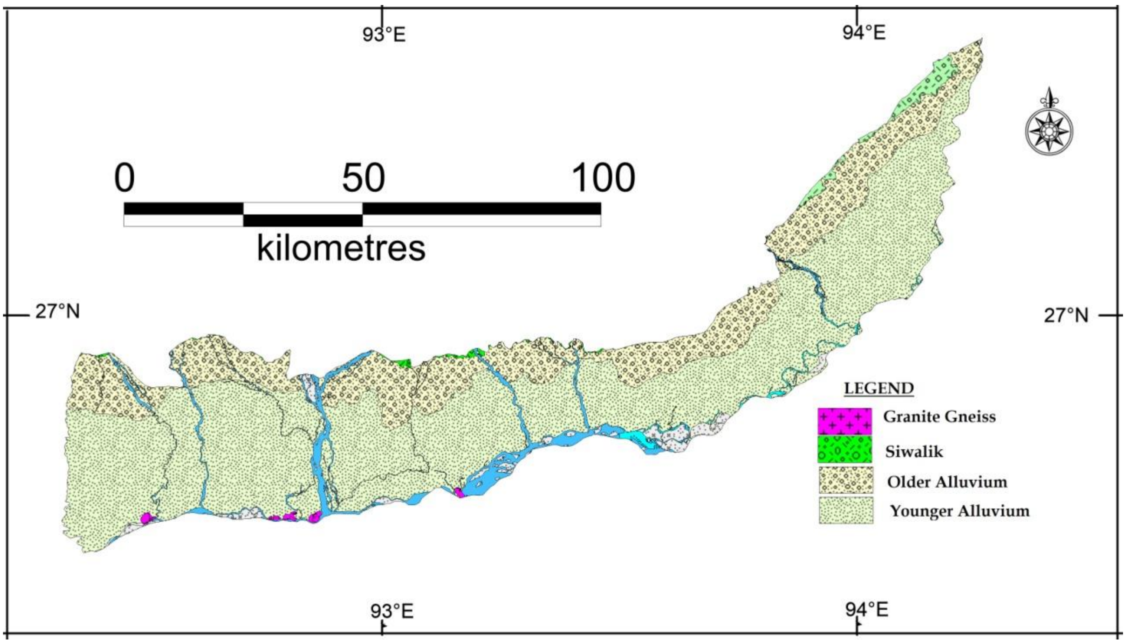

Fig 2: Geology of the Model Area

3.0 Hydrogeology

The entire model area is underlainby unconsolidated alluvial sediments. In the southern margin, a few inselbergs of consolidated Archaean Rocks can be seen. In the alluvial plain ground water occurs in regionallyextensiveaquifers down to the explored depth of 300 m. The aquifers have a very good yield prospects for ground water development by both shallow and deep tube wells.Based on the behaviour, occurrence and ground water development pointofviewthe aquifers systems can be divided into two majorcategories; (a) Shallow aquifer within 50 mdepth, (b) Deeper aquifer between 50 and 200m.

Theaquiferoccurringwithinadepthof50mbgliscategorised asshallowaquifer zone. The cumulative thickness varies from 15 to 49 m as revealed front the lithological logs of the Exploratory Wells drilled by Central Ground Water Board. Thisaquifer accounts for the dynamic resources of ground water, which occur underunconfined conditions. The development of ground waterfromthisaquifer for domestic and irrigational purpose is by open wells (dug wells)andshallowtube wells. The performance of the shallow tube wells constructed by StateGovernmentfor irrigation purpose indicates that the shallow aquifer system is quite potential. The shallow tube wells are constructed down to depths of 30 to 40 m, tapping 6to 15 m of aquifer,givesdischargeof10-36m^3/hour foradrawdownoflessthan2m.Theexploratory tube well constructed by Central Ground Water Board at Napamto depth of about 45 m, tapping 15 m of aquifer, gives discharge of about 45m^3/hr for a drawdown of only 2 m.

The pre-monsoon depth to water level ranges between 1.27 to 8.27mbgl and the post-monsoon water level ranges from 0.68 to 6.47mbgl. Water table contour map is shown in Fig 3.

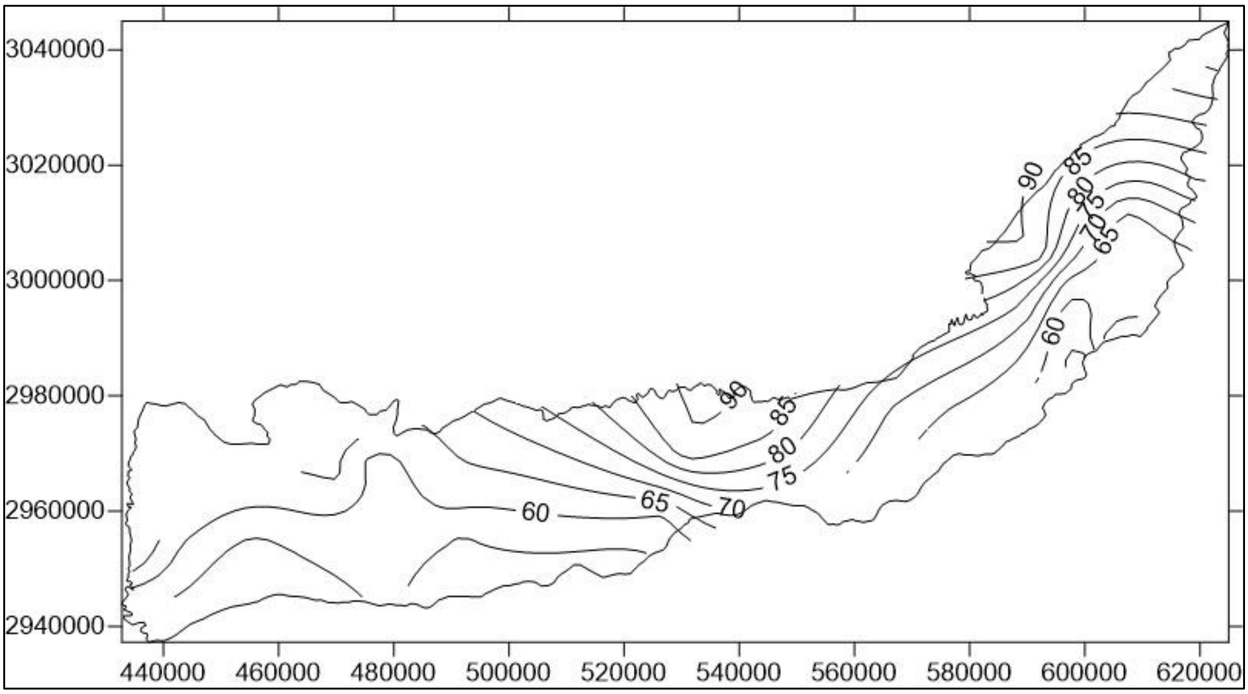

Fig3: Water Table Contour Map, Post-monsoon 2016

3.1 Ground Water Exploration

CGWB has drilled 55 nos. of wells in the area. To know the subsurface geology of the area, lithologs were plotted and is shown in Fig 4, 5 and 6. The aquifer parameters viz., permeability computed during the Aquifer tests wells were used as input parameters in the model.

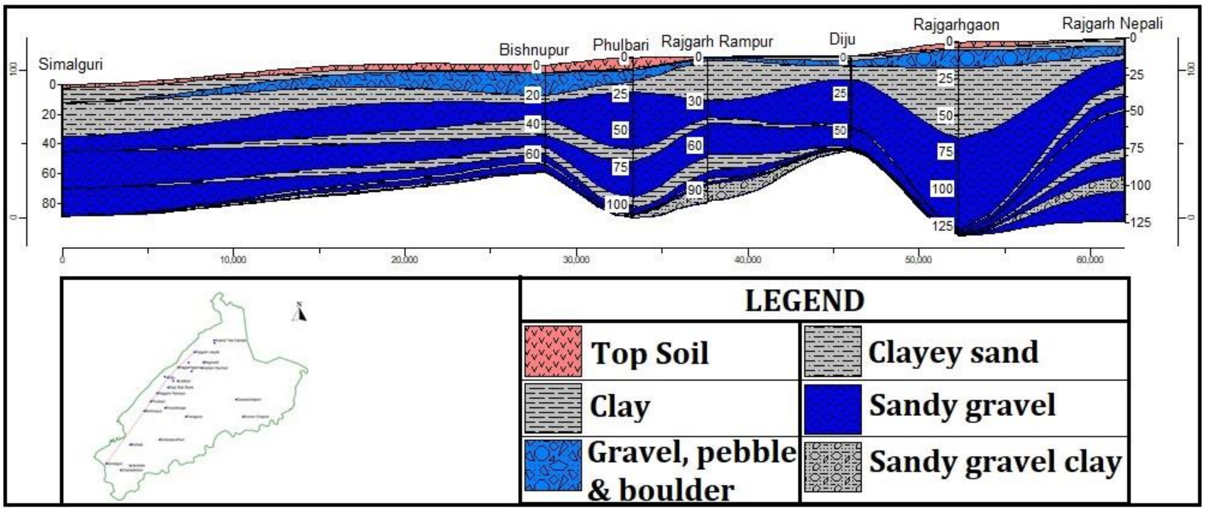

Fig 4: Subsurface geology along foot hills in Lakhimpur district.

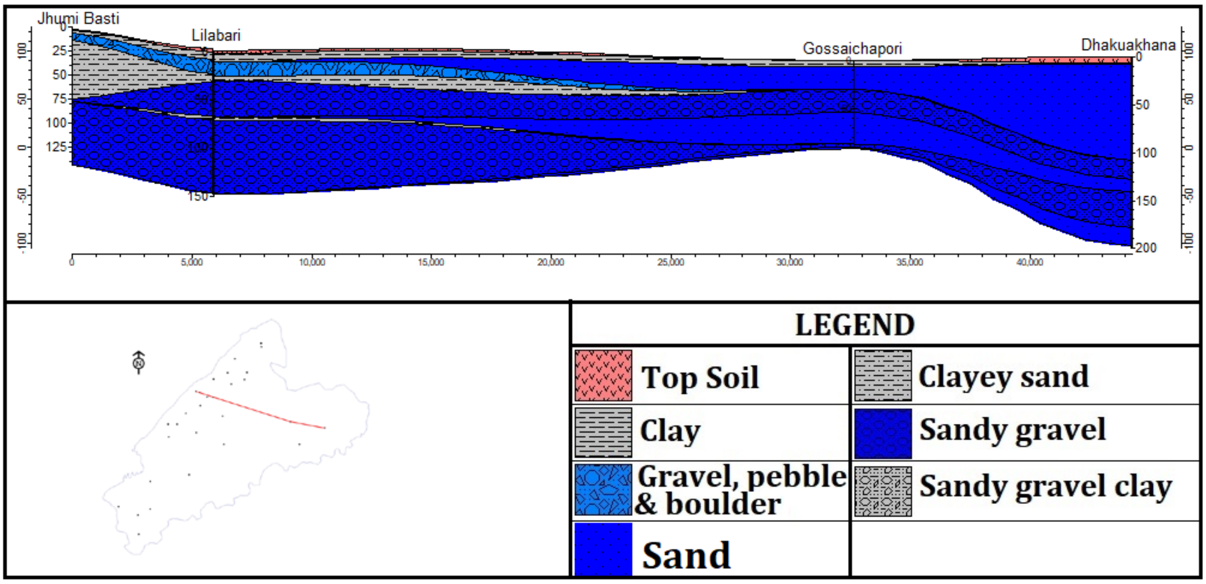

Fig 5: Sub-surface geology in a NW-SE direction (Foothills to Near Brahamaputra R) in Lakhimpur district

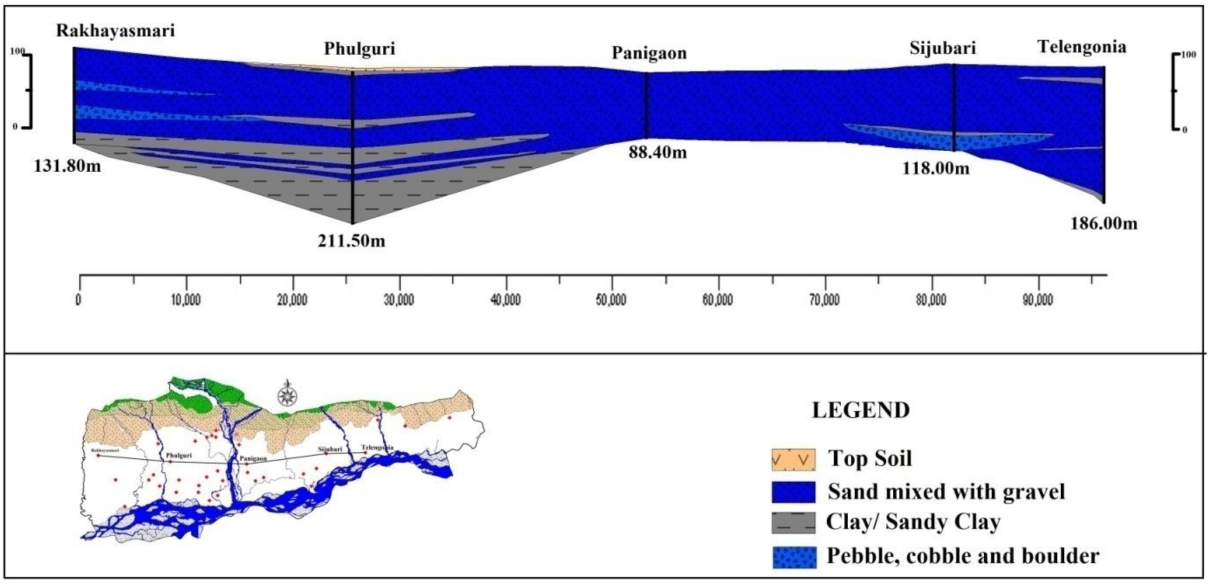

Fig 6: Sub-surface geology along E-W in Sonitpur district

4.0 MODELLING PROTOCOL

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

- Data collection, acquisition and processing of primary data
- Conceptual model building by field data input
- Numerical model building
- Model design/application by parameter input
- Model Calibration
- Presentation of Results

4.1 Development of Conceptual Model

Based on the available geological, hydrogeological, hydrological, geophysical and meteorological data, a ground water model in parts of Northern bank of Brahmaputra basin has been conceptualized. The area is underlain by unconsolidated sediments like sand, gravel, pebble, silt and clay. Ground water occurs under unconfined condition. Regionally ground water movement is towards south i.e., the Brahmaputra river. After going through the exploration data from CGWB layer conceptualisation was a difficult task. Clay beds are not continuous throughout the area. However, mainly shallow aquifer within 50 m depth is being developed. So, a single layer model has been conceptualized.

Assumptions Used in the Conceptual Model

Some of the major simplifying assumptions in the present modelling study include

1. all pumpage in a model cell has been simulated as coming from the cell center;
2. the pumpage throughout a stress period is applied equally throughout the stress period;
3. recharge is invariant over large periods of time;
4. small scale variations of hydraulic conductivity within cells are negligible.

4.2 Selection of Solver and Software

Strongly Implicit Procedure package (SIP) iterative solver was used for steady state with head change criteria of 0.01 m for convergence and maximum number of outer and inner iteration were fixed as 200. To overcome convergence problem, suitable fine tuning of some parameters were made using field experience to achieve steady state run. The model was first run for steady state. Visual Modflowwas used to construct the groundwater model.

4.3 Model Design

The steps in Numerical Model Design includes design of the grid, setting boundary and initial condition, preliminary selection of values for the aquifer parameters and hydrologic stresses (Anderson and Woessner, 2002).The study area is a part of Northern bank of “Brahmaputra Basin” representing Sonitpur and Lakhimpur districts of Assam covering 5709Sq.Km. It lies between latitude 26.55459°and 27.52589° N and longitude 92.32462° and 94.26807° E.

The total area of the model is discrete into 107 rows and 192 columns, with the cell size of 1000 x 1000 m (Fig. 7). Within the area white color cell are considered as active cells.The graycolor cells outside the model boundaries are assigned inactive cells.

Fig. 7: Model grids with active (white) and inactive (gray) cells

The ground elevation data for 136 stations within the study area from exploratory wells, key wells established during NAQUIM and water level monitoring stations has been assigned from SRTM and interpolated for grid model by inverse distance method. The elevation for bottom of the layer was also assigned for known locations by deducting 50m from top of layer and was interpolated.

4.3.1 Single Layer Model

The area is occupying by unconsolidated sediments. The aquifer disposition is continuous and grain size generally decreases from north to south as evident from the lithologs of exploratory well data (table 2). The study area is characterized by single layer up to depth of 50 m (unconsolidated sand, gravel, pebble and clay aquifer)

Table 2: Layer Characterization of Sonitpur and Lakhimpur Model

Layers	Aquifer Type		Top Elevation Range (m AMSL)	Bottom Elevation Range (m AMSL)	Average Thickness (m)
Layer I	Unconfined	Dynamic GW	50.3 to 132	0.3 to 82	50

4.3.2 Boundary Conditions

Boundary conditions are defined along the edges of the simulation domain including the top and the bottom. The entire northern part of the model domain consists of hilly terrains. So no flow boundary is applied to northern boundary. Southeastern part consists of Subansiri river and Southern part consists of Brahmaputra river. Constant head boundary has been applied in these parts. Western boundary of the model coincides with a small river, again regional water table map show that no water is flowing from west to east, so no flow boundary has been applied in this part. Boundary conditions applied in the model is shown in Fig 8.

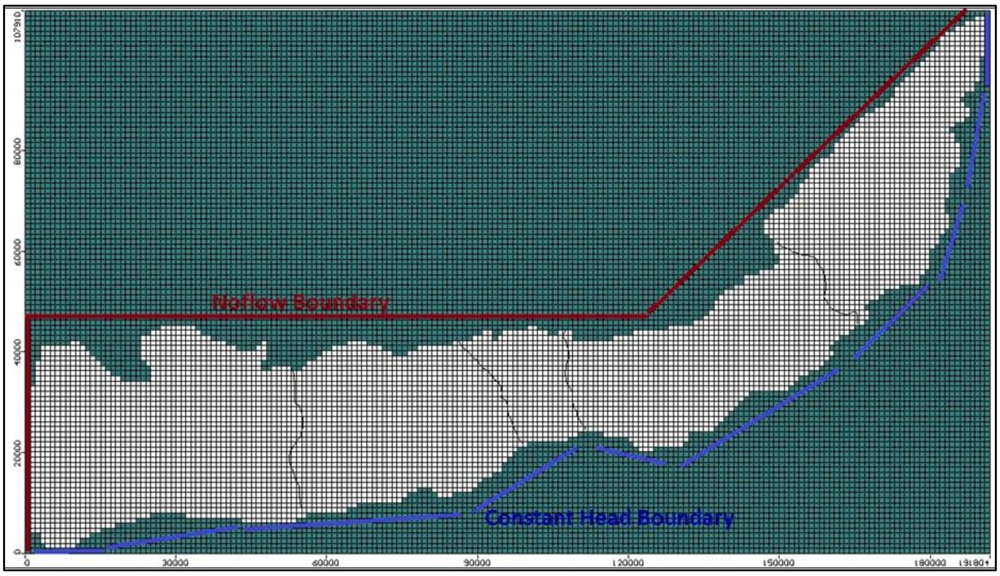

Fig 8: Boundary Conditions of the Modelling Area.

5.0 Input Parameters

5.1 Initial head

After detailed analysis of the hydrographs, rainfall and water level fluctuation, it was decided that the water table elevation data from 33 stations for post-monsoon (November) 2016 is to be taken as initial heads in steady state simulation and is shown in Fig 3.

5.2 Hydraulic conductivity and Storage parameters

The hydraulic conductivity data obtained from pumping test were utilized in the preparation of model. Horizontal hydraulic conductivity of 50 m/day has been applied in the piedmont/ foot hills part and 40m/day applied in the rest of the area (Fig9).Vertical hydraulic conductivity has been taken as 10% of the horizontal hydraulic conductivity. Specific yield of 8% has been applied.

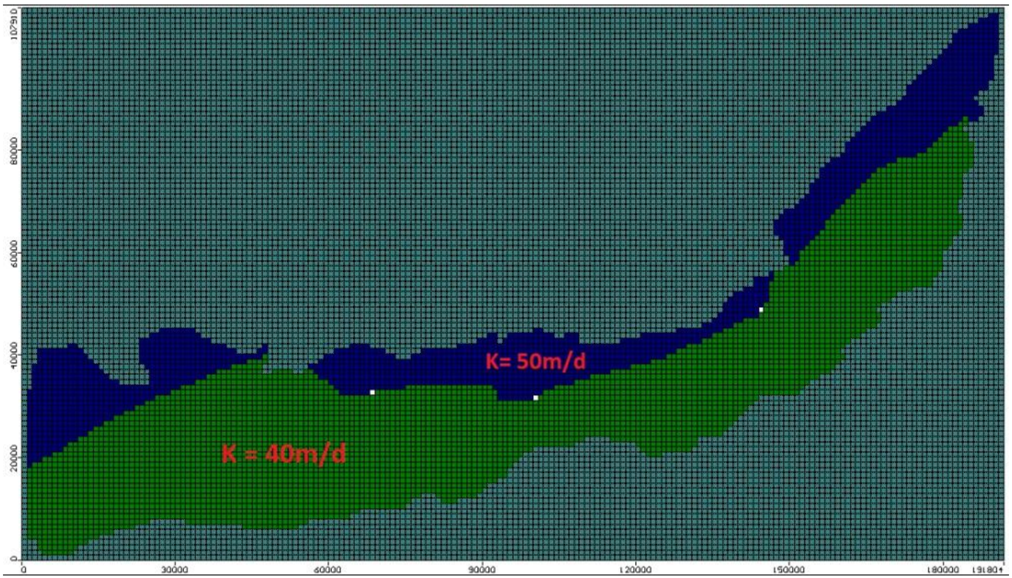

Fig 9: Horizontal Hydarulic Conductivity zones in the Area

5.3 Recharge

Recharge to the area is only from precipitation and thus vertical recharge is the only source of ground water in the basin. As water level in major parts of the area remains shallow throughout the year, recharge from other sources (e.g., irrigation) has not been considered. Recharge was applied to the active model area as zones. Each district is considered as a separate zone and shown in Fig 10. The unit of recharge used in the model is m/day. Recharge for rainy season and dry season have been estimated separately using GEC 2015 methodology. In both the cases, 15% of rainfall for respective seasons has been considered for recharge estimation. Recharge rate was assigned in the model during steady state simulation is 0.00083 m/day for Sonitpur district and 0.00117 m/day for Lakhimpur district. During transient state calibration, recharge rates applied were shown in Table 3.

Table 3: Zone-wise/ District-wise Recharge for all time steps

Start time	Stop time	Recharge (m/day)	
		Sonitpur	Lakhimpur
0	214	0.00028	0.00039
214	365	0.00009	0.00012
365	579	0.00028	0.00039
579	730	0.00009	0.00012
730	944	0.00028	0.00039
944	1095	0.00009	0.00012

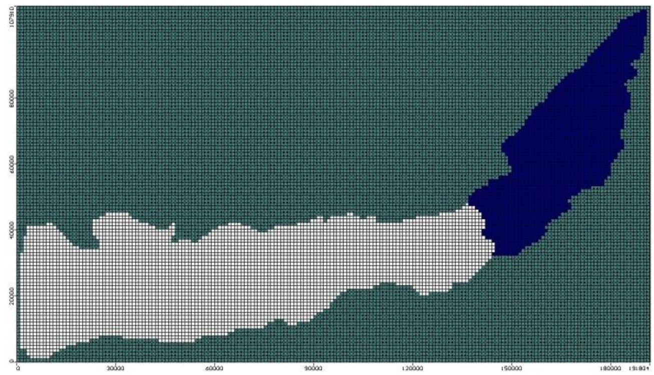

Fig 10: Zones for recharge and draft input

5.4 Draft

Within the study domain, discharge input is the groundwater pumping in the area. The time variant groundwater draft has been assigned to each grid using the annual draft from Ground Water Resource Estimation. Each district is considered as a separate zone and shown in Fig 6. Unit draft has been put into each cell as pumping well in the model domain. The unit of draft used in the model is cubic m/day.During transient state calibration, draft rates applied were shown in Table 4.

Table 4: Zone-wise/ District-wise Draft for all time steps

Start time	Stop time	Draft (m^3/day)	
		Sonitpur	Lakhimpur
0	214	105	90
214	365	175	127
365	579	105	90
579	730	175	127
730	944	105	90
944	1095	175	127

5.5 Evapotranspiration

Within the study domain, another important main discharge input is the evapotranspiration from the area. Due to lack of data, monthly evaporation data obtained from CROPWAT 8.0 model was used. Time variant evapotranspiration has been assigned to uppermost cells of active layer. During rainy season ETo was taken as 0.0039 m/day and ETo for dry season (Nov – Mar) was taken as 0.0026 m/day.

5.6 River

The study area is drained by many rivers, amongst them Jia Bharali and Dikrang are two important rivers. These rivers are having a good hydraulic connection with the aquifer as these are adequately incised into the aquifer and have sandy river banks. Also the water level in the aquifer adjacent to the river in general corresponds to the river stage.The river head and bed bottom elevations are incorporated by taking clue from nearby cells and this has been done from field experience.

6.0 MODEL CALIBRATION

The main purpose of this model is to predict changes in groundwater heads caused by changes in stresses on the system. Before the model is used for prediction, it must be calibrated, i.e. the groundwater head simulated by the model for the known stresses of the past must match the observed heads. The criteria used to determine an acceptable match between calculated and measured hydraulic heads are subjective, despite the goal of minimizing the difference between calculated and measured heads. Calibration of a flow model refers to a demonstration that the model is capable of producing field measured head and flows, which are the calibration values. Calibration is accomplished by finding a set of parameters, boundary conditions, and stress that produce simulated heads and fluxes that matches field measured values within a pre-established range of errors (Aderson and Woessner, 1992). During the study, the strategy for calibration of model applied is 'vary the best-known parameters as little as possible, and vary the poorly known or unknown values the most'. It is done by sequential adjustment of the model parameters until the closed match found between the observed and the calculated heads (Anderson and Woessner, 1992).

6.1 STEADY STATE CALIBRATION

Steady state conditions are usually taken to be historic conditions that existed in the aquifer before significant development has occurred (i.e., inflow are equal to outflows and there is no change in aquifer storage). In this model, quasi-steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW during a period of unusually high recharge.

The model was simulated in steady state condition by using water table elevation of post-monsoon (November) 2016 as initial hydraulic head. Calibration involved making minor adjustments to the hydraulic conductivity and the river bed hydraulic conductivity levels until the steady state model was calibrated to a reasonable satisfaction. The present calibration targets in the present study included

a. Normalised RMS between measured and simulated heads is 5.94% (Fig 11) and
b. a good visual match between the measured and the simulated head.
c. Quantitatively correct flow directions and flow gradients.

In the present study, steady state model was calibrated for the hydraulic conductivity values of 50 and 40 m/day to achieve the observed heads. The calibration was made using 33observation wells monitored during November 2016.

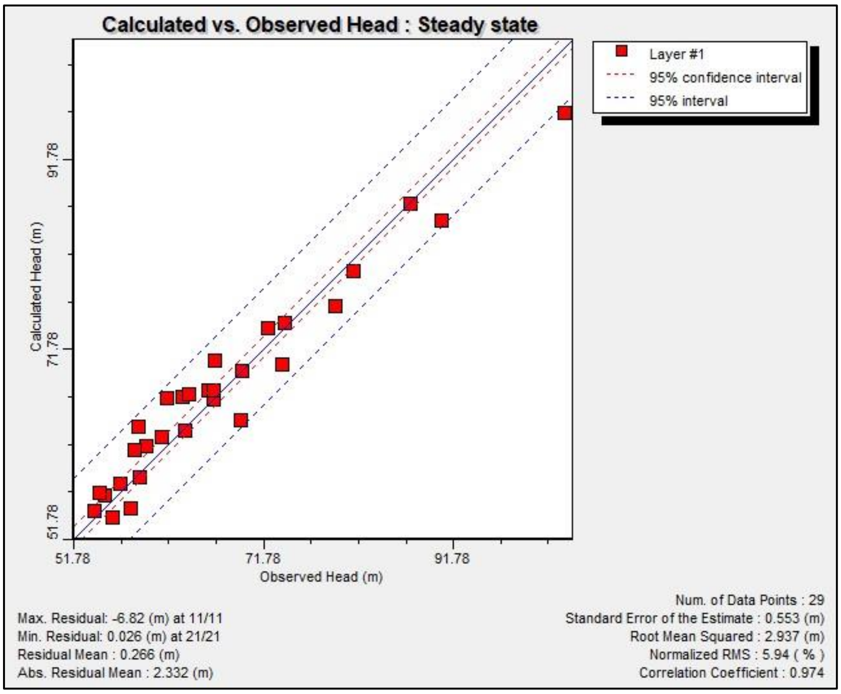

Fig 11: Head Scatter Graph for Steady State

The computed water level of March 2016 (steady state) indicate prevailing trend of groundwater flow in the interfluves region and is shown in Fig 12.

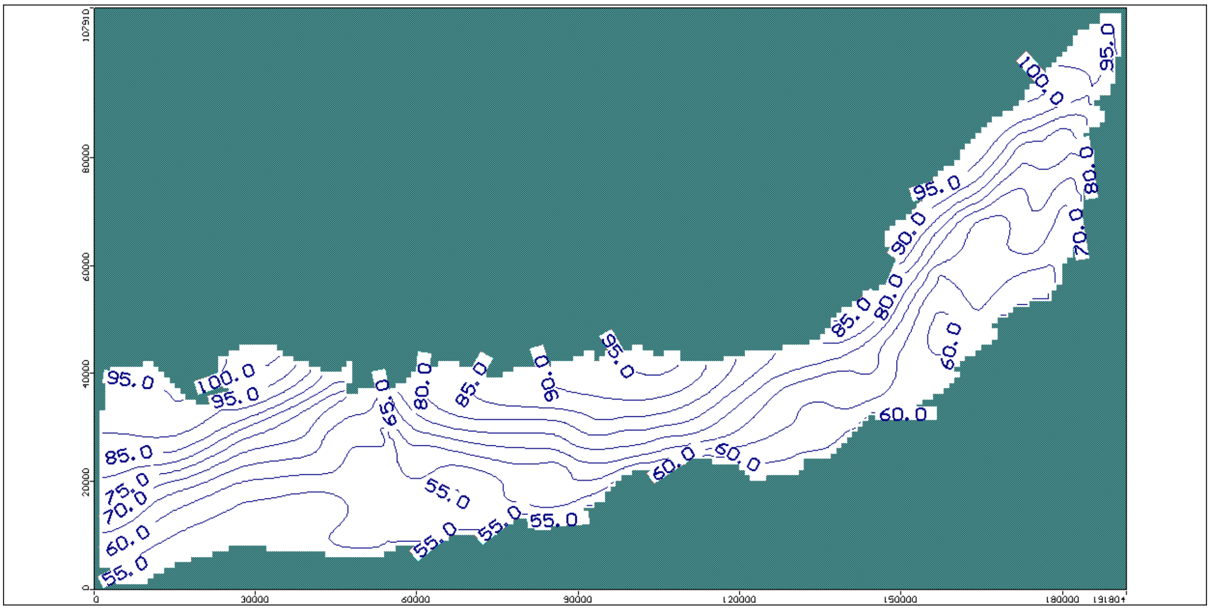

Fig12: Computed Head in Steady state.

Water Budget – Steady State

The ground water budget for steady state simulation gives an accounting of recharge to the area, discharge from the area, and flow between hydrogeologic units viz., Storage, Constant Heads, Wells, Recharge etc. in the area and out is given in Table 5 and Fig 13.

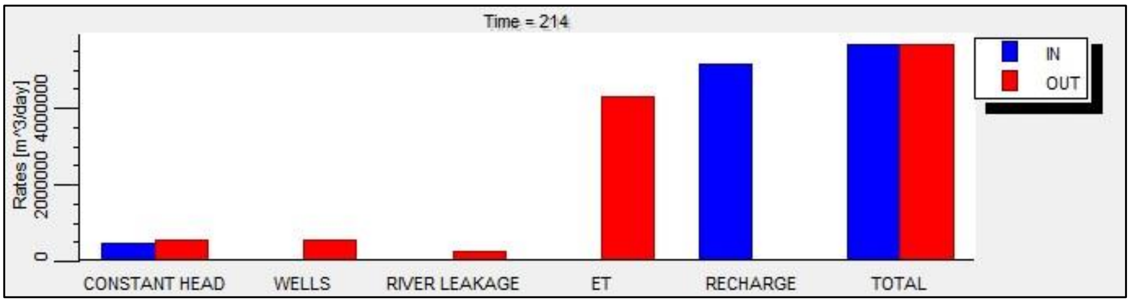

Fig 13: Zone budget for the Steady State

Table 5: Water budget (m^3) of Ground water for the Steady run

Input Report	**Output Report**
Constant Head = 461680 [m^3/day] Recharge = 5162600 [m^3/day] River Leakage = 53163 [m^3/day]	Constant Head = 568220 [m^3/day] Wells = 550330 [m^3/day] ET = 4316900 [m^3/day] River Leakage = 240950 [m^3/day]
Total IN = 5677500 m^3/day	Total OUT = 5676400 m^3/day
Difference: IN - OUT = 1029.3 [m^3/day] Percent Discrepancy = 0.02%	

6.2 TRANSIENT STATE CALIBRATION

The groundwater flow is said to be transient or unsteady or in non-equilibrium state when the magnitudes or direction of specific discharge changes with time. Change in the storage of the aquifer is involved in non-steady flow. Transient state flow is described with respect to boundary and initial conditions (Karanth, 1999). Successful transient calibration depends mainly on the good estimation of hydraulic conductivities and boundary conditions obtained from the steady state calibration. Generally, specific yield for unconfined aquifers and storage coefficient for confined aquifers are the main parameters that are changed during the transient calibration (Anderson and Woessner, 1992).

For the purpose of calibration 37 observation wells were selected. The water level data of these well is available from November 2016 onwards. Hence, for transient state calibration water level data from November 2016 to March 2019 has been used.6stress periods were included into the model and data for each stress period was entered separately. After entering all the input parameters for each stress period, the model was run for the transient state calibration. Then the parameter values were adjusted judiciously in order to obtain a good match between the observed and calibrated head. With the convergence of the transient model, scenario of different stress period is generated for 1095 days. Details of stress periods applied in transient state in shown in Table 6.

Table.6:Stress periods applied in the transient state calibration.

Stress period	Time from	Time to	Start	End	Duration	Season
1	01/04/2016	31/10/2016	0	214	214	Monsoon
2	01/11/2016	31/03/2017	214	365	151	Non-Monsoon
3	01/04/2017	31/10/2017	365	579	214	Monsoon
4	01/11/2017	31/03/2018	579	730	151	Non-Monsoon
5	01/04/2018	31/10/2018	730	944	214	Monsoon
6	01/11/2018	31/03/2019	944	1095	151	Non-Monsoon

The head condition calculated by the model is to be tested against the monitoring data for different stress periods is an essential part of model calibration. This is done by plotting head potential contours and water table contours in the map and visually interpreting the goodness of matching. The calibration of transient model was achieved by several trials until a good match between computed and observed heads was obtained over space and time by slight modification of the input and output parameters for every run. Head scatter diagram for Transient state is shown in Fig 14.

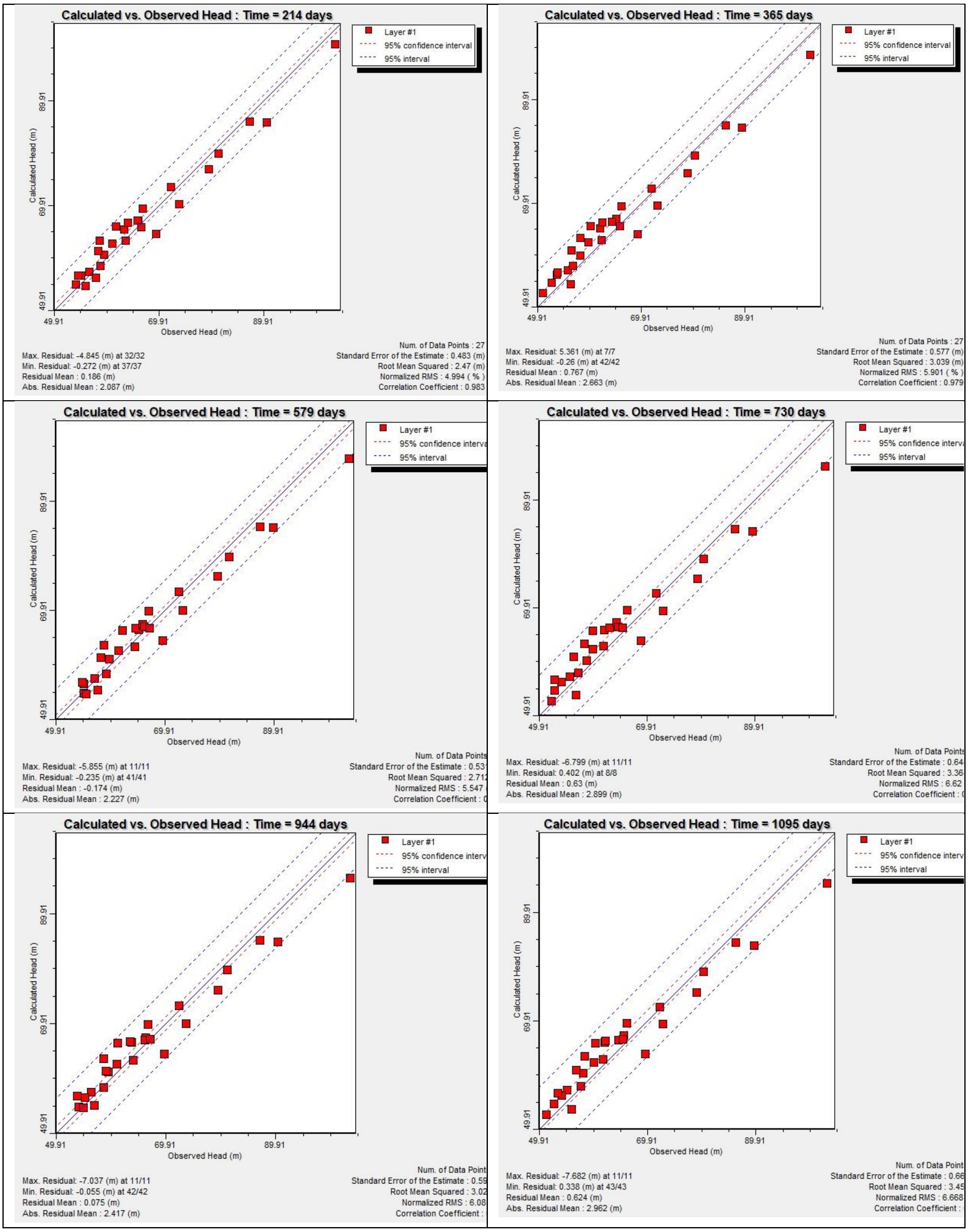

Fig 14: Head Scatter Graphs for Different Time Steps of Calibrated Model

WATER LEVEL HEAD

Generated water level head after transient calibration and shown in Fig 15for the period for March 2019.

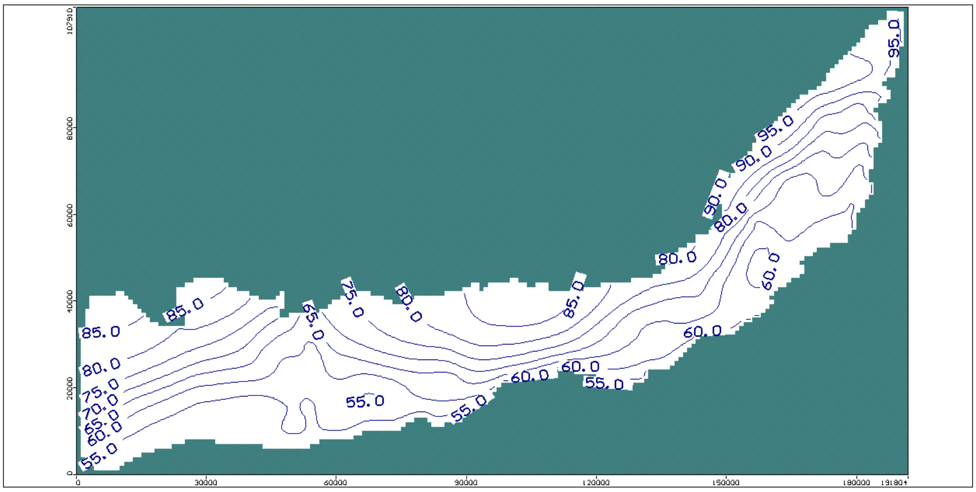

Fig15: Water level head generated after Transient Calibration

Observed and Calculated Head Difference

The hydrographs of all 24 wells with observed and calculated heads are shown in Fig 16.Hydrograph of Well no. 5, 14, 16, 38 and 42 are shown in Fig 17.Borgang, Dejoo and Dolanghat observation points shows maximum variation in heads.

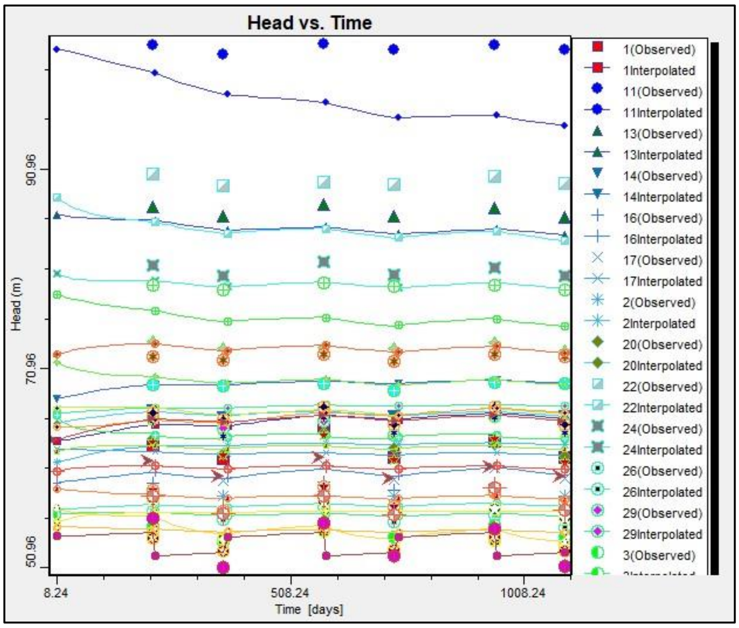

Fig 16: Hydrographs of Observation Points

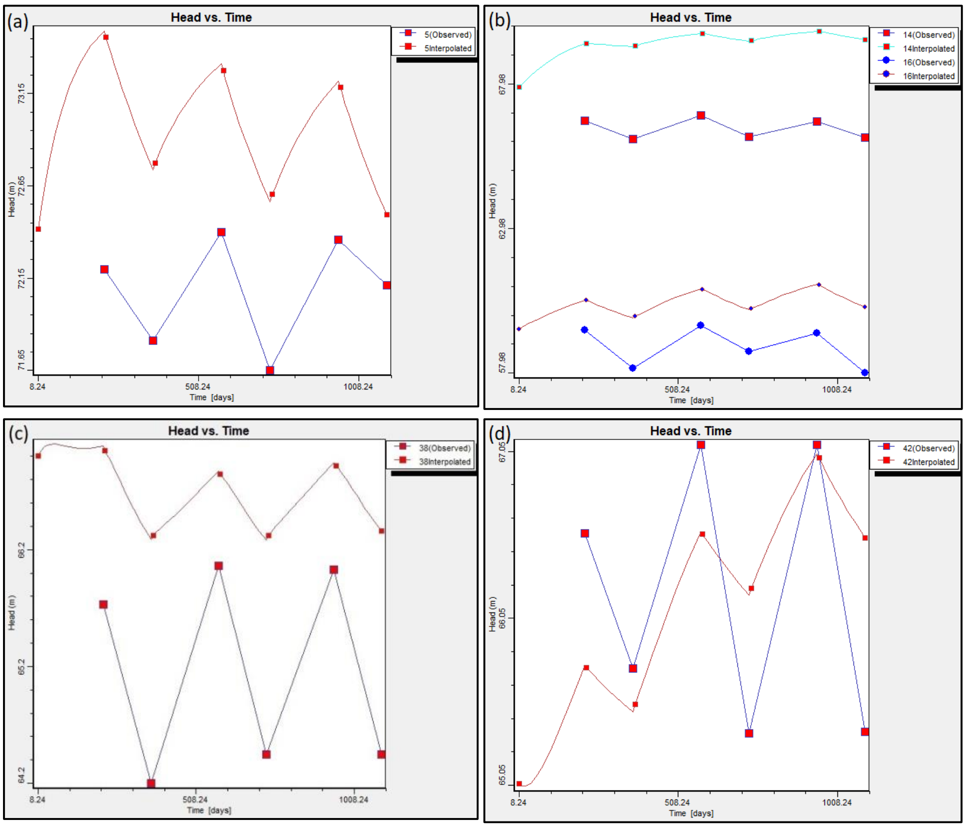

Fig 17: Head Vs Time (a) Well no.5, (b) Well No. 14 & 16, (c) Well no. 38 and (d) Well no. 42

Cumulative Budget – Transient State

The ground water budget for transient state simulation gives an accounting of recharge to the area, discharge from the area, and flow between hydrogeologic units viz., Storage, Constant Heads, Wells, Recharge etc in the area. The transient run for different stress periods along with the percent discrepancy between the total in and out is given in Table 7. Zone budget for stress period 214 and 1095 days are shown in Fig 18.

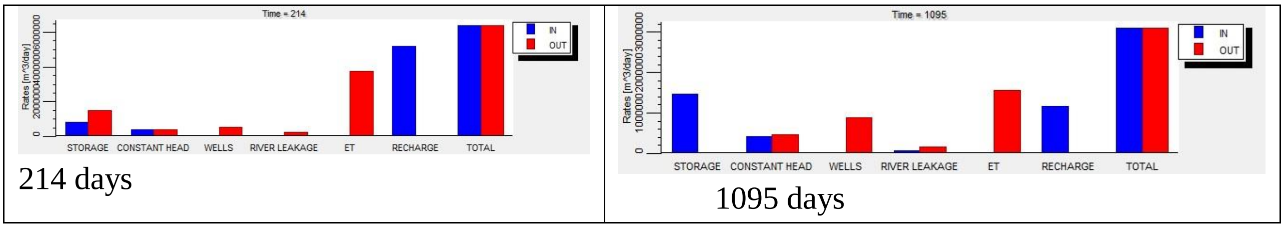

Fig 18: Zone budget for the stress period 214 and 1095 days

Table 7: Water budget (m^3) of Ground water for the transient run for the stress period 214 and 1095 days

Stress Period: 1 **Time (days): 214** Input Report Storage = 794830 [m^3/day]	**Stress Period: 6** **Time (days): 1095** Input Report Storage = 1461200 [m^3/day]

Constant Head = 403780 [m^3/day] Recharge = 5162600 [m^3/day] River Leakage = 41362 [m^3/day] **Total IN = 6402600 m^3/day** Output Report Storage = 1500600 [m^3/day] Constant Head = 386100 [m^3/day] Wells = 551250 [m^3/day] ET = 3743600 [m^3/day] River Leakage = 221110 [m^3/day] **Total OUT = 6402600 m^3/day** Difference: IN - OUT = -3.2827 [m^3/day] Percent Discrepancy = 0%	Constant Head = 409470 [m^3/day] Recharge = 1169300 [m^3/day] River Leakage = 64664 [m^3/day] **Total IN = 3104600 m^3/day** Output Report Storage = 32042 [m^3/day] Constant Head = 456010 [m^3/day] Wells = 882850 [m^3/day] ET = 1561800 [m^3/day] River Leakage = 171880 [m^3/day] **Total OUT = 3104600 m^3/day** Difference: IN - OUT = -9.3203 [m^3/day] Percent Discrepancy = 0%

Mass Balance

Mass balance is one of the key indicators of a successful simulation of a ground water flow model. The mass balance showing cumulative inflows and outflow and percent discrepancy in each time step provides the detail information about the entire model domain. If the mass balance error for a simulation is less than 2% the results of the simulation may be considered to be acceptable provided model is also calibrated. The mass balance of the present simulated model for stress period 1 (214 days) and stress period 6 (1095 days) is presented in Table 8.

Table 8: Mass Balance of Model of Northern bank of Brahmaputra basin for 2190 days

Cumulative volumes report[m^3]	**Rates for time steps report[m^3]**
214 days	**214 days**
IN: Storage = 441900736 [m^3] Constant Head = 49096552 [m^3] Recharge = 1104801152 [m^3] River Leakage = 6780628.5 [m^3] Total IN = 1602579072 [m^3] **OUT:** Storage = 401803872 [m^3] Constant Head = 116070184 [m^3] Wells = 117967496 [m^3] ET = 905378560 [m^3] River Leakage = 61361516 [m^3] Total OUT = 1602581632 [m^3] IN - OUT = -2560 [m^3]	**IN:** Storage = 794829.9375 [m^3/day] Constant Head = 403777.2812 [m^3/day] Recharge = 5162622 [m^3/day] River Leakage = 41362.3359 [m^3/day] Total IN = 6402591.5 [m^3/day] **OUT:** Storage = 1500555.875 [m^3/day] Constant Head = 386097.9062 [m^3/day] Wells = 551250 [m^3/day] ET = 3743578.25 [m^3/day] River Leakage = 221112.9844 [m^3/day] Total OUT = 6402595 [m^3/day] IN - OUT = -3.5 [m^3/day]

Discrepancy = 0%	Discrepancy = 0%
1095 days	**1095 days**
IN: Storage = 1471243008 [m^3] Constant Head = 402186720 [m^3] Recharge = 3844099072 [m^3] River Leakage = 60767704 [m^3] Total IN = 5778296832 [m^3] **OUT:** Storage = 1180665856 [m^3] Constant Head = 570566720 [m^3] Wells = 753832064 [m^3] ET = 3035950848 [m^3] River Leakage = 237269232 [m^3] Total OUT = 5778284544 [m^3] IN - OUT = 12288 [m^3] Discrepancy = 0%	**IN:** Storage = 1461155.625 [m^3/day] Constant Head = 409474.875 [m^3/day] Recharge = 1169307.5 [m^3/day] River Leakage = 64663.7969 [m^3/day] Total IN = 3104601.75 [m^3/day] **OUT:** Storage = 32041.9844 [m^3/day] Constant Head = 456009.4375 [m^3/day] Wells = 882847 [m^3/day] ET = 1561830 [m^3/day] River Leakage = 171882.7812 [m^3/day] Total OUT = 3104611.25 [m^3/day] IN - OUT = -9.5 [m^3/day] Discrepancy = 0%

7.0 Model Limitations

- Present model requires further refinement. Future modelling study requires additional hydraulic conductivity in the northern part of the basin.
- Draft and recharge values are assigned to the model as per the Ground Water Resource estimation, 2016-17.

8.0 PREDICTIONS AND ASSESSMENT

In a prediction simulation, the parameters determined during calibration and verification were used to predict the response of the system to future events (Anderson and Woessner, 2002). Faust et al. (1981) suggest that a predictive simulation should not be extended into the future more than twice the period for which calibration data are available. This, however, may not be possible if regulations require longer simulation.

Two different prediction scenarios were considered to predict the drawdown for the study area during the period of 2019 to 2025. These scenarios are explained below. Stress periods applied in different prediction scenarios is shown in Table 9.

Table 9:Stress periods applied in the Prediction Scenarios.

Stress period	Time from	Time to	Start	End	Duration	Season
1	01/04/2016	31/10/2016	0	214	214	Monsoon
2	01/11/2016	31/03/2017	214	365	151	Non-Monsoon
3	01/04/2017	31/10/2017	365	579	214	Monsoon
4	01/11/2017	31/03/2018	579	730	151	Non-Monsoon
5	01/04/2018	31/10/2018	730	944	214	Monsoon
6	01/11/2018	31/03/2019	944	1095	151	Non-Monsoon
7	01/04/2019	31/10/2019	1095	1309	214	Monsoon
8	01/11/2019	31/03/2020	1309	1460	151	Non-Monsoon
9	01/04/2020	31/10/2020	1460	1674	214	Monsoon
10	01/11/2020	31/03/2021	1674	1825	151	Non-Monsoon
11	01/04/2021	31/10/2021	1825	2039	214	Monsoon
12	01/11/2021	31/03/2022	2039	2190	151	Non-Monsoon
13	01/04/2022	31/10/2022	2190	2404	214	Monsoon
14	01/11/2022	31/03/2023	2404	2555	151	Non-Monsoon
15	01/04/2023	31/10/2023	2555	2769	214	Monsoon
16	01/11/2023	31/03/2024	2769	2920	151	Non-Monsoon
17	01/04/2024	31/10/2024	2920	3134	214	Monsoon
18	01/11/2024	31/03/2025	3134	3285	151	Non-Monsoon

8.1 Prediction Scenario 1: Constant recharge and increase in current withdrawal rate by incorporating tube wells constructed under PMKSY GW Irrigation

In this scenario, tube wells constructed under PMKSY Groundwater Irrigation has been taken into consideration. In Sonitpur District 892 tube wells and in Lakhimpur district 510 tube wells were constructed under PMKSY GW Irrigation. The average discharge of the wells is found to be 24 m^3/hr. Considering 8 hr per day pumping for 20 day during monsoon, the total draft estimated for monsoon season is 343 ham in Sonitpur district and 143 ham in Lakhimpur district (model area). Again, considering 8 hr per day pumping for 80 days during non-monsoon season, the total draft estimated for non-monsoon season is 1370 ham in Sonitpur district and 572 ham in Lakhimpur district (model area). This extraction is distributed in the entire area and addition in extraction made from 1309 days to 3285 days. Then prediction scenario was developed upto 3285 days. It was observed during this prediction run (from 2020 to 2025) that drawdown is more than 10 m in eastern foothills corner in Lakhimpur district (Fig 19). It is also observed from the time series of hydrographs that water level almost remains unchanged (Fig 20).

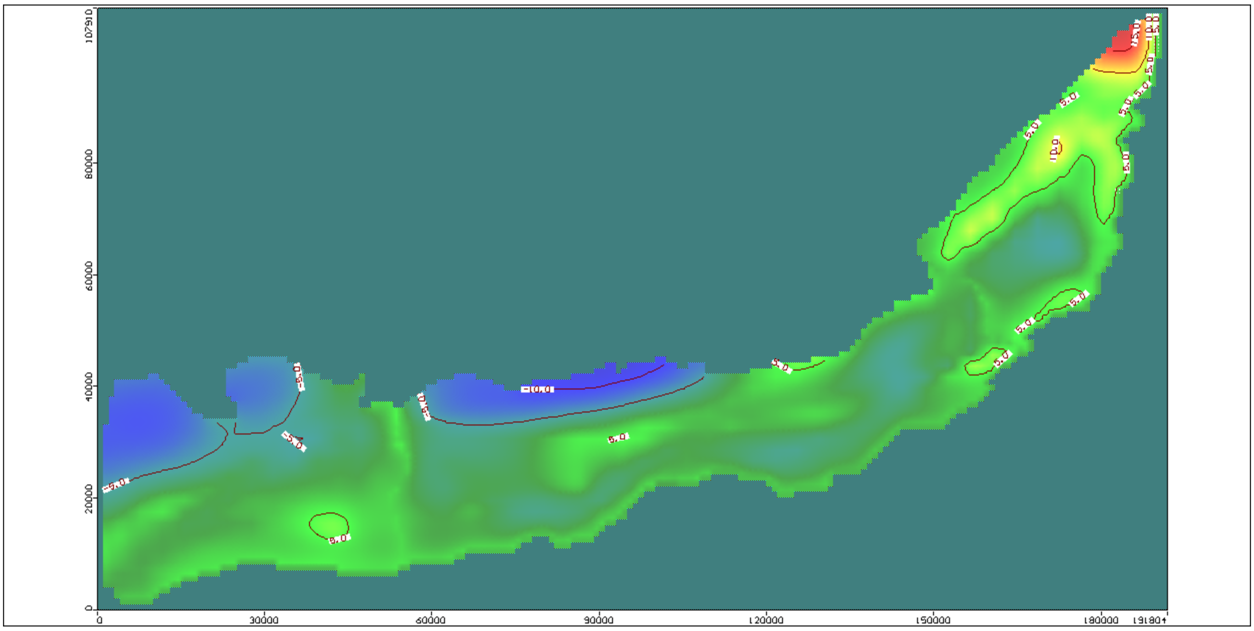

Fig. 19: Drawdown in scenario 1 (2024-25)

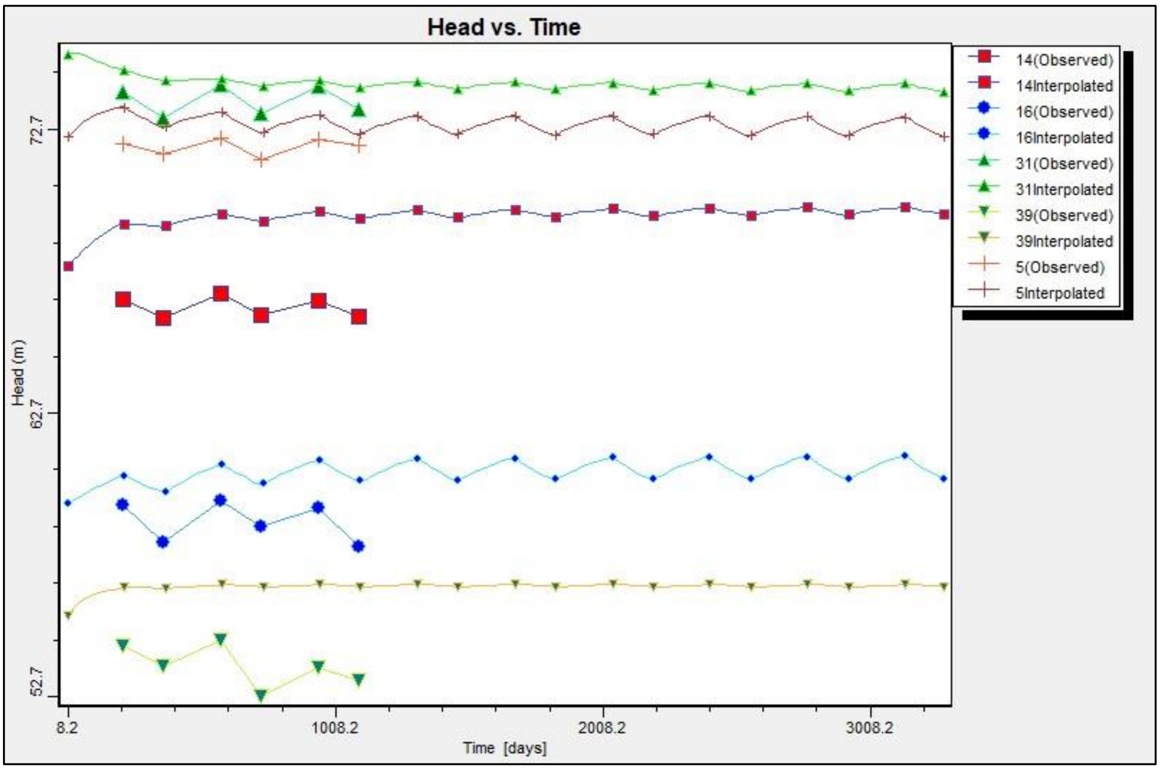

Fig 20: **Behaviour of well hydrographs up to 2021 under prediction scenario 1.**

8.2 Prediction Scenario 2: Constant recharge and increase in current withdrawal rate by incorporating NAQUIM planning to install more tube wells for irrigation

In the Aquifer Management Plan reports of Sonitpur and Lakhimpur districts, it has been shown that about 10500 tube wells in Sonitpur and about 11900 tubewells in Lakhimpur districts can be constructed to bring areas under assured irrigation. The average discharge of the wells drilled under PMKSY GW Irrigation is found to be 24 m^3/hr. Considering 8 hr per day pumping for 20 days during monsoon, the total draft estimated for monsoon season is 4032 ham in Sonitpur district and 3335 ham in (model area) of Lakhimpur district. Again, considering 8 hr per day pumping for 80 days during non-monsoon season, the total draft estimated for non-monsoon season is 16128 ham in Sonitpur district and 13343 ham in Lakhimpur district (model area). This extraction is distributed in the entire area and addition in extraction is made from 1309 days to 3285 days. Then prediction scenario was developed upto 3285 days. It was observed during this prediction run (from 2020 to 2025) that drawdown is > 10 m in eastern foothills corner in Lakhimpur district (Fig 21). Time series of hydrographs showed a declining water level in the area (Fig 22).

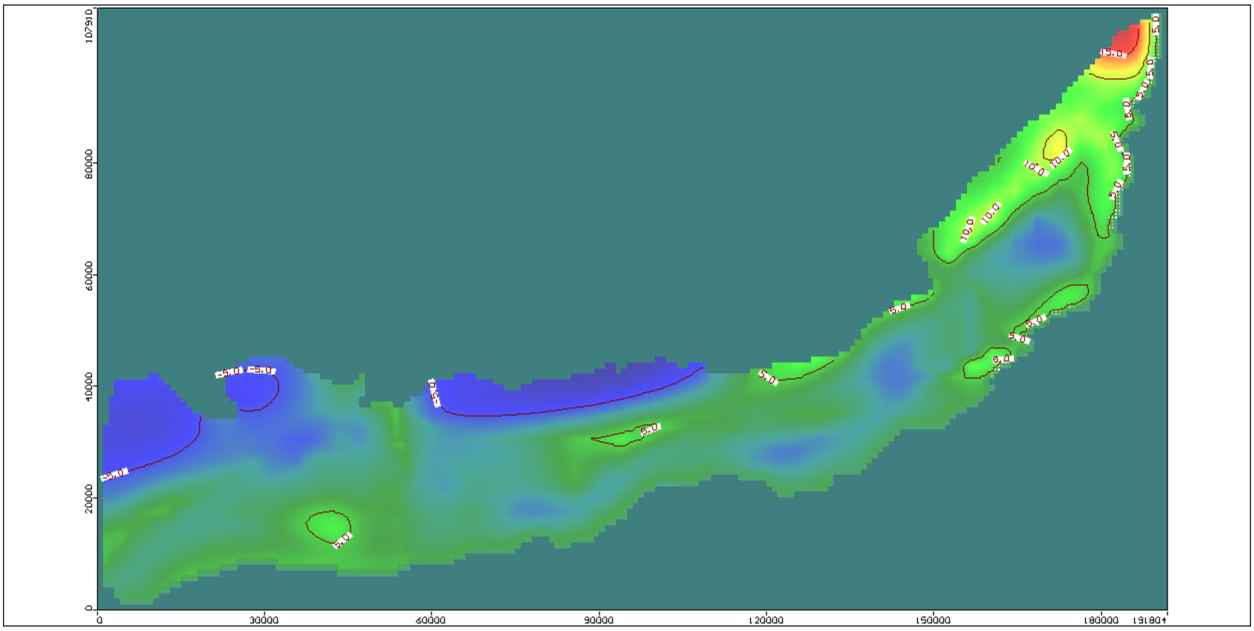

Fig. 21: Drawdown in scenario 2 (2024-25)

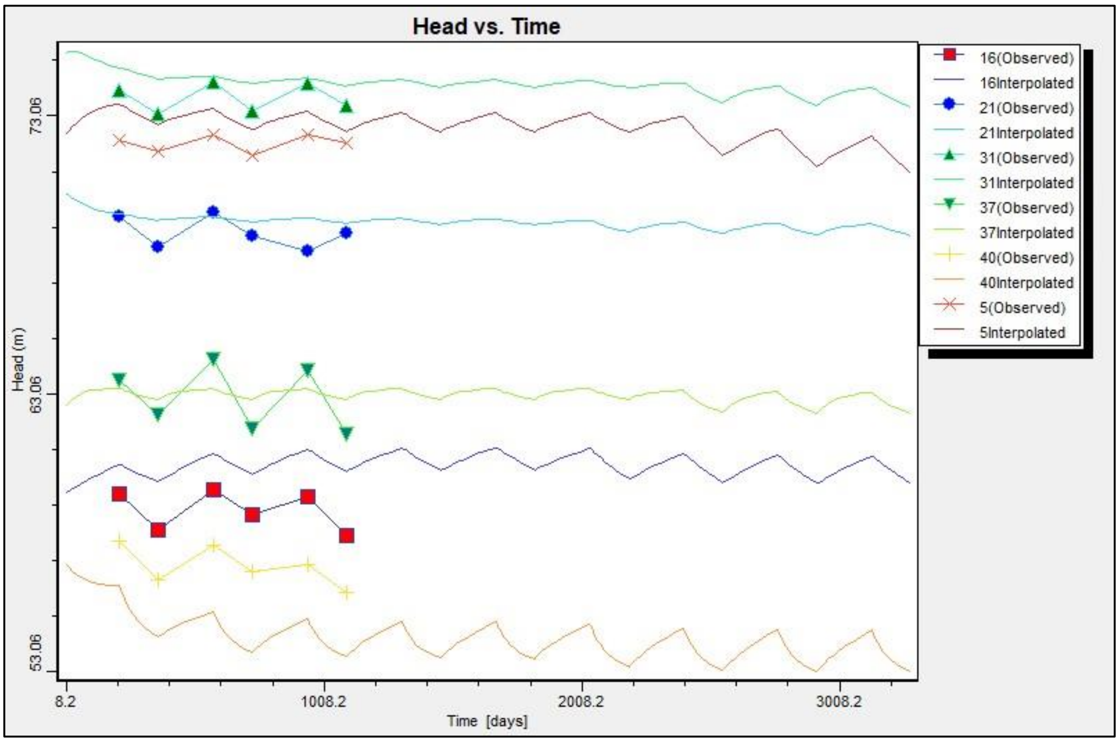

Fig 22: **Behavior of well hydrographs up to 2025 under prediction scenario 2**

9.0 AQUIFER MANAGEMENT PLAN

Aquifer management plan (AMP) of both Sonitpur and Lakhimpur districts emphasised that the districts are having huge balance net ground water availability for future irrigation use. Groundwater development in the area is in nascent stage. Again, after Kharif crops are over major portion of this area remains fallow during Rabi season. Another problem reported is water logging in the middle portion i.e., area between the Brahmaputra River and foot hills. So, Aquifer management plan of both Sonitpur and Lakhimpur districts advocated for providing irrigation facilities through ground water development as agriculture is the main means of livelihood of the people living in the districts.

In Sonitpur district, 10457 no. of tube wells and in Lakhimpur district 11913 no. of tube wells were proposed to be constructed in AMP.

10.0 SUM UP, FINDINGS AND CONCLUSIONS

10.1 SUM UP

Visual Modflow is used in this study to simulate the groundwater flow for steady state & transient conditions and to forecast the future changes that occurred under different stresses.

Post-monsoon 2016 situation is taken as the initial condition for steady state model calibration. Model calibration for steady state condition shows good agreement between observed and simulated heads. The model was calibrated to transient state from Post-monsoon 2016 to Pre-monsoon 2019. A comparison of observed and calculated heads at different observation wells shows a good agreement between observed and computed heads.

Two prediction scenario was prepared during present study, i.e. 1st one is constant recharge and increase in current withdrawal rate by incorporating tube wells constructed under PMKSY GW Irrigation and 2nd one is Constant recharge and increase in current withdrawal rate by incorporating NAQUIM planning to install more tube wells for irrigation for the year 2019 to 2025. According to first scenario, it was observed during this prediction run (from 2019 to 2025) that drawdown is >10m in the eastern foothills corner in Lakhimpur district. According to second scenario, drawdown scenario is almost the same as that of first scenario.

The present study wasundertaken to establish a Groundwater Flow model for the area, so that impact of agricultural draft on groundwater regime may be understood as well as the model can be utilized to better understand the hydrogeological set up of area in the context of groundwater exploration, resource estimation, quality assessment and utilization. As the area is completely agricultural, the optimum additional groundwater irrigation potential may also be estimated, that may be safely harnessed without disturbing the natural flow pattern.

The total area of the model is 5709 Km^2 which is discretized into 107 rows and 192 columns, with the dimension of 1000 x 1000 m grid size.15% of annual rainfall is assigned as a recharge to the model. Recharge rate was assigned in the Sonitpur part of model is 0.00083 m/day and in the Lakhimpur part of model is 0.00117 m/day. The lithological data of 22tube wells were utilized for sketching horizontal and vertical disposition of aquifers and aquitards in the study area to a depth of 50 m bgl.

10.2 FINDINGS

Findings of the study may be summarized as

- Overall Groundwater flow is towards south.
- Ground water is abstracted in the area mainly for irrigation and domestic purposes.
- Water Budget have been calculated for steady state (November 2016), so that water transfer mass balance may be understood.
- Aquifer can be sustainably developed for implementation of Aquifer management plan proposed under NAQUIM studies.

10.3 CONCLUSIONS

Conclusions of the study may be summarized as

1. Conceptualization, construction and calibration of the model even with limited hydro-geological database put significant lights towards understanding of hydrogeological setup of the study area.
2. Significant understanding the hydrodynamics of groundwater flow regime with respect to aquifer parameters came out through the study.
3. Impact of agricultural practices can be understood through prediction scenarios carried out in present study.

Acknowledgement

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Annexure I

Top and Bottom Elevation Data for parts of Northern Brahmaputra basin for the model

Location	Easting	Northing	Top (m)	Bottom (m)
Dakhin Ku	615678.1	3024404	89.2	39.2
11th Mile	611050.9	2995292	50.3	0.3
18th Mile	483105.2	2965403	64.4	14.4
18th Mile	480113.3	2958762	60.2	10.2
1no Laimek	615209.4	3019503	77.9	27.9
2no Itakhu	496143.4	2963487	64.7	14.7
2no Laimek	614132	3019338	77.1	27.1
Amaribari	473369.1	2967014	76.1	26.1
Amguri	576148	2973740	66.7	16.7
Balipara	478138	2966518	60.2	10.2
Balipara	488959.9	2966725	65.5	15.5
Barchola	438602.7	2943200	57.0	7.0
Batasipur	444951.3	2965323	103.3	53.3
Behali	535551.8	2967911	87.9	37.9
Bhogpurch	582931.1	2990399	73.7	23.7
Bhumuragur	485296.2	2943692	76.5	26.5
Bihpuria	590092.8	2990448	59.9	9.9
Bihupukhur	524859.1	2958460	68.1	18.1
Bishnupur	591358.8	3005844	78.4	28.4
Biswanath	517414.8	2948602	60.5	10.5
Biswanath	518643.8	2958760	57.1	7.1
Biswanath	515097.3	2956019	67.9	17.9
Biswanath	516917	2948789	72.7	22.7
Boginadi(b	617967.8	3030164	97.2	47.2
Borbil Tar	615500.8	3031714	105.0	55.0
Borgang	528812.9	2968836	93.1	43.1
Borpukhuri	602395.2	3009564	69.4	19.4
Buragaon	481370.9	2968761	70.4	20.4
Buroighat	541361.6	2971861	89.0	39.0
Chacara Ka	447885.4	2956195	69.1	19.1
Charaidolo	581341.7	2980053	66.3	16.3
Charduar	477650.3	2971691	69.5	19.5
Checha Raj	571281.2	2987702	109.1	59.1
Chengai Ga	562290.8	2976045	75.9	25.9
Dagaon	458971.5	2955124	58.5	8.5
Dakhinpat	621645.2	3035308	88.4	38.4
Dalikathi	480713.3	2974012	73.2	23.2
Dejoo	591724.9	2982961	54.2	4.2
Dekargaon	475315.9	2951261	50.4	0.4
Dhakuwakha	609081.8	3012878	78.0	28.0
Dhakuwakha	608914.5	3012754	81.8	31.8
Dhalaibil	490526.1	2961640	63.1	13.1

Dhalpur (D	579815.5	2976510	62.7	12.7
Dhekiajuli	447715.4	2953560	64.0	14.0
Dhekiajuli	445346.8	2953326	64.5	14.5
Dhenudhari	607995.1	3002322	74.9	24.9
Dholpur	577785.3	2975600	72.7	22.7
Dighalia M	583030.6	2973861	69.3	19.3
Diju	601423.7	3020545	95.4	45.4
Dolabari	481372.9	2949833	59.5	9.5
Dolanghat	599071.4	3005294	64.6	14.6
Durpang (J	575271.9	2990627	109.4	59.4
Gagaldubi	616899.6	3023928	88.7	38.7
Ganakdalan	577875.4	2978691	79.0	29.0
Garumari	481375.3	2971685	65.4	15.4
Garumari/G	477717.9	2959319	65.4	15.4
Gergeria	616948.6	3026067	92.3	42.3
Gobindapur	574080.9	2984029	84.9	34.9
Gohpur	562069.5	2974593	70.4	20.4
GomiriGha	544500.5	2963421	75.0	25.0
Harmoti	584798.2	3000292	92.6	42.6
Hathkhola	519028.8	2967211	78.2	28.2
Hatijuri	497725.4	2972114	91.8	41.8
Hawajan	573670.3	2972806	75.0	25.0
Helem	546226.3	2969873	82.6	32.6
Islampur	589231.1	2995826	70.0	20.0
Jalukata	585328.6	2982107	66.4	16.4
Jamuguri N	492540.3	2955060	57.8	7.8
Jamugurigh	492819.3	2955979	66.6	16.6
Janakpur	606983.8	3019584	86.3	36.3
Janambasti	604776.5	3019620	77.4	27.4
Japoriguri	518974.6	2957032	73.4	23.4
Japoriguri	517621.5	2957440	60.4	10.4
Jokobari	513274.5	2958686	65.8	15.8
Jorabari	581610.8	2973774	64.6	14.6
Kadam	616198.5	3024830	80.1	30.1
Kadam Goha	612878.8	3021088	80.9	30.9
Kakoi	611972.9	3017313	93.8	43.8
Kamalabaor	609550.7	3005747	86.6	36.6
Karigaraj	481806.1	2946609	58.2	8.2
Ketela TE	532105	2967492	79.4	29.4
Kettle Sid	544488.5	2966843	81.8	31.8
Kheroni	561517.8	2977747	75.7	25.7
Kimin	596938.7	3019534	132.0	82.0
Koilamari	602275.7	3020430	92.3	42.3
Kolabari	570316.5	2975711	66.6	16.6
Kowadanga	600432.5	3007299	78.9	28.9

Kuhiarbari	609956.9	2997896	81.6	31.6
Laluk	590019.5	3000606	75.2	25.2
Laluk	592348.9	3000589	73.4	23.4
Madhupur	596778.7	2985336	70.1	20.1
Merbit Har	584985.7	3000415	85.8	35.8
Missamari	460667.3	2966283	78.9	28.9
Moridirgha	612234	3022356	79.0	29.0
N.lakhipur	609752.6	3010923	81.0	31.0
Na Pam	438098.2	2952041	74.9	24.9
Naoboisa	601358.4	3005523	68.7	18.7
Napam	486181.3	2951986	56.2	6.2
Narayanpur	585077.6	2982537	65.0	15.0
NatunDhan	569660.8	2968585	65.9	15.9
NizBehali	537134.8	2963497	69.5	19.5
Nonkey Goh	562570.4	2971727	66.5	16.5
Notchpur	570832	2986425	105.7	55.7
Padumani	618233.2	3032394	99.7	49.7
Panigaon	610187.5	2999848	67.8	17.8
Panigaon	609550.4	3003532	92.1	42.1
Panigaon	491570.8	2962913	66.2	16.2
Porua char	480094.1	2946579	63.5	13.5
Rajgarh	612979.3	3031724	123.6	73.6
Rajgarh Ra	596915.5	3013652	97.0	47.0
Rajgharh	571929.3	2988868	107.5	57.5
Rakshyasma	440354.8	2962209	85.9	35.9
Rangajan	605253.7	3017043	80.5	30.5
Roumari	483337.3	2960562	58.7	8.7
Samardolon	498617.4	2954161	54.2	4.2
Senchowa	614102.2	3028987	109.0	59.0
Siajulist	610576.9	3026174	100.4	50.4
Sijubari-I	521182.6	2962795	77.4	27.4
Simalguri	574852.3	2982815	73.6	23.6
Sinatoli	606992.3	3025455	107.4	57.4
Singlijan	542138.5	2977169	99.3	49.3
Singri	448759.9	2943687	53.0	3.0
Solalgaon	610187.7	3004302	84.4	34.4
Sootia	504147	2956897	56.7	6.7
Sukhankutt	529866.2	2968772	85.0	35.0
Talakbari	495642.8	2952932	57.1	7.1
Tariani Ra	613908.6	3031733	119.2	69.2
Telengonia	535287	2963137	78.3	28.3
Tezpur	480091.5	2944917	63.1	13.1
Thelamara	459210.6	2952166	56.2	6.2
Thelamara	458883.9	2952655	58.2	8.2
Tolakbari	495026.2	2953209	58.5	8.5

Tupia	491054.9	2964287	72.0	22.0
Tupia	472945.7	2964191	71.1	21.1
Tupia	489754.3	2965982	70.0	20.0
Udmari	478201.3	2968655	66.0	16.0

Annexure II

Initial Head Data for parts of Northern Brahmaputra basin for the model

Location	Easting	Northing	Initial Head (m bgl)
Amguri	576148	2973740	63.24
Balipara	478138	2966518	58.56
Barchola	438602.7	2943200	55.07
Bhogpurch	582931.1	2990399	72.20
Bihpuria	590092.8	2990448	58.21
Bihupukhur	524859.1	2958460	61.66
Biswanath	517414.8	2948602	55.88
Borbil Tar	615500.8	3031714	103.43
Borgang	528812.9	2968836	91.32
Buroighat	541361.6	2971861	87.23
Charduar	477650.3	2971691	66.70
Dejoo	591724.9	2982961	52.79
Dhalaibil	490526.1	2961640	59.47
Dhekiajuli	447715.4	2953560	61.02
Dolanghat	599071.4	3005294	62.24
Garumari	481375.3	2971685	63.94
Gohpur	562069.5	2974593	69.46
Harmoti	584798.2	3000292	90.47
Helem	546226.3	2969873	81.29
Islampur	589231.1	2995826	66.45
Jamuguri N	492540.3	2955060	56.63
Kolabari	570316.5	2975711	65.96
Laluk	590019.5	3000606	74.00
Madhupur	596778.7	2985336	69.31
N.lakhipur	609752.6	3010923	79.32
Na Pam	438098.2	2952041	73.73
Narayanpur	585077.6	2982537	63.53
Panigaon	610187.5	2999848	65.73
Sootia	504147	2956897	54.48
Tezpur	480091.5	2944917	57.78
Thelamara	459210.6	2952166	53.98
Tupia	472945.7	2964191	66.56
18th Mile	480113.3	2958762	58.71

Annexure III

Head Observation Data from November 2016 to March 2019

Well Name	Easting	Northing	Screen ID	Screen Elev. [m]	Obs. Time [day]	HEAD [m]
Amguri	576148	2973740	1	56.7	214	93.81
					365	92.27
					579	95.43
					730	92.28
					944	94.00
					1095	92.28
Balipara	478138	2966518	2	50.2	214	70.37
					365	69.95
					579	70.45
					730	70.41
					944	70.40
					1095	70.06
Barchola	438602.7	2943200	3	47.0	214	71.55
					365	70.62
					579	72.03
					730	71.01
					944	72.19
					1095	71.07
Bhogpurch	582931.1	2990399	5	63.7	214	65.56
					365	65.11
					579	65.70
					730	64.95
					944	65.66
					1095	65.41
Bihpuria	590092.8	2990448	6	49.9	214	62.54
					365	60.47
					579	62.20
					730	60.40
					944	63.13
					1095	60.84
Bihupukhur	524859.1	2958460	7	58.1	214	94.49
					365	92.08
					579	93.99
					730	91.79
					944	93.01
					1095	92.10
Biswanath	517414.8	2948602	8	50.5	214	78.68
					365	74.46
					579	78.91
					730	75.64
					944	78.35

					1095	74.66
BorbilTariyani	615500.8	3031714	11	95.0	214	79.45
					365	79.45
					579	79.56
					730	78.95
					944	79.44
					1095	78.99
Borgang	528812.9	2968836	12	83.1	214	102.62
					365	101.49
					579	102.01
					730	100.12
					944	102.14
					1095	100.12
Buroighat	541361.6	2971861	13	79.0	214	80.38
					365	79.21
					579	80.38
					730	79.20
					944	80.07
					1095	79.18
Charduar	477650.3	2971691	14	59.5	214	67.14
					365	66.57
					579	67.39
					730	66.66
					944	67.17
					1095	66.62
Dejoo	591724.9	2982961	15	44.2	214	53.73
					365	52.90
					579	53.80
					730	53.11
					944	53.84
					1095	52.79
Dhalaibil	490526.1	2961640	16	53.1	214	86.26
					365	85.04
					579	86.52
					730	85.62
					944	86.26
					1095	84.88
Dhekiajuli	447715.4	2953560	17	54.0	214	99.84
					365	98.66
					579	100.32
					730	98.86
					944	100.00
					1095	98.93
Dolanghat	599071.4	3005294	19	54.6	214	72.93

					365	72.08
					579	73.64
					730	72.65
					944	73.44
					1095	73.16
Garumari	481375.3	2971685	20	55.4	214	76.46
					365	74.98
					579	77.15
					730	75.55
					944	75.98
					1095	74.75
Gohpur	562069.5	2974593	21	60.4	214	75.06
					365	73.94
					579	75.20
					730	74.36
					944	73.77
					1095	74.43
Harmoti	584798.2	3000292	22	82.6	214	70.89
					365	69.72
					579	70.09
					730	69.78
					944	70.68
					1095	69.96
Helem	546226.3	2969873	24	72.6	214	93.87
					365	92.60
					579	94.11
					730	92.77
					944	93.53
					1095	92.61
Islampur	589231.1	2995826	25	60.0	214	66.70
					365	65.10
					579	67.16
					730	65.16
					944	66.91
					1095	65.10
Jamuguri N	492540.3	2955060	26	47.8	214	77.06
					365	75.96
					579	77.24
					730	75.81
					944	76.53
					1095	75.18
Kolabari	570316.5	2975711	29	56.6	214	66.21
					365	65.42
					579	66.12

					730	64.67
					944	66.54
					1095	65.85
Laluk	590019.5	3000606	31	65.2	214	63.83
					365	62.92
					579	64.06
					730	63.04
					944	64.02
					1095	63.22
Madhupur	596778.7	2985336	32	60.1	214	73.11
					365	73.07
					579	73.39
					730	72.62
					944	73.45
					1095	73.34
N. Lakhipur	609752.6	3010923	34	71.0	214	90.44
					365	89.85
					579	90.51
					730	90.25
					944	90.37
					1095	89.90
Na Pam	438098.2	2952041	35	64.9	214	53.68
					365	53.08
					579	53.20
					730	53.03
					944	53.67
					1095	52.86
Narayanpur	585077.6	2982537	37	55.0	214	77.84
					365	76.29
					579	78.32
					730	75.80
					944	77.89
					1095	75.62
Panigaon	610187.5	2999848	38	57.8	214	74.20
					365	72.40
					579	74.26
					730	72.65
					944	74.23
					1095	72.65
Sootia	504147	2956897	39	46.7	214	77.02
					365	76.09
					579	76.97
					730	75.00
					944	76.02

					1095	75.57
Tezpur	480091.5	2944917	40	53.1	214	57.75
					365	56.25
					579	57.51
					730	56.55
					944	56.80
					1095	55.81
Thelamara	459210.6	2952166	41	46.2	214	61.64
					365	60.44
					579	62.80
					730	60.52
					944	61.84
					1095	60.42
Tupia	472945.7	2964191	42	61.1	214	68.56
					365	67.65
					579	68.99
					730	67.26
					944	68.99
					1095	67.57
18th Mile	480113.3	2958762	43	50.2	214	57.46
					365	56.66
					579	57.90
					730	55.95
					944	57.30
					1095	56.32

Annexure IV
District- wise ground water resources (ham)

District	GW Recharge from Rainfall in Monsoon*	GW Recharge from Rainfall in Non-Monsoon*	GW DraftIrrigation (Monsoon)	GW Draft Domestic and Industrial (Monsoon) *	GW DraftIrrigation (Non-Monsoon)	GW Draft Domestic and Industrial (Non-Monsoon) *	Stage of Extraction (%)	Categorisation
Sonitpur	82361	9172	1722	7038	6889	3453	7.79	Safe
Lakhimpur (Modelling Area)	47483	5203	445	2604	2435	1747	4.85	Safe

- Re-estimated according to modelling stress period. Others values taken from GWR estimation 2017

Annexure IV

Hydraulic Conductivity values from EWs constructed byCGWB

Location	**Latitude**	**Longitude**	**Hydraulic Conductivity (m/d)**
Erabari	26.70^0	92.57083^0	63
Dagaon	26.71667^0	92.5875^0	29
Dekargaon	26.68222^0	92.90194^0	72
Jamugurighat	26.725^0	92.92778^0	69
Samardoloni	26.70861^0	92.98611^0	64
Sijubari	26.78639^0	93.21306^0	35
Telongonia	26.78917^0	93.35444^0	18
Karigaraj	26.875^0	93.49944^0	4
Missamari	26.8175^0	92.60417^0	18
Dolabari	26.15^0	92.08333^0	90
Singri	26.61306^0	92.48528^0	19
Japoriguri	26.73806^0	93.17722^0	114
Panigaon	26.7525^0	92.925^0	83
Tupia	26.81528^0	92.89694^0	39
Udmari	26.83917^0	92.78056^0	10
Rajgarhnepali	27.404^0	94.1428^0	6
Diju	27.304^0	94.0250^0	10
Panigaon	27.150^0	94.1056^0	192
MerbitHarmoty	27.124^0	93.8575^0	66
Jalukata	26.958^0	93.8597^0	187
Jorabari	26.883^0	93.8217^0	164
Ghilamara	27.312^0	94.4139^0	2